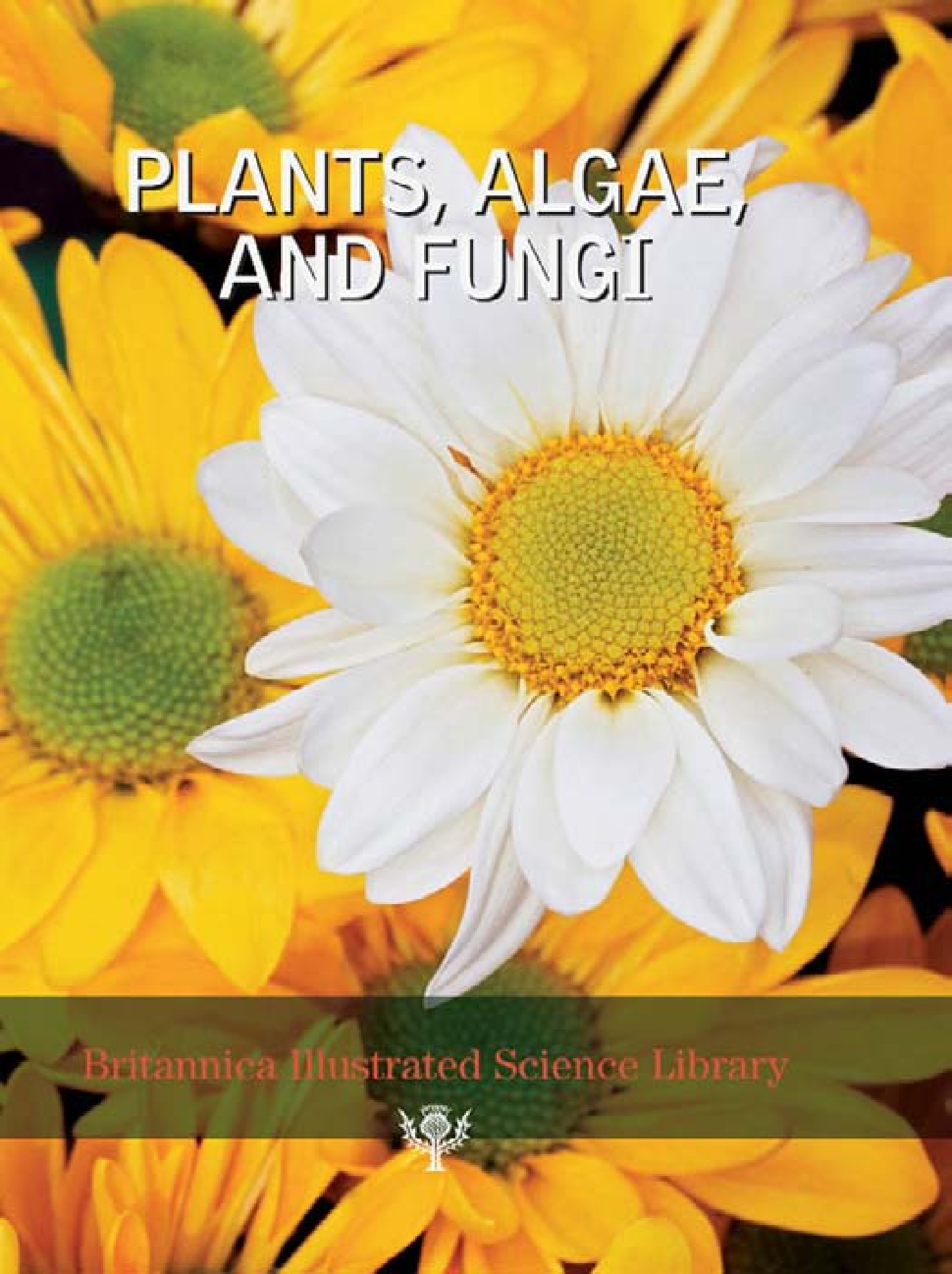

PLANTS, ALGAE, AND FUNGI
Britannica Illustrated Science Library

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PLANTS, ALGAE, AND FUNGI



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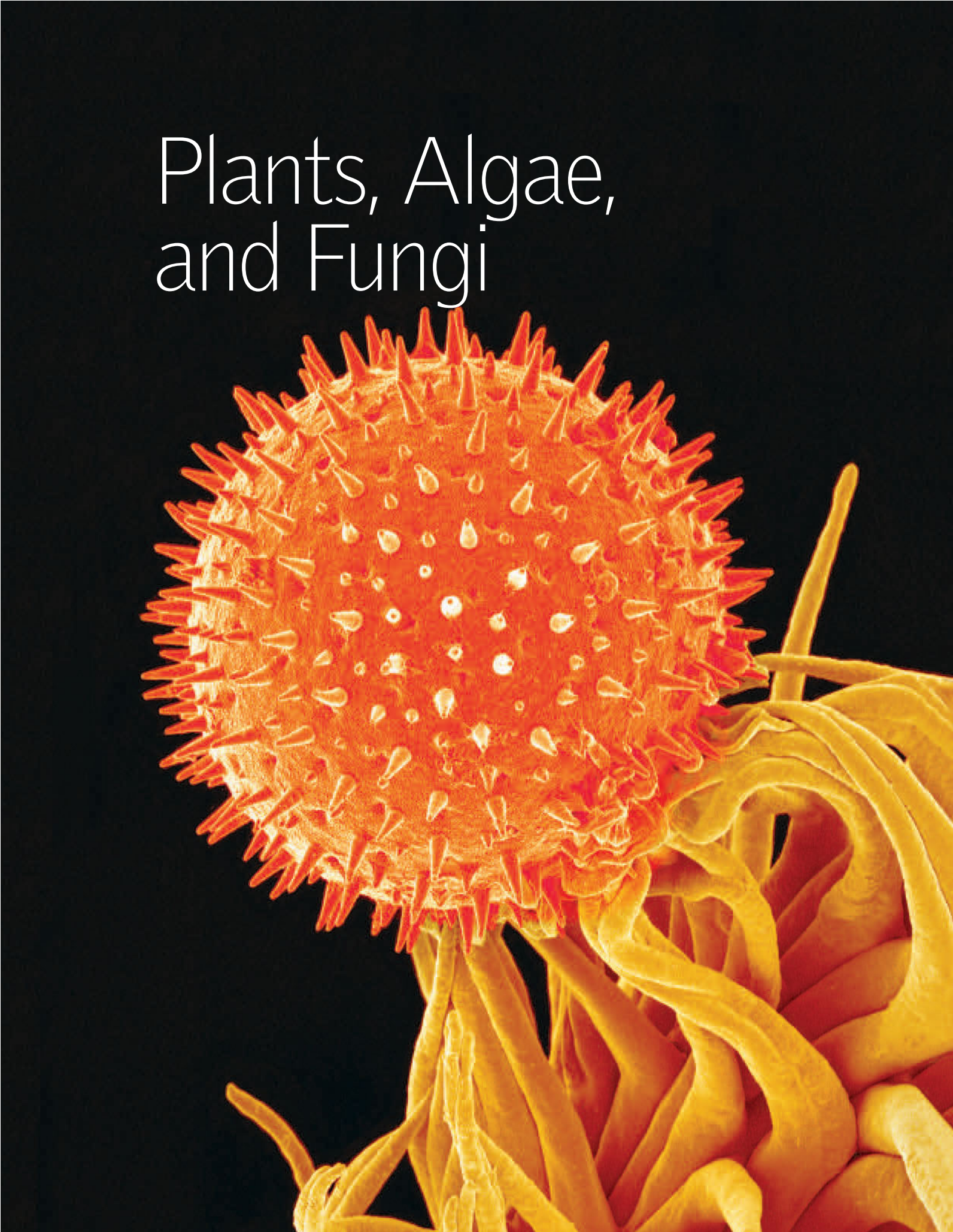
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Plants, Algae, and Fungi



Contents

Grain of mallow pollen, magnified 600 times, pictured on page 1. Pollen's function is to fertilize the female organs of the plant, a task that is achieved with the help of bees.

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Green Revolution



RICE CROP
Rice is synonymous with food security in much of Asia. It is also a staple food in western Africa, the Caribbean, and the tropical regions of Latin America.

There are approximately 300,000 plant species in the world, and they live in a variety of regions, from the frozen Arctic tundra to the lush tropical rainforests. Without plants we would not be able to live; they have always been intimately linked to life on Earth. Thanks to photosynthesis, plants provide us with food, medicines, wood, resins, and oxygen, among other things. Discovering plants' processes for converting sunlight into carbohydrates such as sugars and starches is almost magical. It is marvelous to understand how an organism that cannot move learned to maximize the energy that it receives from the Sun, as well as to discover the mechanisms that enable it to face so many different environmental challenges. Some leaves have essential adaptations, such as thick skin, thorns, or fleshy stalks, which allow them to survive in very dry environments. Others, such as the tomato plant, form certain proteins when temperatures drop in order to protect themselves from damage caused by freezing.

You may be surprised to learn why plants invest so much energy and effort into producing flowers. In this book we will describe for you in detail, step by step, how fertilization takes place. Did you know that pollination is aided by the wind and insects and that some flowers can be pollinated only by a certain species of insect? You will find all this and much more in the pages of this book, which includes spectacular images and illustrations that give an inside view of the core of a tree and even show the functions of its tissues and the veins of its leaves.

What were the first plants to conquer the Earth like, and how did they help convert bare rock into soil? What happened next, and which species evolved and spread worldwide during the Carboniferous Period? A complete historical overview of plants is included in this book, as is an explanation of the radical differences between plants, algae, and fungi—the latter two of which are now considered to be more closely related to animals than to plants. Although the place of plants in the human diet is nothing new, the search for other beneficial uses of plants is a more modern development. Crops—such as rice, corn, wheat, rye, barley, oats, soy, lentils, and chickpeas—are grown worldwide as sources of proteins, vitamins, minerals, and other nutrients necessary for our bodies to function, and they also provide people with an important source of income.

Background

GIANT SEQUOIA
Some trees of this species are found in central California.

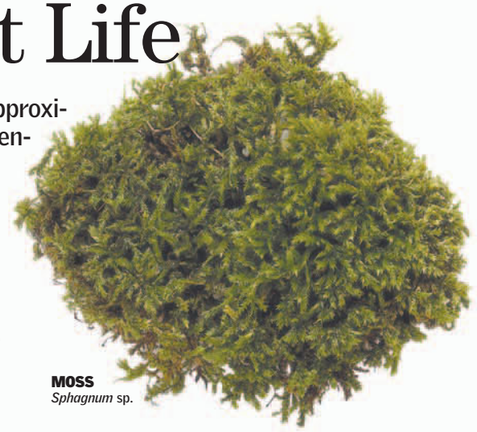
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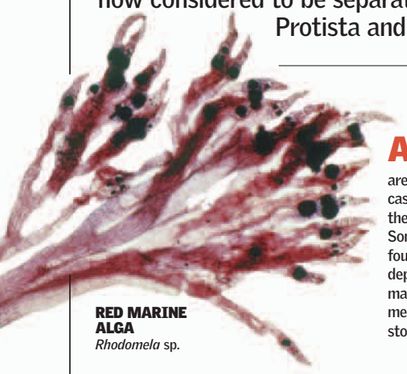
According to scientific evidence, the nearest relatives of plants are algae that lived on the shores of lagoons. Later, from these habitats, which were at times dry and at times damp, the first land plants emerged. Most had to adapt in order to prosper in a different environment. Such adaptation enabled them to achieve amazing growth, as exemplified by the giant sequoia *(Sequoiadendron giganteum)*, which can measure 260 feet (80 m) tall and 100 feet (30 m) in circumference at its base. Did you know that plants grow bigger as their cells multiply and expand? Many can grow 0.4 inch (1 cm) per day, and their growth can create enough pressure to open cracks in asphalt. ●

Kingdoms of the Quiet Life

Representing a vast array of life-forms, the plant kingdom includes approximately 300,000 species. Their most outstanding feature is the presence of chloroplasts with chlorophyll, a pigment that enables them to transform solar energy into chemical energy. They use this energy to produce their food. Plants need to attach themselves to a substrate (usually the ground), from which they can extract water and nutrients. This attachment, however, also keeps them from moving from place to place. Algae and fungi were once included in the plant kingdom, but they are now considered to be separate from plants and to belong to the kingdoms Protista and Fungi, respectively. ●



MOSS
Sphagnum sp.



RED MARINE ALGA
Rhodomela sp.

Algae

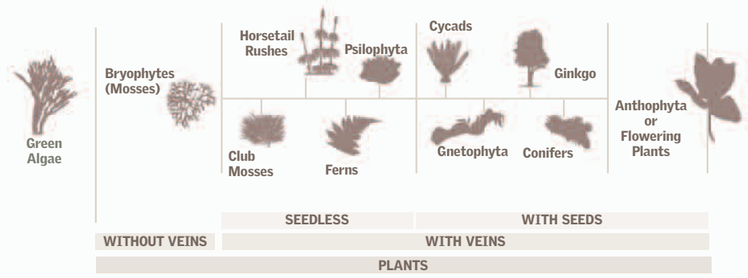
are commonly considered water plants, but this is not the case. Algae have neither roots nor stalks. Because they live in the water (freshwater or salt water), they need no substrate. Some are microscopic, but large algae formations can be found in the ocean. Algae are classified into families depending on their color. Together green algae and plants make up the group of organisms called the "green line," whose members are characterized by having chloroplasts and by storing grains of starch in the cytoplasm as a reserve.

Bryophytes

include mosses and worts. Mosses have rhizoids rather than roots. They can also absorb water through their entire body surface. Bryophytes lack a means of surviving long periods of drought. When dry periods come, bryophytes enter a latent state. Because they have no system of veins for transporting nutrients, they can barely grow beyond 0.4 inch (1 cm) long. In order to reproduce they need to be near liquid water.

Plants

The plant kingdom (Plantae) includes organisms whose characteristics include the presence of the pigment chlorophyll to convert solar energy into chemical energy for producing food from water and carbon dioxide. This ability is called autotrophy. All plants, whether large or small, play an extremely important role in providing food for all other living beings. Plants cannot move from place to place, but their gametes, spores (cells that separate from a plant and can germinate), and seeds can move about, especially with the help of water and wind.





SITKA SPRUCE
Picea sitchensis



CYCADS
are tropical plants that look like palm trees. Their reproduction is similar to that of pine trees, but they are dioecious (each plant has flowers of only one sex).



GINKGOS
Only one species is left in this group, which is the oldest genus of living trees.

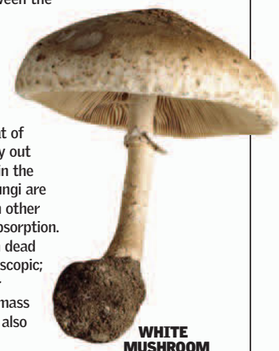


GNETOPHYTA
Plants with naked seeds and a vascular system similar to that of angiosperms

CONIFERS
are the most abundant plants with seeds today. Their reproductive structures are called cones. Most conifers are evergreens.

Gymnosperma

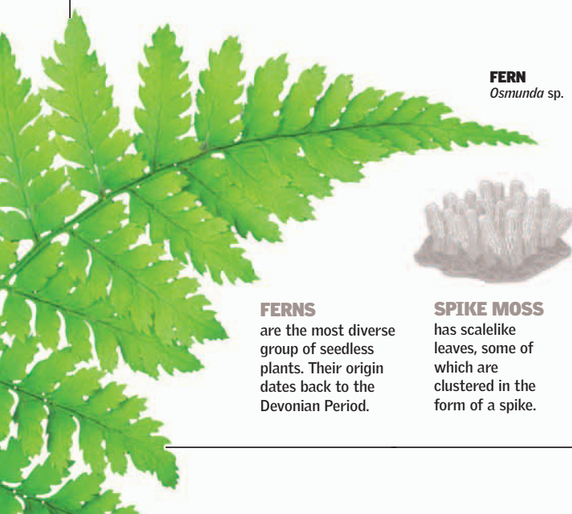
The Greek word means "naked seed." Gymnosperms are vascular plants with exposed seeds and no flowers. Ginkgos (Ginkgophyta) and cycads (Cycadophyta) were the most common plant groups in ancient times. Today conifers (such as pines, larches, cypresses, and firs) are the most common type. Conifers are monoicous—that is, the same plant has both male and female sexual organs—and their seeds are held between the scales of a structure called a cone.



WHITE MUSHROOM
Agaricus bisporus

Fungi

belong to a different kingdom from that of plants. Fungi, unlike plants, do not carry out photosynthesis, and they store energy in the form of glycogen rather than starch. Fungi are heterotrophic (they get their food from other organisms), and they take in food by absorption. Fungi can be either parasitic or feed on dead organic material. Some fungi are microscopic; others are large and conspicuous. Their bodies are composed of a mycelium, a mass of filaments called hyphae. Some fungi also have a fruit-bearing structure.



FERN
Osmunda sp.

FERNS
are the most diverse group of seedless plants. Their origin dates back to the Devonian Period.



SPIKE MOSS
has scalelike leaves, some of which are clustered in the form of a spike.

PSILOPHYTA
are extremely simple plants; they lack roots and true leaves, but they have a stalk with veins.



HORSETAIL RUSHES
have roots, stems, and true leaves. The leaves are small and encircle the stems.

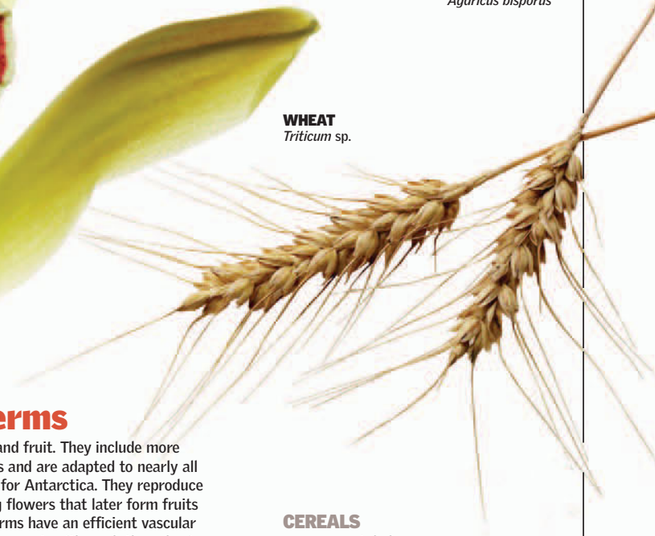
Seedless

Ferns are the most common seedless plants today. Many are thought to have originated during the Devonian Period and reached their greatest splendor in the Carboniferous Period. Their tissues are simpler than those of plants with seeds, and their green stems have a large surface area, giving them a great capacity for photosynthesis. Ferns need water so that they can reproduce by means of spores. The spores are produced in spore cases called sporangia, which grow on leaves called sporophylls.



ORCHID
Cattleya trianae

ORCHIDS
have many petals; their number of petals is always a multiple of three. This makes them, along with cereal grains, monocotyledons (monocots).



WHEAT
Triticum sp.

Angiosperms

have seeds, flowers, and fruit. They include more than 250,000 species and are adapted to nearly all environments except for Antarctica. They reproduce sexually by producing flowers that later form fruits with seeds. Angiosperms have an efficient vascular system for transporting water (through the xylem) and food (through the phloem). Angiosperms make up a division of the plant kingdom that includes plants with bright flowers; grains, such as rice and wheat; other crops, such as cotton, tobacco, and coffee; and trees, such as oak, cherry, and chestnut.

CEREALS
are monocotyledons. Their seeds have only one cotyledon (embryonic leaf), and their mature leaves have parallel veins.

Aquatic Plants

These plants are especially adapted for living in ponds, streams, lakes, and rivers—places where other land plants cannot grow. Although aquatic plants belong to many different families, they have similar adaptations and are therefore an example of adaptive convergence. They include submerged plants and floating plants; plants that may or may not be rooted at the bottom; amphibious plants, which have leaves both above and below the water's surface; and heliophilic plants, which have only their roots underwater.

A Vital Role

Aquatic plants play an important role in the ecosystem not only for crustaceans, insects, and worms but also for fish, birds, and mammals because they are an important source of food and shelter for these categories of animals. Aquatic plants also play a major role in converting solar energy into the organic materials upon which many living things depend.

Rooted Plants with Floating Leaves

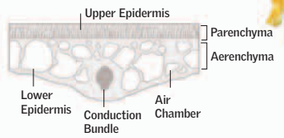
Such plants are often found in standing or slow-moving water. They have fixed rhizomes and petiolate leaves (leaves with a stalk that connects to a stem) that float on the surface of the water. Some of the plants have submerged leaves, some have floating leaves, and some have leaves outside the water, with each type having a different shape. In the case of floating leaves the properties of the upper surface are different from those of the lower surface, which is in contact with the water.

PARROT FEATHER
Myriophyllum aquaticum
This plant is native to temperate, subtropical, and tropical regions, and it is highly effective at oxygenating water.

TROPICAL WATER LILY
Victoria cruciana
It grows in deep, calm waters. Its leaves can measure up to 7 feet (2 m) across.



Floating Leaves
The rhizomes are fixed, the leaves grow on long stalks, and the leaf surface floats on the water.



YELLOW FLOATING HEART
Nymphoides peltata
It produces small creased yellow flowers all summer long.

LACHENALIA
Lachenalia viridiflora
This plant is attractive, with a large number of flowers.

Aquatic plant with especially beautiful flowers.

Amphibious or Wetland Plants

These species live on the edges of ponds, rivers, and swamps. They are also found in salt marshes, which are periodically flooded by tides or river overflows. These plants are a transition between aquatic and land plants. Their limiting factor is the availability of oxygen, so they have well-developed aerenchyma.

300 THE NUMBER OF WELL-KNOWN SPECIES OF WATER PLANTS

CATTAILS
Typha sp.
grow in moist soil, around lake margins, and in marshes in both temperate and tropical climates.

ARROWHEAD
Sagittaria sagittifolia
Its flowers, with three white petals and purple stamens, form during the summer.

Rooted Underwater Plants

The entire plant is submerged. The small root system serves only to anchor the plant since the stem can directly absorb water, carbon dioxide, and minerals. These plants are often found in flowing water. The submerged stems have no system of support—the water holds up the plant.

SAGO PONDWEED
Potamogeton densus
This water plant can be found in shallow depressions of clear-flowing streams.

HORNWORT
Ceratophyllum sp.
This plant has an abundance of fine leaves that form a conelike structure on each stem.

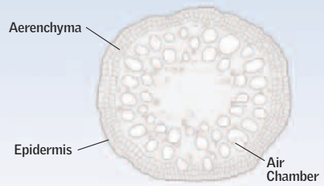
They produce and release oxygen as a result of photosynthesis.

Aquatic but Modern

The evolutionary history of plants began in water environments. They later conquered land by means of structures such as roots. Modern aquatic plants are not a primitive group, however. On the contrary, they have returned to the water environment by acquiring highly specialized organs and tissues. For example, some tissues have air pockets that enable the plant to float.

Aerenchyma

is always found in floating organisms. This tissue has an extensive system of intercellular spaces through which gases are diffused.



Submerged stems have no support system because the water holds up the plant. Their limiting factor is oxygen availability, so the aerenchyma helps make this substance available to the plant.

The roots and rhizomes under the water are well developed.

Submerged or Free

Some underwater plants are free, without roots, but with developed stalks and divided leaves. Other floating plants have a rosette shape and leaves modified for floating; they have well-developed roots with root caps but without absorbent hairs. The roots help the plant to stay balanced on top of the water.

KNOTWEED
Polygonum sp.
This aquatic plant grows in marshy vegetation.

BLADDERWORT
Utricularia vulgaris
These carnivorous plants complement their diet with small aquatic creatures.

EELGRASS
Vallisneria sp.
This oxygenating plant is found in ponds and aquariums.

The underwater parts do not have an impermeable outer layer, so they can absorb minerals and gases directly from the water.

Pneumatophores

are floating roots that are involved in air exchange. They take oxygen from the surface, and it circulates to the rest of the plant through its intracellular spaces. They probably also allow carbon dioxide to escape. Certain plants have a special adaptation that consists of air sacs that store oxygen for periods when the plant will be submerged or that speed up the plant's transpiration.

Conquest of Land

The movement of plants from shallow water onto land is associated with a series of evolutionary events. Certain changes in the genetic makeup of plants enabled them to face the new and extreme conditions found on the Earth's surface. Although land habitats offered plants direct exposure to sunlight, they also presented the problem of transpiration and the loss of water that it produces. This difficulty had to be overcome before plants could spread over land.

Vital Changes

Roots are among the most important adaptations for plants' success in land habitats. Root systems anchor the plant in the substrate and serve as a pathway for water and mineral nutrients to enter it. Besides roots, the development of a cuticle (skin membrane) to cover the entire plant's surface was crucial. Cells in the epidermis produce this waterproof membrane, which helps the plant tolerate the heat generated by sunlight and the wear and loss of water caused by the wind. This protection is interrupted by pores, which allow for gas exchange.

Green Revolution

Leaves are the main organs for photosynthesis in land plants. After plants appeared on land more than 440 million years ago, the amount of photosynthesis taking place gradually increased. This increase is believed to be one of the reasons the concentration of carbon dioxide in the atmosphere decreased. As a result, the Earth's average temperature also decreased.

50,000

SPECIES OF FUNGUS LIVE ALONGSIDE LAND-DWELLING PLANTS.

MOSS
***Sphagnum* sp.**
Bryophytes are the simplest of all land plants.

MALE FERN
Dryopteris filix-mas
These vascular plants need liquid water to reproduce.

Epiphytes

grow on plants or on some other supporting surface. Their anatomy includes secondary adaptations that enable them to live without being in contact with the soil.

Grasses

take advantage of long hours of summer daylight to grow and reproduce. Their stalks do not have reinforcing tissues that would enable them to remain erect.

SWEET VIOLET
Viola odorata
This plant's spring flowers have a pleasant scent.

STEMLESS SOW THISTLE
Sonchus acaulis
These plants lack a stem.

Giants

Trees are distinguished by their woody trunks. As a tree grows from a tender shoot, it develops a tissue that gives it strength, enabling it to grow over 330 feet (100 m) tall. Trees are found in the principal terrestrial ecosystems.

CHESTNUTS
Castanea sp.

WALNUTS
Juglans sp.

BEECHES
Fagus sp.

MAPLES
Acer sp.

OAKS
Quercus sp.

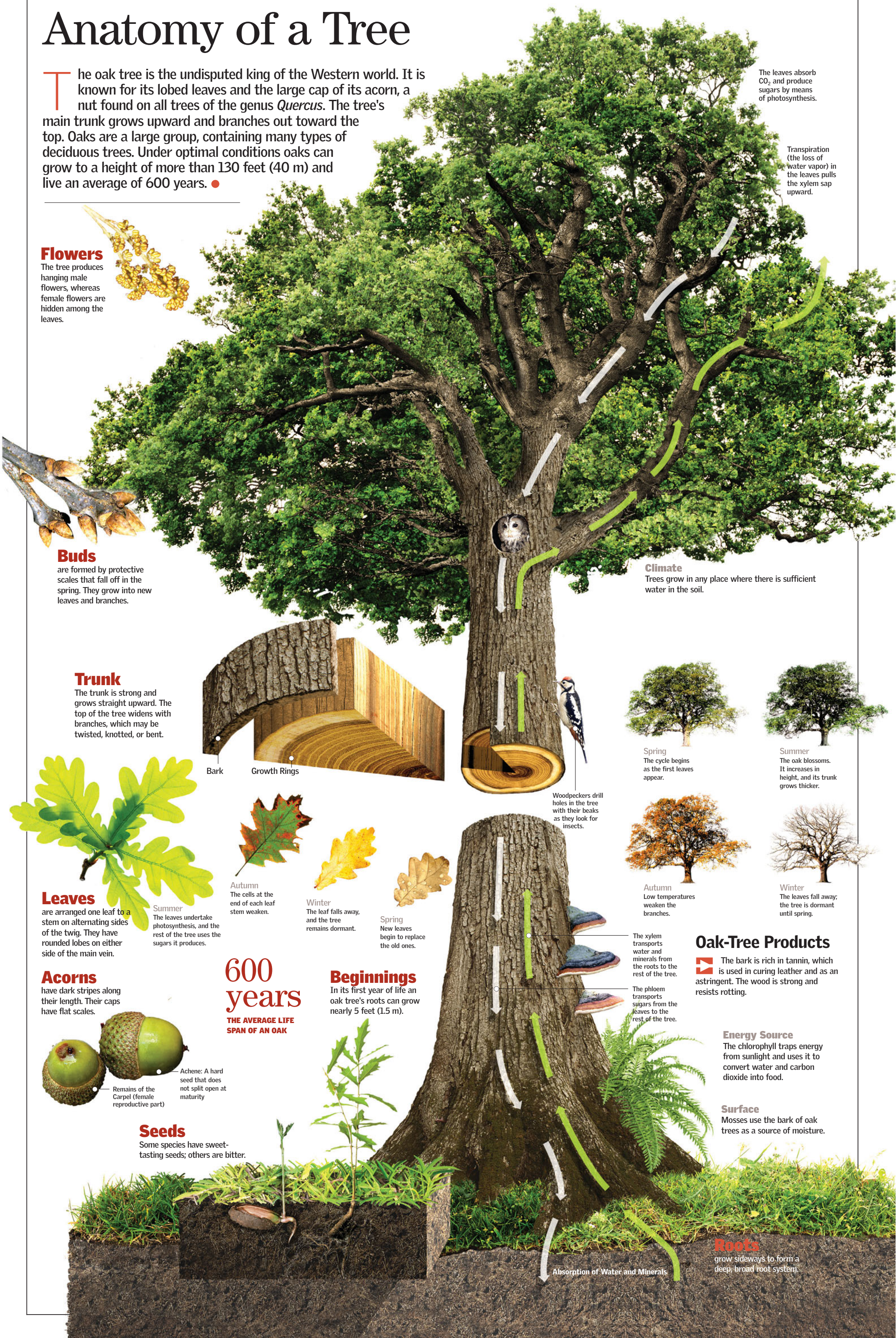
LINDENS
Tilia sp.

360 Feet
(110 M)

THE HEIGHT REACHED BY SOME SEQUOIA SEMPERVIREN TREES

Anatomy of a Tree

The oak tree is the undisputed king of the Western world. It is known for its lobed leaves and the large cap of its acorn, a nut found on all trees of the genus *Quercus*. The tree's main trunk grows upward and branches out toward the top. Oaks are a large group, containing many types of deciduous trees. Under optimal conditions oaks can grow to a height of more than 130 feet (40 m) and live an average of 600 years.



Flowers
The tree produces hanging male flowers, whereas female flowers are hidden among the leaves.

Buds
are formed by protective scales that fall off in the spring. They grow into new leaves and branches.

Trunk
The trunk is strong and grows straight upward. The top of the tree widens with branches, which may be twisted, knotted, or bent.

Bark

Growth Rings

Leaves
are arranged one leaf to a stem on alternating sides of the twig. They have rounded lobes on either side of the main vein.

Summer
The leaves undertake photosynthesis, and the rest of the tree uses the sugars it produces.

Autumn
The cells at the end of each leaf stem weaken.

Winter
The leaf falls away, and the tree remains dormant.

Spring
New leaves begin to replace the old ones.

Acorns
have dark stripes along their length. Their caps have flat scales.

Achene: A hard seed that does not split open at maturity

Remains of the Carpel (female reproductive part)

Seeds
Some species have sweet-tasting seeds; others are bitter.

600 years
THE AVERAGE LIFE SPAN OF AN OAK

Beginnings
In its first year of life an oak tree's roots can grow nearly 5 feet (1.5 m).

The leaves absorb CO_2 and produce sugars by means of photosynthesis.

Transpiration (the loss of water vapor) in the leaves pulls the xylem sap upward.

Woodpeckers drill holes in the tree with their beaks as they look for insects.

Spring
The cycle begins as the first leaves appear.

Summer
The oak blossoms. It increases in height, and its trunk grows thicker.

Autumn
Low temperatures weaken the branches.

Winter
The leaves fall away; the tree is dormant until spring.

The xylem transports water and minerals from the roots to the rest of the tree.

The phloem transports sugars from the leaves to the rest of the tree.

Oak-Tree Products
The bark is rich in tannin, which is used in curing leather and as an astringent. The wood is strong and resists rotting.

Energy Source
The chlorophyll traps energy from sunlight and uses it to convert water and carbon dioxide into food.

Surface
Mosses use the bark of oak trees as a source of moisture.

Climate
Trees grow in any place where there is sufficient water in the soil.

Absorption of Water and Minerals

Roots
grow sideways to form a deep, broad root system.

Feeding on Light

An important characteristic of plants is their ability to use sunlight and the carbon dioxide in the air to manufacture their own complex nutrients. This process, called photosynthesis, takes place in chloroplasts, cellular components that contain the necessary enzyme machinery to transform solar energy into chemical energy. Each plant cell can have between 20 and 100 oval-shaped chloroplasts. Chloroplasts can reproduce themselves, suggesting that they were once autonomous organisms that established a symbiosis, which produced the first plant cell.



Why Green?

Leaves absorb energy from visible light, which consists of different colors. The leaves reflect only the green light.

Leaves

are made of several types of plant tissues. Some serve as a support, and some serve as filler material.

Algae

perform photosynthesis underwater. Together with water plants, they provide most of the atmosphere's oxygen.

O_2 IS RELEASED BY PLANTS INTO THE EARTH'S ATMOSPHERE

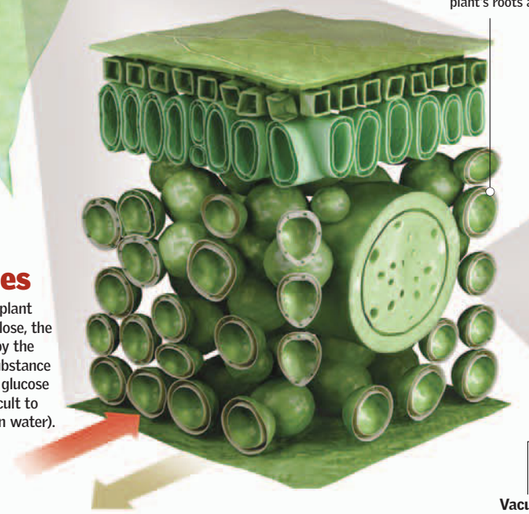


CHLOROPHYLL
is the most abundant pigment in leaves.

WATER
Photosynthesis requires a constant supply of water, which reaches the leaves through the plant's roots and stem.

Plant Cells

have three traits that differentiate them from animal cells: cell walls (which are made up of 40 percent cellulose), a large vacuole containing water and trace mineral elements, and chloroplasts containing chlorophyll. Like an animal cell, a plant cell has a nucleus.

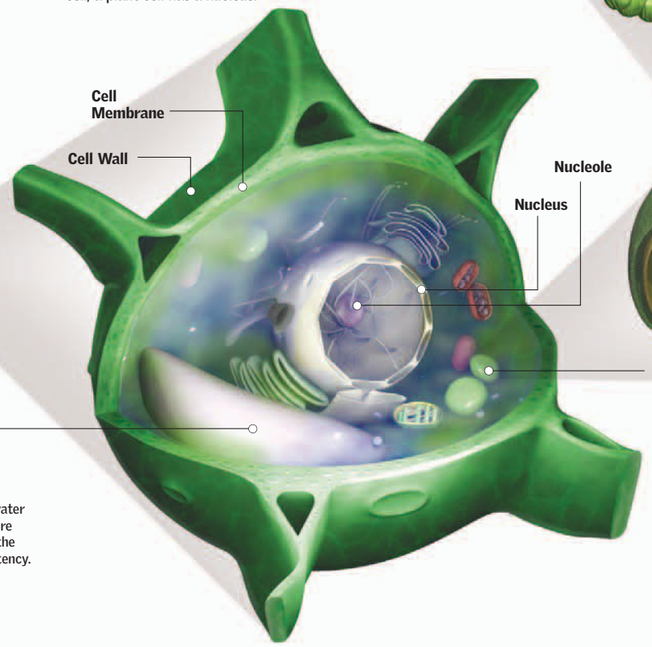


Plant Tissues

The relative stiffness of plant cells is provided by cellulose, the polysaccharide formed by the plant's cell walls. This substance is made of thousands of glucose units, and it is very difficult to hydrolyze (break down in water).

CARBON DIOXIDE
is absorbed by plant cells to form sugars by means of photosynthesis.

OXYGEN
is a by-product of photosynthesis. It exits the surface of the leaves through their stoma (two-celled pores).



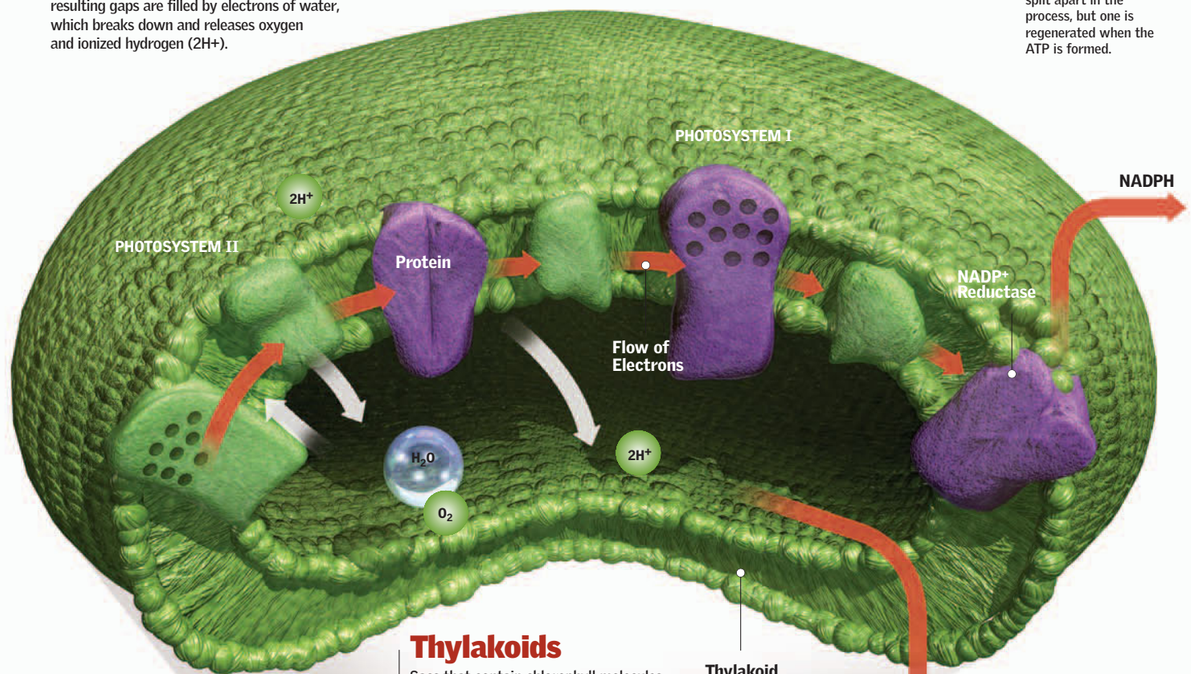
Stages of the Process

Photosynthesis takes place in two stages. The first, called photosystem II, depends directly on the amount of light received, which causes the chlorophyll to release electrons. The resulting gaps are filled by electrons of water, which breaks down and releases oxygen and ionized hydrogen (2H+).

1 ATP formation is powered by the movement of electrons into receptor molecules in a chain of oxidation and reduction reactions.

2 In photosystem I light energy is absorbed, sending electrons into other receptors and making NADPH out of $NADP^+$.

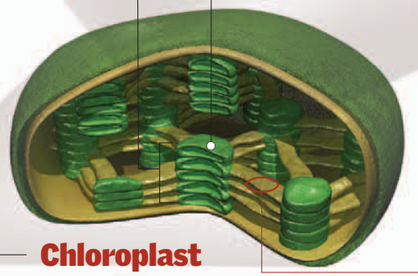
3 The ATP and NADPH obtained are the net gain of the system, in addition to oxygen. Two water molecules are split apart in the process, but one is regenerated when the ATP is formed.



4 In photosystem I ATP is also generated from ADP because of the surplus flow of free electrons.

Thylakoids

Sacs that contain chlorophyll molecules. Inside them ADP is converted into ATP as a product of the light-dependent phase of photosynthesis. Stacked thylakoids form a structure called a grana.

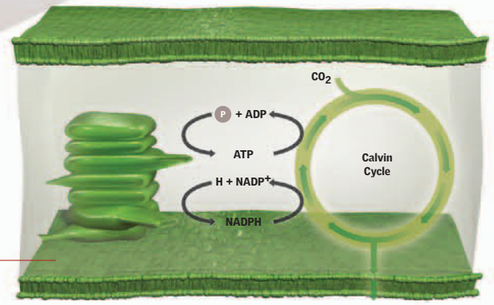


Chloroplast

The part of the cell where both phases of photosynthesis take place. It also contains enzymes.

Stroma

is the watery space inside the chloroplast.



The Dark Phase

This phase, so called because it does not directly depend on light, takes place inside the stroma of the chloroplast. Energy in the form of ATP and NADPH, which was produced in the light-dependent phase, is used to fix carbon dioxide as organic carbon through a process called the Calvin cycle. This cycle consists of chemical reactions that produce phosphoacylglycerides, which the plant cell uses to synthesize nutrients.

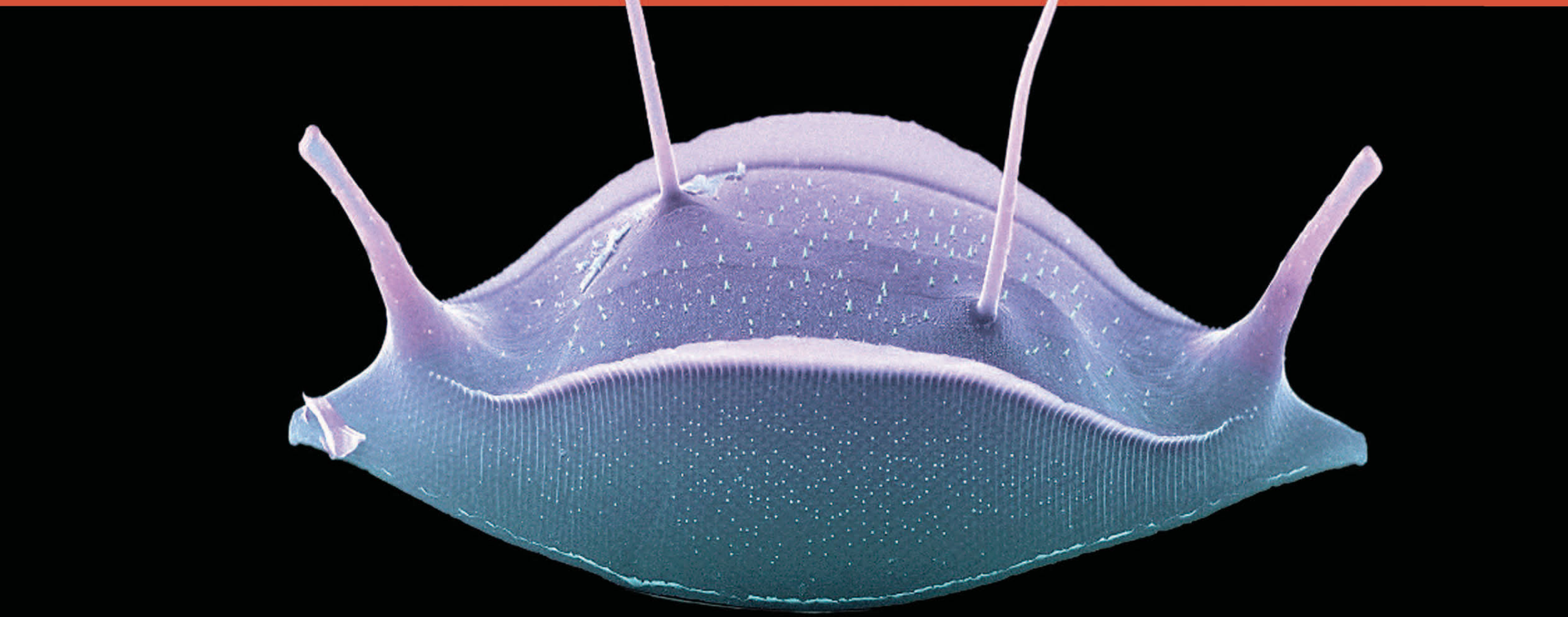
END PRODUCTS
enable the plant to generate carbohydrates, fatty acids, and amino acids.

Carbon
THE BUILDING BLOCK OF ORGANIC MATERIALS

From Algae to Ferns

DIATOMACEOUS ALGAE
The scientific name of this type of single-celled algae is *Biddulphia laevis*. It is usually found close to the surface of very shallow bodies of water.

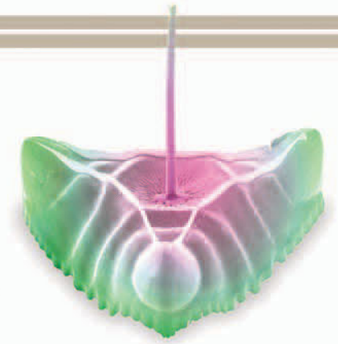
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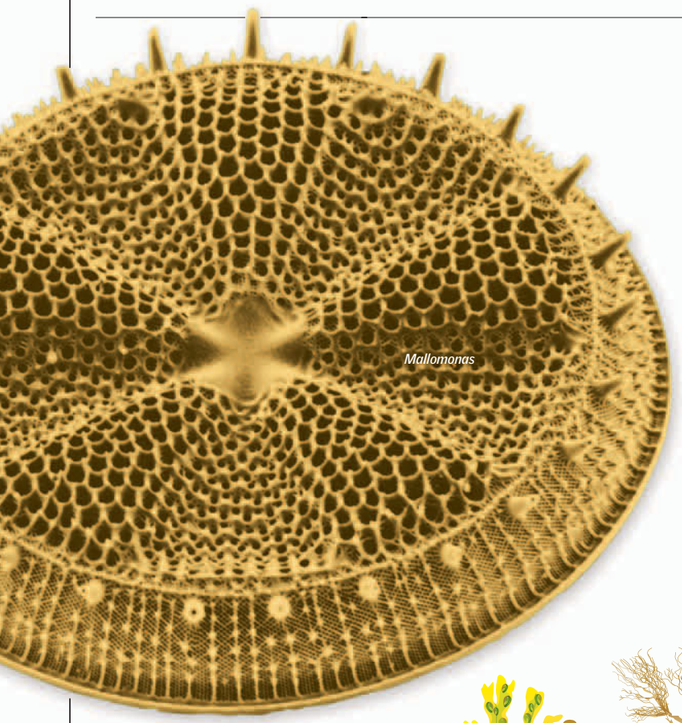


Algae (including seaweed) do not belong to the plant kingdom, because they do not have all the characteristics and functions of plants. Algae have neither roots nor stems. Because they live in water, they do not need these structures for absorbing water. Algae grow on the sea floor or on the surface of rocks in the ocean, in rivers, and in lakes. Their shape and color are extremely varied. The annual world harvest of algae is estimated at more than 1 million tons in dry weight. Asian countries (Japan and China) produce 80 percent of the world's harvest. Algae are used in agriculture, the food industry, pharmaceuticals, preservatives, and medicine. They are an important source of income for many workers. ●

Colors of Life

Algae are living things that manufacture their own food using photosynthesis. Their color is related to this process, and it has been used as a way of classifying them. They are also grouped according to the number of cells they have. There are many kinds of one-celled algae. Some algae form colonies, and others have multicellular bodies. Some types of brown seaweed can reach a length of more than 150 feet (45 m).





Mallomonas

Single-Celled Organisms

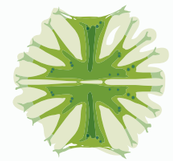
often have flagella that enable them to move through the water. Most have the ability to ingest solid material through phagocytosis. Single-celled algae include some distinctive groups. Diatoms are covered with a protective shell made of silicon. Some single-celled algae, namely red algae, can thrive at relatively high temperatures. Red algae is unique among eukaryote organisms in its ability to live inside thermal water vents.

GREAT OPPORTUNISTS

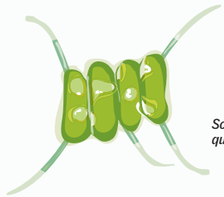
Single-celled algae live near the surface of bodies of water. When they find an area with light and the nutrients necessary for development, they use asexual reproduction to multiply and colonize the area.

Multicelled Organisms

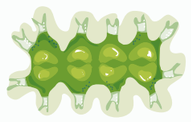
This group of algae includes multicelled structures. They form colonies with mobile, single-celled algae that group together more or less regularly in a shared mucilaginous capsule. They can also appear in threadlike shapes, which branch off, or in bulky shapes, which are made up of layers of cells with a particular degree of cellular differentiation, that together are called a thallus.



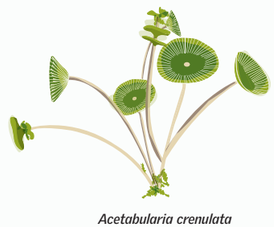
Micrasteria rotata



Scenedesmus quadricauda



Micrasteria staurastrum



Acetabularia crenulata



Pinnularia borealis

2 Chlorophytes

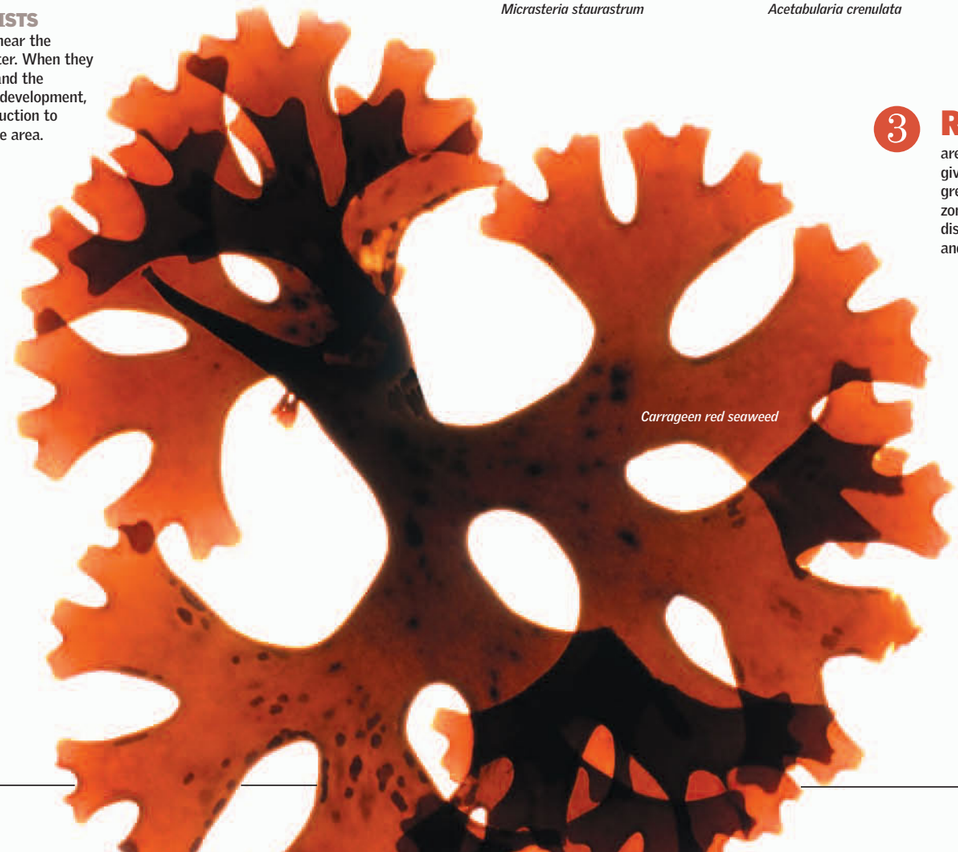
constitute the group of green algae. The majority of species are microscopic, single-celled organisms with flagella. Others form into filaments, and yet others form large multicellular bodies. The group Ulvophyceae includes sea lettuce, which resembles a leaf of lettuce and is edible. The group Charophyceae includes stoneworts, which contain calcium carbonate deposits. The chlorophytes are linked evolutionally with plants because they contain the same forms of chlorophyll, and their cell walls contain cellulose.

Chlamydomonas

6,000

DIFFERENT SPECIES

have been classified within this group of green algae, or chlorophytes.



Carrageen red seaweed

1 Phaeophytes

are the 1,500 species of brown seaweed. They inhabit temperate regions and the rocky coasts of the coldest seas on Earth. Their color comes from the pigment fucoxanthin, a xanthophyll that masks the green color of their chlorophyll.



Fucus vesiculosus



Dictyota dichotoma implexa



Dictyota dichotoma hudson lamouroux



Cystoseira amantacea stricta



Ectocarpus siliculosus

3 Rhodophytes

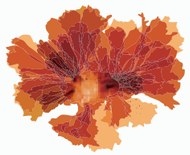
are characterized by their phycoerythrin pigments, which give the algae a reddish color by masking their chlorophyll's green color. Most rhodophytes grow below the intertidal zone near tropical and subtropical coasts. They are distributed throughout the principal oceans of the world and grow mainly in shaded areas in warm, calm water.



Hypoglossum hypoglossoides



Bangia atropurpurea



Nitophyllum punctatum



Halymenia floresia



Apoglossum ruscifolium

How Algae Reproduce

The reproduction of algae can be sexual or asexual in alternating phases, depending on the species and on environmental conditions. Vegetative multiplication occurs through fragmentation or through the production of spores. In sexual reproduction the fertilization of the gametes (sexual cells) produces a zygote that will give rise to a new alga. During asexual reproduction there is no genetic exchange, and the algae produced are clones of the original. Sexual reproduction, in contrast, produces algae with new characteristics that may help them to better adapt to their environment.

Asexual

Asexual reproduction does not involve fertilization. It can take place in either of two ways. In fragmentation, segments of an alga become detached from its body, and, since the alga does not have any specialized organs, the segments continue to grow as long as environmental conditions remain favorable. The other form of asexual reproduction is by means of spores, special cells that form from a normal cell. Some algae spores have one or more filaments, or flagella, that allow the alga to swim freely. When the appropriate environmental conditions are found, the spores germinate into new algae.



ZOOSPORE
A structure that can produce a new individual asexually

Sexual

Sporophytes generate spores in every species of microscopic algae. New individuals born from these spores are called gametophytes, and they produce gametes, which can be male, female, or hermaphrodite. During fertilization the male gametes (antheridia) and the female ones (ovum) form a cell called a zygote, which develops into a new thallus when it grows. Gametocytes and sporophytes can vary in morphology. If they are similar, they are called isomorphic, and if they are different, they are called heteromorphic.



MALE FUCUS
The male fucus has receptacles in which antheridia form.

1

Antheridium

The male gametangia (structure that produces gametes). They produce antherozoids, which have two flagellae and are smaller than the ovum, or female gamete. They swim until they reach an ovum and then surround it.

JOURNEY
Once they become detached, antherozoids use their flagella to move in the water.

Transverse cut from a *Fucus* species thallus

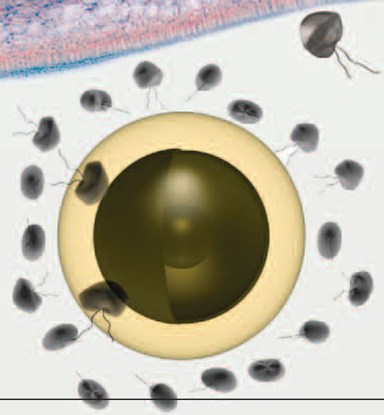


ANOTHER CYCLE
The youthful thallus, when mature, produces spores.

3

New Thallus

After fertilization the zygote divides and creates the embryo, a small cell mass that attaches to rocks, where a new thallus of *Fucus* species grows. The thallus looks similar to the stem of plants, and it contains blades that look like leaves.



2

Fertilization

Both fertilization and asexual reproduction are the natural means of perpetuation for this species. Algae form new individuals similar to themselves through reproduction. When an antherozoid penetrates the ovum, it fertilizes the egg and forms a zygote.

OPENING
The sac that contains the ovum opens.

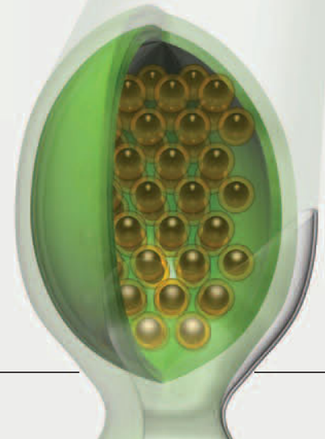


APPROACH
The journey of the antherozoids coincides with the opening of the female gametangia.

1

Ovum

In the reproductive stage female gametangia form at the tips of the thalluses. This is where the female sexual cells (ova) develop.





FEMALE FUCUS
The receptacles secrete a greenish gelatin made up of female gametes. The gametes are freed when the sac that contains them breaks.

Terrestrial and Marine Algae

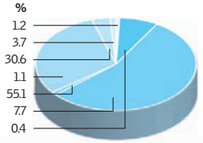
As long as there is water, the survival of an alga is assured. Algae are found both in the oceans and in freshwater, but not all can survive in both environments. Depth, temperature, and salt concentrations of water are characteristics that determine whether algae can live in a given area. Algae can be green, brown, or red. Of the three, red algae are found in the deepest waters. Some species of algae can live outside of water, but they are nevertheless found in humid places, such as in mud or on stone walls or rocks.

2 Concentration of Salts

The waters that cover the Earth's surface are classified into two types: salt water, which forms the oceans and seas, and freshwater, or continental water. Marine water has a concentration of dissolved salts that is generally considered to be uniform. In contrast, the salt concentration of continental water can vary from place to place, causing it to have a different effect on living organisms.

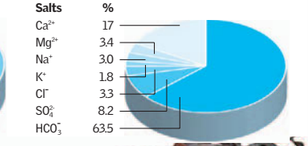
MARINE WATER

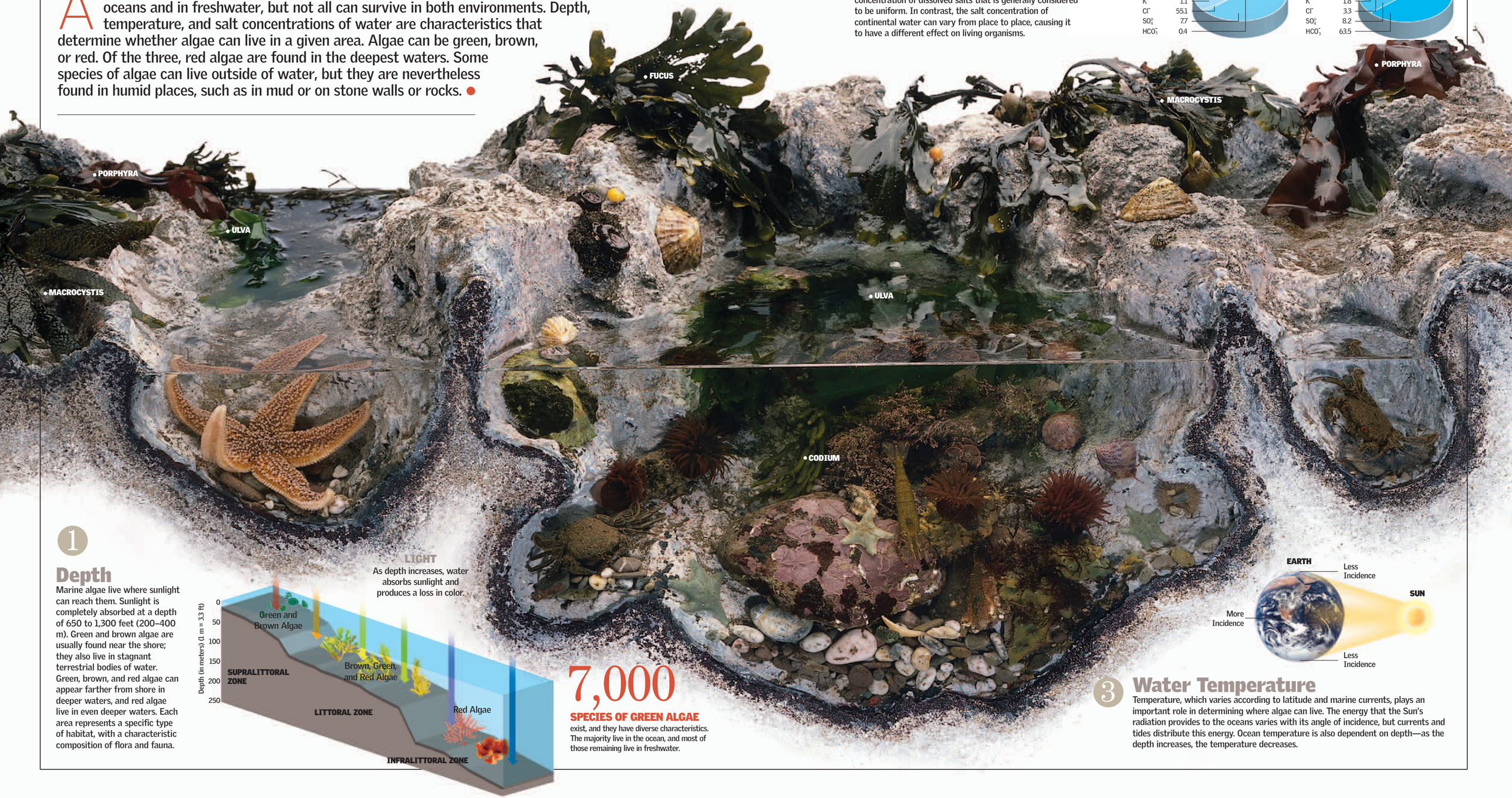
Salts	%
Ca^{2+}	1.2
Mg^{2+}	3.7
Na^{+}	30.6
K^{+}	1.1
Cl^{-}	55.1
SO_4^{2-}	7.7
HCO_3^{-}	0.4



FRESHWATER

Salts	%
Ca^{2+}	17
Mg^{2+}	3.4
Na^{+}	3.0
K^{+}	1.8
Cl^{-}	3.3
SO_4^{2-}	8.2
HCO_3^{-}	63.5





1 Depth

Marine algae live where sunlight can reach them. Sunlight is completely absorbed at a depth of 650 to 1,300 feet (200–400 m). Green and brown algae are usually found near the shore; they also live in stagnant terrestrial bodies of water. Green, brown, and red algae can appear farther from shore in deeper waters, and red algae live in even deeper waters. Each area represents a specific type of habitat, with a characteristic composition of flora and fauna.

7,000

SPECIES OF GREEN ALGAE

exist, and they have diverse characteristics. The majority live in the ocean, and most of those remaining live in freshwater.

3 Water Temperature

Temperature, which varies according to latitude and marine currents, plays an important role in determining where algae can live. The energy that the Sun's radiation provides to the oceans varies with its angle of incidence, but currents and tides distribute this energy. Ocean temperature is also dependent on depth—as the depth increases, the temperature decreases.

The Algae Industry

In China algae have been used for food, as well as for traditional medicine, for thousands of years. However, the algae industry began on a broad scale in the 17th century in Japan with the production of caustic soda and potassium hydroxide from the ashes of brown algae. A century later Western countries began to exploit algae in order to extract iodine and other chemical compounds of great economic value, such as phycocolloids (gelatin-like substances that can be obtained from several species of algae). The most commonly used phycocolloids are agar, carrageenan, and algin.



A World of Uses

Algae extracts are used in the manufacture of food products, medicines, cosmetics, medical supplies, and even tools. They can serve as emulsifying, stabilizing, thickening, or clarifying agents. Algae extracts are used in ice cream pie fillings, puddings, and salad dressings. They are also used for making molds in dentistry, for lubrication in drawing wire, and as a medium for culturing bacteria.



MILLING
The dry ground agar is milled to reduce particle size.

150 pounds
per square inch (10 kg/sq cm)
IS THE PRESSURE AT WHICH HOT AIR IS APPLIED TO DRY THE MASS.



Dulse
Palmaria sp.

How Agar Is Obtained

Most algae collection is still done by hand, although commonly used large species, such as the Caribbean Sargasso, are also collected with special boats in which processing of the algae can begin. The first stages, especially drying, are typically carried out by natural methods, but large fire-heated drying drums are used in some countries of Europe and North America. Although the use of heated drums is more expensive, it can result in a product of higher quality.

1.5
TONS PER DAY
The amount of *Gelidium* algae extractd by hand in Japan.

REGENERATION
In order for the algae to grow back, only 40 percent of it is harvested.



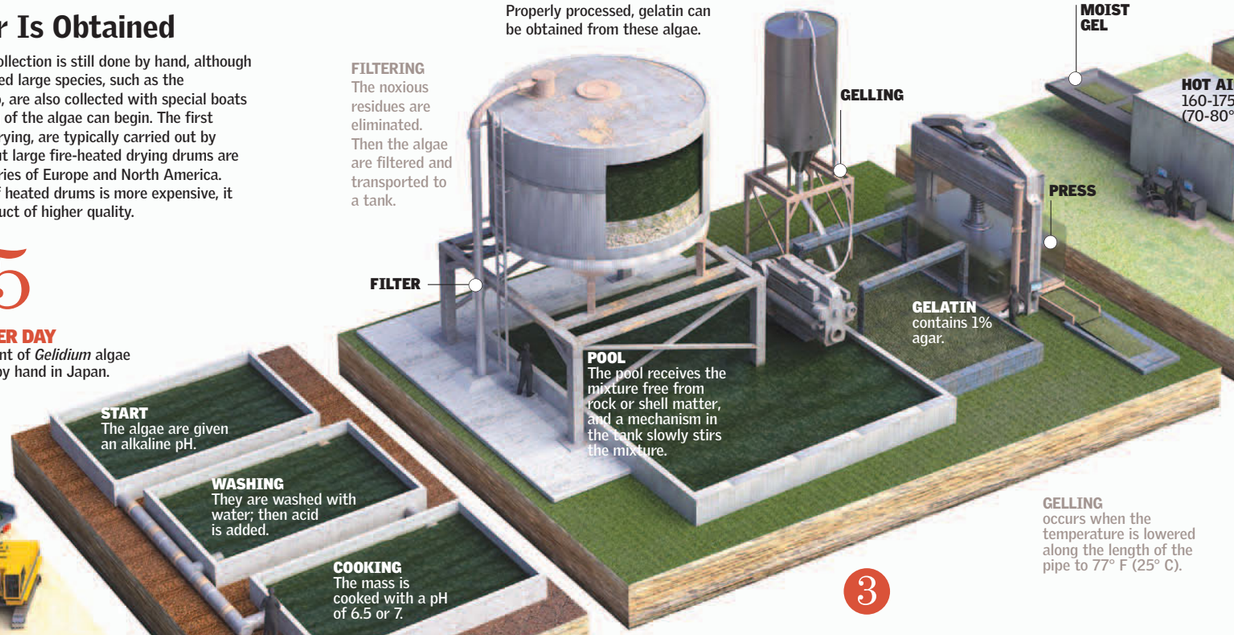
1

Alkalinization

After the dry bundles are gathered, the algae are transported to an alkaline treatment pond. There sodium hydroxide (NaOH) is added, and the mixture is heated to a temperature of 176° F (80° C). The mixture is then washed and hydrated with cold water.

DRY ALGAE
Properly processed, gelatin can be obtained from these algae.

FILTERING
The noxious residues are eliminated. Then the algae are filtered and transported to a tank.



BASINS
can withstand high temperatures. In the last basin the mass is cooked at 212° F (100° C).

2

Washing and Bleaching

After the alkaline treatment algae pass through a process in which they are washed with cold water. To ensure an even processing, compressed air is bubbled through the water. Later sodium hypochlorite is added to bleach the algae. Some sulfuric acid can be added to this mixture to regulate acidity.

2 hours
THE APPROXIMATE LENGTH OF TIME THE ALGAE IS COOKED

GELLING
occurs when the temperature is lowered along the length of the pipe to 77° F (25° C).

3

Transformation

An initial filtering step uses only water and a filtering soil. The mixture must be kept in continuous motion and injected with steam to prevent it from separating. The mixture then passes through stainless steel pipes in which it is cooled to obtain a gelatin that contains 1 percent agar.

9 pounds
(4 kg)
THE QUANTITY OF FRESH ALGAE NEEDED TO OBTAIN ABOUT 2 POUNDS (1 KG) OF DRY ALGAE.



IN MEDICINE
Agar has laxative properties. Agar is also used as a medium for culturing microorganisms.



4

Drying

Gel sheets about 0.4 inch (1 cm) wide come out of the press between layers of nylon. They are placed on platforms, where they begin to dry. The sheets are then placed on a conveyor belt and further dried by a stream of hot air.

PRECAUTION
The dried algae must be ground immediately to prevent it from becoming moist.

5

Finishing

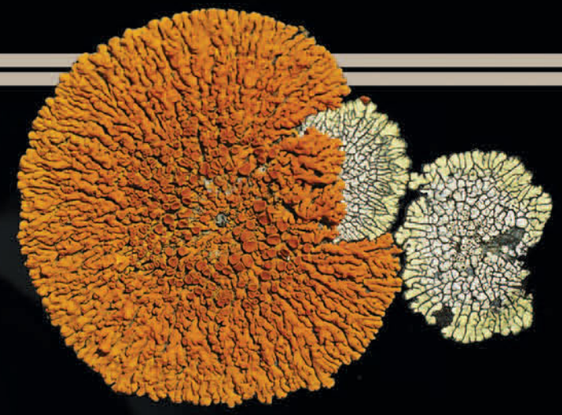
Ground into a powder, the product must go through successive milling and sifting steps to eliminate any lumps and impurities. Samples are taken as the algae product is refined. Once it has passed inspection, the final product is packaged.



COLLOID
Algae extract is soluble only in hot water. It is used to add consistency to dairy products such as cheese, as well as to other food products.

Strange Bedfellows

Lichens are the result of a close relationship between fungi and algae (usually green algae). Although they are most common in cold areas, they adapt easily to diverse climatic conditions. Lichens can grow in the Arctic glacial regions, as well as in deserts and volcanic regions. They live on rocks, from which they obtain all the necessary minerals to live, and they contribute to the formation of soils. Lichens are excellent indicators of the level of environmental pollution, since elevated levels of pollution cause them to die.



Crustaceans

With an appearance of scales, tightly affixed to the substratum, they can be continuous or fragmented in plates or areolas.

Physcia caesia



0.04 to 0.08 inch (1-2 mm)

Where They Live

Lichens grow in cold regions, as well as in the Amazon Rainforest and the desert. They are very sensitive to environmental pollution.

Corticolas
In trunks and branches



Terricolas
In the soil of forests



Saxicola
On rocks and walls.



Fructicose

The long-branched thallus is raised or hanging and can resemble small trees or entangled bushes.

Pseudoevernia sp.



0.08 to 0.15 inch (2-4 mm)

IN THE MOUNTAINS
This lichen is common on the bark of mountain conifers. Its thallus looks like horns.

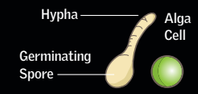
STIPES
The stipes are projections on the surface of the thallus at which vegetative multiplication takes place. Their shape is variable, and their color may be the same as or slightly darker than that of the thallus.

A Symbiotic Relationship

Lichens are the result of symbiosis between a fungus and an alga, a relationship from which both benefit. In a lichen the fungus offers the alga support and moisture and protects it from heat and dehydration. Likewise, the alga produces food for itself and for the fungus through photosynthesis.

HOW IT IS CREATED

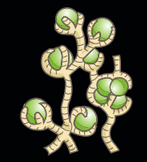
1 The spore of the fungus encounters the alga.



2 The spore grows around the alga, and the alga reproduces.



3 They form a new organism (thallus of the lichen).



Foliaceous

A showy lichen that has the appearance of widely spread leaves. It is the most common macrolichen.

Lobaria pulmonaria

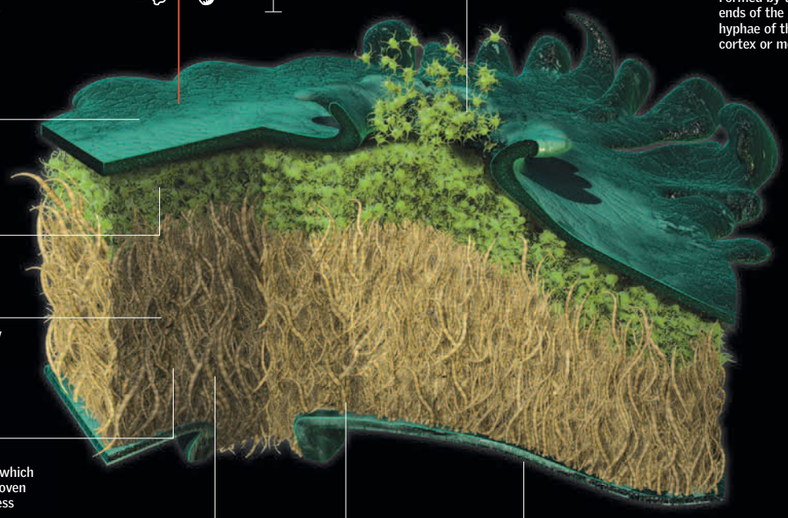


0.1 to 0.2 inch (3-6 mm)

APOTHECIA
intervenes in the reproduction of the fungus because it contains its spores.

SOREDIA
Unit of lichen dispersion, formed by groups of gonidia surrounded by hyphae

HAIRS
Formed by the ends of the hyphae of the cortex or medulla



LAYER OF ALGAE
The layer contains green algae, which carry out photosynthesis to feed the fungus.

GONIDIA
Name given to algae when they form part of a lichen

LAYER OF FUNGI
The fungi are generally ascomycetes. They provide the alga with the moisture it needs to live.

HYPHAE
Fungal filaments, which are interwoven and colorless

MEDULLA
Made up of fungus hyphae

RICIN
Fixation organs that arise from the cortex or from the medulla

CORTEX
External layer of the lichen

15,000
CLASSES OF LICHENS EXIST.

0.8 inch (2 cm)
THE AMOUNT A LICHEN CAN GROW IN A YEAR.

4,000 years
THE LIFE SPAN A LICHEN CAN ACHIEVE

Mosses

Mosses were among the earliest plants to emerge. They evolved from green algae more than 250 million years ago and belong to the group of simple plants called bryophytes. Mosses reproduce only in environments where liquid water is present. Because they grow in groups, they take on the appearance of a green carpet. These primitive plants can serve as indicators of air pollution, and they help reduce environmental degradation.

Fertilization

Reproductive organs that produce gametes develop in the green gametophytes, which live all year long. When there is sufficient moisture, the male gamete reaches a female gamete and fertilizes it. The zygote that arises from this union grows and forms the sporophyte. The sporophyte possesses fertile tissue that undergoes meiosis to generate spores that, after falling to the ground and germinating, will form a new gametophyte.

ZYGOTE
It forms from the union of two sexual cells in a watery environment.

DEVELOPMENT OF THE SPOROPHYTE
The zygote divides through mitosis and forms the sporophyte, which remains united to the gametophyte.

ADULT SPOROPHYTE
The adult sporophyte consists of a capsule (within which the spores form), a stalk (which holds the capsule), and a foot.

DIPLOID

Diploid cells have two sets of chromosomes. Consequently, they have duplicate genetic information.

Spermatozoids

Archegonium: the female sexual organ

Antheridium: the male sexual organ

Ovule

ADULT GAMETOPHYTE
This is what a grown gametophyte looks like.

HAPLOID

A haploid cell is one that contains only one complete set of genetic information. Reproductive cells, such as the ova and sperm in mammals, are haploid, but the rest of the cells in the body of higher organisms are usually diploid—that is, they have two complete sets of chromosomes. In fertilization two haploid gametes unite to form a diploid cell. In the case of mosses all the cells of the gametophyte, the gametes, and the spores are haploid.

GAMETOPHYTE DEVELOPMENT
The gametophyte grows.

HORIZONTAL FILAMENTS
The gametophyte develops from the horizontal filaments.

GERMINATION OF THE SPORE
The spore germinates and gives rise to a filamentous protonema (cellular mass).

Rhizoids

The Cycle of Life

Mosses do not have flowers, seeds, or fruits. As with other plants, mosses have a life cycle formed by alternating generations; however, in contrast with vascular plants, the haploid gametophyte is larger than the diploid sporophyte. Their biological cycle begins with the release of spores, which form in a capsule that opens when a small cap called the operculum is ejected. The spores germinate and give rise to a filamentous protonema (cellular mass) from which the gametophyte develops. The zygote that forms from the union of the two sexual cells develops into the sporophyte.

Capsule
Operculum
Sporophyte
Stalk
Perichaetium
Calyptra
Gametophyte
Rhizoid

Annulus

Operculum
A type of cap that covers the opening of the capsule and normally separates when the spores exit

Meiosis

Meiosis is a type of cellular division in which each daughter cell receives only one complete set of chromosomes. Therefore, the resulting cells have half as many chromosomes as the parent cells had. In general, this mechanism generates the gametes, but mosses generate haploid spores in the capsule of the sporophyte.

Mature Sporophyte
consists of a capsule in which spores are formed.

SPORES
The life cycle of a moss begins with the freeing of the spores that form in the capsule, which opens when a cap called the operculum is expulsed.

FUNARIA HIGROMETRICA
belongs to the group of plants called bryophytes.

Capsule
contains the spores and is found at the tip.

10,000
SPECIES OF MOSSES
have been classified within the bryophite group of nonvascular plants.

Small Plants

Mosses are bryophytes. They are relatively small plants that affix themselves to a substratum via rhizoids and carry out photosynthesis in small "leaves" that lack the specialized tissues of the real leaves of vascular plants. They fulfill a very important ecological role: they participate in the formation of soils by decomposing the rocks on which they grow, and they contribute to the photosynthesis of epiphytes in rainforests. Their asexual reproduction occurs through fragmentation or the production of propagula.

SPOROPHYTE
The sporophyte does not have an independent existence but lives at the expense of the gametophyte. The sporophyte lives a short time and only during a certain time of the year.

0.2 inch (5 mm)

Dispersion of Spores

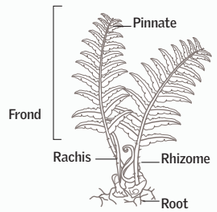
The fern is one of the oldest plants. Ferns have inhabited the surface of the Earth for 400 million years. Their leaves have structures called sori that contain the sporangium, which houses the spores. When the sori dry up, they release the spores into the air. Once on the ground, the spores germinate as gametophytes. In times of rain and abundant moisture the male cells of the gametophyte are able to swim to reach female gametes, which they fertilize to form a zygote that will grow as a sporophyte.

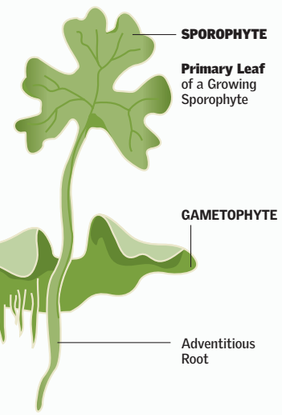


1 Birth

The zygote develops into a structure called a sporophyte; it is the part visible to the naked eye. In some cases it has the appearance of a **serrated leaf.**

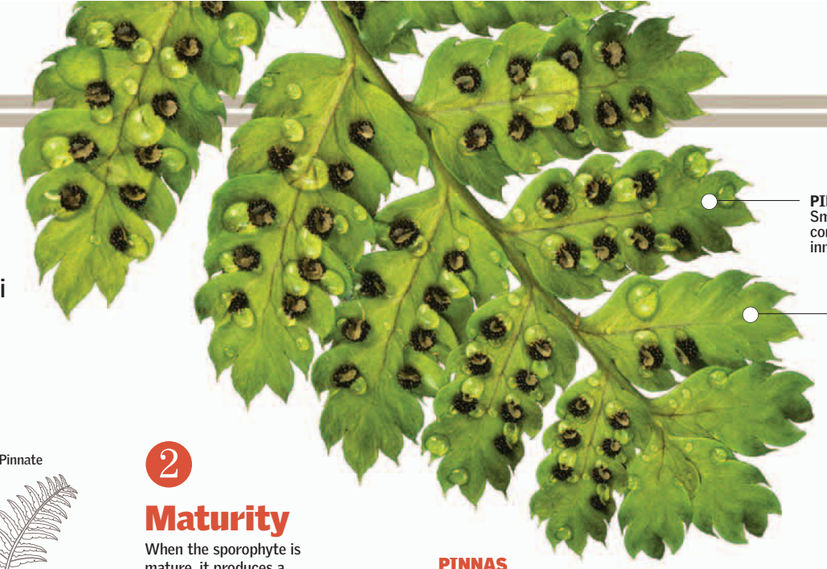
CIRCINATE VERNATION
The manner in which fronds expand from a bud by unfurling from the tip





2 Maturity

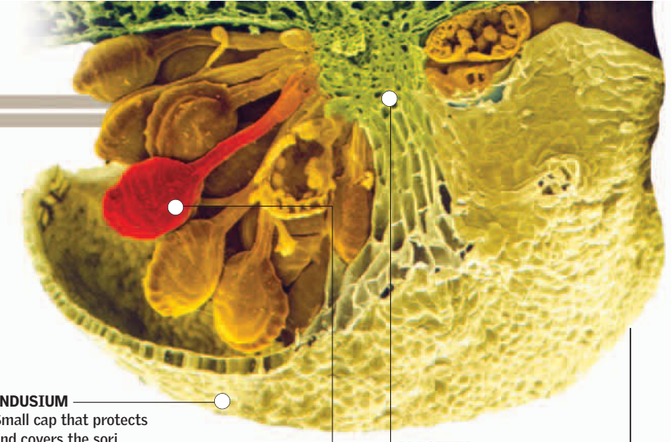
When the sporophyte is mature, it produces a large number of **sporangia** that group together, forming sori on the back of the sporophyte's leaves.



PINNULES
Smaller lobes that contain sori on their inner side

SORI
Contains the sporangia

PINNAS
Petioles into which the leaf is divided



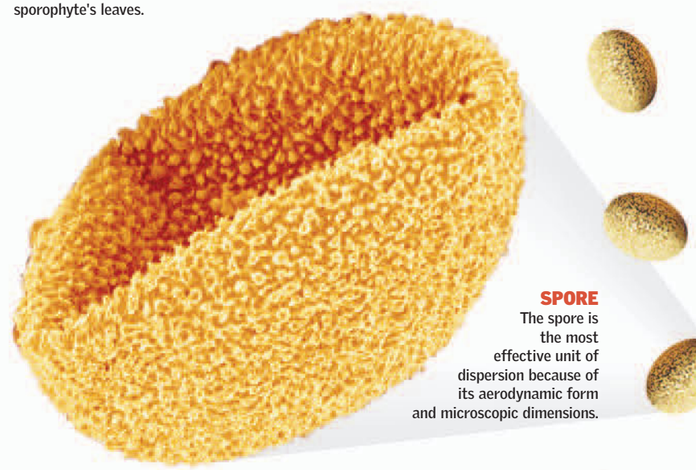
INDUSIUM
Small cap that protects and covers the sori while the spores mature inside each sporangium

PLACENTA

3 Catapult of Spores

When the sporangia dry and wither, they liberate spores through a catapult mechanism.

300 million
THE NUMBER OF SPORES ONE FERN LEAF CAN PRODUCE. THEIR TOTAL WEIGHT IS 0.04 OUNCE (1 G).



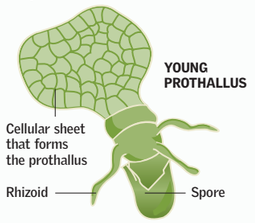
SPORE
The spore is the most effective unit of dispersion because of its aerodynamic form and microscopic dimensions.

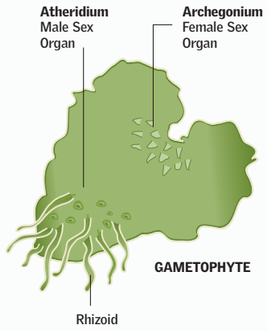




4 Germination

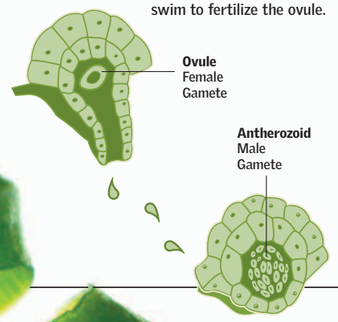
When the spore encounters the right environment, it develops into a multicellular structure that forms the **haploid gametophyte**, called the prothallus.





5 Fertilization

The male and female organs are differentiated in the prothallus. In the presence of liquid water the antheridia swim to fertilize the ovule.



12,000
SPECIES OF FERNS CAN BE FOUND IN THE WORLD.

HOW A LEPTOSPORANGIUM IS FORMED



A It starts as a single initial epidermal cell.

B The lower cell gives rise to a thin stalk.

C The stalk divides into four initial cells and small sporocytes.

D The wall of the mature sporangium is formed by a single layer of cells.

E It forms a fixed number of spores through meiosis.

Seed Plants

THE POLLEN REACHES THE STIGMA
This is the first step toward forming a seed. In this magnified image the grains of pollen can be seen on the stigma of wolfsbane *(Arnica montana)*.

SEEDS, TO AND FRO 36-39
UNDER THE EARTH 40-41
STEMS: MORE THAN A SUPPORT 42-43
WOODEN HEART 44-45
GROWTH SPRINGS ETERNAL 46-47
ENERGY MANUFACTURERS 48-49
FUNCTIONAL BEAUTY 50-51
POLLINATION 52-53
BEARING FRUIT 54-55
CONIFERS 56-57



Unlike animals, plants are limited in their ability to seek favorable conditions for life and growth. Consequently, they have evolved in different ways to reproduce and increase their population through seeds. A seed must arrive at an appropriate location at the best time for germination. Each species achieves its objective in a different way. Some produce a great number of seeds; others wrap their seeds in a layer of hard material that softens with rain and winter's cold to germinate in spring. In this chapter you will find how this process takes place, step by step, from pollination to the formation of a new plant.●

Seeds, To and Fro

Reproduction from seeds is the most prominent evolutionary advantage in plants' conquest of the terrestrial environment. The seed shelters the embryo of the future plant with protective walls. The embryo is accompanied by tissues that provide enough nutrients for it to begin to develop. Optimal temperature and an appropriate quantity of water and air are the factors that stimulate the seed to awaken to a marvelous cycle of development and growth that will culminate in the generation of new seeds.

1 Awakening of the Seed

Seeds, such as those of the field, or corn, poppy *(Papaver rhoeas)*, leave their latent stage when they hydrate and receive enough light and air. Their protective coverings open and the embryo grows thanks to the energy provided by its cotyledons, or seed leaves.

2 Tropism

Because of gravity, amyloplasts are always located in the lower part of cells. They produce a stimulus that encourages the root to grow toward the earth, a process called geotropism.

PLUMULE
The bud of a plant embryo that will produce the first shoot

COTYLEDON
The first embryo leaf. It provides the energy needed for growth.

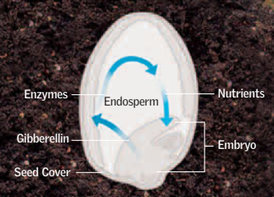
Cell multiplication allows the stem to grow.

ABSORBENT HAIRS
These organs begin to develop in the radicle. They help the seed absorb water from the soil.

HARD COVER
Called the testa, it can appear in very different forms.

RADICLE
The embryo root that will produce the main root of the plant

The testa protects the embryo and the cotyledons during the seed's latent stage.



WATER
is responsible for breaking open seed covers because the hydrated tissues exert pressure on the interior of the seed.

NUTRIENTS
The radicle is in charge of collecting water and nutrients present in the soil.

Gibberellins

are plant hormones that, during the first stages of germination following water absorption, are distributed through the endosperm. Their presence promotes the production of enzymes that hydrolyze starches, lipids, and proteins to turn them into sugars, fatty acids, and amino acids, respectively. These substances provide nutrition to the embryo and later to the seedling.

3 Growth

The seedling grows and breaks through the surface. This causes the plant to be exposed to light so it can begin to carry out photosynthesis. It thus begins to manufacture its own nutrients to replace those provided by the cotyledons.

APICAL GROWTH
Light stimulates the multiplication of cells in the apex of the stem.

The cotyledon is carried by the vertical growth of the stem.

Cotyledons can remain under the soil or, as in this case, grow above the ground.

HYPOCOTYL
The first part of the stem that emerges and develops in the young plant

PRIMARY ROOT
It anchors itself to the ground and branches out to support the plant in the substrate.

4 Vegetative Growth

The first true leaves unfold above the cotyledons, and the stem elongates from formative tissue called the meristem, located at the apex of the plant. Continued growth will lead to the formation of an adult plant, which will develop its own reproductive structures.

TOTIPOTENCY
Characteristic of the vegetative apex cells

FIRST TRUE LEAVES

CONDUCTION
The stem carries water and minerals from the root to the leaves, while taking manufactured substances in the opposite direction.

0.4 inch (1 cm)
IS THE MAXIMUN HEIGHT IT CAN GROW IN ONE DAY.

SECONDARY ROOTS

The root has many fine hairs that create a large surface area for water absorption.

5 Production of the Flower's Parts

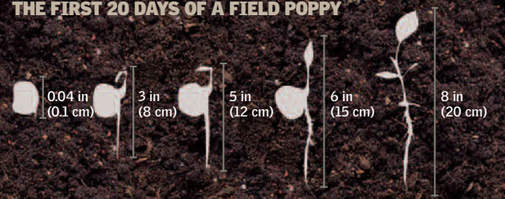
The apical bud begins to produce fertile flower structures (gynoecium and androecium) and sterile structures (petals and sepals). The flower bud forms.

FLOWERING
Internal and external changes stimulate the apical bud to develop a flower.

SESSILE LEAVES
The upper leaves have no petiole.

ALTERNATE LEAVES

THE FIRST 20 DAYS OF A FIELD POPPY



20 inches (50 cm)
THE TYPICAL HEIGHT OF AN ADULT FIELD POPPY PLANT

Autum

THE TIME OF THE YEAR IN WHICH THE SEED OF *PAPAVER RHOEAS* GERMINATES

6 Flowering

Once the bud opens, the parts of the flower begin to unfold. They are arranged in whorls, or cycles. The whorl called the corolla contains the petals, and two inner whorls contain the fertile parts of the flower—the androecium and gynoecium.

ANTHESIS
is the name given to the opening of the flower bud.

ALTERNATE LEAVES

COMPOSITES
The leaves are very divided and participate in photosynthesis.

The absorbent hairs are destroyed by abrasion from the soil but are constantly renewed.

ANDROECIUM
It produces male gametes.

POLLEN

Bees approach flowers in search of nectar and carry away grains of pollen that cling to their hairs.

7 Pollination

The mechanism by which flowering plants reproduce involves the dispersal of pollen.

4 inches
(10 cm)
THE AVERAGE SIZE OF THE FLOWER

Pollination by Wind

Wind is an ideal means for transporting pollen over long distances.

Stigma

Antera

Nectarium

Ovary

Pollination by Animals

Animals, especially insects, help the plant disseminate its pollen after they enter the flower in search of food. This is one of the main mechanisms of pollination.

FRUIT
After fertilization the ovary and adjacent tissues become the fruit.

STAMENS

8 Fruit

The seeds develop inside the fruit. Each seed can develop a new seedling.

FRUIT

SEEDS

9 Ripe Fruit

The fruits scatter the seeds. Field poppies have dry fruits that open when they mature. This facilitates the dispersion of the seed by air.

SEMILLAS

10 Dispersion

The fruit of a field poppy is a capsule with small openings at the top that help scatter the seeds.

11 Seed

Each seed distributed by air, water, or an animal can, under the right environmental conditions, germinate and develop into a new seedling.

3,000
SEEDS CAN BE CONTAINED IN ONE RIPE FIELD POPPY FRUIT.

Something in Common

When a seed encounters the right conditions, it can begin its life cycle. Even though every species of plant with flowers has its own particular life cycle, the various stages of the cycle represented here are typical of angiosperms in general.

Under the Earth

The root is a plant organ that is usually found under the soil. It has positive geotropism; its main functions are absorbing water and inorganic nutrients and attaching the plant to the ground. The root is essential for identifying the particular characteristics of a plant. The anatomical structure of a root can vary, but, because it does not have leaves or nodes, it will always be simpler than that of a stem.

Types of Roots

Roots differ, depending on their origin. The primary root originates in the radicle of the embryo. An adventitious root is one that originates in any other organ of the plant. Roots are also subdivided according to their morphology.



TAPROOT
A taproot grows downward and has lateral secondary roots that are not well developed.

BRANCHED
The main root is divided, creating other secondary roots.



FIBROUS
The root system is formed by a group of roots of similar diameter.



TUBEROUS
Fibrous in structure, some of the roots thicken to store food for the plant.



NAPIFORM
The taproot thickens with stored food and tapers abruptly near its tip.



TABULAR
Tabular roots form at the base of a trunk and create a supporting buttress.

GEOTROPISM
Geotropism, or gravitotropism, is the growth of a plant or parts of a plant in a particular direction because of the stimulus of gravity. The force of gravity orients the stems and their leaves to grow upward (negative geotropism), whereas the roots grow downward (positive geotropism).

Monocotyledons

These plants have embryos with only one cotyledon. Their embryonic root generally has a relatively short life and is replaced by adventitious roots that grow from the stem.

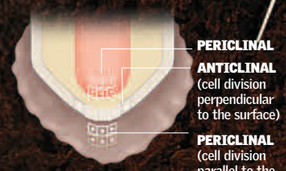
GROWTH AND CELLULAR DIVISION
Through the process of cell division a cell divides into two cells, each with its own nucleus. The new cells elongate, allowing the root to grow in thickness and length.

NECK
Transitional area between the root and the stem

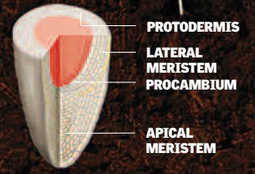
BRANCHING AREA
A porous region whose function is to anchor and absorb

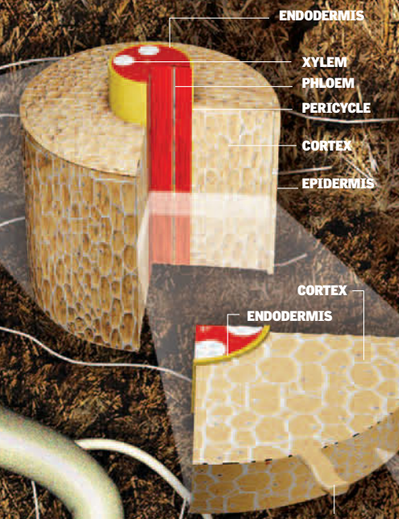
PILIFEROUS AREA
The part of the root covered with slender elongations called roots hairs. The root hairs increase the surface area through which water and minerals can be absorbed.

GROWTH AREA
Area of cell growth and elongation

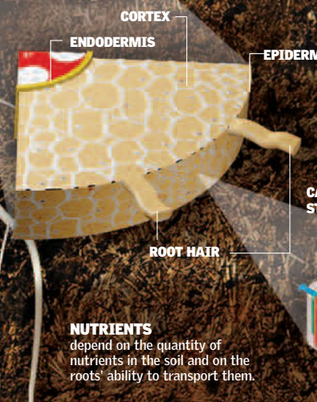


ROOT CAP
The thimble-shaped structure that protects the meristem of the tip of the root as it penetrates the soil





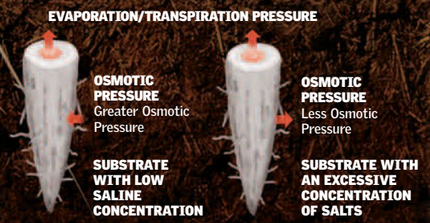
ROOT STRUCTURE
The root cap is found at one end. While the root grows, the root cap protects it from soil abrasion. The interior of the root is formed by the cortex, which has a compact layer of cells that affect the flow of water through the root. This is due to the presence of a waxy substance that forms the Casparian strip.



WATER
enters through the root hairs and travels to the epidermal cells.

NUTRIENTS
depend on the quantity of nutrients in the soil and on the roots' ability to transport them.

OSMOSIS
The process through which plants absorb water from the soil. Water penetrates into the roots when it has a greater concentration in the soil than in the intracellular environment of the root.

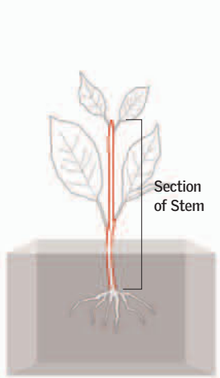


Dicotyledon

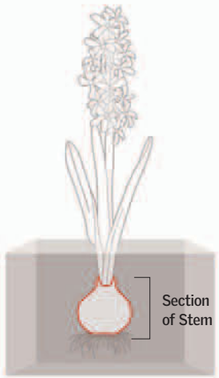
A plant that has seeds with two embryonic leaves (cotyledons). It has a tap root, and the leaves are usually petiolated with a reticulated vein distribution. Their internal organization consists of open conducting vessels in a circular arrangement.

Stems: More Than a Support

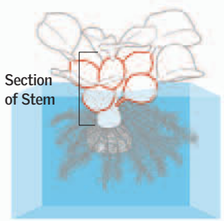
Stems, which occur in a variety of shapes and colors, support a plant's leaves and flowers. They keep it from breaking apart in the wind, and they determine its height. In addition, stems are also responsible for distributing the water and minerals absorbed by a plant's roots. Stems contain conducting vessels through which water and nutrients circulate. In trees and bushes, stems are woody for better support. ●



IN THE AIR
Stems are usually branched, as seen in trees and bushes.

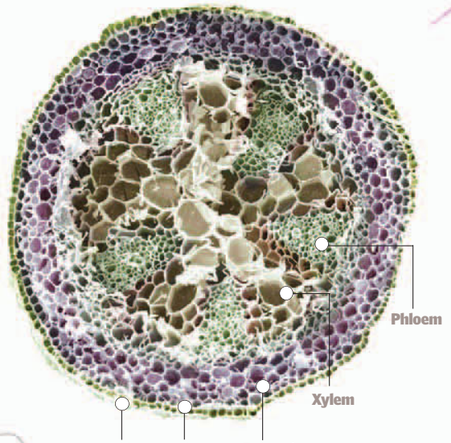


IN THE GROUND
Certain types of stems have unusual characteristics.



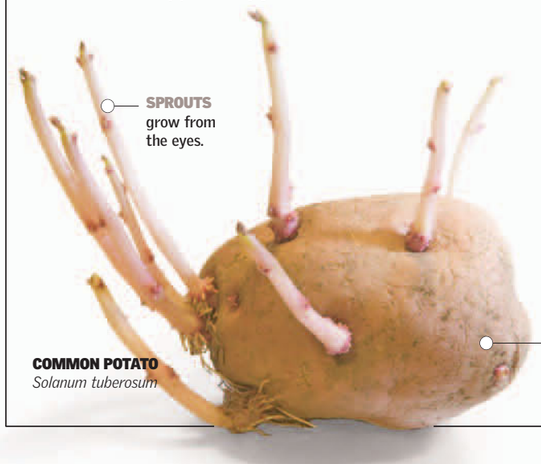
IN THE WATER
The stem of an aquatic plant can lie underwater.

CROSS-SECTION OF A NEW STEM



Development of Stems in Different Mediums

Stems have widely varying sizes and shapes that reflect different adaptations to the environment. Palm trees and wheat are two good examples that show how different mediums can modify the stem through evolution. Palm trees are the tallest non-woody plants. They grow tall because they must compete with many other plants for sunlight. In contrast, wheat is typical of areas with a cold climate and a short growing season. It develops a relatively short stem. This enables it to survive the physical assault of the dry wind and the loss of leaves.



COMMON POTATO
Solanum tuberosum

TUBER
An underground stem composed mainly of parenchymatic cells filled with starch. The potato's small depressions are actually axillary eyes. In an onion, another example of a plant with an underground stem, starch accumulates not in tubers but in thick leaves that grow around the stem.

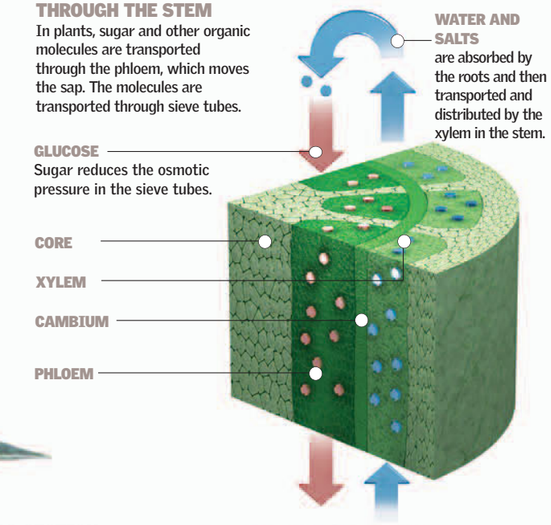


ARTICHOKE THISTLE
Cynara cardunculus

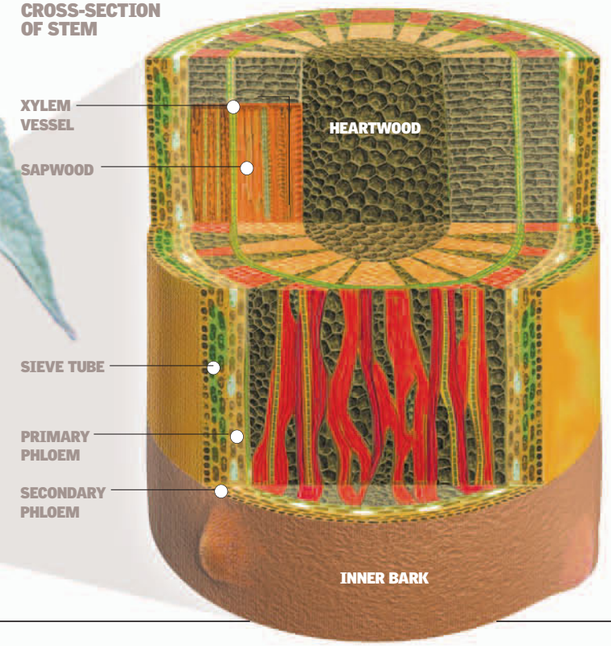
Circulation

Because the stem is the link between the roots, which absorb water and minerals, and the leaves, which produce food, the stem's veined tissues are connected to the roots and leaves. It functions as a transport system for interchanging substances. The stem and its branches hold the leaves up to receive light and support the plant's flowers and fruit. Some stems have cells with chlorophyll that carry out photosynthesis; others have specialized cells for storing starch and other nutrients.

MOVEMENT THROUGH THE STEM
In plants, sugar and other organic molecules are transported through the phloem, which moves the sap. The molecules are transported through sieve tubes.



CROSS-SECTION OF STEM



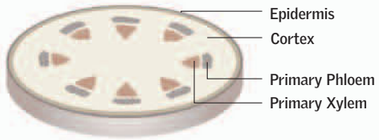
Wooden Heart

Every year a tree thickens its trunk through the production of growth rings, a process called secondary growth. Each new ring is different from the ring that grew the year before. This happens because the wood produced over the course of a year varies in its composition and in the time it takes to form a ring. Trees are the largest producers of wood, which can be processed as hand-cut wood, logs, or sawed lumber—the most common form in the industry. To calculate a tree's age scientists study its growth rings.

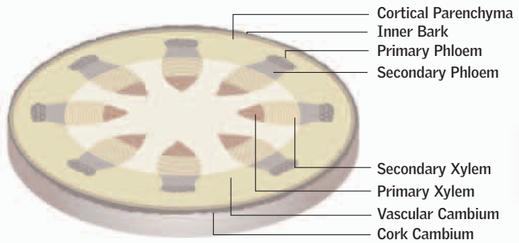
Secondary Growth

Secondary growth takes place in the secondary meristems: the vascular cambium and the cork cambium. The vascular cambium is found between the xylem and the phloem at the end of the plant's primary growth zone. It produces secondary xylem toward the inside of the trunk and secondary phloem toward the outside.

1 Initiation
The layer of meristematic cells formed between the xylem and the phloem develops inside the base tissue until it grows all the way around, forming a cylinder.



2 Lengthening
The primary xylem and phloem form when the vascular cambium divides.



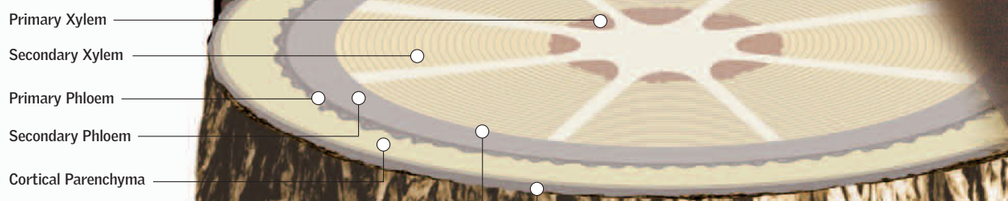
3 Termination
The veined cambium forms the primary and secondary vein tissues.

A Tree's Age

Dendrochronology is the study of the age of trees. The number of growth rings formed since a tree's birth establishes its age.

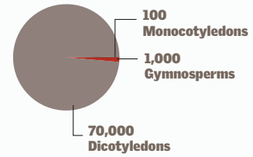


LABURNUM
Laburmun sp.



SPECIES

Most of the 70,000 known tree species are dicotyledons. However, the oldest trees (4,900-year-old bristlecone pines [*Pinus longaeva*]) and the tallest trees (360 foot [110 m] sequoias [*Sequoia sempervirens*]) are gymnosperms. The earliest trees known to paleobotany appeared during the Devonian Period.



TYPES OF WOOD

Wood comes from two main groups of trees:

Wood in angiosperms is the product of the activity of the cambium and the environmental conditions that exist during the wood's formation.



The wood of conifers (gymnosperms) tends to be simpler and more uniform than that of angiosperms. The woody tissue consists mainly of tracheids.



PHLOEM
The phloem transports the products of photosynthesis, mostly in the form of sucrose. This is its main function.

INNER BARK
is the youngest ring, because a new ring is created in each year's growth.

XYLEM
Its main function is to carry water and mineral salts from the roots to the leaves.

SAPWOOD
is the woody part of the trunk and consists of xylem tissue. It is pale in color and of variable thickness.

Rolled Logs
Not processed before use, they are often used in rural and traditional construction.

Hand-Hewn Wood
is chopped by hand with an ax. It is used in rural construction for rafters and posts, but it involves a considerable loss of wood.

Sawed Lumber
It is cut to specified dimensions, either manually or mechanically, in a sawmill. It is the type of wood most often used in construction.



Growth Springs Eternal

Some vascular (veined) plants, also called tracheophytes, are able to continue growing year after year. This is made possible by meristems, groups of stem cells that retain the ability to divide. There are two types of meristems: apical, which carry on the plant's primary growth, and lateral, which give rise to the tissues that increase the plant's girth. As the meristematic cells form new cells, the plant grows and renews its organs. Thanks to their growth buds, the plants maintain their vitality and strengthen their organs or replace them often. Because of this process, the renewed plants are able to increase their number of branches, flowers, and leaves.

Without Bracts
Some buds, such as those in plants of the cabbage family (Brassicaceae), are not covered by bracts. Instead, the vegetable's growth zone is covered by outer leaves.



INFRAPETIOLAR BUD
The axillary bud is joined to the petiole of a leaf. The growth of the leaf carries the bud outward. This often occurs in plants with inflorescences, or flowers that grow on branches.



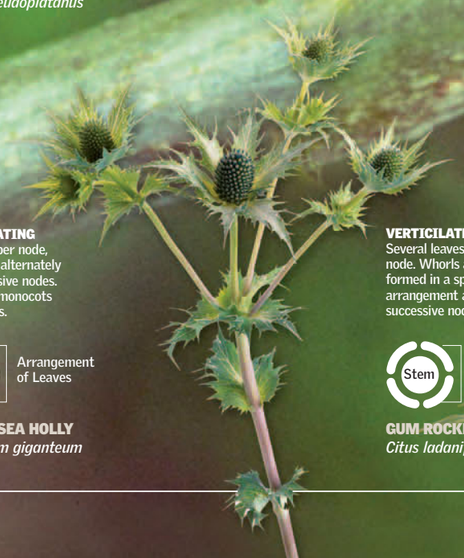
SUPERPOSED BUD
The axillary bud is joined to the stem. As the cells of the internode multiply, they carry the axillary bud, which then appears to be inserted above the leaf.

Branching

Growth buds can be found at the end of the main axis (apical bud) or at the joint where the leaves meet the stem (lateral bud). Growth can take different forms, depending on the type of bud that predominates. If apical buds are more common, the branch growth is called monopodial. If lateral buds predominate, the branch growth is called sympodial. Conifers are an example of monopodial growth. Sympodial growth is widespread among dicotyledon herbs and is found in practically all monocotyledons.

PHYLLOTAXIS
is the name of the order of plants whose leaves are arranged along the nodes of the branches. Each node can have from one to several leaves.

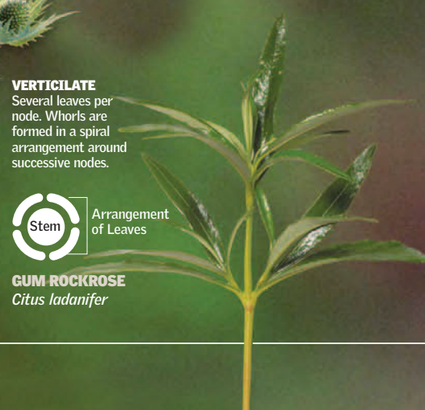
SYCAMORE MAPLE
Acer pseudoplatanus



ALTERNATING
One leaf per node, arranged alternately in successive nodes. Found in monocots and dicots.



GIANT SEA HOLLY
Eryngium giganteum



VERTICILATE
Several leaves per node. Whorls are formed in a spiral arrangement around successive nodes.

GUM ROCKROSE
Citus ladanifer



OPPOSITE
Two leaves per node. They are arranged perpendicularly to earlier and later nodes.



CLARY SAGE
Salvia sclarea



Awakening

Apical buds can remain dormant for long periods of time. With the right physiological and environmental conditions, they can awaken and unfold.

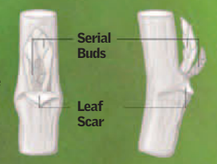
Leaf Shoots

A lengthwise cross-section of a bud shows the curving and overlapping leaf sprouts that protect the bud's growth zone.

Lateral Buds

These buds occur on the side of the stem; typically, only one is located in the stem joint. In some cases many lateral buds are arranged in a series around a column (serial buds). They can also be arranged around the same crosswise line along the branch or stem (collateral buds).

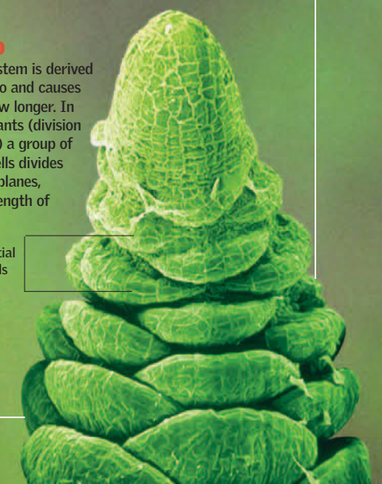
Serial Buds
These buds are situated one above the other at the joint where the protective leaf meets the stem, forming a vertical file. The honeysuckle and the bougainvillea are examples of this type of bud.



Collateral, or Adjacent, Buds
are situated one on either side in the joint of the same leaf, forming a horizontal line. In garlic each clove is an axillary bud.



APICAL BUD
The apical meristem is derived from the embryo and causes the stem to grow longer. In seed-bearing plants (division Spermatophyta) a group of meristematic cells divides along different planes, increasing the length of the stem.



Energy Manufacturers

The main function of leaves is to carry out photosynthesis. Their shape is specialized to capture light energy and transform it into chemical energy. Their thinness minimizes their volume and maximizes their surface area that is exposed to the Sun. However, there are a great many variations on this basic theme, which have evolved in association with different types of weather conditions.

EDGES (MARGINS)
Species are distinguished by a wide variety of edges: smooth, jagged, and wavy.

PRIMARY VEINS
The products of photosynthesis circulate through the veins from the leaves to the rest of the body.

VEINS
Flowering plants (division Angiosperma) are often distinguished by the type of veins they have: parallel veins in monocots and branching veins in dicots.

RACHIS

LEAF STEM (PETIOLE)

LEAF SURFACE
Colorful, usually green, with darker shades on the upper, or adaxial, side. The veins can be readily seen.

***ACER* SP.**

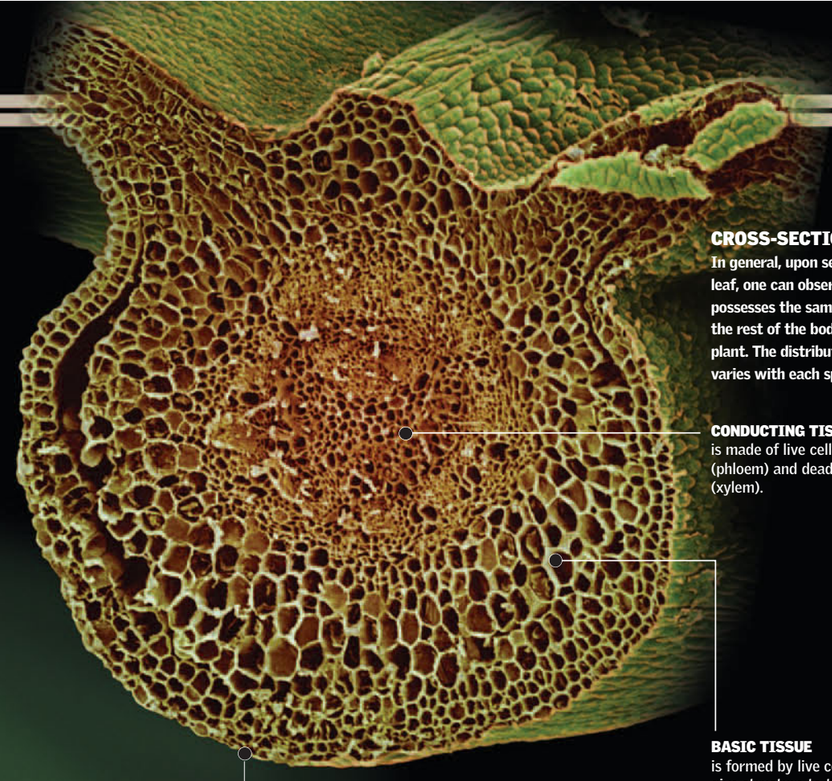
This genus includes trees and bushes easily distinguishable by their opposite and lobed leaves.

Simple Leaves

In most monocotyledon plants the leaf is undivided. In some cases it may have lobes or notches in its side, but these divisions do not reach all the way to the primary vein of the leaf.

Compound Leaves

When the leaf is divided from the primary vein, it forms separate leaflets. A compound leaf is called palmate when the leaflets are arranged like the fingers on a hand and pinnate when they grow from the sides of the leaf stem like the barbs of a feather.

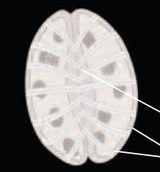


CROSS-SECTION
In general, upon sectioning a leaf, one can observe that it possesses the same tissues as the rest of the body of the plant. The distribution of tissues varies with each species.

CONDUCTING TISSUE
is made of live cells (phloem) and dead cells (xylem).

BASIC TISSUE
is formed by live cells that give structure to the leaf and usually contain some chloroplasts.

EPIDERMAL TISSUE
is composed of live cells. It surrounds all the parts of the leaf and the plant. It produces a substance that forms the cuticle.



1 The stomatic apparatus is closed. No air can enter or leave the leaf. This prevents excessive transpiration, which could damage the plant.

Thickened cell walls in the area of the pore

Cellulose Microfibers



2 The stomatic apparatus is open. The stomatic cells are swollen. As tension increases, the cellular form is modified and is able to exchange gases.

PLANTS AND THE ENVIRONMENT

The flow of carbon dioxide and water vapor between the plant and the environment is essential for the photosynthetic process. This exchange can be affected by internal or external factors, such as changes in light, temperature, or humidity. In response to these stimuli the stomas can open or close.

Change and Its Advantages

Conifers possess an interesting modification in their leaves. In these gymnosperms evolution directed the abrupt reduction of surface foliage area. This gave them an adaptive advantage over plants whose leaves have a large surface area: less resistance to wind and less transpiration in arid climates. In addition, they are able to avoid the excessive weight that would result from the accumulation of snow on large leaves.

VASCULAR BUNDLE
Formed by phloem and xylem

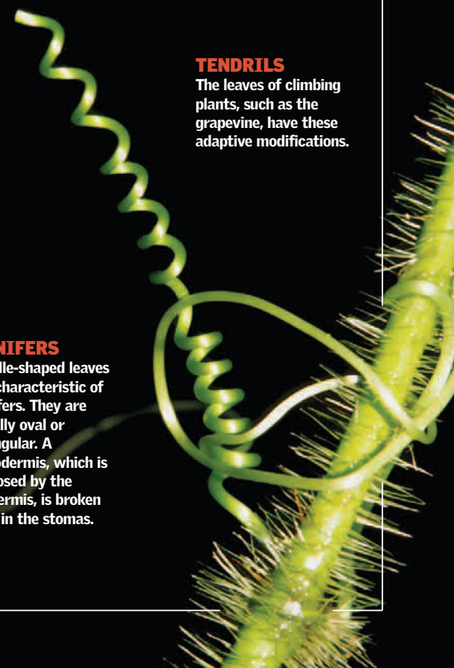
RESIN
functions to prevent freezing. It circulates through the resin ducts.

EPIDERMIS
Cells with thick walls and a thick cuticle



CONIFERS

Needle-shaped leaves are characteristic of conifers. They are usually oval or triangular. A hypodermis, which is enclosed by the epidermis, is broken only in the stomas.



TENDRILS

The leaves of climbing plants, such as the grapevine, have these adaptive modifications.

Functional Beauty

Flowers are not simply beautiful objects; they are also the place where the reproductive organs of angiosperms are located. Many are hermaphroditic, meaning that they contain both the male reproductive apparatus (the androecium) and the female (the gynoecium). The process of pollination is carried out through external agents, such as insects, birds, wind, and water. Following fertilization, flowers produce seeds in their ovaries. The floral parts are arranged in circular or spiral patterns.

Classification

Plants with flowers are classified as dicotyledons or monocotyledons. The first group has seeds with two cotyledons, and the second has seeds with only one. Each represents a different evolutionary line. They are differentiated by the structure of their organs. The cotyledon contains nutrients that the embryo utilizes during its growth until its true leaves appear. When a seed germinates, the first thing that appears is the root. In monocotyledons the stem and the radicle are protected by a membrane; the dicotyledons lack this protection, and the stem pushes itself through the soil.

Dicotyledons

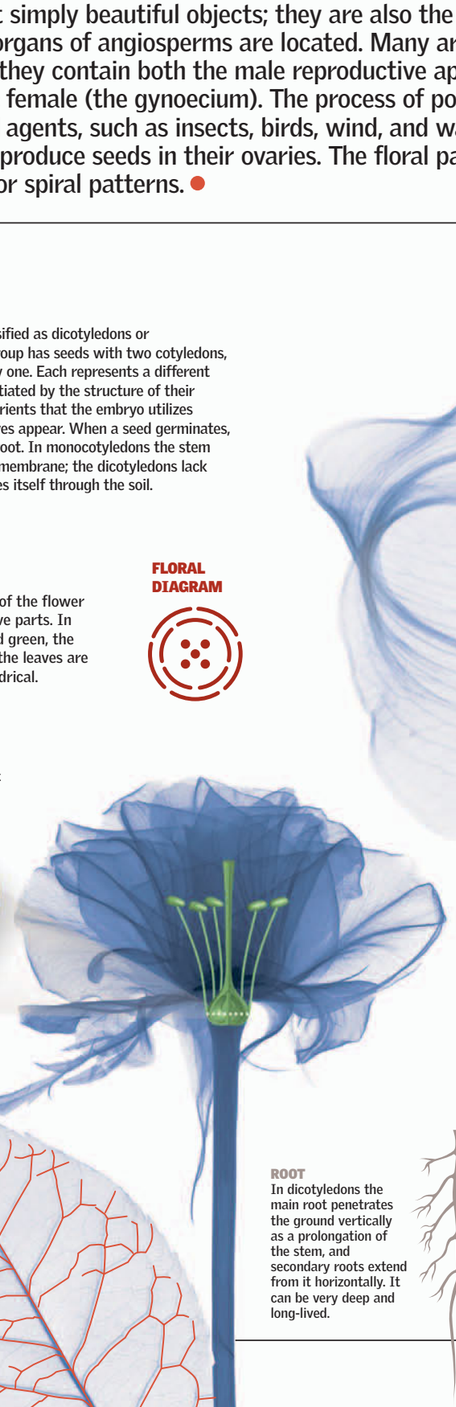
In this class of plants each whorl of the flower is arranged in groups of four or five parts. In dicotyledons the sepal is small and green, the petals are large and colorful, and the leaves are wide. The vascular ducts are cylindrical.

FLORAL DIAGRAM



OVARY
The ovary is found in the receptacle at the base of the gynoecium, inside the carpels. The pollen tube extends into the ovary and penetrates the ovule.





LEAVES
In dicotyledons, leaves have various forms, and they contain a network of veins that connect with a primary vein.



ROOT
In dicotyledons the main root penetrates the ground vertically as a prolongation of the stem, and secondary roots extend from it horizontally. It can be very deep and long-lived.



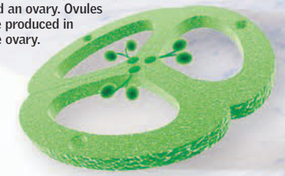
Monocotyledons

Each whorl of these flowers contains three parts, and their sepals and petals are generally not differentiated from one another. The majority are herbaceous plants with scattered vascular conduits. They are the most evolved species of angiosperms.

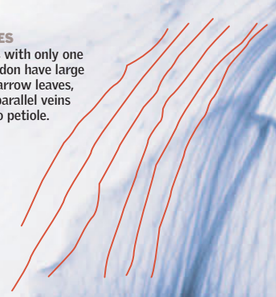
FLORAL DIAGRAM



CARPEL
The carpel consists of modified leaves that together form the gynoecium. It contains a stigma, a style, and an ovary. Ovules are produced in the ovary.



LEAVES
Plants with only one cotyledon have large and narrow leaves, with parallel veins and no petiole.



ROOT
In monocotyledons all the roots branch from the same point, forming a kind of dense hair. They are generally superficial and short-lived.



Gynoecium
The female reproductive system. It is formed by carpels and includes the ovary, ovules, style, and stigma.

STIGMA
It can be simple or divided. It secretes a sticky liquid that captures the pollen. Some are also covered with hair.

Androecium
The male reproductive system. It is formed by a group of stamens, each of which consists of an anther supported by a filament. The base may contain glands that produce nectar.

ANTHER
A sac where grains of pollen (the male gametes) are produced

FILAMENT
Its function is to sustain the anther.

STYLE
Some styles are solid, others hollow. Their number depends on the number of carpels. The pollen tube grows through the style. In corn the tube can reach a length of 15 inches (40 cm).

OVARY
The ovary is found in the receptacle in the base of the gynoecium, inside the carpels. The pollen tube, which conducts the pollen to the ovule, extends to the ovary.

Whorls

Most flowers have four whorls. In a typical flower the outermost whorl is the calyx, followed by the corolla, the androecium (which can have two parts), and the gynoecium. When a flower has all four whorls, it is considered complete; it is incomplete when it lacks at least one of them. Plants that have an androecium and a gynoecium, but in separate flowers, are called monoecious. If the flower lacks a sepal and petals, it is said to be naked.

250,000

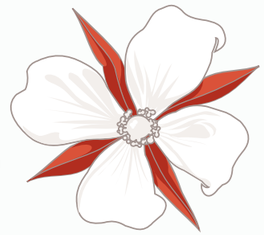
THE NUMBER OF KNOWN SPECIES OF ANGIOSPERM PLANTS, THOUGH ONLY 1,000 SPECIES HAVE ECONOMIC IMPORTANCE. ABOUT TWO THIRDS OF THESE SPECIES ARE NATIVE TO THE TROPICS.

COROLLA
A grouping of petals. If its parts are separated, they are simply called petals; if they are united, the plant is described as gamopetalous.

PETAL
It typically has a showy color to attract pollinating insects or other animals.

CALYX
The grouping of sepals that protects the other parts of the flower. Together with the corolla it forms the perianth. The sepals may be separate or united; in the latter case the plant is called gamosepalous.

SEPAL
Each of the modified leaves that protect the flower in its first stage of development. They also prevent insects from gaining access to the nectar without completing their pollinating function. Sepals are usually green.

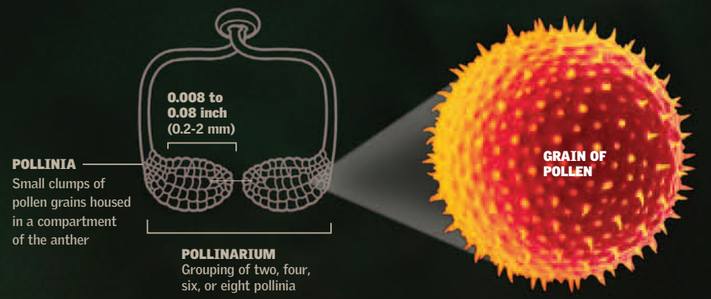


TEPAL
In monocotyledonous plants the petals and sepals are usually the same. In this case they are called tepals, and the group of tepals is called a perianth.



Pollination

The orchid, whose scientific name *Ophrys apifera* means "bee orchid," is so called because of the similarity between the texture of its flowers and the body of a bee. Orchids' flowers are large and very colorful, and they secrete a sugary nectar that is eaten by many insects. The orchid is an example of a zoomophilous species; this means that its survival is based on attracting birds or insects that will transport its pollen to distant flowers and fertilize them.



Pollen

Each grain contains a male gamete.

12,000
THE NUMBER OF SEEDS THAT A SINGLE FERTILIZED ORCHID PRODUCES

ODOR
The odor is similar to bee pheromones.

CAUDICLE
At times it closes, covering the pollinia.

CORBICULUM
Organ for the transport of pollen

COLORATION
is one of the factors of attraction.

POLLINIUM
A small clump of closely packed pollen grains

1 Attraction

When a flower opens, a liquid drips on its lower petal and forms a small pool. The liquid gives off an intense aroma that attracts bees.

POLLINATING INSECT
Male Bee
Gorytes sp.

2 The Fall

Excited by the perfume and the texture, the bee enters the flower, and in this pseudo-copulation it usually falls into the pool and becomes trapped. It cannot fly and can only escape by climbing the flower's stamens.

Bee Orchid
Ophyrys apifera

NECTAR
A sugary liquid that is somewhat sticky

LABELLUM
Its form imitates the abdomen of the bee.

3 The Load

While passing through the narrow tunnel, the bee brushes the pollinarium, and pollen sticks to the bee.

4 Transfer

The bee takes off toward other flowers, with pollen from the orchid stuck to its back.

LOBULES
They have fine, silky hairs that attract the bees.

5 Toward a Destination

When it arrives at another flower of the same species, the bee repeats the incursion and bumps the flower's stigmas (female organs), depositing pollen that is capable of fertilizing it.

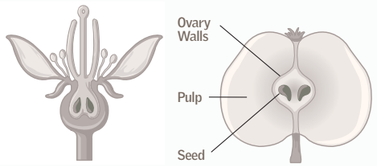
CAMOUFLAGE
Some plants that rely on insects for pollination acquire the appearance of the animal species on which they depend for survival. Each orchid has its own pollinating insect.

Bearing Fruit

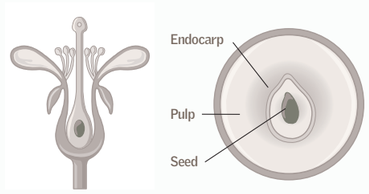
Once the flower is fertilized, its ovary matures and develops, first to protect the seed forming within it and then to disperse the seed. The stigmas and anthers wither, and the ovary transforms into fruit. Its wall forms the cover, or pericarp. Fruits and seeds are of great economic importance because of their key role in human nutrition. The endosperms of some seeds are rich in starch, proteins, fats, and oils.

Simple Fruits

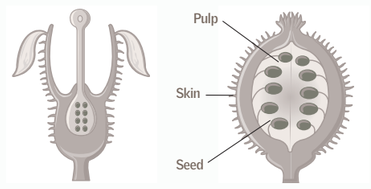
come from a single flower. They may contain one or more seeds and be dry or fleshy. Among them are drupes, berries, and pomes.



A **POMES**
are fleshy fruits that come from epigynous flowers, or flowers whose enclosed ovaries lie below the place where the other parts of the flower are attached. The floral receptacle thickens and forms an edible mesicarp. Apples are one example.



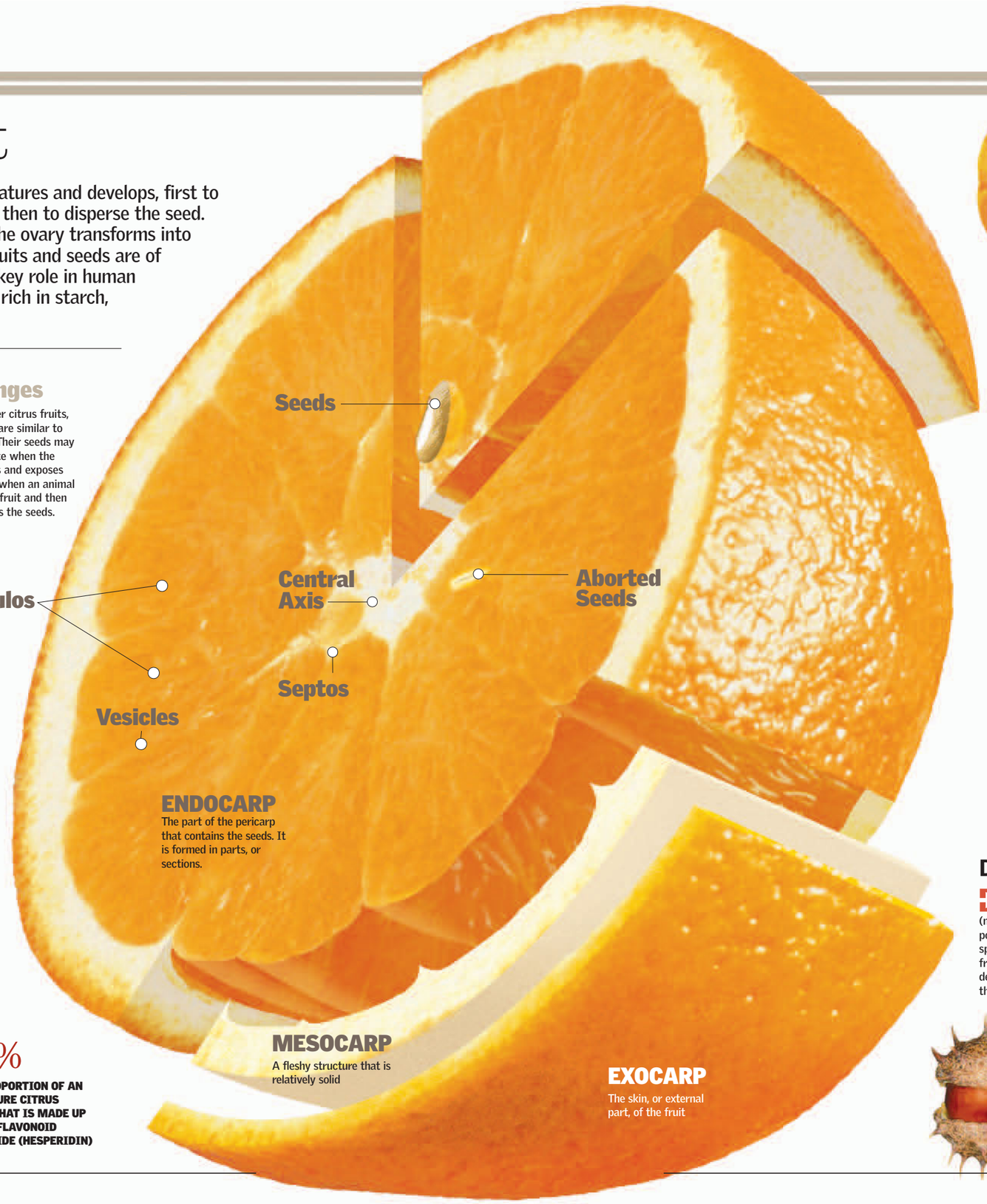
B **DRUPES**
are fleshy fruits, leathery or fibrous, which are surrounded by a woody endocarp with a seed in its interior. They are generally derived from hypogynous flowers—flowers whose ovaries lie above the point where the other flower parts are attached. An example is the peach.



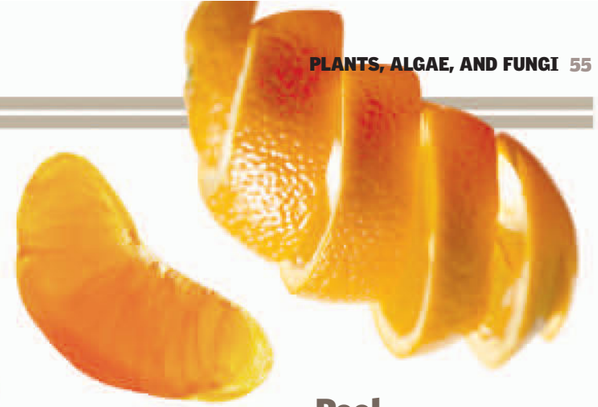
C **BERRIES**
When they mature, berries generally have a bright color and a fleshy or juicy mesocarp. They come from either epigynous or hypogynous flowers. The grape is an example.

Oranges

Like other citrus fruits, oranges are similar to berries. Their seeds may propagate when the fruit rots and exposes them or when an animal eats the fruit and then defecates the seeds.



14%
THE PROPORTION OF AN IMMATURE CITRUS FRUIT THAT IS MADE UP OF THE FLAVONOID GLYCOSIDE (HESPERIDIN)



Section
A sac that fills with juices (reserves of water and sugar) produced by the ovary walls

Peel
It consists of the mesocarp and exocarp of the fruit. It is soft and secretes oils and acids. However, in the case of a nut, its hard "peel" is its endocarp.

Multiple Fruits

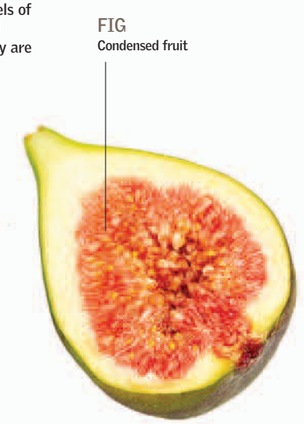
are those that develop from the carpels of more than one flower, in a condensed inflorescence. When they mature, they are fleshy. An example is the fig.

BLACKBERRY
In this aggregate fruit, each berry is a fruit.



A **AGGREGATE FRUIT**
The fruit is made of numerous drupelets that grow together.

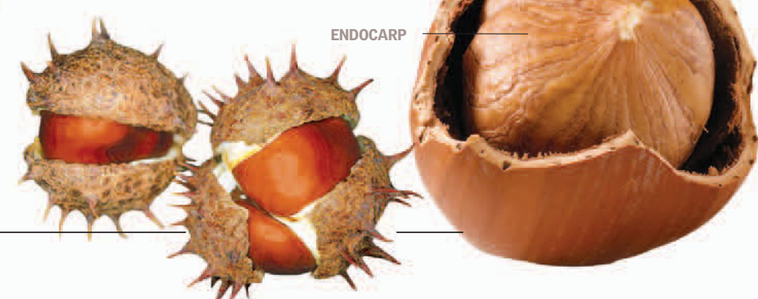
FIG
Condensed fruit



B **SYCONIUM**
The fruit axis dilates and forms a concave receptacle with the shape of a cup or bottle.

Dry Fruits

are simple fruits whose pericarps dry as they mature. They include follicles (magnolias), legumes (peanuts, fava beans, peas), pods (radishes), and the fruits of many other species, including the majority of cereals and the fruits of trees such as maple and ash. Most dehiscent fruits (fruits that break open to expose their seeds) are dry fruits.



Conifers

Are effectively the most representative of the gymnosperms, a group of plants with seeds but not flowers. Through the fossil record it is known that conifers have existed for more than 390 million years. Their leaves are usually needle-shaped and perennial. They are woody plants that reproduce by means of seeds that contain tissues and an embryo that grows until it becomes an adult plant.

YOUNG LEAVES
are covered by a protective capsule.

FEMALE CONE
Small and light, it is likely to be pollinated as soon as it appears.

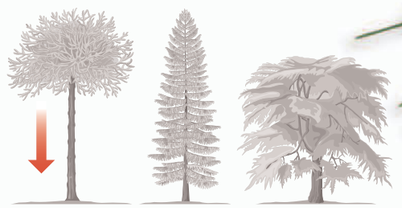
LEAVES
Grouped in sets of two, they have elongated shapes. They carry out photosynthesis.

CONES
The male and female cones are generally not located on the same branch.

MATURE CONE
Three years after the cone appears, its seeds are ready to disseminate.

Classification

The name "conifer" is sometimes erroneously believed to derive from pine trees' conical shape. In reality, there are other forms of coniferous plants.



ARAUCARIA *Araucariaceae*

PINE *Pinaceae*

CEDAR *Taxodiaceae*

Good Wood

The great majority of conifers are evergreens, although some, such as larches (tamarac), are deciduous. Conifers are the tallest and most long-lived trees, and they provide most of the wood used in industry. Most conifers form new shoots during the summer. They produce a resinous substance that protects them from freezing during winter. This adaptation permits vital nutrients to continue to circulate through their vascular systems, even in very cold weather.



14° F (-10° C)
OR LESS: TYPICAL AVERAGE
January temperature across the extensive coniferous forests of the Northern Hemisphere.

LEAFLET

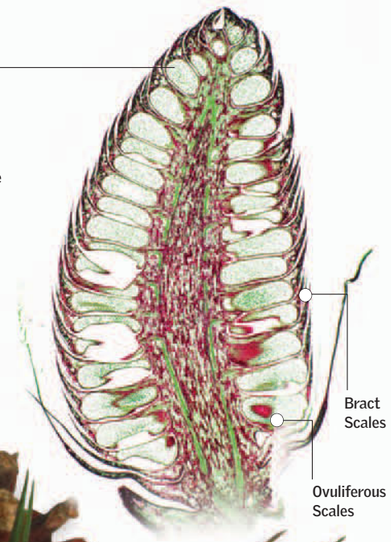
SCALE



DISPERSION
The ovuliferous scales generate a greenish gelatin containing the female gametes. The gametes are freed when the sac that contains them opens. A forest fire can promote reproduction by causing the sac to open.

Pine Cones

The female cone contains ovules that are situated among its ovuliferous scales. The cones are woody and are usually found in the upper branches of the tree. The male cones are not woody and are usually found in the lower branches. When the ovules of a female cone are pollinated, the resulting seeds need about three years to mature inside the cone. Mature ovules are popularly called pine nuts.





CLOSED



OPEN



Pine Nuts

Pine nuts have long been used with honey and sugar to make pastries. When summer arrives, harvested pine cones are placed in the sun, which causes them to open. The pine nuts are then shaken loose from their cones and gathered. In traditional processing the pine nuts are soaked in water to remove their outer covering, which floats to the surface. The pine nuts are then run between two closely spaced mechanical rollers to crack their inner shells. Finally, the pine-nut meat is separated from the shell by hand.

Rare and Useful Plants

VENUS FLYTRAP
The most common carnivorous plant. It is considered to be an active trap.

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How does a carnivorous plant hunt an insect, and what type of traps does it use? Why do many plants have thorns or secrete venomous juices, while others grow on the trunks of trees or on the side of rocks? The truth is that in order to survive in harsh environments, such as places that are extremely dry or cold or places with nutrient-poor soil or herbivorous animals, plants have had to become very strong and develop a number of strategies for survival, which we will tell you about in this chapter. You will also find detailed information about where the paper that we use daily comes from, as well as learn about the production of tomatoes and olive oil, essential elements in the human diet.

Trappers

These carnivorous plants are the most exotic in the entire plant kingdom. Their name is associated with their ability to capture insects and digest them. What do they get from these tiny animals? They get substances rich in nitrogen, which is usually absent from the soil where they grow. By eating insects, they are able to compensate for this nitrogen deficiency because the bodies of the arthropods they catch have amino acids and other nutrients that contain nitrogen. ●



The Terror of the Flies

The exotically named Venus flytrap is a famous carnivorous plant. It produces a nectar that attracts flies. Reaching the leaf is usually fatal for the visiting insect because it sets off a series of physiological reactions in the plant that transform it into a deadly trap. Even larger insects, such as the dragonfly, can be trapped by these carnivorous plants. Upon contact by its prey, a very specific reaction takes place. Hairs detect the presence of the insect and stimulate the closure of the leaves. However, a Venus flytrap's leaves do not react to other types of contact, such as the impact of raindrops.

A Varied Diet

Trappers belong to the group of autotrophic organisms—that is, they can produce organic material to use as food from simple inorganic substances. Carnivorous plants live in environments poor in nutrients. The insects that they trap permit them to make up for this deficiency.

Main Menu: Insects

There are distinct orders of dicotyledons that include carnivorous plants, such as Nepenthales, Sarraceniales, and Scrophulariales. These plants include the pitcher plant, sundews, and bladderworts.

1/5 second

THE TIME NECESSARY FOR THE UPPER PART OF THE LEAF TO CLOSE AFTER A FLY LANDS ON IT.

CARNIVOROUS PLANTS



DIONEA MUSCIPULA
Flytraps are cultivated all over the world. They are grown in slightly acidic soils, such as peat. They flourish if they have many insects to consume.



UTRICULA VULGARIS
These aquatic carnivores are of the family Lentibulariaceae. Their leaves are oval vesicles that open and close to trap microscopic animals.



DROSERA CAPENSIS
Their ribbonlike leaves are covered in sticky hairs. When the leaves receive a stimulus, they roll up and enclose the prey.



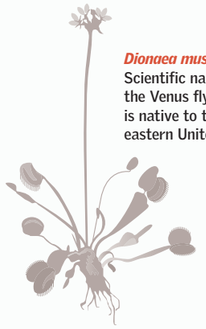
***DARLINGTONIA* SP.**
Unlike other carnivorous pitcher plants in which the pitcher (trap) is attached to a stalk, this plant's pitcher grows directly from the soil.



***SARRACENIA* SP.**
These plants are passive traps that use nectar to attract insects. Full of hairs, the pitchers retain the prey and keep it from escaping.



NEPENTHES MIRABILIS
The cover of its leaf-pitcher prevents water from entering. These plants tend to have very showy colors that are a fatal visual attraction to an insect.



Dionaea muscipula
Scientific name of the Venus flytrap. It is native to the eastern United States.

LATERAL THORNS
are the hardened borders of the leaves, which have a thick cuticle.

DETECTOR HAIRS
are sensitive to contact with insects.

UPPER PART OF THE LEAF
Reniform, or kidney-shaped, it has special cells arranged along a central hinge.

LOWER PART OF THE LEAF
The cells have a great number of chloroplasts.

1

Falling into the Trap

The fly positions itself above the trap and brushes the lateral thorns. This stimulus provokes the swollen cells of the hinge to lose water rapidly, which in turn causes the upper part of the leaf to close. If the insect is slow to react or move as the trap begins to close, it will be unable to escape.

2

No Exit

The fold of the leaf stimulates the lateral thorns on its opposite sides to interlace like the fingers of two hands and create a type of cage. This process occurs in two tenths of a second, so the fly has little chance of avoiding being trapped.

3

Digestion

In less than three minutes the trap has completely closed, and the digestion of the prey's tissue begins. Special glands located in the interior part of the upper leaf secrete acids and enzymes that chemically degrade the soft parts of the insect's body. When the leaf-trap reopens after a few weeks, the wind blows away the parts of the exoskeleton that were not digested.

Hanging from Other Plants

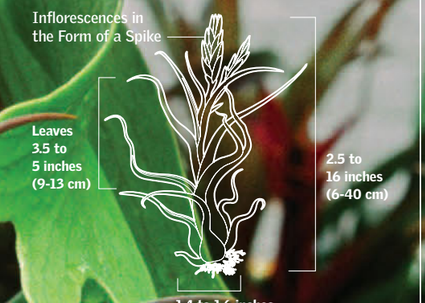
The epiphytes are a very interesting group of plants. They grow on living or dead tree trunks, surfaces of rocks, wall nooks, and even utility poles and wires. Mosses, ferns, orchids, and bromeliads are among the best-known epiphytes. Bromeliads are native to the tropical and humid regions of the Western Hemisphere. They are of special interest because they exhibit evolutionary adaptations that favored their ability to live without contact with soil. They therefore have novel strategies for obtaining the water, minerals, carbon dioxide, and light that they need to survive.

MEDUSA'S HEAD
Tillandsia caput medusae

LEAVES
Few and leathery. They are covered in absorbent hairs.

FRUITS
Fusiform. They measure 1.5 inches (4 cm) in length and barely 0.15 inch (4 mm) in diameter. They contain feathery seeds that disperse with the wind.

SPECIAL SIGNS
These plants are recognized for their bulbs, which have the shape of a small rose, and for their triangular leaves, which are densely covered by hairs. The purple lilac color on their petals is also very characteristic.



Special Leaves

The best-known function of these plants' leaves is to absorb water. In addition, at night they incorporate carbon dioxide and fix it into organic acids. This strategy diminishes their water loss through transpiration during the day through the opening of the stomas for gas exchange. When sunlight is available, photosynthesis takes places. The plants are able to manufacture carbohydrates without opening their stomas, because they can use the carbon dioxide that they took in during the night.

A Different Lifestyle

Bromeliads' roots do not absorb water. Their hard leaves can capture water and nutrients from the air. Using a sticky substance, they usually attach themselves to the branches of trees, where they can have access to sunlight. These traits make it possible for the them to subsist in their natural environment.

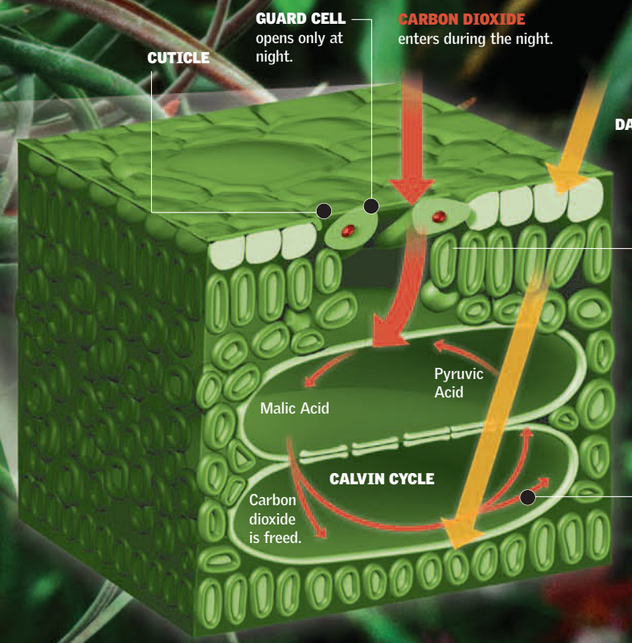
ROOTS
They are in charge of attaching the plant to the substrate, but they do not absorb water or minerals.

BULB
The stalk is very short or nonexistent. They are herbs that form rosette-shaped bulbs with their leaves.

FLOWER
It has the form of a tube, and its color ranges from red to violet. There may be up to 14 flowers in each inflorescence.

FROM THE NEW WORLD
The common origin of the bromeliads is Mexico and the countries of Central and South America. Today bromeliads are cultivated all over the world.





Dangerous Relationships

During their life cycle some plants become a true danger to other plants. There are groups of epiphytes that, in their quest to reach the soil and turn into trees, are capable of strangling and killing the tree on which they begin to grow. Additionally, some plants behave like parasites or semi-parasites. When the seeds of these plants germinate and their embryos have used up their energy reserves, they continue to grow because they obtain food from their hosts.

Deadly Embrace

The genus *Ficus* has some lethal plants among its members. The epiphyte species of the genus, during its young stage, can strangulate and kill the tree on which it supports itself. In this way it can reach the sunlight, which is typically scarce on the forest floor. For example, the strangler fig *(Ficus nymphaeifolia)*, which reaches 23 to 115 feet (7-35 m) in height, produces seeds that can germinate on the branches of another tree. This permits it to grow to a tree of great size that develops an extended crown of long, strong branches. Its roots descend to the ground along the trunk of the host tree and fuse together, forming a thick lattice. The distinct varieties of trees of the *Ficus* genus are characteristic of the rainforests of the intertropical zone. Many are of American origin.

SICONO
This type of infructescence is a pyriform receptacle, hollow and with an apical opening. In its internal walls small berries, commonly called seeds, are found.

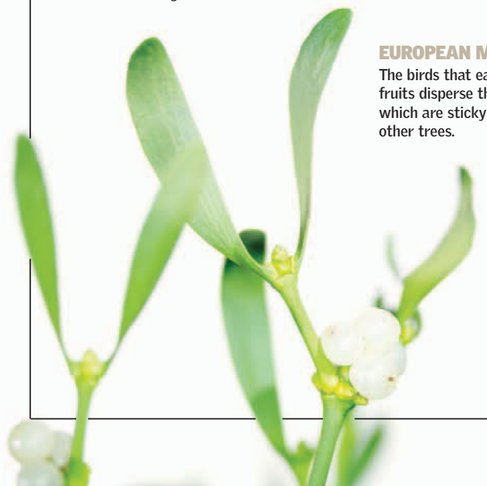


IMPRISONED
The aerial roots of the straggler fig move toward the ground, perhaps as the result of geotropism. As the roots grow, they merge together and imprison the host tree.

Mistletoe

It has chlorophyll but no roots. It parasitizes the branches of a tree, disguising itself as just another branch. Mistletoe appears in places like semi-abandoned olive groves. It is native to humid zones and mountainous areas. The parasite debilitates the host and makes it more vulnerable to insect attacks. The host trees may be killed by the mistletoe or by diseases that attack the tree in its weakened state.

EUROPEAN MISTLETOE
The birds that eat mistletoe fruits disperse the seeds, which are sticky and attach to other trees.



Like a Vampire

Dodder, a plant of the *Cuscuta* genus, parasitizes its host by inserting itself into the host's vascular system and sucking out its nutrients. These parasites do not contain chlorophyll, and their leaves appear as small scales. Dodder germinates on the ground. It then grows around the stalk of a host plant and inserts small rootlike projections, called haustoria, into the stalk. As dodder grows, its many filamentous stems can look like spaghetti. Dodder kills herbaceous plants and debilitates woody ones. It is usually considered a pest because of the economic losses it produces in fodder plants such as alfalfa.

DODDER
It forms a genus, *Cuscuta*, of between 100 and 170 species of parasitic plants that are yellow, orange, or red.

WITHOUT CLOROPHYLL
The stalk and the leaves of these plants do not have chlorophyll; in addition, their leaves are very small.

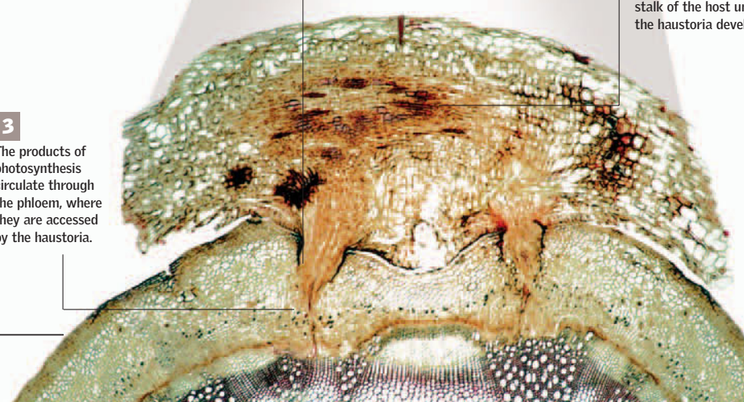
Evolutionary Pressure

The evolution of plants, like that of living beings in general, has favored the rise of the secondary adaptations shown here. These adaptations have benefited certain species with notable characteristics, such as parasitism. The distinctive trait in these plants is the absence of conductive vessels.

1
Upon coming into contact with its host, the vine begins to develop haustoria. They will grow and penetrate the stalk of the host to reach its vascular tissues (xylem and phloem).

2
After germinating, dodder's stems climb and coil around the stalk of the host until the haustoria develop.

3
The products of photosynthesis circulate through the phloem, where they are accessed by the haustoria.

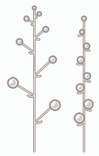


Inflorescences

Inflorescences consist of clusters of flowers on a branch or system of branches. They can be simple or complex. They are simple when a flower forms on the main axis in the axil of each bract. They are complex when a partial inflorescence is born in the axil of the bract that also carries bracteoles or prophylls. Simple inflorescences include racemes, spikes, panicles, catkins, corymbs, and heads. Complex inflorescences include double racemes, double spikes, and double umbels. ●

Types of Inflorescences

Most inflorescences correspond to branching in which the axis grows in an indeterminate manner, and the flowers open in order from the base of the axis toward the apical meristem. There are also determinate inflorescences, in which the end of the axis bears the first flower, and flowers farthest from it open last.



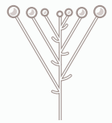
RACEME
The flowers develop on short stalks, called pedicels, along an unbranched axis.



SPIKE
The flowers form directly from the stem instead of from pedicels.



HEAD
The flowers sit on a broad, shortened axis.



CORYMB
The pedicels are of varying lengths.



CATKIN
Similar to a hanging spike, its flowers are entirely male or female.



UMBEL
A group of pedicels spread from the end of the flower stalk.



COMPOUND RACEME
The flower stalks are branched.



SPADIX
It features a spike with a fleshy axis and dioecious flowers.



COMPOUND UMBEL
This form is more common than the simple umbel.

Sunflower

Its inflorescence is a head made of two types of flowers: peripheral florets, which are rayed and unisexual, and disk florets, which are tubular and hermaphroditic.

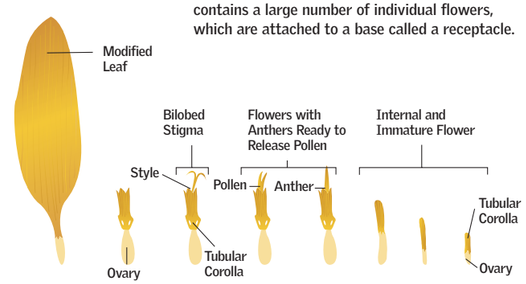
19 feet (6m)
IS THE MAXIMUM HEIGHT OF SUNFLOWERS. THEIR AVERAGE HEIGHT IS 10 FEET (3 M).





DAISY

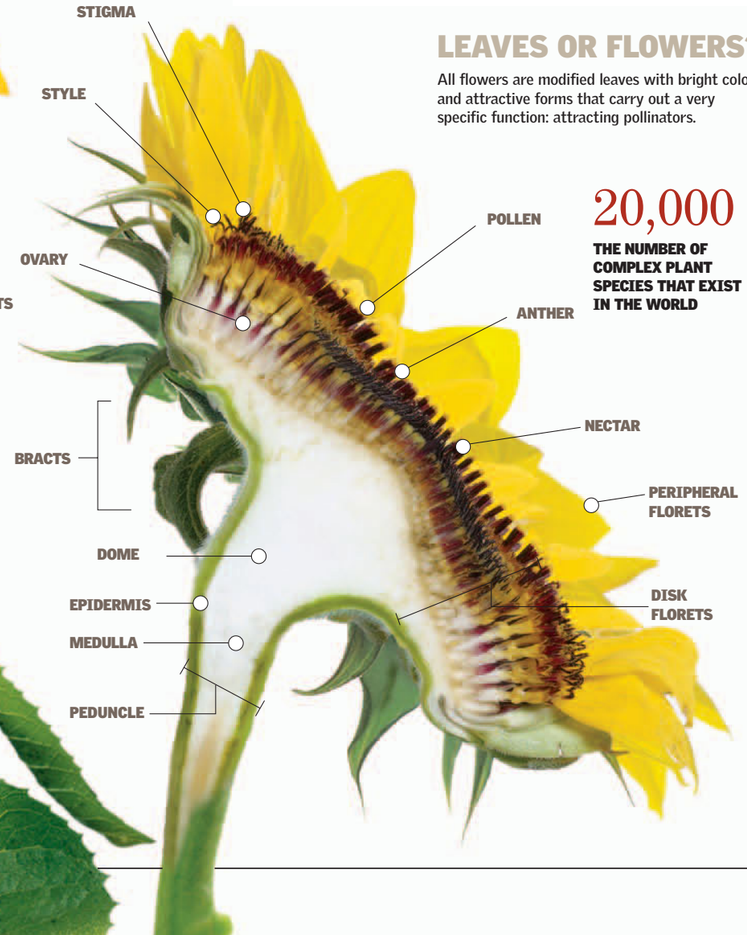
The daisy is a composite flower. As with the sunflower, what appears to be a single flower is, in fact, an inflorescence called a head. The head contains a large number of individual flowers, which are attached to a base called a receptacle.



LEAVES OR FLOWERS?

All flowers are modified leaves with bright colors and attractive forms that carry out a very specific function: attracting pollinators.

20,000
THE NUMBER OF COMPLEX PLANT SPECIES THAT EXIST IN THE WORLD



Between Wind and Sand

The family Cactaceae has 300 genera and thousands of plant species that inhabit predominantly hot and dry places. Cacti are the best known of these species. They have spines that developed to minimize water loss and to provide protection against herbivores. Although cacti originated in the Western Hemisphere, they have spread to other parts of the world. Cacti produce nectar, which plays an important role in pollination by attracting insects and birds to their flowers.

Distribution

Cacti are found in deserts or very dry climates. They have also adapted to the dry and warm climates of Australia, the Mediterranean, and East Africa.

2,000 species
OF PLANTS MAKE UP THE FAMILY CACTACEAE.



THEY RANGE FROM CANADA ALL THE WAY TO SOUTH AMERICA.

Echinopsis pentlandi

FRUIT
Generally fleshy berries. In some cases, however, the fruit is dry.

AREOLE
Axil bud that generates a very short branching of spines

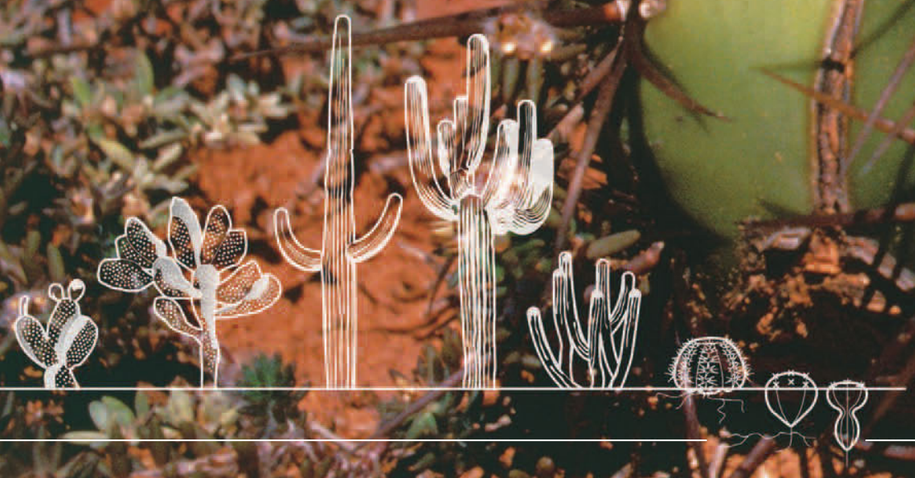
CLADODE
Photosynthetic stem, often succulent, that has the ability to store water

Cactaceae Stems

Green
In the absence of green leaves, photosynthesis takes place in the stem.

Disguised
Epiphyllum cacti do not have leaves, so the stems perform their function.

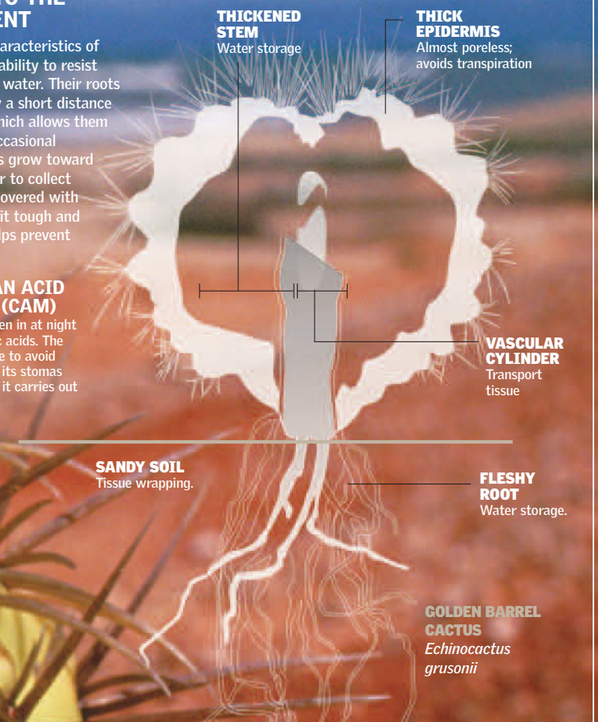
Accordion
They are curvy and expand when they take in water.



ADAPTING TO THE ENVIRONMENT

One of the main characteristics of Cactaceae is their ability to resist drought by storing water. Their roots usually extend only a short distance into the ground, which allows them to better absorb occasional rainfall. Some roots grow toward the surface in order to collect dew. Their skin is covered with wax, which makes it tough and waterproof and helps prevent water loss.

CRASSULACEAN ACID METABOLISM (CAM)
Carbon dioxide is taken in at night and stored as organic acids. The plant is therefore able to avoid water loss by closing its stomas during the day, when it carries out photosynthesis.



LEAVES
In place of simple and alternate leaves, they have thorns, which prevent water loss through transpiration and are a defense against attacks from animals.

STEM
It is succulent and stores a large quantity of water. It contains chlorophyll and is where photosynthesis takes place.

Healing or Harmful?

Poisonous plants are the type that no one wants in the garden. Although some plants have healing properties, others have substances that, when they enter the body, provoke noxious reactions that cause injury or even death. The most infamous of these plants is hemlock, which can also be used medicinally. The primary active components of poisonous plants are alkaloids. One of the most potent poisons from plants is ricin: 0.35 ounce (1 mg) is enough to kill a person. ●

A Matter of Quantity

Poison is a substance that produces illness or tissue lesions or that interrupts natural vital processes when it comes into contact with the human organism. Dosage is a key factor for a substance to act as a poison. The same substance that can produce death in an organism can, in smaller concentrations, act as a medicine and provide relief from certain types of suffering.

Hemlock Water Dropwort
Oenanthe crocata

A plant belonging to the Umbelliferae family that is considered toxic because of its narcotic effects. However, it can also be medically prescribed to treat disorders such as epilepsy.

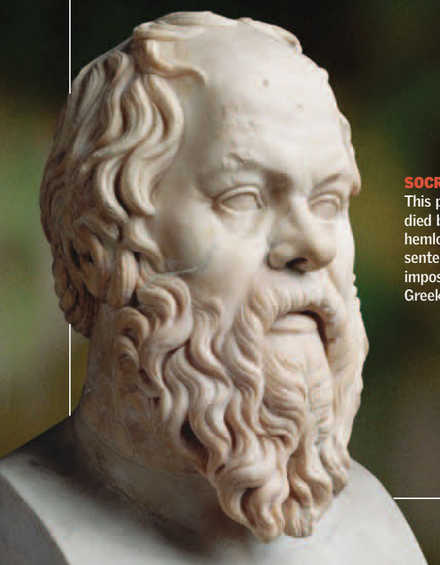
Poison Hemlock

Also known as *Conium maculatum*, this herbaceous plant belongs to the Umbelliferae family. It has a hollow, striated stem, with purple spots at its base. Though poisonous, it has been used to calm strong pains and headaches. Poison hemlock has a characteristic offensive, urinelike odor. The active component in hemlock is coniine, an alkaloid that has neurotoxic effects.



Poison Hemlock
Conium maculatum

HEIGHT
It can grow to a height of 6.5 feet (2 m).



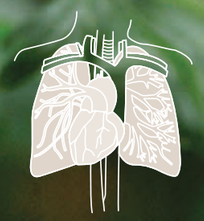
SOCRATES
This philosopher died by drinking hemlock, a sentence imposed by the Greek court.



1.
BURNING
Intoxication produces a dry mouth, dilated pupils (mydriasis), and nausea.



2.
PARALYSIS
The legs weaken, the muscles become paralyzed, and respiratory failure and asphyxia take place.



3.
DEATH
The subject remains conscious until the moment of death.

Other Poisonous Plants

Several cultivated and wild plants have active ingredients that have various levels of toxicity for people and animals. The castor bean *(Ricinus communis)* contains ricin, and chewing two of its seeds can be fatal for a child. *Digitalis* contains substances that can cause a heart attack. Other common poisonous plants, such as oleanders, provoke diarrhea, nausea, and other symptoms if their flowers or fruits are eaten.



Poison Ivy
Toxicodendron radicans

Poison Ivy

is a low vine that grows along the ground and often climbs walls, tree trunks, and bushes. It has bright green leaves that have an oily toxin, which causes light to severe allergic reactions. The symptoms can appear between one and three days after having touched the plant.



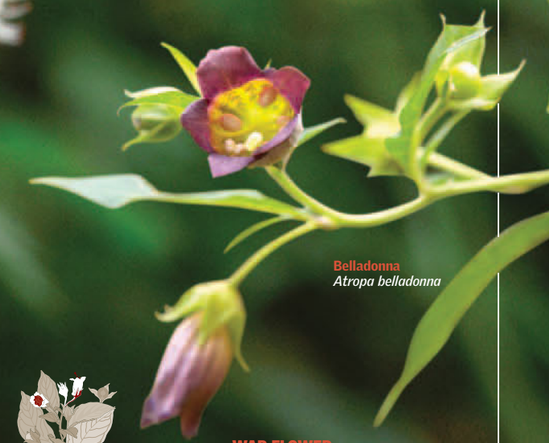
HEIGHT
It can grow to a height of 10 feet (3 m).

IDENTIFICATION
In winter the plant has no leaves but greenish white berries. In the summer the berries are green; they are red in the spring and can be yellow in early autumn.

10%
OF VEGETABLE SPECIES
have alkaloids, compounds formed with nitrogen.

Belladonna (Deadly Nightshade)

has three alkaloids that are considered poisonous: hyoscine, scopolamine, and atropine. These substances affect the autonomous nervous system, which regulates breathing and cardiac rhythm. In medicine atropine in low dosages decreases the intensity of intestinal contractions.



Belladonna
Atropa belladonna

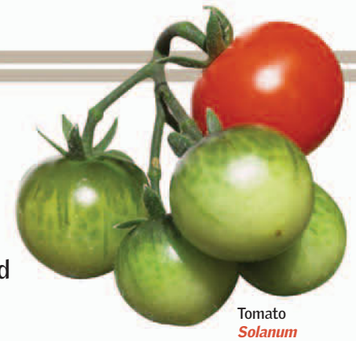


HEIGHT
It grows to a height of 5 feet (1.5 m).

WAR FLOWER
It is said that belladonna was used to poison Mark Antony's troops during the Parthian wars.

Tomato Factories

The colonization of America brought about the discovery of an extraordinary variety of plants that have been used as food for a long time. An important example is the tomato, which is consumed globally. The cultivation of the tomato has reached marked levels of technological complexity that help address problems of infestation and adverse environmental conditions, as well as make it possible to grow tomatoes without using soil. ●



Tomato
Solanum lycopersicum

Traditional Cultivation

In gardens, tomato plants are grown in accordance with their annual growth cycle, using adequate soil and pest control.

Planting	End of Winter
Harvesting	Beginning of Summer

5.5 pounds (2.5 kg)
THE AVERAGE WEIGHT OF TOMATOES A PLANT CAN PRODUCE IN ONE YEAR

GREENHOUSE
Seedlings grow protected from frosts.

FERTILIZER
provides the soil with nutrients.

IRRIGATION
Every plant requires more than 0.5 gallon (2 l) of water every week as it grows.

GOOD NEIGHBORS
Raising carrot and cabbage crops in the same garden aids the development of tomatoes.

6 to 8 inches (15-20 cm)

TRANSPLANT
The seedling can be transplanted when it has three or four real leaves.

STAKES
help the plants to grow and remain upright.

NETTLES
discourage insects that destroy tomatoes.

SANDY LOAM SOIL
allows for the best development of tomatoes.

LEVEL A
has nutrients that are essential to the plant.

Water Absorption Area
2 feet (0.7 m)
3 feet (1 m)

25% Lime
10% Clay
65% Sand

LEVEL B
allows for good water drainage from rain or irrigation.

Transgenic Crop

Biotechnology is used to create plants that can be cultivated in soils which, under normal conditions, would not be adequate (for instance, soils with high salinity).

Planting	Winter
Harvesting	Summer/Autumn

1 DNA
Genetic material is chosen.

2 GENES
The genes that have the desired characteristic are isolated.

3 BACTERIAL DNA
The genes are inserted into a bacterial plasmid.

4 MULTIPLICATION
Bacteria are cultivated to replicate the altered plasmids.

5 TRANSFER
The genes are inserted into the DNA of the plant.

6 NEW FRUITS
Plants are obtained that produce tomatoes with the desired characteristic.

DRY CLIMATES
These climates are not appropriate for planting tomatoes that are not modified, but they can be used to grow modified crops.

HIGH YIELD
The cultivated fields are designed to make maximum use of the available space.

LATE CROP
Transgenic tomatoes mature more slowly than tomatoes that have not been modified.

SALINE SOILS
Due to a shortage in rain, the minerals remain in Level A and increase its salinity.

LEVEL A
High concentration of salts

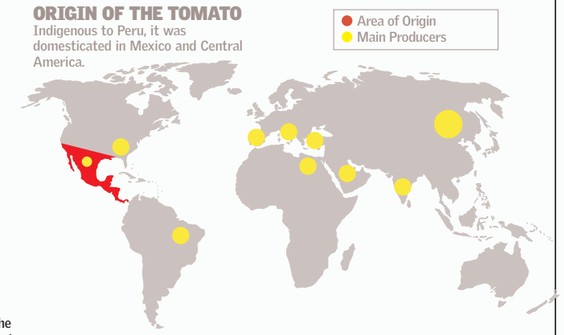
LEVEL B
The clays retain water that soaks into the soil.

40% Clay
30% Sand
30% Lime

More
plants per acre are desired.

64-77° F
(18-25° C)
IS THE OPTIMAL TEMPERATURE.

ORIGIN OF THE TOMATO
Indigenous to Peru, it was domesticated in Mexico and Central America.



Hydroponic Cultivation

Water and nutrients are sufficient to grow tomatoes. For this reason, it is possible to grow crops in inert substrates without any soil. This technique is very useful for obtaining tomatoes in desert areas and for making them available for harvest at any time of the year.

HYDROPONIC GREENHOUSES
allow growers to control the light, water, nutrients, and temperature of cultivation.

WATER TANK
contains water with an optimal amount of nutrients.

Drip-Control Flow Valve

The water flows under the force of gravity.

Irrigating Pipes

PUMP
Propels the water toward the irrigation tank

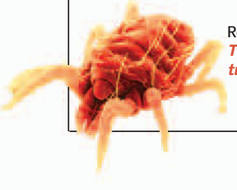
Troughs

COLLECTING TANK
The water is collected, and its physical and chemical properties are analyzed.

SUBSTRATE
Inert materials, such as gravel or sand, work as substrates.

WATER
Water has long been known to be vital to plants.

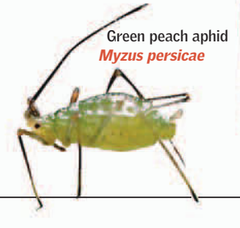
MOST COMMON INFESTATIONS



Red Spider Mite
Tetranychus turkestani



Sweet Potato Whitefly
Bemisia tabaci



Green peach aphid
Myzus persicae

Olive Oil

Olive oil has been a part of people's diet since antiquity, and even today it is one of the most popular oils because of its flavor and nutritious properties. Obtaining high-quality olive oil involves a chain of processes that begins at the tree and ends with the packaging of the end product. The quality begins in the fields and depends on a combination of soil, climate, oil variety, and cultivation and harvesting techniques. The remaining operations in the extraction process (transportation, storage, manufacturing, and extraction of the oil) are responsible for maintaining that quality.



Olive
Olea europaea

22 pounds (10 kg)

IS THE QUANTITY OF OLIVES NEEDED TO EXTRACT **0.5 GALLON (2 L)** OF OIL.



TYPES OF OIL

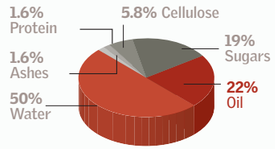
The classification of oil depends on the manufacturing process and on the properties of the product. The shorter the processing, the higher the quality.

Virgin Olive Oil is obtained by pressing, without any refining. It has less than 2 percent acidity.

Refined Olive Oil When this oil is refined, filtering soils are first added to purify it and then decanted. Its acid content is lower than that of virgin olive oil.

Olive Oil can also be obtained by treating the residues with solvents.

COMPOSITION OF AN OLIVE



THE QUALITY OF THE OIL

The oil that comes out of the first pressing from good quality fruits and with an acid level lower than 0.8 percent is called extra virgin. After this pressing the other levels of oil quality are obtained.



PRESS The press has a hydraulic mechanism that compresses the disks.

DISKS The olive paste is placed between them to be pressed.

1 Cultivation

Plowed land, a moderate climate, an altitude of up to 2,300 feet (700 m) above sea level, and up to 15 inches (40 cm) of rain per year sum up the conditions needed for the development of olive plants.

NEW PLANTINGS are propagated through staking, layering, or the taking of cuttings.

80 to 120 plants IS THE OPTIMUM DENSITY PER ACRE (0.4 HA).

COLLECTION Harvesting is done by hitting the tree branches, either by hand or mechanically, so that the fruits fall to the ground.



2 Washing and Classification

The fruits are carefully washed with water and then classified according to their variety.

3 Milling

Machines break open the fruit and mix it to create a homogenous paste. This must be done on the day the fruit is harvested.

STONE WHEEL Hammer systems are also used.

4 Pressing

Traditionally, the paste that includes the entire olive is placed on a system of stacked discs and then compressed by a hydraulic press.

FILTER Centrifugal machines are now used.

RESIDUE can be used to obtain other oils.

5 Refining

The oil obtained is separated from the other solid residues, impurities, and water. Since antiquity, this process has been carried out by decantation, which requires letting the oil sit undisturbed after it comes out of the press. Today it can also be carried out with vertical centrifugal machines.

STAINLESS STEEL HOPPER The residues are decanted at a temperature that is low, but not too low: oil crystallizes between 32° and 36° F (0°-2° C).

HOMOGENIZING The oil from several hoppers is mixed in the final stage to obtain a uniform product.

Large Residues

Residues

3 months IS THE LENGTH OF THE REFINING PERIOD.

6 Storage

Virgin olive oil has nonfat components that have to be preserved during storage and packaging. It must be kept in a dark place at a stable temperature.

THINGS TO AVOID

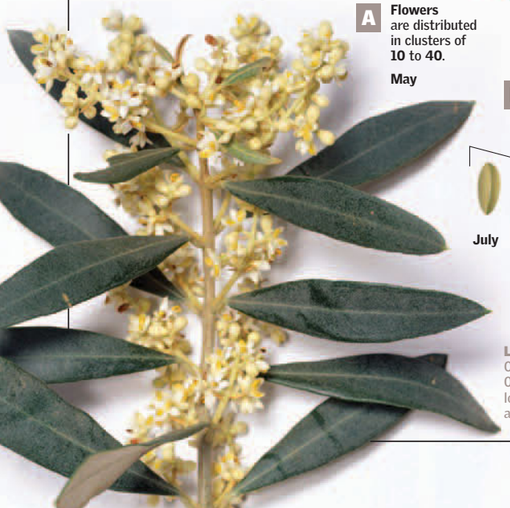
Contact with Air
Heat
Exposure to Light

BOTTLE This is how the oil is sent to the market.

7 Bottling

is carried out in a plant, although sometimes it is done manually to ensure product quality. Glass, aluminum, and plastic containers are used. It cannot be stored where it will be exposed to light, odors, or heat for extended periods.

OLIVE GROWTH STAGES (In the Southern Hemisphere)



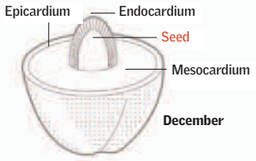
A Flowers are distributed in clusters of **10** to **40**.
May

B Growth The pit or drupe (endocardium) has hardened; the fruit grows.
July
August
September

C Green Olive The appearance of this color tells us the fruit is edible.
October

D Maturing Purple spots begin to show.
November

E Mature Fruit The oxidation process has given it a black color.



December

LEAVES Opposed and lengthened, 0.8 to 3 inches (2-8 cm) long, and with a pointed apical meristem

Alternating Years

After a good crop, olive trees usually do not produce well the following year.

From Tree to Paper

The basic process of manufacturing paper has not changed for 2,000 years, although technology today allows us to manufacture paper in quantities that are immeasurably greater than those of the papyrus produced in antiquity. Paper is manufactured from a slurry that contains cellulose from tree trunks. Today the paper industry consumes 4 billion tons of wood each year. Worldwide, one of the most commonly used trees for paper manufacture is the eucalyptus because of its quick growth, its capacity to resprout trees from the stumps of young trees, its wood's quality, its consistency, and its yield. A disadvantage of eucalyptus is that it requires more water for its growth than most other trees do.

Eucalyptus
Eucalyptus globulus

1 Cultivation

The seedlings are obtained in greenhouses and are transplanted outdoors in furrows in the soil.

21,000 gallons (80,000 l)
OF WATER ARE NEEDED DAILY TO IRRIGATE 1 ACRE (0.4 HA).

TRACTOR
Opens the furrows in the earth

GREENHOUSE
Keeps seedlings between 69° and 80° F (21-27° C)

SEEDLINGS
are transplanted without using a hoe in order not to bend the plant.

WEEDING AND FUMIGATION
eliminate weeds and other plants.

GROWTH RATE
After approximately 10 years the growth rate slows.

Wood Production by Hectare (1 ha = 2.5 ac)
300
250
50
0
Years
0 Initial
5 Maximum
10 Moderate
15

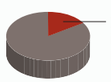
SOIL
Clay-like and siliceous, with a pH between 5 and 7

STAKE
Helps keep the plant upright

TRANSPLANT
The plant is placed in the center of the hole by hand.

FERTILIZED
In furrows perpendicular to the incline of terrain to prevent soil erosion by the water

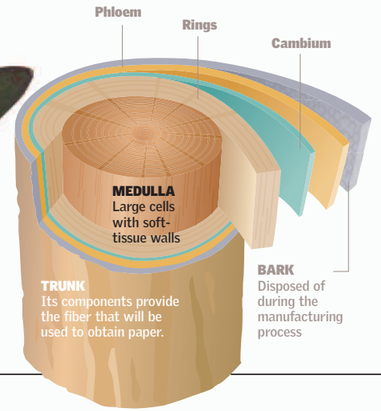
4 billion
TONS OF WOOD IS CONSUMED EVERY YEAR.



USES OF EUCALYPTUS GLOBULUS

FLOWER
In Australia the flower is most important for honey production.

LEAVES
Their resin is used in making perfumes.



2 Clear-Cutting

The timing of the clear-cutting will determine the financial success of the forestry venture. Replanting takes place right away.

10-13 years
IS THE OPTIMAL AGE FOR CUTTING.

CLEAR-CUTTING MACHINE
Cuts cleanly without damaging the bark

TRANSPORTATION
By trunks 8 feet (2.5 m) long

50 cubic feet (15 cu m)
IS THE AMOUNT OF WOOD PRODUCED PER HECTARE.

4 tons
IS THE AMOUNT OF WOOD NEEDED TO PRODUCE ONE TON OF CELLULOSE.

About **80,000 gallons (300,000 l)**
OF WATER PER TON OF WOOD IS REQUIRED FOR THE PRODUCTION OF CARDBOARD, AND ABOUT 50,000 GALLONS OF WATER PER TON (200,000 L PER MT) OF WOOD ARE USED IN THE PRODUCTION OF PRINTING PAPER.

3 Debarking, Washing, and Splintering

The bark is separated from the trunk and eliminated from the industrial process. The debarked trunk is washed and cut into chips to facilitate handling.

DEBARKER
Machine with toothed cylinders

WASHER
Eliminates sand and impurities

CHIPPING MACHINE
The wood is cut into chips.

4 Manufacture of the Pulp

The fibers are separated and suspended in water so they can be purified and bleached.

5 Bleaching and Inclusion of Additives

Bleaching is done with hydrogen peroxide, oxygen, sodium hypochlorite, and other chemicals; glues, kaolin, talcum, plaster, and colorants can be added.

6 Forming the Paper

The mixture of pulp, suspended in water, passes into a machine with screens that hold the fibers and allow the water to drain off. Sheets of paper are the result.

7 Drying

Heated rotating cylinders are used to press some of the remaining water from the paper. The final moisture content depends on the type of paper being made.

DRYING ROLLERS
leave the water content of the paper between 6 and 9 percent.

8 Rolling and Converting

The dried paper is rolled onto reels, and the rolls are cut. The paper can later be cut into various sizes for distribution and sale.

Healing Plants

Among nature's many gifts are herbs, plants, and flowers that, since antiquity, have been used from generation to generation for therapeutic purposes. Since humans began to care for their health, these plants have been a key source of nutrition and healing. Likewise, modern medicine uses compounds derived from or obtained from herbs, roots, stems, leaves, flowers, and seeds.



Contributions from the New World

Various plants were found to possess an impressive number of substances that could be used for therapeutic purposes, as antibiotics, contraceptives, anesthetics, and antipyretics (fever reducers), among others. One example is quinine, used in the treatment of malaria, which was originally obtained from the bark of the quinine tree (*Chinchona* species), a tree native to South America.



SHAMANS
fulfill a central role in ancient communities as repositories of wisdom. Shamans seek to cure illnesses naturally, by means of herbs, roots, and other vegetable substances.



ECHINACEA SP.
The medicinal plant most used by native North Americans. This plant stimulates the immune system.

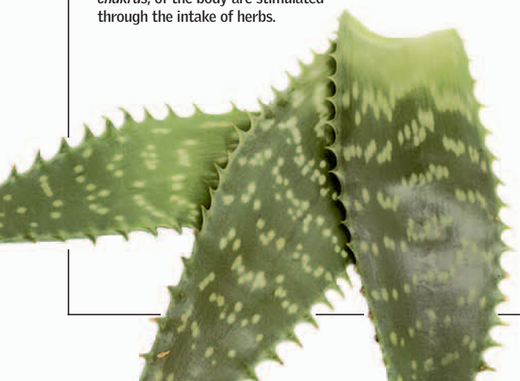


INDUSTRY
Echinacea is consumed around the world as a natural medicine.



Ayurvedic Medicine in India

The knowledge of life is the central principle of ayurvedic medicine. The representation of the elements that form the Universe (fire, air, water, earth, and ether) in three humors (*vata, pitta*, and *kapha*) indicate a person's health and temperament. The energy centers, or *chakras*, of the body are stimulated through the intake of herbs.



THE THREE TYPES OF HUMORS

Vata (wind) is associated with air and ether, *pitta* (anger) is associated with fire and water, and *kapha* (phlegm) is associated with earth and water. A holistic approach, Ayurvedic medicine provides integrated treatments that link physical care and meditation with nutrition.

VATA
(Wind)
In excess, it influences the intestines, the colon, the ears, the bones, the hips, and the skin.

DESCRIPTION
It is associated with a melancholic personality, characteristic of dreamy and erratic people.



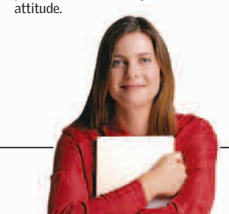
PITTA
(Anger)
It affects the liver, gallbladder, stomach, eyes, skin, and pancreas.

DESCRIPTION
It represents a choleric personality—people who are decisive, with a tendency to embrace new ideas.



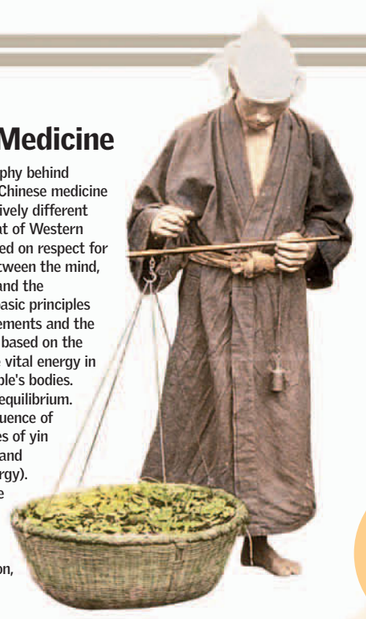
KAPHA
(Phlegm)
In excess, it can affect the throat, airways (upper and lower), and joints.

DESCRIPTION
It is associated with tranquility and serenity, typical characteristics of persons with a naturally sensitive attitude.



Chinese Medicine

The philosophy behind traditional Chinese medicine involves a qualitatively different approach from that of Western medicine. It is based on respect for the interaction between the mind, the body, energy, and the environment. Its basic principles include the five elements and the yin and yang. It is based on the concept of chi, the vital energy in equilibrium in people's bodies. Chi regulates lost equilibrium. It is under the influence of the opposing forces of yin (negative energy) and yang (positive energy). Traditional Chinese medicine includes herbal therapies, nutrition, physical exercise, meditation, acupuncture, and healing massages.



TAI CHI OR TAI JI
is the generating principle of all things, according to Chinese philosophy. It is represented with the yin and the yang, which together make up the Taoist symbol known as the "Taijitu diagram." In order to maintain good health, it is necessary to balance yin and yang.



THE THEORY OF THE FIVE ELEMENTS

Chinese tradition adds metal to the elements of the Greek model (water, fire, air, and earth). The interaction among all these elements must be kept in equilibrium, with no single element predominating over the others. Should an imbalance occur, an illness might appear.



Bitter Herbs
Their action is focused on the heart and the small intestine. They lower fevers and sensations of heat, and they redirect vital energy, or chi.



YIN
Motherwort (*Leonurus cardiaca*), Elecampane (*Inula helenium*), English lavender (*Lavandula angustifolia*)

YANG
Hawthorn (*Crataegus oxyacantha*), sour orange (*Citrus aurantium*), meadowsweet (*Filipendula ulmaria*)



Sweet Herbs
are tonic and nutritious. They harmonize with other herbs, relieve pain, and stop the progression of severe illnesses.



YIN
Garden angelica (*Angelica archangelica*), Italian cyprus (*Cupressus sempervirens*), common hop (*Humulus lupulus*), rosemary (*Rosmarinus officinalis*)

YANG
Greater plantain (*Plantago major*), dandelion (*Taraxacum officinale*), marjoram (*Origanum majorana*)

YIN
Chamomile (*Matricaria chamomilla*), cinnamon (*Cinnamomum zeylanicum*), yellow gentian (*Gentiana lutea*), Minor centaury (*Centaurium umbellatum*)

YANG
Lemon (*Citrus limonum*), common juniper (*Juniperus communis*), lemon balm (*Melissa officinalis*), cranberry (*Vaccinium myrtillus*), olive (*Olea europaea*)



Salty Herbs
are refreshing; they soften hard spots, lubricate the intestines, and promote their emptying. They reduce constipation, kidney stones, gout, etc.



Sour Herbs
basically act on the liver and the gallbladder. They activate bilious secretions.

YIN
Heather (*Calluna vulgaris*), blessed milk thistle (*Silybum marianum*), ginseng (*Panax ginseng*)

Spicy Herbs
induce sweating, blood circulation, and chi, or vital energy. They are generally used for superficial disorders.



YIN
Ginger (*Zingiber officinale*), peppermint (*Mentha piperita*), thyme (*Thymus vulgaris*)

Ginger



YANG
Shepherd's purse (*Capsella bursa-pastoris*), red sandwort (*Arenaria rubra*), rough bindweed (*Smilax aspera*)

YANG
Corn poppy (*Papaver rhoeas*), Tasmanian bluegum (*Eucalyptus globulus*), common borage (*Borago officinalis*)





Fungi

AMANITA MUSCARIA
The quintessential toadstool has unpleasant psychoactive effects. Depending on the dose, they range from dizziness, muscle cramps, and vomiting to amnesia.

ANOTHER WORLD 82-83
THE DIET OF FUNGI 84-85
POISON IN THE KINGDOM 86-87
PATHOGENS 88-89
DESTROYING TO BUILD 90-91



For nearly a billion years the ability of fungi to break down substances has been important to life on Earth. These life-forms break down carbon compounds and return carbon and other elements to the environment to be used by other organisms. They interact with roots, enabling them to better absorb water and mineral nutrients. For many years fungi were classified within the plant kingdom. However, unlike plants, they cannot produce their own food. Many are parasites. Some fungi are pathogens—they can cause sickness in humans, animals, or plants. ●

Another World

For many years fungi were classified within the plant kingdom. However, unlike plants, they are heterotrophic—unable to produce their own food. Some fungi live independently, whereas others are parasitic. Like animals, they use glycogen for storing reserves of energy, and their cell walls are made of chitin, the substance from which insects' outer shells are made.

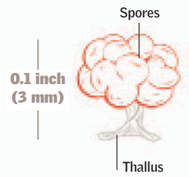


Fungi: A Peculiar Kingdom

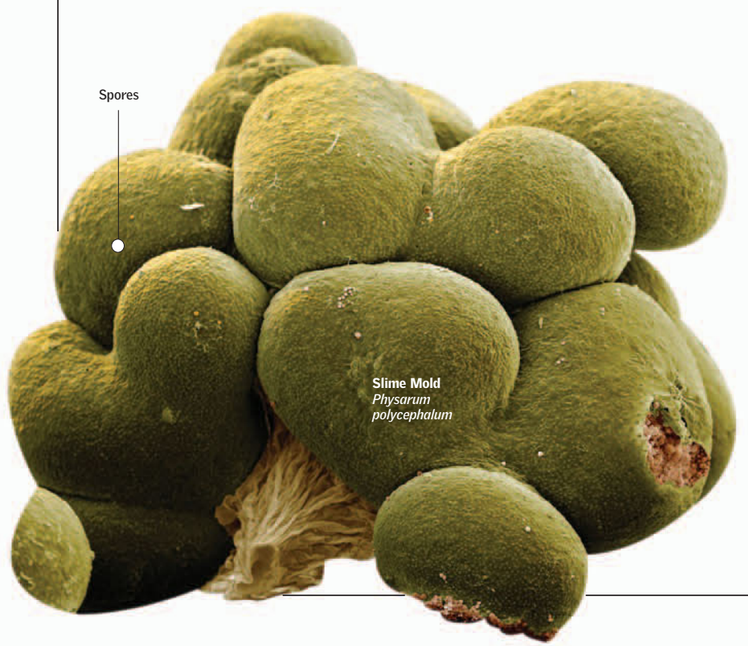
Fungi can develop in all sorts of environments, especially damp and poorly lit places, up to elevations of 13,000 feet (4,000 m). They are divided into four large phyla, in addition to a group of fungi called "imperfect" because they generally do not reproduce sexually. At present, 15,000 species of fungi fall into this category. DNA analysis has recently reclassified them as Deuteromycetes.

Chytridiomycota

are the only fungi that, at some point in their lives, have mobile cells—male and female gametes, which they release into water in order to reproduce. They live in water or on land, feeding on dead material or living as parasites on other living organisms. Their cell walls are made of chitin.



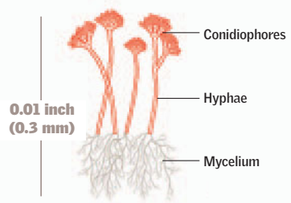
VARIETY
There are great anatomical differences among the Chytridiomycetes. In the same reproductive phase they can produce haploid and diploid spores.



Slime Mold
Physarum polycephalum

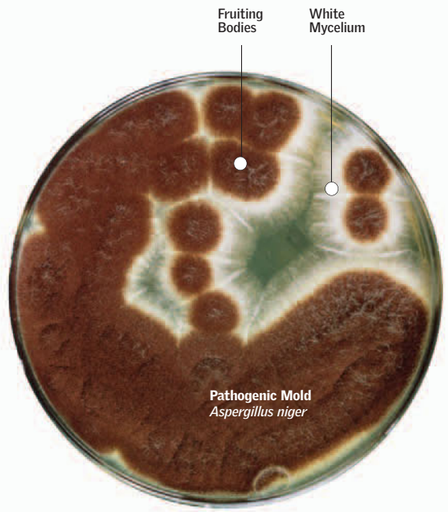
Deuteromycota

are also called "imperfect fungi" because they are not known to have a form of sexual reproduction. Many live as parasites on plants, animals, or humans, causing ringworm or mycosis on the skin. Others—such as *Penicillium*, which produces penicillin, and *Cyclospora*—have great medicinal and commercial value.



OF UNKNOWN SEX
In Deuteromycetes, conidia are tiny spores that function asexually. They are contained in structures called conidiophores.

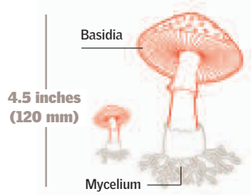
39° to 140° F
(4°-60° C)
THE TEMPERATURE RANGE IN WHICH MOST FUNGI CAN LIVE IN HUMID CLIMATES



Pathogenic Mold
Aspergillus niger

Basidiomycota

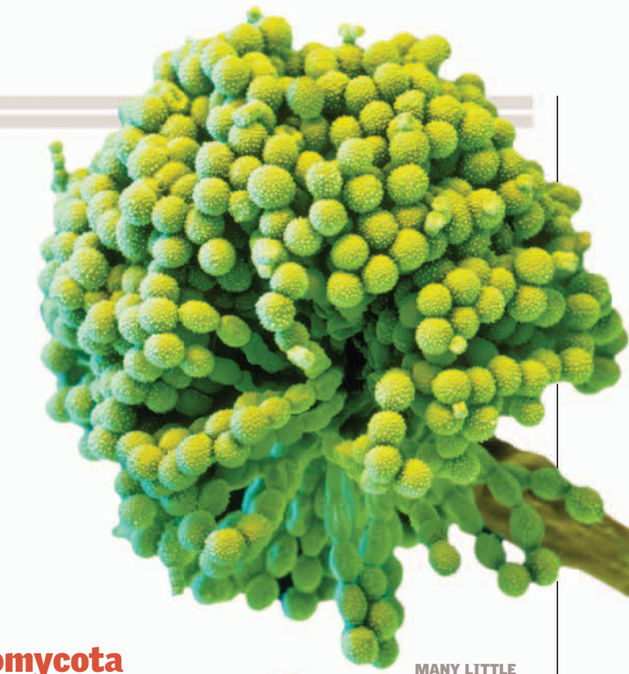
This phylum, which includes mushrooms, is the most familiar of the fungi. The mushroom's reproductive organ is its cap. Its branches grow underground or into some other organic substrate.



CAPPED MUSHROOMS
With its recognizable shape, the mushroom's cap protects the basidia, which produce spores.

Chanterelle Mushroom
Cantharellus cibarius

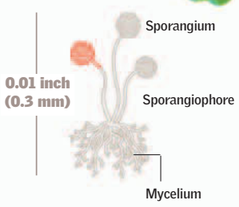
80,857
DIFFERENT SPECIES
HAVE BEEN IDENTIFIED IN THE FUNGI KINGDOM. THERE ARE BELIEVED TO BE APPROXIMATELY 1,500,000 SPECIES.



Black Bread Mold
Rhizopus nigricans

Zygomycota

is a phylum of land-growing fungi that reproduce sexually with zygosporangia, diploid cells that do not break their cell walls until conditions are right for germinating. They also reproduce asexually. Most zygomycetes live in the soil and feed on plants or dead animal matter. Some live as parasites on plants, insects, or small land animals.



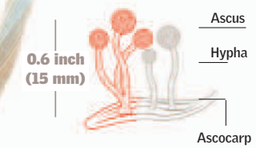
MANY LITTLE POUCHES
Its spores are formed when two gametes of opposite sexes fuse. It can also reproduce asexually, when the sporangium breaks and releases spores.



Ascomycota

is the phylum with the most species in the Fungi kingdom. It includes yeasts and powdery mildews, many common black and yellow-green molds, morels, and truffles. Its hyphae are partitioned into sections. Their asexual spores (conidia) are very small and are formed at the ends of special hyphae.

EXPLOSIVE
At maturity the asci burst. The explosion releases their sexual spores (ascospores) into the air.



Ergot
Claviceps purpurea

The Diet of Fungi

Fungi do not ingest their food like animals. On the contrary, they absorb it after breaking it down into small molecules. Most of them feed on dead organic material. Other fungi are parasites, which feed on living hosts, or predators, which live off the prey they trap. Many others establish relationships of mutual benefit with algae, bacteria, or plants and receive organic compounds from them.

Chemical Transformation

The organic or inorganic substances that fungi feed on are absorbed directly from the environment. Fungi first secrete digestive enzymes onto the food source. This causes a chemical transformation that results in simpler, more easily assimilated compounds. Basidiomycetes are classified according to their diet. For example, they colonize different parts of a tree depending on the nutrients they require.



PARASITES

Fungi such as *Ceratocystis ulmi* and *Agrocybe aegerita* (shaded areas on the leaf) live at the expense of other plants, which they can even kill. Others live parasitically off animals.



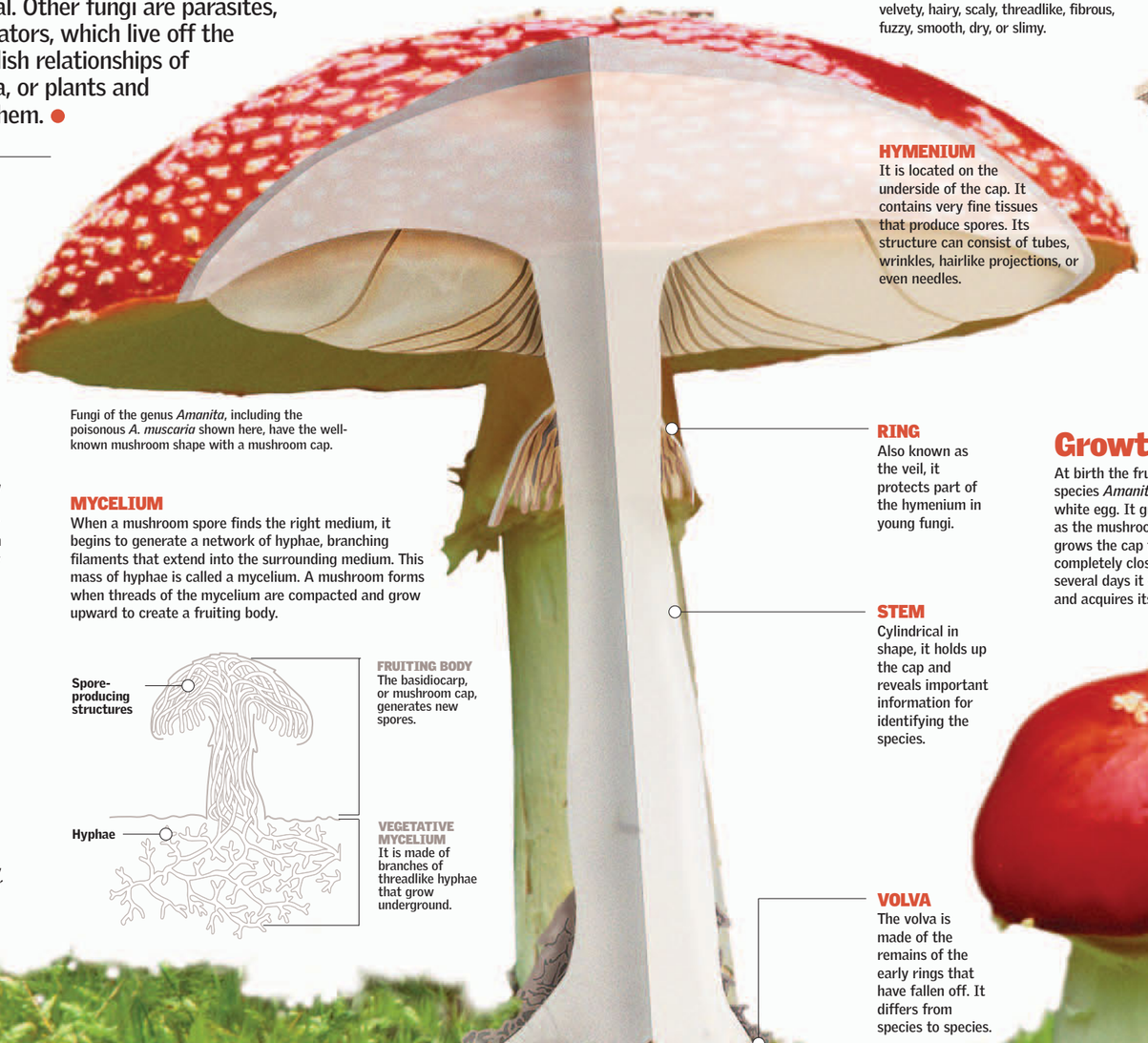
SAPROBES

There is no organic material that cannot be broken down by this type of fungus. They actually live on the dead parts of other plants, so they cause no harm to the host.



SYMBIOTIC

While feeding off the plant, they help it to obtain water and mineral salts more easily from the soil. Each species has its own characteristics.



Fungi of the genus *Amanita*, including the poisonous *A. muscaria* shown here, have the well-known mushroom shape with a mushroom cap.

CAP

Besides being easy to spot, the cap is the fertile part of basidiomycetes; it contains spores.

CUTICLE

The skin, or membrane, that covers the cap, or pileus, is called the cuticle. It can have a variety of colors and textures, such as velvety, hairy, scaly, threadlike, fibrous, fuzzy, smooth, dry, or slimy.

GILLS

are the structures that produce spores. Their shape varies according to the species.

HYMENIUM

It is located on the underside of the cap. It contains very fine tissues that produce spores. Its structure can consist of tubes, wrinkles, hairlike projections, or even needles.

RING

Also known as the veil, it protects part of the hymenium in young fungi.

STEM

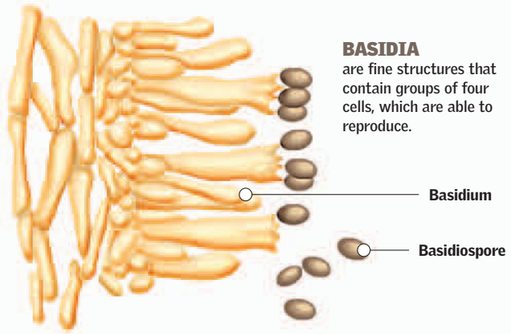
Cylindrical in shape, it holds up the cap and reveals important information for identifying the species.

VOLVA

The volva is made of the remains of the early rings that have fallen off. It differs from species to species.



Detail of a Gill



BASIDIA

are fine structures that contain groups of four cells, which are able to reproduce.

MYCELIUM

When a mushroom spore finds the right medium, it begins to generate a network of hyphae, branching filaments that extend into the surrounding medium. This mass of hyphae is called a mycelium. A mushroom forms when threads of the mycelium are compacted and grow upward to create a fruiting body.

FRUITING BODY

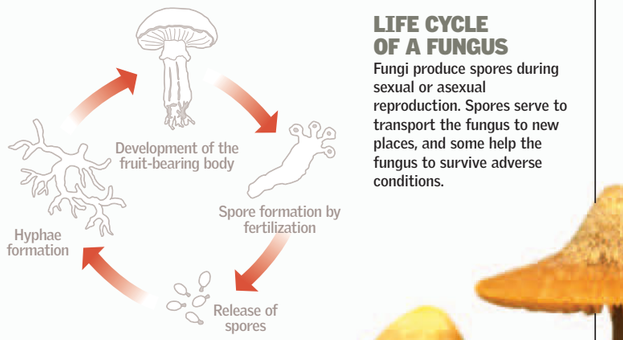
The basidiocarp, or mushroom cap, generates new spores.

VEGETATIVE MYCELIUM

It is made of branches of threadlike hyphae that grow underground.

Growth

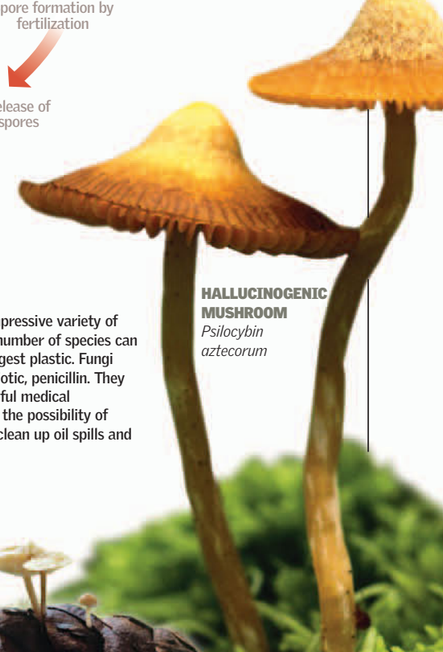
At birth the fruiting body of the species *Amanita muscaria* looks like a white egg. It grows and opens slowly as the mushroom's body unfolds. As it grows the cap first appears completely closed. During the next several days it opens like an umbrella and acquires its color.



LIFE CYCLE OF A FUNGUS

Fungi produce spores during sexual or asexual reproduction. Spores serve to transport the fungus to new places, and some help the fungus to survive adverse conditions.





HALLUCINOGENIC MUSHROOM
Psilocybin aztecorum

Did You Know?

Fungi can break down an impressive variety of substances. For example, a number of species can digest petroleum, and others can digest plastic. Fungi also provided the first known antibiotic, penicillin. They are now a basic source of many useful medical compounds. Scientists are studying the possibility of using petroleum-digesting fungi to clean up oil spills and other chemical disasters.

Strobilurus esculentus

lives on the cones of various pine trees.



Poison in the Kingdom

A poisonous fungus is one that, when ingested, causes toxic effects. In terms of its effects on the eater, the toxicity can vary according to the species and to the amount ingested. At times poisoning is not caused by eating fungi but by eating foods, such as cereal products, that have been contaminated by a fungus. Rye, and to a lesser extent oats, barley, and wheat, can host toxic fungi that produce dangerous mycotoxins. These mycotoxins can cause hallucinations, convulsions, and very severe damage in the tissues of human organs. ●



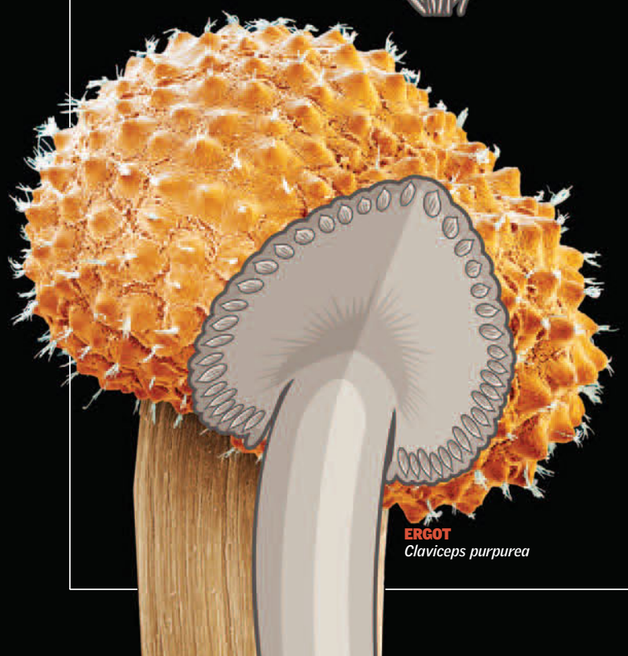
ERGOTISM (ST. ANTHONY'S FIRE)

Attack on Rye

Ergot (*Claviceps purpurea*) is a parasite of rye and produces alkaloid mycotoxins—ergocristine, ergometrine, ergotamine, and ergocryptine. When barley with ergot is processed for use in food, the mycotoxins can be absorbed when eaten. All these toxic substances can act directly on nerve receptors and cause the constriction of blood vessels.

1. Release

Within the enclosing structures a stroma, or compact somatic body, is formed. Inside it reproductive growths develop, which contain a large number of perithecia.



ERGOT
Claviceps purpurea

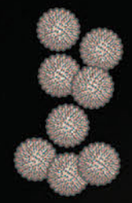
2. Fruit

The perithecium is a type of fruiting, or reproductive, body in ascomycetes. It is a type of closed ascocarp with a pore at the top. The asci are inside the perithecium.



3. Spores

The asci are sac-shaped cells that contain spores called ascospores. In general, they grow in groups of eight and are light enough to be scattered into the air.



4. Parasites

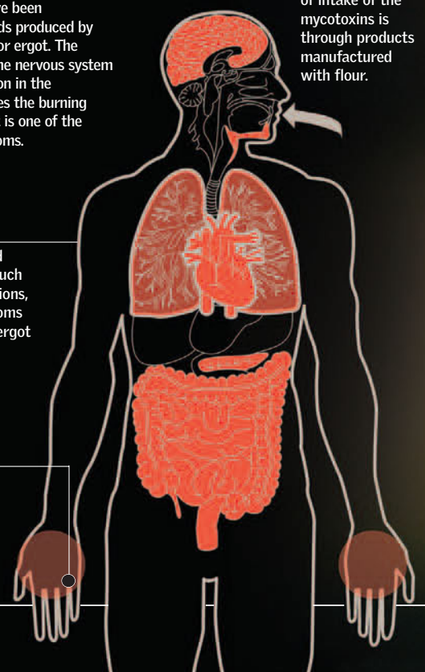
Ascospores of sexual origin or asexual conidia develop as parasites in the ovary of the rye flower. They cause the death of its tissues and form sclerotia. In some languages ergot's name is related to the word for "horn" because of sclerotia's hornlike shape.

Ergotism

Ergotism, or St. Anthony's Fire, is a condition caused by eating products such as rye bread that have been contaminated with alkaloids produced by *Claviceps purpurea* fungi, or ergot. The alkaloids typically affect the nervous system and reduce blood circulation in the extremities, which produces the burning sensation in the limbs that is one of the condition's notable symptoms.

NERVOUS SYSTEM
Lethargy, drowsiness, and more severe conditions, such as convulsions, hallucinations, and blindness, are symptoms caused by the effects of ergot on the nervous system.

EXTREMITIES
Ergotamine alkaloids cause the constriction of blood vessels, leading to gangrene.



INGESTION
The main means of intake of the mycotoxins is through products manufactured with flour.



Derived from Rye

In Europe during the Middle Ages wheat bread was a costly food, not part of the common diet. Most people ate bread and drank beer prepared from rye. This made them susceptible to ingesting mycotoxins from *Claviceps purpurea*. Thus, the largest number of cases of ergotism occurred during this time. Today preventative controls in the production of bread and related products from rye and other cereals have greatly reduced instances of ergotism.

Poisonous Mushrooms

Eating the fruiting bodies of some species can be very dangerous if it is not clearly known which are edible and which are poisonous. There is no sure method for determining the difference. However, it is known for certain that some species—such as certain species of the genera *Amanita, Macrolepiota*, and *Boletus*—are poisonous.



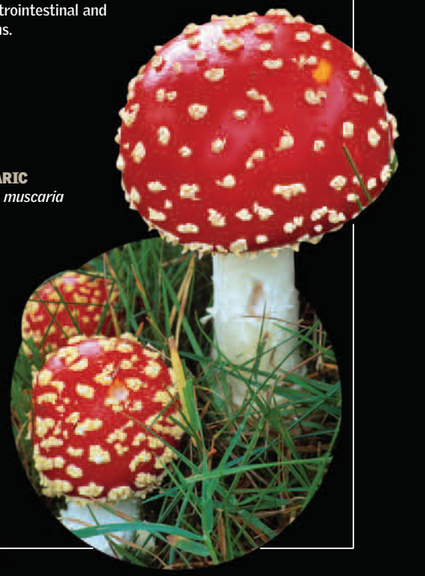
DESTROYING ANGEL
Amanita virosa

Pretty But Deadly

This mushroom is toxic to the liver. It grows from spring to fall, often in sandy, acidic soil in woodlands and mountainous regions. Its cap is white and 2 to 5 inches (5-12 cm) in diameter. Its stem and gills are also white, and the gills may appear detached from the stem. The base of the stem has a cuplike volva, but it may be buried or otherwise not visible.

Insecticide

The fly agaric's name is thought to come from its natural fly-killing properties. Its cap is typically red and 6 to 8 inches (15-20 cm) in diameter. It may be covered with white or yellow warts, but they are absent in some varieties. The stem is thicker at the base, which looks cottony. It also has a large white ring that looks like a skirt. It grows in summer and fall in coniferous and deciduous forests.
If eaten, it causes gastrointestinal and psychotropic symptoms.



FLY AGARIC
Amanita muscaria

Pathogens

Fungi that are able to cause illnesses in people, animals, or plants are called pathogens. The nocive, or toxic, substances that these organisms produce have negative effects on people and cause significant damage to agriculture. One reason these pathogens are so dangerous is their high tolerance to great variations in temperature, humidity, and pH. *Aspergillus* is a genus of fungi whose members create substances that can be highly toxic.

CONIDIA CHAIN
Conidia are asexual spores that form at the ends of the hyphae. In this case they group together in chains.

CONIDIA
are so small that they spread through the air without any difficulty.

PHIALIDES
are cells from which conidia are formed.

CONIDIOPHORE
The part of the mycellium of the fruiting, or reproductive, body in which asexual spores, or conidia, are formed

Aspergillum

Aspergillus are "imperfect" fungi, or deuteromycetes, that are characterized by having reproductive structures called conidial heads. The head is composed of a vesicle that is surrounded by a crown of phialides shaped like a bottle, at the end of which spore chains form.

CONIDIAL HEAD
Has a greenish mycellium and short and abundant conidiophores.

ALLERGENICS *Aspergillus flavus*

This species is associated with allergic reactions in people with a genetic predisposition to this allergy. They also cause the contamination of seeds, such as peanuts. They produce secondary metabolites, called micotoxins, that are very toxic.

SAPROBIA *Aspergillus* sp.

In addition to the pathogen species, there are some species of *Aspergillus* that decompose the organic matter of dead insects, thus incorporating nutrients into the soil.

BREAD MOLD *Aspergillus niger*

The fruiting body is yellowish white, but it will turn black when the conidia mature. Its conidiophores are large and have phialides that cover all its conidial head vesicle. They can be found in mold-covered food.

OPPORTUNISTIC *Aspergillus fumigatus*

This pathogen can affect people whose immune systems are weakened. It can cause serious invasive diseases.

900

THE NUMBER OF *ASPERGILLUS* SPECIES. THEY HAVE BEEN CLASSIFIED INTO 18 GROUPS. MOST OF THESE SPECIES ARE ASSOCIATED WITH HUMAN ILLNESSES, SUCH AS ASPERGILLOSIS.

12

SPECIES ARE ASSOCIATED WITH HUMAN ILLNESSES. *ASPERGILLUS FUMIGATUS*, *A. FLAVUS*, *A. NIGER*, AND *A. TERREUS* ARE EXAMPLES.

Destroying to Build

Yeasts, like other fungi, decompose organic material. This capacity can be beneficial, and, in fact, human beings have developed yeast products for home and industrial use, such as bread, baked goods, and alcoholic beverages, that attest to its usefulness. Beer manufacturing can be understood by analyzing how yeasts feed and reproduce and learning what they require in order to be productive.

Precious Gems

Yeast from the genus *Sacchromyces cerevisiae* can reproduce both asexually and sexually. If the concentration of oxygen is adequate, the yeasts will reproduce sexually, but if oxygen levels are drastically reduced, then gemation will take place instead. Gemation is a type of asexual proliferation that produces child cells that split off from the mother cell. Starting with barley grain, this process produces water, ethyl alcohol, and a large quantity of CO_2, the gas that forms the bubbles typically found in beer.

Fermentation

Under anaerobic conditions yeasts can obtain energy and produce alcohol. By means of the alcoholic fermentation process they obtain energy from pyruvic acid, a product of the breakdown of glucose by glucolysis. In this process CO_2 is also produced and accumulated, as is ethyl alcohol. The carbon dioxide will be present in the final product: the beer.



1 MEIOSIS
A diploid cell forms four haploid cells.

2 SPORES
A sac called an ascus is formed that contains ascospores of yeast.

3 RELEASE OF THE ASCOSPORES
The opening of the ascus releases the spores, which then reproduce by mitosis.

4 UNION OF THE ASCOSPORES
The haploid cells fuse and form a new diploid cell.

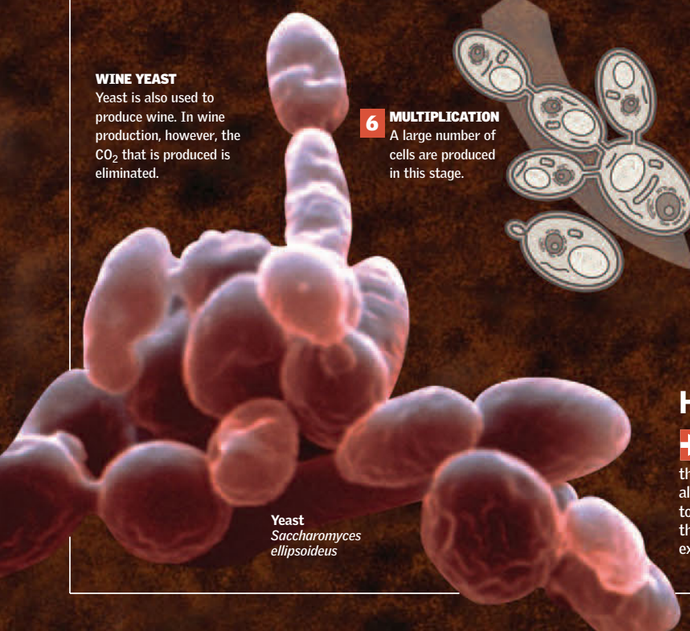
5 GEMATION
Under the right conditions the diploid cells begin to reproduce asexually.

6 MULTIPLICATION
A large number of cells are produced in this stage.

Cycle

GROW AND MULTIPLY
As long as they have adequate nutrients, yeasts will continuously repeat their reproductive life cycle.

WINE YEAST
Yeast is also used to produce wine. In wine production, however, the CO_2 that is produced is eliminated.



Yeast
Saccharomyces ellipsoideus

Homemade Bread

Many products are made with yeasts, and one of the most important is bread. In the case of bread, yeasts feed off the carbohydrates present in flour. Bread products, unlike alcoholic beverages, need to have oxygen available for the yeast to grow. The fungi release carbon dioxide as they quickly consume the nutrients. The bubbles of carbon dioxide make the dough expand, causing the bread to rise.

Yeast
Saccharomyces cerevisiae

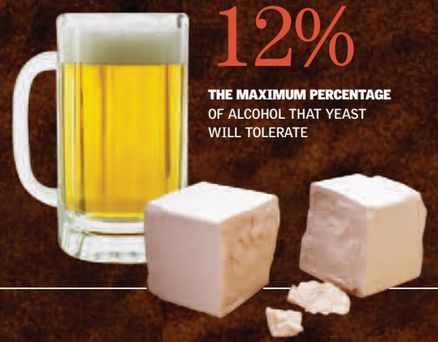
GEMATION
Buds, or gems, which will become independent in a new cell, are formed in different parts of a yeast.



NUCLEUS
It coordinates all the cell's activities. Its duplication is vital in making each child cell the same as its progenitor cell.

MITOCHONDRIA
These subcellular structures become very active when the cell is in an environment rich in oxygen.

CELL MEMBRANE
The cell membrane controls what enters or exits the cell. It acts as a selective filter.



12%
THE MAXIMUM PERCENTAGE OF ALCOHOL THAT YEAST WILL TOLERATE

ENZYME PRODUCTION
Internal membrane systems produce the enzymes that regulate the production of alcohol and carbon dioxide in the cells.

VACUOLE
This organelle contains water and minerals that are used in the cell's metabolism. The concentration of these nutrients helps regulate the activity of the cell.

Glossary

Adventitious Root

Root that appears in unusual places, such as on the stem

Algae

Organisms of the Protist kingdom, at one time considered plants, but without roots, stems, or leaves. They live in water or in humid areas. They can be pluricellular or unicellular.

Allele

Gene variant that encodes a trait. One diploid cell contains one allele from each parent for each characteristic.

Anaerobic

Reaction, or series of reactions, that does not require oxygen

Analogy

Similarity produced in similar environments through the adaptation of species that do not have a common ancestor

Angiosperms

From the Greek *angion* (recipient) and *sperm* (seed). Plants with flowers whose seeds are contained in structures that develop into fruits.

Anther

Structure of the stamen composed of two locules and four pollen sacs

Asexual Reproduction

Process through which a single progenitor generates descendants identical to itself

ATP

Adenosine triphosphate. Molecule produced by the mitochondria, which functions as the main source of energy for cells.

Berry

Simple fleshy fruit formed by one or more carpels

Biome

Ecosystem that occupies a large area and is characterized by specific types of vegetation

Bryophytes

Group of small flowerless plants that comprise the hepaticae, anthocerotae, and mosses

Bulb

Modified structure of the stem in which starch accumulates in thickened leaves

Cambium

Interior part of the root and the stem of a plant that forms xylem on one side and phloem on the other. It makes stems grow thicker.

Carpel

Female part that bears the ovules of a flower. The grouping of carpels forms the gynoecium.

Cell

Smallest vital unit of an organism. Plant cells have a wall that is more or less rigid.

Cellular Membrane

Flexible cover of all living cells. It contains cytoplasm and regulates the exchange of water and gases with the exterior.

Cellular Respiration

Aerobic processes that extract energy from food, including glycolysis, oxidative phosphorylation, and the Krebs cycle. Eukaryote cells carry out these processes in the cytoplasm and the mitochondria.

Cellulose

Fibrous carbohydrate that a plant produces as part of its structural material. Main component of the cell wall.

Chitin

Polysaccharide that contains nitrogen. It is present in the cell walls of mushrooms.

Chlorophyll

Pigment contained in the chloroplasts of plant cells. It captures the energy of light during photosynthesis.

Chloroplast

Microscopic sac, located on the inside of green-plant cells, where the chemical processes of photosynthesis take place

Cilium

Short external appendage that propels a cell and is composed of microtubules

Class

Taxonomic group superior to order and inferior to phylum. For example, the Charophyceae class includes green algae related to higher plants.

Cotyledon

First leaf of flowering plants, found on the inside of the seed. Some store food and remain buried while the plant germinates.

Cytoplasm

Compartment of the cells of eukaryotes, marked by the cellular membrane and the membranes of the organelles of the cell

Deciduous

Describes a plant that loses all its leaves in specific seasons of the year

Dicotyledon

Flowering plant whose seed has two cotyledons

Diploid

Cell with two complete sets of chromosomes

DNA

Deoxyribonucleic acid. Double helix molecule with codified genetic information.

Drupe

Simple fleshy fruit that develops from hypogynous flowers—flowers in which the ovary lies above the point where the other flower parts are attached. It has one seed in its interior. Examples include the olive, peach, and almond.

Ecosystem

Grouping of the organisms of a community and the nonbiological components associated with their environment

Embryo

Product of an egg cell fertilized by a sperm cell; it can develop until it constitutes an adult organism.

Endodermis

Layer of specialized cells, composed of thicker cells; in young roots it is found between the bark and the vascular tissues.

Endoplasmic Reticulum

Network of membranes connected through the cytoplasm that serves as a site of synthesis and assembly for the cell to form its proteins

Enzyme

Protein that helps to regulate the chemical processes in a cell

Epidermis

The most external cellular layers of stems and leaves

Epiphyte

Plant that grows and supports itself on the surface of another plant but does not take water or nutrients from it

Family

Taxonomic category, inferior to order, that groups the genera

Fertilization

Fusion of the special reproductive cells (contained in the pollen and in the ovules) in order to give rise to a new plant

Filament

Structure, in the form of a thread, that forms the support of a flower's stamen

Fruit

Ovary or group of ovaries of a flower, transformed and mature. It contains the seeds.

Gametangium

Unicellular or multicellular structure from which the gametes, or reproductive sexual cells, originate

Gene

Unit of information of a chromosome. Sequence of nucleotides in the DNA molecule that carries out a specific function.

Genetic Drift

Phenomenon produced in small populations that demonstrates that the frequency of alleles can vary by chance or throughout generations

Germination

Process in which a plant begins to grow from a seed or a spore

Gymnosperm

Plants with seeds that are not sealed in an ovary. Examples are conifers (pine, fir, larch, cypress).

Gynoecium

Grouping of carpels of a flower that make up the female sexual organ of angiosperms

Haploid

From the Greek *haplous*, singular: cell with one set of chromosomes, unlike diploids. It is characteristic of the gametes, the gametophytes, and some mushrooms.

Haustoria

Vessels with which some parasitic plants penetrate other species in order to feed themselves from substances photosynthesized by the host

Host

Plant from which another organism (parasite) obtains food or shelter

Hyphae

Interwoven filaments that form the mycelium of fungi

Inflorescence

Groupings of flowers in a specific form on a peduncle

Kingdom

Taxonomic group superior to a phylum and inferior to a domain, such as the kingdom Plantae

Legume

Simple fruit of some species that come from one carpel divided in two. Examples are garbanzos and peas.

Lichen

The symbiotic union of a fungus and an alga; the food is synthesized by the algae and used by the fungus, which offers the alga a moist and protected habitat in which to live.

Lignin

A substance related to cellulose that helps form the woody parts of plants

Ligula

Petal developed on the border of the head of certain composite flowers. Its color may be blue or yellow, or more commonly, white, as in the case of daisies.

Macronutrient

Essential chemical element that a plant needs in relatively large quantities and that is involved in its vital processes. Examples are nitrogen and phosphorus.

Medulla

Basic tissue formed inside the vascular tissue

Meiosis

Type of cellular division in which two successive divisions of the diploid nucleus of a cell give rise to four haploid nuclei. As a result, gametes or spores are produced.

Meristem

Region of tissue consisting of cells that produce other cells through cellular division

Mitochondria

Organelle delimited by a double membrane. In it, the final stage of aerobic respiration is carried out, in which ATP is obtained from the decomposition of sugars.

Mitosis

Nuclear division that forms two descendant nuclei identical to the progenitor

Molecular Clock

Marker used to calculate the evolutionary distance between two species. It is evaluated by comparing the gradual accumulation of differences in amino acids among the proteins of each species.

Monocotyledons

Flowering plants with only one cotyledon. Examples are the onion, orchid, and palm.

Mycelium

Interwoven mass of hyphae of a fungus

Nectar

Sweet liquid, produced by flowers and some leaves, that attracts insects and birds, which serve as pollinating agents

Node

Axillary bud, the part of the stem of a plant where one or more leaves appear

Nucellus

Structure located inside plants with seeds, where the embryonic sac is developed

Nucleic Acid

A molecule that carries genetic information about the cell

Nucleus

The part of the cell that contains the DNA, which carries the genetic material

Osmosis

The movement of a liquid through a selectively permeable membrane

Ovary

The part of a flower consisting of one or more carpels and containing the ovules. Fertilized, it will form all or part of the fruit.

Ovule

The part of the ovary in flowering plants that contains the female sexual cells. After fertilization it transforms into seed.

Parasite

An organism that lives at the expense of another, from which it obtains its nutrients

Petal

Modified leaves that form the corolla

Phloem

Vessels that conduct the sap throughout the entire plant

Photorespiration

Process through which some plants close their stomas in order to avoid dehydration

Photosynthesis

Process through which the energy of light is used to produce carbohydrates from carbon dioxide and water

Phytoplankton

Group of free-living microscopic aquatic organisms with the capacity to carry out photosynthesis

Pollen

Fine powder of plants with seeds whose grains contain the male sexual cells

Pollination

Passage of pollen from the male organ of a flower to the female organ of the same flower or another

Polymer

Macromolecule formed from repeated structural units called monomers

Polypeptide

Polymer of amino acids; examples are proteins.

Protein

Macromolecule composed of one or more chains of amino acids. They define the physical characteristics of an organism and regulate its chemical reactions when they act as enzymes.

Protoplast

Plant cell without a cell wall

Rhizoids

Cellular formation or filament in the form of a thin and branching tube that attaches mosses to the soil

Rhizome

Horizontal subterranean stem

Ribosome

Organelle located in the cytoplasm that directs the formation of proteins on the basis of information given by the nucleic acids

Root

Organ that fixes a plant to the soil and absorbs water and minerals from it

Sap

Watery liquid that contains the products of photosynthesis and is transported by the phloem

Seed

Structure consisting of the embryo of a plant, a reserve of food called the endosperm, and a protective cover called the testa

Seedling

First sprouting of the embryo of a seed, formed by a short stem and a pair of young leaves

Sepal

Modified leaf that forms the outer covering of a flower that protects the bud before it opens

Sexual Reproduction

Reproduction based on the fertilization of a female cell by a male cell; it produces descendants different from both progenitors.

Sori

Set of sporangia found on the underside of fern leaves

Spore

Reproductive structure formed by one cell, capable of originating a new organism without fusing with another cell

Sporangia

Structure in which spores are formed

Stamen

Element of the male reproductive apparatus of a flower that carries pollen. It is formed by a filament that supports two pollen sacs on its upper part.

Stem

Part of a plant that holds up the leaves or the reproductive structures

Stigma

Upper part of the female reproductive apparatus of a flower. The receptor of pollen, it connects with the ovary.

Storage organ

Part of a plant that consumes sugars or functions to store sugars. Examples are stems, roots, and fruit.

Thallus

Plantlike body of brown seaweed. Also the long, rigid part that holds up the reproductive structures of some fungi.

Thylakoid

Small, flat sac that makes up part of the internal membrane of a chloroplast. Site where solar energy is transformed into chemical energy as part of the process of photosynthesis.

Tissue

Group of identical cells with the same function

Tuber

Modified, thickened underground stem where the plant accumulates reserves of food substances

Vascular

Describes plants with a complex structure and highly organized cells for transporting water and nutrients to all parts of the plant

Xerophyte

Plant that grows in deserts and other dry environments

Xylem

Part of a plant's vascular system. It transports water and minerals from the roots to the rest of the plant.

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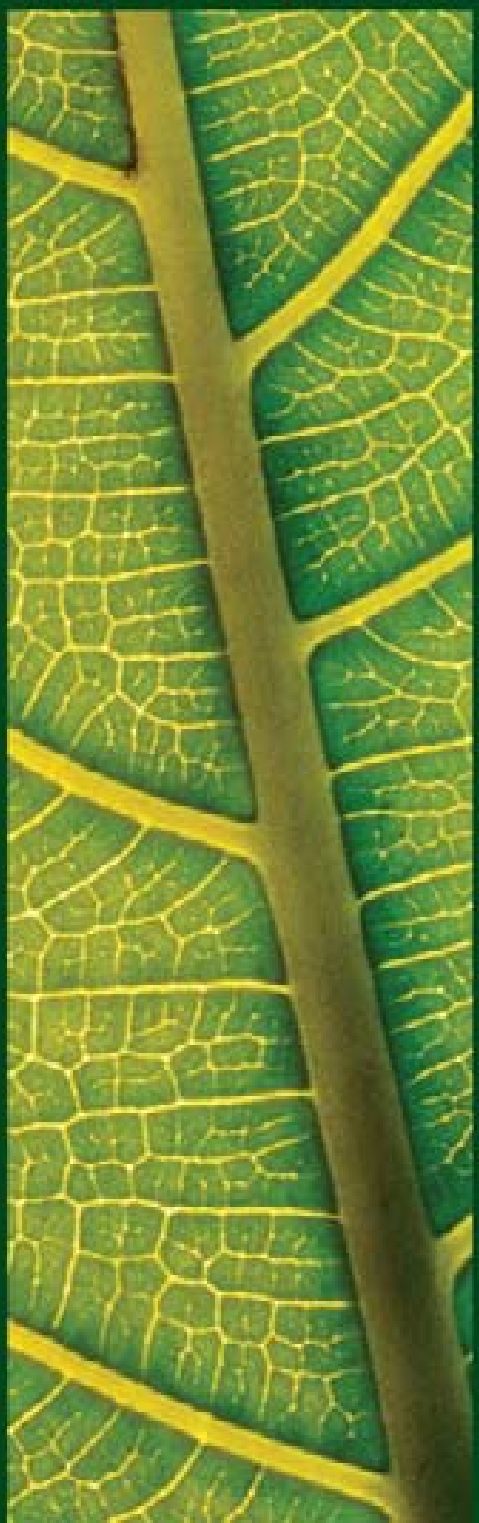
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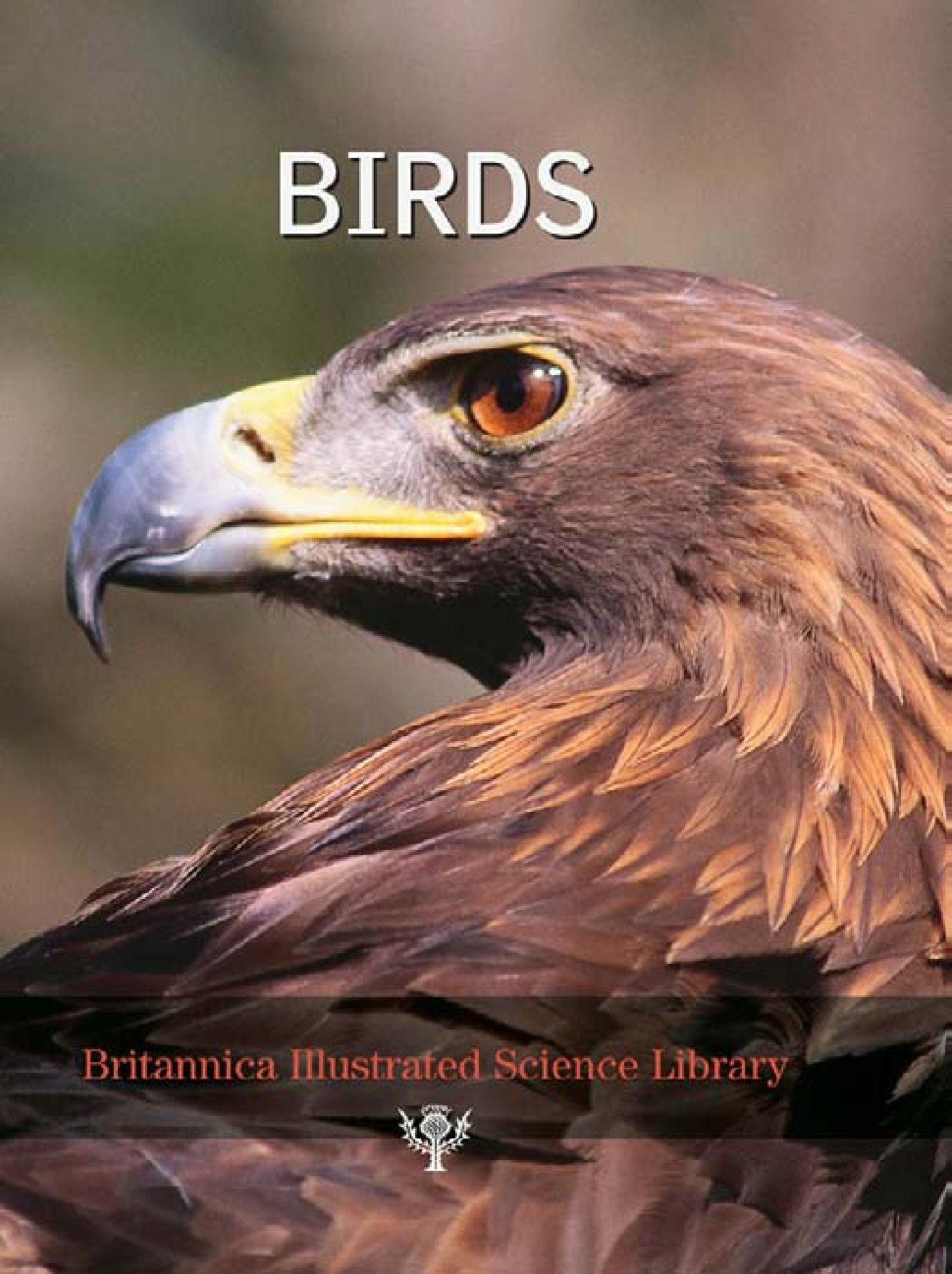
PLANTS, ALGAE, AND FUNGI

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Birds



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A Universe of Birds

Welcome to the world of birds. No matter how you approach it, this is a wonderful book not only for its pictures, splendid illustrations, size, and format but also because, as you read it, you will discover secrets about these inhabitants of the Earth, which, according to the history of evolution, came into being before humans. The text is written in a direct, easy-to-understand style. Most birds have a much-envied ability that has inspired poems and all types of experiments: they can fly. This enables them to see the Earth from afar, with its seas, mountains, rivers, cities, and other features. It has been estimated that more than 200 million birds migrate each year, all over the planet. Many of them fly thousands of miles, crossing desolate deserts and windy seas to arrive in Africa or Antarctica. Some find their way using the sun, the moon, and the stars; others follow their parents or use the course of rivers or mountain chains as references. In general, smaller birds migrating across continents stop several times to get food. It is surprising how fast they travel, in spite of these stops: it has been calculated that some small species cover almost 2,500 miles (4,000 km) in five or six days. Several studies have shown that carrier pigeons and white-headed sparrows, for example, can travel more than 600 miles (1,000 km) per day. Some ducks, such as the blue-winged teal, complete their trip from Canada to central Mexico in about 35 days, making several stops to feed along the way.



WHITE HERON *(Egretta alba)*
A species easy to distinguish in the proximity of rivers, lakes, and lagoons

Birds never cease to amaze us, whether hiding in trees, flying over high mountaintops, or nesting in Antarctica or on tall buildings. Perhaps the reason for such amazement is their behavior, which continues to be a mystery to human beings, as well as the differences among them. It is believed that there are approximately 9,700 living bird species in the world—more species than in any other vertebrate group except for fish. Once they reach adulthood, birds' weight varies from a mere 0.06 ounce (1.6 g), in the case of hummingbirds, to as much as 330 pounds (150 kg) for African ostriches. Even though most birds fly, there are some—such as kiwis, rheas, and ostriches—that run quickly on the ground. Some birds, being perfectly adapted to aquatic life, live in oceans, rivers, and lakes. The shape of their feet and bills varies according to the environment in which they live. Some aquatic species have bills modified to filter small water particles, whereas birds of prey have strong bent bills to hold down and tear apart their prey. What is the diet of birds based on? Because of their great diversity and wide distribution, their diets differ greatly. In general, birds eat a bit of everything, although insects are the most important element of their diet. They eat fruit, seeds, nectar, pollen, leaves, carrion, and other vertebrates. Most birds lay their eggs in nests. Worthy of mention is the protective attitude that both males and females have toward their young. Adult birds care for their chicks, warn and protect them against the danger of predators, and guide them to safe places where they can live and feed. We invite you to investigate up close the world of these fascinating beings that are able to run, climb, swim, dive, and cross the skies.

The Nature of Birds

OWL *(Bubo capensis)*
This owl is native to Africa. It feeds on birds and mammals.

BEYOND FEATHERS 8-9
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Many scientists maintain that birds descended from dinosaurs because fossils of dinosaur specimens with feathers have been found.

As a group, birds have exceptional eyesight—they have the largest eyes in relation to the size of their bodies. In addition, they have very light bones, which are suitable for flight. Just like their bills, birds' feet have also changed in accordance with the functions and particular needs of each species. For instance, walking birds—like other vertebrate groups—display a marked tendency toward having a reduced number of toes; ostriches, for example, have only two. Some birds of prey, such as eagles, have feet that are veritable hooks.●

Beyond Feathers

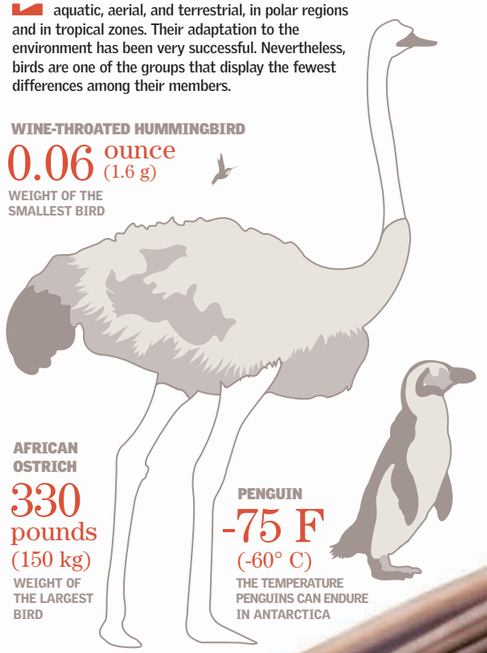
Defining what a bird is brings to mind an animal covered with feathers that has a toothless bill and anterior extremities morphed into wings. Other distinguishing characteristics are that they are warm-blooded and have pneumatic bones—bones filled with air chambers instead of marrow. Birds have very efficient circulatory and respiratory systems and great neuromuscular and sensory coordination. ●



Variety and Uniformity

We can find birds in every type of environment: aquatic, aerial, and terrestrial, in polar regions and in tropical zones. Their adaptation to the environment has been very successful. Nevertheless, birds are one of the groups that display the fewest differences among their members.

WINE-THROATED HUMMINGBIRD
0.06 ounce (1.6 g)
WEIGHT OF THE SMALLEST BIRD



AFRICAN OSTRICH
330 pounds (150 kg)
WEIGHT OF THE LARGEST BIRD

PENGUIN
-75 F (-60° C)
THE TEMPERATURE PENGUINS CAN ENDURE IN ANTARCTICA

WHITE-THROATED SPARROW
A small bird that lives in North America and on the Iberian Peninsula

Adaptation to Flying

Some crucial anatomic and physiological characteristics explain birds' ability to fly. Their bodies and feathers reduce friction with the air and improve lift. Their strong muscles, light bones, air sacs, and closed double circulatory system also play a role in their ability to fly.

FEATHERS
Unique. No other living animal has them. They are appealing for their structure, variety, and constant renewal.

WINGS
propel, maintain, and guide birds during flight. They have modified bones and characteristic plumage.

105.8° F (41° C) IS THEIR BODY TEMPERATURE.

SENSES
Great visual acuteness and well-developed hearing

INNER EAR

EYE

NAPE

CREST

NOSTRILS

BILL
Originates in the epidermis. It is hard and resistant, with a consistency similar to that of horns. It grows continuously, like nails and feathers.

CHEST

COVERTS

FLIGHT FEATHERS

THORAX

ABDOMEN

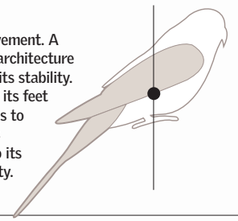
THIGH

UNDERTAIL COVERTS

TARSUS

TAIL
The last vertebrae merge into the pygostyle. The tail feathers develop in this area.

STRUCTURE
Balance in movement. A bird's internal architecture contributes to its stability. The location of its feet and wings helps to concentrate its weight close to its center of gravity.

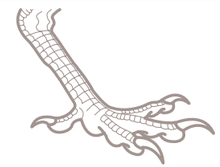


High Metabolism
The high demands of flying are compensated by a high metabolic rate. Birds extract as many nutrients from food as they can.

FEET
Birds walk on their toes. In general, they have three toes pointing forward and one pointing backward.

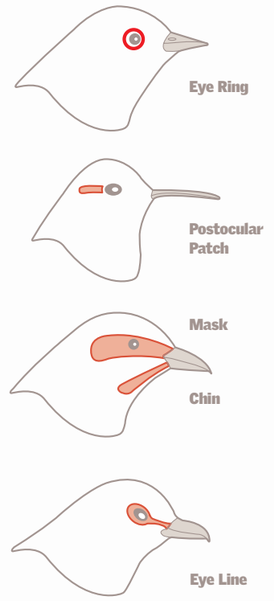
TOES

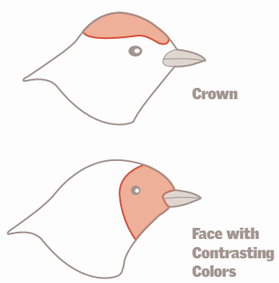
NAILS



IDENTIFICATION

There are differences in plumage and skin that make it possible to identify birds. The bill, because of its variations, also helps to establish bird groups.





SONGBIRDS

Passeriformes, or passerines, form the most numerous group among birds; they are characterized by a well-developed syrinx that enables them to emit harmonious songs and trills and by a soft plumage of varied colors. Because of their brain development, it is believed that passerines were the most recent birds to come into existence.

Origin

The evolution of birds is a debated theme in science. The most widespread theory states that birds descend from theropods, dinosaurs that walked on two legs. Fossils of dinosaur specimens with feathers have been found, but Archaeopteryx, a primitive bird that lived 150 million years ago, is the oldest relative known. Completely covered with feathers, it had a pair of wings that enabled it to fly. However, it retained many dinosaur traits.

Archaeopteryx lithographica

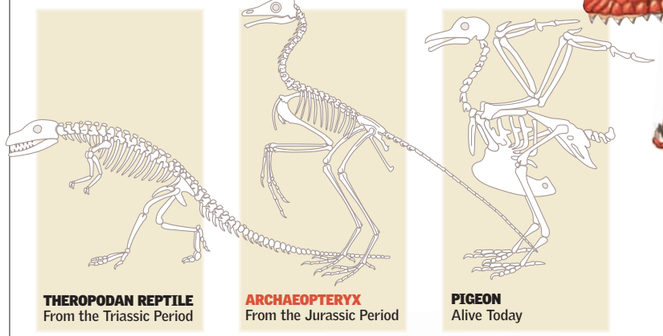
lived in the Jurassic Period, 150 million years ago.



Comparison to a Human

Order	Saurischians
Suborder	Theropods
Diet	Carnivore
Length	10 inches (25 cm)
Height	8 to 12 inches (20-30 cm)
Weight	18 ounces (500 g)

From Reptile to Bird



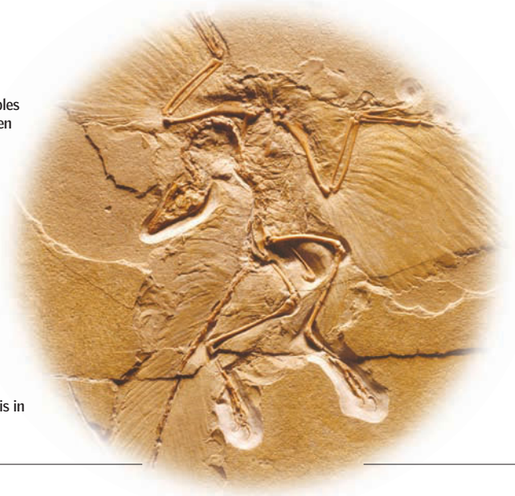
THEROPODAN REPTILE
From the Triassic Period

ARCHAEOPTERYX
From the Jurassic Period

PIGEON
Alive Today

Fossils

Several fossil samples were found between 1861 and 1993. The first one, found in Bavaria, Germany, was very important because its discovery coincided with the publication of *On the Origin of Species* by Charles Darwin, at a time when the search for evolutionary "missing links" fascinated scientists. The original is located in the British Museum. Another fossil, which includes the head, is in the Berlin Museum.



THREE TOES WITH TALONS
The hand has three extended fingers, each of which is equipped with a strong curved talon.

Talons for climbing trees

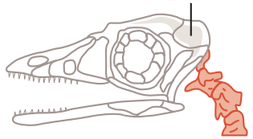


WRIST
Its wrist joint was more flexible than that of modern birds, a trait it shared with dinosaurs.

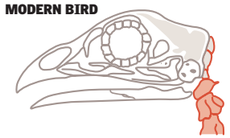
REPTILIAN JAWBONES WITH TEETH Unlike modern birds, it did not have a horn bill. There was a tight row of sharp teeth on each jawbone.

SPINE
Movable. The cervical vertebrae have a concave joint like that of the theropods, not a saddle-shaped one like that of birds.

ARCHAEOPTERYX Brain



MODERN BIRD



SKULL
Similar to that of present-day reptiles and early theropods. The arrangement of the brain and ears reveals that it had a great sense of orientation and that it was able to perform complicated maneuvers.

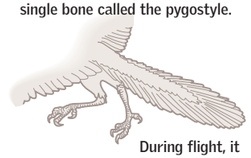
FURCULA
(Merged Collarbone) Shaped like a boomerang, as in many theropods

RIBS
Presence of ribs in the abdomen (gastralia), typical of reptiles and dinosaurs

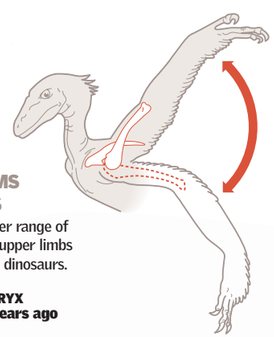
SAURIAN PELVIS
Hip and femur of the archosaurian, not avian, type

UNMERGED METATARSUS
In modern birds, the tarsus and metatarsus are fused into the tarsometatarsus.

VERTEBRATE TAIL
Composed of 21 or 22 pieces. Modern birds have tail vertebrae that are fused together into a single bone called the pygostyle.

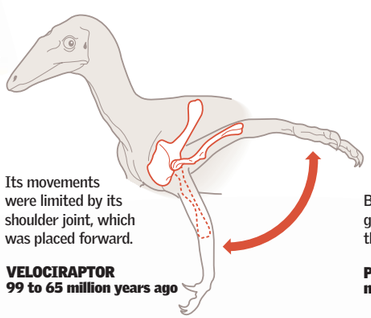


During flight, it functioned as a rudder. On the ground, it provided balance for walking.



FROM ARMS TO WINGS
It had a greater range of motion in the upper limbs than primitive dinosaurs.

ARCHAEOPTERYX
150 million years ago



Its movements were limited by its shoulder joint, which was placed forward.

VELOCIRAPTOR
99 to 65 million years ago



Birds have greater mobility than Archaeopteryx

PIGEON
modern

TOES
The foot is functionally tridactyl. Its first toe (hallux), which usually points backward and typically does not touch the ground, is opposable, like that of modern birds (it can move in a direction perpendicular to toes II, III, and IV).

ARCHAEOPTERYX LITHOGRAPHICA
Graphic Reconstruction

Skeleton and Musculature

Both lightweight and resistant, the skeleton of birds underwent important changes in order to adapt to flight. Some bones, like those of the skull and wings, fused to become lighter. Birds have fewer bones than other vertebrates. Because their bones are hollow, containing internal air chambers, the total weight of their bones is less than that of their feathers. Birds' spines tend to be very flexible in the cervical region and rigid near the rib cage, where a large, curved frontal bone called the sternum attaches. The sternum features a large keel, to which the pectoral muscles attach. These large, strong muscles are used for flapping the wings. In contrast, running birds, such as ostriches, have more developed muscles in their legs.

Flapping Wings

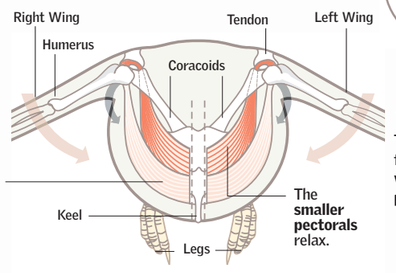
Flying demands an enormous amount of energy and strength. Consequently, the muscles responsible for flapping the wings become very large, easily comprising 15 percent of the weight of a flying bird. Two pairs of pectorals, in which one muscle of the pair is bigger than the other, work to raise and lower the wings. They function symmetrically and in opposition to each other: when one contracts, the other relaxes. Their placement within the thoracic cavity corresponds roughly to the bird's center of gravity. The motion of the wings also requires strong tendons.



HUMMINGBIRD
Because of its adaptation to stationary flight, its pectoral muscles can account for 40 percent of its total weight.

DOWNWARD FLAP





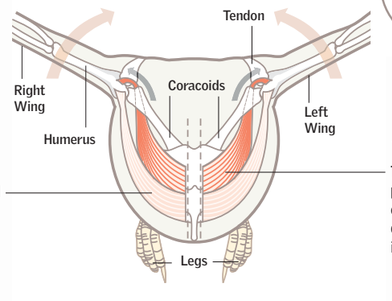
1. The **larger pectorals** contract.

2. The descending flapping of the wings takes place.

The **smaller pectorals** relax.

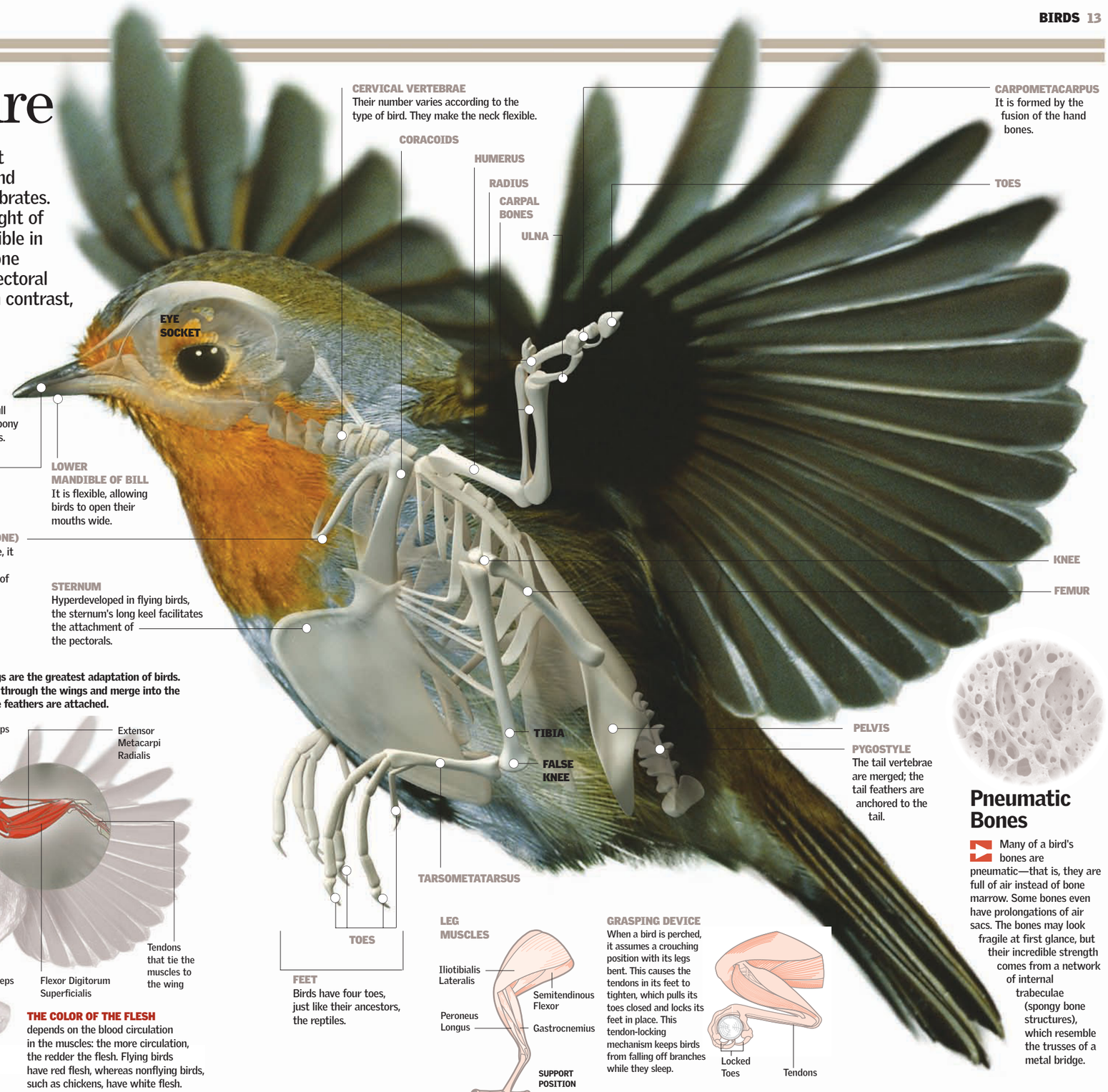
UPWARD FLAP





1. The **pectoral muscles** relax.

2. The **smaller pectorals** contract and draw the wings inward.



SKULL
Light because of the fusing of bones, the skull does not have teeth, a bony jaw, or grinding muscles.

UPPER MANDIBLE OF BILL
In some species, it is flexible.

LOWER MANDIBLE OF BILL
It is flexible, allowing birds to open their mouths wide.

FURCULA (COLLARBONE)
Known as the wishbone, it is unique to birds and results from the fusion of the collarbones.

STERNUM
Hyperdeveloped in flying birds, the sternum's long keel facilitates the attachment of the pectorals.

CERVICAL VERTEBRAE
Their number varies according to the type of bird. They make the neck flexible.

CORACOIDS

HUMERUS

RADIUS

CARPAL BONES

ULNA

CARPOMETACARPUS
It is formed by the fusion of the hand bones.

TOES

KNEE

FEMUR

TIBIA

FALSE KNEE

PELVIS

PYGOSTYLE
The tail vertebrae are merged; the tail feathers are anchored to the tail.

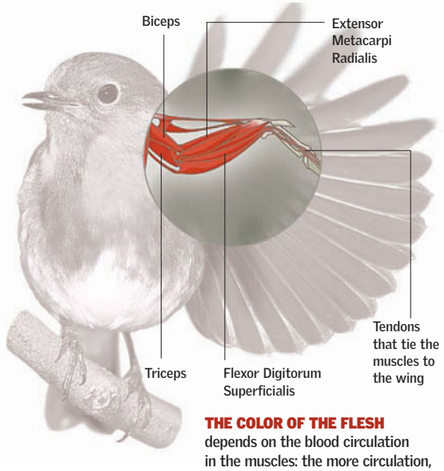
TARSOMETATARSUS

TOES

FEET
Birds have four toes, just like their ancestors, the reptiles.

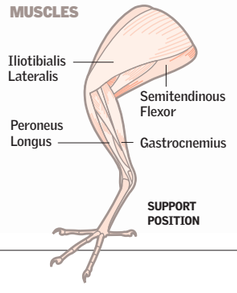
Wings

Without a doubt, wings are the greatest adaptation of birds. Strong tendons travel through the wings and merge into the hand bones, where the feathers are attached.



THE COLOR OF THE FLESH depends on the blood circulation in the muscles: the more circulation, the redder the flesh. Flying birds have red flesh, whereas nonflying birds, such as chickens, have white flesh.

LEG MUSCLES



GRASPING DEVICE
When a bird is perched, it assumes a crouching position with its legs bent. This causes the tendons in its feet to tighten, which pulls its toes closed and locks its feet in place. This tendon-locking mechanism keeps birds from falling off branches while they sleep.

Pneumatic Bones

Many of a bird's bones are pneumatic—that is, they are full of air instead of bone marrow. Some bones even have prolongations of air sacs. The bones may look fragile at first glance, but their incredible strength comes from a network of internal trabeculae (spongy bone structures), which resemble the trusses of a metal bridge.

Internal Organs

Birds in flight can consume oxygen at a rate that a well-trained athlete would not be able to withstand for even a few minutes. Because of this oxygen consumption, all their organs have had to adapt. The lungs of birds, though smaller than those of mammals of similar size, are much more efficient. Their lungs have several air sacs that both increase the efficiency of their respiratory systems and make them lighter. A special feature of the digestive system is a crop in the esophagus, where food is stored for digestion or for feeding the young. A bird's heart can be four times larger in relation to its body size than a human's in relation to its body size. ●

Digestive System

Birds have no teeth. They therefore ingest food without chewing, and their stomachs break it down. The stomach is divided into two parts: the glandular (or proventriculus) part, which secretes acids, and the muscular (or gizzard) part, whose muscular walls grind up what is eaten. In general, the process is very fast because flying requires a lot of energy, and the bird has to replenish that energy quickly. The digestive system ends at the cloaca, which is an excretory orifice shared with the urinary system. Birds absorb almost all the water they drink.

FOOD ITINERARY

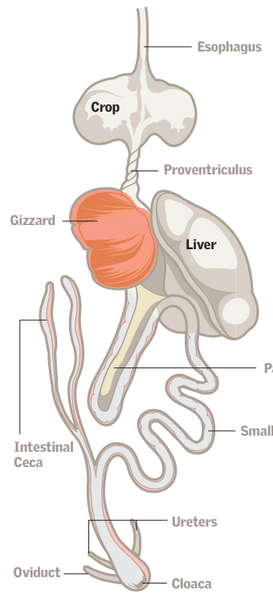
1 STORAGE
Some birds have a crop, which enables them to store food and digest it later. This way they decrease their exposure to predators.

2 PRODUCTION
The proventriculus secretes the gastric juices that initiate digestion.

3 BREAKDOWN
In the gizzard, a strong and muscular pouch, food is broken down with the help of swallowed stones or sand. The stones and sand play the role of teeth.

4 WATER ABSORPTION
occurs in the small intestine. Birds normally get water from the food they ingest.

5 EXCRETION
The cloaca expels feces mixed with urine coming from the excretory system.



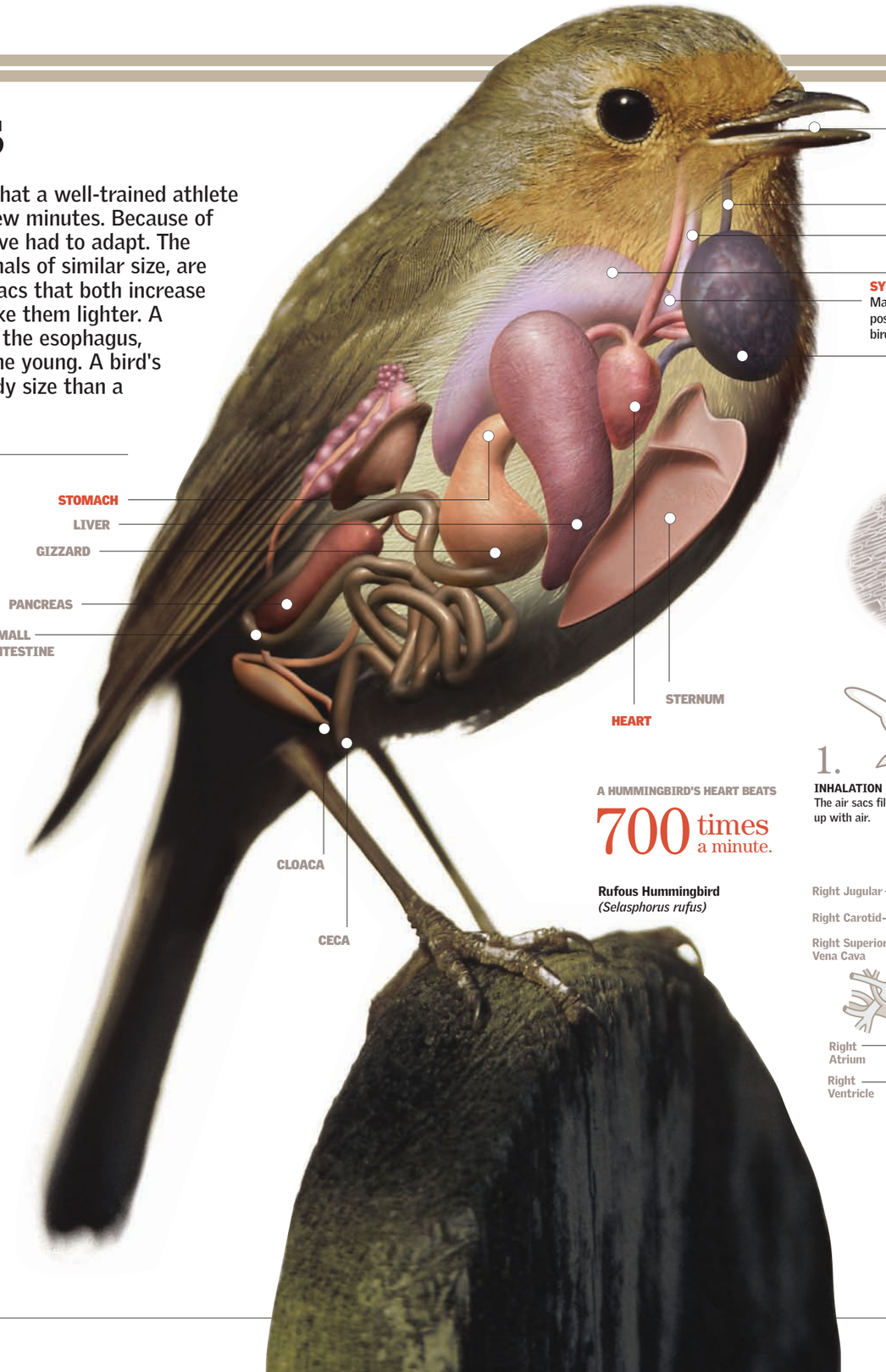
TYPES OF GIZZARD

Granivorous Birds have thick muscle walls and strong mucous membranes (or internal skin) to break down seeds.



Carnivorous Birds have thin muscle walls because digestion takes place in the proventriculus.





A HUMMINGBIRD'S HEART BEATS

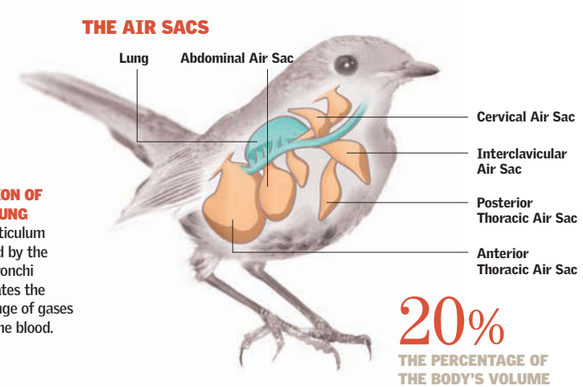
700 times a minute.

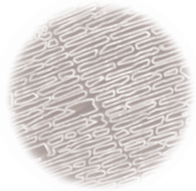
Rufous Hummingbird
(Selasphorus rufus)

Respiratory System

Birds have the most efficient respiratory system of any vertebrate because of the great effort that flying demands. It has two small, almost rigid lungs that are assisted by nine air sacs distributed throughout the body. The air sacs work as bellows, but they do not carry out gas exchange. Oxygen enters the bloodstream through the parabronchi, which are much like the alveoli in human lungs, in that they serve as the tissue for gas exchange. In the parabronchi, blood and air flow past each other in tiny passages. Because air flows in one direction through the lungs, and blood in the lung capillaries flows in the opposite direction, birds can make use of all the air they inhale, much like fish can with their gills and in contrast with mammals, which cannot.

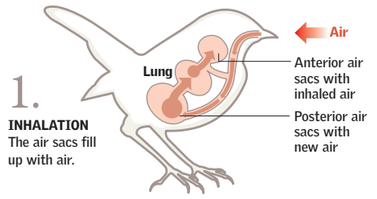
THE AIR SACS



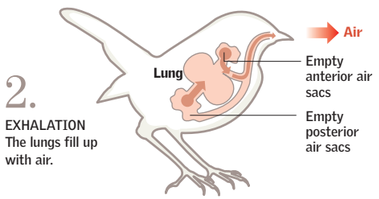


SECTION OF THE LUNG
The reticulum formed by the parabronchi facilitates the exchange of gases with the blood.

20%
THE PERCENTAGE OF THE BODY'S VOLUME TAKEN UP BY LUNGS AND AIR SACS



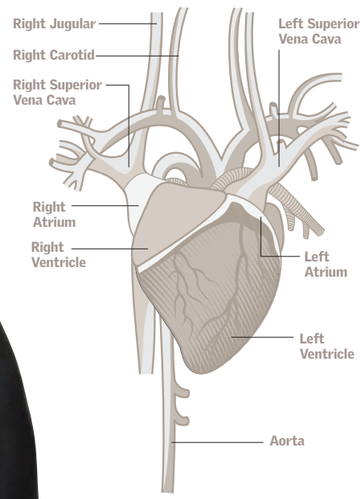
1. INHALATION
The air sacs fill up with air.



2. EXHALATION
The lungs fill up with air.

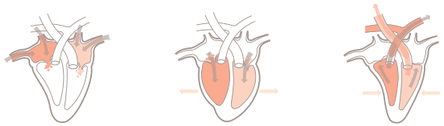
A Highly Complex Heart

Similar to that of reptiles, but having a heart with four chambers instead of three, the circulatory system distributes nutrients and oxygen throughout the body according to the body's needs. The heart's size and rate vary, depending on the bird's weight and activities. In general, bigger birds have smaller and slower hearts. For example, the heart of a seagull on the ground beats 130 times a minute; in flight, it beats 625 times a minute. A hummingbird's heart can beat 700 times a minute.



THE HEART'S ASYMMETRY

The left side of the heart is more developed, because it pumps blood to the whole body. The right side pumps blood only to the lungs.



1 The Blood enters through the right and left arteries.

2 Relaxed Ventricles They open the atrioventricular valves.

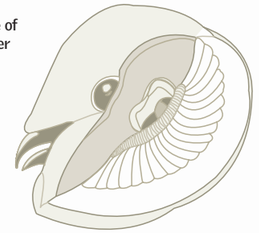
3 Contracted Ventricles The blood enters the bloodstream.

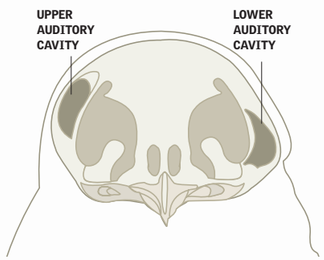
The Senses

In birds, the sense organs are concentrated on the head, except for the sense of touch, which is found all over the body. Birds have the largest eyes with respect to the size of their bodies. This enables them to see distant objects with considerable precision. Their field of vision is very broad, over 300 degrees, but in general they have little binocular vision. The ear—a simple orifice, but very refined in nocturnal hunters—helps them notice sounds inaudible to humans, which facilitates the detection of prey while flying. The senses of touch and smell, on the other hand, are important only to some birds, and the sense of taste is almost nonexistent. ●

The Ear

Birds' ears are simpler than those of mammals: a bird's ear has no outer portion, and in some cases it is covered with rigid feathers. A notable part of the ear is the columella—a bone that birds share with reptiles. The ear is nonetheless well developed, and birds have very acute hearing; whereas human beings can detect just one note, birds can detect many. The ear is essential to a bird's balance, a key factor in flying. It is also believed that in certain species the ear works as a barometer, indicating altitude.





LOCATION OF THE EARS

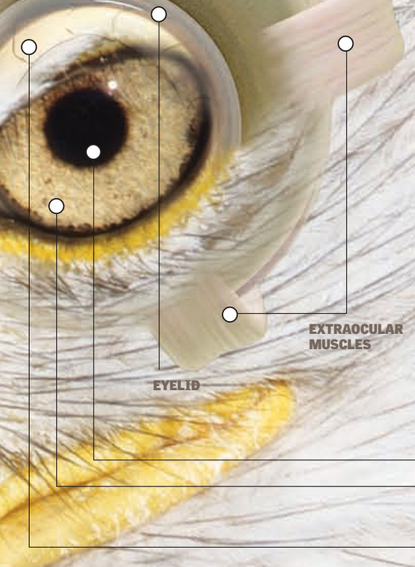
Located at different heights on the head, the ears cause the sense of hearing to occur with a slight delay. In nocturnal hunters, such as owls, this asymmetry allows for the triangulation of sounds and the tracking of prey with a minimal margin of error.

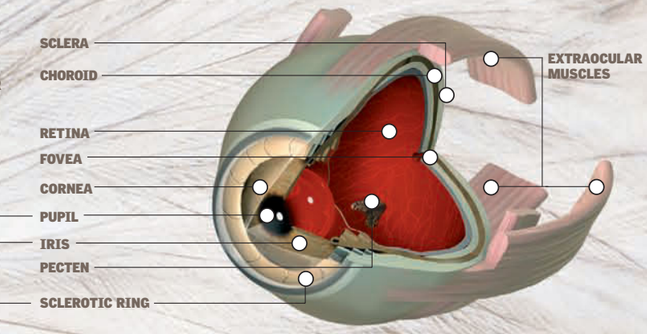
Touch, Taste, and Smell

The sense of touch is well developed in the bill and tongue of many birds, especially in those birds that use them to find food, such as shore birds and woodpeckers. Usually the tongue is narrow, with few taste buds, but they are sufficient to distinguish among salty, sweet, bitter, and acidic tastes. The sense of smell is not very developed: although the cavity is broad, the olfactory epithelium is reduced. In some birds, such as kiwis and scavengers (condors, for example), the olfactory epithelium is more developed.

Vision

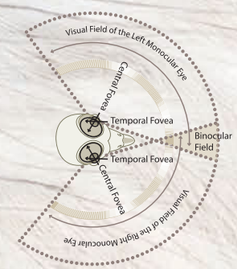
Is the most developed sense in birds because some flight maneuvers, as well as the recognition of food from afar, depend on it. Birds have relatively large eyes. In most cases, they are wider than they are deep because the lens and the cornea—which is supported by a series of sclerotic bony plates—project beyond the eye socket. In hunting birds, the eyes are almost tubular. The muscles around the eye change its shape, alter the lens, and create greater visual acuity: birds typically have a 20-fold magnification (and sometimes, as in the case of some diving birds, a 60-fold magnification), in comparison with humans. Their sensitivity to light is also remarkable, with some species being able to recognize light spectra invisible to the human eye.





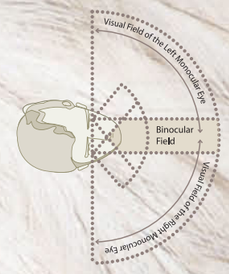
FIELD OF VISION

The eyes—when located on the sides of the head, as is the case with most birds—create a broad field of vision: more than 300 degrees. Each eye covers different areas, focusing on the same object only when looking ahead through a narrow binocular field of vision.



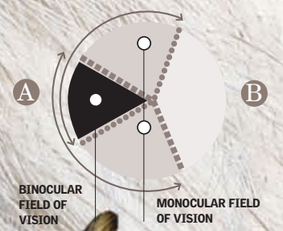
THE HUMAN FIELD OF VISION

The eyes, located at the front, move together, covering the same area. Because human beings cannot move their eyes independently from each other, they have only binocular vision.



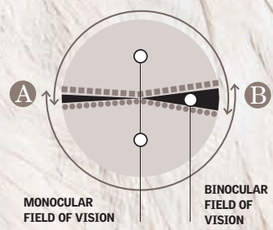
COMPARISON OF BINOCULAR FIELDS OF VISION

Binocular vision is essential for measuring distances without making mistakes. The brain processes the images that each eye generates separately as if they were a single image. The small differences between the two images allow the brain to create a third one in depth, or in three dimensions. Hunting birds, for which the correct perception of distance is a life-and-death matter, tend to have eyes located toward the front, with a wide field of binocular vision. In contrast, birds with lateral eyes calculate distance by moving their heads, but they record a larger total field of vision to avoid becoming prey. Owls are the birds with the greatest binocular vision—up to 70 degrees.



HUNTING BIRDS' FIELD OF VISION

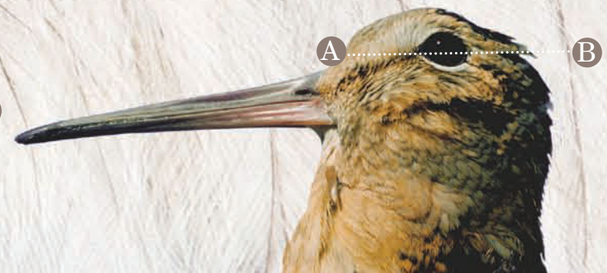
Frontal eyes reduce the total field of vision but allow for a wide field of binocular vision.



NONHUNTING BIRDS' FIELD OF VISION

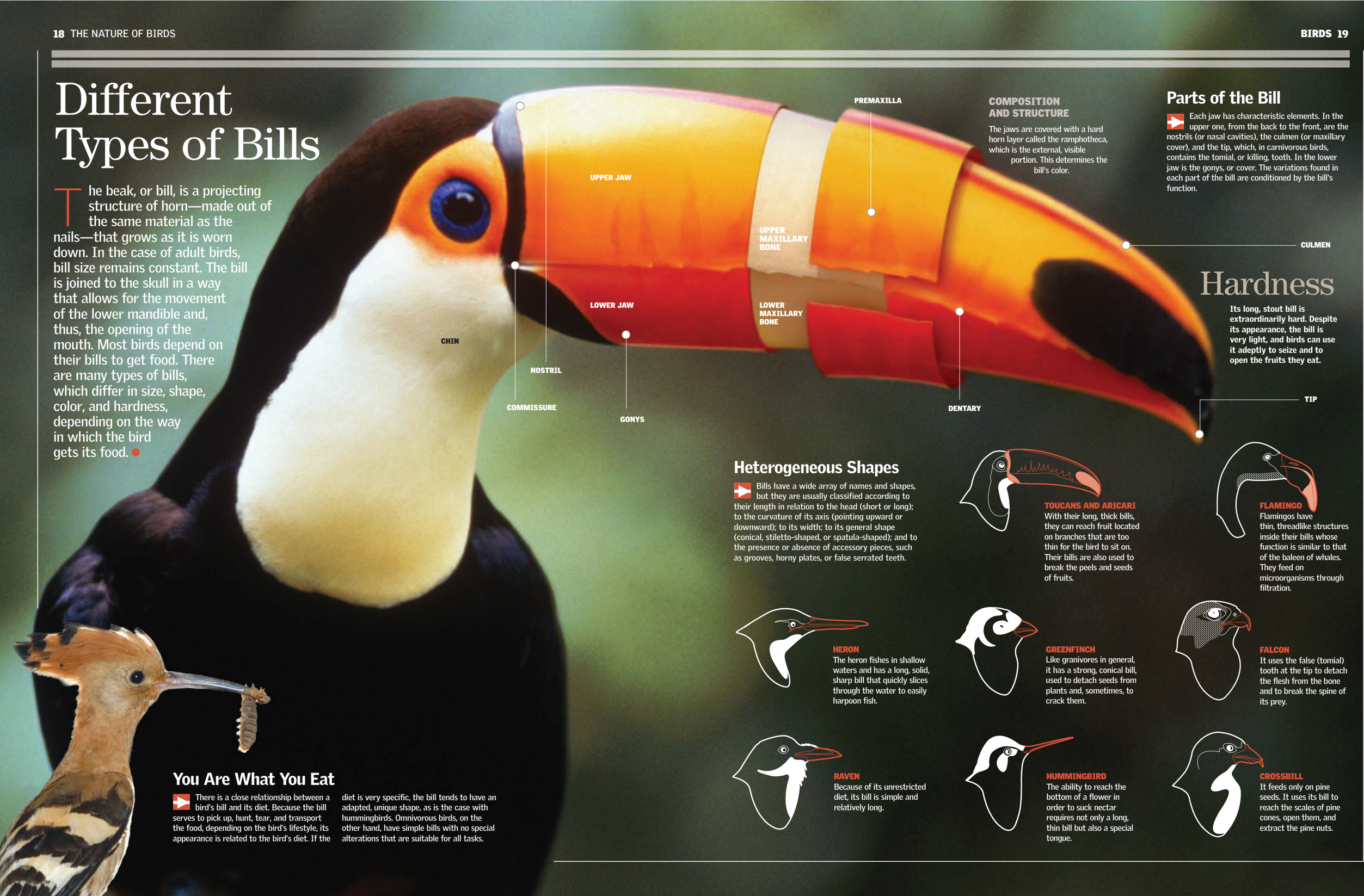
The lateral eyes open the field of vision to as much as 360 degrees but reduce the binocular field.





Different Types of Bills

The beak, or bill, is a projecting structure of horn—made out of the same material as the nails—that grows as it is worn down. In the case of adult birds, bill size remains constant. The bill is joined to the skull in a way that allows for the movement of the lower mandible and, thus, the opening of the mouth. Most birds depend on their bills to get food. There are many types of bills, which differ in size, shape, color, and hardness, depending on the way in which the bird gets its food.



COMPOSITION AND STRUCTURE

The jaws are covered with a hard horn layer called the ramphotheca, which is the external, visible portion. This determines the bill's color.

Parts of the Bill

Each jaw has characteristic elements. In the upper one, from the back to the front, are the nostrils (or nasal cavities), the culmen (or maxillary cover), and the tip, which, in carnivorous birds, contains the tomial, or killing, tooth. In the lower jaw is the gonys, or cover. The variations found in each part of the bill are conditioned by the bill's function.

Hardness

Its long, stout bill is extraordinarily hard. Despite its appearance, the bill is very light, and birds can use it adeptly to seize and to open the fruits they eat.

You Are What You Eat

There is a close relationship between a bird's bill and its diet. Because the bill serves to pick up, hunt, tear, and transport the food, depending on the bird's lifestyle, its appearance is related to the bird's diet. If the diet is very specific, the bill tends to have an adapted, unique shape, as is the case with hummingbirds. Omnivorous birds, on the other hand, have simple bills with no special alterations that are suitable for all tasks.

Heterogeneous Shapes

Bills have a wide array of names and shapes, but they are usually classified according to their length in relation to the head (short or long); to the curvature of its axis (pointing upward or downward); to its width; to its general shape (conical, stiletto-shaped, or spatula-shaped); and to the presence or absence of accessory pieces, such as grooves, horny plates, or false serrated teeth.

TOUCANS AND ARICARI
With their long, thick bills, they can reach fruit located on branches that are too thin for the bird to sit on. Their bills are also used to break the peels and seeds of fruits.

FLAMINGO
Flamingos have thin, threadlike structures inside their bills whose function is similar to that of the baleen of whales. They feed on microorganisms through filtration.

HERON
The heron fishes in shallow waters and has a long, solid, sharp bill that quickly slices through the water to easily harpoon fish.

GREENFINCH
Like granivores in general, it has a strong, conical bill, used to detach seeds from plants and, sometimes, to crack them.

FALCON
It uses the false (tomial) tooth at the tip to detach the flesh from the bone and to break the spine of its prey.

RAVEN
Because of its unrestricted diet, its bill is simple and relatively long.

HUMMINGBIRD
The ability to reach the bottom of a flower in order to suck nectar requires not only a long, thin bill but also a special tongue.

CROSSBILL
It feeds only on pine seeds. It uses its bill to reach the scales of pine cones, open them, and extract the pine nuts.

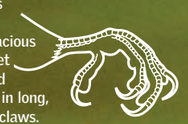
Exposed Legs

Taking a quick look at the extremities of birds, including their toes and claws, can help us learn about their behavior. The skin of their legs and feet can have some striking features. All these characteristics reveal information about the environments in which different groups of birds live, as well as about their diets. Scientists use these characteristics as a basis for classifying birds. The detailed study of the anatomy of a bird's leg and foot can offer useful information. The shape and placement of bones, muscles, and tendons make it possible to understand how birds hold their prey or perch on branches, as well as to learn about the mechanics of their movement across the ground and in the water.

Different Types

The foot usually has four toes. Three of them have a similar size and position. Opposite them is a smaller toe called the hallux. This pattern varies among different bird groups. For example, the position and shape of toes can differ. There are even cases in which two toes are functional while the others have been reduced in size. This is the case with flightless birds such as rheas. Differences are also found in the skin, which may form a web between the toes and projections of horn. All these characteristics become tools to help the bird survive in its environment and face challenges regarding obtaining food.

FEET DESIGNED FOR SEIZING
Found on birds of prey and nocturnal rapacious birds. Their feet are strong, and their toes end in long, curved, sharp claws. They seize prey and transport it in flight.



FEET DESIGNED FOR CLIMBING
Found on parrots, woodpeckers, and cuckoos. The hallux and the fourth toe are pointed backward. This arrangement provides the birds with more strength for climbing tree trunks.



FEET DESIGNED FOR WALKING
Found on herons, flamingos, and storks. The toes and legs are very long. The hallux is pointed backward. They live in places with soft ground, such as swamps and river banks.



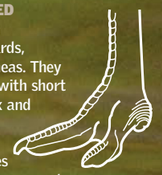
FEET DESIGNED FOR PERCHING
Found on hummingbirds, kingfishers, ovenbirds, and nightjars. They have small feet, with the second, third, and fourth toes joined together. This makes it possible for them to stand still.



FEET DESIGNED FOR SWIMMING
Alcas, patos y Found on auks, ducks, and penguins, which have a membrane between their toes that forms a web and increases the surface of the foot that is in contact with the water.



FEET DESIGNED FOR RUNNING
Found on bustards, curlews, and rheas. They have long legs with short toes. The hallux and the fourth toe are very small, which decreases contact with the ground while running.





Adaptation to Trees
The common waxbill perches and sleeps on tree branches without expending much energy. The weight of the body alone causes its toes to close tightly around the branch.

THE FOOT I
Toes 1 (hallux) and 2 have three phalanges, toe 3 has four, and toe 4 has five.



TRICOLORED HERON
Its feet have long, thin toes that allow it to move on soft ground, such as in swamps, on river banks, and on lake shores. It lives in the regions of Arica and Coquimbo in Chile.

THE FOOT II
The distal tarsal bones merge into the metatarsal bone and create tarsometatarsal bones.

KNEE AND THIGH
The thigh is included in the body and has a shortened femur. The knee is near the center of gravity.

TIBIA
The tibia merges into tarsal bones and forms the tibiotarsus. It has a slightly developed fibula on its lateral face.

ANKLE
Also known as a false knee because it looks like a knee that flexes backward. In reality, it is the ankle.

Claws, Scales, and Spurs

These striking foot structures play a role in finding food, movement, protection, and defense, among other things. The claws can be long and sharp, in the case of birds of prey, or short and round, in the case of walking birds. Owls have a comblike claw that they use to groom their plumage. Their scales, inherited from reptiles, help protect their feet. In some cases, they help the birds to move through water. Many birds, such as chickens, pheasants, and crested screamers (a South American waterbird), have a spur, which they use as a defensive or offensive weapon.



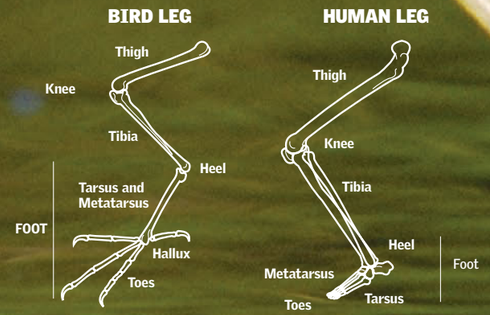
BALD EAGLE (Talons)
Very long, curved, pointed claws. They envelop the body of the prey and pierce it.



GREAT CRESTED GREBE (Lobed Toes)
In some swimming birds, the toes look like oars. They have a continuous wide border.



SCOTS DUMPY ROOSTER (Spurs)
The spurs originate in skin and bone tissues. When males fight over territory or over a female, they use their spurs to defend themselves.



Internal/External Structure

Birds walk on their toes, which form the first portion of their feet. The second portion is formed by the tarsometatarsus. Its top part is connected to the tibia, through a joint similar to that of our ankle. That is why the leg flexes backward. The knee, equivalent to ours, is higher up and works like a hip. It is located close to the body, and it helps to maintain balance. The thigh bone also stabilizes the body by adding weight to the skeleton. All the movements of these bones are controlled by tendons and muscles.

The Art of Flying

PARROT FEATHER
Detail of the feathers worn by these colorful aerial acrobats

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FEATHERS 26-27
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TO RENEW IS TO LIVE 32-33
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Birds move in the air the same way a glider does, that is, by making the most of air currents to gain height and speed while moving. The shape of the wings varies according to the needs of each bird group. Some cover considerable distances and thus have long, narrow wings, whereas others have short, rounded wings that allow them to make short flights from branch to branch. Birds also have shiny, colorful feathers that males frequently use both to attract females and to hide from enemies. Feathers are usually renewed once a year, and this process is as vital to birds as feeding. ●

Adaptations

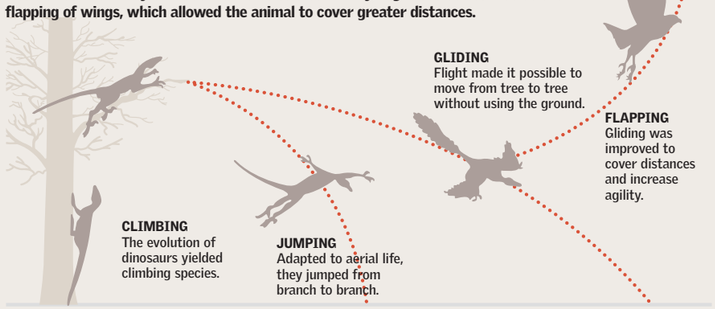
There are three main theories to explain why birds developed the ability to fly. The evidence that supports each of them tells a story of adaptations to an aerial world in which the fight for food and survival is key. One reasonable theory argues that birds descended from an extinct line of biped reptiles that fed on plants and used to jump from branch to branch to flee.

From Reptile to Bird

It is known that several evolutionary lineages from both reptiles and birds did not survive the evolutionary process, and that the lineage that truly links these two animal groups has not yet been found. However, some theories state that the change from reptile to bird took place through a long process of adaptation. There are two arguments and a variant: the arboreal theory, which posits an air-ground flight model; the cursory (or running) theory, which focuses on the need for stability when running; and a variant, related to parental care, which posits that dinosaurs started to fly as a way of keeping their eggs safe.

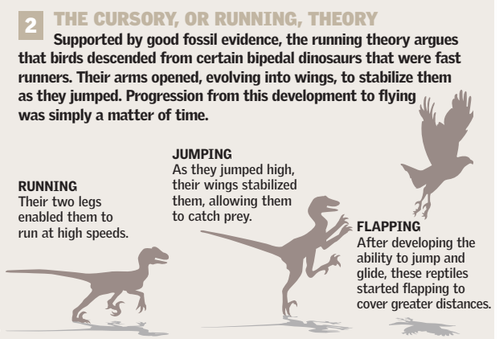
1 THE ARBOREAL THEORY

This theory, the most accepted for a long time, states that flight was an adaptation to the environment in which certain herbivorous climbing reptiles lived. At first, dinosaurs developed a kind of parachute to protect them if they missed a branch when jumping, and later it became a way to move from tree to tree. Finally, flight evolved to involve the flapping of wings, which allowed the animal to cover greater distances.



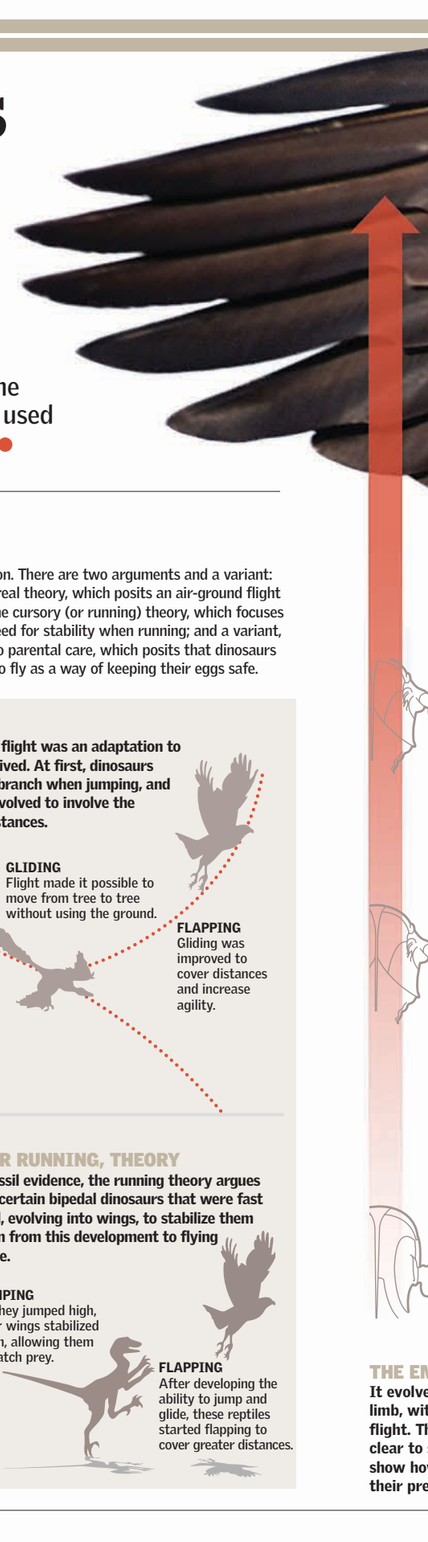
2 THE CURSORY, OR RUNNING, THEORY

Supported by good fossil evidence, the running theory argues that birds descended from certain bipedal dinosaurs that were fast runners. Their arms opened, evolving into wings, to stabilize them as they jumped. Progression from this development to flying was simply a matter of time.



3 PARENTAL CARE VARIANT

This variant proposes that reptiles started to climb trees to prevent their young from becoming prey. Gliding removed the need to climb out of the trees.



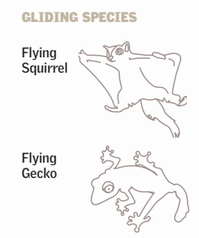
THE EMERGENCE OF THE WING

It evolved from an arm with a talon into a limb, without a talon, that was adapted for flight. The causes of this change are not yet clear to scientists. However, fossil records show how bones merged until they reached their present forms.



OTHER FLYING ANIMALS

In flying animals, from primitive pterodactyls to bats, wings have always been a flap of skin. A tear creates serious problems because it takes time to heal, and the wing may be misshapen afterward.



THE BEST SOLUTION

Feathers are a unique evolutionary advantage. Their versatility, strength, individual nature, and ease of replacement make them an ideal adaptation to flight for vertebrates.

EAGLE

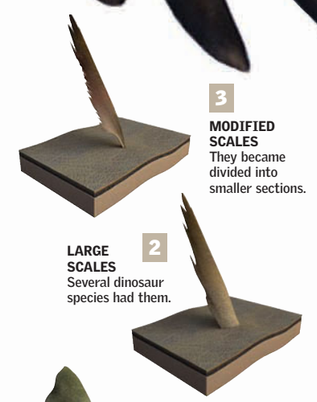
In its maneuvers, this great hunter displays the entire evolution of flight.

4 FEATHERS

Today found only on birds, feathers are scales partitioned into three smaller sections. They form a light, uniform, resistant network that covers the whole body.

26 pounds (12 kg) IS THE MAXIMUM WEIGHT AN EAGLE CAN CARRY DURING FLIGHT.

The eagle itself usually weighs about 13 pounds (6 kg) and can generally carry prey weighing 6.5 pounds (3 kg). Some eagles, however, have been seen carrying prey estimated to weigh 13 pounds (6 kg). Carrying any more weight would require bigger wings, which would be more difficult to move and less efficient. It is believed that large flying animals disappeared because of this limitation.



FROM SCALES TO FEATHERS

The development of feathers brought great advantages to birds because feathers enabled them to fly. Feathers evolved from scales, and they are made of the same material. Feathers keep the body's temperature constant and are lighter than scales.

Feathers

Feathers are the feature that distinguishes birds from all other animals. They make birds strikingly colorful, protect them against cold and intense heat, enable them to move easily through the air and water, and hide them from enemies. Feathers are also one of the reasons why human beings have domesticated, caught, and hunted birds. A bird's set of feathers is called its plumage, and its color is essential for reproductive success.



Structure

The structure of feathers has two parts: a shaft and a blade. The shaft is called the rachis, and the part connected to the bird's skin is called the calamus. The movement of a feather is generated in the rachis. The blade is composed of barbs that branch into barbules. The feather's blade, in which the barbules have a series of barbicels, or hooklets, at the tip, is called a vane. The interlocking hooklets in the vane create a network that adds rigidity and resistance to the feather. It also defines the characteristic aerodynamic shape of feathers and helps make the feather waterproof. When feathers wear out, birds have the ability to replace them with new ones.

1 A swelling, or papilla, develops in the bird's skin.

2 In the papilla, special skin cells form a follicle.

3 A tube that will extend from its base and become a feather grows in the follicle.



HOLLOW INTERIOR

INFERIOR UMBILICUS
The orifice at the base of the calamus, into which the dermic papilla penetrates. New feathers receive nourishment through it.

INNER PULP OF THE SHAFT

CALAMUS
It provides the necessary nutrients for feathers to grow. Nerve endings that stimulate the feather's movement are found at its base. This allows the bird to detect changes in its surroundings.

SUPERIOR UMBILICUS
It contains some loose barbs. Some feathers have a secondary rachis, the hyporachis.

BARBS
are slim, straight ramifications that grow perpendicular to the rachis.

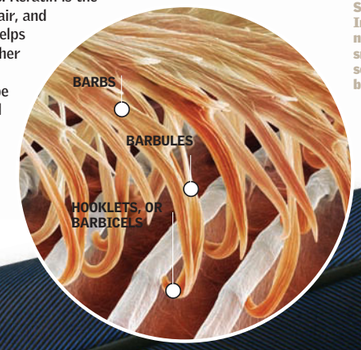
RACHIS
A feather's main shaft, similar to a hollow rod

EDGE
The edge presents an excellent aerodynamic profile for flying.

VANE, OR BLADE
Its outer portion contains a great number of barbicels.

WHAT IS KERATIN?

Keratin is a protein that forms part of the outermost layer of a bird's skin, just as it does in other vertebrate animal groups. Keratin is the main component of feathers, hair, and scales. Its distinct resistance helps keep the hooklets woven together in the vane. This allows birds' feathers to maintain their shape in spite of the pressure exerted by the air during flight.



25,000

THE NUMBER OF FEATHERS THAT LARGE BIRDS, SUCH AS SWANS, CAN HAVE. In contrast, the number of feathers small birds, such as songbirds, can have varies between 2,000 and 4,000.



TRAILING EDGE NOTCH
The turbulence during flight is reduced by this notch, found near the tip of the wing.

PREENING THE PLUMAGE

Birds need to preen their feathers with their bills not only to keep them clean and free of parasites but also to keep them lubricated, which helps birds resist inclement weather. Birds touch their uropygial, or preen, glands with their bills. Then they distribute the oil and wax this gland produces all over their plumage. This task is a matter of survival.

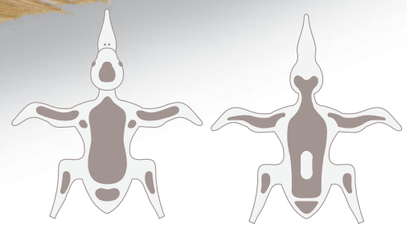


SELF-CLEANING WITH ANTS

Some birds, such as certain tanagers, catch ants with their bills and grind them. They then oil their feathers with the ground-up ants. It is believed that the acid juices from the squashed ants work as a repellent against lice and other external parasites.

DUST BATH

Birds such as pheasants, partridges, ostriches, pigeons, and sparrows perform dust baths to control the amount of grease on their feathers.



PTERYLAE AND APTERIA

At first glance, a bird's body is covered with feathers. However, feathers do not grow all over the body but rather in particular areas called pterylae. This is where the papillae, which create new feathers, are found. The shape and placement of pterylae vary according to species. Pterylae are surrounded by naked areas, called apteria, in which feathers do not grow. Penguins are the only birds whose bodies are completely covered with feathers. This characteristic makes it possible for them to live in cold regions.



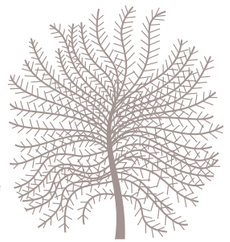
IMPERIAL HERON
Powder down keeps its plumage waterproof.

Types of Feathers

There are three main types of feathers, classified according to placement: those closest to the body are down, or underlying feathers; those at the top are contour feathers; and those on the wings and tail are flight feathers, which are often referred to as remiges (on the wings) and rectrices (on the tail).

DOWN

These light and silky feathers protect the bird against the cold. They have a short rachis, or none at all. Their barbs are long, and their barbules lack hooklets. In general, down is the first type of feather that birds develop when they hatch.



CONTOUR

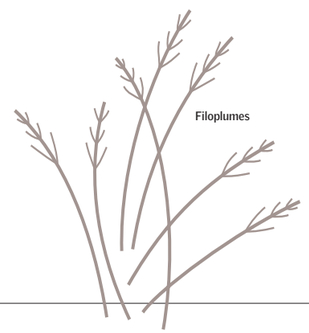
Also called covert feathers, they are short and rounded. They are more rigid than down feathers. Because they cover the body, wings, and tail, they give birds their shape as they fly.



SPECIAL FEATHERS

Vibrissae are special feathers formed by only one filament. Sometimes they have loose barbs at the base that perform a tactile function. They are located at the base of bills or nostrils or around the eyes. They are very thin and are usually blended with contour feathers.





POWDER DOWN

This special type of feather can be found on some aquatic birds. They grow constantly and break off at the tip into small waxy scales. This "powder" is preened into the plumage to provide protection.

Wings to Fly

Wings are highly modified arms that, through their unique structure and shape, enable most birds to fly. There are many types of wings; they vary by species. For instance, penguins, which are flightless, use their wings for the specialized task of swimming. Among all wings that have existed in the animal kingdom, those of birds are the best for flying. Their wings are light and durable, and in some cases their shape and effectiveness can be modified during flight. To understand the relationship between wings and a bird's weight, the concept of wing loading, which helps explain the type of flight for each species, is useful.

Wings in the Animal Kingdom

Wings have always been modified arms, from the first models on pterosaurs to those on modern birds. Wings have evolved, beginning with the adaptation of bones. Non-avian wings have a membranous surface composed of flexible skin. They extend from the bones of the hand and body usually down to the legs, depending on the species. Avian wings, on the other hand, are based on a very different principle: the arm and hand form a complex of skin, bone, and muscle, with a wing surface consisting of feathers. Furthermore, the avian wing allows for important changes in form, depending on the bird's adaptation to the environment.

PTERODACTYLS
still had talons, and only one finger extended their wings.

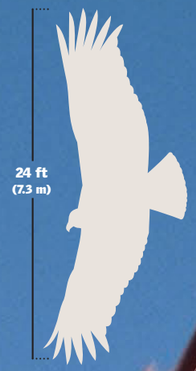
BATS
Four fingers extend the membrane, and the thumb remained as a talon.

BIRDS
The fused fingers form the tip of the wing where the rectrices, or primary feathers, are attached.

Wing Size and Loading

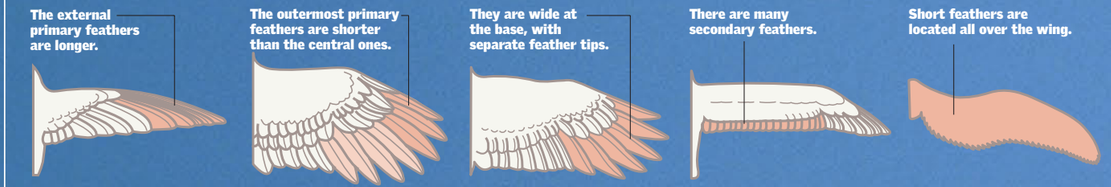
The wingspan is the distance between the tips of the wings. Together with width, it determines the surface area, which is an essential measurement for bird flight. Not just any wing can support any bird. There is a close relationship between the animal's size (measured by weight) and the surface area of its wings. This relationship is called wing loading, and it is crucial in understanding the flight of certain species. Albatrosses, with large wings, have low wing loading, which makes them great gliders, whereas hummingbirds have to flap their small wings intensely to support their own weight. The smaller the wing loading, the more a bird can glide; the bigger, the faster a bird can fly.





Types of Wings

According to the environment in which they live and the type of flight they perform, birds have different wing shapes that allow them to save energy and to perform efficiently during flight. The wing shape also depends on the bird's size. Consequently, the number of primary and secondary feathers changes depending on the needs of a given species.



FAST WING
Remiges are large and tight to allow for flapping; the surface is reduced to prevent excessive friction.

ELLIPTICAL WINGS
Functional for mixed flights, they are very maneuverable. Many birds have them.

WINGS FOR SOARING ABOVE LAND
Wide, they are used to fly at low speeds. The separate remiges prevent turbulence when gliding.

WINGS FOR SOARING ABOVE THE OCEAN
Their great length and small width make them ideal for gliding against the wind, as flying requires.

WINGS FOR SWIMMING
In adapting to swimming, the feathers of penguins became short, and they serve primarily as insulation.



Flightless Wings

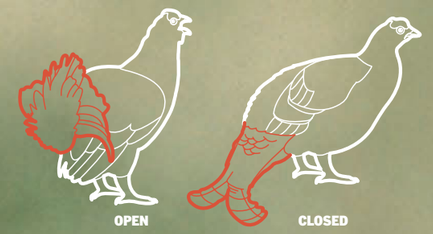
Among these, penguins' wings are an extreme case of adaptation: designed for rowing underwater, they work as fins. On running birds, wings' first and foremost function is to provide balance as the bird runs. These wings are also related to courtship, as birds show off their ornamental feathers during mating season by opening their wings or flapping them. Wings are also very efficient at controlling temperature, as birds use them as fans to ventilate their bodies.



Over the course of evolution, birds' tail vertebrae fused into a pygostyle, and in their place feathers of different sizes and colors emerged. These feathers have multiple uses: they can control aerial maneuvers during flight, work as brakes during landing, and make noise. Males also use them during courtship to dazzle and win over females. Usually the tail is formed by rectrices that vary in number, length, and rigidity depending on the species.

Courtship Display

The tail feathers of the female black grouse are straight, whereas those of the male have a half-moon shape. They usually keep the feathers closed and near the ground, but during the courtship displays they spread them out and show them off completely. To finish the show, the male runs back and forth in front of the female.





The Key to How It Works

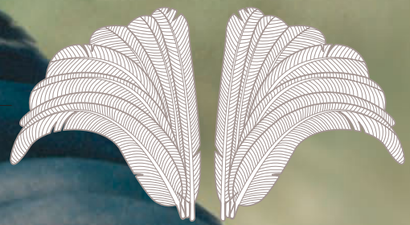
The tail can perform a variety of functions because of the movement and shape of the feathers. The powerful muscles in the pygostyle prepare the plumage for courtship displays and for flight, provide balance in walking and alighting on trees, and work as rudders for swimming.



LANDING I
The plumage spreads out, and the main axis of the body is positioned parallel to the ground.

LANDING II
The body leans backward, and the tail closes. The legs prepare to grab the branch.

LANDING III
The spread-out tail feathers, together with an intense flapping of the wings, make it possible for the bird to slow down and prepare its body to land.



RECTRICES
Tail feathers can wear out and fray because of friction during flight or by brushing against vegetation.



UNDERTAIL COVERTS
Feathers that cover the lower part of rectrices, protecting them against the wear and tear caused by air friction

Black Grouse
Lyrurus tetrix

The male is recognized by its bluish black plumage and the red caruncle over its eyes.

Fan of Rectrices

On flying birds, it is light and aerodynamic. On tree-climbing birds, such as woodpeckers, the plumage is rigid, which allows them to use it as a support (pointed tail). The coverts of male peacocks are more developed than their rectrices so that the peacock can show them off.

FORKED TAIL
Found on swallows and frigate birds. The external feathers are very long and look like scissors.



ROUNDED TAIL
Found on some songbirds. The central feathers are only slightly longer than the external ones.



GRADUATED TAIL
Found on trogons and kingfishers. When closed, the tail has a layered shape.



MARGINATED TAIL
Found on blue jays. The central feathers are only slightly shorter than the external ones.



SQUARE TAIL
Found on quails. The tail is short, with even-sized feathers.



To Renew Is to Live

The periodic renewal of plumage is called molting. It is the replacement of worn-out, older feathers with new ones that are in better condition. In a bird's life cycle, molting is as important an event as migrating or caring for young. The beginning of this phenomenon is determined by environmental factors that trigger a series of hormonal stimuli in birds: they start to eat more and to decrease their other activities. This, in turn, causes them to gain weight through an accumulation of fat that will serve as the source of energy for developing new plumage.

Plumage Molting

The main function of molting is to replace worn-out plumage. It also helps the bird adapt its appearance to the seasons and to different stages in life. The renewal can be partial or total. Some feathers are replaced before the spring, when the task is to attract a partner for reproductive purposes. In the fall, before birds have to start caring for their young, the renewal is complete. On most birds, molting takes place in each pteryla, following a determined order. Penguins, however, renew all their feathers at the same time, within two to six weeks.

SEASONAL CHANGE

In the high mountains, snow transforms the landscape during winter. During this time, nonmigratory birds exchange their summer plumage for a winter one. This change helps them to protect themselves from predators.

PTARMIGAN



SUMMER PLUMAGE
The feathers have deep pigmentation. This helps birds blend in with the vegetation.

WINTER PLUMAGE
The new, unpigmented feathers make it possible for ptarmigans to blend with the white snow.

Order of Replacement

Many species start molting, a process triggered by hormones, in a specific order. Molting starts with remiges and wing coverts, continues with rectrices, and finishes with body coverts. This gradual process keeps the body temperature stable.

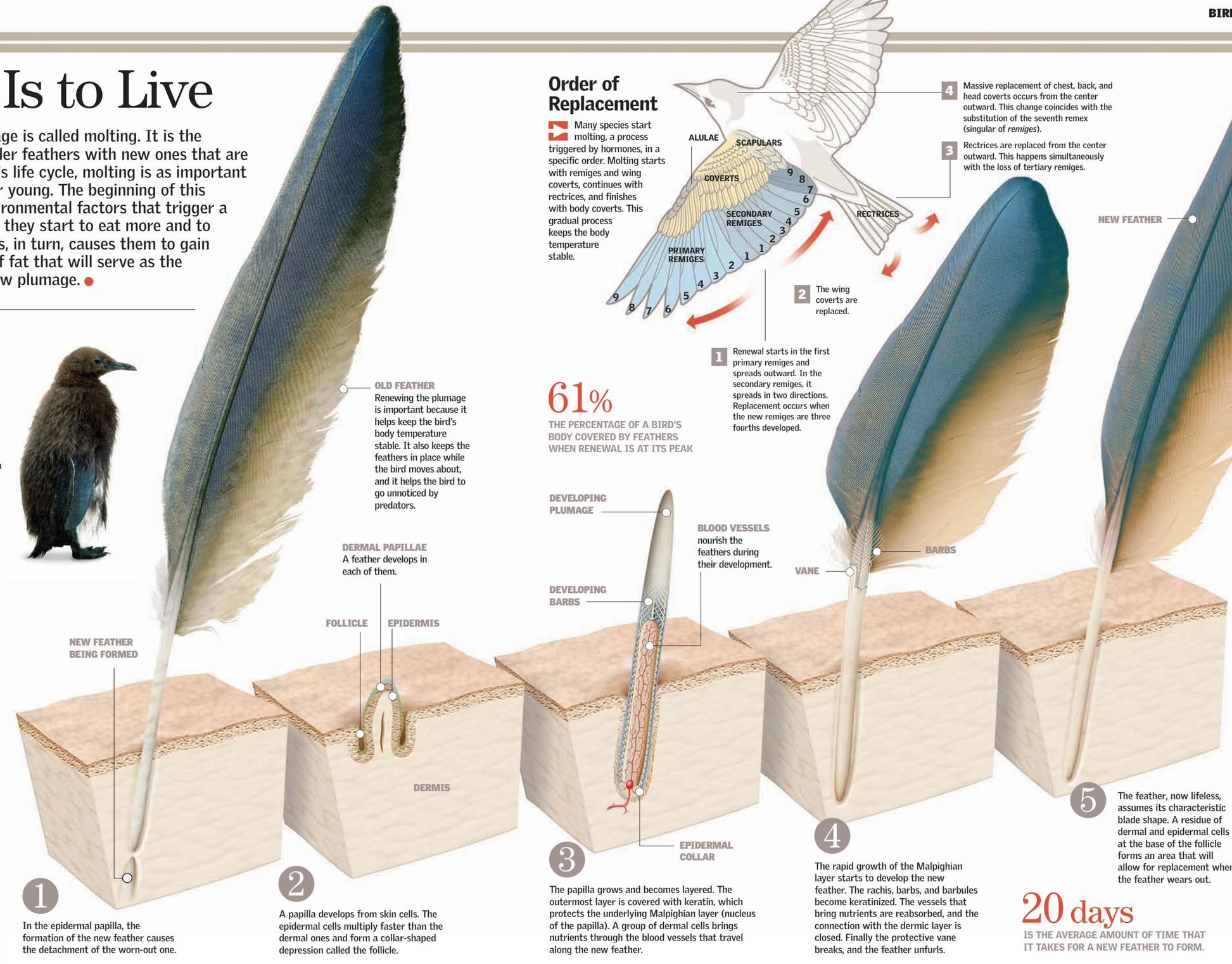
4 Massive replacement of chest, back, and head coverts occurs from the center outward. This change coincides with the substitution of the seventh remex (singular of *remiges*).

3 Rectrices are replaced from the center outward. This happens simultaneously with the loss of tertiary remiges.

2 The wing coverts are replaced.

1 Renewal starts in the first primary remiges and spreads outward. In the secondary remiges, it spreads in two directions. Replacement occurs when the new remiges are three fourths developed.

61%
THE PERCENTAGE OF A BIRD'S BODY COVERED BY FEATHERS WHEN RENEWAL IS AT ITS PEAK



1 In the epidermal papilla, the formation of the new feather causes the detachment of the worn-out one.

2 A papilla develops from skin cells. The epidermal cells multiply faster than the dermal ones and form a collar-shaped depression called the follicle.

3 The papilla grows and becomes layered. The outermost layer is covered with keratin, which protects the underlying Malpighian layer (nucleus of the papilla). A group of dermal cells brings nutrients through the blood vessels that travel along the new feather.

4 The rapid growth of the Malpighian layer starts to develop the new feather. The rachis, barbs, and barbules become keratinized. The vessels that bring nutrients are reabsorbed, and the connection with the dermic layer is closed. Finally the protective vane breaks, and the feather unfurls.

5 The feather, now lifeless, assumes its characteristic blade shape. A residue of dermal and epidermal cells at the base of the follicle forms an area that will allow for replacement when the feather wears out.

20 days
IS THE AVERAGE AMOUNT OF TIME THAT IT TAKES FOR A NEW FEATHER TO FORM.

Gliding

Involves using air currents to fly and save energy when traveling long distances. There are two types of gliders, terrestrial birds and marine birds, each of which is adapted to different atmospheric phenomena. Terrestrial birds rise on thermals (rising air currents). Marine birds make use of oceanic surface winds. Once the birds gain altitude, they glide off in straight paths. They slowly lose altitude until encountering another thermal that will lift them. Both terrestrial and marine gliders have wings of considerable size.

TYPES OF GLIDING FEATHERS

Terrestrial Glider
A large wing surface allows it to make the most of rising air currents at moderate speed.



Marine Glider
Thin and long wings allow it to make the most of the constant surface winds and offer less resistance to forward movement.



Takeoff

Usually, a powerful jump followed by the vertical flapping of the wings is enough to make a bird take flight. As it descends, the tip feathers are stacked on top of each other, forming an airtight surface that helps drive the bird upward. As the bird raises its wings to repeat the movement, the feathers curve and open until the wing reaches its highest point. With a couple of flaps of the wings, the bird is in flight. Bigger birds need a running start on the ground or water in order to take off.

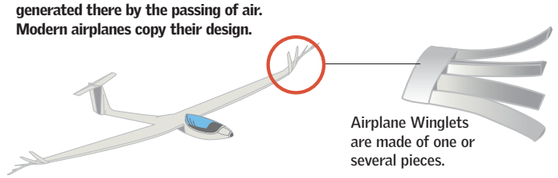




70%
THE ENERGY SAVED BY A SEAGULL WHILE GLIDING

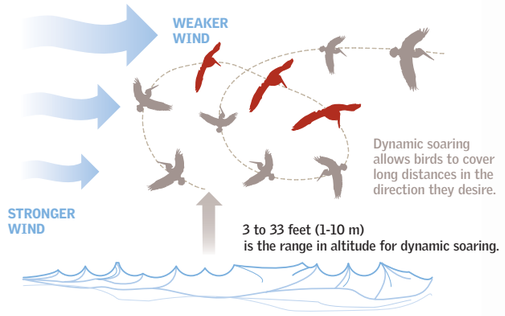
WINGLETS

Terrestrial gliders usually have separate primary feathers (toward the tip of the wing) that serve to decrease the noise and tension generated there by the passing of air. Modern airplanes copy their design.



Marine Birds

Dynamic soaring is performed by birds with long and thin wings, such as the albatross. These wings are designed to take advantage of horizontal air currents, which are responsible for the formation of waves in the ocean. The result is a flight consisting of a series of loops as the bird is lifted upward when it faces the wind and moved forward when it faces away from the wind. This kind of flight can be performed at any time.



FLIGHT PATTERNS

Flying in formation is a way for birds in flapping flight to save energy. The leader encounters more resistance as it flies, while the others take advantage of its wake. There are two basic patterns: "L" and "V." The first is used by pelicans, and the second is used by geese.



Relay
When the leader gets tired, another bird takes its position.

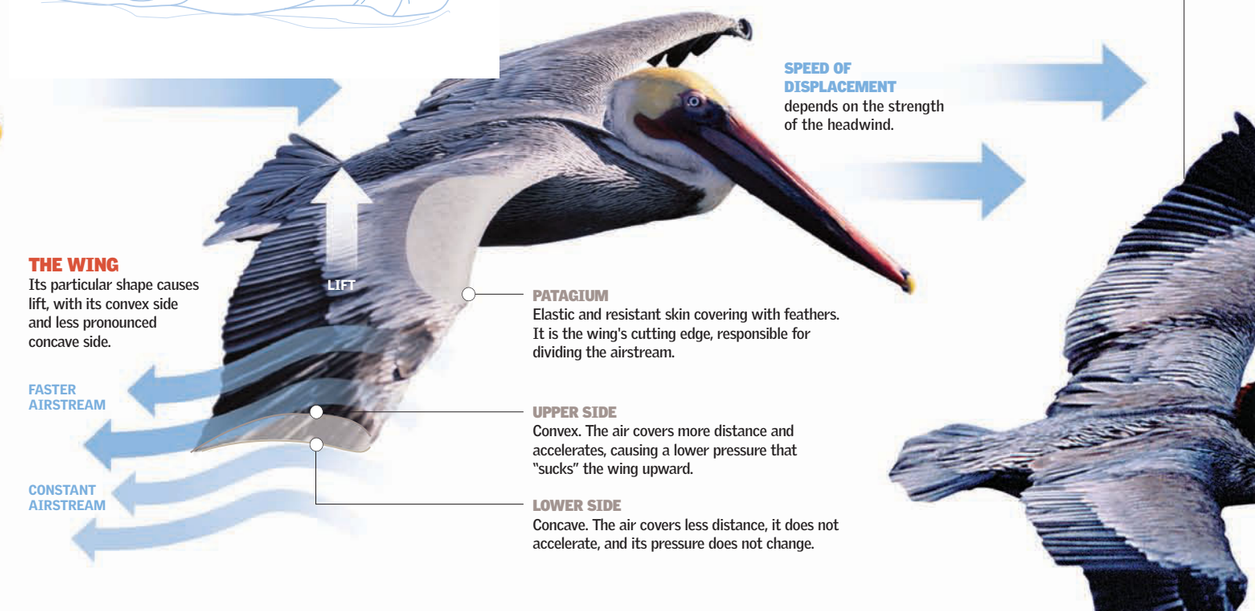
14%
THE PERCENTAGE OF WING FLAPPING THAT GEESE SPARE THEMSELVES BY FLYING IN FORMATION



"L" FORMATION
Leader
The leader makes the most effort, as it "parts" the air.

The Rest of the Formation
The other birds make use of the turbulence produced by the leader's flapping to gain height, following along behind.

"V" FORMATION
The principle is the same, but the birds form two lines that converge at a point. This is the usual formation used by geese, ducks, and herons.



TERRESTRIAL BIRDS

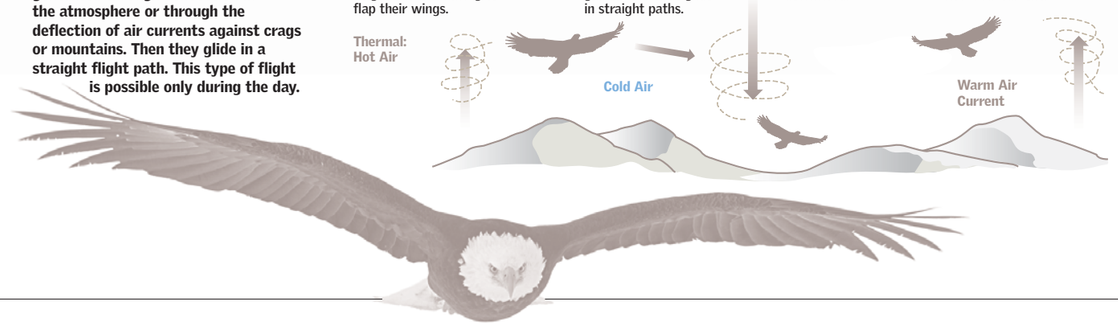
They use warm, rising air currents generated through convection in the atmosphere or through the deflection of air currents against crags or mountains. Then they glide in a straight flight path. This type of flight is possible only during the day.

1 Ascent
When birds find a warm air current, they gain height without having to flap their wings.

2 Straight Gliding
Once the maximum possible height is gained, the birds glide in straight paths.

3 Descent
The birds slowly glide downward.

4 Ascent
They rise again when they encounter another warm air current.



Flapping Flight

Most flying birds use flapping flight all the time. It consists of moving through the air as if rowing with the wings. With each flap (raising and lowering), the wing both sustains the bird in the air and pushes its body forward. There are different types of flapping flight and different rates of flapping. In general, the larger the bird, the more powerful and less frequent its flapping will be. Because flapping is an activity that consumes much energy, birds have adapted a variety of flight patterns: some, like hummingbirds, always flap their wings, whereas others alternate flapping with short-term gliding. The wing shape also varies according to the bird's needs. Birds that cover long distances have long, narrow wings; those that fly among trees have short, rounded wings.



THE HEAD
Tilted backward to bring it closer to the center of gravity (between the wings) and attain balance

THE TAIL
Slightly curved, it works as a rudder during flight and as a brake during landing.

THE LEGS
remain at rest until landing. They stay very close to the body.

THE CROP
Made of elastic skin. It can hold food during flight.

THE BILL
Projected forward, its aerodynamic shape decreases the bird's air resistance.

ANGLE OF THE WING
Variable, depending on the wing's position. It closes on the downstroke.

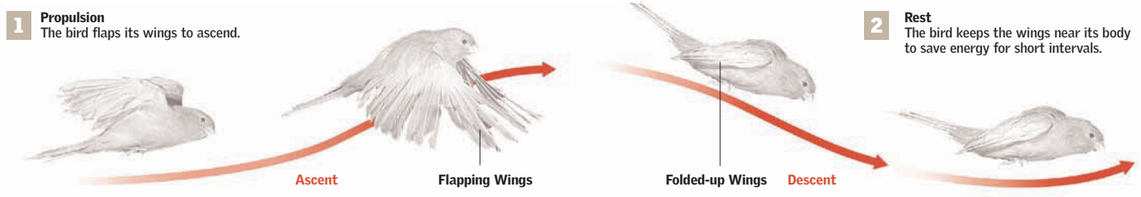
30 miles per hour (50 km/h)
THE AVERAGE SPEED OF AN ADULT PELICAN DURING FLIGHT ON A WINDLESS DAY

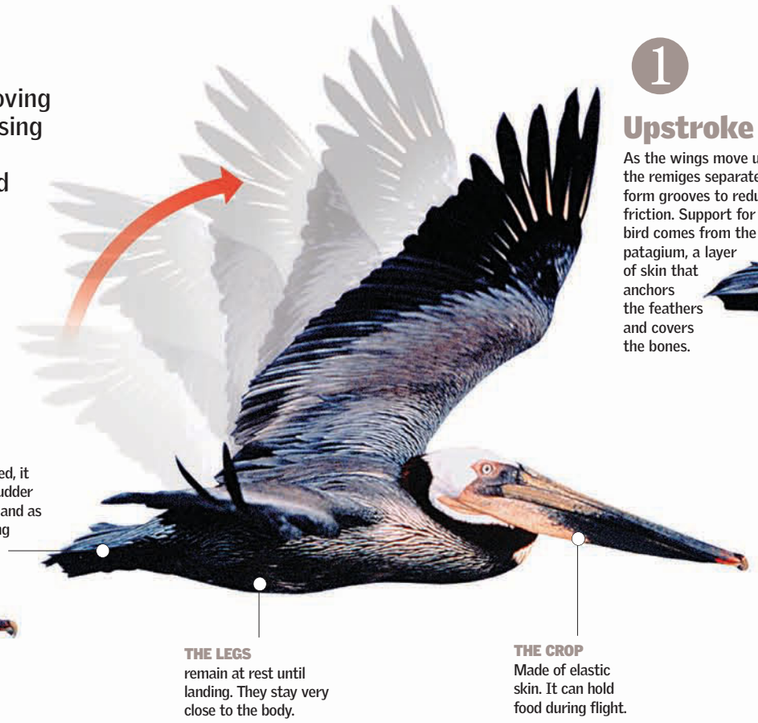
A Specialized Design

Flapping flight is an activity that requires much effort. Therefore, birds must eat large amounts of food. A migrating swallow uses 4 kilocalories (4,000 calories) per 1.6 miles (2.5 km) of flight, whereas a small mammal needs only about 0.025 kilocalorie (25 calories) to travel the same distance.

WAVELIKE FLIGHT PATH

Ideal for high speeds, it consists of flapping the wings to gain height and then folding them in order to descend along the flight's trajectory. Afterward the bird flaps its wings again, making use of the inertia of its descent to regain height. A variation of this type of flight involves gliding between flaps of the wings.





1 Upstroke
As the wings move upward, the remiges separate and form grooves to reduce friction. Support for the bird comes from the patagium, a layer of skin that anchors the feathers and covers the bones.

STRENGTH
To gain height above the ground, the wings flap in big arches in a manner that generally produces a lot of noise.

2 Downstroke
As the wings move downward, the remiges are forced together, and the wing moves forward a little for extra support. The wing also bends at the tips to push the bird forward, as if it were rowing.

Muscular strength is distributed to the entire wing, but it increases near the tip.

The downstroke of the wing provides propulsion.

WING STROKE
The wing acts like an oar as it traps air and pushes the bird forward.

WINDMILL FLIGHT: HUMMINGBIRDS

Hummingbirds are able to hover in order to suck the nectar out of flowers. In contrast to other birds, hummingbirds' wings are attached only at the shoulders, which provides greater freedom of wing movement, allowing the hummingbird to hold itself in the air during both the upstroke and the downstroke. The hummingbird has to flap its wings up to 4,800 times per minute during directional flight and for hovering.

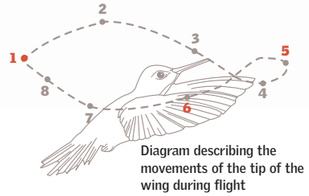


Diagram describing the movements of the tip of the wing during flight

The wings flap 80 times per second during normal flying.

Courtship Display
Certain hummingbird species can flap their wings up to 200 times per second during courtship.

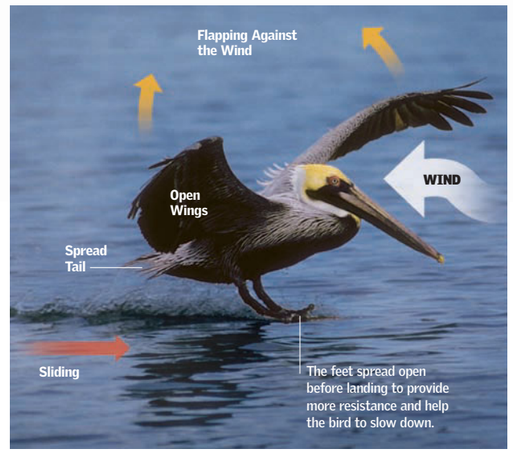


The wing has short, sturdy bones; the muscles are very powerful.

Great Maneuverability: Hummingbirds are the only birds capable of moving backward.

Landing

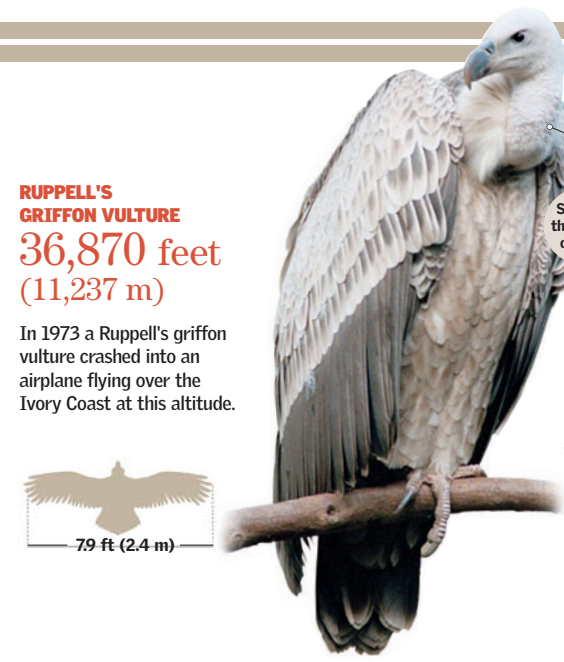
Landing requires reducing speed until the bird becomes motionless and settles. The bird faces the wind and spreads out its tail, wings, and alulae (bastard wings, characterized by their stiffness and growth from the first digit), while lifting up its body and extending its legs forward to increase the surface area in contact with the air. In addition, the bird flaps its wings intensely in the direction opposite to its flight. Everything works like an aerodynamic brake. Some birds—such as the albatross, with its long, narrow wings—tend to have problems slowing down. As a result, they are ungainly when landing on the ground, but on the water they are able to ski on their feet until coming to a stop.



Speed Records

The world of birds is amazing when expressed in numbers. Most birds travel at speeds between 25 and 45 miles per hour (40–70 km/h), but when diving, peregrine falcons can reach more than 200 miles per hour (320 km/h). Many species can reach an altitude of 6,600 feet (2,000 m), although climbers have seen geese flying over the Himalayas at more than 26,000 feet (8,000 m). The fastest swimmer is the Gentoo penguin, which can swim 22.4 miles per hour (36 km/h). Considering its small size, it is surprising that the *Selasphorus rufus*, or Rufous hummingbird, which is only 4 inches (10 cm) long, carries out an extensive round-trip migration each year from northern Alaska to Mexico. Here are some more incredible facts.

RUPPELL'S GRIFFON VULTURE
36,870 feet (11,237 m)
In 1973 a Ruppell's griffon vulture crashed into an airplane flying over the Ivory Coast at this altitude.

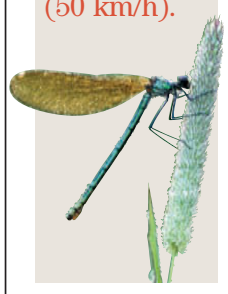


Air

SPEED

Most birds fly between 25 and 45 miles per hour (40 and 70 km/h), but the fastest birds can beat the cheetah, the most famous of the fast animals.

DRAGONFLY
The fastest flying insect. It reaches
31 mph (50 km/h).



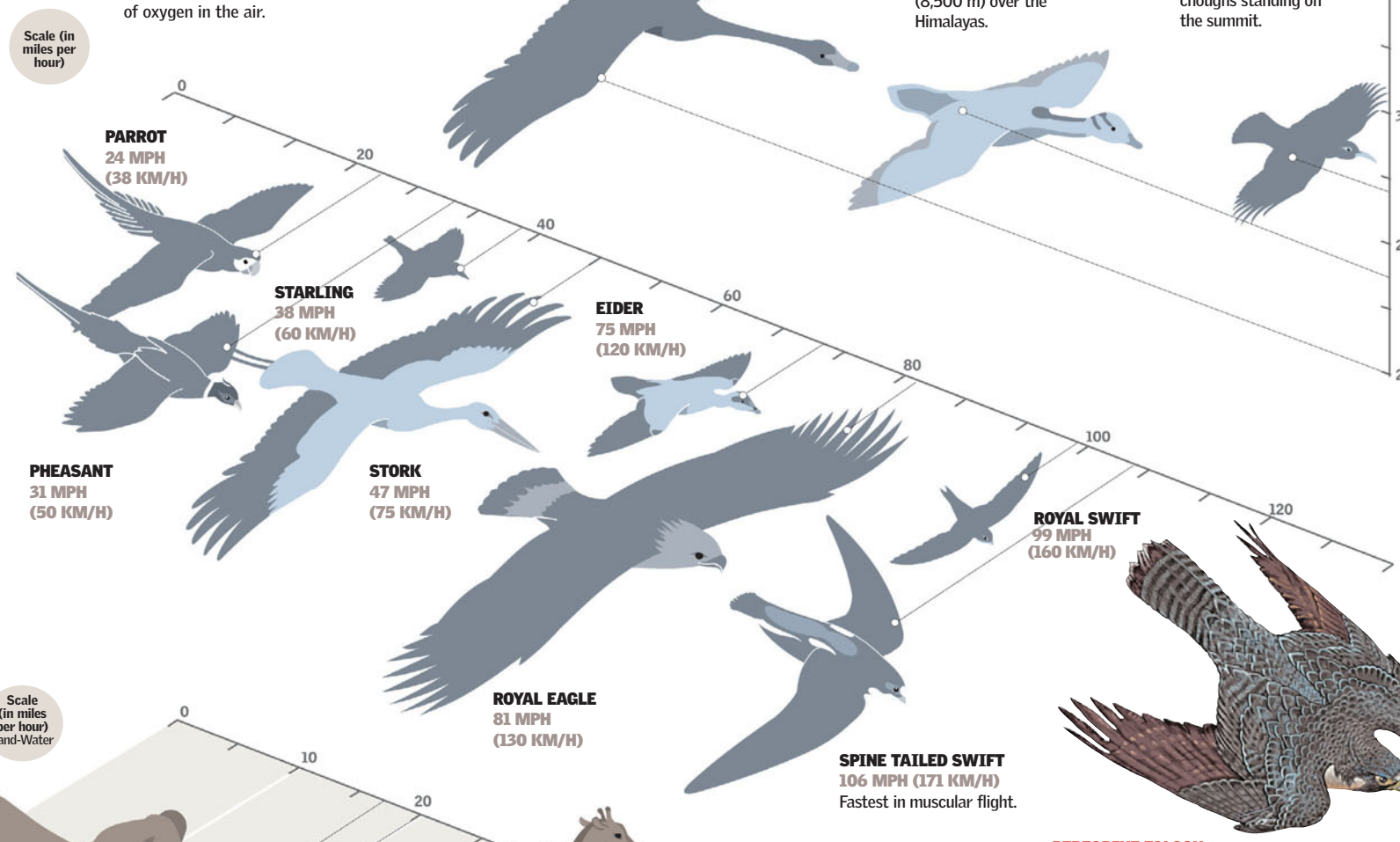
ALTITUDE

Flying at high altitudes requires a strengthened circulatory system to make up for the scarcity of oxygen in the air.

BLACK SWAN
27,000 FEET (8,230 M) OF ALTITUDE,
according to a pilot who witnessed a flock over the Hebrides Islands

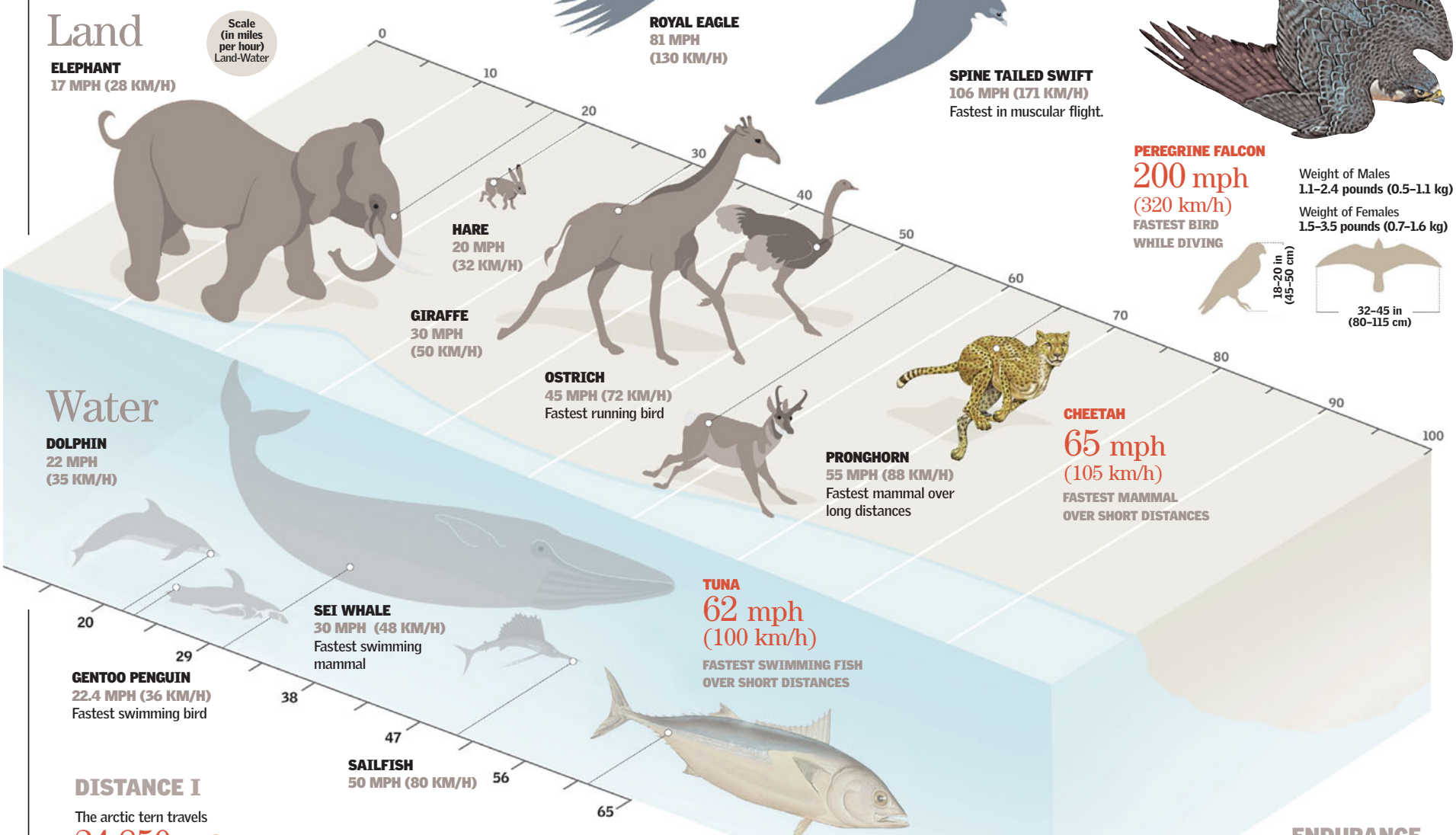
BAR-HEADED GOOSE
28,000 FEET (8,500 M)
Some climbers reported having seen specimens of geese flying at 28,000 feet (8,500 m) over the Himalayas.

CHOUGH
29,030 FEET (8,848 M)
A group of climbers on Mt. Everest found choughs standing on the summit.



PEREGRINE FALCON
200 mph (320 km/h)
FASTEST BIRD WHILE DIVING
Weight of Males
1.1–2.4 pounds (0.5–1.1 kg)
Weight of Females
1.5–3.5 pounds (0.7–1.6 kg)
18–20 in (45–50 cm)
32–45 in (80–115 cm)

Land

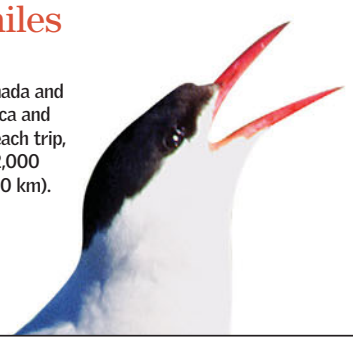


Water

DISTANCE I

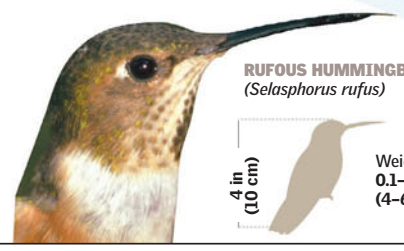
The arctic tern travels
24,850 miles (40,000 km).
It migrates from Canada and Labrador to Antarctica and the Austral Sea. On each trip, it travels 9,000 to 12,000 miles (15,000–20,000 km).

ARCTIC TERN
(Sterna paradisea)



DISTANCE II

The Rufous hummingbird flies from northern Alaska to Mexico and back—a journey of
6,000 miles (10,000 km/h).



RUFOUS HUMMINGBIRD
(Selasphorus rufus)

ENDURANCE

The endurance record goes to the golden plover, which is able to fly a distance of
1,900 miles (3,000 km)
without stopping.

GOLDEN PLOVER
(Pluvialis apricaria)



The Lives of Birds

PARTRIDGE EGGS *(Lagopus lagopus scoticus)*
The female lays eggs at intervals of one to two days, and she is the one who incubates them.

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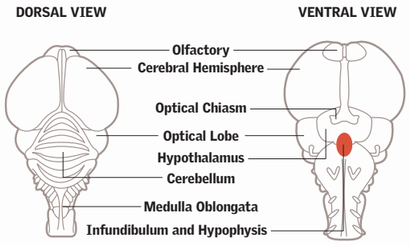
The behavior of birds is closely connected to the seasons. To survive, birds must prepare for the arrival of fall and winter and adjust their behavior accordingly. Gliding over the oceans, a wandering albatross, for example, can travel anywhere from 1,800 to 9,300 miles (2,900 to 15,000 km) in a single day in search of food. When the time comes to choose a partner, the behavior of males is different from that of females: males employ a variety of tactics to win over females and convince them of their fitness. Some bird couples stay together forever, whereas other birds change partners every year. As for caring for chicks and building nests, in most species both parents participate.●

The Annual Cycle

The annual cycle of seasons is like the daily cycle of night and day. Fluctuations in the intensity of light over time create a series of physiological and behavioral changes in birds, whether throughout the year or throughout the day. This biological clock is clearly reflected in birds' reproduction and migrations. Changes in light that are detected by a bird's retinas induce the secretion of melatonin by the pineal gland. The blood level of this hormone acts on the hypothalamus-hypophysis axis, which regulates internal processes. This is one reason why birds start to change their plumage and feel the need to fly to other areas.

How the Hypophysis Works

Reproduction is the main activity under the control of the hypophysis, which determines behaviors such as finding a place to court females and mate, building a nest, incubating the eggs, and stimulating unborn chicks to break their shells. The hypophysis is a gland in the brain that has several functions. It receives nervous and chemical stimuli and produces hormones. These hormones regulate the metabolic activities that cause birds' internal and external sexual organs to develop. For example, the gonads become enlarged, and secondary sexual characteristics, such as ornamental crests or plumes, appear.





Sleep Regulator

The pineal gland, or epiphysis, produces melatonin. The level of this hormone determines the phases of sleep and wakefulness.

THE MOST IMPORTANT GLAND

The hypophysis is located in the ventral area of the brain, below the hypothalamus. Its secretions control vital functions, from blood pressure and the balance of water and salts in the body to the activity of the gonads and the thyroid.

Survival Manual

Birds' most striking behaviors are associated with the reproductive season. During courtship parades, birds engage in elaborate choreographies; there are also extraordinary fights between males. The blue-footed booby, the male frigate bird, and the ruff are just a few examples of birds that engage in these behaviors. Others, such as the snowy egret *(Egretta thula)*, prefer to offer twigs for the construction of the nest. The Vogelkop bowerbird *(Amblyornis inornata)* builds bowers with leaves, flowers, or any other object that may help him to win over the female. Birds' performances are not connected only to courtship. The killdeer *(Charadrius vociferus)* fakes being wounded to defend the eggs or chicks in the nest from predators. It offers itself as easy prey by dragging a wing as if it were broken. This trick shifts the danger away from the young.

SHOWING OFF

The magnificent frigate bird *(Fregata magnificens)* is a large bird that lives in coastal areas. It has large wings, powerful talons, and a strong hooked bill. During the reproductive season, it is responsible for building the nest. With its impressive appearance, it endeavors to attract a female.



New House
While it prepares the nest, its chest rests, with its skin pink and relaxed.

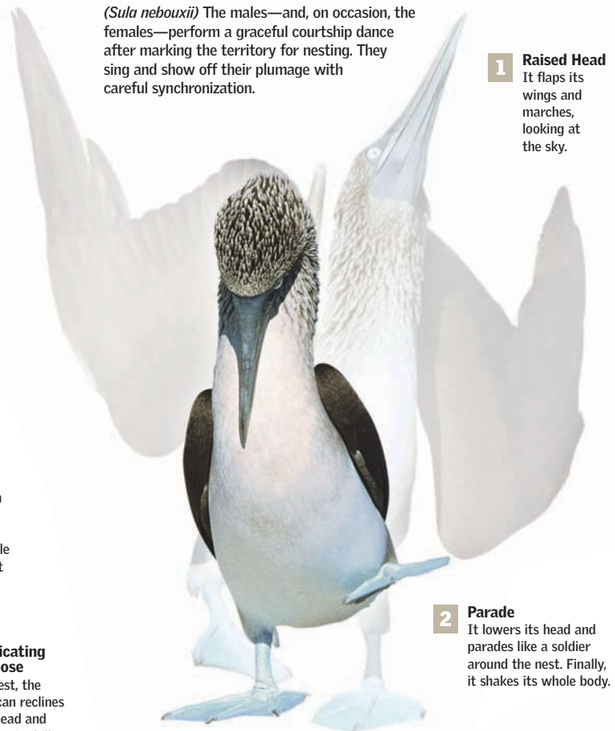


Red Chest
The throat pouch remains inflated for several hours or until the female chooses the most seductive male.

Indicating Repose
To rest, the pelican reclines its head and places its bill under a wing.

DANCE OF THE BLUE-FOOTED BOOBY

(Sula nebouxii) The males—and, on occasion, the females—perform a graceful courtship dance after marking the territory for nesting. They sing and show off their plumage with careful synchronization.



1 Raised Head
It flaps its wings and marches, looking at the sky.

2 Parade
It lowers its head and parades like a soldier around the nest. Finally, it shakes its whole body.

IN COMBAT

In the summer, male ruffs develop a huge "ruff" and auricular feathers around their necks. Their courtships are violent and striking. When competing for mating territory, they struggle fiercely. Afterward they docilely sprawl their bodies on the ground until the female chooses the lucky one.



Male Ruff
Philomachus pugnax

ANNUAL CYCLE

Incubation, migration, and courtship activities vary according to the amount of light available during each season.

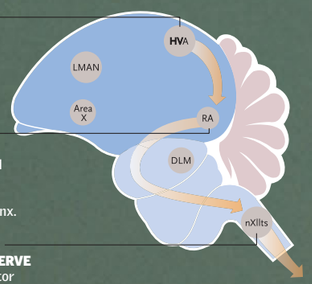


How They Communicate

Sound is an important form of expression in the lives of birds. Birds' sounds can be of two types: calls and songs. The former have a simple acoustic structure, with few notes. They are associated with coordinating the activities of a group, establishing communication between parents and their young, and maintaining contact between birds during migration. Songs, on the other hand, are more complex in rhythm and modulation. They are controlled by the sex hormones, primarily the male hormones. For this reason, males produce the most varied melodies. Songs are linked to sexual behavior and territorial defense. In general, birds either inherit or learn them.

1 THE SONG AND THE BRAIN

Birds have a brain that is well developed for this function. Testosterone acts on the upper vocal center of the brain, which is in charge of memorizing, identifying, and transmitting the orders for the execution of the song.



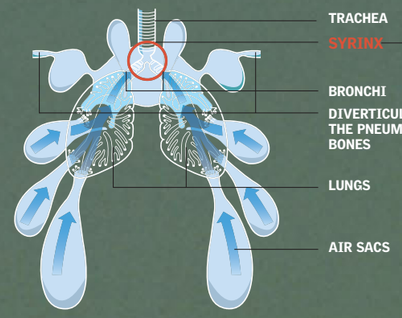
HIGH VOCAL CENTER
It is controlled by the central nervous system and orders the bird to sing.

ROBUST NUCLEUS OF THE ARCHISTRIATUM
It sends the information to the muscles of the syrinx.

NUCLEUS OF THE HYPOGLOSSAL NERVE
It controls the motor functions of the syrinx.

2 EXPULSION OF AIR TO THE BRONCHI

The air stored in the air sacs and lungs is expelled. As it passes through the syrinx (located between the bronchi and the trachea), it vibrates the tympaniform membranes. These membranes are the equivalent of vocal cords in humans.

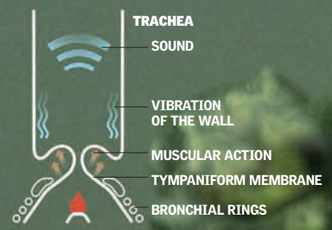


3 THE PRODUCTION OF SOUND IN THE SYRINX

The participation of both the sternotracheal muscles and five to seven pairs of small internal muscles is needed for producing sounds. These muscles control the elongation and contraction of the syrinx, which varies the pitch of the sound. The air sac is also important because it adds external pressure, which causes the tympaniform membranes to tighten. The esophagus works like a resonating box, amplifying the sound. The articulation of the sounds occurs in the buccopharyngeal cavity. There are two types of articulation: guttural and lingual.

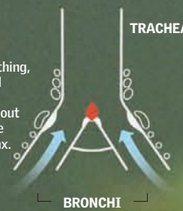
SIMPLE SYRINX

The tympaniform membranes are located above the place where the bronchi divide. They are moved by a pair of external muscles.

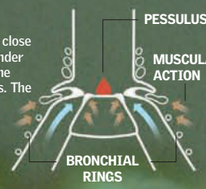


SONG-PRODUCING SYRINX

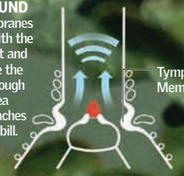
A AIR AND BRONCHI
During breathing, the songbird maintains airflow without affecting the resting syrinx.



B CLOSED MEMBRANE
The membranes close on both sides, under pressure from the external muscles. The bronchi rise slightly and also adjust the membranes.

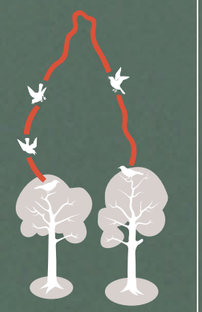


C THE SOUND
The membranes vibrate with the air current and propagate the sound through the trachea until it reaches the bird's bill.



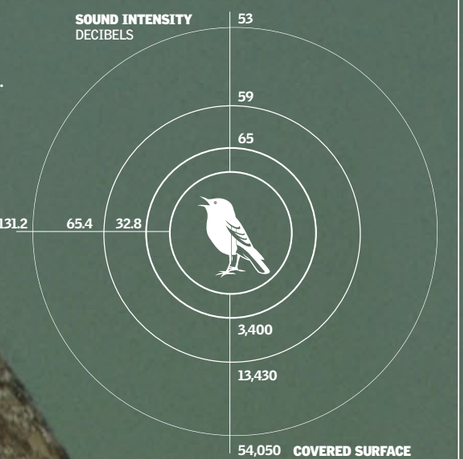
Territoriality and Range

One of the most studied functions of birds' songs is territorial demarcation. When a bird occupies a territory, it sings to announce its claim to competitors, as the pipit shown to the left is doing. When birds must share territory, as in a colony, they develop dialects (variations of sounds produced by the species). When a bird born and raised in one location moves, it must learn the dialect of the new location in order to be accepted and participate in the community. There are also mechanical sounds produced by wing strokes, legs, and bills. In a display of territorial defense, the eared nightjar combines singing with beating its wings.



4,000 bird species

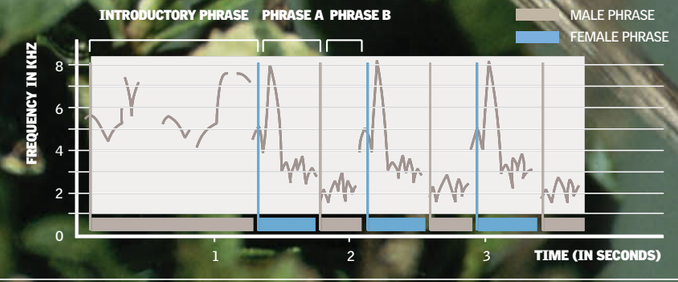
SHARE WITH HUMAN BEINGS AND WHALES THE NEED FOR "SOMEBODY" TO TEACH THEM TO VOCALIZE (SONGBIRDS, HUMMINGBIRDS, AND PARROTS ARE EXAMPLES).



INTENSITY
can vary widely from bird to bird. The larger the territory, the greater its reach. Its frequencies can change as well: the lower the frequency, the greater the coverage.

Strengthening Ties

Some songbirds develop very complex singing rituals. The duet is perhaps the most striking because it requires both a shared repertoire and good coordination between both birds. In general, the male initiates the song with a repeated introduction; the female then alternates with different phrasing. The phrasing allows for more or less cyclical variations that make it unique. It is believed that this strengthens ties between the pair (as demarcation of territory does) and serves as a stimulus for cooperative behaviors, such as nest building, in which both the male and female may participate.



Nuptial Parade

Finding a mate is not easy for any species. For birds, the exhibition of plumage with bright colors, the presentation of offerings and gifts, and the performance of dances and highly elaborate flight patterns are some of the particular behaviors seen during this period. They are known as nuptial or courtship displays. The male resorts to all these strategic gestures to attract the female's attention and prevent her from paying attention to other males. Some of these rituals are extremely complicated; others are very tender and delicate.



A
When its sexual arousal peaks, the male northern harrier *(Circus cyaneus)* flies in a wavelike pattern to attract the female.

B
During courtship, the male northern harrier pretends to attack the female.

AERIAL EXHIBITIONS

Certain birds, such as goshawks or male northern harriers, court the female in flight. They ascend in the air in broad circles, only to let themselves fall in daring, sharp dives.

MUTUAL DANCES AND COURTSHIPS

Great crested grebes *(Podiceps cristatus)* perform incredible aquatic dances. They bow to each other, dive, and run through the water side by side.

Special Courtship

Avian courtship is a phenomenon that, depending on the species, can take the form of various rituals. Lek rituals are one of the most intriguing forms of courtship. The males gather in a small area, called an arena, where they perform their courtship displays for the females. The females form a circle around the arena and end up mating with the male that has the most striking secondary sexual characteristics. Lek is a system controlled by the dominant male, who ends up mating with most of the females (polygyny). The less experienced males will mate with only a few, or even none, of the females. For some species, lek rituals can be very intricate. At least 85 species perform this special type of courtship ritual, among them manakins, pheasants, cotingas, and hummingbirds. Manakins, for example, stand in line and wait their turn to perform.

TIMING

The courtship display is directly related to reproduction cycles. It takes place before copulation, although it can continue to occur thereafter.



Prenuptial
Prenuptial courtship starts with territorial establishment and the search for a partner, which can take place simultaneously.



Postnuptial
With this display, the great crested grebe ensures the continuity of the pairing even after the eggs are laid.

5.9 feet (1.8 m)

IS THE SIZE OF THE TAIL OF THE PEACOCK WHEN IT UNFURLS ITS MORE THAN 200 SHINING FEATHERS AND FORMS A FAN TO ATTRACT THE FEMALE.

Gray Crowned Crane
Balearica regulorum
Two cranes perform a courtship dance consisting of a series of impressive leaps.



DISPLAYING PHYSICAL ATTRIBUTES

To find a partner, birds such as the snowy egret resort to a series of very elaborate signals, such as songs, poses, dances, flight patterns, noisemaking, and displays of their ornamental feathers.



BUILDING BOWERS

Australian bowerbirds build a structure called a bower, which they decorate with pieces of paper and fabric that inevitably attract the female.



GIFTS

Another courtship strategy is the presentation of gifts. Male eagles give females prey, and European bee-eaters offer insects. These offerings are called courtship food.

Emperor Penguin
Aptenodytes forsteri
A monogamous species. Each recognizes its partner by its voice, and couples will spend their entire lives together.

Monogamy or Polygamy

Monogamy is the most common mating system, in which two birds, one of each sex, participate, leading to the formation of a couple. This couple can endure for a single reproductive season or for life. Polygamy is an alternative pattern, but it is not very common. Polygamy is divided into two classes: polygyny, in which the male mates with several females, and polyandry, in which the female mates with several males (and may even be able to keep them all together in a harem). In either case, one partner has the sole responsibility of caring for the eggs and chicks. There is also an exceptional case within polygamy: promiscuity. In this arrangement, a couple is not formed, and the relationship is limited to copulation.

Home Sweet Home

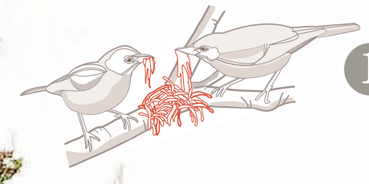
Most birds lay their eggs in a nest, where they are incubated by the body heat of an adult sitting on them. To build a nest, the couple normally uses mud mixed with saliva, small stones, branches, and feathers. When the nest is in a visible location, the bird covers it with lichens or loose twigs to hide it from predators. Nest shapes vary according to the bird group: they can take the form of a bowl, a hole in a tree (woodpeckers), or an excavated burrow on a slope of sand or soil. There are even birds that use nests built by other species.

How the Nest Is Built

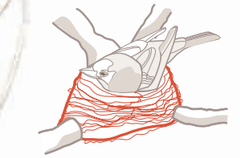
A cup-shaped nest is built at a fork between two or three branches. The bird arranges twigs, grass blades, and small sticks, as if building a platform. The bird then interlaces some of these materials with the tree to give the nest solidity. It then interweaves the materials in a circular pattern. As the nest takes shape, lighter, more adhesive materials—such as mud, spiderwebs, caterpillar silk, and certain plant fibers—are used. Although the outside is rough, the inside is lined with feathers for softness and warmth. In general, if both the male and female participate in the construction, a few hundred trips are enough to complete the nest. In some species, such as weavers, males have to display a nest during courtship; in others (African black eagles, for instance), the same nest is used every year.



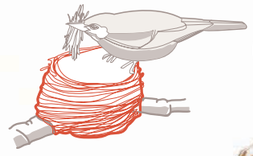
THE LITTLE MASKED WEAVER builds solid nests, weaving together leaves and grass blades. Sometimes the male builds several nests before the female chooses him.



1 BASE
The bird gathers branches and small sticks on a fork to lay the foundations of the nest, setting up a platformlike structure. The bird then ties it to the tree, making it sturdy.



2 SHAPE
The bird intertwines grass blades, small sticks, and hairs; fastens them; and gives them a circular shape. As construction advances, the bird uses adhesive materials, such as spiderwebs.



3 END
The finish includes moss and feathers to smooth out the interior and provide insulation against the wind and cold, which makes the nest more suitable for incubation.

BASE
This is the nest's foundation, and it is the first section built by the bird. It is solid and is usually built with bulkier materials.

WALLS
Eare the most important component in a nest's construction, and they give it its characteristic shape. The materials used vary, depending on the habitat.

LINING
It is composed of fibers, hairs, feathers, and down. It insulates the eggs from the cold and helps with incubation.

Structure

The cup shape is important for preventing eggs from rolling out and falling. Besides making the construction of the nest easier, the use of different materials helps make the nest sturdier, as the smaller and more flexible pieces firm up the base, walls, and lining of the structure. Different materials also provide more efficient insulation, keeping warmth in and cold out during the incubation and raising of chicks. As an added reinforcement, birds usually make the side facing the prevailing winds thicker and the side facing the sun thinner. Thus, the whole nest is an incubator that conserves energy. Finally, an exterior finish camouflages the nest among branches, hiding it from predators.



SOME VARIATIONS



WOVEN NESTS
Weaver birds intertwine grass blades until they form a structure. The entrances are underneath.



BURROWS
Parrots and kingfishers dig their nests in sandy river banks.



PLATFORM NESTS
The sparrow hawk gathers a large number of branches and assembles a high, solid base for its eggs.



SEWN NESTS
The tailorbird sews two large leaves together with grass blades. The nest is inside the leaves.

Types and Locations

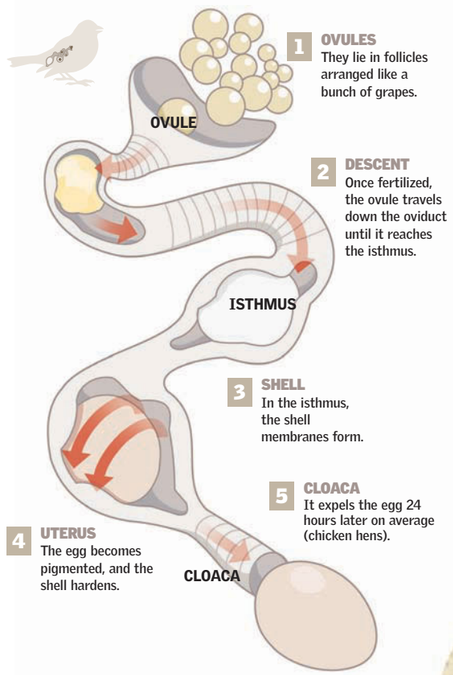
Nests are classified according to their shape, material, and location. They vary depending on the amount of warmth the species needs, as well as in terms of the level of protection they offer. The greater the pressure from predators, the higher or better hidden a nest must be. Good examples are isolated nests resembling high platforms; nests in deep depressions in the soil or hidden in tree trunks, which are very safe and provide good insulation; and nests made of clay, which are very hard. The most typical nests resemble a cup and are found at various locations, most often between two or three high, remote branches.

First, the Egg

Birds may have inherited their reproductive method from their predecessors, the theropod reptiles. In general, they lay as many eggs as they can care for until the chicks become independent. Highly adapted to the environment, the eggs of the same species have varying shapes and colors. These variations help keep them safe from predators. They also vary greatly in size: the egg of an ostrich is 2,000 times bigger than that of a hummingbird.

How It Forms

Birds have only one functional ovary, the left one, which grows dramatically during the mating season. The ovule can descend and form what are known as unfertilized eggs (the type used in cooking). If the egg is fertilized, embryonic development begins. The ovule, fertilized or not, descends to the cloaca in a few hours or days. The eggshell begins to be formed at the isthmus, through the secretion of calcium. At first soft, the shell hardens when it comes in contact with the air.



1 OVULES
They lie in follicles arranged like a bunch of grapes.

2 DESCENT
Once fertilized, the ovule travels down the oviduct until it reaches the isthmus.

3 SHELL
In the isthmus, the shell membranes form.

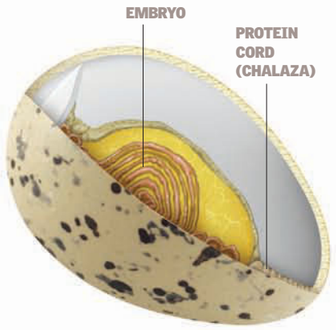
4 UTERUS
The egg becomes pigmented, and the shell hardens.

5 CLOACA
It expels the egg 24 hours later on average (chicken hens).

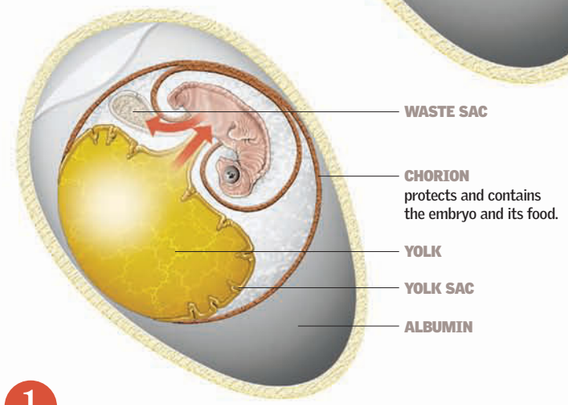


LAYING
A group of eggs laid at one time is called a laying. During the mating season, a sparrow can have several layings. If some eggs are removed, the sparrow can replace them without difficulty.

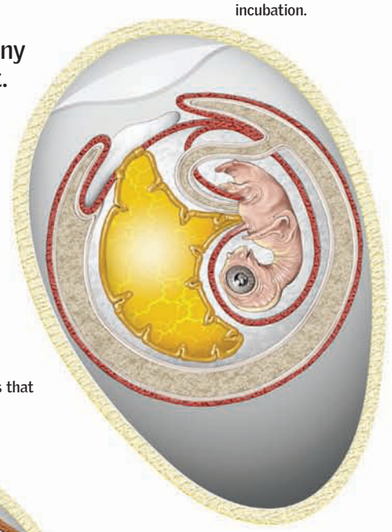
1
The egg contains an embryo in one side of the yolk. The yolk is held in the middle of the white (albumin) by a protein cord that isolates it from the outside world.



2
As it feeds to grow, the embryo produces wastes that are kept in a special sac.



3
Most birds' organs are formed in the first hours of incubation.



SHAPE
It depends on the pressure exerted by the oviduct walls. The large end emerges first.

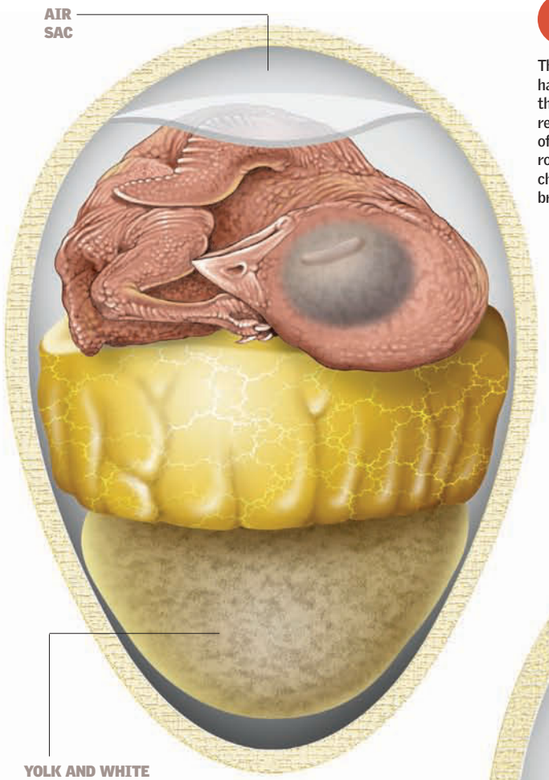


Oval: The most frequent | Conical: Prevents falling | Spherical: Reduces the surface area

COLOR AND TEXTURE
Both texture and color help parents locate the egg.



Light Egg | Dark Egg | Speckled Egg



YOLK AND WHITE
They decrease in size.

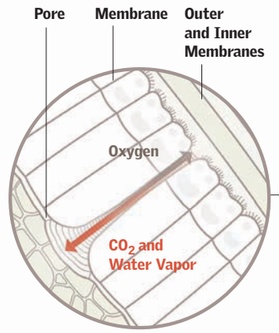
4
The bill and scales of the legs harden toward the end, when the chick is formed and reaches a size similar to that of the egg. At that point, rotation begins so that the chick will be positioned to break its shell.

5
When the chick is ready to break the shell, it is taking up all the space inside the egg. The chick is cramped with its legs against its chest. This enables it to open the shell with small movements and with the help of a hard point at the tip of its bill (called an egg tooth).

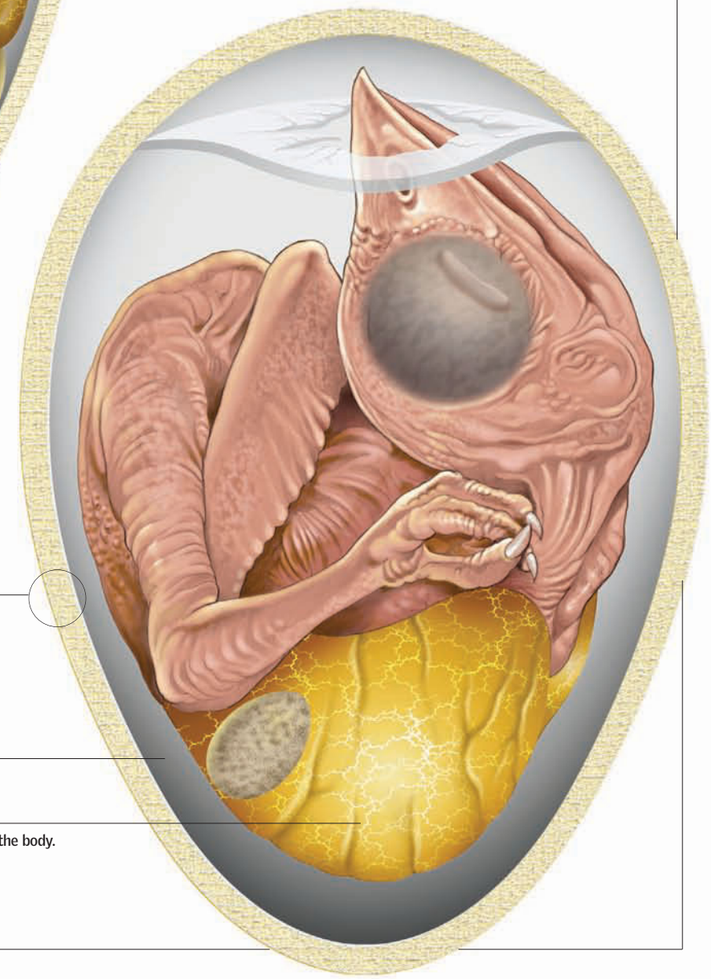
SIZE
There is no exact proportion between the size of a bird and its egg.

1 lb (500 g) — Kiwi Egg
2 oz (60 g) — Chicken Hen's Egg

THE SHELL
Formed by a solid layer of calcium carbonate (calcite), it has pores that make it possible for the chick to breathe. Bacteria are kept out by two membranes that cover the egg, one on the inside and the other on the outside.



8%
THE PROPORTION OF AN EGG TAKEN UP BY THE EGGSHELL



ALBUMIN
was consumed.

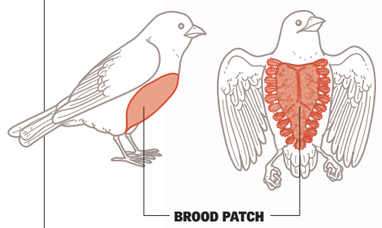
YOLK
disappears into the body.

Birth in Detail

When a chick is about to hatch, it starts to make itself heard from inside the egg. This allows it to communicate with its parents. It then starts to peck at the shell with its tiny egg tooth, which is lost after birth. Next, it turns inside the egg and opens a crack with new perforations, at the same time pushing with its neck and legs until it manages to stick out its head. This job demands a lot of effort and can take 30 to 40 minutes or, in the case of kiwis and albatrosses, even three to four days. In most species, newborn chicks are blind and naked, and they can open their bills only to receive food.

INCUBATION

For the embryo to develop, it needs constant temperatures between 99° and 100° F (37-38° C). The parents ensure these temperatures by sitting on the eggs and warming them with their brood patches.



During incubation, some species lose their chest feathers and increase their number of blood vessels in this area. Others pluck out their feathers. Direct contact with the eggs helps keep them warm.

DURATION BY SPECIES
The incubation period varies considerably: between 10 and 80 days, depending on the species.



PIGEON
Females and males incubate. They both develop a brood patch.
18 days

PENGUIN
Both males and females incubate. The emperor male has a special pouch for incubation.
62 days

ALBATROSS
Lacking brood patches, the parents hold the egg between their feet and abdomen.
80 days

Breaking the Shell

This process may take from a few minutes to three or four days, depending on the species. In general, the parents do not intervene or help their young. When the shell is empty, they throw it out of the nest, apparently to avoid attracting the attention of predators. In species whose young hatch with the feathers already developed, hatching is extremely important. It has been observed that the singing of the chicks stimulates the stragglers and delays those that have gotten ahead; it is important that they all be ready to leave the nest together.

35 minutes
IS THE APPROXIMATE TIME IT TAKES A SPARROW TO COME OUT OF THE EGG.



1

CRACK IN THE EGG
The chick turns inside until its bill targets the egg's midline. It then punctures the air sac. With a few more tries, it pierces the shell. The chick then breathes for the first time.

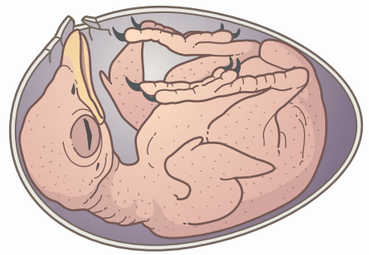
ASKING FOR HELP
The chick calls for its parents from inside. The reply encourages it to continue the effort.

SEQUENCE OF PECKING
Between each sequence of pecking, the chick must take long breaks.

2

THE CRACK EXPANDS
After making a hole in the shell, the chick opens a crack with successive pecks at other points. Air gets in and dries up the membrane, which makes the task easier.

WHAT COMES OUT FIRST?
The head usually comes out first, because the sharp bill helps break the shell. Most birds then get out of the egg by pushing themselves out with their legs. For wading birds and other terrestrial birds, however, the wings usually unfold first.



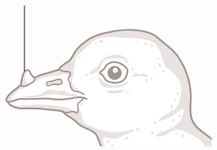
Adaptations for Hatching

Getting out of the egg is an intricate operation because the space is tight, and a chick's muscles have little vigor. Birds count on a few adaptations, such as the egg tooth and the hatching muscle, to accomplish the task. The tooth is used for making the first perforation, which allows air into the egg. The muscle exerts the necessary strength, while stimulating the chicken's motor functions to intensify the effort. Both the egg tooth and the hatching muscle disappear shortly after the eggshell is broken.

HATCHING MUSCLE
It exerts pressure against the shell and helps to break it.



EGG TOOTH
A protuberance on the bill that punctures the egg. Its presence depends on the species.



4

THE CHICK IS BORN
Once outside the chick, almost featherless, looks for warmth and food from its parents. In the case of some birds that hatch without feathers, not all eggs hatch simultaneously; this benefits the firstborn if food is scarce.

A GREAT EFFORT
Getting out of the shell requires much energy from the chick.

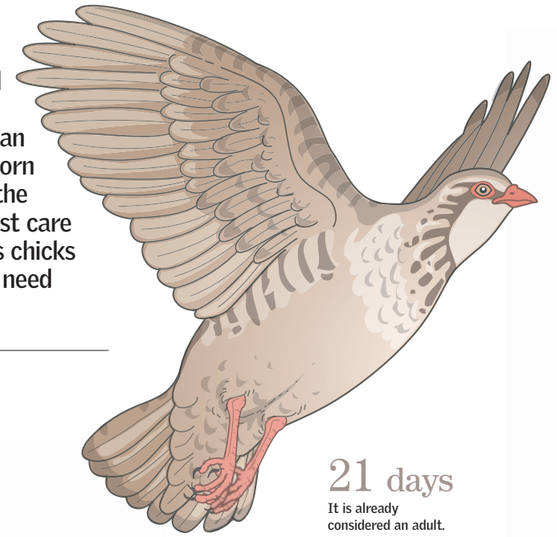


3

GETTING OUT OF THE EGG
Once the shell is open, the chick pushes itself out with its legs and by crawling on its abdomen. For birds that hatch without feathers, this is more difficult, because they are less developed.

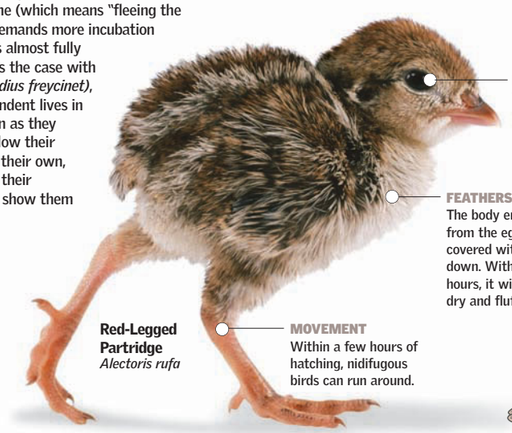
Postnatal Development

Chicks develop at highly variable rates after hatching. Some birds are born with their eyes open and with a thick layer of down feathers. These birds can also feed themselves. That is why they are called precocious, or nidifugous. Ducks, rheas, ostriches, and certain beach birds can walk and swim as soon as they are born. Other species are born naked and develop their feathers later. They need to stay in the nest until they have sufficiently developed, so adult birds must care for them. These birds are called nidicolous. The most helpless chicks are the young of songbirds and hummingbirds, because they need warmth from their parents to grow strong. ●



Nidifugous Young

Nidifugous young are fully developed at the moment of birth. They can move and even leave the nest, hence their name (which means "fleeing the nest"). This adaptation demands more incubation time because the chick is almost fully developed at birth. This is the case with incubator birds *(Megapodius freycinet)*, which begin their independent lives in the outside world as soon as they leave the shell. Ducks follow their parents but find food on their own, whereas chickens follow their parents, and the parents show them where to find food.



EYE
They are born with open eyes.

FEATHERS
The body emerges from the egg covered with damp down. Within three hours, it will become dry and fluffy.

Red-Legged Partridge
Alectoris rufa

MOVEMENT
Within a few hours of hatching, nidifugous birds can run around.

GROWTH STAGES



30 hours
The chick keeps warm with the down that covers its body. It can walk and begins to be fed by its parents.

7 to 8 days
Growth quickens, and the first covert feathers appear at the tip of the wing. The bird leaves the nest. Its diet consists of:
66% invertebrates.
The rest consists of seeds and flowers.



24 hours
IS THE MINIMUM AMOUNT OF TIME THE BLACK-HEADED DUCK NEEDS TO BE READY TO FLY.

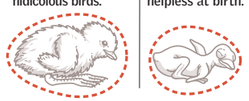
15 days
It starts to perform short flights. It reverses its diet, eating:
66% seeds and flowers.
The rest consists of invertebrates.



21 days
It is already considered an adult. Its flights are longer. Its diet is composed of 97 percent vegetables; the rest is made up of lichens and insects.

SIZE COMPARISON

NIDIFUGOUS	NIDICOLOUS
The egg is larger, the chick is born more developed, and the incubation period is longer than that of nidicolous birds.	They lay small eggs, with a brief incubation period, and the young are helpless at birth.



Nidicolous Broods

Most of these chicks are born naked, with closed eyes and with only enough strength to get out of their shells. They stay in the nest. For the first few days, they cannot even regulate their own body temperature; they need their parents in order to stay warm. Within one week, they have a few feathers, but they require constant care and food. They form a numerically important group that includes Passeriformes (songbirds).

FOOD
They need much food to develop. The parents must feed them 24 hours a day.



House Sparrow
Passer domesticus

An adult bird can feed its young up to **400 times a day.**

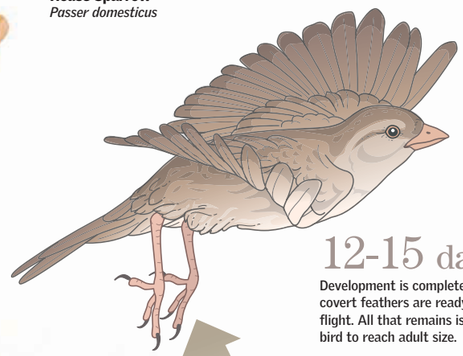
INTERIOR OF THE BILL
Its color is bright to stimulate the parents to regurgitate the food.

Shining Areas
Some species have shiny areas that can be seen even in the dark.

EYES
Nidicolous chicks are born blind. They open their eyes a few days after birth.

FEATHERS
The chicks are born either naked or with down feathers in some areas.





12-15 days
Development is complete, and the covert feathers are ready for flight. All that remains is for the bird to reach adult size.

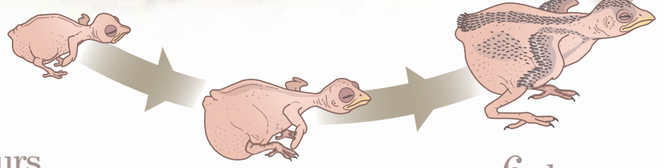


10 days
Feathers cover everything, but they are not yet developed. The chick can stay warm on its own, and it is voracious. Growth is very fast.



8 days
Feathers cover the chick almost completely, except around its eyes. Its legs are well developed, and the sparrow moves around in the nest.

STAGES OF GROWTH



25 hours
It performs a few instinctive movements. It can barely raise its head to ask for food.

4 days
The eyes open. The tips of the first feathers appear. It performs a few movements.

6 days
Some feathers begin to unfold, the nails are formed, and the wings continue to grow with the body. It can stand up.

12-15 days
IS THE ESTIMATED TIME THAT IT TAKES THIS NIDICOLOUS CHICK TO LEAVE THE NEST.

A Diet for Flying

Most birds eat assorted foods that are rich in energy and proteins. Their high level of activity requires that they eat almost constantly. Their sources of food are varied and include seeds, fruits, nectar, leaves, insects and other invertebrates, and meat of all kinds (including carrion). Many species eat more than one type of food; some even alternate according to the seasons and to the migration cycle. This guarantees their survival. However, there are others birds—a minority—that consume only one type of food, for which they have no competition. Because their dependence on this single source of food is greater, though, the risk is higher. Feeding behavior also varies among different species. For example, some eat alone, and others eat in groups.

A Complex System

Feeding on microorganisms that live in salty water demands a complex filtration system. The flamingo's bill is specially suited to this task. Its tongue and throat pump the water inside the bill as they ascend and descend, bringing water through the hornlike lamellae, which resemble whale baleen, to retain the food passing through them. Their tongues also have a depressed area, where the stones and sediments that come in with the water collect. The whole operation requires that the flamingo submerge its bill upside down. Because of the number of microorganisms they need to consume and the time it takes to filter them, flamingos usually spend many hours in the water. The risks involved in this activity are mitigated by the fact that flamingos do not eat alone, but rather in groups. Occasionally, there are instances of aggression, possibly because of territorial conflicts.

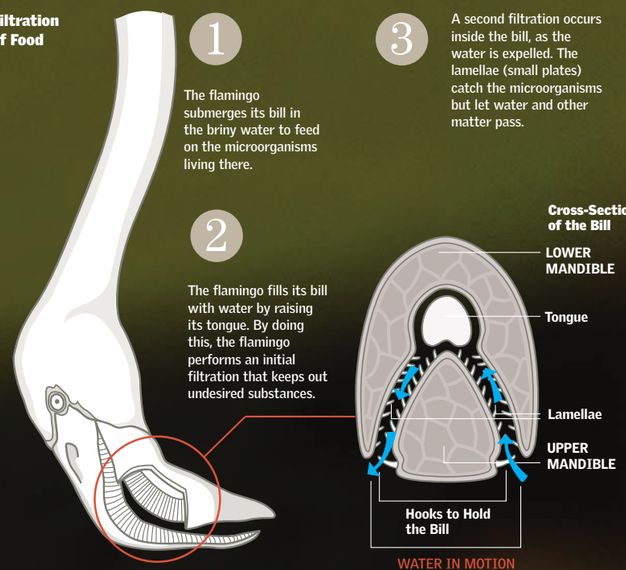


Filtration of Food

1 The flamingo submerges its bill in the briny water to feed on the microorganisms living there.

2 The flamingo fills its bill with water by raising its tongue. By doing this, the flamingo performs an initial filtration that keeps out undesired substances.

3 A second filtration occurs inside the bill, as the water is expelled. The lamellae (small plates) catch the microorganisms but let water and other matter pass.



Cross-Section of the Bill

From Parents to Children

Flamingos and pigeons feed their young a special "milk" that is produced in the crop and has a nutritional value similar to the milk of mammals. Both males and females produce it as soon as food is ingested so that the chick is not fed regurgitated food.

1. The flamingo produces milk in its crop only when it is not eating. A protein called prolactin participates in its preparation, just as with mammals.

2. It is given to the young through the bill. Easy to digest and nutritious, it is an excellent food.

3. This milk has high concentrations of the pigment that colors the feathers; that is why the bird's color changes to the characteristic pink while molting in adolescence.

Types of Diet

Birds expend a great deal of energy, and their diet must be suited to their high metabolic rates. They eat practically anything, although the diet of some birds is very specific. The same foods are not always available, which causes most birds to adjust their diets throughout the year.



THE HUMMINGBIRD'S TONGUE
Long channeled or tubular tongues suck the nectar and catch insects at the bottom of the corolla of a flower.

NECTAR
is a solution of sugar and water that flowers produce. It is very high in energy and easy to digest. In order to get it, a bird must have a long, sharp bill. In temperate regions, nectar is plentiful in the spring and summer, whereas in the tropical regions, it is available year round. Hummingbirds and honeycreepers are very fond of this juice.



SEEDS AND GRAINS
The high energy and protein content of seeds make them an ideal food for birds. The problem is that they are seasonal.



MEAT
Hunting and scavenging birds feed on meat. They rarely specialize in one type of prey, but the prey's size determines its selection.



FISH
The abundance of fish throughout the year makes them one of the favorite foods of marine birds. They have a high nutritional value.



LEAVES AND PLANTS
Few birds feed on leaves because they have low energy value. Birds that do have undergone adaptations that permit them to digest cellulose.



FRUIT
In the tropics, this diet is very common because fruits are available throughout the year. In temperate and cold regions, fruit can be found only in the summer. Fruit has a high energy value, and many birds eat it.



INSECTIVORES
Insects are rich in energy and proteins, and they are highly abundant. Thus, many bird species eat them. In cold regions, they can be found only in the summer.

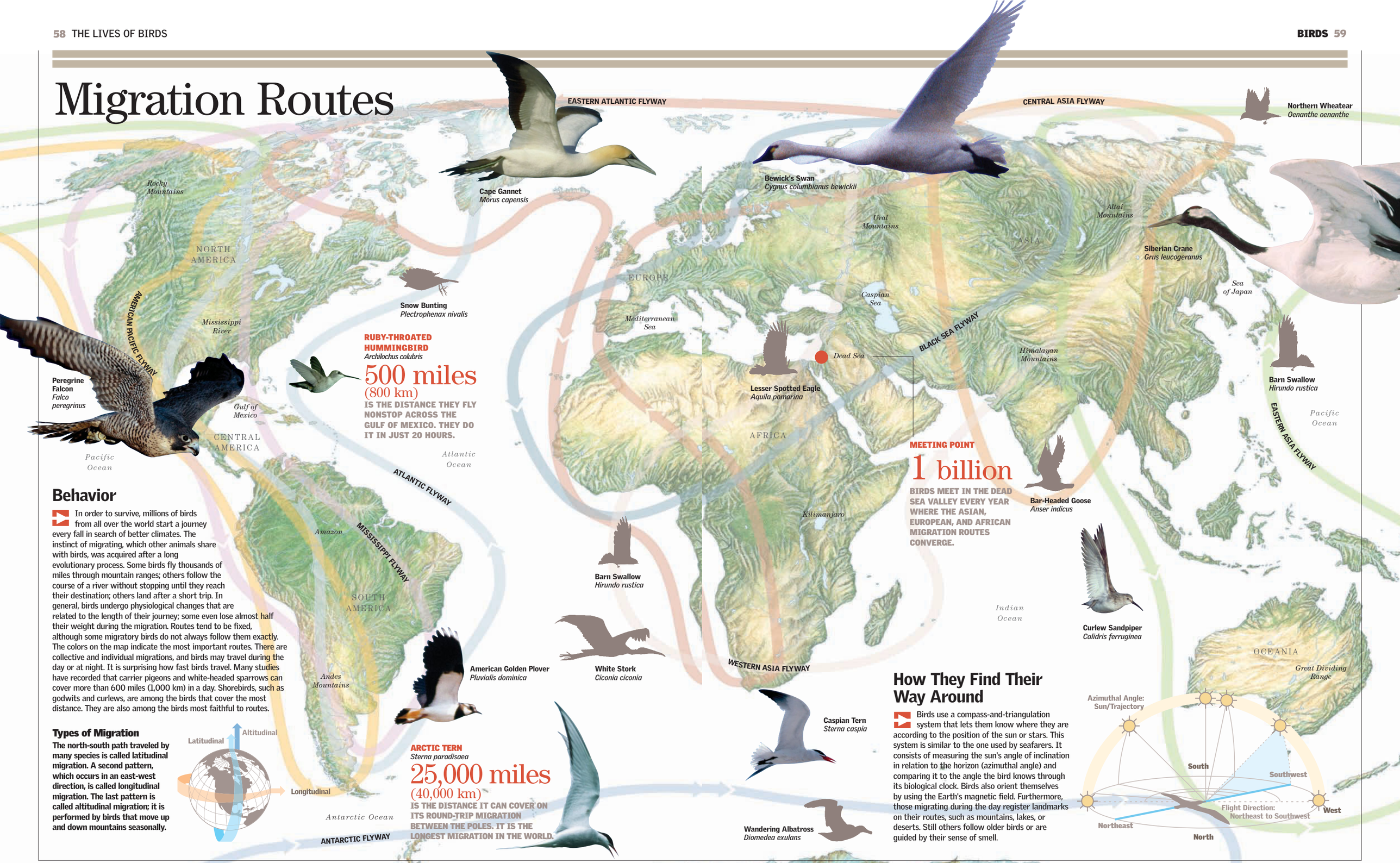
Strategies

Depending on the abundance of resources, the needs of the species, and the strategies for getting food, birds may eat alone or in groups. If food is scarce or widely scattered throughout a region, birds eat alone and defend their territory. On the other hand, if food is abundant, they prefer to eat within the safe confines of the group.

SOLITARY
Usually birds of prey, such as eagles and owls, hunt alone because food is scarce and is randomly distributed. Hunting alone has a drawback in that birds must also watch out for predators, which takes time away from hunting.

TOGETHER
This behavior is typical of ocean birds, such as pelicans and seagulls, and of aquatic birds, such as flamingos. When birds eat in groups, each group member can warn the others about possible dangers, which is beneficial.

Migration Routes



Behavior

In order to survive, millions of birds from all over the world start a journey every fall in search of better climates. The instinct of migrating, which other animals share with birds, was acquired after a long evolutionary process. Some birds fly thousands of miles through mountain ranges; others follow the course of a river without stopping until they reach their destination; others land after a short trip. In general, birds undergo physiological changes that are related to the length of their journey; some even lose almost half their weight during the migration. Routes tend to be fixed, although some migratory birds do not always follow them exactly. The colors on the map indicate the most important routes. There are collective and individual migrations, and birds may travel during the day or at night. It is surprising how fast birds travel. Many studies have recorded that carrier pigeons and white-headed sparrows can cover more than 600 miles (1,000 km) in a day. Shorebirds, such as godwits and curlews, are among the birds that cover the most distance. They are also among the birds most faithful to routes.

Types of Migration

The north-south path traveled by many species is called latitudinal migration. A second pattern, which occurs in an east-west direction, is called longitudinal migration. The last pattern is called altitudinal migration; it is performed by birds that move up and down mountains seasonally.

How They Find Their Way Around

Birds use a compass-and-triangulation system that lets them know where they are according to the position of the sun or stars. This system is similar to the one used by seafarers. It consists of measuring the sun's angle of inclination in relation to the horizon (azimuthal angle) and comparing it to the angle the bird knows through its biological clock. Birds also orient themselves by using the Earth's magnetic field. Furthermore, those migrating during the day register landmarks on their routes, such as mountains, lakes, or deserts. Still others follow older birds or are guided by their sense of smell.

Defense Strategies

Birds have many predators, including cats, snakes, crocodiles, and other birds. To defend themselves against these predators, birds use various strategies, the most common of which is camouflage. Some birds blend in with their surroundings and thus go unnoticed by their enemies. Chaparral birds, whose plumage colors and patterns make them difficult to discern when they are on the ground, use this strategy. Other birds take flight in the face of a threat. There are also those that keep still in the presence of unknown animals, feigning death, whereas others face an enemy and fight. It is not uncommon to see magpies, thrushes, and other birds chasing away strangers that get close to their nests.

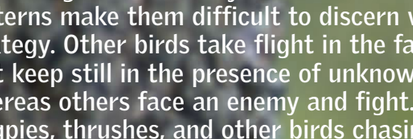
Individual Strategies

Among solitary birds, it is common to flee quickly if a stranger is present. Not all solitary birds react this way, though; some have developed specific techniques to defend themselves.

ESCAPE
In the presence of terrestrial predators, a bird's first reaction is to take flight. If the bird cannot fly, it looks for shelter or a hiding place.



EXPANSION
Owls spread out their wings to look bigger than they really are.



DISTRACTION
Little bustards shoot their excrement in the face of birds that prey on them. This distracts the predator and makes it possible to escape.



CAMOUFLAGE
is very common and is one of the most efficient defensive strategies. Many birds develop plumage to imitate the dominant colors and shapes of the environment where they live. When they notice the presence of a potential enemy, they stay motionless to avoid calling attention to themselves. There are a few notable cases, such as that of the tawny frogmouth *(Podargus strigoides)*, pictured above. Many partridges and terrestrial birds are experts at the art of blending in with the landscape; the rock ptarmigan, for example, has white plumage in the winter that becomes terra-cotta in the summer.

Collective Strategies

Birds that have group behaviors usually develop group strategies to protect themselves against predators. Being numerous is a guarantee that the species will go on. They also adopt other tactics as a group.

COLONIES
A great number of birds can defend themselves better from predators when in groups. For that reason they even form colonies with other bird species when raising their young.

FLOCK
In the presence of predators, birds form flocks that fly in a synchronized manner, which makes it hard for the predators to focus on any one individual.

ATTACKS AND COLLECTIVE AID
Many birds that live in groups have developed several hounding behaviors in the presence of potential enemies. They perform them to help an individual that is in danger or is unable to flee.

WARNING
They emit callings that warn the whole colony. The great majority of species have a specific and characteristic cry that is usually simple, brief, and very audible.
They often emit these warnings while adopting postures (such as stretching the neck or shaking the wings) that alone are enough to warn other individuals of the intruder's presence.

Defense of the Brood

Hatching and youth are times of critical vulnerability for birds. During these phases, they are forced to keep still because they are easy prey. For this reason, parents permanently watch over their nests, even attacking strangers if they get too close.



FEIGNING INJURY
A very widespread behavior is to pretend to be wounded or sick. This allows a bird to avoid being chosen as prey. This behavior is common among warblers, partridges, and pigeons.



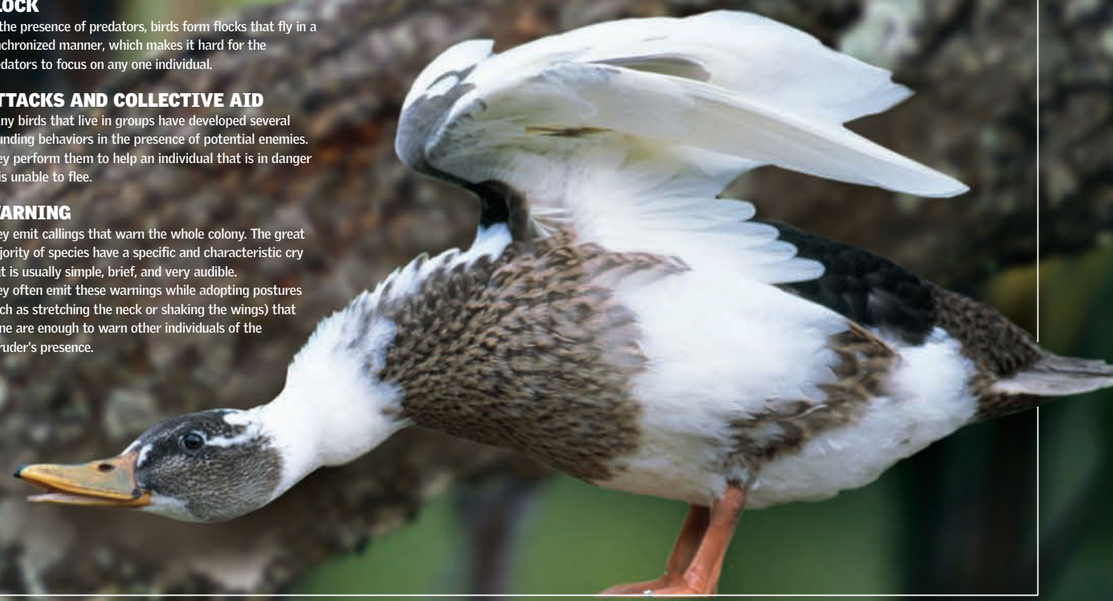
ATTACK
In other situations, birds adopt openly aggressive behaviors in the presence of intruders or predators. Magpies can even hound and chase away eagles if the latter threaten their brood. Such active defenses are more common among birds of prey.



PROTECTION
When a parent detects danger, it gets close to its young and covers them so that they are not alone. This behavior is common among tropical birds (tropical seabirds). Several species of curlews and sandpipers place their young between their legs, whereas grebes carry their chicks on their backs when swimming.



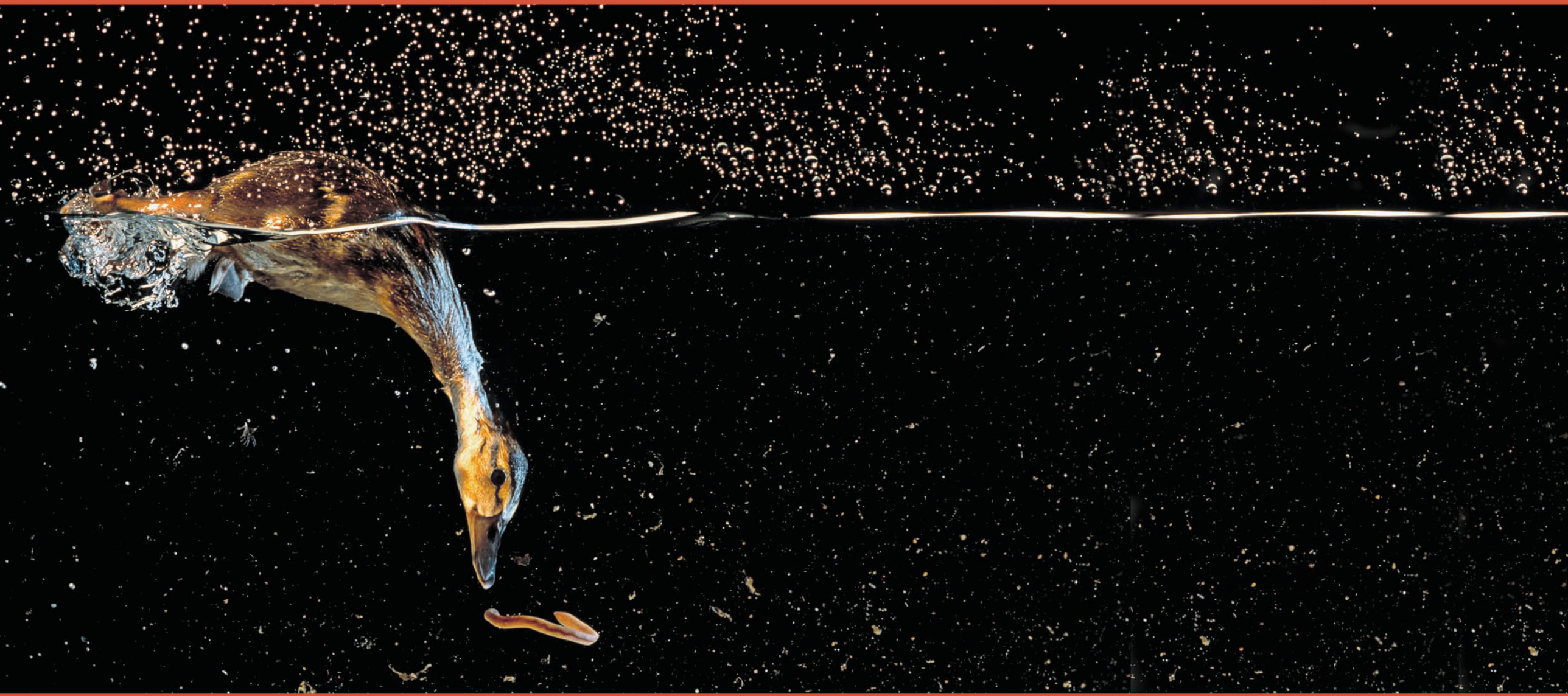
TO DEFEND ITSELF from the falcon's attack, a flock of starlings squeezes together in a dense formation. If they are near a tree, they do not hesitate to hide in it.



Diversity and Distribution

DUCK (Anatidae family)
A natural-born fisher, ducks feed on small snails and aquatic insect larvae.

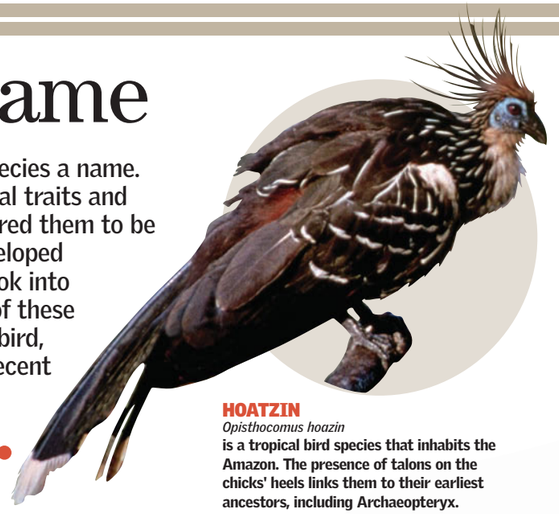
ONE BIRD, ONE NAME 64-65
WHERE THEY LIVE 66-67
NO FLYING ALLOWED 68-69
MARINE RESIDENTS 70-71
FRESHWATER BIRDS 72-73
ARMED TO HUNT 74-75
TALKATIVE AND COLORFUL 76-77
THE PERCHERS CLUB 78-79



The environment in which an organism usually lives is called its habitat. In their habitats, birds find food, the best places to build nests, and escape routes in case of danger. An almost universal pattern of distribution shows that more species live in the tropics than elsewhere. With evolution, birds with a common origin have diversified as they have begun to occupy different environments. This phenomenon is called adaptive radiation. We find ocean birds, which have undergone many changes in order to live near the sea, as well as birds that live in freshwater environments, in forests, and so on. Each type has acquired special physical traits and behaviors as a result of the adaptive process. ●

One Bird, One Name

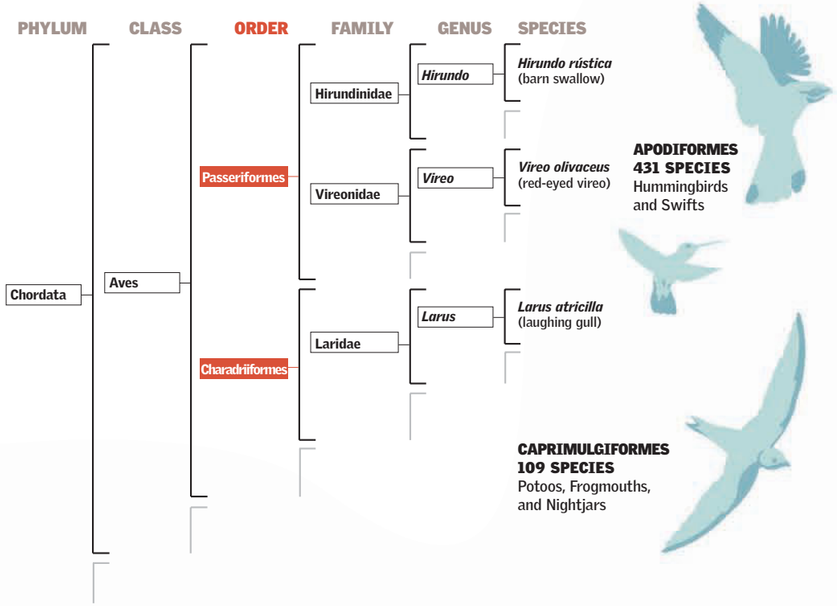
To learn more about different birds, we give each species a name. Ancient peoples grouped birds according to practical traits and mystical beliefs. They used birds as food or considered them to be bad omens or symbols of good luck. The people who developed scientific thought created a classification system that took into consideration the external form as well as the behavior of these vertebrates; hence, the denominations predator, wading bird, and songbird were developed, among others. The most recent system of classification, which is based on genetic and evolutionary criteria, has generated a hierarchical organization of names that is constantly being updated.



HOATZIN
Opisthocomus hoazin
is a tropical bird species that inhabits the Amazon. The presence of talons on the chicks' heels links them to their earliest ancestors, including Archaeopteryx.

What Is a Classification?

Since the early Renaissance in the 16th century, scientific classifications assigned compound names to birds, as well as to other living creatures. The first part stands for a genus and the second for a specific name. Thus, the rock (domestic) pigeon is called *Columba livia* in scientific terms. The discovery of new species in different parts of the world widened the array of birds so that compound names were no longer enough. The level of family was established to group genera of birds that share similar traits. In turn, bird families that share common traits were grouped into orders. These were then combined into a category called class. Classes include all current and extinct birds. Birds share a higher category in the hierarchy—the phylum—with fish, amphibians, reptiles, mammals, and vertebrates in general.



Diversity and the Environment

Living birds are distributed among a wide variety of habitats. They can be found in aquatic (freshwater or marine) and aero-terrestrial environments. Marine birds live on cliffs, on islands, or in mangrove swamps. They are excellent fishers, and they use seashores or crannies between rocks as refuges for nesting. In freshwater bodies, such as rivers and streams, ducks feed on plants and surface microorganisms. Muddy shores are rich in insects and mollusks, which are the favorite dishes of ibis. Herons, storks, and egrets spear fish with their sharp bills as they wade in water with their long legs without getting wet. Forests, jungles, mountain ranges, and wide plains form most of the world's aero-terrestrial environments. In jungles and forests, predatory birds hunt their prey, while trogons and parrots gorge on insects and fruit. Rocky peaks are the refuge of condors, which fly for hours in search of the remains of dead animals. Ostriches run over prairies and savannas.

FALCONIFORMES
295 SPECIES
Condors, Buzzards, Eagles, Vultures, and Falcons

COLIIFORMES
6 SPECIES
Mousebirds

PSITTACIFORMES
360 SPECIES
Parrots, Parakeets, Lories, Cockatoos, and Macaws

CUCULIFORMES
160 SPECIES
Cuckoos, Turacos, and Hoatzins

CORACIIFORMES
204 SPECIES
Common Kingfishers and Bee-Eaters

COLUMBIFORMES
317 SPECIES
Pigeons and Doves

PASSERIFORMES
5,400 SPECIES
Perching Birds and Songbirds

PICIFORMES
382 SPECIES
Woodpeckers, Toucans, and Puffbirds

APODIFORMES
431 SPECIES
Hummingbirds and Swifts

CHARADRIIFORMES
350 SPECIES
Seagulls, Lapwings, and Plovers

UPUPIFORMES
1 SPECIES
Hoopoe

STRIGIFORMES
174 SPECIES
Owls

TROGONIFORMES
39 SPECIES
Trogons and Quetzals

CAPRIMULGIFORMES
109 SPECIES
Potoos, Frogmouths, and Nightjars

CICONIIFORMES
120 SPECIES
Herons, Storks, Ibises, and Egrets

GRUIFORMES
190 SPECIES
Moorhens, Cranes, and Coots

STRUTHIONIFORMES
1 SPECIES
Ostrich

SPHENISCIFORMES
18 SPECIES
Penguins

GAVIIFORMES
5 SPECIES
Loons (diving birds)

PROCELLARIIFORMES
110 SPECIES
Albatrosses, Petrels, and Fulmars

PODICIPEDIFORMES
21 SPECIES
Grebes

ANSERIFORMES
150 SPECIES
Ducks, Geese, and Swans

PELECANIFORMES
62 SPECIES
Pelicans, Boobies, and Cormorants

PHOENICOPTERIFORMES
1 SPECIES
Flamingos

GALLIFORMES
274 SPECIES
Chickens, Turkeys, Quails, Pheasants, and Partridges

TINAMIFORMES
47 SPECIES
Tinamous

CASUARIIFORMES
4 SPECIES
Cassowaries and Emus

APTERYGIFORMES
4 SPECIES
Kiwis

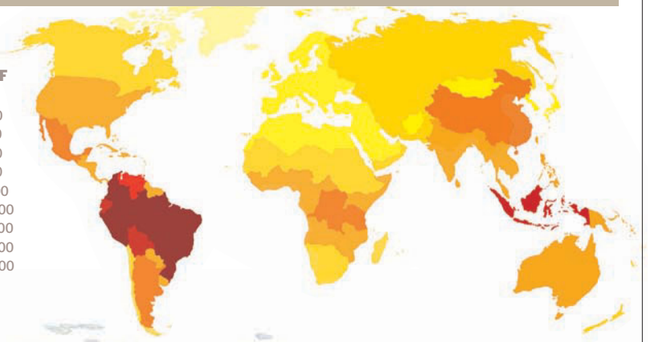
RHEIFORMES
2 SPECIES
Rheas

Where They Live

With their mobility, birds have conquered all areas of the Earth. Despite this characteristic, there are few cosmopolitan species—that is, most birds have specific habitats determined by climate and geographic features. Count de Buffon in the 18th century was the first person to notice that living beings are not distributed homogeneously. By analyzing how animals were dispersed on the planet, he realized that different places had different types of fauna. After the work of naturalist Charles Darwin and ornithologist Philip Sclater, it became clear that organisms are situated in specific biogeographic regions.

Biodiversity in the World

The most diverse regions in terms of bird populations are the tropics because of the favorable conditions of abundant food and warm climate found in them. Temperate regions, however, with their seasons, are destinations for migrating birds from tropical and polar regions. Cold regions, on the other hand, have little diversity but are rich in population density. The rule is that diversity of life-forms happens in places where the environment requires less severe adaptations.





PUFFIN
Fratercula artica

NORTH AMERICA

Atlantic Ocean

Pacific Ocean

CENTRAL AMERICA

SOUTH AMERICA

EUROPA

ASIA

AFRICA

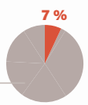
Indian Ocean

Pacific Ocean

OCEANIA

Nearctic

732 Species
62 Families



CHARACTERISTICS

- Climatic barrier of cold weather and oceanic isolation
- Most migrating species
- Many insectivorous and aquatic birds
- Affinity with Palearctic

Endemic Avifauna: **loons and puffins**

Palearctic

937 Species
73 families



CHARACTERISTICS

- Climatic barrier of cold weather and oceanic isolation
- Low diversity of species
- Most are migratory species
- Many insectivorous and aquatic birds

Endemic Avifauna: **wood grouse, waxwings, flycatchers, cranes**

Because of similar climatic conditions, many authors merge the Palearctic and Neoarctic regions, calling the combined region Holarctica.

Oceania

187 Species
15 Families

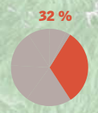
CHARACTERISTICS

- Large area and number of climates
- Gliders, divers, and swimmers
- Abundance of fish-eating species
- Many cosmopolitan species

Endemic Avifauna: **albatrosses, sheathbills, petrels, penguins, and seagulls**

Neotropic

3,370 Species
86 Families



CHARACTERISTICS

- Long-lasting geographic isolation
- Many primitive species
- Great numbers of frugivores

Endemic Avifauna: **rheas, tinamous, oilbirds, hoatzins, cotingas, and stripe-backed antbirds**

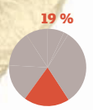
This region undoubtedly has the greatest diversity of birds. The variety in the South American tropics, the most important tropical zone in the world, is one and a half times greater than that of tropical Africa. With more than 1,700 species, Colombia, Brazil, and Peru are the countries with the greatest diversity of avifauna. Even Ecuador, a much smaller country, has more than 1,500 species.

HOATZIN
Opisthocomus hoazin



Afrotropic

1,950 Species
73 families



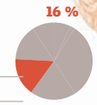
CHARACTERISTICS

- Maritime and desert isolation
- Great number of Passeriformes
- Many flightless birds

Endemic Avifauna: **ostriches, turacos, cuckoos**

Indomalaya

1,700 Species
66 families



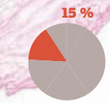
CHARACTERISTICS

- Affinities with the Afrotropical zone
- Tropical birds
- Many frugivores

Endemic Avifauna: **ioras, pittas, swifts**

Australasia

1,590 Species
64 families



CHARACTERISTICS

- Long isolation
- Many flightless and primitive birds

Endemic Avifauna: **emus, kiwis, cockatoos, birds of paradise**



RUBY-THROATED HUMMINGBIRD
Archilochus colubris



OSTRICH
Struthio camelus

Adaptations According to the Environment

Birds are found in all habitats of the world, although most live in tropical regions. Their ability to adapt, however, is remarkable. From jungles to deserts, from mountains to coasts, and even on the sea, birds have succeeded in acclimating themselves. They have undergone a highly varied array of changes in form and behavior. Emperor penguins not only nest in Antarctica but they also incubate their eggs between their feet for 62 to 66 days. The male Lichtenstein's sandgrouse has developed a sponge of feathers to bring water to its chicks, and hummingbirds have special wings that enable them to make all sorts of maneuvers.

COUNTRIES WITH THE MOST SPECIES

More than 1,500

Colombia
Brazil
Peru
Ecuador
Indonesia

More than 1,000

Bolivia
Venezuela
China
India
Mexico
Democratic Republic of the Congo
Tanzania
Kenya
Argentina

No Flying Allowed

A few birds have lost their ability to fly. Their main characteristic is wing loss or reduction, although for some a remarkable size may be the cause of their inability to fly. Such birds weigh more than 39 pounds (18 kg). This is the case with runners (ostriches, cassowaries, emus, rheas, kiwis), extremely fast birds that live in remote areas of New Zealand, and swimmers, such as penguins, that have developed extraordinary aquatic abilities.

AFRICAN OSTRICH
A single species inhabits eastern and southern Africa. Adults reach a height of 9 feet (2.75 m) and a weight of 330 pounds (150 kg).

The Ratites

Running birds belong to the group of the ratites (*rata* = raft, an allusion to the flat sternum). The front limbs either are atrophied or have functions unrelated to flying. The hind limbs have very strong muscles as well as sturdy, vigorous bones. Another difference is found in the sternum. It is a flat bone without a keel, which flying and swimming birds possess. Wild ratites can be found only in the Southern Hemisphere. The Tinamidae, native to Central and South America, belong to this group (partridges).



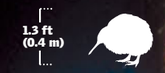
STRUTHIONIFORMES
The ostrich is the only species in this group. It uses its wings for balance when running fast. It has only two toes on each foot. The adult male can weigh up to 330 pounds (150 kg).



RHEIFORMES
Rhea are common in South American countries, such as Argentina. They look like ostriches but are smaller. Their three-toed feet allow them to chase prey. Their long necks and excellent eyesight make them skillful hunters.



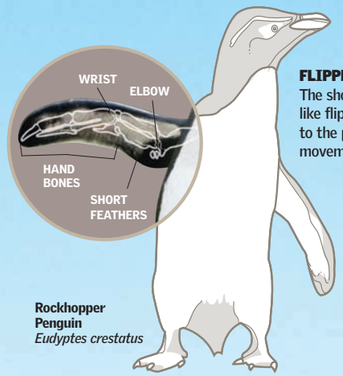
CASUARIIFORMES
Agile runners and swimmers. The colors on their necks and heads are distinctive. A bony hoof protects them from vegetation when they run. They have long, sharp talons on their feet.



APTERYGIFORMES
Kiwis. These birds have four toes on each foot, and their feathers look like fur because they do not have barbules. They normally use their keen sense of smell to find insects at night. They lay only one large egg.

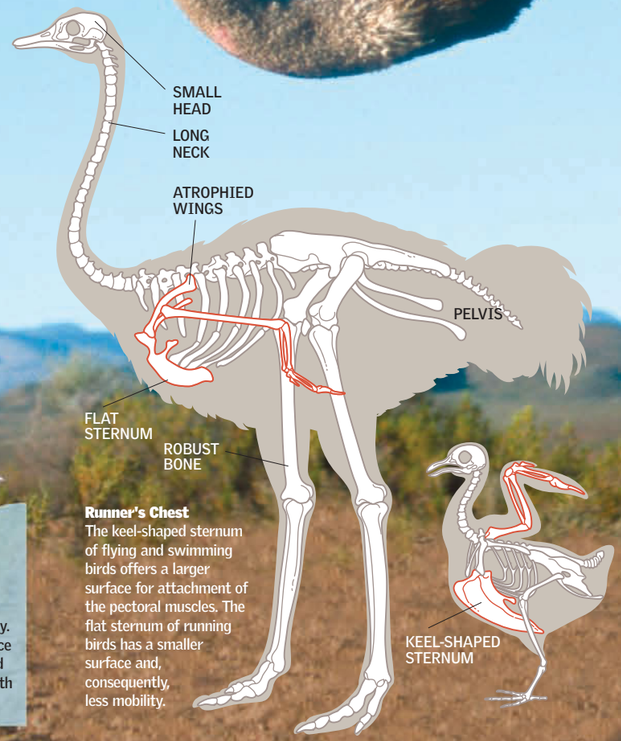
Super Swimmers

Penguins' bodies are covered with three layers of small, overlapping feathers. A penguin has small limbs and a hydrodynamic shape that helps it swim with agility and speed. Dense, waterproof plumage and a layer of fat insulate the bird from the low temperatures of the regions where it lives. Since its bones are rigid and compact, it is able to submerge itself easily. This adaptation distinguishes it from flying birds, whose bones are light and hollow.



FLIPPERS
The short, compact wings look like flippers. They are essential to the penguin's underwater movements.

Rockhopper Penguin
Eudyptes crestatus



Runner's Chest
The keel-shaped sternum of flying and swimming birds offers a larger surface for attachment of the pectoral muscles. The flat sternum of running birds has a smaller surface and, consequently, less mobility.

PENGUIN HEADING TO THE WATER



HUNTING
The wings work like flippers. The foot—with four joined toes pointing backward—and the tail steer the direction of the dive.

BREATHING
When looking for food, penguins need to leave the water and take a breath between plunges.

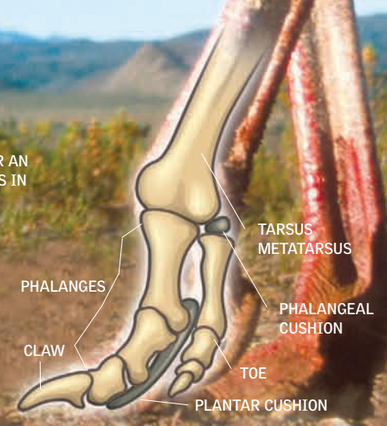
RELAXING
When resting in the water, they move slowly. They float on the surface with their heads up and balance their bodies with their wings and feet.

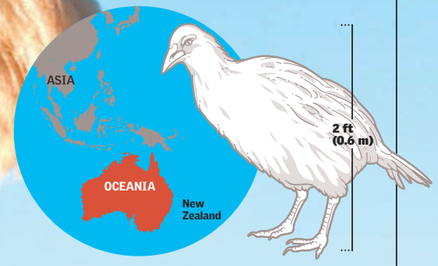
Running and Kicking

Ostriches usually run to escape from predators or to hunt small lizards and rodents. In both cases, because of their strong legs, they are able to reach a speed of 45 miles per hour (72 km/h) and to maintain it for 20 minutes. When running is not enough to protect the bird, kicking is a valid recourse that discourages the attacker. In courtship displays, forceful stamping is also used to win over females.

18
VERTEBRAE
THE NUMBER AN OSTRICH HAS IN ITS NECK

ON TWO TOES
With just two toes, the contact surface between the foot and the ground is relatively small. This is an advantage when moving on land.





GREATER DIVERSITY
In many cases, running birds can be found in many parts of the world because of human intervention. The area where flightless birds have diversified the most is Oceania, due to continental isolation.

Other Walkers

More than 260 species belong to the order Galliformes, which includes chickens, turkeys, and pheasants. The birds in this group have keels, and they perform abrupt and fast flights, but only in extreme situations. Their feet are suitable for walking, running, and scratching the ground. This group includes the birds that human beings use the most. In general, males are in charge of incubating and raising the young.

FLYING WITH LITTLE GRACE

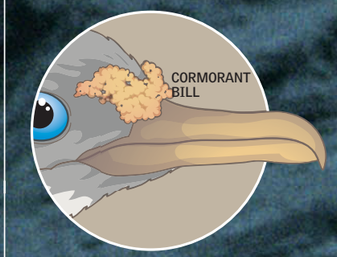


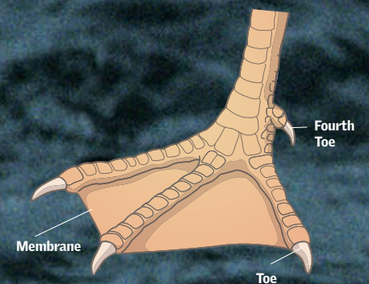
Marine Residents

Of the more than 10,000 bird species inhabiting the Earth, only about 300 have managed to adapt to marine life. To survive at sea, they have undergone multiple adaptations. For instance, marine birds have a more efficient excretory system than that of other species, including a specific gland that helps them eliminate excess salt. Most marine birds live on the coasts and have mixed behaviors; others are more aquatic than aerial. A few—such as albatrosses, petrels, and shearwaters—can fly for months at a time, landing only to raise their chicks. They are called pelagic birds.

Adaptations

Marine birds are well prepared to live on water, especially those that fish out at sea. The tips of their bills are hook-shaped, and their feet have webbed membranes between the toes. They also have an admirable ability to float. The saline water is not a problem; these birds can even drink it. In some pelagic birds, sense of smell plays an important role in enabling them to detect the oil of the fish in the water to find schools of fish. They also use their sense of smell to find their nests in colonies.





TOTIPALMATE FEET
A characteristic of many marine birds. The posterior toe (hallux) is joined to the other toes by a membrane. It creates more surface area, and therefore more push, as the bird swims. Birds with this kind of foot walk clumsily.

VARIOUS MARINE BIRDS

IMPERIAL SHAG
Phalocrocorax atriceps
This great coastal diver has solid bones and strong swimming feet. It does not oil its plumage so that it can better submerge.



BROWN PELICAN
Pelecanus occidentalis
It stays on the shore. It uses its crop as a fishing net while it swims.



HERRING GULL
Larus argentatus
A voracious fisher and great glider. There are many species, some truly cosmopolitan.



CAPE GANNET
Morus capensis
Skillful spearfishers. They live in colonies in Africa. To help cool themselves, they have a strip of naked skin on their throats.



148 feet (45 m)

IS THE MAXIMUM DEPTH THEY REACH. COMMON LOONS—BIRDS INDIGENOUS TO NORTH AMERICA THAT SPEND THE WINTER AT SEA—HAVE BEEN RECORDED TO REACH THIS DEPTH. ALMOST UNABLE TO WALK, COMMON LOONS ARE EXCELLENT SWIMMERS AND DIVERS. THEY NEST AT INLAND LAKES DURING THE SUMMER.



COMMON LOON
Gavia immer

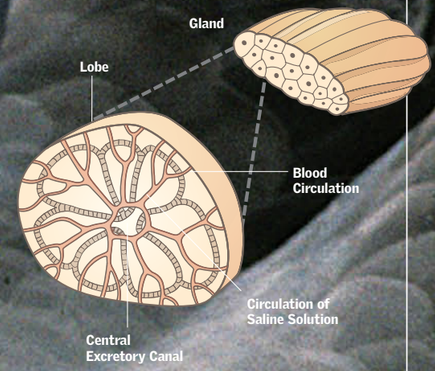
TUBULAR NOSTRILS
Albatrosses have one on each side of their bills. On petrels and shearwaters, the tubular nostrils have merged on top of the bill, forming a single nasal tube.

HOOK-SHAPED TIP
Prevents the fish from sliding and falling away, once caught

BILL
It is composed of several hard plates.

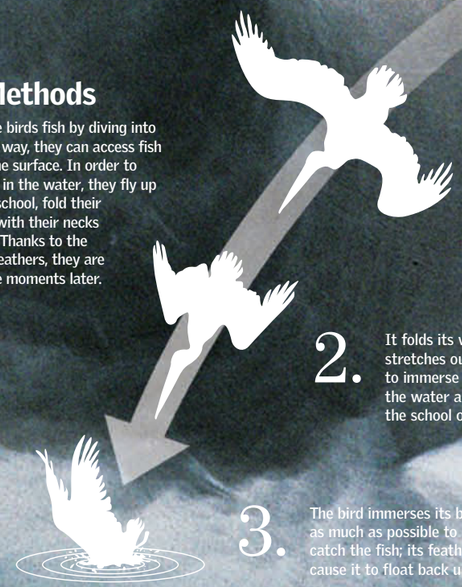
Salt Gland

Living in the ocean requires a few adaptations. The most notable one is the salt gland, which eliminates excess salt from the bloodstream. This way, marine birds can even drink salt water without suffering dehydration, as would be the case with humans. This gland is very efficient: it has been observed that 20 to 30 minutes after drinking a saline solution with concentrations similar to that of the ocean (4 percent), birds eliminate another solution (through the nostrils) with 5 percent salt, in the shape of water drops.



Fishing Methods

Many marine birds fish by diving into the sea. This way, they can access fish that swim below the surface. In order to reach deeper levels in the water, they fly up several feet, spy a school, fold their wings, and plunge with their necks stretched forward. Thanks to the buoyancy of their feathers, they are back on the surface moments later.



DIVE FISHING

1. The bird dives to gain speed.

2. It folds its wings and stretches out its neck to immerse itself in the water and reach the school of fish.

3. The bird immerses its body as much as possible to catch the fish; its feathers cause it to float back up.

Freshwater Birds

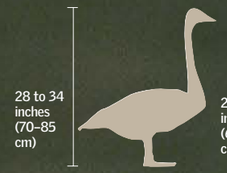
This group includes birds that vary greatly—from common kingfishers to ducks to storks—and covers a wide spectrum. Freshwater birds live in rivers, lakes, and ponds for at least part of the year and are perfectly adapted to aquatic life. Some are excellent swimmers, whereas others are great divers. An important group wades in watercourses with long legs as they fish. Freshwater birds have a varied diet and are mostly omnivorous.

Ducks and Distant Cousins

The order Anseriformes includes birds that are very familiar to humans: ducks, geese, and swans, for example. They have short, webbed feet and wide, flat bills lined with lamellae (false teeth) that enable them to filter their food, catch fish, and scrape the beds of rivers and ponds. Most are omnivorous and aquatic (either staying on the surface or diving), although some species spend more time on land. They are widely distributed, and the plumage of males becomes very colorful during the courtship season.



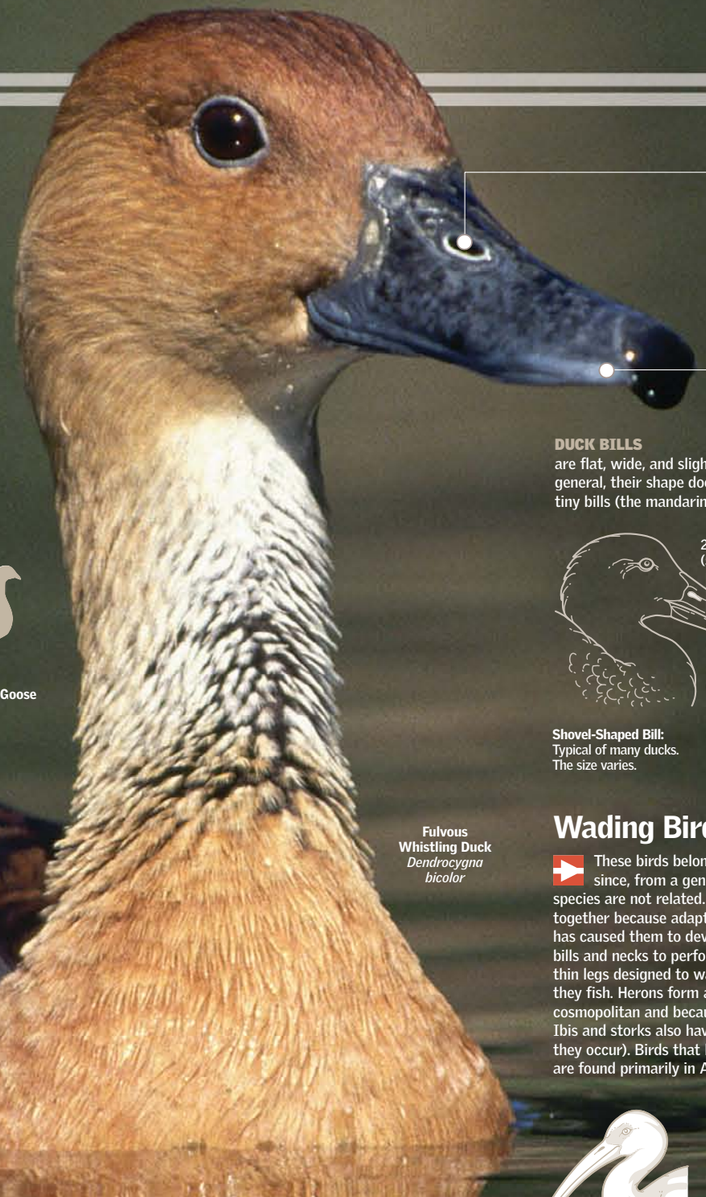
Muscovy Duck
Cairina moschata



Black-Necked Swan
Cygnus melancoryphus

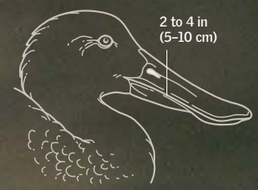


White-Fronted Goose
Anser albifrons

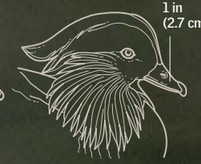


Fulvous Whistling Duck
Dendrocygna bicolor

DUCK BILLS
are flat, wide, and slightly depressed toward the middle. In general, their shape does not vary, but there are species with tiny bills (the mandarin duck, for example).



Shovel-Shaped Bill:
Typical of many ducks. The size varies.



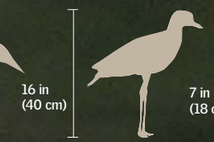
Mandarin Duck Bill:
One of the smallest-billed species.

Divers and Other Fishers

Diving birds belong to the family Podicipediformes. They feed on small fish and aquatic insects. They are very clumsy on the ground. In the Coraciiformes order, common kingfishers and other similar birds find their prey by closely watching the water. When one of these birds notices a small fish, it spears it, catching it with its bill. In the order Charadriiformes, curlews wander around the edges of ponds in search of food. Their long legs keep their bodies out of the water. They are not swimmers.



GREBE
Podiceps sp.



STONE CURLEW
Burhinus oedicnemus



COMMON KINGFISHER
(also known as European Kingfisher)
Alcedo attlis



THE BILL OF AN IBIS
is long and thin, ideal to stick in the mud to look for food.

Wading Birds

These birds belong to an artificial order since, from a genetic perspective, the species are not related. They are grouped together because adaptation to the same habitat has caused them to develop similar shapes: long bills and necks to perform skillful movements and thin legs designed to wade across the water as they fish. Herons form a special group because they are cosmopolitan and because they have powder down feathers. Ibis and storks also have a wide distribution (area in which they occur). Birds that have spoon- and hammer-shaped bills are found primarily in Africa.



IBIS (*Ibis* sp.): Some filtrate, and others fish.



STORK (*Ciconia* sp.): It fishes with its long bill.



SHOEBILL (*Balae-niceps rex*): It eats among floating sedges.



HERON (*Egretta* sp.): It fishes with its sharp bill.



COMMON SPOONBILL (*Platalea leucorodia*): It eats several types of aquatic animals.

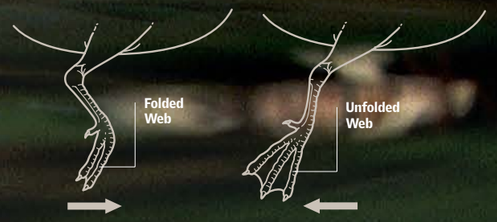


HAMMERKOP (*Scopus umbretta*): It fishes and hunts small animals.

White Ibis
Edocimus albus

THE LEGS OF AN IBIS
keep the bird above the water but close enough to fish. Ibis also stir up the beds of lakes and ponds.

HOW THEY USE THEIR FEET TO SWIM
A duck moves its feet in two ways. To advance, it spreads out its toes and uses its webbed feet to row. It closes the toes to bring the foot forward again. If the bird wants to turn, only one foot pushes to the side.



A DUCK'S DIET



1. It swims on the surface, looking for food underneath the water.
2. It sticks its head into the water, abruptly pushes back its feet, and turns its neck downward.
3. It floats face-down and pokes the bottom with its bill.

Armed to Hunt

Birds of prey are hunters and are carnivorous by nature. They are perfectly equipped to eat living animals. Their eyesight is three times sharper than that of human beings; their ears are designed to determine the precise status of their prey; they have strong, sharp talons; and they can kill a small mammal with the pressure of their talons alone. Their hook-shaped bills can kill prey by tearing its neck with a single peck. Eagles, falcons, vultures, and owls are examples of birds of prey. Birds of prey can be diurnal or nocturnal, and they are always on the lookout.

Diurnal and Nocturnal

Eagles, falcons, and vultures are diurnal birds of prey, whereas owls are nocturnal—that is, they are active during the night. These two groups are not closely related. These birds' main prey includes small mammals, reptiles, and insects. Once they locate the victim, they glide toward it. Nocturnal birds of prey are specially adapted: their eyesight is highly developed, their eyes are oriented forward, and their hearing is sharp. The feathers on their wings are arranged in such a way that they make no noise when the bird is flying. In order to protect themselves while sleeping during the day, they have dull plumage, which helps them blend in with their surroundings.



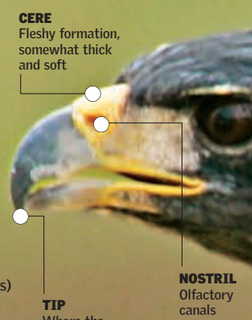
EURASIAN EAGLE OWL
Bubo bubo
Its ears are asymmetrical and can determine the location of prey with great precision.



BALD EAGLE
Haliaeetus leucocephalus
It has a visual field of 220 degrees and a bifocal vision of 50 degrees.

Bills

The bills of birds of prey are hook-shaped. Some birds of prey have a tooth that works like a knife, allowing them to kill their prey, tear its skin and muscle tissues, and get to the food easily. The structure and shape of the bills of birds of prey changes depending on the species. Scavengers (for example, vultures and condors) have weaker bills because the tissues of animals in decomposition are softer. Other species, such as falcons, catch prey with their talons and use their bills to finish it off with a violent stab to the neck, breaking its spine.





BALD EAGLE
Its hook-shaped bill is common to many birds of prey.



SPARROW HAWK
Its thin bill enables it to take snails out of their shells.



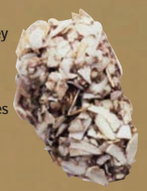
FALCON
It can break the spine of its prey with its upper bill.



GOSHAWK
Its strong bill can catch prey as large as hares.

Zone-Tailed Hawk
Buteo albonotatus

OWL PELLETS
Owls produce pellets. They swallow their prey whole and regurgitate the indigestible substances. The study of pellets makes it possible to determine the fauna of small areas with great precision.



5 miles (8 km)
IS THE DISTANCE FROM WHICH A FALCON CAN PERCEIVE A PIGEON.

Feet

Most birds of prey catch and kill their prey with their talons and tear away the meat with their bills. For this reason, birds' feet constitute one of the morphological characteristics of a species. The toes end in strong, sharp nails that the bird uses as pincers to catch its prey in flight. The osprey also has thorns on the soles of its feet, which help it to catch fish.



GRIFFON VULTURE
Its long toes do not have a good grasp.



FISHING EAGLE
Its toes have rough scales that look like thorns, which help it to catch fish.



GOSHAWK
It has calluses at the tips of its toes.

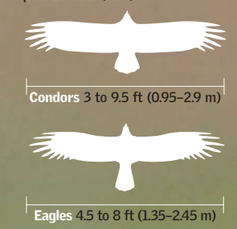


SPARROW HAWK
Its feet have tarsi and short, strong toes.



DIMENSIONS

The wings of birds of prey are adapted to suit their flying requirements. They can measure up to 10 feet (3 m).

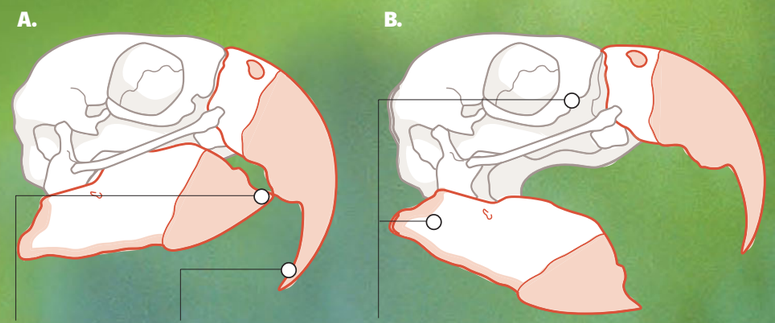


Talkative and Colorful

Parrots form a very attractive bird group with a great capacity for learning. This group comprises cockatoos, macaws, and parakeets. They share physical characteristics, such as a big head, a short neck, a strong hook-shaped bill, and climbing feet. They have plumage in many colors. Toucans and woodpeckers share with parrots the colors of their feathers and their type of feet. Toucans have a wider, thicker bill, but it is light. Woodpeckers are climbing birds with a strong, straight bill, a tail of stiff feathers, and a distinctive crest. They form numerous groups, and most nest in trees.

Eating, Climbing, and Chattering

Parrots use their bills to feed and to move about tree branches; they use their bills as an extension of their feet to give them support when they climb. Parrots also have a curved profile, a pointed tip on their upper mandible, and sharp edges on their lower one. These adaptations are practical when it comes to cutting and breaking fruits and seeds. The largest species like fruits with shells, such as walnuts, hazelnuts, and peanuts. The smaller ones prefer nectar and pollen, which they obtain with the help of brush-shaped bristles on their tongues. Their ability to imitate the human voice has made them very popular. However, they are far from being able to produce language. In reality, they are merely good imitators: they use their excellent memory to imitate sounds. They do this when they are hungry or when they detect the presence of unknown people.



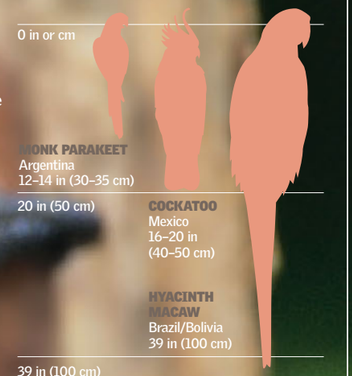
UPPER PART OF THE BILL
It is where the most pressure is exerted and fruits are torn open.

HOOK
Sharp projection used to open seeds

UPPER AND LOWER MANDIBLES
The hook-shaped bill is flexible; the mandibles are joined to the skull by hinges. At its base, the upper mandible has a fleshy protuberance called a cere.

WINGS
Usually they are short and rounded, suitable for flying among branches.

COMPARISON
American parrots vary in size, from the monk parakeet *(Myopsitta monachus)*, which is 12 inches (30 cm) tall, to the hyacinth macaw *(Anodorhynchus hyacinthiinus)* from South America, which is 33 inches (1 m) tall.



The Feet

are referred to as zygodactyl. This means that two toes project forward and two project backward. Parrots appear to strut because their feet have a tibiotarsus that is shorter than that of other birds.



FEET LIKE HANDS
In some species, the left foot is longer. They use it to grab fruits and tear them with their bills.

NOSTRILS
They are located at the base of the bill's upper portion.

HOOKED BILL

FEATHERS AND COLORS

They have tough and lustrous plumage. An abundance of green feathers helps them to hide among the leaves. In South America, the array of colors includes hues of blue, yellow, and red.



WOODPECKERS
hollow out tree trunks with pecks in order to build a nest and to feed on insects that eat wood.

THE HABITAT OF WOODPECKERS

They live in the woods and can often be heard there. Their adaptations to arboreal life are demonstrated by their strong, thick bills and their stiff tails, which they use for support, together with their feet. They use their hearing to locate tree-boring insects; they then peck the wood incessantly until they find them.



TOUCANS
Their big bills have serrated edges that suit their diet of fruit. They live in the South American jungles.

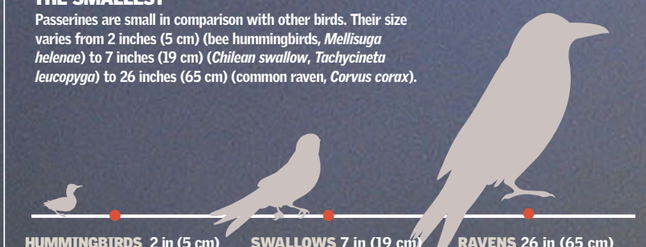
QUETZALS
They belong to the family Trogonidae. They have feet adapted to arboreal life. Males have brilliant plumage and long, attractive tails.

The Perchers Club

Passerines—or Passeriformes, the scientific name—form the widest and most diverse order of birds. What distinguishes them? Their feet are suited for perching and, therefore, for living among trees, although they can also stroll on the ground and through the brush. They inhabit terrestrial environments all over the world, from deserts to groves. Their complex sounds and songs originate from a very well-developed syrinx. Their chicks are nidicolous—that is, naked and blind at birth. In their youth, they are agile and vivacious, with very attractive, abundant, and colorful plumage.

THE SMALLEST

Passerines are small in comparison with other birds. Their size varies from 2 inches (5 cm) (bee hummingbirds, *Mellisuga helenae*) to 7 inches (19 cm) (*Chilean swallow, Tachycineta leucopyga*) to 26 inches (65 cm) (common raven, *Corvus corax*).



HUMMINGBIRDS 2 in (5 cm)
They get so much energy from nectar that they can double their body weight by eating. However, they use this energy up during their frantic flights.

SWALLOWS 7 in (19 cm)
Swallows have great agility and skill. These popular migratory birds have bodies suited for long trips.

RAVENS 26 in (65 cm)
They eat everything: fruits, insects, reptiles, small mammals, and birds. They are skillful robbers of all kinds of food.

PASSERIFORMES BIRDS

Passerines have been classified into 79 families, with more than 5,400 different species.



50%

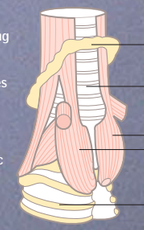
THE PERCENTAGE OF BIRDS THAT ARE INCLUDED IN THE ORDER PASSERIFORMES

SINGER

This blue-and-white swallow *(Notiochelidon cyanoleuca)* intones its pleasant and trilling chant while it flies or when it alights. Larks, goldfinches, canaries, and other passerines delight us with their trills and sounds.

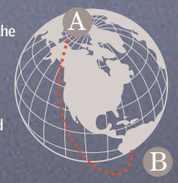
HARD, SHORT BILL
The bill of a swallow is very short and tough. The swallow can use it to catch insects in flight.

SYRINX
This sound-producing organ is located at the end of the trachea. The muscles in the syrinx move the bronchial walls, which, as the air passes through, produce the melodic sounds that characterize songbirds.



LIVING AT THE EXTREMES

They range from one hemisphere to the other. They raise their chicks in the north and fly to the south to spend winter there. They fly all the way to Tierra del Fuego. Their sense of direction is remarkable. They can find and reuse their nests after returning from a migration.





BARN SWALLOW
(*Hirundo rustica*)
Barn swallows spend most of their time traveling to temperate zones.

A In the summer, during the reproductive season, they live in the Northern Hemisphere on the American continent. In general, neotropical migratory birds are those that reproduce above the Tropic of Cancer.

B When winter arrives in the Northern Hemisphere, they perform a mass migration to the south, occupying the Caribbean and South America. The barn swallow travels 14,000 miles (22,000 km) during its migratory trip from the United States to southern Argentina.

PERCHING FOOT

Three toes project forward, and the well-developed hallux projects backward. This type of foot allows the bird to hold on tightly to branches.

Family Album

Four basic groups have been established to facilitate the study of families: passerines with wide bills; ovenbirds, whose plumage is dull and brown (ovenbirds are noted for the great care they take in building nests); lyrebirds, whose tails have two external feathers that are longer than the others; and songbirds, with their elaborate and pleasant singing. Songbirds form the most numerous and varied group; it includes swallows, goldfinches, canaries, vireos, and ravens.



LYREBIRDS

There are only two species of these Passeriformes, and they are found only in Australia. They are very melodic and are excellent imitators of other birds. They can even imitate the sound of inanimate objects, such as horses' hooves.



WIDE BILLS

They are native to Africa and Asia and inhabit tropical zones with dense vegetation. They eat insects and fruits. They produce nonvocal sounds with the flapping of their wings. They do this during courtship, and the sound can be heard 200 feet (60 m) away.



OVENBIRDS AND THEIR RELATIVES

Their nests are completely covered structures, similar to ovens. Other members of this family build nests with leaves and straw, weaving interesting baskets. Still others dig tunnels in the ground.

Humans and Birds

ROBIN CHICKS *(Erithacus rubecula)*
Although their natural habitats are humid groves, they usually seek shelter in cities, always close to water.

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Human beings have long taken an interest in studying these high-flying creatures. They have served as a source of food and have sometimes been used as indicators of the arrival of rain, storms, or the presence of common enemies, such as dangerous reptiles. Evidence of ancient peoples' veneration of birds can be found in documents, paintings, and reliefs. The Egyptians were the first to domesticate pigeons. Today several species brighten up homes with their colors and cooing. Other types of birds, such as sparrows and swallows, live with us in cities. The destruction of bird habitats, through the excessive exploitation of natural resources, is one of the main causes of bird extinctions. ●

Birds and Human Culture

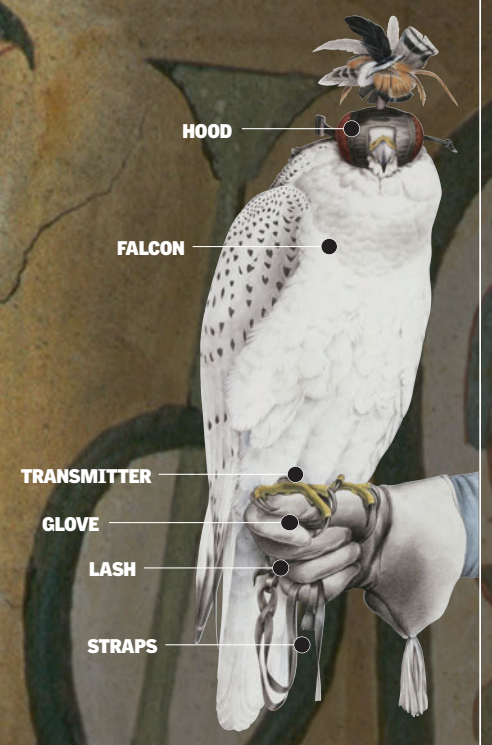
Birds fly, sing, dance, and have showy plumage. Because of these qualities, they have fascinated human beings throughout history. Some species, such as eagles, have played an important role in world literature because of their aggressiveness and beauty. Some birds have also been assigned symbolic meanings: doves, which currently represent peace, are one example. Human beings have also been able to make use of birds. In the past, they were often used by sailors to find land, and in other cases they were trained to hunt.

Falconry

This practice originated in Asia, in the homeland of the nomadic Mongols—descendants of Genghis Khan—where, to this day, it is commonly used as a form of subsistence by part of the population. It consists of using birds of prey (mainly falcons) to hunt. Trained birds are typically carried, hooded, and perched on their masters' arms. When released, they fly at high altitudes looking for prey, and then dive toward the ground to hunt it. They carry the prey back to their masters, who reward them with food. The basic training process takes a little over a month and a half.



ELEMENTS
Birds and masters wear specific clothes. In addition to gloves, hoods, and straps, radio transmitters are now also used to locate the birds as they fly.



Rites and Beliefs

Birds have long enjoyed a prominent place in religion—first as totems and then as iconic representations of gods. Many religions have featured deities with the wings or heads of birds. Birds were also celestial messengers, and the future was interpreted through their flights. The crow was Apollo's messenger in ancient Greece; the Maya and Aztecs had Quetzalcóatl, their supreme god, who was named after the quetzal (a brightly colored Central American bird); and the Egyptians represented their fundamental god Horus with a falcon.

HORUS, THE FALCON, is an important god in Egyptian mythology. His eyes represent the sun and the moon, and together with Seth he watches over the boat of Ra, which carries the dead away on the Nile.



FENGHUANG was the messenger bird of Xi Wangmu, goddess of fertility and eternity in ancient China. A detail of a painting in the caves of Mogao, Dunhuang, China, is pictured above.



QUETZAL Pictured above is a detail of a Mayan ceramic piece featuring quetzals, Mesoamerican birds with long green tails, from which, according to myth, the god Quetzalcóatl took his clothing and name: "feathered serpent."



GARUDA FRESCO Pictured above is a winged deity, featured on a fragment of a mural from the Hindu temple of Garuda, in Ananta Samarkhom, Bangkok, Thailand.`

Bird Symbolism

Throughout history and across cultures, human beings have used birds to symbolize several concepts. The fascination that their flight creates was a source of inspiration for such interpretations. Today the strongest and most widespread association is that of the flight of birds with freedom. In distant times (and in not so distant times), however, birds have represented many other things, from fertility and happiness, with their spring songs, to deep mourning, in the case of crows and vultures. Wisdom has been associated with owls, and shrewdness with crows. According to a certain modern tale, storks are responsible for bringing babies, and eggs are the universal symbol of gestation.

PIGEON Sometimes their numbers in urban areas become excessive.

COMPETITOR BIRDS
When birds share a habitat with humans, they often compete for resources (light, water, space, and nutrients). This is the case with birds that feed on cultivated crops. Urban areas, which have buildings that offer good nesting sites, attract many birds. This fact can be commonly observed in squares and open spaces, where pigeons and sparrows form veritable flocks.



SPARROW The sparrow is one of the birds best adapted to the urban environment.





EAGLE
In Greek mythology, it was the symbol of Zeus. The Romans used it on their legions' banners. For many native North American cultures, it represented war, and it was the emblem of feudal lords and emperors. Today it is the national symbol of Mexico and the United States.



DOVE
Doves currently stand for peace, but in ancient Greece, Syria, and Phoenicia, they were used as oracles. In Mesopotamia and Babylon, they embodied fertility. For Christians, they symbolize the Holy Spirit and the Virgin Mary.

Dressing Up in Feathers

Almost all cultures have used bird feathers for decorative and ritualistic purposes. Their use as ornaments extended to North and South America, Africa, and the Western Pacific. North American indigenous peoples featured them on their war outfits, Hawaian kings wore them on their royal costumes, and the Mayans and Aztecs used them in works of art.



NORTH AMERICAN INDIGENOUS MAN wearing a war costume covered with feathers

How to Get to Know Birds

Ornithology (from the Greek *ornitho*, "bird," and *logos*, "science") is a branch of zoology that studies birds. Ornithologists and a great number of bird lovers, who enthusiastically want to know more about these creatures, carry out the task methodically and patiently. They observe, analyze, and register birds' sounds, colors, movements, and behavior in their natural environments. To undertake this fieldwork, they develop methods and techniques and use technological resources to track specimens and learn about what happens to them during given times of the year.

WORK CLOTHES
Although seemingly a small detail, clothes can be a hindrance. They should be comfortable and soft, appropriate for the weather, and of colors that blend into the environment.

STUDIES
Many studies on anatomy, physiology, and genetics of different bird species are carried out in laboratories.

BINOCULARS
They make it possible to see details in color and shape without disturbing the birds. Their usefulness depends on the power of their lenses.



CAMERA WITH ZOOM LENS
A camera with a powerful lens provides the opportunity to record details that simple cameras cannot.

TAPE RECORDER
Recording birds' noises and songs makes it possible to distinguish among birds. Experts can identify species by listening to their recordings.

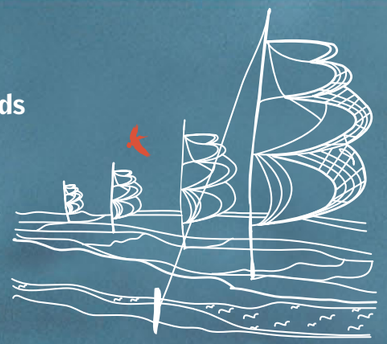


Direct Observation

Observing in a bird's natural habitat provides much information. For the greatest success, bird-watchers typically place themselves in front of rocks or trees in order not to form a silhouette. An alternative technique is to create a hiding place, such as a hollow cardboard rock. In both cases, the watcher needs to be facing away from the sun and must be prepared to stay for a long time.

Catching Birds

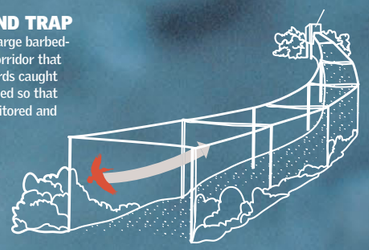
MIST NET
These fine nets are usually placed over swamps or marshes, and they can catch small birds. Once the birds are identified with a ring or some other tag, they are set free.

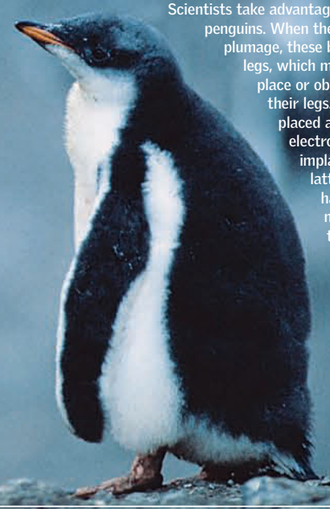


CANNON NETS
These nets are "shot" over birds using cannons or rockets. They unroll and catch birds as they are eating or resting. They are used to catch large birds.



HELIGOLAND TRAP
It consists of a large barbed-wire funnel or corridor that ends in a box. Birds caught like this are tagged so that they can be monitored and studied later on.





Scientists take advantage of molting to study penguins. When they are changing plumage, these birds stand on their legs, which makes it difficult to place or observe any rings on their legs. Instead, strips are placed around their wings, or electronic chips are implanted in their skin. The latter technique is less harmful because it does not potentially hinder the animal.

The Marking of Captured Birds

This technique provides data on migration, survival, and reproduction rates, among other data. The bird should not suffer adverse effects in its behavior, longevity, or social interactions. Under no circumstances should this procedure hurt a bird. To avoid hurting birds, rings are designed to be placed on them rapidly and easily, yet to stay in place until the research is completed.

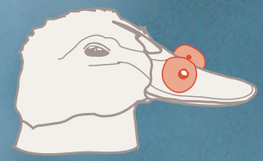


RINGED
Numbered aluminum rings are used. When placing one on a bird, one should make sure that it slides and turns around the tibiotarsus to avoid hurting the bird or causing it to change its activity.

WING MARKERS
They are very visible and can be codified for individual identification. They stay on the bird for long periods of time and are normally used on birds of prey.

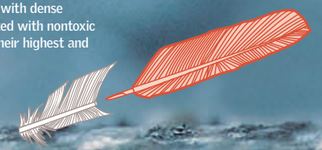
NECK MARKERS
When placed appropriately, necklaces are effective markers with few adverse effects on geese, swans, or other aquatic birds with long necks.





NASAL MARKERS
These are colored, numbered plastic disks placed on the bill. They are fastened to the nasal orifices of aquatic birds.

PAINTS AND DYES
Birds that visit environments with dense vegetation are normally marked with nontoxic colorings on the feathers of their highest and most visible body parts.



Among Us

The urban environment presents opportunities for birds. It offers advantages in finding food and shelter. People, young and old, give bread crumbs to these interested visitors. When birds come to cities, houses and parks offer them protection. They can find more options when it comes to building a nest. Seagulls and owls have changed their behavior by adapting to the city, and other species, such as some sparrows, are no longer able to survive without a human presence. However, not everything is an advantage. In the city, birds have to face dangers and obstacles that do not exist in their natural habitat: a utility wire or a car can be fatal.

Where to Find Them

In big cities, groups of birds can be found in different areas. Busy and noisy areas, such as squares, parks, and gardens, attract many species. Calm, deserted spaces, such as cemeteries or deserted buildings, are chosen by birds in search of peace. Other places where birds choose to eat and sleep include plots and landfills with lots of food, as well as nooks in high places, such as balconies, belfries, and roosts.

PLOTS AND CEMETERIES

Plants with seeds usually grow in these places, which are located far from urban centers. For this reason, magpies and nightingales favor them.

DAY/NIGHT

Artificial night lighting intensifies birds' activities. They organize their tasks according to street lighting.

URBAN CENTERS

With the arrival of cold weather, different bird species from the countryside and the mountains come to the city. In general, they stay until the beginning of spring. In the winter, more birds, such as chiffchaffs, great tits, and robins, can be observed in cities.

FALCONS
Diurnal birds of prey. They nest on the roofs of high buildings.

PIGEONS
spend a lot of time together. They are granivores but eat all kinds of food.

SWIFTS
are insectivores. They catch their prey in flight.

STORKS
build their nests on rooftops.

SEAGULLS
usually fight among themselves for the food they get from landfills.

LANDFILL

OWLS
Belfries or abandoned buildings are the homes or dormitories of these birds.

ABANDONED BUILDING

PARKS AND GARDENS

Royal peacocks and green peafowls share these places, where they can find the microhabitats of insects on which they feed. Parks and gardens may have ponds that are visited by other bird species as well. Few species nest in these places because these spaces offer little quiet.

BLACKBIRDS
were originally migratory, but as they adjusted to cities, they became nonmigratory.

SPARROWS
Small birds with a highly varied diet

GROVE

ROBINS
They get close only to find food. Their trills and plumage are attractive.

WAGTAILS
nest in holes or crannies, always near water.

FEEDER WITH FRUITS

DIET

Some species, which are veritable strategists, benefit from human activities. For example, seagulls can feed on garbage; great tits drink milk from containers by adroitly uncapping them; and some magpies have learned to tear cardboard containers to eat the eggs inside.

The Urban Environment

This setting is characterized by environmental and climatic factors that are different from the natural ones. It has more varieties of plants, higher average temperatures, less wind, more rain, cloudier skies, and less solar radiation. Polluted air and soil are harmful factors for both humans and birds.

10%
RAIN
INCREASE

15%
WIND
INTENSITY DECREASE

1.5°
TEMPERATURE
INCREASE DOWNTOWN

Population Control

Without enough predators and with an abundance of food, urban bird populations grow exponentially.

800,000
RAVENS, CROWS, AND RELATED BIRDS
LIVE IN MOSCOW.

160,000
PIGEONS
DESCEND ON THE SQUARES AND STREETS OF BARCELONA.

Bird Domesticators

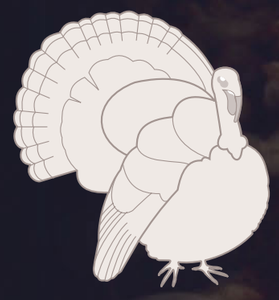
The breeding of birds in captivity has great social and economic value. This activity is carried out all over the world on industrial poultry farms and family farms where birds are raised for consumption and sale. A great variety of domestic birds have been developed from species inhabiting natural environments. We use their flesh and eggs as food and their feathers in coats to protect us against the cold. We also use birds for communication and as colorful and melodic pets. They are so dependent on people that in some cases they cannot survive when they are freed.



CAGED
Canaries, native to the Canary Islands, have been selectively bred by humans for nearly four centuries.

At Your Service

Domestic birds have been bred from the following orders: Galliformes (hens, quails, turkeys, and pheasants), Anseriformes (ducks and geese), Columbiformes (pigeons), Passeriformes (canaries), and Psittaciformes (parakeets and parrots). In poultry farming, they are divided according to their use: barnyard birds (Galliformes, Anseriformes, and Columbiformes) and companion birds or pets (Passeriformes and Psittaciformes). Commercial poultry farming of barnyard birds generates high revenues worldwide. Farmers can take advantage of the fact that birds are very active during the day, that they readily live in groups, and that they have a high reproductive rate due to polygamous behavior. Pets have commercial appeal, with their colorful plumage, ability to express themselves, and friendliness toward humans. These characteristics make them much-appreciated pets.



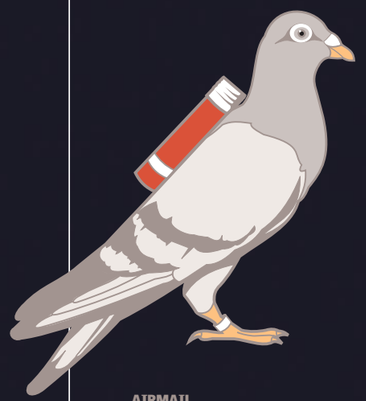
TURKEY
On the American continent, these birds were domesticated by the indigenous pre-Columbians from a wild Mexican species called *Meleagris gallopavo gallopavo.*



GOOSE
Contemporary domestic breeds descend from wild Asian and eastern European species. They are voracious, which makes fattening them easy.



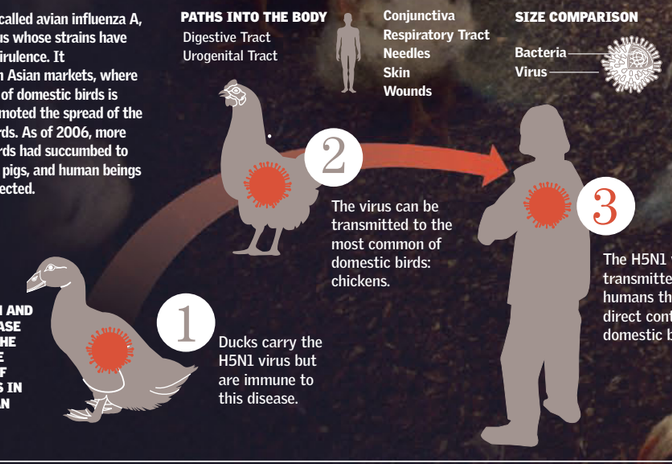
DUCK
These birds are an important source of food in Southeast Asia. In Central and South America, the consumption of ducks is less widespread.



AIRMAIL
For more than 1,700 years, human beings have used pigeons to send messages. Armies have used them as communication aids during wars. Pigeon keeping is the practice of breeding and preparing pigeons to become messengers, a task that makes the most of their agility and intelligence.

BIRD FLU

This disease, also called avian influenza A, is caused by a virus whose strains have various levels of virulence. It disseminated from Asian markets, where the overcrowding of domestic birds is common. This promoted the spread of the disease to wild birds. As of 2006, more than 30 million birds had succumbed to this disease. Cats, pigs, and human beings have also been infected.



50%
THE COMMOTION AND FEAR OVER DISEASE HAVE REDUCED THE DEMAND FOR THE CONSUMPTION OF DOMESTIC BIRDS IN MAJOR EUROPEAN CITIES BY HALF.

1 Ducks carry the H5N1 virus but are immune to this disease.

2 The virus can be transmitted to the most common of domestic birds: chickens.

3 The H5N1 virus is transmitted to humans through direct contact with domestic birds.

Farm Model

When compared to other farm animals, birds grow and reproduce easily. They need to have a place with appropriate temperature, humidity, and ventilation in order to yield the desired amount of meat or eggs. For this reason, it is necessary to maintain continuous environmental and sanitary control of the area in which they are bred. Ideally they should be able to walk, run, scratch the earth in search of food, and take sunbaths. Additionally, to protect them from predators and from inclement weather, it is important to shelter them in coops. This allows them to rest peacefully and sleep at night.

QUENCHING THIRST
Ten chickens drink from 0.5 to 0.8 gallon (2–3 l) of water a day. The farmer provides them with water in troughs, which are placed all over the henhouse.

MIXED DIET
Birds look for insects and plant shoots as they peck the soil. The breeder complements this diet with nutritionally balanced foods.

DOMESTICATION IN HISTORY

The domestication of birds is a very old activity, as shown by records from different cultures in different parts of the world. It was related to the adoption of a sedentary way of life by human populations.

5000 BC
India
There are records of domestic geese in India, beginning in 5000 BC.

2000 BC
Far East
Descendants of the royal duck *(Anas platyrhynchos)* were domesticated in this area of the Asian continent (what is now China).

1492
Mexico
The Spanish colonizers encountered turkeys domesticated by inhabitants of the New World.

Endangered Species

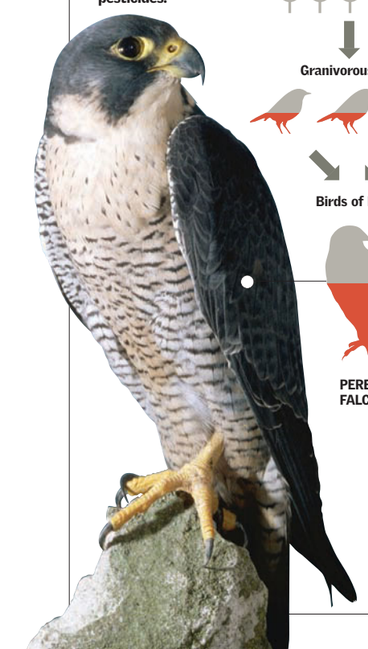
Since early civilization, people have affected the Earth's environment. The cutting of trees in rainforests and woodlands has destroyed many bird habitats, the loss of which is the leading cause of bird extinctions today. Also, the introduction of animals such as cats, dogs, and rats to new areas has created a threat for many bird species. Indirect poisoning with pesticides, the trafficking of exotic birds as pets, and the sale of feathers have done further damage to many species. Fortunately, all is not lost. The first step to conserving the world's avifauna is to learn about the extinction of birds and its magnitude.

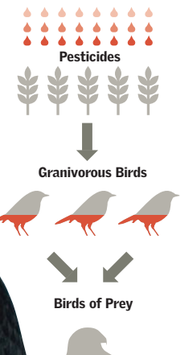
The Most Important Causes

Birds are very sensitive to changes in their habitats, and this is the main cause of extinction (87 percent of species are affected by it). Excessive hunting is another of the greatest dangers, affecting 29 percent of the endangered species in the world. The introduction of foreign species is yet another major danger, jeopardizing 28 percent of species. In addition, the intervention of human beings through the destruction of habitats and the introduction of pollution combined with the occurrence of natural disasters harms more than 10 percent of species.

POISONING

Most birds of prey are endangered by the excessive use of nonbiodegradable pesticides.





1. Pesticides are sprayed on crops to eliminate pests, and they stick to the seeds.
2. Small quantities of poison in seeds accumulate in larger amounts in birds and other granivorous animals.
3. Birds of prey eat the granivores. The increasing use of pesticides impacts hunting birds the most.



CALIFORNIA CONDOR
Gymnogyps californianus
Until 1978, there were 30 specimens in the wild. Bred in captivity, new specimens have been set free since 1993. Their adaptation is being studied.

HYACINTH MACAW
Anodorhynchus hyacinthinus
It is estimated that 1,000 to 9,000 specimens live in the Amazon.

MANGROVE FINCH
Camarhynchus heliobates
There are about 100 remaining species on the Galapagos Islands.

ROYAL CINCLODES
Cinclodes aricomae
live on humid mountain ranges, at altitudes between 11,500 and 15,000 feet (3,500–4,500 m). Their number is unknown.

SAVING THE PEREGRINE FALCON FROM EXTINCTION

1942 There were 350 couples of peregrine falcons in the United States.

1960 Peregrine falcons disappeared in the wild because of excessive use of pesticides (DDT and dieldrin).

1970 Falcons were bred in captivity at Cornell University, to be set free later.

1986 850 birds were set free in the southern United States.

BirdLife International
It monitors endangered species and develops conservation programs.

CLASSIFICATION OF RISK

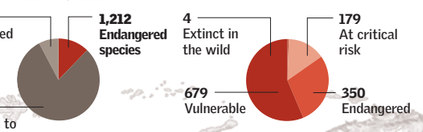
Extinct in the Wild Species surviving only in captivity

Critical Risk Extinction is imminent

Endangered Fast-decreasing population

Vulnerable High risk of extinction in the wild

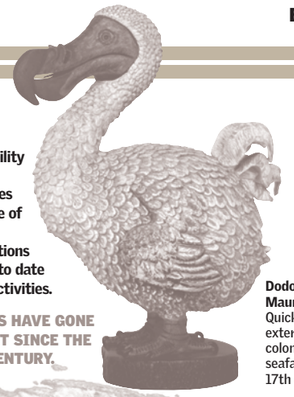
BIRDS OF THE WORLD



EXTINCT BIRDS

Although the responsibility of human beings is undeniable, many species became extinct because of natural phenomena. However, all the extinctions from the 18th century to date are related to human activities.

129 SPECIES HAVE GONE EXTINCT SINCE THE 18TH CENTURY.



Dodo from Mauritius
Quickly exterminated by colonizers and seafarers in the 17th century

INDIAN VULTURE
Gyps indicus
Its population has decreased significantly as a result of the veterinary use of diclofenac. The vulture eats the carrion of animals treated with this drug and becomes poisoned.

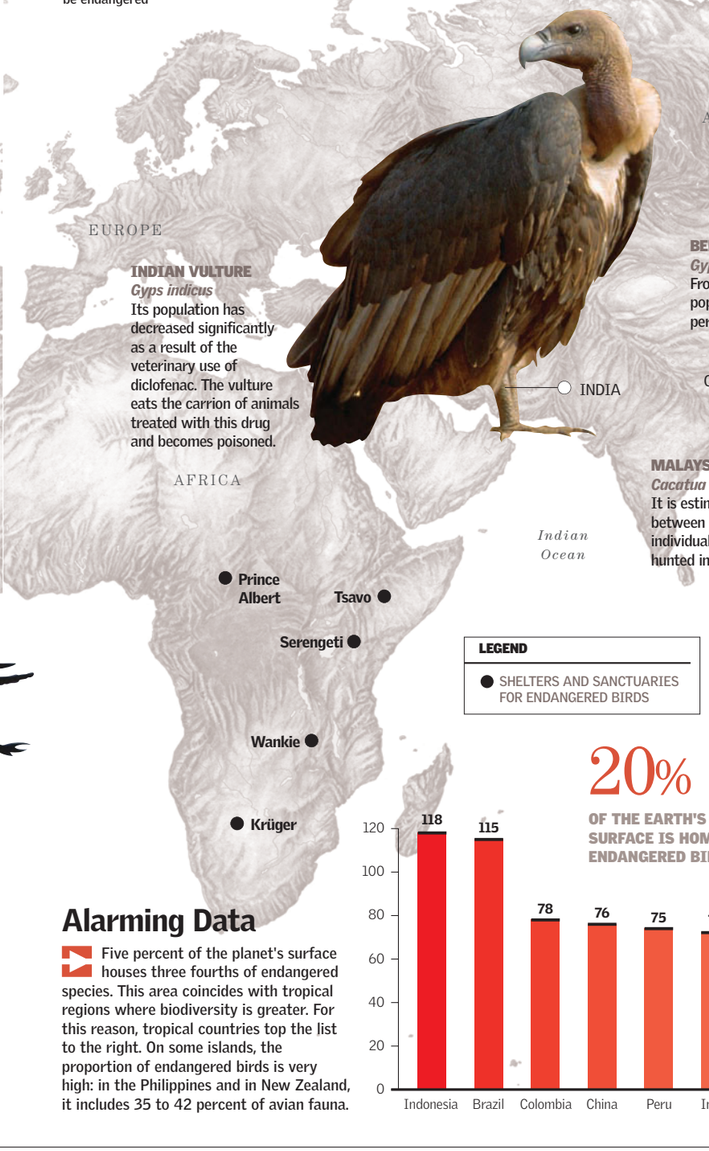
BENGAL VULTURE
Gyps bengalensis
From 1996 to date, its population has fallen by 95 percent, especially in India.



MALAYSIAN COCKATOO
Cacatua haematuropygia
It is estimated that there are between 1,000 and 4,000 individuals remaining. It was hunted indiscriminately.

YELLOW-CRESTED COCKATOO
Cacatua sulphurea
In three generations, its population fell by 80 percent because of hunting.

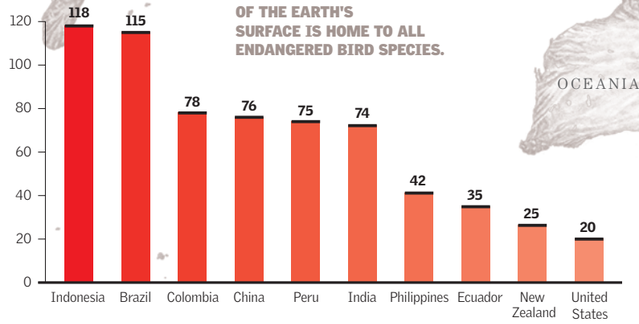
CAMPBELL ISLAND TEAL
Anas nesiotis
Only 50 individuals remain because of the introduction of mammals to the island.



Alarming Data

Five percent of the planet's surface houses three fourths of endangered species. This area coincides with tropical regions where biodiversity is greater. For this reason, tropical countries top the list to the right. On some islands, the proportion of endangered birds is very high: in the Philippines and in New Zealand, it includes 35 to 42 percent of avian fauna.

20%
OF THE EARTH'S SURFACE IS HOME TO ALL ENDANGERED BIRD SPECIES.



Glossary

Adaptation

Change in the body of a bird or another animal that allows it to reproduce better in a given environment

Adaptive Radiation

Evolution of an initial species, adapted to a given way of life, into other species, each adapted to its own way of life

Aerodynamic

Having an appropriate shape to decrease resistance to the air. Birds' bodies are aerodynamic.

Alulae

Rigid feathers whose function is to decrease air turbulence during flight

Amino Acid

Molecule from which proteins are produced

Ancestor

Progenitor, more or less remote, that passes down a set of characteristics to its descendants

Angle of Attack

The change in position of a bird's wing to increase or decrease speed and altitude while hunting prey by air

Apterylae

Naked areas of the skin where feathers do not grow

Atrophy

Significant decrease in the size of an organ. The wings of nonflying birds have undergone atrophy during evolution.

Barbs

Thin, straight, parallel blades, perpendicular to the shaft. They resemble the leaves of a palm tree.

Bill

Hard cover of a bird's mandibles; also called the bill.

Biodiversity

Variety of species that live in a given natural or artificial environment

Biogeographic Regions

Geographic regions that biologists analyze to determine the distribution of animals and other living organisms, according to the geographic conditions of a place. Migratory birds usually travel through different biogeographic regions between winter and summer.

Biped

Aero-terrestrial animal that walks on its posterior limbs. Birds are bipeds.

Briny

Water sample or body of water containing between 0.08 and 4.25 ounces (0.5-30 g) of salt per gallon of aqueous solution

Bronchus

Each of the branches into which the trachea divides. The syrinx originates in the bronchi.

Calamus

The lower part of the vane that is wider, hollow, and, in general, naked. The feather is attached to the skin through the calamus.

Camouflage

A characteristic that enables the animal to blend into its environment. It allows the animal to go unnoticed in the presence of predators.

Carnivore

An animal that feeds on meat

Carrion

The remains of dead animals used as food by some birds or other animals. Vultures are scavengers (i.e., animals that feed on carrion).

Center of Gravity

Point at which the sum of all the gravitational forces that act on a body converge

Cere

Thin skin layer that covers the base of the bill

Chick

A baby bird that has just come out of the eggshell and that has not yet left the nest. Its diet and safety depend on its parents.

Chorion

One of the coverings that wraps the embryo of reptiles, birds, and mammals

Class

One of the many divisions scientists use to classify animals. Birds form a class of their own.

Climate

Average temperature, humidity, and pressure that determine the atmospheric conditions of a region and that are related to other geographic characteristics of that region

Cloaca

The widened and dilatable final portion of the intestine of a bird or other animal in which the urinogenital tubes converge

Courtship

Behavior patterns that males and females follow to try to attract partners

Coverts

Layers of contour feathers that provide a bird's body and wings with support and an aerodynamic surface

Crepuscular

Active at dawn or twilight, when there is little light

Crest

Extended or raised feathers located on the upper part of a bird's head

Crop

Membranous sac that communicates with a bird's esophagus, where food is softened

Dermal Papilla

Structure from which a feather develops. It is composed of epidermal and dermal cells.

Display

Behavior directed at attracting the attention of a partner. It can also be done to threaten or distract another animal.

Distribution

Place where a species is located. It includes the area the species occupies in different seasons.

Down Feather

A very thin and light feather, similar to silk, that birds have underneath their external plumage. Down feathers constitute the first plumage of chicks.

Ecosystem

Community of living beings whose vital processes are interrelated and develop according to the physical factors of the same environment

Egg

Large rounded shell, laid by a female bird, that contains a yolk and a white. If fertilized, the egg has a tiny embryo that will develop into a chick (the chick feeds itself on the yolk and white). When ready, the chick will break the eggshell.

Egg Tooth

Sharp calcium growth, in the shape of a tooth, that forms on the tip of a chick's bill during the embryonic phase. The chick uses the egg tooth to break its shell at birth.

Environment

The natural conditions, such as vegetation and land, that surround animals and influence their development and behavior

Epiphysis

Endocrine gland located below the corpus callosum in the brain. It produces a hormone that regulates sexual activity.

Evolution

Gradual process of change that a species undergoes to adjust to the environment

Extinct

No longer existing. Many bird species are now extinct (for example, ictiornites).

Feather

Each unit of the covering (plumage) of a bird. The feathers are composed of a hard substance called keratin. They have a long quill, to which two blades are joined. The blades—formed by a great number of barbs, uniformly distributed—give the feather its shape and color.

Fertilization

Union of the reproductive cells of a male and a female that will create a new individual

Field Mark

Natural distinct feature or artificial identification of an individual of a bird species that helps ornithologists distinguish it from other individuals of the same or other avian species

Fledgling

Very young bird that lives in the nest where it was raised

Fossils

Vestiges of ancient creatures of different types (vegetal or animal) on a stone substratum. Fossils can be found in the geologic strata of the Earth's surface.

Gastric Juice

Set of fluids produced by the stomach glands of birds and other animals

Gizzard

Muscular stomach of a bird. It is very robust, especially in granivores, and it is used to grind and soften the food by means of mechanical pressure. The food arrives at the gizzard mixed with digestive juices.

Gland

Type of structure that is present in most multicellular living beings. It produces substances that act either inside or outside a bird's body.

Gonad

Organ that makes male or female gametes. In birds, the testicles and ovaries are gonads.

Granivore

Bird that feeds on seeds or grains. Many birds are granivores (for example, parrots and toucans).

Gular Sac

Skin fragment in the shape of a sac that hangs from the lower mandible of certain birds (for example, pelicans)

Habitat

Native or natural environment of an animal or plant

Hatching

Cracking of the eggshell so that the bird cancome out

Histologic

Related to tissues and their study. When the anatomy of a bird is studied, the tissues that form the bird's organs are analyzed.

Hormones

Secretion of certain glands that circulates through the body. They excite, inhibit, or regulate the activities of organs or of systems of organs.

Horn

Made of horn or of a consistency similar to that of horn. The bill of birds is hornlike.

Hypophysis

Internal secretion organ located at the hollow of the skull's base (called silla turca). It is composed of two lobes: one anterior and glandular and the other posterior and nervous. The hormones produced by the hypophysis influence growth and sexual development, among other things.

Hypothalamus

Region of the encephalon located at the cerebral base, joined to the hypophysis by a nerve stem, in which important centers for vegetative life are found

Incubation

The act of keeping the eggs warm so that the embryos inside can grow and hatch. Usually the chick's parents use their own bodies to warm the eggs, but some birds use sand or decomposing plants to cover them.

Insectivore

Bird that eats insects as part of its diet

Instinct

Innate behavior that a bird or other animal develops and that is not learned. The offspring of ducks start to swim by instinct.

Invertebrate

Animal that lacks a spinal column. Worms, crabs, and jellyfish are examples.

Lethargy

Sleep through which a bird can reduce its cardiac rhythm and its body temperature to save energy, especially at night and during extended periods of cold

Malpighian Layer

Layer of epithelial cells that forms the bird's epidermis

Mangrove Swamp

Type of ecosystem often considered a type of biome. It is composed of trees that are very tolerant to salt. These trees are found in the intertidal zone of tropical coasts. Areas with mangrove swamps include estuaries and coastal zones.

Migration

The movement of birds from one region to another; it usually takes place in the spring and fall. It is also common among other species of animals.

Molt

Process through which birds lose old worn feathers, replacing them with new ones

Monogamous

Birds that mate with only one individual of the opposite sex. Many penguins have monogamous behavior.

Morphology

Study of the form of an object or structure. For instance, the morphology of the feet of birds is an area of study.

Nectar

Sweet and sugary secretions found in flowers that attract birds and other animals. Hummingbirds feed on nectar.

Nidicolous

A helpless chick that depends on its parents' care after birth

Nidifugous

A chick that can move and leave the nest as soon as it breaks its shell. In less than a day, such chicks can move agilely.

Nocturnal

Active at night. Many birds of prey, such as owls, specialize in nocturnal hunting.

Nutrient

Any substance obtained through diet that participates in the vital functions of a living being.

Omnivore

Bird that has a varied diet, including animal and vegetal foods

Pelagic

Birds that live in areas over open waters, away from the coast

Pellet (Bolus)

Small, hard mass that some birds regurgitate (vomit). It contains parts of the food that they could not digest, such as bones, fur, feathers, and teeth.

Pigment

Substance that colors the skin, feathers, or tissues of animals and plants

Piscivore

Birds living in continental or oceanic waters that feed on fish

Pollution

A consequence of human actions for natural environments. The emission of industrial gases into the atmosphere, for example, produces pollution.

Polygamy

Reproductive relationship between one animal of one sex and several animals of the other. When one male mates with several females, it is called polygyny. Only rarely do females have multiple male reproductive partners (polyandry).

Population

Set of individuals of the same species that live together in the same space at the same time

Predator

Animal that hunts other animals. Birds of prey hunt other birds, mammals, and vertebrates.

Prey

Animal hunted by another to serve as food for the latter. Animals that hunt prey are called predators.

Protein

Organic macromolecule that is part of living beings. By including proteins in their diet, birds get the necessary amino acids to build their own organs.

Protein Cord

Embryonic structure: each of the two filaments that sustain the yolk of the egg within the white

Proventriculus

The first portion of the stomach, or the true stomach, of a bird. The other portion of a bird's stomach is the gizzard.

Rectrices

Technical term used by ornithologists to describe a bird's tail feathers

Scale

Dermic or epidermic layer that totally or partially covers the feet of birds. They are reptilian vestiges.

Song

Sound or series of sounds produced by a bird to demarcate its territory or to find a mate. The songs of birds can be simple or elaborate, and some are very melodic.

Songbirds

Singing birds. Passerines include songbirds.

Species

Set of individuals that recognize themselves as belonging to the same reproductive unit

Sternum

Central chest bone. The sternum of flying birds has a large surface in which muscles are inserted.

Survival

A bird's ability to face the demands of its environment and of intra- and interspecies relationships

Swamp

Depression on the ground in which water is gathered, sometimes called a marsh. Its bottom is more or less boggy. It is the habitat of many wading birds.

Thermal

Hot air current that rises. Many birds make use of it to gain height effortlessly.

Theropods

Group to which carnivorous dinosaurs belong

Training

Teaching an animal new skills. Carrier pigeons are trained.

Tundra

Vast plains without trees in the Arctic regions of northern Asia, Europe, and North America

Uropygial Gland

Produces an oily secretion that birds, using their bills, spread on their feathers to make them impermeable

Vertebrate

Animals that have a spinal column, such as birds, fish, reptiles, amphibians, and mammals

Virus

Infectious agent that depends on a living being to reproduce. Avian flu is transmitted this way.

Vulnerable

Birds that are endangered in their natural habitats

Yolk

Yellow part of the egg. If the egg is fertilized, a small embryo grows that will use the yolk (and white) as food.

Young

Bird or any other animal at an early stage of life. Some young show color patterns that are very different from that of adults of the same species, which makes it difficult for predators to identify them.

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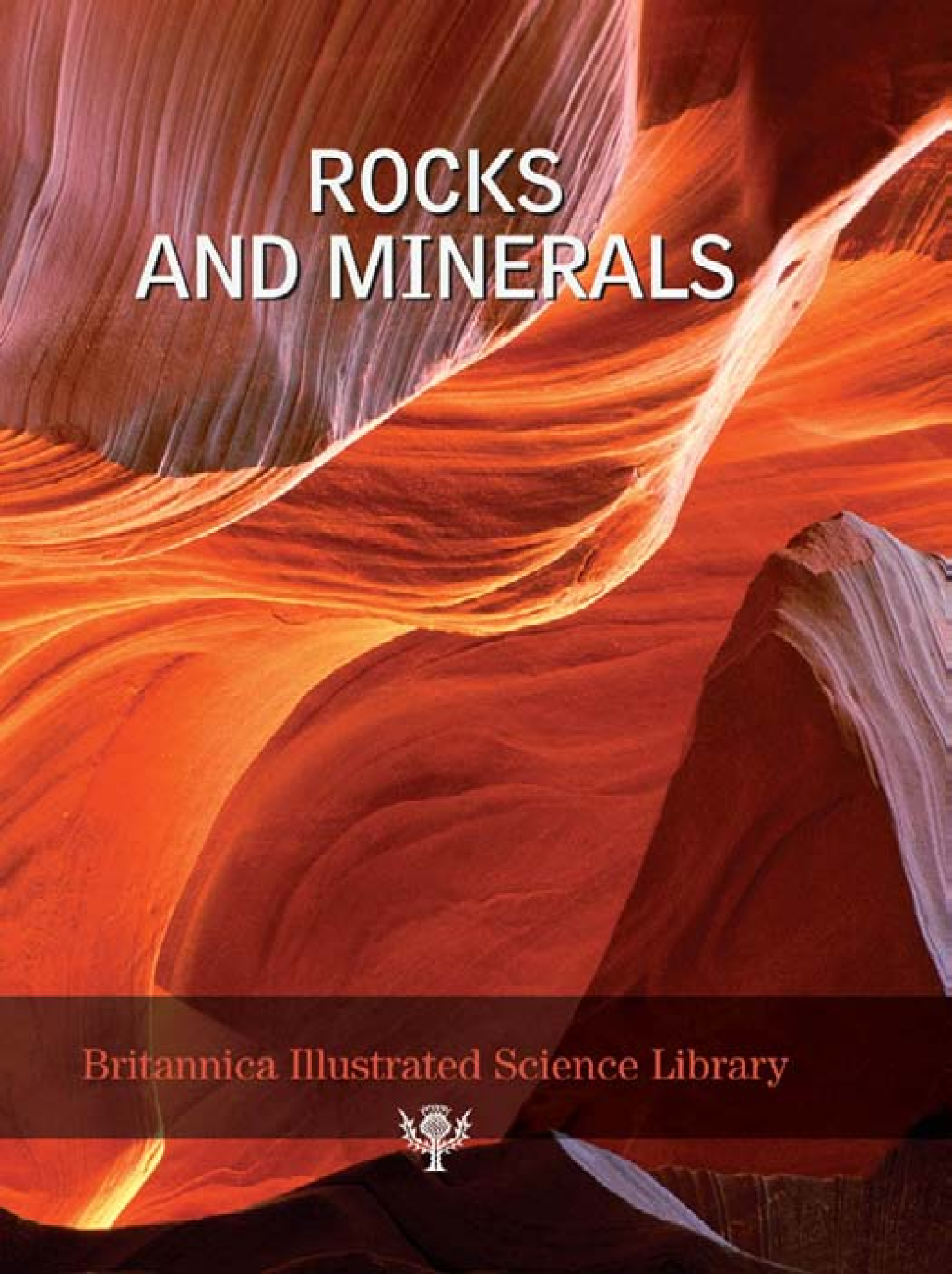
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ROCKS AND MINERALS



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ROCKS AND MINERALS



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Rocks and Minerals



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PHOTOGRAPH ON PAGE 1
A stone with a blue opal in its center is a product of time, since it forms over millions of years.

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Classes of Rocks

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THE MONK'S HOUSE
This orthodox monk lives in a volcanic cave, very close to the 11 Christian churches located in the Ethiopian town of Lalibela.

Memory of the Planet

Rocks, like airplane flight recorders, store in their interior very useful information about what has happened in the past. Whether forming caves in the middle of mountains, mixed among folds, or lying at the bottom of lakes and oceans, stones are everywhere, and they hold clues to the past. By studying rocks, we can reconstruct the history of the Earth. Even the most insignificant rocks can tell stories about other times, because rocks have been around since the beginning of the universe. They were part of the cloud of dust and gases that revolved around the Sun over four billion years ago. Rocks have been silent witnesses to the cataclysms our planet has experienced. They know the cold of the glacial era, the intense heat of the Earth's interior, and the fury of the oceans. They store much information about how external agents, such as wind, rain, ice, and temperature changes, have been altering the planet's surface for millions of years.

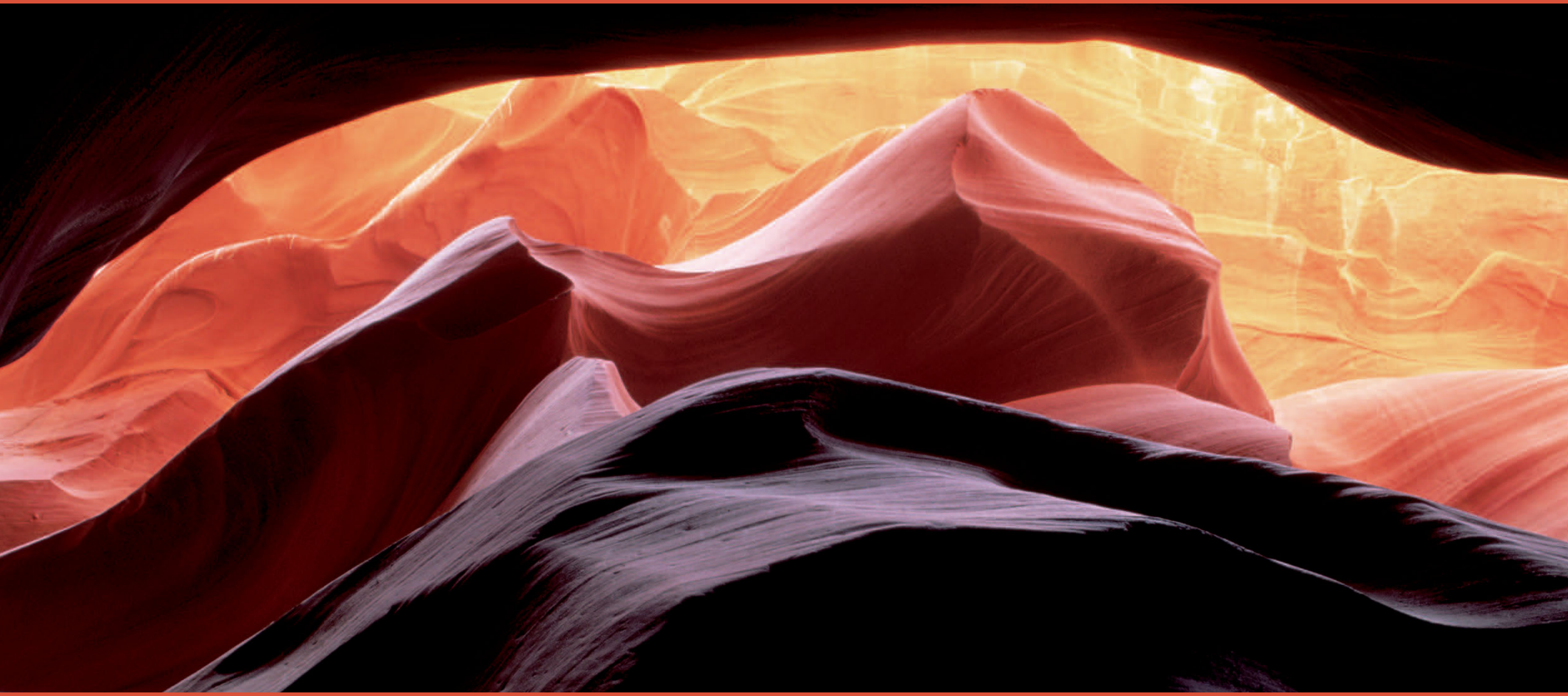
For ancient civilizations, stones symbolized eternity. This idea has persisted throughout time because stones endure, but they are recycled time and again. Fifty million years from now, nothing will be as we now know it—not the Andes, nor the Himalayas, nor the ice of Antarctica, nor the Sahara Desert. Weathering and erosion, though slow, will never stop. This should free us from any illusion of the immortality of the Earth's features. What will everything be like in the future? We don't know. The only sure thing is that there will be rocks. Only stones will remain, and their chemical composition, shape, and texture will provide clues about previous geological events and about what the Earth's surface was like in the past. In the pages of this book, illustrated with stunning images, you will find invaluable information about the language of rocks and natural forces in general. You will also learn to identify the most important minerals, know their physical and chemical properties, and discover the environments in which they form.

Did you know that the Earth's crust and its oceans are sources of useful and essential minerals for human beings? Coal, petroleum, and natural gas found in the crust allow us to travel and to heat our homes. Furthermore, practically all the products that surround us have elements provided by rocks and minerals. For example, aluminum is used to produce beverage cans; copper is used in electric cables; and titanium, mixed with other durable metals, is used in the construction of spacecraft. We invite you to enjoy this book. It is full of interesting and worthwhile information. Don't miss out on it!

Dynamics of the Earth's Crust

MOUNTAINS OF SAND
Corkscrew Canyon in Arizona contains an array of shapes, colors, and textures. The sand varies from pink to yellow to red depending on the sunlight it receives.

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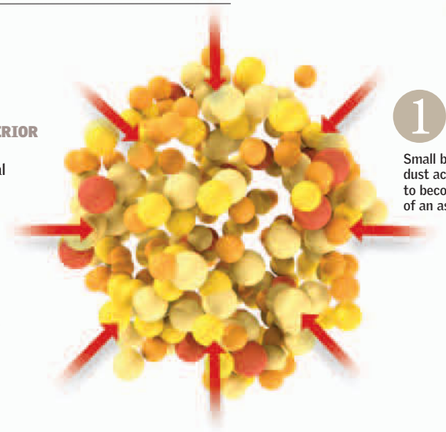
The Earth is like a blender in which rocks are moved around, broken, and crumbled. The fragments are deposited, forming different layers. Then weathering and erosion by wind and rain wear down and transform the rock. This produces mountains, cliffs, and sand dunes, among other features. The deposited material settles into layers of sediment that eventually become sedimentary rock. This rock cycle never stops. In 50 million years, no single mountain we know will exist in the same condition as it does today. ●

Traversing Time

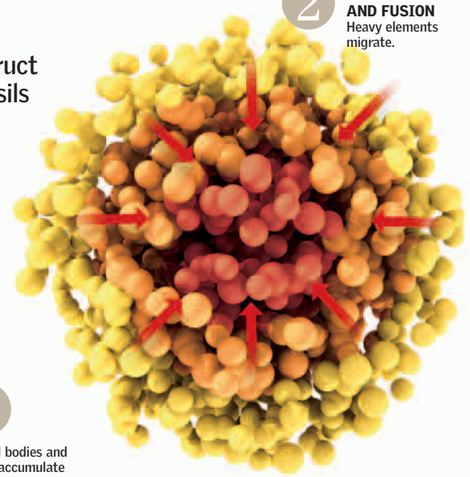
Geologists and paleontologists use many sources to reconstruct the Earth's history. The analysis of rocks, minerals, and fossils found on the Earth's surface provides data about the deepest layers of the planet's crust and reveals both climatic and atmospheric changes that are often associated with catastrophes. Craters caused by the impact of meteorites and other bodies on the surface of the Earth also reveal valuable information about the history of the planet.

Complex Structure

THE FORMATION OF THE INTERIOR
Cosmic materials began to accumulate, forming a growing celestial body, the precursor of the Earth. High temperatures combined with gravity caused the heaviest elements to migrate to the center of the planet and the lighter ones to move toward the surface. Under a rain of meteors, the external layers began to consolidate and form the Earth's crust. In the center, metals such as iron concentrated into a red-hot nucleus.



1 Small bodies and dust accumulate to become the size of an asteroid.

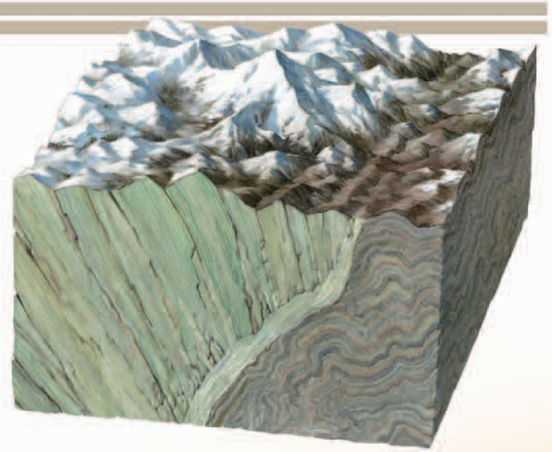


2 **COLLISION AND FUSION**
Heavy elements migrate.



3 **METALLIC CORE**
The light elements form the mantle.

THE CORE
The Earth's core is extremely hot and is made mostly of iron and nickel.



Mountains

are external folds of the crust produced by extremely powerful forces occurring inside the Earth.

Age in millions of years

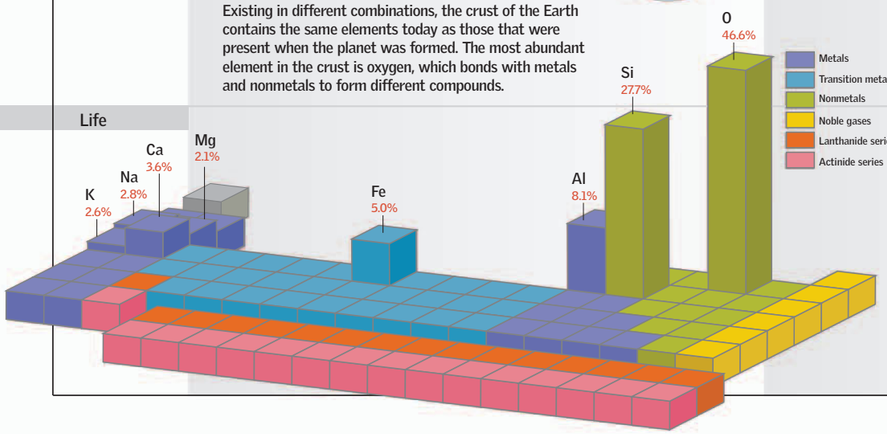
	4,600	2,500	542	488.3	443.7	416	359.2	299
ERA	Hadean	Proterozoic	Paleozoic THE ERA OF PRIMITIVE LIFE					
PERIOD	Pregeologic	Precambrian	Cambrian	Ordovician	Silurian	Devonian	Carboniferous	Permian
EPOCH								

Climate

Consolidation begins under a rain of meteors.

The Earth cools and the first ocean is formed.

ELEMENTS PRESENT ACCORDING TO THE TABLE
Existing in different combinations, the crust of the Earth contains the same elements today as those that were present when the planet was formed. The most abundant element in the crust is oxygen, which bonds with metals and nonmetals to form different compounds.



The oldest minerals, such as zircon, form.

The oldest rocks metamorphose, forming gneiss.

1,100 Rodinia, an early supercontinent, forms.

A meteorite falls in Sudbury, Ontario, Canada.

2,500 Glaciations: White Earth
The Earth undergoes the first of its massive global cooling events (glaciations).

800 Second glaciation
600 Last massive glaciation

542 The supercontinent Panotia forms, containing portions of present-day continents. North America separates from Panotia.

OROGENIES
Geological history recognizes long periods (lasting millions of years) of intense mountain formation called orogenies. Each orogeny is characterized by its own particular materials and location.

The first major orogeny (Caledonian folding) begins. Gondwana moves toward the South Pole.

Laurentia and Baltica converge, creating the Caledonian range. Gneiss forms on the coast of Scotland.

The region that will become North America moves toward the Equator, thus initiating the development of the most important carboniferous formations. Gondwana moves slowly; the ocean floor spreads at a similar speed.

The fragments of continents combine to form a single continent called Pangea.

The Appalachian Mountains form. The formation of slate through sedimentation is at its peak.

Baltica and Siberia clash, forming the Ural Mountains.

Eruptions of basalt occur in Siberia.

Temperatures fall. The level of carbon dioxide (CO_2) in the atmosphere is 16 times higher than it is today.

It is thought that the Earth's atmosphere contained far less carbon dioxide during the Ordovician than today. Temperatures fluctuate within a range similar to what we experience today.

By this period, vertebrates with mandibles, such as the placoderms, osteichthyans (bony fish), and acanthodians, have already emerged.

Temperatures were typically warmer than today, and oxygen (O_2) levels attained their maximum.

Hot, humid climates produce exuberant forests in swamplands.

The largest carbon deposits we observe today form where forests previously existed.

Life

THE FIRST ANIMALS
Among the most mysterious fossils of the Precambrian Period are the remains of the Ediacaran fauna, the Earth's first-known animals. They lived at the bottom of the ocean. Many were round and reminiscent of jellyfish, while others were flat and sheetlike.

THE CAMBRIAN EXPLOSION
Fossils from this time attest to the great diversity of marine animals and the emergence of different types of skeletal structures, such as those found in sponges and trilobites.

TRILOBITES
Marine arthropods with mineralized exoskeletons





SILURIAN
One of the first pisciform vertebrates, an armored fish without mandibles

The rocks of this period contain an abundance of fish fossils.

Areas of solid ground are populated by gigantic ferns.

Amphibians diversify and reptiles originate from one amphibian group to become the first amniotes. Winged insects such as dragonflies emerge.

Palm trees and conifers replace the vegetation from the Carboniferous Period.

MASS EXTINCTION
Near the end of the Permian Period, an estimated 95 percent of marine organisms and over two thirds of terrestrial ones perish in the greatest known mass extinction.

IMPACT FROM THE OUTSIDE
It is believed that a large meteor fell on Chicxulub, on the Yucatán Peninsula (Mexico), about 65 million years ago. The impact caused an explosion that created a cloud of ash mixed with carbon rocks. When the debris fell back to Earth, some experts believe it caused a great global fire.

62 miles (100 km)

The diameter of the crater produced by the impact of the meteor on the Yucatán Peninsula. It is now buried under almost 2 miles (3 km) of limestone.

The heat caused by the expansion of fragments from the impact together with the greenhouse effect brought about by the spreading of ashes in the stratosphere provoked a series of climatic changes. It is believed that this process resulted in the extinction of the dinosaurs.



FORMATION OF MOUNTAIN CHAINS
60 Central Rocky Mountains
30 Alps
20 Himalayas

North America and Europe drift apart. North and South America are joined at the end of this time period. The formation of Patagonia concludes, and an important overthrust raises the Andes mountain range.



The African Rift Zone and the Red Sea open up. The Indian protocontinent collides with Eurasia.

251 | 199.6 | 145.5 | 65.5 | 23.03

Mesozoic THE ERA OF REPTILES
Triassic | Jurassic | Cretaceous

Cenozoic THE AGE OF MAMMALS
Paleogene: Paleocene | Eocene | Oligocene
Neogene: Miocene | Pliocene | Pleistocene | Holocene

Carbon dioxide levels increase. Average temperatures are higher than today.

The level of oxygen (O_2) in the atmosphere is much lower than today.

THE AGE OF FLOWERING PLANTS
At the end of the Cretaceous Period, the first angiosperms—plants with protected seeds, flowers, and fruits—appear.

The global average temperature is at least 62° F (17° C). The ice layer covering Antarctica later thickens.

Temperatures drop to levels similar to those of today. The lower temperatures cause forests to shrink and grasslands to expand.



THE LAST GLACIATION
The most recent period of glaciation begins three million years ago and intensifies at the beginning of the Quaternary period. North Pole glaciers advance, and much of the Northern Hemisphere becomes covered in ice.

Proliferation of insects

Appearance of dinosaurs

The first mammals evolve from a group of reptiles called Therapsida.

Birds emerge.

The dinosaurs undergo adaptive radiation.

ALLOSAURUS
This carnivore measured 39 feet (12 m) long.



ANOTHER MASS EXTINCTION
Toward the end of the Cretaceous Period, about 50 percent of existing species disappear. The dinosaurs, the large marine reptiles (such as the Plesiosaurs), the flying creatures of that period (such as the Pterosaurs), and the ammonites (cephalopod mollusks) disappear from the Earth. At the beginning of the Cenozoic Era, most of the habitats of these extinct species begin to be occupied by mammals.

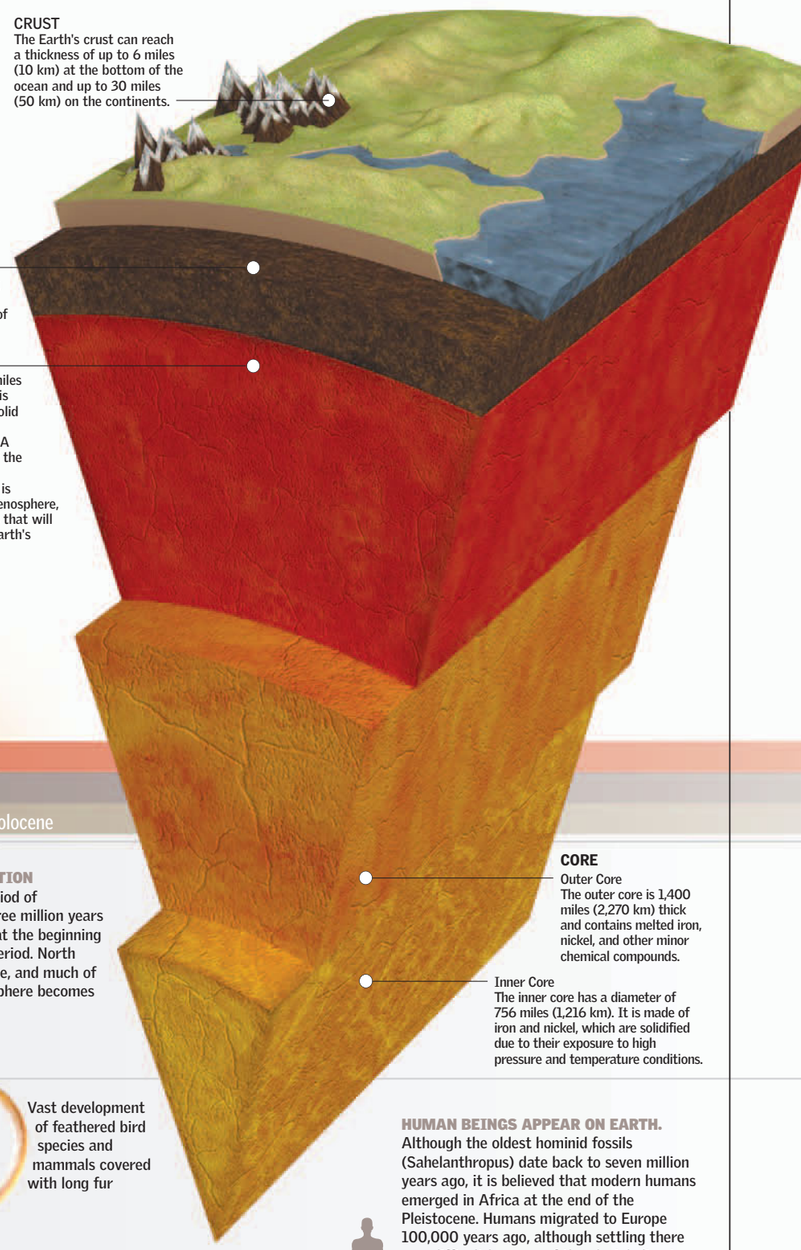


Vast development of feathered bird species and mammals covered with long fur

MAMMOTHS
Mammoths lived in Siberia. The cause of their extinction is still under debate.

Elements in Equilibrium

Minerals, such as iron and silicates, are widely spread among the major constituents of the crust. Only the movements of the crust on the molten mantle disrupt their equilibrium.



HUMAN BEINGS APPEAR ON EARTH.
Although the oldest hominid fossils (Sahelanthropus) date back to seven million years ago, it is believed that modern humans emerged in Africa at the end of the Pleistocene. Humans migrated to Europe 100,000 years ago, although settling there was difficult because of the glacial climate. According to one hypothesis, our ancestors reached the American continent about 10,000 years ago by traveling across the area now known as the Bering Strait.

Under Construction

Our planet is not a dead body, complete and unchanging. It is an ever-changing system whose activity we experience all the time: volcanoes erupt, earthquakes occur, and new rocks emerge on the Earth's surface. All these phenomena, which originate in the interior of the planet, are studied in a branch of geology called internal geodynamics. This science analyzes processes, such as continental drift and isostatic movement, which originate with the movement of the crust and result in the raising and sinking of large areas. The movement of the Earth's crust also generates the conditions that form new rocks. This movement affects magmatism (the melting of materials that solidify to become igneous rocks) and metamorphism (the series of transformations occurring in solid materials that give rise to metamorphic rocks).

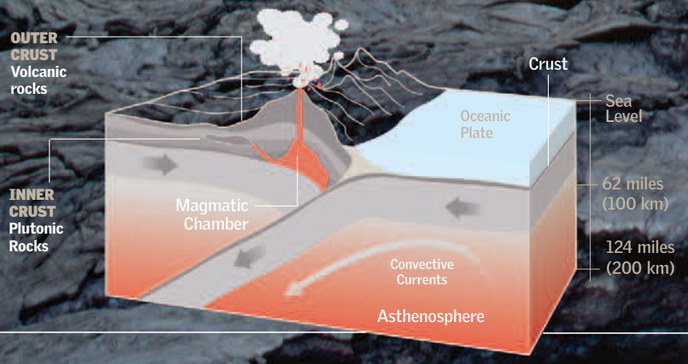


KILAUEA CRATER
Hawaii

Latitude 19° N
Longitude 155° W

Magmatism

Magma is produced when the temperature in the mantle or crust reaches a level at which minerals with the lowest fusion point begin to melt. Because magma is less dense than the solid material surrounding it, it rises, and in so doing it cools and begins to crystallize. When this process occurs in the interior of the crust, plutonic or intrusive rocks, such as granite, are produced. If this process takes place on the outside, volcanic or effusive rocks, such as basalt, are formed.

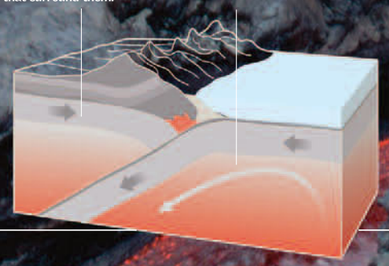


Metamorphism

An increase in pressure and/or temperature causes rocks to become plastic and their minerals to become unstable. These rocks then chemically react with the substances surrounding them, creating different chemical combinations and thus causing new rocks to form. These rocks are called metamorphic rocks. Examples of this type of rock are marble, quartzite, and gneiss.

PRESSURE
This force gives rise to new metamorphic rocks, as older rocks fuse with the minerals that surround them.

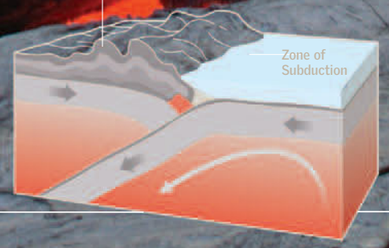
TEMPERATURE
High temperatures make the rocks plastic and their minerals unstable.



Folding

Although solid, the materials forming the Earth's crust are elastic. The powerful forces of the Earth place stress upon the materials and create folds in the rock. When this happens, the ground rises and sinks. When this activity occurs on a large scale, it can create mountain ranges or chains. This activity typically occurs in the subduction zones.

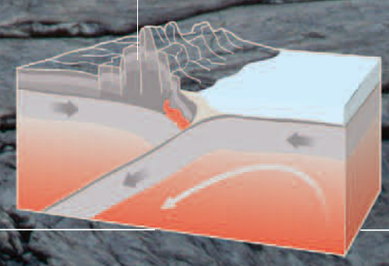
FOLDS
For folds to form, rocks must be relatively plastic and be acted upon by a force.



Fracture

When the forces acting upon rocks become too intense, the rocks lose their plasticity and break, creating two types of fractures: joints and faults. When this process happens too abruptly, earthquakes occur. Joints are fissures and cracks, whereas faults are fractures in which blocks are displaced parallel to a fracture plane.

RUPTURE
When rocks rupture quickly, an earthquake occurs.



A Changing Surface

The molding of the Earth's crust is the product of two great destructive forces: weathering and erosion. Through the combination of these processes, rocks merge, disintegrate, and join again. Living organisms, especially plant roots and digging animals, cooperate with these geologic processes. Once the structure of the minerals that make up a rock is disrupted, the minerals disintegrate and fall to the mercy of the rain and wind, which erode them.

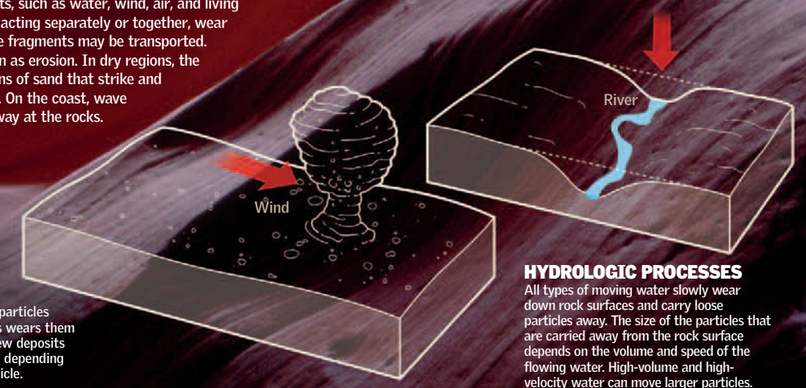


CORKSCREW CANYON
Arizona

Latitude 36° 30´ N
Longitude 111° 24´ W

Erosion

External agents, such as water, wind, air, and living beings, either acting separately or together, wear down, and their loose fragments may be transported. This process is known as erosion. In dry regions, the wind transports grains of sand that strike and polish exposed rocks. On the coast, wave action slowly eats away at the rocks.



EOLIAN PROCESSES

The wind drags small particles against the rocks. This wears them down and produces new deposits of either loess or sand depending on the size of the particle.

HYDROLOGIC PROCESSES

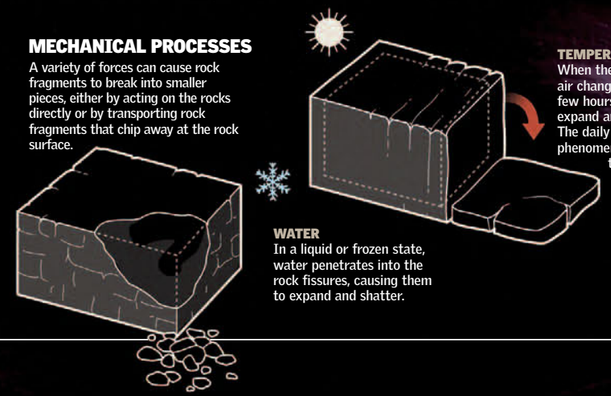
All types of moving water slowly wear down rock surfaces and carry loose particles away. The size of the particles that are carried away from the rock surface depends on the volume and speed of the flowing water. High-volume and high-velocity water can move larger particles.

Weathering

Mechanical agents can disintegrate rocks, and chemical agents can decompose them. Disintegration and decomposition can result from the actions of plant roots, heat, cold, wind, and acid rain. The breaking down of rock is a slow but inexorable process.

MECHANICAL PROCESSES

A variety of forces can cause rock fragments to break into smaller pieces, either by acting on the rocks directly or by transporting rock fragments that chip away at the rock surface.



WATER

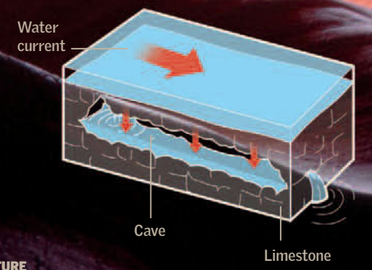
In a liquid or frozen state, water penetrates into the rock fissures, causing them to expand and shatter.

TEMPERATURE

When the temperature of the air changes significantly over a few hours, it causes rocks to expand and contract abruptly. The daily repetition of this phenomenon can cause rocks to rupture.

CHEMICAL PROCESSES

The mineral components of rocks are altered. They either become new minerals or are released in solution.



Transportation and Sedimentation

In this process, materials eroded by the wind or water are carried away and deposited at lower elevations, and these new deposits can later turn into other rocks.

Before Rock, Mineral

The planet on which we live can be seen as a large rock or, more precisely, as a large sphere composed of many types of rocks. These rocks are composed of tiny fragments of one or more materials. These materials are minerals, which result from the interaction of different chemical elements, each of which is stable only under specific conditions of pressure and temperature. Both rocks and minerals are studied in the branches of geology called petrology and mineralogy.

From Minerals to Rocks

From a chemical perspective, a mineral is a homogeneous substance. A rock, on the other hand, is composed of different chemical substances, which, in turn, are components of minerals. The mineral components of rocks are also those of mountains. Thus, according to this perspective, it is possible to distinguish between rocks and minerals.



QUARTZ
Composed of silica, quartz gives rock a white color.



MICA
Composed of thin, shiny sheets of silicon, aluminum, potassium, and other minerals, mica can be black or colorless.



FELDSPAR
A light-colored silicate, feldspar makes up a large part of the crust.

GRANITE
Rock composed of feldspar, quartz, and mica

12 million years ago

rock batholiths formed during a period of great volcanic activity and created the Torres del Paine and its high mountains.



TORRES DEL PAINE
Chilean Patagonia

Latitude 52° 20´ S
Longitude 71° 55´ W

Composition	**Granite**
Highest summit	**Paine Grande (10,000 feet [3,050 m])**
Surface	**598 acres (242 ha)**

Torres del Paine National Park is located in Chile between the massif of the Andes and the Patagonian steppes.



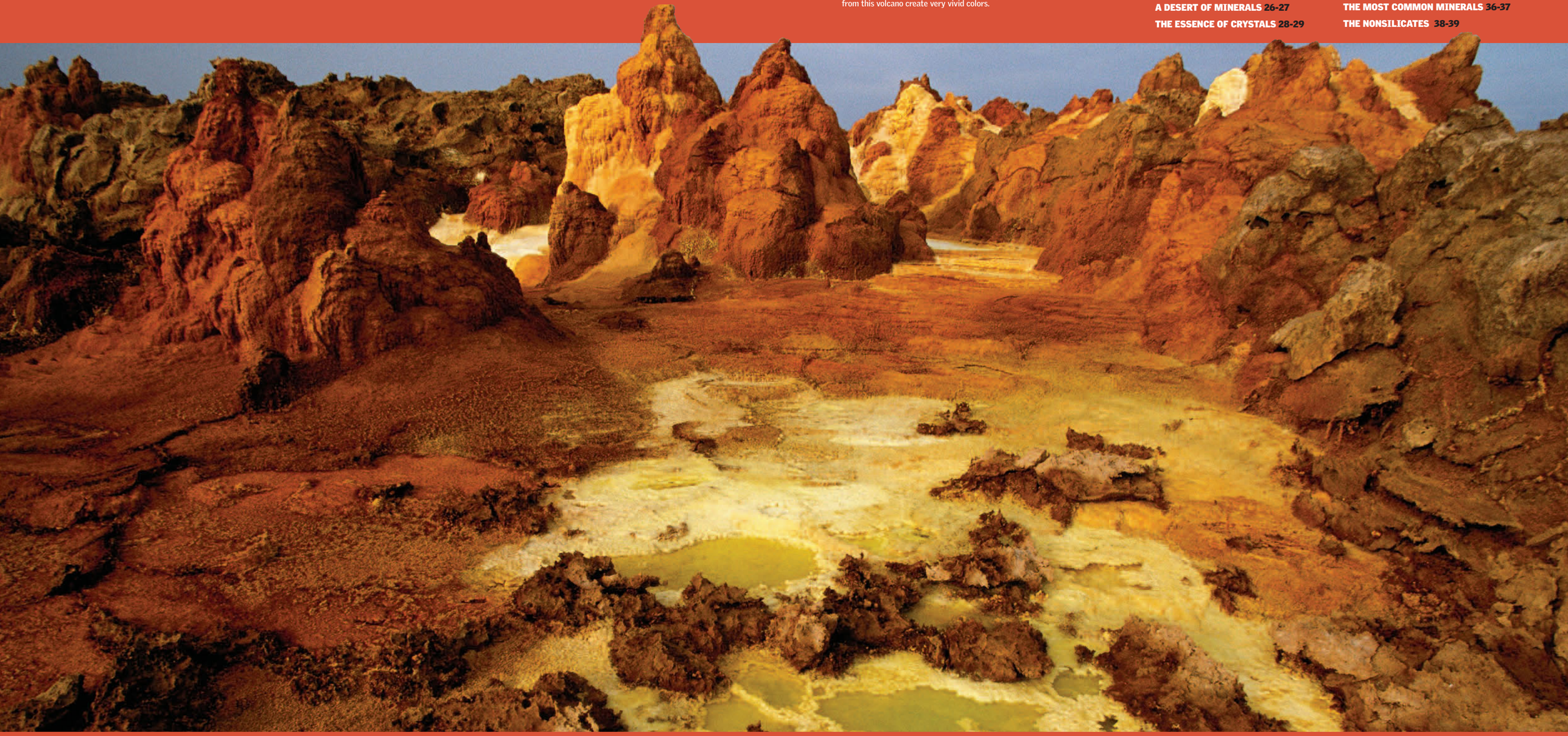
CHANGE OF STATE

Temperature and pressure play a prominent part in rock transformation. Inside the Earth, liquid magma is produced. When it reaches the surface, it solidifies. A similar process happens to water when it freezes upon reaching 32° F (0° C).

Minerals

DALLOL VOLCANO
Located in Ethiopia, Dallol is the only non-oceanic volcano on Earth below sea level, making it one of the hottest places on the planet. Sulfur and other minerals that spring from this volcano create very vivid colors.

YOU ARE WHAT YOU HAVE 20-21
A QUESTION OF STYLE 22-23
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A DESERT OF MINERALS 26-27
THE ESSENCE OF CRYSTALS 28-29
CRYSTALLINE SYMMETRY 30-31
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Dallol is basically a desert of minerals whose ivory-colored crust is scattered with green ponds and towers of sulfur salts in shades of orange. Some minerals belong to a very special class. Known as gems, they are sought and hoarded for their great beauty. The most valuable gems are diamonds.

Did you know it took human beings thousands of years to separate metal from rock? Did you also know that certain nonmetallic minerals are valued for their usefulness?

Graphite, for instance, is used to make pencils; gypsum is used in construction; and halite, also known as salt, is used in cooking. ●

You Are What You Have

Minerals are the "bricks" of materials that make up the Earth and all other solid bodies in the universe. They are usually defined both by their chemical composition and by their orderly internal structure. Most are solid crystalline substances. However, some minerals have a disordered internal structure and are simply amorphous solids similar to glass. Studying minerals helps us to understand the origin of the Earth. Minerals are classified according to their composition and internal structure, as well as by the properties of hardness, weight, color, luster, and transparency. Although more than 4,000 minerals have been discovered, only about 30 are common on the Earth's surface.

Components

The basic components of minerals are the chemical elements listed on the periodic table. Minerals are classified as native if they are found in isolation, contain only one element, and occur in their purest state. On the other hand, they are classified as compound if they are composed of two or more elements. Most minerals fall into the compound category.

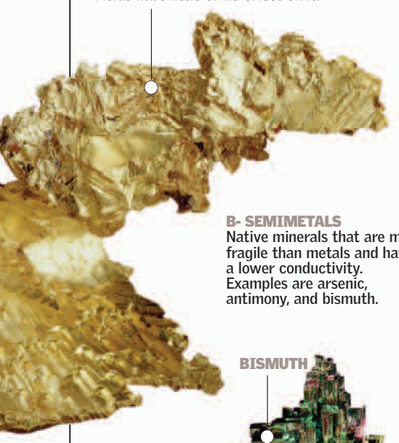
MINERALS COME FROM **112 elements** listed in the periodic table.

1 NATIVE MINERALS

These minerals are classified into:

A- METALS AND INTERMETALS
Native minerals have high thermal and electrical conductivity, a typically metallic luster, low hardness, ductility, and malleability. They are easy to identify and include gold, copper, and lead.

GOLD
An excellent thermal and electrical conductor. Acids have little or no effect on it.



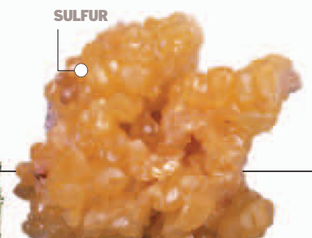
B- SEMIMETALS
Native minerals that are more fragile than metals and have a lower conductivity. Examples are arsenic, antimony, and bismuth.

BISMUTH



C- NONMETALS
An important group of minerals, which includes sulfur

SULFUR





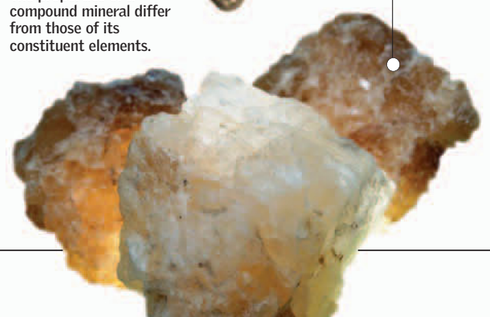
SILVER
The close-up image shows the dendrites formed by the stacking of octahedrons, sometimes in an elongated form.

Microphotograph of silver crystal dendrites

2 COMPOUND MINERALS

Compound minerals are created when chemical bonds form between atoms of more than one element. The properties of a compound mineral differ from those of its constituent elements.

HALITE
is composed of chlorine and sodium.



Polymorphism

A phenomenon in which the same chemical composition can create multiple structures and, consequently, result in the creation of several different minerals. The transition of one polymorphous variant into another, facilitated by temperature or pressure conditions, can be fast or slow and either reversible or irreversible.

Chemical Composition	Crystallization System	Mineral
$CaCO_3$	Trigonal	**Calcite**
$CaCO_3$	Rhombic	**Aragonite**
FeS_2	Cubic	**Pyrite**
FeS_2	Rhombic	**Marcasite**
C	Cubic	Diamond
C	Hexagonal	Graphite

DIAMOND AND GRAPHITE
A mineral's internal structure influences its hardness. Both graphite and diamond are composed only of carbon; however, they have different degrees of hardness.

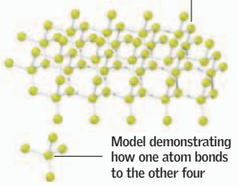
Diamond



Graphite



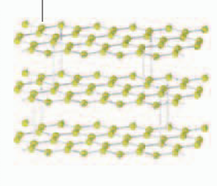
Carbon Atom



Model demonstrating how one atom bonds to the other four

Each atom is joined to four other atoms of the same type. The carbon network extends in three dimensions by means of strong covalent bonds. This provides the mineral with an almost unbreakable hardness.

Hardness of 10
on the Mohs scale



Atoms form hexagons that are strongly interconnected in parallel sheets. This structure allows the sheets to slide over one another.

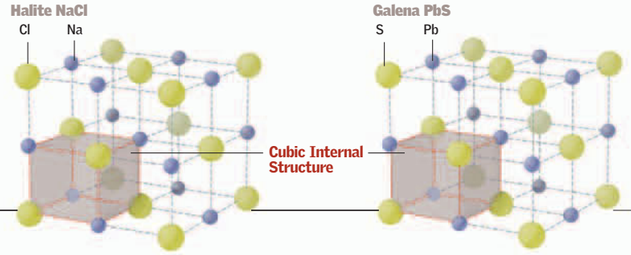
Hardness of 1
on the Mohs scale

MORE THAN **4,000 types of minerals** have been recognized by the International Association of Mineralogy.

Isotypic Minerals

Isomorphism happens when minerals with the same structure, such as halite and galena, exchange cations. The structure remains the same, but the resulting substance is different, because one ion has been exchanged for another. An example of this process is siderite (rhombic $FeCO_3$), which gradually changes to magnesite ($MgCO_3$) when it trades its iron (Fe) for similarly-sized magnesium (Mg). Because the ions are the same size, the structure remains unchanged.

HALITE AND GALENA



A Question of Style

Optical properties involve a mineral's response to the presence of light. This characteristic can be analyzed under a petrographic microscope, which differs from ordinary microscopes in that it has two devices that polarize light. This feature makes it possible to determine some of the optical responses of the mineral. However, the most precise way to identify a mineral by its optical properties is to use an X-ray diffractometer.

Color

is one of the most striking properties of minerals. However, in determining the identity of a mineral, color is not always useful. Some minerals never change color; they are called idiochromatic. Others whose colors are variable are called allochromatic. A mineral's color changes can be related, among other things, to the presence of impurities or inclusions (solid bodies) inside of it.

INHERENT COLOR

Some minerals always have the same color; one example is malachite.



MALACHITE



SULFUR

EXOTIC COLOR

A mineral can have several shades, depending on its impurities or inclusions.

QUARTZ



ROCK CRYSTAL
Colorless; the purest state of quartz



ROSE
The presence of manganese results in a pink color.

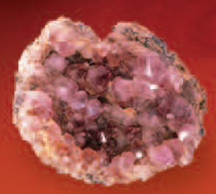
Other secondary minerals, known as exotic minerals, are responsible for giving quartz its color; when it lacks exotic minerals, quartz is colorless.



CITRINE
The presence of iron produces a very pale yellow color.



SMOKY
Dark, brown, or gray minerals



AMETHYST
The presence of iron in a ferric state results in a purple color.

COLOR STREAK

More reliable than a mineral's color is its streak (the color of the fine powder left when the mineral is rubbed across a hard white surface).

HEMATITE
Color: Black



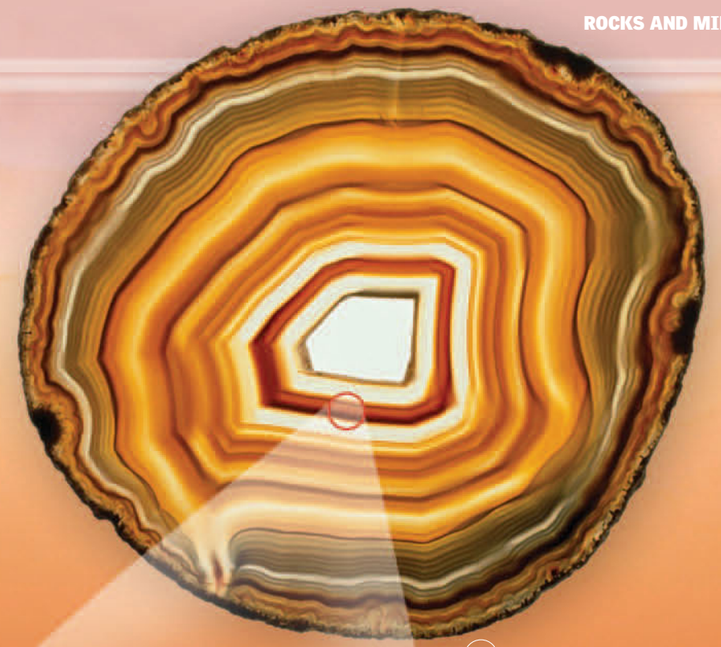
Streak Color: Reddish Brown

Luminescence

Certain minerals emit light when they are exposed to particular sources of energy. A mineral is fluorescent if it lights up when exposed to ultraviolet rays or X-rays. It is phosphorescent if it keeps glowing after the energy source is removed. Some minerals will also respond to cathode rays, ordinary light, heat, or other electric currents.

Refraction and Luster

Refraction is related to the speed with which light moves through a crystal. Depending on how light propagates through them, minerals can be classified as monorefringent or birefringent. Luster results from reflection and refraction of light on the surface of a mineral. In general, it depends on the index of refraction of a mineral's surface, the absorption of incident light, and other factors, such as concrete characteristics of the observed surface (for instance, degree of smoothness and polish). Based on their luster, minerals can be divided into three categories.



AGATE
A type of chalcedony, a cryptocrystalline variety of quartz, of nonuniform coloring

Agates crystallize in banded patterns because of the environments in which they form. They fill the cavities of rocks by precipitating out of aqueous solutions at low temperatures. Their colors reflect the porosity of the stone, its degree of inclusions, and the crystallization process.



METALLIC
Minerals in this class are completely opaque, a characteristic typical of native elements, such as copper, and sulfides, such as galena.

SUBMETALLIC
Minerals in this class have a luster that is neither metallic nor nonmetallic.



NONMETALLIC
Minerals in this class transmit light when cut into very thin sheets. They can have several types of luster: vitreous (quartz), pearlescent, silky (talc), resinous, or earthy.



Streak

is the color of a mineral's fine powder, which can be used to identify it.

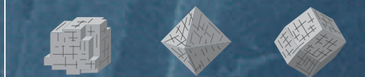
How to Recognize Minerals

A mineral's physical properties are very important for recognizing it at first glance. One physical property is hardness. One mineral is harder than another when the former can scratch the latter. A mineral's degree of hardness is based on a scale, ranging from 1 to 10, that was created by German mineralogist Friedrich Mohs. Another physical property of a mineral is its tenacity, or cohesion—that is, its degree of resistance to rupture, deformation, or crushing. Yet another is magnetism, the ability of a mineral to be attracted by a magnet.

Exfoliation and Fracture

When a mineral tends to break along the planes of weak bonds in its crystalline structure, it separates into flat sheets parallel to its surface. This is called exfoliation. Minerals that do not exfoliate when they break are said to exhibit fracture, which typically occurs in irregular patterns.

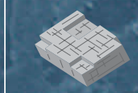
TYPES OF EXFOLIATION



Cubic

Octahedral

Dodecahedral



Rhombohedral



Prismatic and Pinacoidal



Pinacoidal (Basal)



TOURMALINE is a mineral of the silicate group.

COLOR Some tourmaline crystals can have two or more colors.

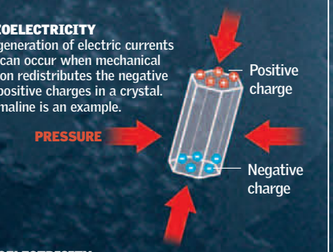
FRACTURE can be irregular, conchoidal, smooth, splintery, or earthy.

IRREGULAR FRACTURE An uneven, splintery mineral surface

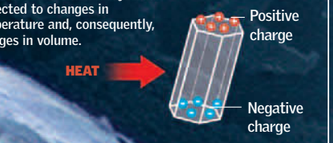
Electricity Generation

Piezoelectricity and pyroelectricity are phenomena exhibited by certain crystals, such as quartz, which acquire a polarized charge because exposure to temperature change or mechanical tension creates a difference in electrical potential at their ends.

PIEZOELECTRICITY The generation of electric currents that can occur when mechanical tension redistributes the negative and positive charges in a crystal. Tourmaline is an example.



PYROELECTRICITY The generation of electric currents that can occur when a crystal is subjected to changes in temperature and, consequently, changes in volume.



DENSITY reflects the structure and chemical composition of a mineral. Gold and platinum are among the most dense minerals.

7 to 7.5

IS THE HARDNESS OF THE TOURMALINE ON THE MOHS SCALE.

MOHS SCALE

ranks 10 minerals, from the softest to the hardest. Each mineral can be scratched by the one that ranks above it.



1. **TALC** is the softest mineral.



2. **GYPSUM** can be scratched by a fingernail.



3. **CALCITE** is as hard as a bronze coin.



4. **FLUORITE** can be scratched by a knife.



5. **APATITE** can be scratched by a piece of glass.



6. **ORTHOCLASE** can be scratched by a drill bit.



7. **QUARTZ** can be scratched by tempered steel.



8. **TOPAZ** can be scratched with a steel file.



9. **CORUNDUM** can be scratched only by diamond.



10. **DIAMOND** is the hardest mineral.

A Desert of Minerals

The Dallol region is part of the Afar depression in Ethiopia. It is known as "the devil's kitchen" because it has the highest average temperature in the world, 93° F (34° C). Dallol is basically a desert of minerals with an ivory-colored crust, sprinkled with green ponds and towers of sulfurous salt, in shades of orange, called hornitos (8 to 10 feet [2.5–3 m] high), many of which are active and spit out boiling water.



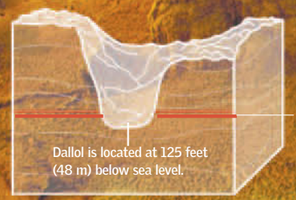
ETHIOPIA
Latitude 9° N
Longitude 39° E



DALLOL VOLCANO

Location	Afar Depression
Type of volcano	Explosion Crater
Elevation	-125 feet (-48 m)
Last eruption	1926
Annual salt extraction	135,000 tons

CROSS SECTION



3.3 billion tons
(3 billion metric tons)

TOTAL RESERVE OF ROCK SALT IN THE AFAR DEPRESSION

Salt Deposits

Hydrothermal activity occurs when underground water comes in contact with volcanic heat. The heat causes the water to rise at high pressure through layers of salt and sulfur. The water then dissolves the salt and sulfur, which precipitate out as the water cools at the surface. As a result, ponds and hornitos are created. The richness of their coloring may be explained by their sulfurous composition and by the presence of certain bacteria.

OLD, INACTIVE HORNITO

TYPES OF HORNITOS
There are two types of hornitos: active ones, which forcefully expel boiling water, and inactive ones, which simply contain salt.

ACTIVE
It expels boiling water, and it is constantly growing.

Boiling water

INACTIVE
Composed of salt, the hornito no longer expels water. It was active in the past.

When its exterior is dark, a hornito is several months old.

Hot water rising from the subsoil

8 to 10 feet (2.5-3 m) high

3 EXIT
The hot water is expelled through the hornito.

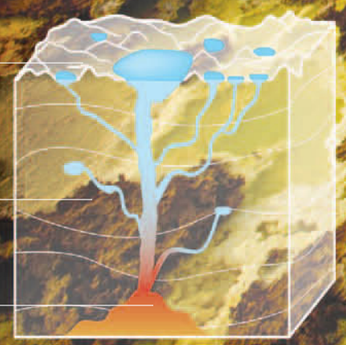
2 HEAT
Contact with hot rock maintains the water's temperature.

1 ASCENT
The hot water starts to rise underground.

YOUNG, ACTIVE HORNITO

MINERALIZATION PROCESS

Water expelled from its magmatic spring erupts, surfacing as thermal water. When the water evaporates, salt deposits are formed.



3 HEAT
The heat causes the water to evaporate. Salt deposits form on the surface.

2 ASCENT
Water rises to the surface through layers of salt and sulfur deposits.

1 HEAT
Volcanic heat warms the water underground.

POND
Boiling water emerges from the hornitos and forms small ponds on the surface.

YOUNG DEPOSIT
Newer deposits have a white color, which becomes darker over time.

OLD DEPOSIT
The dark coloring indicates that this deposit is several months old.



Manual Extraction

Salt is extracted without machinery. Defying the arid climate, inhabitants of the Borena region in southern Ethiopia extract the mineral by hand for a living. They wear turbans to protect themselves from the harmful effects of the Sun. Camels then carry the day's load to the nearest village.

148,800 tons
(135,000 metric tons)
per year

Amount of salt obtained manually in the Afar (or Danakil) depression

Borena

A Black, Muslim, Afar-speaking ethnic group, whose members extract salt in the Dallol. The Borena represent 4 percent of the Ethiopian population.



TURBAN
This piece of clothing protects workers from the extreme temperatures of the desert and the intensity of the Sun while they extract salt.

OTHER MINERALS
In addition to sulfurs and sulfates, potassium chloride, an excellent soil fertilizer, is also extracted from the Dallol.

The Essence of Crystals

All minerals take on a crystalline structure as they form. Most crystals originate when molten rock from inside the Earth cools and hardens. Crystallography is the branch of science that studies the growth, shape, and geometric characteristics of crystals. The arrangement of atoms in a crystal can be determined using X-ray diffraction. The relationship between chemical composition of the crystal, arrangement of atoms, and bond strengths among atoms is studied in crystallographic chemistry. ●

INTERNAL CRYSTALLINE NETWORK

A crystal's structure is repeated on the inside, even in the arrangement of its smallest parts: chlorine and sodium ions. In this case, the electrical forces (attraction among opposite ions and repulsion among similar ones) form cubes, which creates stability. However, different mineral compositions can take many other possible forms.

LEGEND

Chlorine Anion
This nonmetal can only acquire a maximum negative charge of 1.

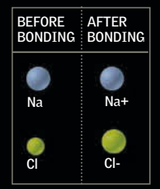
Sodium Cation
This metal can only acquire a maximum positive charge of 1.

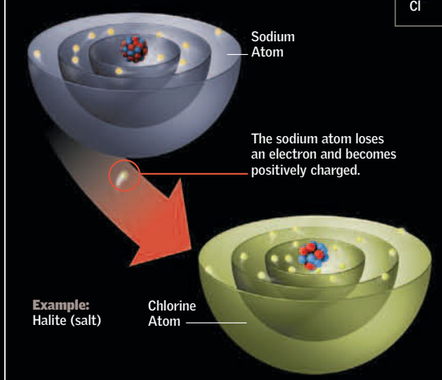
7 Crystalline Systems

The combination of two ions results in a cubic form. When there are more than two ions, other structures are formed.

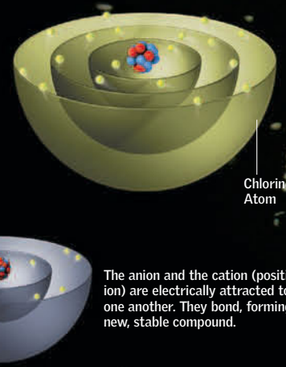
IONIC BOND

Typical of metallic elements that tend to lose electrons in the presence of other atoms with a negative charge. When a chlorine atom captures an electron from a sodium atom (metallic), both become electrically charged and mutually attract each other. The sodium atom shares an electron (negative charge) and becomes positively charged, whereas the chlorine completes its outer shell, becoming negative.



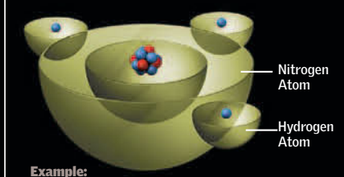


The chlorine atom gains an electron (negative charge) and becomes a negatively charged ion (anion).



COVALENT BOND

This type of bond occurs between two nonmetallic elements, such as nitrogen and oxygen. The atoms are geometrically organized to share electrons from their outer shells. This way, the whole structure becomes more stable.



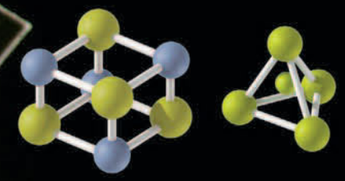
The nitrogen atom needs three electrons to stabilize its outer shell; the hydrogen atom needs only one. The union of all four atoms creates a stable state.así la logran.



CRYSTALS OF COMMON SALT
When salt forms larger crystals, their shape can be seen under a microscope.

BASIC FORMS OF ATOMIC BONDING

This graphic represents an atom's internal crystalline network.



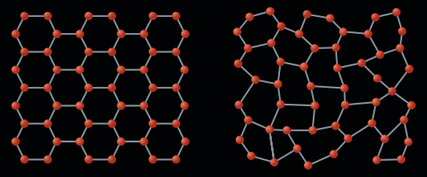
CUBE
Salt (Halite)
1 chlorine atom +
1 sodium atom

TETRAHEDRON
Silica
1 silicon atom +
4 oxygen atoms

CUBIC STRUCTURE
is created through the spatial equilibrium between different ions, which attract each other, and similar ions, which repel each other.

DIFFERENCES BETWEEN CRYSTAL AND GLASS

Glass is an amorphous solid. Because it solidifies quickly, the particles lose mobility before organizing themselves.



ATOMIC MODEL OF A CRYSTAL
The particles combine slowly in regular, stable shapes.

ATOMIC MODEL OF GLASS
Solidification prevents the particles from organizing themselves. This makes the structure irregular.

Crystalline Symmetry

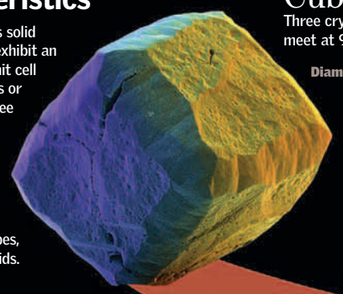
There are more than 4,000 minerals on Earth. They appear in nature in two ways: without an identifiable form or with a definite arrangement of atoms. The external expressions of these arrangements are called crystals, of which there are 32 classes. Crystals are characterized by their organized atomic structure, called a crystalline network, built from a fundamental unit (unit cell). These networks can be categorized into the seven crystalline systems according to the crystal's arrangement. They can also be organized into 14 three-dimensional networks, known as the Bravais lattices.

Typical Characteristics

A crystal is a homogeneous solid whose chemical elements exhibit an organized internal structure. A unit cell refers to the distribution of atoms or molecules whose repetition in three dimensions makes up the crystalline structure. The existence of elements with shared symmetry allows the 32 crystal classes to be categorized into seven groups. These groups are based on pure geometric shapes, such as cubes, prisms, and pyramids.

Cubic
Three crystallographic axes meet at 90° angles.

Diamond



Hexagonal
prisms have six sides, with 120° angles. From one end, the cross section is hexagonal.

Vanadinite



Monoclinic
Prisms look like tetragonal crystals cut at an angle. Their axes do not meet at 90° angles.

Brazilianite



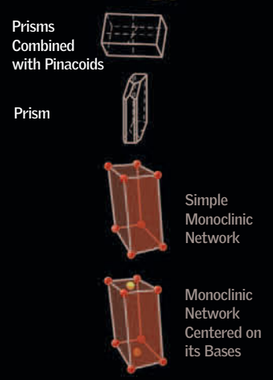
THE MOST COMMON SHAPES



LEGEND

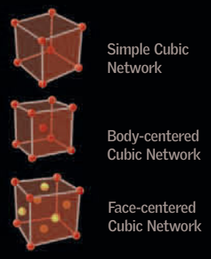






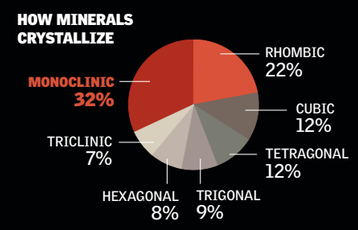
Bravais Lattices

In 1850, Auguste Bravais demonstrated theoretically that atoms can be organized into only 14 types of three-dimensional networks. These network types are therefore named after him.



Only 14 network combinations are possible.

THESE COMBINATIONS ARE CALLED BRAVAIS LATTICES.

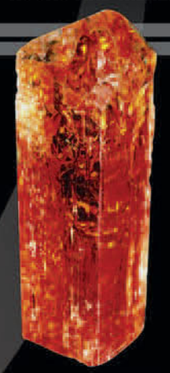


There are seven crystalline systems.

The 32 existing crystal classes are grouped into these crystalline systems.

Rhombic
Three nonequivalent crystallographic axes meet at 90º angles.

Topaz



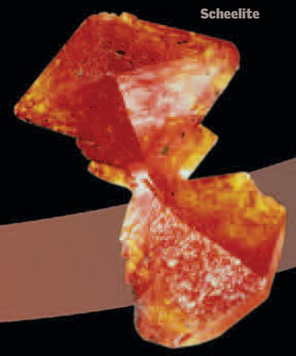
Trigonal
This system includes the most characteristic rhombohedrons, as well as hexagonal prisms and pyramids. Three equal axes meet at 120º, with one axis meeting at 90º to the center.

Rhodochrosite



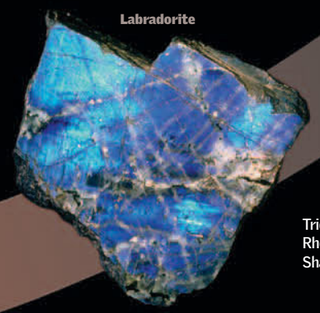
Tetragonal
These crystals are shaped like cubes, but one of their facets is longer than the others. All three axes meet at 90º angles, but one axis is longer than the other two.

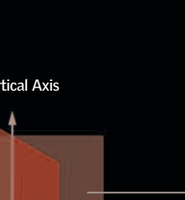
Scheelite



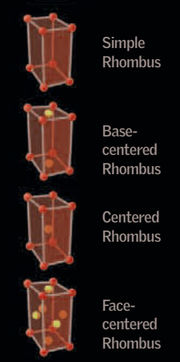
Triclinic
These crystals have very odd shapes. They are not symmetrical from one end to the other. None of their three axes meet at 90º angles.

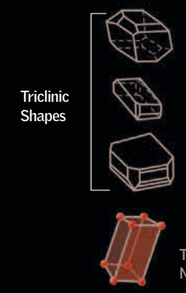
Labradorite

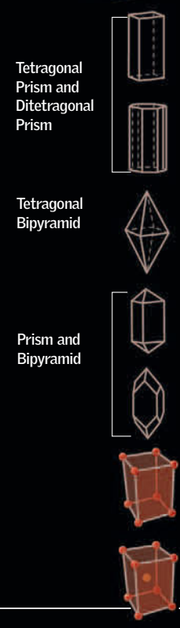




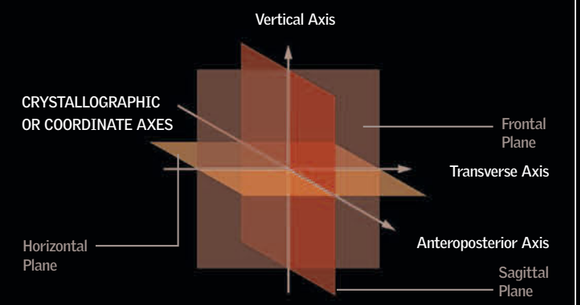








CRYSTAL SYMMETRY
A crystal's ideal plane of symmetry passes through its center and divides it into two equal, symmetrical parts. Its three crystallographic axes pass through its center. A crystal's longest vertical axis is called "c," its transverse axis "b," and its shortest (from front to back) "a." The angle between c and b is called alpha; the one between a and c, beta; and the one between a and b, gamma.



Precious Crystals

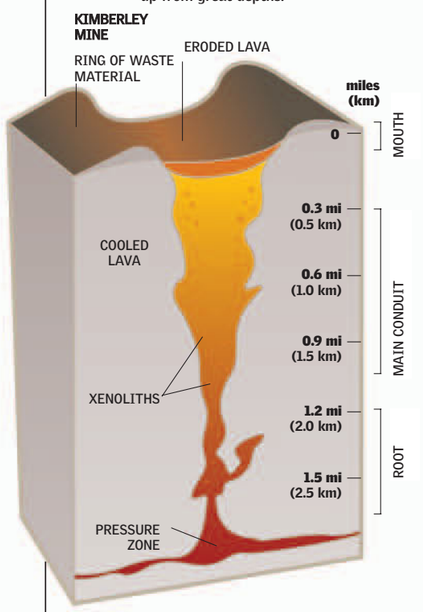
Precious stones are characterized by their beauty, color, transparency, and rarity. Examples are diamonds, emeralds, rubies, and sapphires. Compared to other gems, semiprecious stones are composed of minerals of lesser value. Today diamonds are the most prized gem for their "fire," luster, and extreme hardness. The origin of diamonds goes back millions of years, but people began to cut them only in the 14th century. Most diamond deposits are located in South Africa, Namibia, and Australia.

Diamond

Mineral composed of crystallized carbon in a cubic system. The beauty of its glow is due to a very high refraction index and the great dispersion of light in its interior, which creates an array of colors. It is the hardest of all minerals, and it originates underground at great depths.

1 EXTRACTION

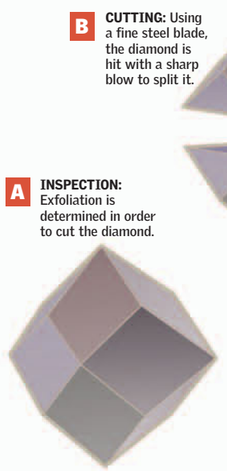
Diamonds are obtained from kimberlite pipes left over from old volcanic eruptions, which brought the diamonds up from great depths.



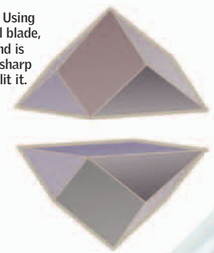
2 CUTTING AND CARVING

The diamond will be cut by another diamond to reach final perfection. This task is carried out by expert cutters.

A INSPECTION: Exfoliation is determined in order to cut the diamond.



B CUTTING: Using a fine steel blade, the diamond is hit with a sharp blow to split it.



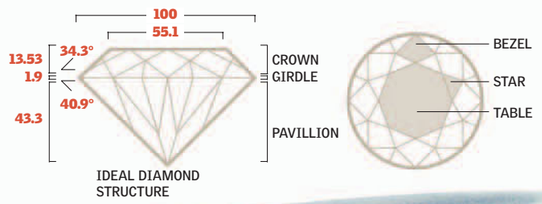
C CARVING: With a chisel, hammer, and circular saws, the diamond is shaped.

27.6 tons
(25 metric tons)
of mineral must be removed to obtain a **1 carat diamond.**

1 carat = 0.007 ounce
(0.2 grams)

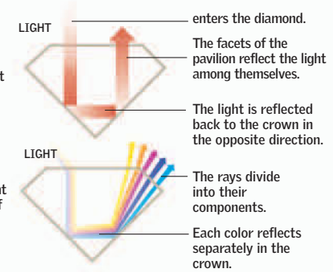
3 POLISHING

The shaping of the facets of the finished gem



BRILLIANCE
The internal faces of the diamond act as mirrors because they are cut at exact angles and proportions.

FIRE
Flashes of color from a well-cut diamond. Each ray of light is refracted into the colors of the rainbow.





320 microns
(0.32 mm)
MEASURED VERTICALLY

THE CHEMISTRY OF DIAMONDS

Strongly bonded carbon atoms crystallize in a cubic structure. Impurities or structural flaws can cause diamonds to show a hint of various colors, such as yellow, pink, green, and bluish white.

COMMON CUTS

A diamond can have many shapes, as long as its facets are carefully calculated to maximize its brilliance.

Gems

Mineral, rock, or petrified material that, after being cut and polished, is used in making jewelry. The cut and number of pieces that can be obtained is determined based on the particular mineral and its crystalline structure.

PRECIOUS STONES



DIAMOND
The presence of any color is due to chemical impurities.



EMERALD
Chromium gives it its characteristic green color.



OPAL
This amorphous silica substance has many colors.



RUBY
Its red color comes from chromium.



SAPPHIRE
Blue to colorless corundum. They can also be yellow.

SEMIPRECIOUS STONES



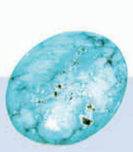
AMETHYST
Quartz whose color is determined by manganese and iron



TOPAZ
A gem of variable color, composed of silicon, aluminum, and fluorine



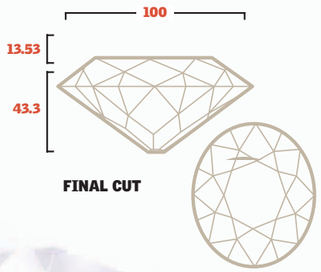
GARNET
A mix of iron, aluminum, magnesium, and vanadium



TURQUOISE
Aluminum phosphate and greenish blue copper

Diamonds in History

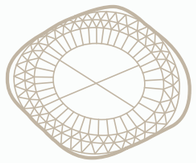
Diamonds are a sign of status, and their monetary value is determined by the law of supply and demand. First discovered by Hindus in 500 BC, diamonds gained fame in the early 20th century when they were advertised in the United States as the traditional gift from husbands to their wives. Some diamonds became famous, however, not only for their economic value but also for the tales and myths surrounding them.

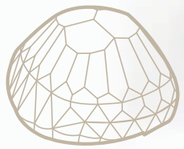


FINAL CUT

The Great Koh-i-noor Diamond

This diamond, which originated in India, now belongs to the British royal family. The raja of Malwa owned it for two centuries, until 1304, when it was stolen by the Mongols. In 1739 the Persians took possession of it. It witnessed bloody battles until finding its way back to India in 1813, after which point it reached the queen.





ORIGINAL CUT
It formerly weighed 186 carats with 30 facets that merged into six facets, which, in turn, became one. This explains its name: Mountain of Light.





Coronation of the Queen Mother

History

In 1856 this diamond was offered to Queen Victoria as compensation for the Sikh wars. She then had it recut. The Koh-i-noor was diminished to 109 carats.

ONLY FOR WOMEN
Because this diamond was believed to bring unhappiness to men, the superstitious Queen Victoria added a clause to her will stating that the diamond should only be handed down to the wives of future kings.



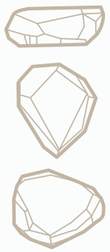
The Queen Mother's Crown



Legend

Over the years, belief in the curse of the Hope Diamond was reinforced as its owners fell into ruin. Evalyn Walsh McLean, the last private owner of the diamond, did not sell it even after several tragedies befell her family.

1669	Louis XIV acquires the gem. He died in agony of gangrene.
1830	Henry Hope buys the diamond and suffers under the curse; he soon sells it.
1918	While the stone is in the hands of members of the McLean family, the patriarch and two of his daughters die.



ORIGINAL CUT The purest of blue from the presence of boronic impurities, the diamond's color is also influenced by the presence of nitrogen, which adds a pale yellow shade.



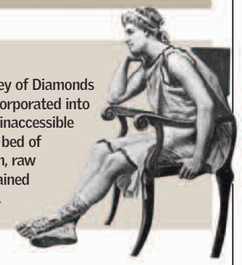
Evalyn Walsh McLean



Elizabeth Taylor

THE TAYLOR-BURTON DIAMOND
This diamond, with a weight of 69.42 carats, was auctioned in 1969. The day after buying it, Cartier sold it to the actor Richard Burton for $1.1 million. His wife Elizabeth Taylor tripled its value when she sold it after divorcing him.

THE LEGEND OF THE VALLEY OF DIAMONDS
Alexander the Great introduced the legend of the Valley of Diamonds to Europe. According to this ancient account, later incorporated into the book *The Thousand and One Nights*, there was an inaccessible valley located in the mountains of northern India. The bed of this valley was covered with diamonds. To obtain them, raw meat was thrown in the valley and then fetched by trained birds, which would return it encrusted with diamonds.



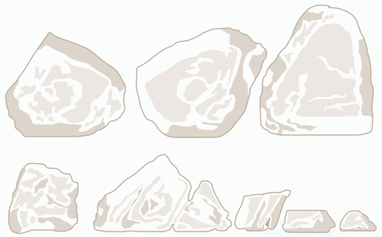
The Misfortune of Possessing Hope

The Hope Diamond is legendary for the harm it brought to its owners since being stolen from the temple of the goddess Sita in India. According to the legend, its curse took lives and devoured fortunes. In 1949 diamond expert Harry Winston bought it and in 1958 donated it to the Smithsonian Institution, in Washington, D.C., where it can be viewed by the public.

Cullinan, the Greatest Find

Discovered in 1905 in South Africa, this diamond is the biggest ever found. It was sold to the government of Transvaal two years after its discovery for $300,000 (£150,000). It was then given to Edward VII on the occasion of his 66th birthday. The king entrusted the cutting of the diamond to Joseph Asscher of The Netherlands, who divided it into 105 pieces.

9 LARGE AND 96 SMALL PIECES
Joseph Asscher studied the huge stone for six months to decide how to cut it; he then divided it into nine primary stones and 96 smaller diamonds.



THE GREAT STAR OF AFRICA
This gem is the second largest cut diamond in the world, weighing 530 carats. Because it belongs to the British Crown, it is on display in the Tower of London.



FINAL CUT

530 carats

is the weight of the Cullinan I, the largest stone obtained from the original Cullinan find. It is followed by Cullinan II, which weighs 317 carats and is set in the imperial crown.



The Most Common Minerals

Silicates, which form 95 percent of the Earth's crust, are the most abundant type of mineral. Units of their tetrahedral structure, formed by the bonding of one silicon and four oxygen ions, combine to create several types of configurations, from isolated simple tetrahedrons to simple and double chains to sheets and three-dimensional complex networks. They can be light or dark; the latter have iron and magnesium in their chemical structures.

Structures

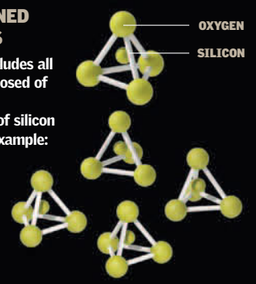
The basic unit of silicates consists of four oxygen ions located at the vertices of a tetrahedron, surrounding a silicon ion. Tetrahedrons can form by sharing oxygen ions, forming simple chains, laminar structures, or complex three-dimensional structures. The structural configuration also determines the type of exfoliation or fracture the silicate will exhibit: mica, which is composed of layers, exfoliates into flat sheets, whereas quartz fractures.

Simple Structure

All silicates have the same basic component: a silicon-oxygen tetrahedron. This structure consists of four oxygen ions that surround a much smaller silicon ion. Because this tetrahedron does not share oxygen ions with other tetrahedrons, it keeps its simple structure.

UNCOMBINED SILICATES

This group includes all silicates composed of independent tetrahedrons of silicon and oxygen. Example: olivine.



OLIVINE

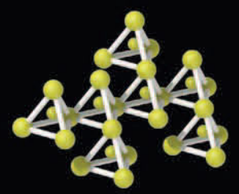


Complex Structure

This structure occurs when the tetrahedrons share three of their four oxygen ions with neighboring tetrahedrons, spreading out to form a wide sheet. Because the strongest bonds are formed between silicon and oxygen, exfoliation runs in the direction of the other bonds, parallel to the sheets. There are several examples of this type of structure, but the most common ones are micas and clays. The latter can retain water within its sheets, which makes its size vary with hydration.



AUGITE

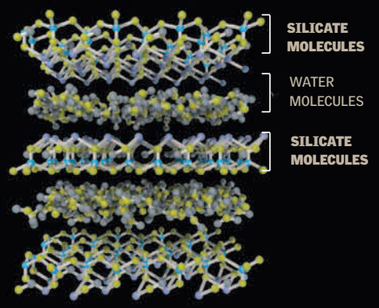


CHAINS

Clays are complex minerals with a very fine grain and a sheetlike structure.



KAOLINITE

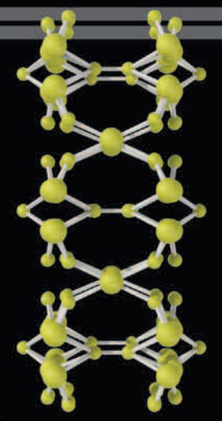


Three-dimensional Structure

Three fourths of the Earth's crust is composed of silicates with complex structures. Silicas, feldspars, feldspathoids, scapolites, and zeolites all have this type of structure. Their main characteristic is that their tetrahedrons share all their oxygen ions, forming a three-dimensional network with the same unitary composition. Quartz is part of the silica group.

THREE-DIMENSIONAL STRUCTURE

Quartz has a complex three-dimensional structure composed only of silicon and oxygen.



LATERAL VIEW

VIEW FROM ABOVE

MINERAL COMBINATIONS

DARK SILICATES

IRON AND MAGNESIUM
EXAMPLE: BIOTITE

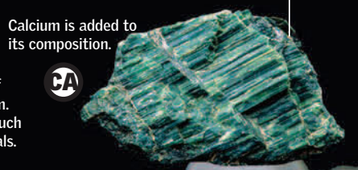
The color and heaviness of this mineral are caused by the presence of iron and magnesium ions. Known as a ferromagnesian mineral, biotite's specific gravity varies between 3.2 and 3.6.



LIGHT SILICATES

MAGNESIUM
EXAMPLE: MINERAL TALC

This mineral contains variable amounts of calcium, aluminum, sodium, and potassium. Its specific gravity is, on average, 2.7—much lower than that of ferromagnesian minerals.





RESULTING SHAPE

The quartz crystal maintains a hexagonal shape with its six sides converging to a tip (pyramid).

A CRYSTAL OF GREAT VOLUME

For a quartz crystal to acquire large dimensions, it needs a great deal of silicon and oxygen, much time, and ample space.

The Nonsilicates

Sulfurs, oxides, sulfates, pure elements, carbonates, hydroxides, and phosphates are less abundant than silicates in the Earth's crust. They make up eight percent of minerals, but they are very important economically. They are also important components of rock. Since ancient times, some have been appreciated for their usefulness or simply for their beauty. Others are still being researched for possible industrial uses.

Very Few in a Pure State

It is rare for native chemical elements to be found in the Earth's crust in a pure state. In general, they must be extracted from other minerals by means of industrial chemical processes. However, they can occasionally be found in rocks in a pure state. Diamonds, for instance, are pure carbon.

Native Elements

In addition to carbon—which forms minerals such as diamond and graphite when crystallized—copper, gold, sulfur, silver, and platinum are other minerals that are found as native elements.

ASSOCIATION
The greenish color indicates the formation of copper sulfate.

FORMATION OF CHALCOPYRITE
Iron, copper, and sulfur are present.

DENDRITES
Microscopic forms that appear when copper solidifies and crystallizes

COPPER

1.2 inches (3 CM)

Copper nuggets can reach a high degree of purity.

MAGNETITE

Oxides

Metal associations with oxygen atoms. Ilmenite, hematite, and chromite are ores from which titanium, iron, and chrome are extracted. Rubies and sapphires are extracted from corundum.

LIMONITE

Hydroxides

Known in chemical terms as a base, these types of minerals appear through the association of oxide with water. Limonite, an iron ore used as pigment because of its reddish color, and bauxite (or aluminum hydroxide) are among the most abundant hydroxides. Bauxite is the ore from which aluminum, a metal that is becoming more and more widely used, is extracted.

APATITE

Phosphates

Both apatite, used as fertilizer, and the semiprecious stone turquoise are phosphates. These materials have a complex structure based on an ion composed of one phosphorus and four oxygen atoms. These ions, in turn, are associated with compound ions of other elements.

GYPSUM ROSETTE

Sulfates

Gypsum, widely used in construction, is a calcium sulfate that forms in the sea and contains water in its structure. Without water, calcium sulfate forms another mineral, anhydrite, which is also used in construction. Barytine is a sulfate from which the metal barium is extracted.

In Alloys and Compounds

As was the case with silicates, it is very difficult to find rocks composed of pure nonsilicate elements—elements with atoms of only one type. The constituent elements of nature, metal and nonmetal, tend to join together and form compounds and alloys. From a chemical perspective, even ice, solidified water, is a compound of hydrogen and oxygen atoms. Some compounds are used as ores, meaning that they are mined for their constituent elements. For example, pure aluminum is obtained from bauxite. Other compound minerals, however, are used for their specific properties, which can be very different from those of each of their constituent elements. This is the case with magnetite, which is an iron oxide.

FLUORITE

Halides

are binary compounds. One halite is table salt (or sodium chloride). Halites have many uses: fluorite is used in the industrial production of steel, and sylvite (potassium chloride) is used as fertilizer.

MALACHITE

Carbonates

Simpler than silicates, minerals in this group are composed of a complex anion associated with a positive ion. Calcium carbonate (calcite, the main component of limestone) and calcium magnesium carbonate (dolomite) are the most common carbonates.

ENCRUSTED IN ROCK
Here crystals are encrusted in slate, a metamorphic rock.

"FOOL'S GOLD"
was an early name for pyrite because of its glitter.

0.04 inch (1 mm)

PYRITE

Sulfides

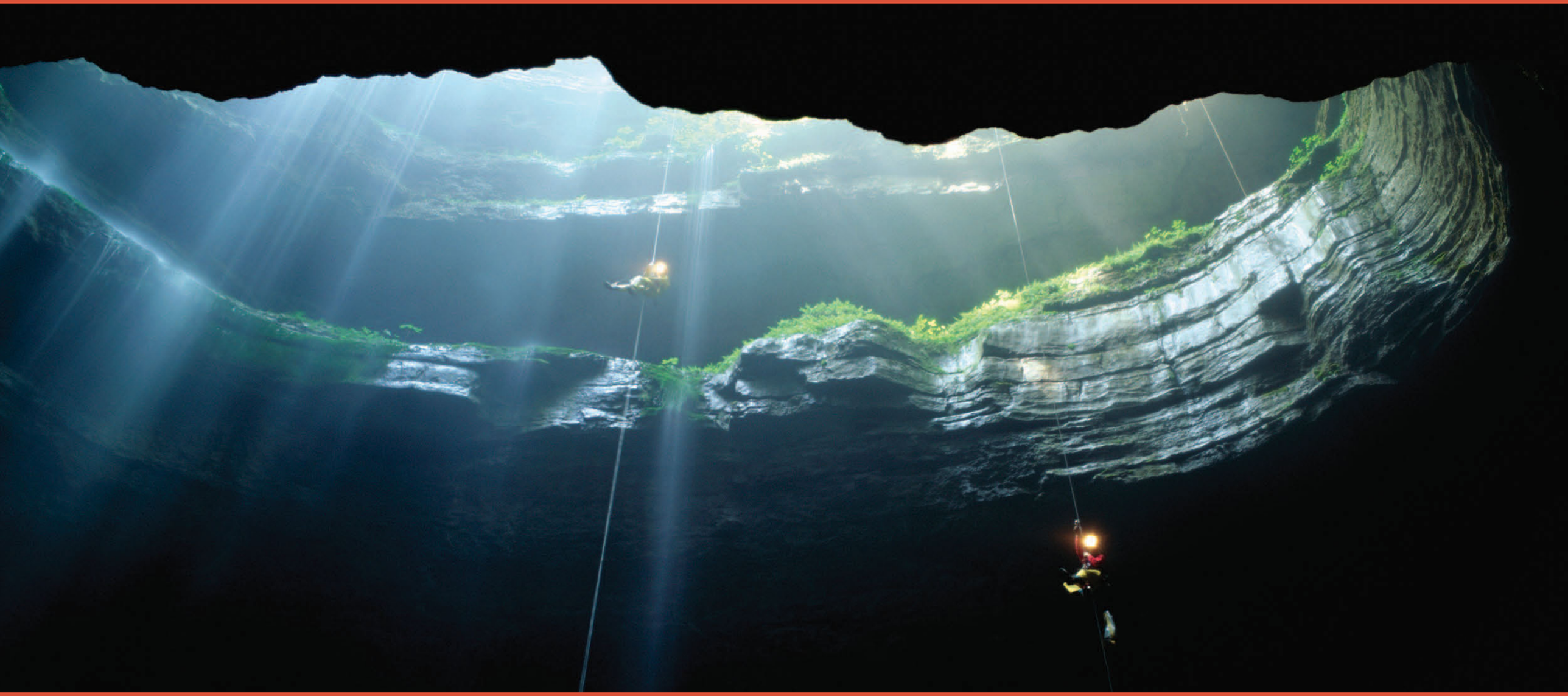
are found in metal ores and are associated with sulfur. Examples of sulfides are pyrite (iron), chalcopyrite (iron and copper), argentite (silver), cinnabar (mercury), galena (lead), and sphalerite (zinc).

STRUCTURE OF PYRITE
The cubic shape of crystals comes from the balanced location of iron and sulfur atoms.

Formation and Transformation of Rocks

SUBTERRANEAN WORLD
This awe-inspiring limestone cave in Neversink Pit (Alabama) looks like no other place on Earth.

ROCKS OF FIRE 42-43
SCULPTED VALLEY 44-45
EVERYTHING CHANGES 46-49
DARK AND DEEP 50-51
IF STONES COULD SPEAK 52-53
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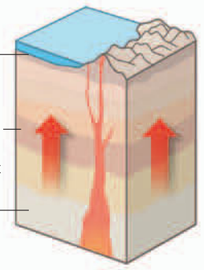
Natural forces create an incredible variety of landscapes, such as deserts, beaches, elevated peaks, ravines, canyons, and underground caves. Settings like the one in the picture amaze us and arouse our interest in finding out what is hidden in the cave's depths. Rocks subjected to high pressure and temperatures can undergo remarkable changes. An initially igneous rock can become sedimentary and later metamorphic. There are experts who overcome every type of obstacle to reach inhospitable places, even in the bowels of the Earth, in search of strange or precious materials, such as gold and silver. They also look for fossils to learn about life-forms and environments of the past. ●

Rocks of Fire

Igneous (from Latin *ignis*, "fire") rocks form when magma coming from the rocky mantle (underneath the crust) rises, cools, and solidifies. When magma comes to the surface as lava and solidifies relatively quickly, it creates extrusive rocks, such as basalt or rhyolite. On the other hand, when magma seeps into caves or between rock layers and slowly solidifies, intrusive igneous rocks, such as gabbro and granite, are formed. These rocks usually have thicker grains and are less dense than the extrusive ones. They are arranged in structures called dikes, sills, and batholiths beneath the surface. Igneous rocks make up most of the Earth's crust.

A Complex Process

The Earth's crust is 44 miles (70 km) deep at most. Farther down, rocks are molten or semimolten, forming magma that rises through the crust and opens paths through cracks, cavities, or volcanoes. Magma can solidify when it is moving or still or when underground or expelled to the surface. All these characteristics together with different mineral compositions create a wide variety of igneous rocks.



BENEATH THE SURFACE
PLUTONIC ROCKS

Most magma is underground in the form of plutons, which undergo a solidification process. This forms intrusive (or plutonic) rocks. When magma intrudes into vertical fissures, the resulting rock formations are called dikes; those between sedimentary layers are sills; and batholiths are masses hundreds of miles long. In general, intrusive rocks crystallize slowly, and their minerals form thick grains. But the solidification process will determine the structure; the rock will be different depending on whether solidification is slow (over millions of years) or fast and whether it loses or gains materials along the way.

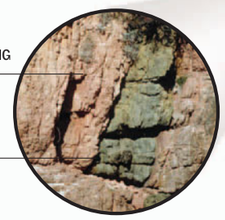


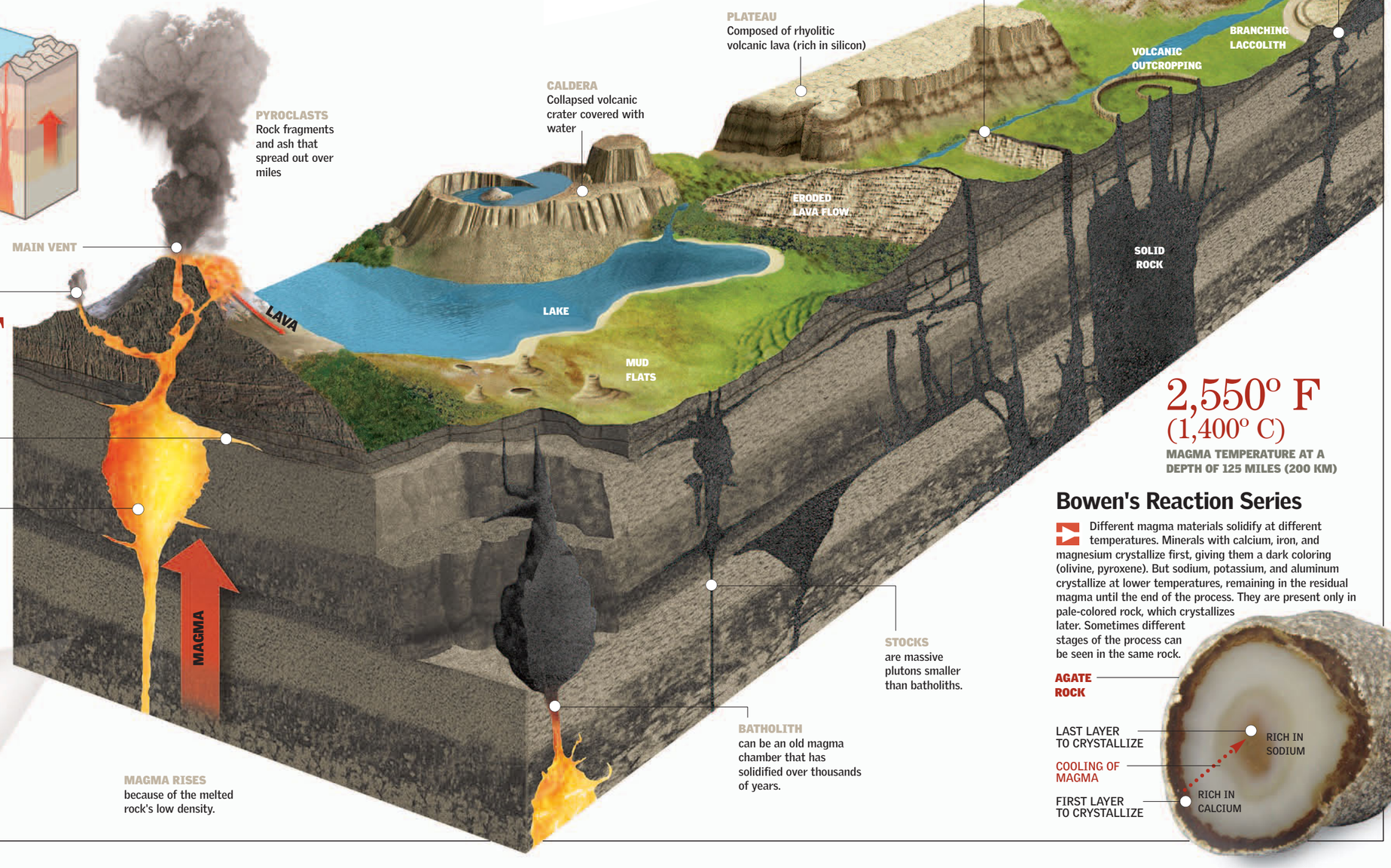
GRANITE
Composed of feldspar and quartz crystals, it is rich in sodium, potassium, and silica.

70% SILICA CONTENT

DIKES

The structure of the rock depends on its formation process. Thus, a rock resulting from magma intrusion into a dike will have a structure and coloring different from the rock around it because of having crystallized faster.





ON THE SURFACE
VOLCANIC ROCK

Volcanic, or extrusive, rocks are those that reach the surface as lava because of volcanic activity. They solidify relatively quickly on the surface. Some, like the obsidians, solidify too quickly to crystallize. This class of rock is distinguished by its viscosity, caused by the low silica content and dissolved gas at the moment of eruption, which give these rocks a particular texture. Highly liquid lava, such as basalt, usually covers large surfaces because it solidifies on the outside while still remaining fluid underground.

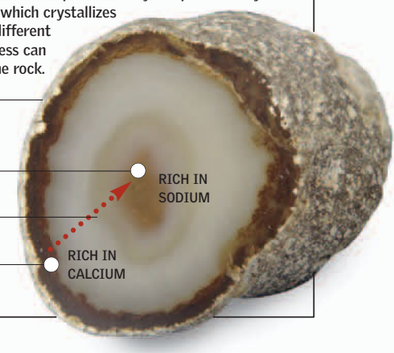


BASALT ROCK originates from highly liquid fluid magma that cools quickly.

50% SILICA CONTENT According to the type of lava

Bowen's Reaction Series

Different magma materials solidify at different temperatures. Minerals with calcium, iron, and magnesium crystallize first, giving them a dark coloring (olivine, pyroxene). But sodium, potassium, and aluminum crystallize at lower temperatures, remaining in the residual magma until the end of the process. They are present only in pale-colored rock, which crystallizes later. Sometimes different stages of the process can be seen in the same rock.



Sculpted Valley

Yosemite National Park is located 200 miles (320 km) east of San Francisco, California. This park is known worldwide for its granite cliffs, waterfalls, crystalline rivers, and forests of giant sequoias. It covers an area of 1,190 square miles (3,081 sq km) and extends along the eastern slopes of the Sierra Nevada range. Yosemite National Park has over three million visitors every year.

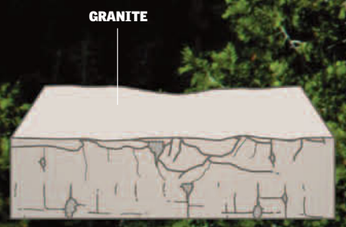
Yosemite

This park has an average elevation of 1,300 to 2,000 feet (400-600 m) above sea level. The geology of the area is mostly composed of a granitic batholith, but five percent of the park is composed of formations from the metamorphism of volcanic and sedimentary rocks. Erosion at different elevations and fracture systems created valleys, canyons, hills, and other current geological formations. The wide separation between fractures and joints is caused by the amount of silica present in the granite and in the metamorphic rocks.

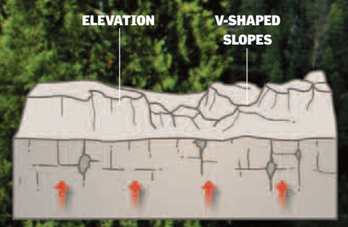
FORMATION OF THE LANDSCAPE

Erosion in the joints resulted in valleys and canyons. The strongest erosive forces of the last several million years have been glaciers, which changed the V-shaped valleys created by rivers into U-shaped glacial valleys.

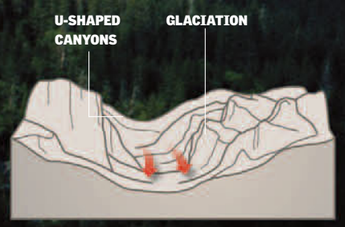
1 BATHOLITH FORMATION
Almost all rocky formations at Yosemite Park are composed of granite; they belong to the original batholith.



2 ASCENT
Ten million years ago, the Sierra Nevada underwent a tectonic elevation that caused the batholith to emerge.



3 EROSION
One million years ago, the descending flow of glacial ice gave the valley a U shape.



103 Million Years

EL CAPITAN
300-foot-high (1,000 m) granite cliff used for mountain climbing

87 Million Years Ago

HALF DOME
Granite monolith of unique beauty. It is lower than El Capitan, being 2,160 feet (660 m) high.

616 feet (188 m)

FREE FALL

BRIDAL VEIL FALLS
This huge waterfall formed as a consequence of glacial thaw in a "hanging" valley.

103 Million Years Ago

CATHEDRAL ROCKS
One of the main rock formations, with compacted and scratched granite walls



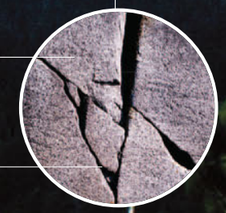
YOSEMITE NATIONAL PARK
United States
Latitude 37° N
Longitude 119° W

Location	California
Surface	1,190 square miles (3,081 sq km)
Visitors in 2005	3,380,038
Opened on	9/25/1890
Administered by	National Park Service

CASCADES

Some rock formations in the park serve as platforms for waterfalls, especially in April, May, and June when the snow melts upstream. The valley has nine waterfalls, five of which are over 1,000 feet (300 m) high; Yosemite Falls is 2,600 feet (800 m) high. This is the highest waterfall in North America and the third highest in the world.

FOREST
The park has three groves of giant sequoias, among other species.



ROCK
Compact granite forming a large batholith

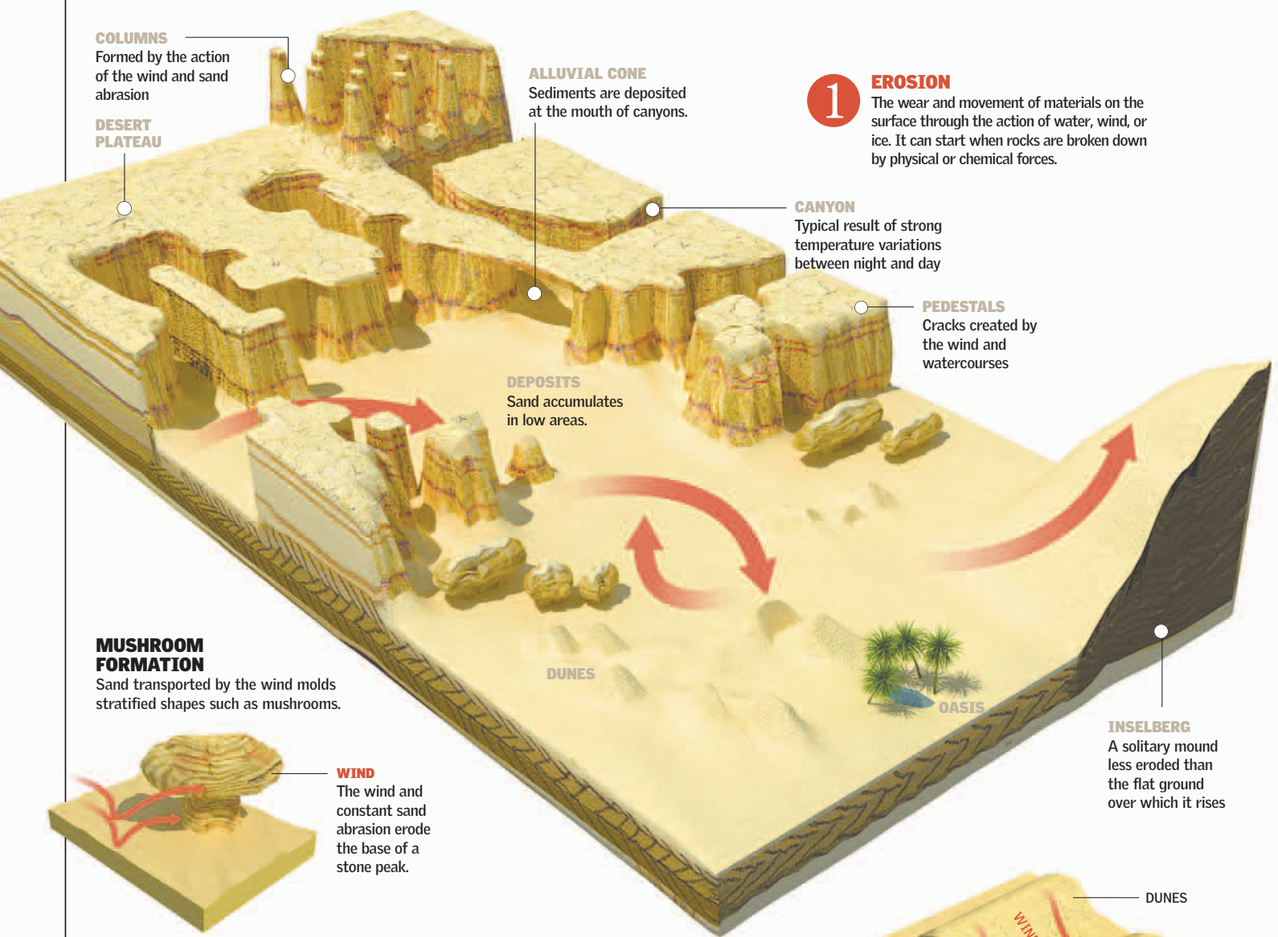
FISSURE
Produced by erosion at rock joints

FISSURES

The erosion at rock joints causes fissures within them, and this process leads to the formation of valleys and canyons. The downward flow of the glacial mass of ice cut and sculpted the valley into a U shape. Today this unique landscape attracts great numbers of visitors.

Everything Changes

Wind, ice, and water. These natural elements cause great changes in the Earth's landscape. Erosion and transportation are processes that produce and spread rock materials. Then, when these materials settle and become compacted, new rocks are created, which in turn will revert to sediment. These are sedimentary rocks: the most widely known rocks, they cover 70 percent of the Earth's surface. By observing sedimentary rocks of different ages, scientists can estimate how the climate and the environment have changed. ●



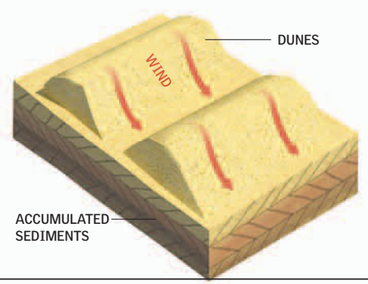
1 EROSION
The wear and movement of materials on the surface through the action of water, wind, or ice. It can start when rocks are broken down by physical or chemical forces.

MUSHROOM FORMATION
Sand transported by the wind molds stratified shapes such as mushrooms.

Deserts

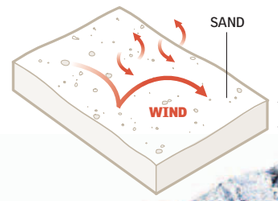
The largest environments sculpted by wind are the deserts. Because of the scarcity of water and the widely varying temperatures, the rock is broken down by physical forces. Rocks fragment and are swept to low-lying areas by occasional water currents. Then sand and mud will be swept away by the wind in a process called deflation. Through this process particles can be transported into semiarid regions.

DUNE EROSION
By transporting sand grains from the crest of the ridge, the wind moves the dunes. The grains can be transported up to 100 feet (30 m) per year.

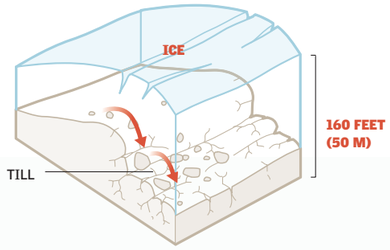


TRANSPORT OF SEDIMENTS

DESERT
TINY GRAINS
In the desert, the wind moves particles in three ways: suspension (very fine grains and dust), transport (the most basic way), and sliding along the surface.



GLACIER
FINE AND HETEROGENEOUS
Glaciers transport rock fragments, which accumulate in moraines. They are made up of a heterogeneous material called till, which, together with rocks, is carried along by the glacier.



GLACIAL CIRQUE
At the upper end of the valley, the walls erode in a semicircular form.

2 TRANSPORT
After erosion, fragments are transported to an area where they will be deposited. In deserts, the wind transports the sand grains, forming dunes; with glaciers, the debris forms frontal and lateral moraines.

SLOPES
Rocks fall from slopes onto glaciers. They are included in the material that makes up the moraine.

CENTRAL MORAINE
forms when two valley glaciers meet, creating only one mass of ice.

CRACKS

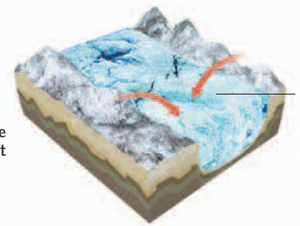
TRANSPORTED ROCK
will be deposited on the moraines.

LATERAL MORAINE
Formed by the fragments accumulated along the sides of the glacier

ERRATICS
are large rock fragments that the glacier transports and deposits.

FINE SEDIMENT
is deposited under the glacier and at its front end. The deposited material is called till.

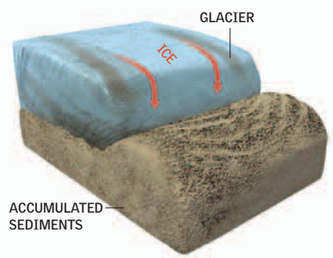
U-SHAPED VALLEYS
Glaciers erode valleys, forming a U shape because erosion is greatest at the bottom.



Glaciers

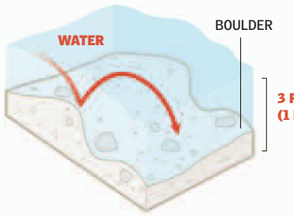
These huge ice masses form on the ground, slowly moving downward through the action of gravity. As they advance, they carry away rocks in their path. At the head of a glacier valley, the walls erode in a semicircle, forming what is called a glacial cirque. The simultaneous, progressive erosion of the walls creates a pyramidal horn, or peak. The valleys through which a glacier has passed are U-shaped instead of the V shape typical of the erosion of river valleys.

TERMINAL MORAINE
Rocks that fall onto the glacier, along with the rock it was already carrying, accumulate at the front of the glacier and form what is called a terminal moraine.

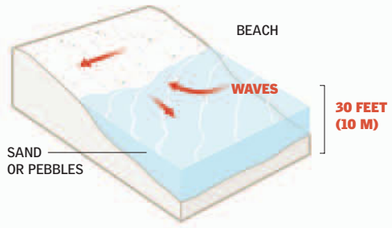


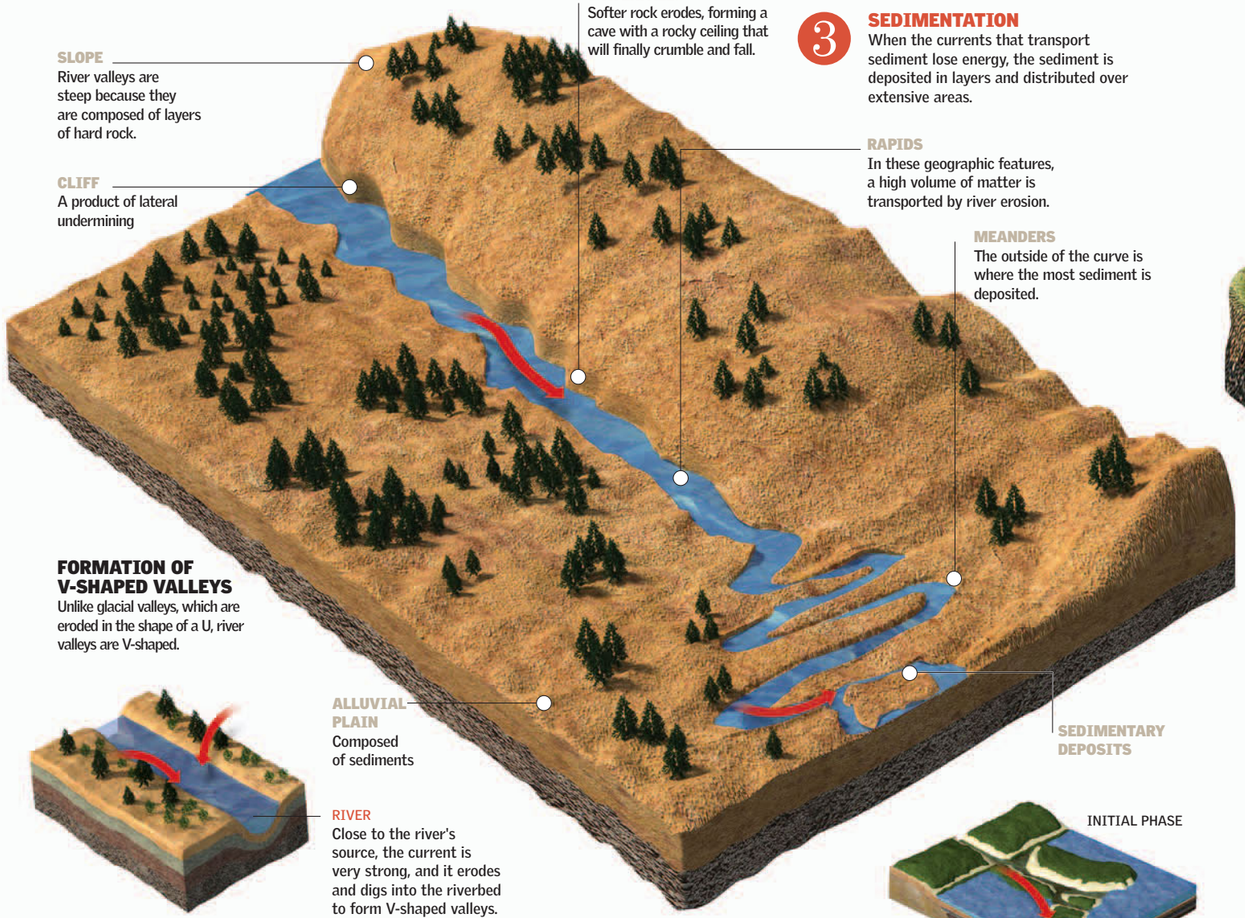
TRANSPORT OF SEDIMENTS

RIVER
GREAT DISTANCES
A river can transport sediments over great distances. Rivers originate in elevated areas, from which they flow to lower areas and then to the sea. When the current gathers speed, it transports big boulders. When the energy is less, the current carries only smaller rocks.



COAST
LOCAL DEPOSITS
After each wave breaks, the undertow descends the beach slope, creating an accumulation of sand that has been transported by the waves in a process called a coastal current. Sand is also transported by rivers, which deposit sediments in their deltas.





FORMATION OF V-SHAPED VALLEYS
Unlike glacial valleys, which are eroded in the shape of a U, river valleys are V-shaped.

RIVER
Close to the river's source, the current is very strong, and it erodes and digs into the riverbed to form V-shaped valleys.

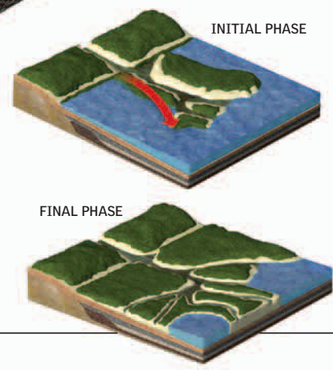
3 SEDIMENTATION

When the currents that transport sediment lose energy, the sediment is deposited in layers and distributed over extensive areas.

Rivers

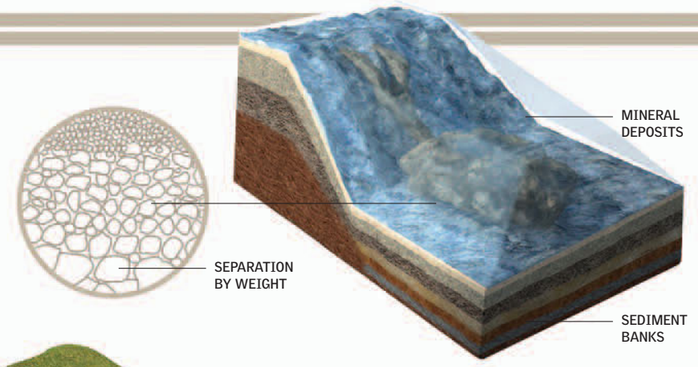
Close to their source, rivers flow through areas of high elevation. The water descends there with great force and energy, which enables the current to transport large boulders. At low elevations, rivers flow more smoothly over sediments, forming meanders and eroding laterally. On reaching the coast, rivers deposit sediments and form estuaries or deltas.

DELTA FORMATION
The sediment deposited at the river's mouth creates a delta, an area with sandbars through which the river flows in various directions.



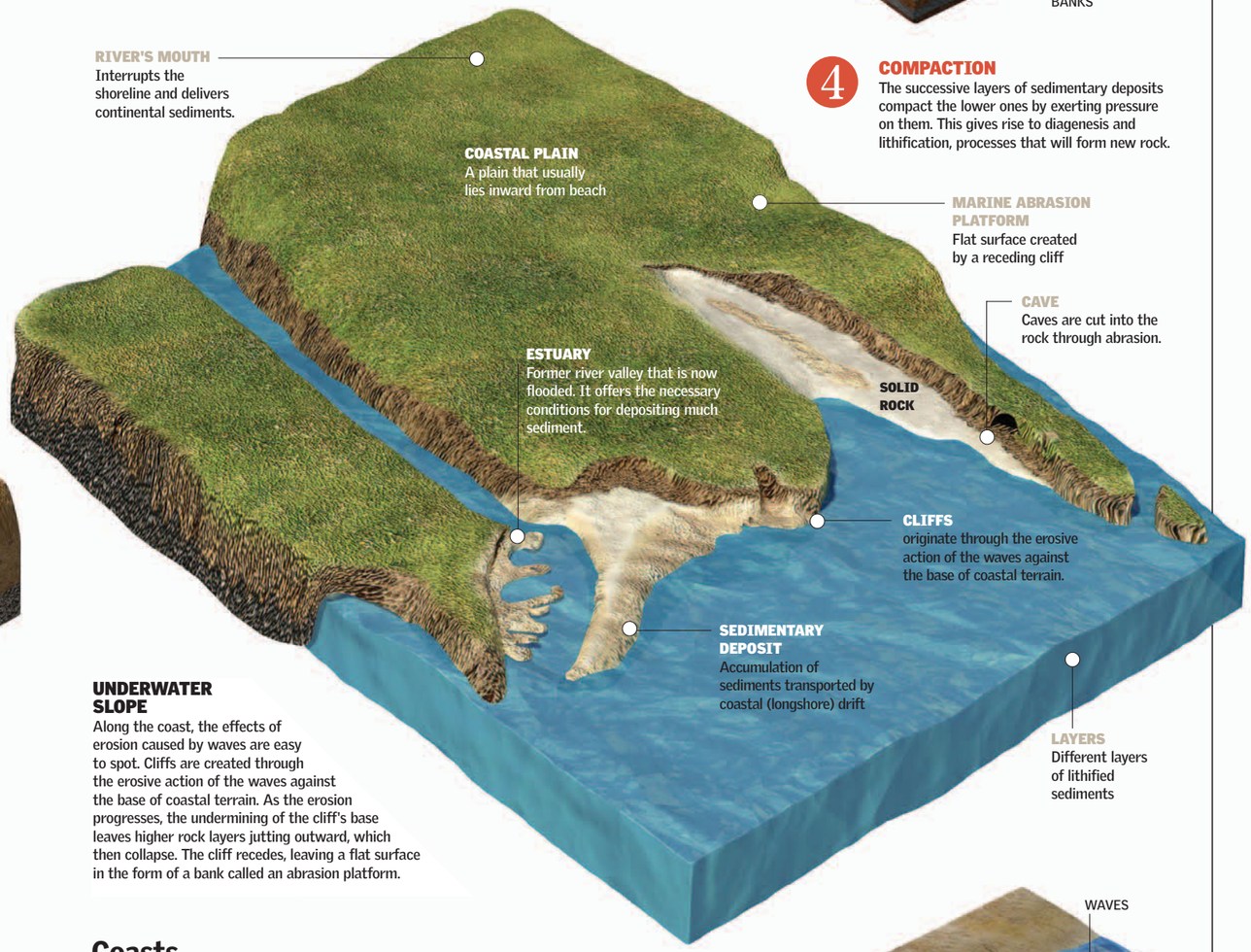
CEMENTATION PROCESS

This is the most important process that transforms sediment into rock. Cementation occurs when particles join with the materials precipitated from the water currents. Sedimentary rocks are formed through the union of different minerals that have been dissolved in water. When the water evaporates or cools, the dissolved minerals can precipitate and form deposits that accumulate with other sediments, or they can form rocks on their own. Salts and sandstone are common examples of cemented rocks.



4 COMPACTION

The successive layers of sedimentary deposits compact the lower ones by exerting pressure on them. This gives rise to diagenesis and lithification, processes that will form new rock.

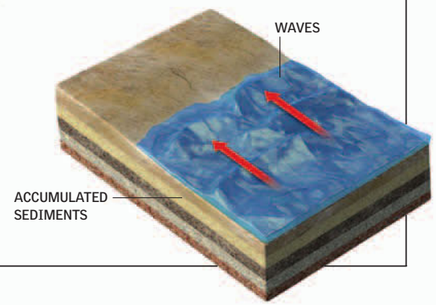


UNDERWATER SLOPE
Along the coast, the effects of erosion caused by waves are easy to spot. Cliffs are created through the erosive action of the waves against the base of coastal terrain. As the erosion progresses, the undermining of the cliff's base leaves higher rock layers jutting outward, which then collapse. The cliff recedes, leaving a flat surface in the form of a bank called an abrasion platform.

Coasts

Ocean coasts are the most changing landscapes in the Earth's geography thanks to a process called coastal drift. The elements that build up the coastline—wind, rain, and waves—also erode and mold it. Thus, the waves that bring the sediments that form beaches and carry them away are the same waves that can create or knock down a cliff or cave. Its remnants will be the building material for another beach, along with the sediment that comes from rivers and their deltas.

BEACH FORMATION
Beaches are formed from the gradual deposits of waves in low-energy coastal zones. They can be made of fine sediment, such as mud and sand, or of larger materials, such as boulders.

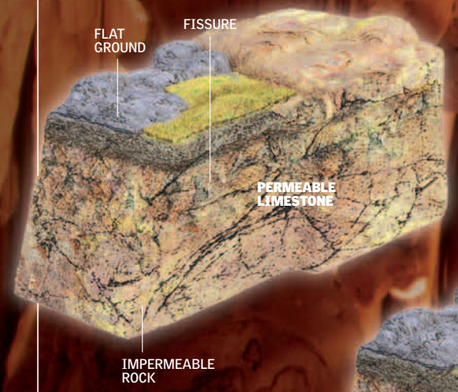


Dark and Deep

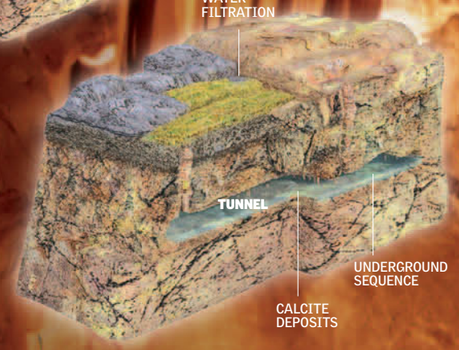
A cave is a hollow space created essentially through the chemical action of water on a soluble, usually chalky, material. Caves have three structures: stalactites (conical structures that hang from the cave ceiling), stalagmites (structures that jut from the cave floor), and columns (created when stalactites and stalagmites join). The cycle of cave formation is called the karst cycle, which lasts a total of around one million years. For this reason, young, active caves have noisy streams and cascades, whereas old caves are silent wonders decorated with stalagmites, stalactites, and columns.

The Karst Cycle

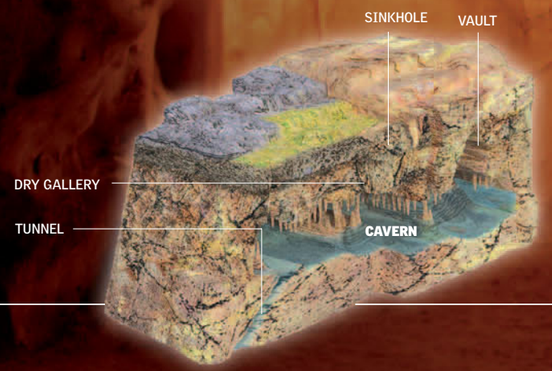
When water dissolves high calcium content rock through the corrosive effect of carbonic acid, it forms networks of conduits and galleries. The initial fissures widen not only through this chemical process but also mechanically through the abrasive action of pebbles and other insoluble elements. Water is filtered until it reaches lower levels, leaving in its wake openings arranged in levels and separated by vertical pits and passages that connect the different levels.



1 STRUCTURE OF THE STRATUM OF A CAVE
The ground's original structure is composed of permeable limestone. It has fissures through which river or rainwater is filtered. This starts the erosive process.



2 INITIAL CAVE
Water, following the contour of the terrain, forms an underground river. The first calcite or calcium carbonate deposits start to form in the shape of stalactites.



3 EXTENDED CAVE SYSTEM
Formed when several tunnels are joined together. Sometimes the surface of the soil starts to sink, creating sinkholes. If the cave extends below the water table, tunnels are formed.

COLUMN
If stalactites and stalagmites grow until they join together, they become columns.

130 feet
(39 m)
THE HIGHEST COLUMN IN THE WORLD

STALAGMITE
Water droplets containing dissolved carbonate create stalagmites as they drip down.

100 feet
(30 m)
THE TALLEST STALAGMITE IN THE WORLD

Stalactite Formation

Limestone is a rock composed almost exclusively of calcium carbonate, which dissolves in naturally acid water. Rainwater absorbs carbon dioxide from the air and microorganisms from the ground, becoming a weak acid. When filtered, it can dissolve limestone over time. If this water drips into a cave, it loses carbon dioxide to the air and deposits the excess calcium in stalactites and stalagmites, thereby maintaining chemical equilibrium. Stalactites are excellent examples of chemical sedimentary rocks.

65° F
(18° C)
IDEAL TEMPERATURE FOR THE PRECIPITATION OF CARBONATE



1 WATER DROPLET
Every stalactite starts from a simple water droplet containing dissolved salts.

2 CALCITE
When the droplet falls, it leaves behind a narrow calcite trail.

3 MORE LAYERS
Each successive droplet that falls deposits another fine calcite layer.

4 INTERIOR TUBE
The layers form around a narrow pipe (0.02 inch [0.5 mm]) through which the water seeps.

5 STALACTITE
If many droplets are deposited over this pipe, stalactites are formed.

STALACTITES
can form on ceilings and cement floors, although they form much faster in a cave's natural environment that contains carbon-rich solutions.

23 feet
(7 m)
THE BIGGEST STALACTITE IN THE WORLD



CANGO CAVES
SOUTH AFRICA
Latitude 33º S
Longitude 18º E

Length	3.3 miles (5.3 km)
Depth	200 feet (60 m)
Location	East of Cape Town

Other Formations

A passing underground current forms two types of landscape: canyons and tunnels. Underground rivers and waterfalls above the water table create deep, undulating canyons by eroding and dissolving limestone and by abrading the rock layers with sediment. Below the water table, caves are full of water that moves slowly, dissolving walls, floors, and ceilings of carbonate rock to create tunnels.

CANGO CAVES

Isolated in a narrow strip of limestone from the Precambrian, in the highlands of Oudtshoorn, the Cango Caves are remarkable for their abundant deposits of calcite. They are left over from a larger channel below the water table. This channel dried up when the neighboring surface valleys were worn down to lower levels. The impressive stalagmites were then formed..

If Stones Could Speak

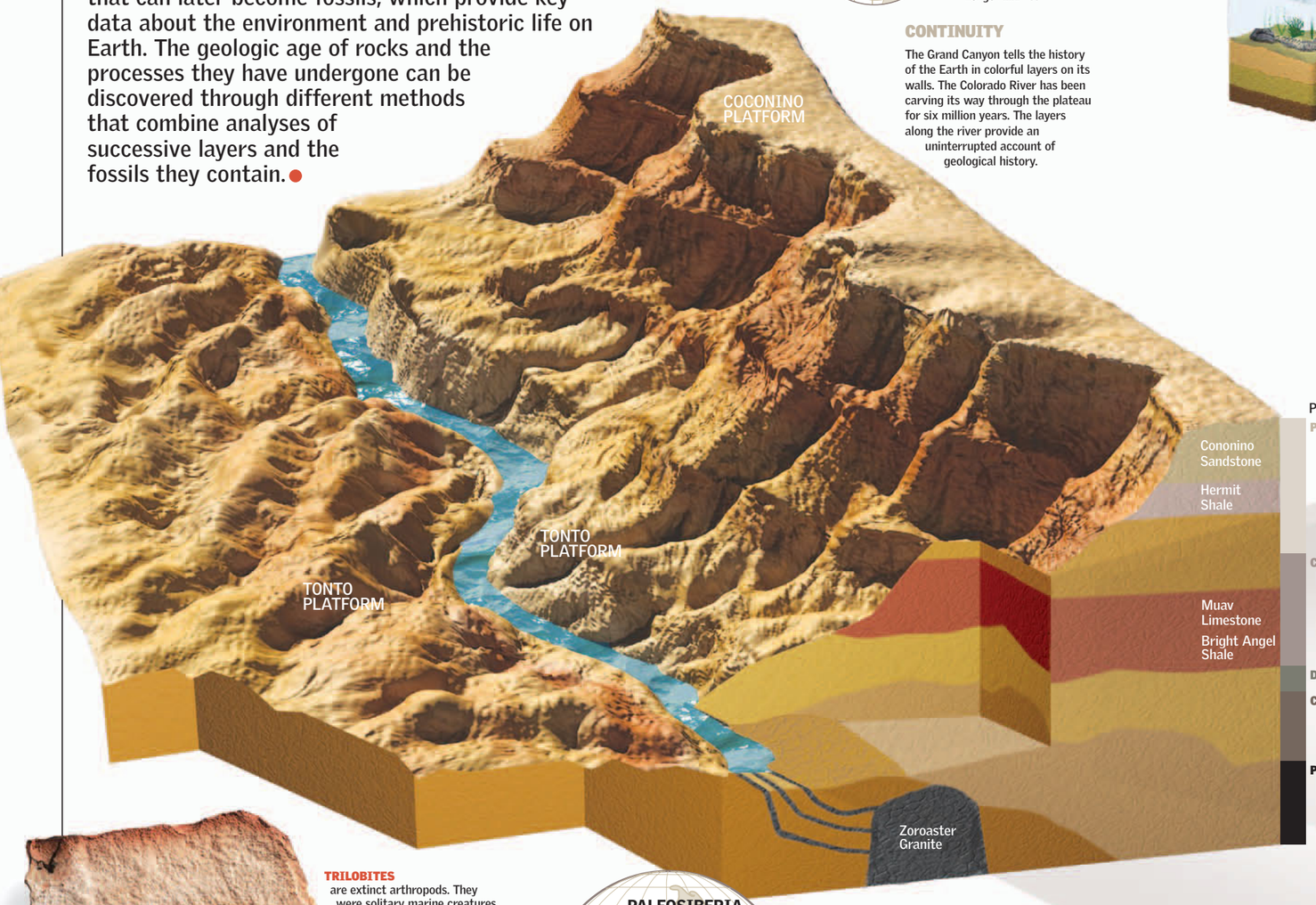
Rock strata form from sediments deposited over time in successive layers. Sometimes these sediments bury remains of organisms that can later become fossils, which provide key data about the environment and prehistoric life on Earth. The geologic age of rocks and the processes they have undergone can be discovered through different methods that combine analyses of successive layers and the fossils they contain.

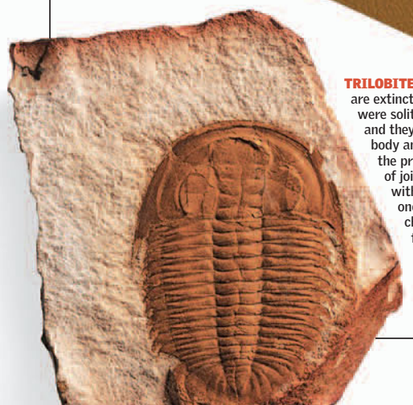


GRAND CANYON
Colorado River
Arizona
Latitude 36° N
Length 112° W

CONTINUITY

The Grand Canyon tells the history of the Earth in colorful layers on its walls. The Colorado River has been carving its way through the plateau for six million years. The layers along the river provide an uninterrupted account of geological history.





TRILOBITES
are extinct arthropods. They were solitary marine creatures, and they had a segmented body and an exoskeleton of the protein chitin, with pairs of jointed limbs. Together with graptolites they are one of the most characteristic fossils from Paleozoic marine sediments.



PRINCIPLE OF SUCCESSION

Fossils succeeded one another in a definite order, which makes it possible to date past events. The existence of identical fossils on different continents helps establish correlations and assigns the same age to widely separated geographic areas.

A Fossil's Age

Fossils are remains of organisms that lived in the past. Today scientists use several procedures, including carbon-14 dating, to estimate their age. This method makes it possible to date organic remains with precision from as long ago as 60,000 years. If organisms are older, there are other methods for absolute dating. However, within a known area, a fossil's location in a given sedimentary layer enables scientists to place it on an efficient, relative time scale. Following principles of original horizontality and of succession, it is possible to find out when an organism lived.

1. When it dies, an animal can be submerged on a riverbed, protected from oxygen. The body begins to decompose.



2. The skeleton is completely covered with sediments. Over the years, new layers are added, burying the earlier layers.





During fossilization, molecules of the original tissue are replaced precisely with minerals that petrify it.

3. Once the water disappears, the fossil is already formed and crystallized. The crust's movements raise the layers, bringing the fossil to the surface.



4. Erosion exposes the fossil to full view. With carbon-14 dating, scientists can determine if it is less than 60,000 years old.



Rock Layers and the Passage of Time

Rock layers are essential for time measurement because they retain information not only about the geologic past but also about past life-forms, climate, and more. The principle of original horizontality establishes that the layers of sediment are deposited horizontally and parallel to the surface and that they are defined by two planes that show lateral continuity. If layers are folded or bent, they must have been altered by some geologic process. These ruptures are called unconformities. If the continuity between layers is interrupted, it means that there was an interval of time and, consequently, erosion in the layer below. This also is called unconformity, since it interrupts the horizontality principle.

TEMPORAL HIATUS

Unconformity between the Tonto Group and the Redwall Limestone indicates a temporal hiatus. Between the Redwall Limestone and the Supai Group, there is temporal continuity.

Metamorphic Processes

When rocks are subjected to certain conditions (high pressure and temperature or exposure to fluids with dissolved chemicals), they can undergo remarkable changes in both their mineral composition and their structure. This very slow process, called metamorphism, is a veritable transformation of the rock. This phenomenon originates inside the Earth's crust as well as on the surface. The type of metamorphism depends on the nature of the energy that triggers the change. This energy can be heat or pressure.

570° F (300° C)

SLATE
Metamorphic rock of low grade that forms through pressure at about 390° F (200° C). It becomes more compact and dense.

930° F (500° C)

SCHIST
Very flaky rock produced by metamorphism at intermediate temperatures and depths greater than six miles (10 km). The minerals recrystallize.

1,200° F (650° C)

GNEISS
Produced through highly metamorphic processes more than 12 miles (20 km) beneath the surface, it involves extremely powerful tectonic forces and temperatures near the melting point of rock.

1,470° F (800° C)

FUSION
At this temperature, most rocks start to melt until they become liquid.

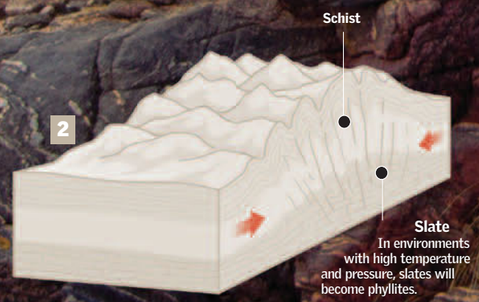


SCOTLAND, United Kingdom
Latitude 57° N
Longitude 04° W

Scotland was raised in the Caledonian orogeny 400 million years ago. This pressure produced the gneiss shown in the photo.

Dynamic Metamorphism

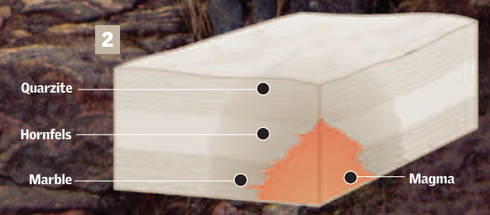
The least common type of metamorphism, dynamic metamorphism happens when the large-scale movement of the crust along fault systems causes the rocks to be compressed. Great rock masses thrust over others. Where they come in contact new metamorphic rocks, called cataclasites and mylonites, are formed.



Regional Metamorphism

As mountains form, a large amount of rock is deformed and transformed. Rocks buried close to the surface descend to greater depths and are modified by higher temperatures and pressures. This metamorphism covers thousands of square miles and is classified according to the temperature and pressure reached. Slate is an example of rock affected by this type of process.

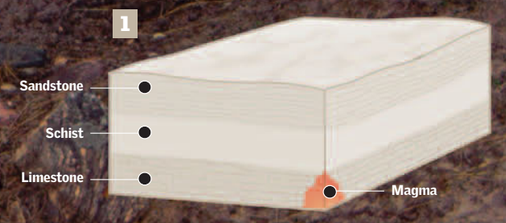




PRESSURE
As the pressure increases on the rocks, the mineralogical structure of rocks is reorganized, which reduces their size.

Contact Metamorphism

Magmatic rocks transmit heat, so a body of magma can heat rocks on contact. The affected area, located around an igneous intrusion or lava flow, is called an aureole. Its size depends on the intrusion and on the magma's temperature. The minerals of the surrounding rock turn into other minerals, and the rock metamorphoses.



TEMPERATURE
The closer the rock is to the heat source and the greater the temperature, the higher the degree of metamorphism that takes place.

The Basis of Life

Organisms are born, live, reproduce, and die on a natural layer of soil. From this layer, crops are harvested, livestock are raised, and construction materials are obtained. It establishes the link between life and the mineral part of the planet. Through the action of climate and biological agents, soil forms where rocks are broken down.

300 years

The time needed for the natural formation of soil with its three basic layers, or horizons.

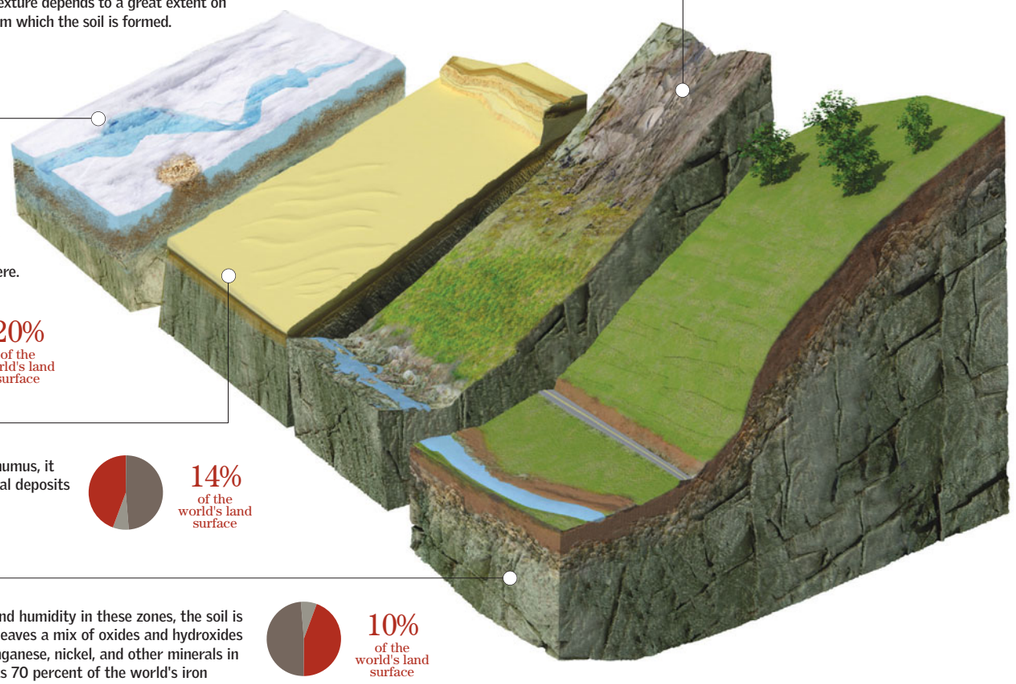
Types of Soil

In the soil we find bedrock materials that have been greatly altered by air and water, living organisms, and decomposed organic materials. The many physical and chemical transformations that it undergoes produce different types of soil, some richer in humus, other with more clay, and so on. The soil's basic texture depends to a great extent on the type of bedrock from which the soil is formed.

RANKER
develops on top of slightly altered bedrock. It is typical in high mountains, especially if it forms on granite or other acidic rocks.



0.2% of the world's land surface



PERMAFROST
Areas near the poles
The soil is saturated with frozen water. In the parts that thaw, big puddles are formed. Because of its characteristics, many animals cannot live there.



20% of the world's land surface

DESERTIC
Arid soil
Containing very little humus, it rests directly on mineral deposits and rock fragments.

14% of the world's land surface

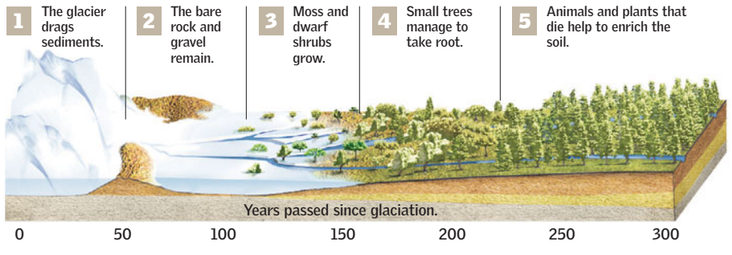
LATERITE
Typical tropical soil
With abundant rains and humidity in these zones, the soil is well drained. The rain leaves a mix of oxides and hydroxides of aluminum, iron, manganese, nickel, and other minerals in the soil. This represents 70 percent of the world's iron reserves.



10% of the world's land surface

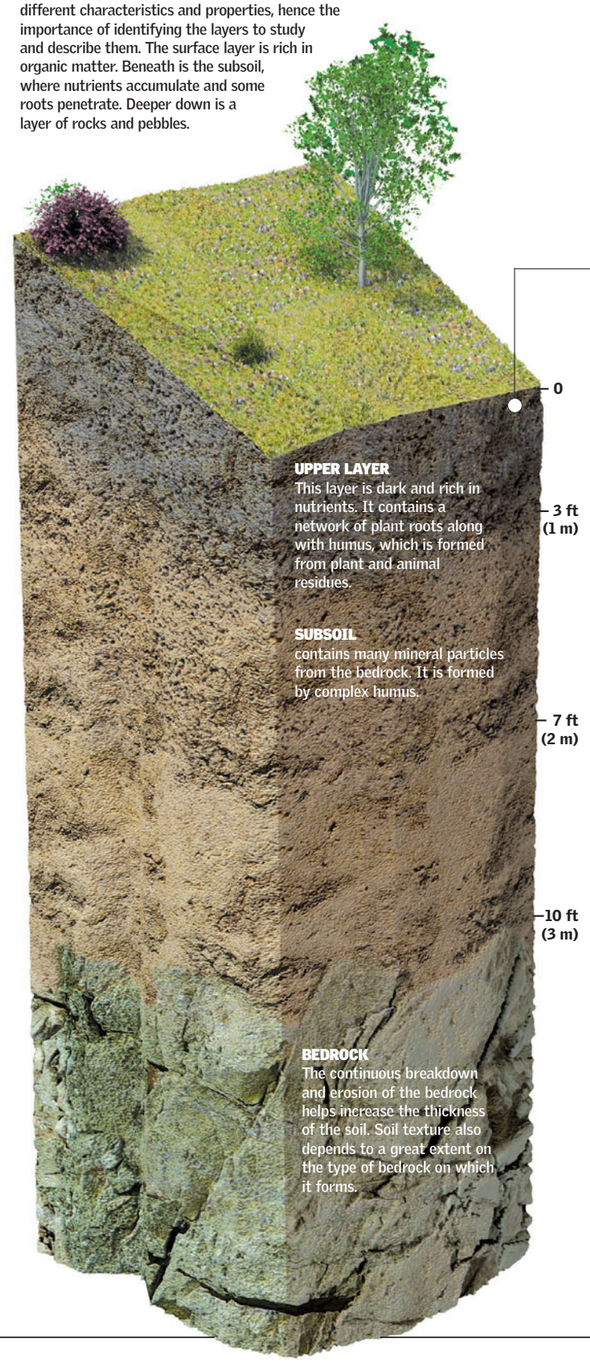
HOW IT FORMS

Much of the Earth's crust is covered with a layer of sediment and decomposing organic matter. This layer, called soil, covers everything except very steep slopes. Although it is created from decomposing plant and animal remains, the soil is a living and changing system. Its tiniest cavities, home to thousands of bacteria, algae, and fungi, are filled with water or air. These microorganisms speed up the decomposition process, turning the soil into a habitat favorable to plant roots as well as small animals and insects.



Different Characteristics

Observing the soil profile makes it possible to distinguish layers called horizons. Each layer has different characteristics and properties, hence the importance of identifying the layers to study and describe them. The surface layer is rich in organic matter. Beneath is the subsoil, where nutrients accumulate and some roots penetrate. Deeper down is a layer of rocks and pebbles.



UPPER LAYER
This layer is dark and rich in nutrients. It contains a network of plant roots along with humus, which is formed from plant and animal residues.

SUBSOIL
contains many mineral particles from the bedrock. It is formed by complex humus.

BEDROCK
The continuous breakdown and erosion of the bedrock helps increase the thickness of the soil. Soil texture also depends to a great extent on the type of bedrock on which it forms.

Living Organisms in the Soil

Many bacteria and fungi live in the soil; their biomass usually surpasses that of all animals living on the surface. Algae (mainly diatoms) also live closest to the surface, where there is most light. Mites, springtails, cochineal insects, insect larvae, earthworms, and others are also found there. Earthworms build tunnels that make the growth of roots easier. Their droppings retain water and contain important nutrients.

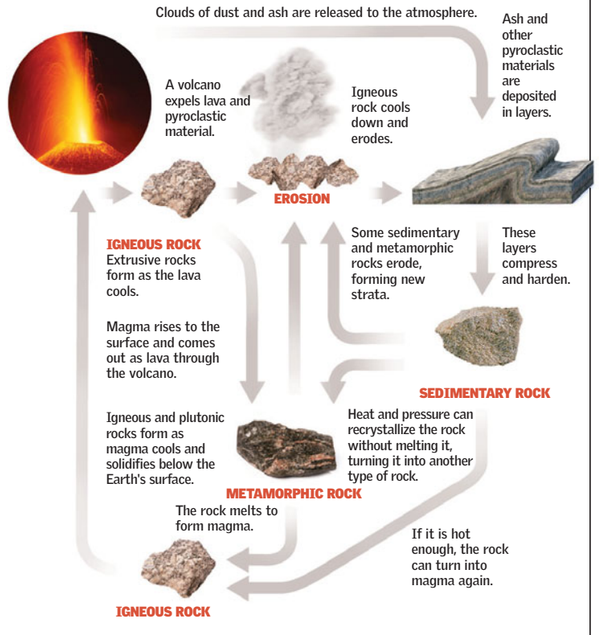
EARTHWORMS
It takes approximately 6,000 earthworms to produce 3,000 pounds (1,350 kg) of humus.

HUMUS
is the substance composed of organic materials, usually found in the upper layers of soil. It is produced by microorganisms, mainly acting on fallen branches and animal droppings. The dark color of this highly fertile layer comes from its high carbon content.



Rock Cycle

Some rocks go through the rock cycle to form soil. Under the action of erosive agents, rocks from the Earth's crust take on characteristic shapes. These shapes are a consequence partly of the rock's own composition and partly of several effects caused by erosive agents (meteorological and biological) responsible for breaking down rocky material.



Divine and Worshiped

Formed millions of years ago, some rocks enjoy the privilege of being considered deities. Pagans, Christians, Muslims, and Aborigines of Australia base part of their beliefs on the myths, properties, or legends of a rock. Among the best known are Uluru (Ayers Rock), the Black Stone located in the cube-shaped sepulcher of the Ka`bah, and the rocks of Externsteine, a destination of Christian pilgrimages and a sacred site for many ancient pagan religions. Their origins are described and studied in theology as well as in geology. Resistant to the passing of time, they are transformed into myths that remain to the present.

Beliefs

Each crack, protuberance, or groove of a rock has meaning to Aborigines. For example, a rock's orifices symbolize the eyes of a dead enemy.

Uluru

Sacred place for Australian Aborigines for thousands of years, Uluru (Ayers Rock) is four miles (9.5 km) in circumference and rises 1,100 feet (340 m) above the Australian desert. Uluru was discovered by Caucasians in 1872 and renamed Ayers Rock in honor of the Australian Prime Minister Henry Ayers. In this enormous sandstone mass, dozens of dream paths traversed by the Aborigines and the paths already traveled by their ancestors in the past converge through a series of myths. In this manner, all the sacred places are connected. On the rock are forms such as Kuniya women and the wounded head of the Liru warrior, among others.

ULURU-KATA TJUTA NATIONAL PARK, Australia

Latitude 25° S
Longitude 131° E

The great reddish rock of Uluru was created during the Alice Springs orogeny, 400 million years ago. The sandstone and conglomerates that formed the ancient alluvial fans folded and fractured deeply, turning horizontal layers on their ends.



CAVE PAINTINGS

Uluru contains some of the most representative features of the ancestral history of the Aborigines. The caves surrounding the base of the rock have some Aboriginal paintings illustrating the paths and limits of the Dream Time. Many carvings in the caves are considered to be of divine origin.



100 feet
(30 m)

the height of the Externsteine formation. It consists of five limestone pillars, riddled with caves, passages, and secret chambers.

Externsteine

Made of oddly twisted limestone rocks, Externsteine is located in the Teutoburg Forest north of the Rhine River in Rhineland, Germany. It was the place of heroic myths and German legends. It is also related to the Scandinavian Eddas and, during Nazism, to the Aryan myth. According to popular belief, the stones were placed there at night by giants; they were then burned by the devil, which explains their grotesque appearance.



MUSLIM TRADITION

Muslims who have the necessary means are expected to go to Mecca at least once in their lives.

The Black Stone of the Ka`bah

Located in one corner of the Ka`bah, the Black Stone is the most sacred treasure of the Islamic world. The Ka'bah is a cubic building located in Mecca, toward which Muslims face as they pray five times a day. The stone's exposed surface is 6 x 8 inches (16 x 20 cm), and its pieces are held together by a frame with a silver band. Muslims relate its origin to Adam and say that Abraham and his son Ishmael built the Ka`bah, but it was the Prophet Muhammad who converted Mecca into the sacred center of Islam in the 7th century.

Classes of Rocks

BEAUTIFUL AND STRANGE
The inside of a geode, a rock filled with crystals, usually displays a beautiful formation.

HOW TO IDENTIFY ROCKS 62-63
IGNEOUS ROCKS 64-65
MARINE SEDIMENTS 66-67
COLLECTION OF DETRITAL ROCKS 68-69
ORGANIC ROCKS 70-71
COMMON METAMORPHIC ROCKS 72-73
INCREDIBLE PETRA 74-75



Different types of rocks can be distinguished based on their luster, density, and hardness, among other properties. A geode looks like a common rock on the outside, but when it is cut in half, a fantastic range of colors and shapes can be revealed. The several classes of rocks can also be grouped according to how they formed, giving us the categories of igneous, metamorphic, and sedimentary rocks. Most characteristics of rocks depend on their constituent minerals. There are also organic rocks, formed through the accumulation of the remains of organisms that decomposed millions of years ago. Coal and some types of carbonate and siliceous rocks are part of this group. ●

How to Identify Rocks

Rocks can be classified as igneous, metamorphic, or sedimentary according to the manner in which they were formed. Their specific characteristics depend on the minerals that constitute them. Based on this information, it is possible to know how rocks gained their color, texture, and crystalline structure. With a little experience and knowledge, people can learn to recognize and identify some of the rocks that they often see.

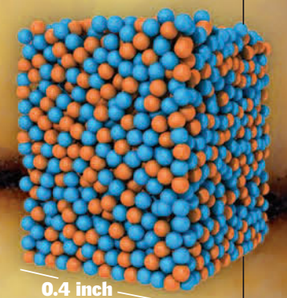


Color

The color of a rock is determined by the color of the minerals that compose it. Some colors are generated by the purity of the rock, whereas others are produced by the impurities present in it. Marble, for instance, can have different shades if it contains impurities.

WHITE
If the rock is a marble composed of pure calcite or dolomite, it is usually white.

BLACK
Various impurities give rise to different shades in the marble.





Shapes

The final shape that a rock acquires depends to a great extent on its resistance to outside forces. The cooling process and subsequent erosion also influence the formation of rocks. Despite the changes caused by these processes, it is possible to infer information about a rock's history from its shape.

ANGULAR
Rocks have this shape when they have not been worn down.



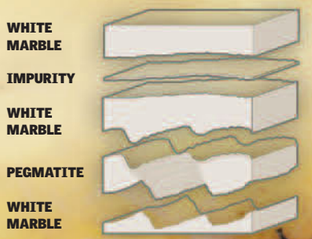
ROUNDED
The wear caused by erosion and transport gives rocks a smooth shape.

Age

Being able to accurately determine the age of a rock is very useful in the study of geology.

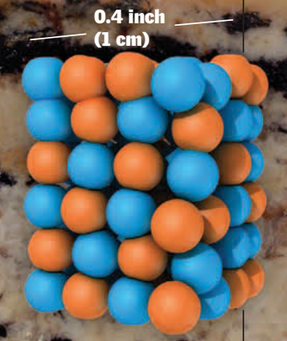
Fracture

When a rock breaks, its surface displays fractures. If the fracture results in a flat surface breaking off, it is called exfoliation. Rocks usually break in locations where their mineral structure changes.



Texture

refers to the size and arrangement of grains that form a rock. The grains can be thick, fine, or even imperceptible. There are also rocks, such as conglomerates, whose grains are formed by the fragments of other rocks. If the fragments are rounded, there is less compaction, and the rock is therefore more porous. In the case of sedimentary rocks in which the sedimentary cement prevails, the grain is finer.



GRAIN
is the size of the individual parts of a rock, be they crystals and/or fragments of other rocks. A rock's grain can be thick or fine.

Mineral Composition

Rocks are natural combinations of two or more minerals. The properties of rocks will change in accordance with their mineralogical composition. For instance, granite contains quartz, feldspar, and mica; the absence of any of these elements would result in a different rock.



CRYSTALS
form when a melted rock cools and its chemical elements organize themselves. Minerals then take the shape of crystals.

Igneous Rocks

Formed from magma or lava, igneous rocks can be classified according to their composition. This classification specially takes into account: the relative proportion of silica, magnesium, and iron minerals found in these type of rocks; their grain size (which reveals how fast they cooled); and their color. Rocks that contain silica, along with much quartz and feldspar, tend to have pale colors; those with low silica content have dark colors created by iron and magnesium-containing minerals, such as olivine, pyroxene, and amphiboles. A rock's texture is determined by the configuration of its crystal grains.

Underground: Plutonic or Intrusive Rocks

Rocks of this type formed through the solidification of magma masses deep within other rocks. In general, they have undergone a slow cooling process in the Earth's crust, which has permitted the formation of pure mineral crystals large enough to be seen with the unaided eye. Usually they display a compact structure and have low porosity. Depending on the composition of the magma, there are acidic plutonic rocks (rich in silicon) or basic rocks (with low silicon content). Granite is the most common type of intrusive rock.



MACROPHOTOGRAPHY OF PINK GRANITE

GRANITE

This rock is formed by big grains of feldspar, quartz, and mica. Its light-colored components indicate an abundance of silicon and that the rock is acidic. Because of its great resistance to wear, granite is often used as a construction material.

1 mile (1.6 km)

THE MINIMUM DEPTH AT WHICH GRANITE FORMS



GABBRO

This rock contains ferromagnesian minerals, such as olivine, pyroxene, and augite, which form dark-colored crystallizations, and feldspars, which give a white coloring to some of its parts. Gabbro generally solidifies slowly, leaving it with thick grains.

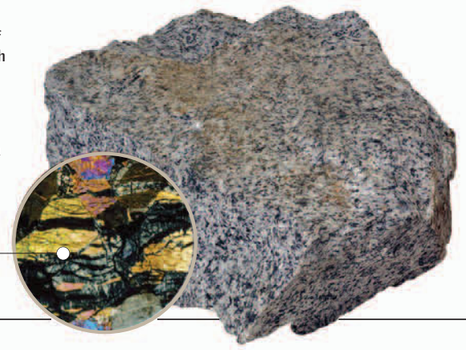


GRANODIORITE

This rock is often confused with granite, but it is grayer since it contains larger numbers of quartz and sodic plagioclase crystals than it does feldspar. It has thick grains and contains dark crystals called nodules.

PERIDOTITE

This rock is mainly composed of olivine (which gives it a greenish color) and pyroxene. It is less than 45 percent silicon and is rich in magnesium, a very light metal. It is abundant in the upper layers of the mantle (at a depth of about 40 miles [60 km]) as a residue of old crust.



MACROPHOTOGRAPHY OF GRANODIORITE

Dikes and Sills: Rocks Formed in Seams

Some types of igneous rocks are formed from ascending magma that solidifies in seams or fissures. The resulting sheetlike body of rock is called a dike if it has a vertical orientation or a sill if it has a horizontal orientation. The composition of these rocks is similar to those of intrusive and extrusive rocks. In fact, like dikes and sills, intrusive and extrusive rocks can also form in cracks. However, the manner in which the materials in a sill or dike solidify causes them to form crystalline structures different from those of their volcanic and plutonic relatives.



PEGMATITE IS NATURALLY SMOOTH.

PEGMATITE

This very abundant, acidic rock has a mineral composition identical to that of granite. However, its solidification process was very slow, thus enabling its crystals to grow to a size of several feet.



CRYSTAL JOINED BY VITREOUS MASS

PORPHYRITICS

These rocks solidify in two phases. In the first, slower phase, thick phenocrystals form. Then in the second phase, the phenocrystals are dragged along by magma, which causes the formation of smaller, vitreous crystals. The name porphyritic alludes to the color purple.

Index

PEGMATITE IS ASSOCIATED WITH THE PRESENCE OF GEMS AND RARE METALS.

Extrusive Rocks, Products of Volcanoes

Extrusive rocks form through the fast cooling of magma on or near the Earth's surface. Their structure and composition are closely related to the volcanic activity in the areas where they emerge. Because they are typically products of a fast solidification process, they usually have a very fine grain. When they are expelled from a volcano, they do not have a chance to crystallize before they cool, so they acquire a vitreous (glasslike) texture.

PUMICE

This rock is produced from lava with a high silicon and gas content, which gives it a foamy texture. This explains its porous consistency—acquired during rapid solidification—which enables it to float in water.





OBSIDIAN

This rock is black; its shades vary in accordance with its impurities. Because it undergoes rapid cooling, its structure is vitreous, not crystalline; thus, it is commonly called volcanic glass. Strictly speaking, obsidian is a mineraloid. It was often used to make arrowheads.

BASALT

This rock forms most of the oceanic crust. Its low silicon content gives it its characteristic dark color (between blue and black). Its rapid cooling and solidification gives it a very fine grain. Because of its hardness, it is used to build roads; it is not, however, used to make paving stones because it is too slippery.



GEOMETRIC PRISMS

These prisms were formed in the Giant's Causeway (Northern Ireland) through contraction, expansion, and rupture of basaltic lava flows that crystallized gradually.

Hexagon

THE MOST COMMON SHAPE INTO WHICH BASALT CRYSTALLIZES

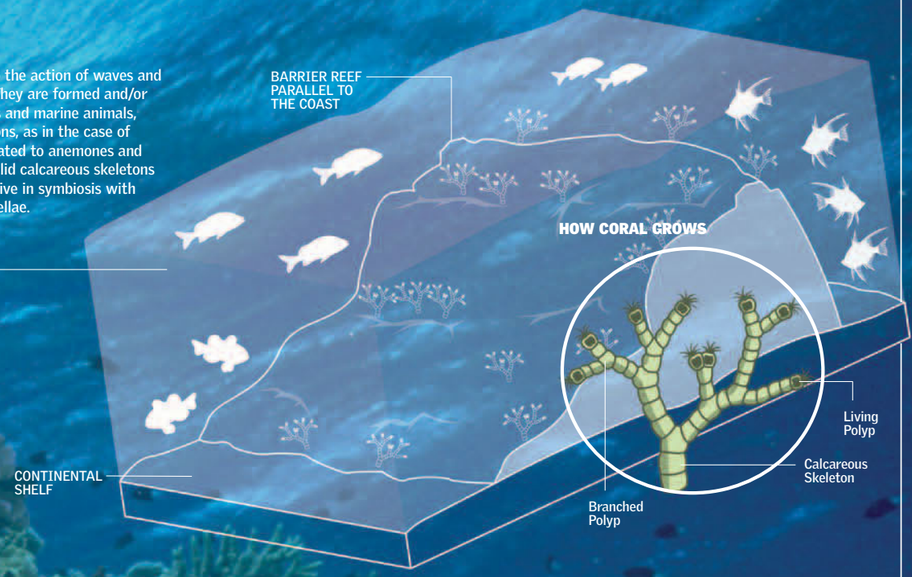
Marine Sediments

Sedimentary rocks can also form through the accumulation and lithification of organic remains. The most common example is coral reefs, which develop underwater, surrounding the coasts of many temperate seas. Many limestone rocks also originate this way; they are made of calcium carbonate (calcite) or calcium and magnesium (dolomite). Because of their porous consistency, they often serve as repositories for fossil fuels, which are also of organic origin. Other rocks, like coquina, form through the accumulation of fragments of marine shells, lithified over time as materials filled and cemented their interstices.

68° F (20° C)
MINIMUM WATER TEMPERATURE NEEDED FOR THE FORMATION OF CORAL REEFS

Coral Reefs

are rocky structures resistant to the action of waves and to the movement of the water. They are formed and/or colonized by photosynthetic organisms and marine animals, some of which have calcareous skeletons, as in the case of coral polyps. These soft organisms, related to anemones and jellyfish, live in colonies. When their solid calcareous skeletons sediment, they turn into calcite. They live in symbiosis with single-celled algae known as zooxanthellae.



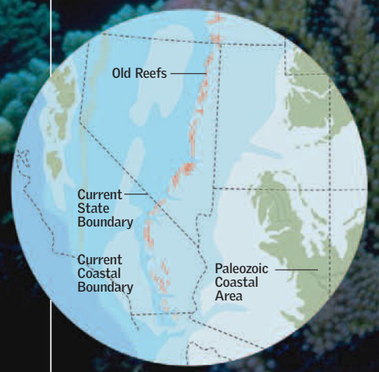
FROM SEDIMENT TO ROCK
Under pressure from overlying layers, sediments are compacted and lithified, reducing their volume by 40 percent. Other substances dissolved in water (calcite, silica, and iron oxide) fill up the interstices between the particles of sediments, and when the water evaporates, cementation occurs.



BRANCH CORAL

BRAIN CORAL

CORALS IN ARIZONA
In the first phase of the Paleozoic Era (500 million years ago), the current mountainous region of the American West was a coastal area with much coral activity. This is how the abundant calcareous formations that can be seen today in Arizona's Grand Canyon originated. These formations also coexist with much younger rocks.



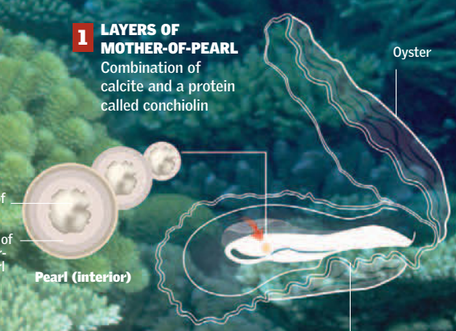
FLAT CORAL
Corals typically grow in colonies and create reefs, layer by layer.

3 feet (1 m)
THE HEIGHT THAT A REEF CAN GROW TOWARD THE SURFACE IN ONE YEAR

Pearl, Jewel of the Sea

In order to protect themselves from the intrusion of a foreign body—such as a sand grain that becomes lodged between their mantle and shell—bivalve mollusks cover the intruding object with alternating concentric layers of protein (conchiolin) and calcite. This process ultimately yields a pearl. Fine pearls are produced by pearl oysters (Pinctada) in the warm, clear waters of tropical seas.

1 LAYERS OF MOTHER-OF-PEARL
Combination of calcite and a protein called conchiolin



2 PEARL LUSTER
results from the optical properties of crystallized mother-of-pearl.



Collection of Detrital Rocks

Among the sedimentary rocks, detrital rocks are the most abundant. They form through the agglomeration of rounded fragments (clasts) of older rocks. Depending on the size of the clasts, they are classified as (from smallest to largest) pelite, lutite and limestone, sandstone, and conglomerates. The analysis of their components, cementation matrix, and arrangement in layers makes it possible to reconstruct the geologic history both of the rocks and of the areas in which they are found. Some break off easily and are used in industrial processes and construction as rock granules, whereas others are appreciated for their toughness and hardness.

Clay, Lime, and Ash

These materials form the less porous, fine-grained detritic rocks. Lutites are rocks of clay, composed of particles whose diameter does not exceed 0.0002 inch (0.004 mm). In general, they are compacted and cemented through chemical precipitation. Limestone rocks are also called limolites, named after lime, a sedimentary material with a somewhat thicker grain (up to 0.0025 inch [0.06 mm]). Some rocks composed of volcanic ash have a similar granulation. These rocks are very important in construction.



COMPACTED ASH
It is possible to find one or more layers of fine-grained pyroclastic material (volcanic ash) in many sedimentary rocks. Rocks formed from larger pyroclasts, which solidified in the air during an eruption before they touched the ground, are rarer. Their origin is igneous, but their formation is sedimentary.

40%
THE REDUCTION IN THE VOLUME OF CLAY AS IT IS COMPACTED



TUFF
is rock that is formed from deposits of volcanic ash that has been cemented together. There are several types: crystalline tuff, which is largely composed of igneous glass; lithic tuff, which contains rock fragments; and hybrid tuff, which is formed from fragmented volcanic material combined with some clay.



CLAY (KAOLINITE)
When hydrated, it increases in size.

CLAY
The substance commonly known as clay is an unconsolidated rock, made of hydrated aluminum silicates and typically full of impurities. Kaolin is the name for pure granular clay; it is soft and white and keeps its color even after it has been fired in a kiln. It has scale-shaped microcrystals and generally contains impurities.



CHALK
Composed of calcite debris of biochemical origin, this mineral originates in the sea near the coast. After being eroded and transported, it accumulates on slopes where it becomes compacted. The chalk we use on blackboards is, in reality, gypsum.

COMPACTED
Very fine sediment

A Variety of Sandstones

Sandstone is rock composed of grains that are mostly between 0.003 and 0.08 inch (0.06 and 2 mm) in size. Sandstones are classified according to their mineral composition, their level of complexity (or geologic history), and the proportion of cementation material they contain. Quartzarenite (which is more than 95 percent quartz), arkose (which is mostly feldspar), red sandstone (which is cemented by iron compounds), and graywacke belong to this class of rocks.



SANDSTONE
is made up of small grains of sand that are here stratified by color and texture. This type of sandstone indicates that an alternating process of sedimentation involving two types of particles has occurred.

ARKOSE
possesses a varied composition, although it contains up to 25 percent quartz and feldspar. Generally, it has a porous consistency, and less than one percent of its interstices are empty. In this specimen, the pinkish section is composed of feldspar, and the white portion is quartz.





GRAYWACKE
has a defined proportion of calcium carbonate, quartz, feldspar, and mica. It differs from common sandstone because it contains a higher amount of cementation materials (more than 15 percent), which form its grain matrix. This makes it more compacted.

20%
OF SEDIMENTARY ROCKS ARE SANDSTONES.

Conglomerates

Most of the grains that compose these rocks are larger than 0.08 inch (2 mm). In some cases, it is possible to identify with the unaided eye the primary rocks from which a conglomerate is formed. As a result, it is possible to determine the areas where the sediments originated. Accumulations of gravel and cementation material can indicate either slopes in the rocks where the conglomerates formed or the action of fluvial currents. All this information makes it possible to reconstruct the geologic history of a rock.



MICROPHOTOGRAPH OF BRECCIA



CONGLOMERATE
Formed by large fragments, they are good examples of sediments that have been compacted after landslides. The irregularity of this specimen's clasts points to a chaotic origin, which could be alluvial in nature or associated with a glacial moraine.

85%
PERCENTAGE OF CLASTS LARGER THAN 0.08 INCH (2 MM)

BRECCIA
Its grains are thick but with straight angles and edges. This shows that the sediments have not traveled far and that cementation has taken place near the area from which the materials originated.

Organic Rocks

Organic rocks are composed of the remains of living organisms that have undergone processes of decomposition and compaction millions of years ago. In these processes, the greater the depth and heat, the greater the caloric power and thermal transformation of the rock. The change experienced by these substances is called carbonization.

26%

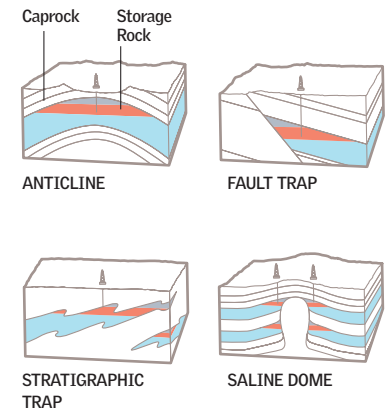
OF THE PRIMARY ENERGY CONSUMED IN THE WORLD COMES FROM COAL.

FORMATION OF PETROLEUM

In an anaerobic environment at a depth of about 1 mile (2 km), organic sediments that developed in environments with little oxygen turn into rocks that produce crude oil.

KEY
- Gas
- Petroleum (Oil)
- Water

PETROLEUM TRAPS



Coal Formation

Plant materials, such as leaves, woods, barks, and spores, accumulated in marine or continental basins 285 million years ago. Submerged in water and protected from oxygen in the air, this material slowly became enriched with carbon through the action of anaerobic bacteria.

Transformation of Vegetation into Hard Coal



1. Vegetation

Organic compounds on the surface became covered by oxygen-poor water found in a peat bog, which effectively shielded them from oxidation.

2. Peat

Through partial putrefaction and carbonization in the acidic water of the peat bog, the organic matter changes into coal.

Contains 60% carbon



3. Lignite

is formed from the compression of peat that is converted into a brown and flaky substance. Some primary plant structures can still be recognized in it.

Contains 70% carbon



4. Coal

has a content of less than 40 percent mineral substance on the basis of dry material. It has a matte luster, is similar to charcoal, and is dirty to the touch.

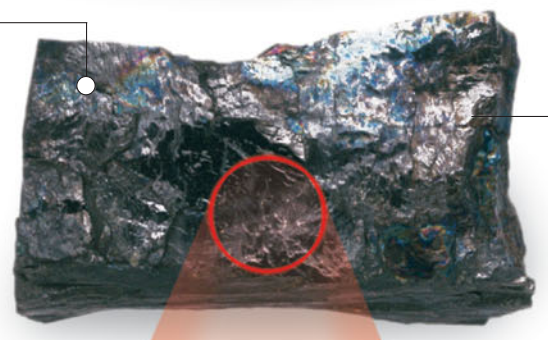
Contains 80% carbon



5. Anthracite

is the type of coal with the greatest concentration of carbon. Its high heat value is mostly due to this type of coal's high carbon content and low concentration of volatile material. It is harder and denser than ordinary coal.

Contains 95% carbon



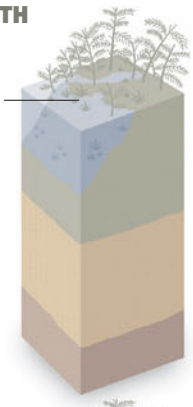
ANTHRACITE ROCK



At times, the surface of anthracite can appear to have traces of plant fossils.

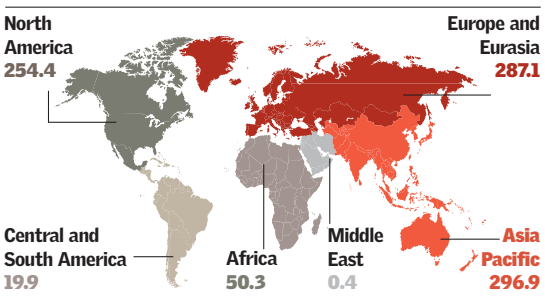
LOCATION INSIDE THE EARTH

The movements of the Earth's crust subjected the strata rich in organic remains to great pressure and transformed them into hard coal over the course of 300 million years.



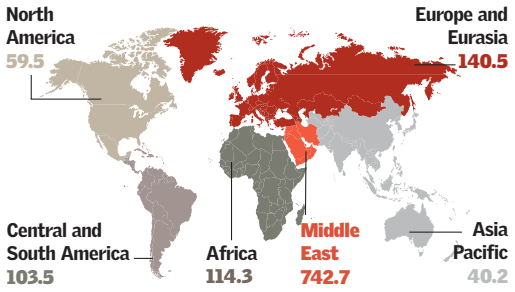
WORLD COAL RESERVES

Billions of tons



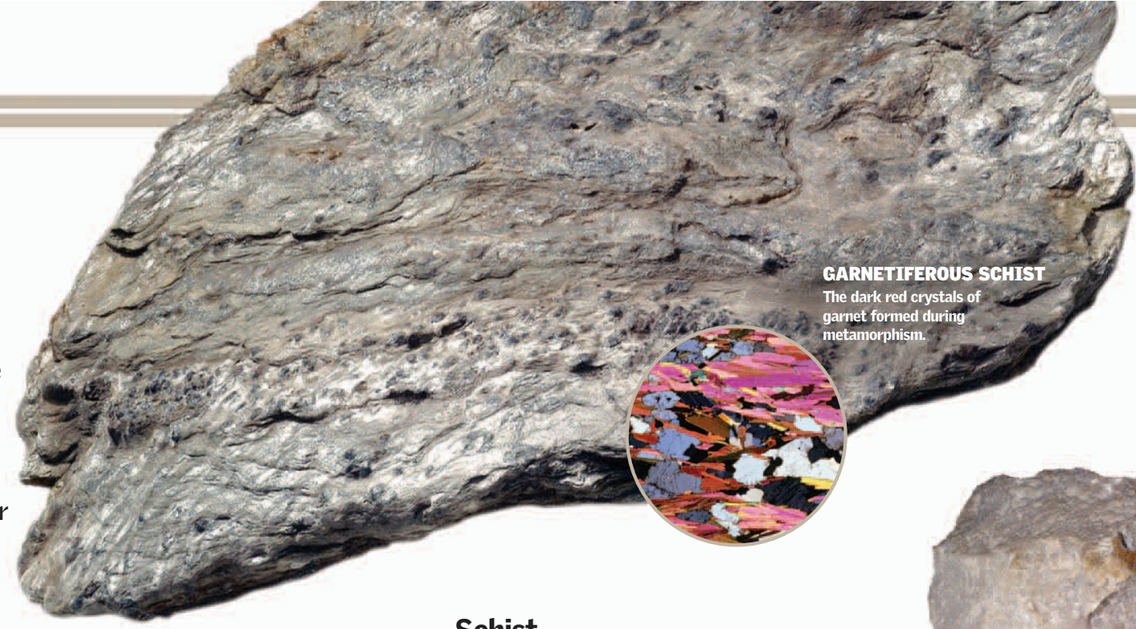
WORLD PETROLEUM RESERVES

Billions of barrels



Common Metamorphic Rocks

The classification of metamorphic rocks is not simple because the same conditions of temperature and pressure do not always produce the same final rock. In the face of this difficulty, these rocks are divided into two large groups, taking into account that some exhibit foliation and others do not. During the transformation process, the density of rock increases, and recrystallization can induce the formation of bigger crystals. This process reorganizes the mineral grains, resulting in laminar or banded textures. Most rocks derive their color from the minerals of which they are composed, but their texture depends on more than just their composition.



GARNETIFEROUS SCHIST
The dark red crystals of garnet formed during metamorphism.

Marble and Quartzite

These rocks are compacted and nonfoliated. Marble is a thick-grained crystalline rock, derived from limestone or dolostone. Because of its color and toughness, marble is used in the construction of large buildings. Quartzite is a very hard rock, usually made of sandstone rich in quartz, which, under elevated metamorphic conditions, melts like pieces of glass. Quartzite is normally white, but iron oxide can give it a reddish or pinkish tone.

7 IS THE LEVEL OF HARDNESS OF QUARTZITE.



SLATE MICROGRAPHY
Composed of foliated or laminated clay minerals

SLATE
Its black color comes from the carbon in organic matter present in sediments.

GARNETIFEROUS SCHIST
This rock's name comes from its components. Schist determines its texture and garnet its color and distinctive features.

Schist

This rock is more prone to foliation, and it can break off in small sheets. It is more than 20 percent composed of flat, elongated minerals, which normally include mica and amphiboles. For schist to be formed, a more intense metamorphism is needed. The different schistose rocks' names and characteristics depend on the predominant mineral that composes them or on the one that produces exfoliation. Among the most important schistose rocks are mica, hornblende, and talc. Because this type of rock has different layers, it has been used in sculpture.



QUARTZITE
It is hard and tough; it is compacted because the quartz grains entwine.



MICACEOUS SCHIST
Its characteristic coloring is determined by colorless or white muscovite crystals.

HORNBLENDE SCHIST
It contains some sodium as well as considerable amounts of iron and aluminum.

Slates and Phyllites

These foliated rocks recrystallized under moderate pressure and temperature conditions. Slate has very fine grains made of small mica crystals. It is very useful in the production of roof tiles, floor tiles, blackboards, and billiard tables. It almost always is formed through low-grade metamorphism in sediments and, less often, from volcanic ash. Phyllite represents a gradation in metamorphism between slate and schist; it is composed of very fine mica crystals, such as muscovite or chlorite.



PHYLLITE
Similar to slate, it is notable for its silky luster.

Gneiss

Striped rock that usually contains long and granular minerals. The most common types are quartz, potash feldspar, and plagioclase. It can also have smaller amounts of muscovite, biotite, and hornblende. Its characteristic stripes are due to a segregation of light and dark silicates. Gneiss rock, which has a mineral composition similar to that of granite, is formed through sedimentary processes or derived from igneous rocks. However, it can also form through high-grade metamorphism of schists. It is the last rock of the metamorphic sequence.



SLATE
Because of exfoliation, it tends to break into flat sheets.

Foliation

LAMINATED OR STRIPED TEXTURE, RESULTING FROM THE PRESSURE TO WHICH THE ROCK WAS SUBJECTED

Stripes

MAKE IT POSSIBLE TO DETERMINE THE DIRECTION IN WHICH PRESSURE WAS EXERTED ON THE ROCK.

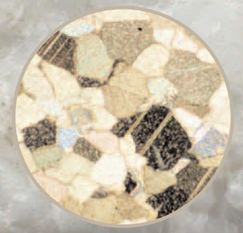
0.04 inch (1 mm)

OR MORE. THE SIZE OF MICA GRAINS IN SCHIST—LARGE ENOUGH TO SEE WITH THE UNAIDED EYE.

MARBLE
It is highly valued for its texture and color. It is used in sculpture and architecture.



GNEISS
Heat and pressure can change granite into gneiss.



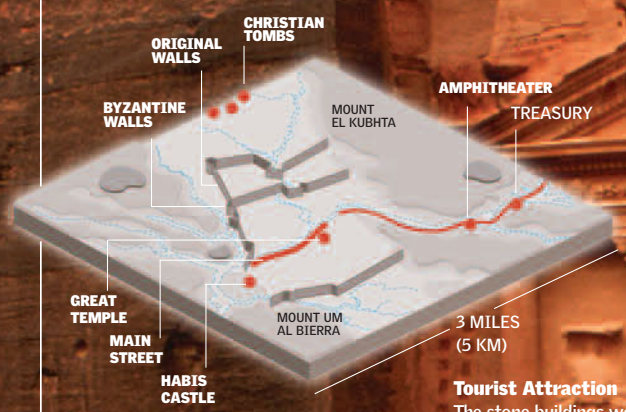
MARBLE MICROGRAPH
Impurities and accessory minerals color the marble.

Incredible Petra

Historians from ancient Rome used to talk about a mysterious city of stone. In 1812 Johann Ludwig Burckhardt of Switzerland rediscovered it. Traces of Neolithic civilizations were found in Petra; however, its foundation in the 4th century BC is attributed to the Nabataeans, a nomadic people. The Nabataeans were merchants and raiders who became prosperous by controlling the spice trade. The city, carved in sandstone, knew times of splendor, but it eventually fell into ruin.

Temples and Tombs

The only way to reach Petra is by foot through a narrow passage among the rocks. The passage is 1 mile (1.5 km) long and, at some points, less than 3.3 feet (1 m) wide. The Treasury (Khasneh) is the first seen upon entering the city, followed by a Roman amphitheater. The buildings are carved into cliffs, and more than 3,000 old tombs have been excavated. The city also has fortifications.



Tourist Attraction
The stone buildings were erected at different times over a period of 1,000 years.

HIDDEN IN THE DESERT

Petra is hidden in the mountains 155 miles (250 km) south of Amman, the capital of Jordan, and north of the Red Sea and the Great Rift Valley in Africa.

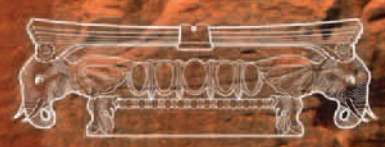


On the Rift

ITS CLIFFS ARE PART OF THIS FRACTURE; IN THE YEAR 363, IT WAS DAMAGED BY AN EARTHQUAKE.

Uncertain Origins

Petra's architecture is dominated by Greek, Egyptian, and Roman features; however, their symbiosis with Eastern elements is so great that to this day experts find it difficult to establish Petra's origin and dates of construction. The city's exterior adornments contrast with the interior sobriety of its temples. It contained sumptuous public baths that date from a time of splendor (1st century BC). However, most of Petra's population, which reached a peak of 20,000 inhabitants, lived in adobe houses.



ELEPHANTS (Interpretation)
Native to Africa or India, elephants were not represented in classic culture. Here, however, they are seen adorning Greek-style capitals. This particular merging of cultures created expressions found nowhere else in the ancient world. Archaeologists find it difficult to date the pieces of art found in Petra.

The Treasury

IT WAS BELIEVED THAT THIS BUILDING HOUSED A PHARAOH'S TREASURE. ITS CUBE-SHAPED INTERIOR HAS SMOOTH WALLS AND IS LINED WITH MORTUARY CHAMBERS.

A Door Between Worlds

The statue represents the god Serapis, whose cult was established in the 4th century BC in both Greece and Egypt. Serapis is of Greek origin, but obelisks and cubic stones, typical Egyptian monuments, also abound in Petra. For a long time, it was believed that Petra was the biblical town of Edom. Its strategic location made it a transit area for Indians and Africans. The Roman and Byzantine empires had a profound influence: Petra was their gateway to the East. Beginning in the 7th century, though, Nabataean culture began to merge with Islamic culture, and it ultimately disappeared.

SERAPIS
God of prosperity and concealed mysteries. In Egyptian iconography, Serapis has horns.



CORINTHIAN CAPITAL (Interpretation)
One of the most classic capitals of Greek architecture, along with the Ionic and Doric styles



WINGED LIONS (Interpretation)
These carvings were located in the temple of Atargatis, goddess of fertility in the Nabataean culture.

Carved in Stone

The construction over sandstone respects and takes advantage of the characteristics of the landscape. To create openings, builders used the cracks and fissures that already existed in the rock. The sandstone in Petra is composed of at least two original types of sediments of different colors. Some people believe they are from different geologic phases, but it is more likely that the original sand was made of different grains.

SANDSTONE
A sedimentary rock with medium-sized grains (less than 0.08 inch [2 mm]), with great toughness and hardness. Its mineralogical composition can vary. In the Jordanian desert, it forms cliffs.

Use of Rocks and Minerals

FOUND ALL OVER THE WORLD
Coal is found in almost all regions of the world, but today the only deposits of commercial importance are located in Europe, Asia, Australia, and the Americas.

IN DAILY LIFE 78-79
MOUNTAINS OF GOLD AND SILVER 80-81
AN OPEN-AIR MINE 82-83
BLINDED BY BRILLIANCE 84-85
BLACK AS COAL 86-87
BLACK GOLD 88-89
RADIOACTIVE MINERALS 90-91



Human beings have been extracting coal since ancient times, and mining generally takes place underground because most veins are hundreds of feet down. Human beings have to make incursions into the bowels of the Earth to extract its wealth. The materials extracted from the Earth are the basis of modern civilization, the raw material from which many products people use are made. Unfortunately, the Earth's reserves of coal, oil, and gas are being depleted. For this reason, other sources of energy to replace them are being sought. One of these alternative sources is nuclear energy. It requires uranium, an element found in certain rocks. ●

In Daily Life

It is impossible to conceive of modern life without the constant use of objects and materials made of rocks and minerals, metallic or nonmetallic. To illustrate this, it is enough simply to consider the elements that make up a car, trace them back to their origins, and consider the processes that shaped them. In some cases, the texture and characteristics of each material can be easily seen. Other materials, especially nonmetals such as coal and sulfur, are less noticeable, but they are a part of the production process as well. This process tends to emphasize and improve the physical, chemical, and electric characteristics of each material. ●

Hydrocarbons, the Source of Energy

The combustion of petroleum derivatives provides energy for propulsion. The combustion pathway begins with the storage of gas in the tank and ends with the expulsion of waste gases through the exhaust pipe. There a catalyst with thousands of cells filters the most toxic gases: carbon monoxide and nitrogen oxide.



EXHAUST PIPE

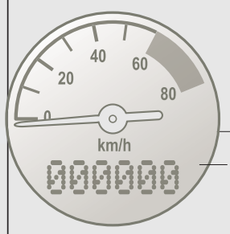


FUEL TANK

Electric Properties: Conductors, Insulators, and Semiconductors

Metals, which tend to lose electrons, are the soul of electric cables and circuits. Nonmetals (and their polymeric derivatives) hinder the flow of electrons and are used as insulators. Other minerals, such as silicon, have intermediate properties: electronic components are manufactured by adding impurities to modify their properties.

CONTROL PANEL
In smaller contact areas, more expensive metals are used (gold is the best conductor). Chips and other electronic components contain silicon. Phosphorescent displays have strontium paint.



CIRCUITS
Gold, silver, palladium

DISPLAYS
Strontium



Metals

The body of a car is made of iron (present in both steel and magnetite), aluminum, and magnesium. Other metals are used to produce parts that are resistant to torsion (vanadium, cadmium), temperature (cobalt), and corrosion (nickel and zinc). Barium and platinum are used in very specific parts, and other metals are used in smaller amounts in lubricants, fluids, or paints.

BODYWORK
Aluminum, titanium, magnesium, and steel

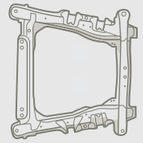
ALUMINUM
Light and durable

IRON
Strong and resistant

20%
MORE ALUMINUM IS REQUIRED BY VOLUME FOR THE SAME WEIGHT OF STEEL.



SPRINGS
Cadmium



ENGINE BLOCK
It sustains the engine and is made of magnetite, an iron ore.



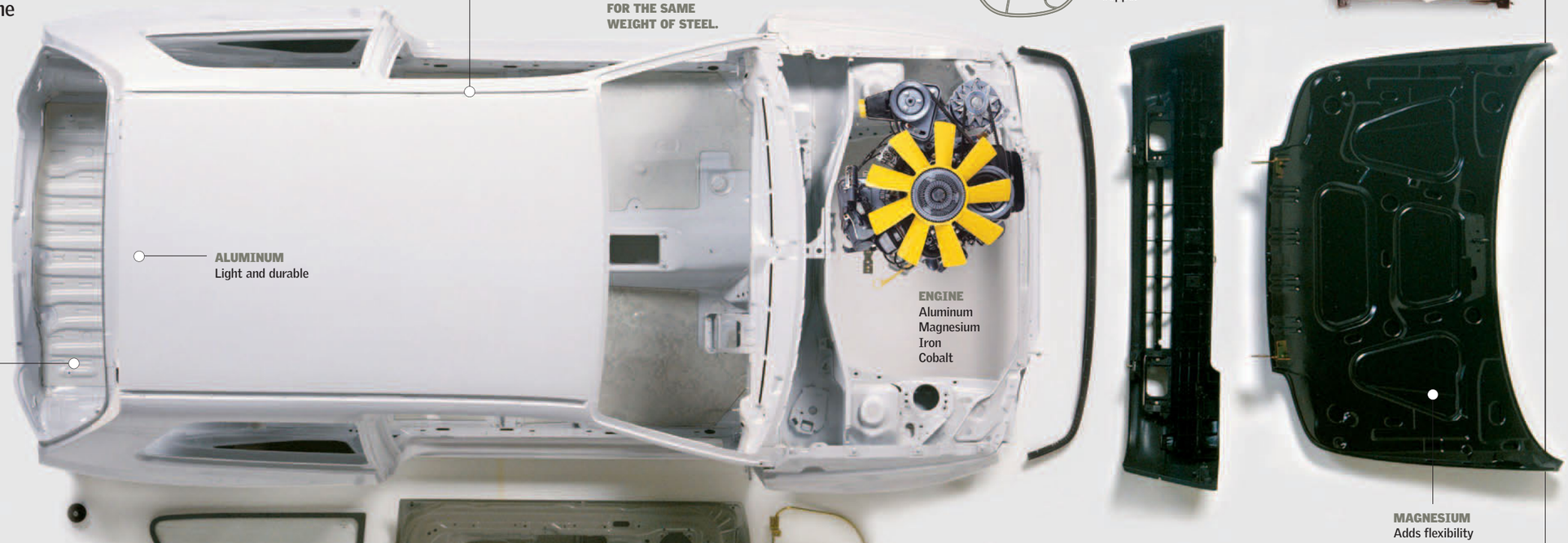
WIRING SYSTEM
Copper

SEAT

BACK
Glass fiber

SPRINGS
Steel





ENGINE
Aluminum
Magnesium
Iron
Cobalt

MAGNESIUM
Adds flexibility

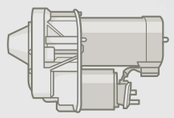
0.07 pound (0.03 kg)
PER CUBIC INCH MAGNESIUM IS THE LIGHTEST METAL USED FOR INDUSTRIAL PURPOSES.

LOCKS
Covered with zinc

DISTRIBUTOR
Platinum



IGNITION COIL
Barium



HEADLIGHTS
Tungsten



MIRRORS
Glass and lead

WINDOWS
Glass (silica)

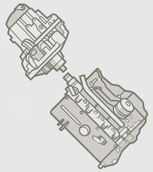
Nonmetals

Silicon and its derivatives (silicone, silica, and silicates such as asbestos) are omnipresent materials in car manufacturing. They appear in crystallized form, such as quartz, and in noncrystallized—or glass—form. Other nonmetals aid in the strengthening of metals—for example, carbon in the production of steel and sulfur in the vulcanization of rubber.

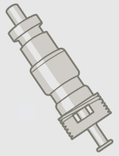
WHEELS
Titanium is often used in alloys and in the car's finish.



STEERING WHEEL
Silicon coating



ENGINE JOINTS
Asbestos



SPARK PLUGS
Porcelain (kaolin)



TIRES
Vulcanized steel mesh

Mountains of Gold and Silver

From the decision to exploit an area where valuable minerals are suspected to exist to obtaining these minerals in major amounts, large-scale mining operations require complex work that lasts for years. For instance, the exploitation of Veladero, an open-air gold-and-silver mine located in the province of San Juan in the Argentinean Andes and exploited by the Canadian company Barrick Gold, required more than a decade of research and development before the first ingots were obtained in October 2005. To reach the deposits, roads and housing were built for the workers. The potential environmental impact of the mine was analyzed since explosives had to be used and toxic substances, such as cyanide, were needed for extracting and separating the rock from other metals. ●



VELADERO, ARGENTINA

Latitude 29° S

Longitude 70° W

Total land area	**1,158 square miles (3,000 sq km)**
Employed builders (peak)	**5,000**
Gold reserves (1st estimate)	**900 tons**
Estimated life span	**17 years**

HUGE OPEN-AIR MINE

Veladero—located in the Argentinean province of San Juan, as shown on the map—required 2,300 tons of metallic structures and consumes 2,520 tons of sodium cyanide per year for extracting gold.



13,120 feet (4,000 m)

ABOVE SEA LEVEL
The elevation of the mine

1. PROSPECTING
1 TO 3 YEARS
COST: $10 MILLION

Prospecting began in 1994. During this phase, the possible existence of a deposit covering a vast area was analyzed. It was necessary to draw maps, conduct studies, make satellite images, and undertake field trips to analyze superficial rocks.

3. BLUEPRINT OF THE MINE
2 TO 5 YEARS
COST: $547 MILLION

Once the reserves and costs were analyzed, it was necessary to open the mineral deposit and evaluate the environmental impact of the operation. The infrastructure was then built; it included paths, houses, and river diversions.



2. EXPLOITATION
2 TO 5 YEARS
COST: $90 MILLION

The first phases are involved with field prospecting. During this process, preliminary research is confirmed or revised. Once the existence of the deposit is confirmed, the next step is to establish its dimensions, reserves, yield, and extraction costs.

An Open-Air Mine

There are many types of mines. Some are located in the depths of the Earth, and some show their contents at its surface. Bingham Canyon, a copper mine located in Utah, is not only one of the most important open-air mines but also one of the largest excavations in the world. It is so large that it can be seen from space. It has been in operation since 1903, and it has been excavated in the form of terraces, like those used in agriculture. Its activity never stops, continuing even on weekends and holidays. The manner in which copper is extracted involves not only the use of machinery of extraordinary dimensions but also the use of a hydro-metallurgic chemical process called lixiviation, or leaching. Thanks to this process it is possible to obtain 99.9 percent of copper in its pure state from a copper concentration of 0.02 ounce per pound (0.56 gram per kg) of raw material.



BINGHAM CANYON UNITED STATES
Latitude 40° 32′ N
Longitude 112° 9′ W

Diameter of the pit	2.5 miles (4 km)
Depth of the pit	2,300 feet (700 m)
Opening year	1903
Closing year	2013
Number of employees	1,700

WATER BASIN
The phreatic layer, the closest aquifer to the surface below the water table, emerges at the bottom and forms a water basin with a peculiar color because of the copper salts in the deposit.

TERRACING OF THE SURFACE
The mine acquires a steplike shape because it is excavated in spiral terraces. The machines can move easily over the terraces, collecting the extracted material.

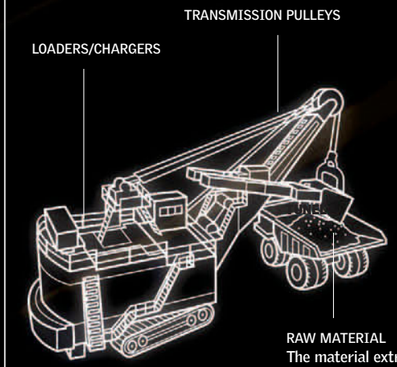
PATHS
The roads are well built, and they can withstand loads of up to 1,765 cubic feet (50 cu m) of rock on only one truck.

How the Metal Is Extracted

Thousands of pounds of explosives, trucks and shovels as large as a house, and massive grinding machines that can reduce hard rocks to dust are involved in the extraction process, and rock temperatures are raised to 4,500° F (2,500° C). In this way, copper is extracted from one of the largest open-air mines on the planet. The raw material excavated from the terraces in the mine contains oxidized copper minerals. This material is transported to grinders, which produce rock fragments 1.5 inches (4 cm) in diameter. These materials are placed in a pile that is treated with a solution of water and sulfuric acid. This process is called lixiviation, or leaching. Lixiviation is a hydro-metallurgic treatment that makes it possible to obtain copper present in the oxidized minerals. The treated material begins the process of sulfatation of copper contained in the oxidized minerals.

1 HOW MATERIAL IS OBTAINED

The process begins with rock perforation and blasting. The rock is removed from the pit and loaded by large shovels onto trucks. Then it is unloaded onto a mobile grinder. The ground rock is removed from the mine on conveyor belts and then sprayed with a solution of water and sulfuric acid.



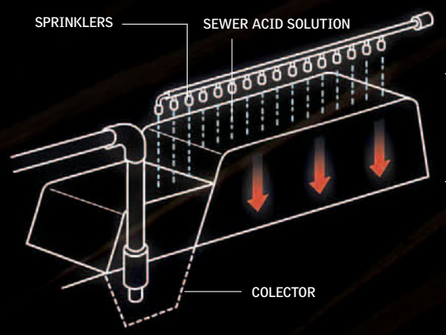
RAW MATERIAL
The material extracted from the pit is loaded on a mobile grinder.

0.56 %
COPPER CONCENTRATION IN THE RAW MATERIAL

2 ARRANGEMENT OF THE STACK

When on the conveyor belts, the material is taken to a place where it will form a lixiviation pile or stack, and a trickle irrigation system is installed on top of this pile. Sprinklers cover the entire exposed area. The material will spend 45 days here.

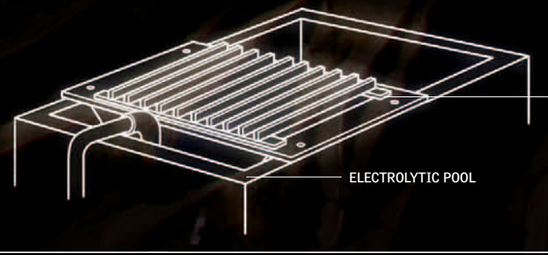
6 ounces/gallon (45 g/l)
OF COPPER IN THE SOLUTION AT THE END OF THE LIXIVIATION PROCESS



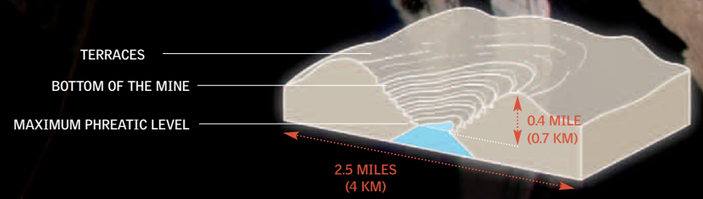
3 COPPER RECOVERY

The resulting copper solution is collected in conduits and then undergoes a process of electrolytic refining. During this process, electricity passes between two copper plates suspended in the solution; copper from the solution adheres to the sheets as it is separated through electrolysis.

99.9 %
COPPER IN A PURE STATE



LIXIVIATION
The hydro-metallurgic process that makes it possible to obtain copper from the oxidized minerals by applying a solution of sulfuric acid and water. Oxidized minerals are sensitive to attack by acid solutions.

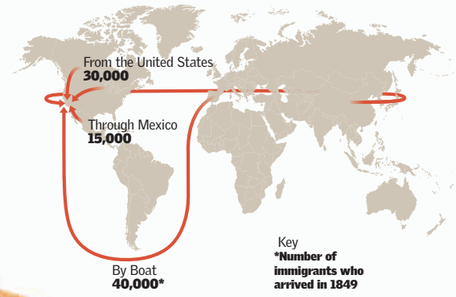


FORMATION OF THE MINE
Surface mines take the shape of large terraced pits, which grow ever deeper and wider. Viewed from above, an enormous spiraling hollow can be seen. This is a relatively inexpensive and simple method to extract high-purity materials.

Blinded by Brilliance

The discovery of gold in the Sacramento River in California in the mid-19th century started one of the largest migrations of its time. Fortune hunters came from the Americas as well as from Asia, but few were able to achieve their goal of striking it rich. Each year, obtaining gold required a larger investment of time and equipment, and equipment suppliers were the ones who ultimately earned the highest profits. Gold was the key force in settling California, now the wealthiest state in the United States. At its peak, immigration overwhelmed the state's social and municipal services as up to 30 houses were being built each day.

FLOW OF IMMIGRANTS
In 1848, California had a population of 14,000. However, within four years and with the gold fever at its peak, the population rose to 223,856.





UNITED STATES
California
Sacramento River

ENCAMPMENTS
Bad living conditions led to the death of many workers; many were also killed by epidemics and illnesses.

DRAGGING
Mules dragged large stones, used to break other quartz stones, thus releasing the gold within.

CHANNELED RIVER

ARTIFICIAL CANAL

DRY RIVERBED

SLUICE BOX
Water flowed through the artificial canal, where riffles (barriers) along the bottom of the sluice box caught the gold and let the other material pass through.

100
SLUICE BOXES COULD BE USED IN THE CONSTRUCTION OF JUST ONE WASHER.

THEY SHOVELED THE GRAVEL.

WASHED PARTICLES

WASHING CONTAINERS

PARTICLES BEING WASHED

DRY RIVERBED

GOLD IN THE SOIL
Gold could be found in dry riverbeds as dust, as nuggets, or as small rock fragments.

SLOPE
The water flowed and deposited gold at the serrated bottom.

GOLD SELECTOR

ORIGINAL RIVERBED

RETURN TO THE RIVER
Once the water had been used to pan for gold, it was channeled back into the river from which it came.

BY HAND
Resources and tools were scarce. Almost everything was done by hand.

PAN
The swirling movement of the pan allowed for the separation of sediments, and the gold could be identified by a difference in weight.

CHINESE
Chinese immigrants, attracted by the prospect of wealth, constituted most of the labor force.

HOPPER
The gravel was placed in the hopper and the deposited material was moved with a lever. When water was added, the dirt could be carried away, leaving the gold at the barrier since the density of gold is greater than that of water.

DRY RIVER
In 1853, $3 million was invested to change the course of the Yuba River, which merged with the Sacramento River. The water of the new canal was used to wash the gold.

1 1848

On the morning of January 24, while James Marshall was building a sawmill for his employer John Sutter, he discovered gold on the banks of the Sacramento River. This irrevocably changed the history of California.

$16
WAS THE PRICE OF A PLOT OF LAND; 18 MONTHS LATER, IT WAS PRICED AT $45,000.

2 1850

California became the 31st state of the Union. Slavery was abolished because of the large influx of immigrants and the fear that it would reduce workers' salaries. However, the Fugitive Slave Act was sanctioned by the state. According to this law, every fugitive slave that entered California had to be returned to his or her owner.

$500
MILLION IN GOLD WAS EXCHANGED DURING THE ENTIRE DECADE.

3 1852

When the surface gold was exhausted, more complex technology was required to extract it from the ground. Hydraulic mining, which used water jets, was a technique used for this purpose. Miners then became employees, enduring long workdays.

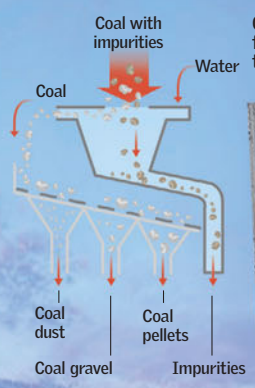
Black as Coal

In gallery or subterranean mines people must enter the bowels of the Earth to be able to extract the planet's mineral wealth. Some mines for extracting coal—the legendary driving force of the Industrial Revolution—are a clear example of this type of exploitation. Although these mines imply higher costs and labor risks, they have a lower environmental impact.

How Coal Is Extracted

6. DISTRIBUTION
Mine trains transport the coal from the mine to the point of consumption.

5. WASHING AND CLASSIFICATION
Coal that leaves the mine is mixed with mud and rocks. It must be washed and classified according to quality and size.



Coal is separated from other materials through decantation.

WASHING AND CLASSIFICATION BUILDING

EXTRACTION TOWER

VENTILATION
Without good ventilation, methane, an explosive gas, condenses in the galleries and creates the risk of explosions.

FRESH-AIR ENTRANCE

4. ELEVATION
From the main shaft, the coal is transferred to cargo elevators that transport it to the surface.

EXIT FOR CONTAMINATED AIR

SECONDARY SHAFT

GALLERY
Tunnel that is used for communication in the mine

MINER'S TRANSPORT

MOVEMENT IN THE GALLERIES
The miners travel on foot or by train to the coal vein.

3. TRANSPORTATION
The extracted coal is placed on the conveyor belts that take it to the main shaft, and from there it is taken to the surface.

MAIN SHAFT
16 TO 23 FEET (5 TO 7 M)

2. EXTRACTION
The method that is widely used is that of continuous mining. A machine extracts the coal mechanically.

Mobile Arm

Coal Vein

1. PERFORATION
A vertical shaft is perforated, allowing access to the coal vein.

1.8 tons
IS THE AMOUNT OF COAL THE PERFORATOR EXTRACTS IN AN HOUR.

CARGO ELEVATOR

TRANSPORTER BELT

5,000 feet (1.52 km)
THE SHAFTS CAN REACH THIS DEPTH.

60%
OF EXPLOITATION IS CARRIED OUT UNDERGROUND.

MAIN PRODUCERS
Year 2003. In millions of tons.

China	1,635
United States	1,070
India	503
Russia	294
South Africa	264

MAIN CONSUMERS
Year 2003. In millions of tons.

China	1,531
United States	1,094
India	430
Germany	273
South Africa	264

Black Gold

Because of its economic importance as a source of energy, petroleum, or oil, is called black gold. Searching for it requires large amounts of money and years of investigation and exploration, all with no guarantees. Once discovered, petroleum extraction entails the use of expensive machinery, which includes everything from oil pumps to refineries that convert oil into many derivative products. The oil trade is one of the most lucrative businesses worldwide, and a change in its price can affect national economies and put whole countries on guard. Petroleum is a nonrenewable source of energy.

How Petroleum Is Obtained

1. SEARCH
Indirect methods are used to detect the presence of hydrocarbons. However, the information obtained is not conclusive.

2. EXPLORATION
Once a deposit is detected, the soil is drilled to verify that there is petroleum with economic potential.

3. EXTRACTION
If the well is productive, the drilling towers are removed and extraction systems are installed.

4. TRANSPORTATION
Tankers transport crude oil to the refinery, where various products can be derived from it.

5. REFINING
The components of crude oil are separated, making use of the fact that each component boils at a different temperature. Refining is carried out by means of two main processes: fractional distillation and cracking.

NATURAL WAYS TO PUMP PETROLEUM

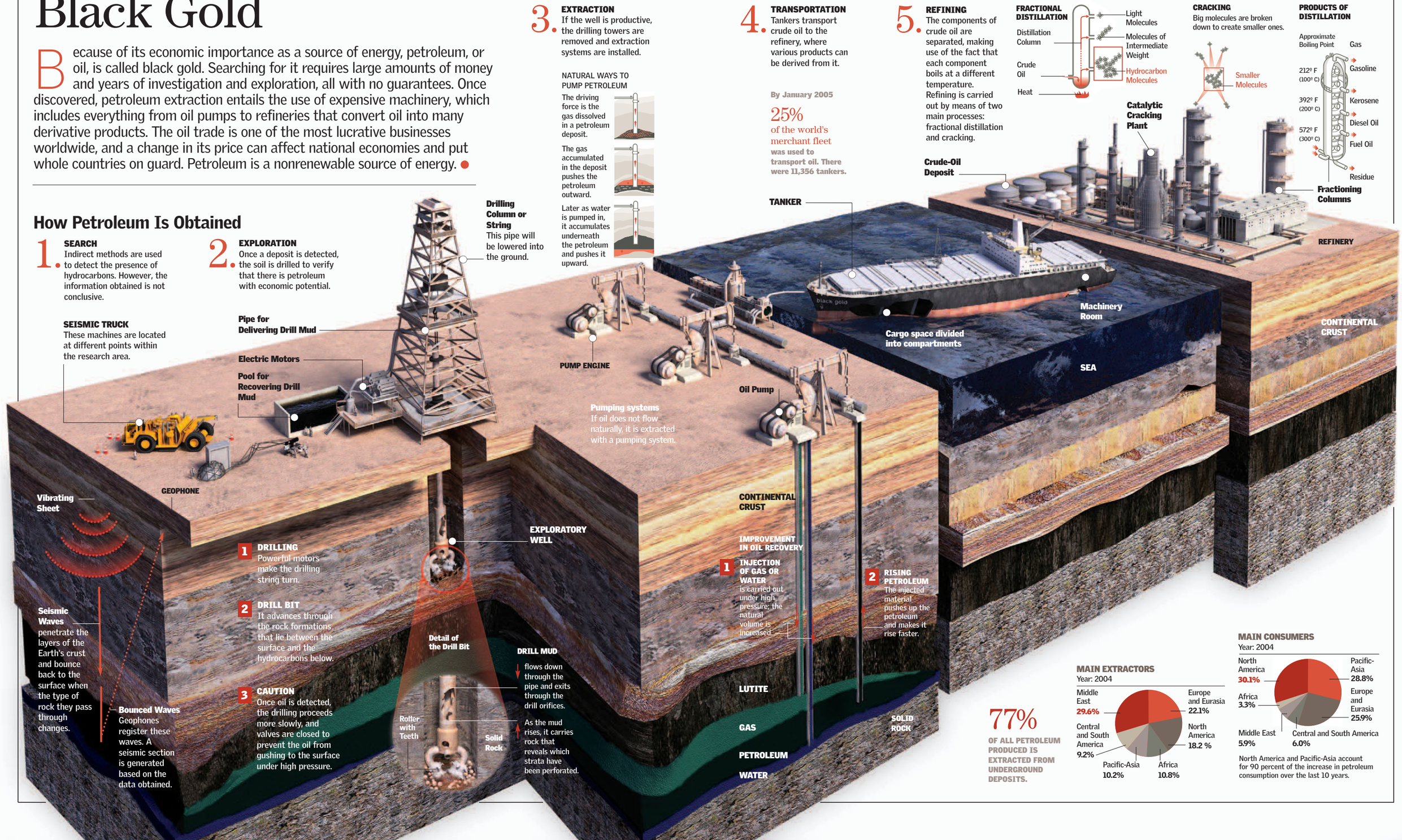
The driving force is the gas dissolved in a petroleum deposit.

The gas accumulated in the deposit pushes the petroleum outward.

Later as water is pumped in, it accumulates underneath the petroleum and pushes it upward.

By January 2005

25%
of the world's merchant fleet was used to transport oil. There were 11,356 tankers.



77%
OF ALL PETROLEUM PRODUCED IS EXTRACTED FROM UNDERGROUND DEPOSITS.

MAIN EXTRACTORS
Year: 2004

MAIN CONSUMERS
Year: 2004

North America and Pacific-Asia account for 90 percent of the increase in petroleum consumption over the last 10 years.

Radioactive Minerals

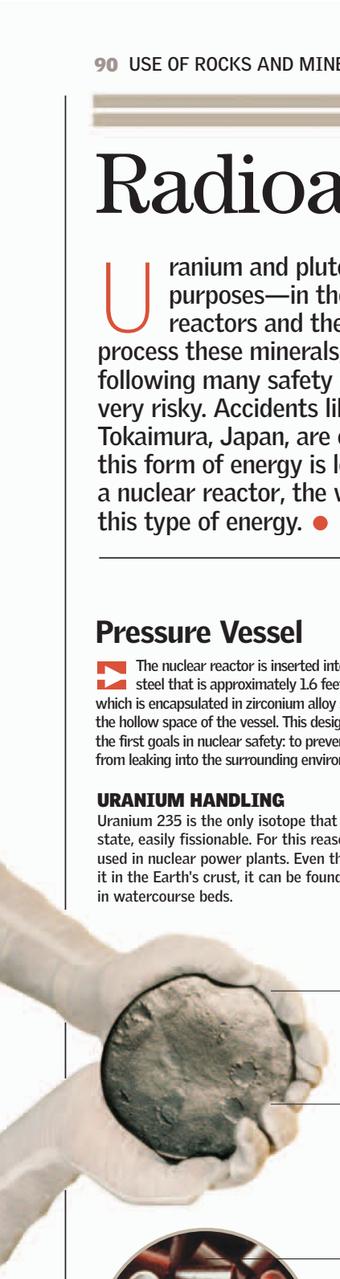
Uranium and plutonium were used for the first time—for military purposes—in the 1940s. Once World War II ended, nuclear reactors and their fuels began to be used as sources of energy. To process these minerals, nuclear plants are necessary. They must be built following many safety guidelines, since nuclear energy is considered to be very risky. Accidents like the one in Chernobyl and, more recently, in Tokaimura, Japan, are clear examples of what can happen when control of this form of energy is lost. These images show the structure and heart of a nuclear reactor, the way uranium is processed, and the peaceful uses of this type of energy.

Pressure Vessel

The nuclear reactor is inserted into a vessel formed by steel that is approximately 1.6 feet (0.5 m) thick. The fuel, which is encapsulated in zirconium alloy sheaths, is located inside the hollow space of the vessel. This design helps to meet one of the first goals in nuclear safety: to prevent radioactive products from leaking into the surrounding environment.

URANIUM HANDLING

Uranium 235 is the only isotope that is found in a natural state, easily fissionable. For this reason, it is the main fuel used in nuclear power plants. Even though it is rare to find it in the Earth's crust, it can be found in enriching deposits in watercourse beds.

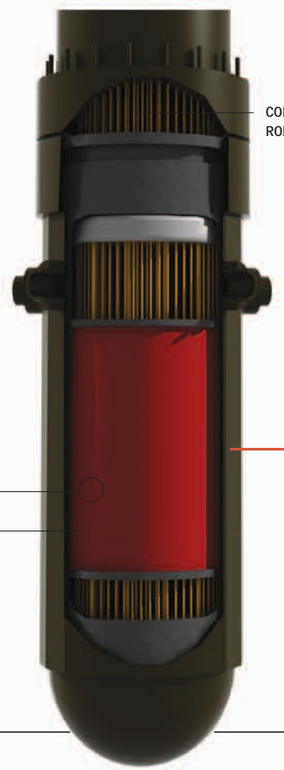


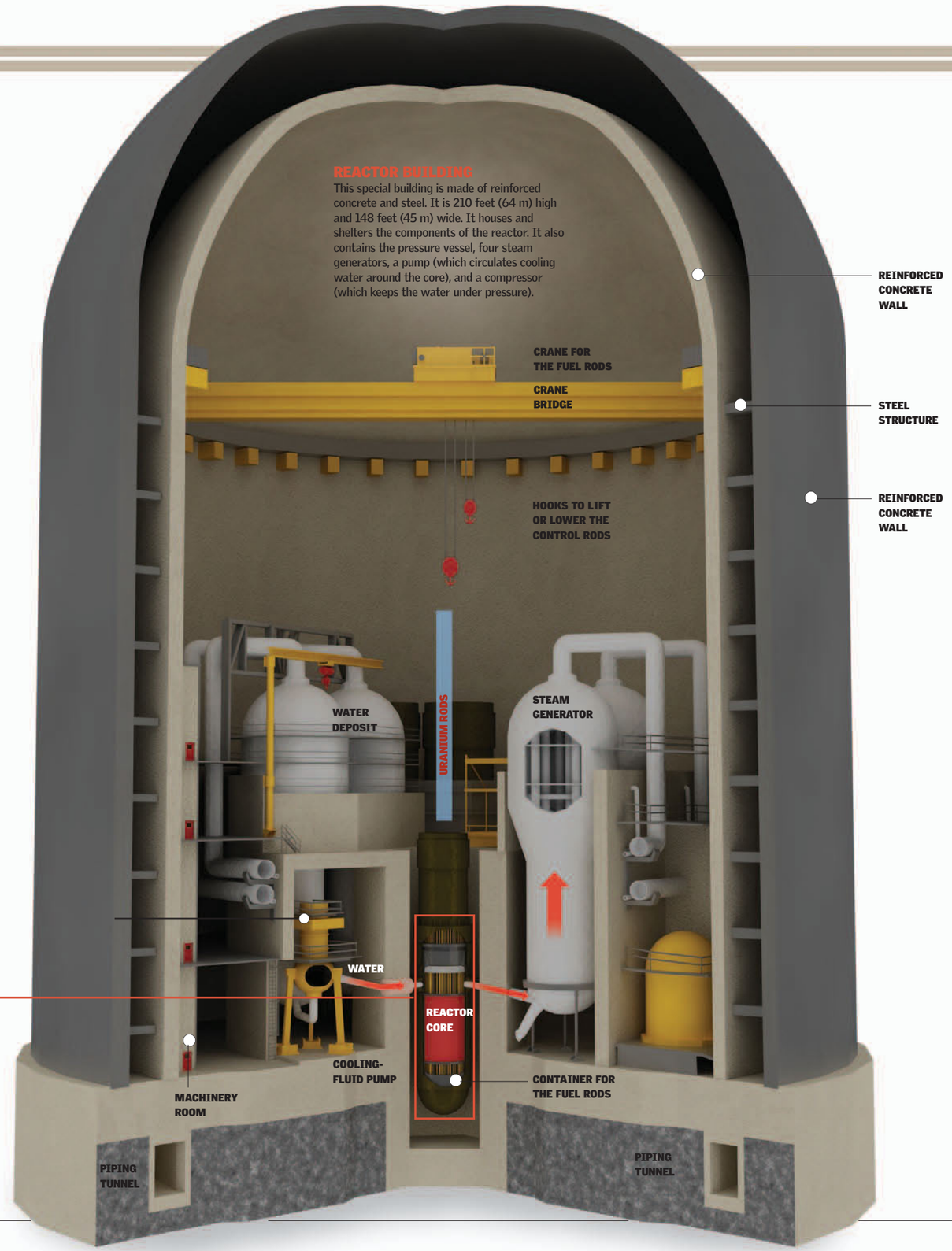
264
FUEL RODS IN EACH GROUP

THE NUCLEUS OF THE REACTOR

is in the lower part of the safety vessel, in which there are about 200 groups of fuel sheaths sized 0.4 inch (1 cm) in diameter and 13 feet (4 m) in height.

572° F
(300° C)
THE TEMPERATURE OF THE WATER PELLET





Carbon 14

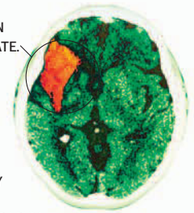
is a method for dating organic fossil samples based on the exponential decay law of radioactive isotopes. After a living organism has been dead for 5,730 years, the amount of ^{14}C present in its body has decreased by half. Thus, when the amount of latent ^{14}C is measured in organic materials, it is possible to calculate the amount remaining in the material and, therefore, to calculate when the organism died.

50,000 years



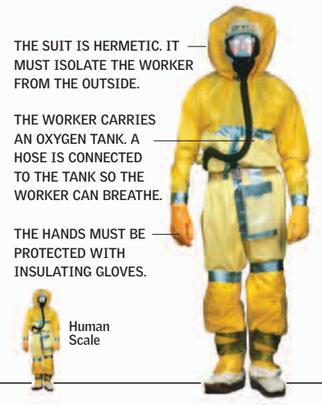
USE OF URANIUM IN MEDICINE

The application of nuclear energy helps with the diagnosis and treatment of diseases such as cancer. It can detect alterations long before symptoms develop clinically, which allows for more effective early treatment.



SAFETY SUIT

To handle radioactive material, such as spent fuel bars, workers must wear a special suit because of the high levels of radiation.



Glossary

Alkalines

Minerals that have a high content of potassium, sodium, lithium, rubidium, and calcium.

Amorphous

Mineral with fractured surfaces instead of crystalline faces. Noncrystalline.

Anticline

A fold of sedimentary strata sloping upwards like an arch.

Asthenosphere

Layer inside the Earth, below the lithosphere. It is part of the upper mantle and is composed of easily deformable rock.

Atom

The smallest unit of matter.

Bacteria

Microscopic and unicellular life-form found in air, water, plants, animals, and on the Earth's crust.

Batholith

Great mass (larger than 60 square miles [100 sq km] of surface) of intrusive igneous rocks.

Bravais Lattices

Three-dimensional crystal systems, based on certain mathematical principles, that represent the 14 types of cell units.

Butte

Hill with a flat top and sloping sides, found in areas that have undergone intense erosion.

Canyon

Deep, narrow valley formed by fluvial erosion.

Carat

Unit of weight used in jewelry, variable in time and place, equivalent to 0.007 ounce (0.2 g).

Cave

Subterranean cavity formed through the chemical action of water on soluble, generally calcareous, ground.

Cementation

Process by which sediment both loses porosity and is lithified through the chemical precipitation of material in the spaces between the grains.

Cementation Zone

Place where lithification occurs. Water infiltrates the area, fills up the spaces between the grains of sediment, and transforms loose sediment into a solid mass.

Chasm, or Rift

Wide valley formed as a consequence of the extension of the crust at the boundaries of diverging tectonic plates.

Chemical Compound

Substance formed by more than one element.

Chemical Element

Substance that contains only one type of atom.

Clay

Fine-grained sediments formed by the chemical decomposition of some rocks. It is malleable when wet and hardens as it dries.

Coal

Combustible black rock of organic origin. It is produced through the decomposition of plant materials that accumulate in swamps or shallow marine waters.

Concretion

Hard mass of mineral material that usually holds a fossil inside.

Contact Metamorphism

Large-scale transformation of a rock into another type of rock. This happens mostly as a consequence of a sudden temperature increase.

Convection Currents

Moving pathways of material that occur inside the mantle as a consequence of the transfer of heat coming from the Earth's core. The hottest zones of the mantle rise, and the coldest ones sink. These movements are probably responsible for the movement of tectonic plates.

Crack

Fissure or cavity in the rock that results from tension. It can be completely or partially filled with minerals.

Crust

External layer of the Earth. There are two types of crust: continental crust forms large terrestrial masses, and oceanic crust forms the bottoms of the oceans.

Crystal

Organized, regular, and periodically repeated arrangement of atoms.

Crystalline System

It includes all crystals that can be related to the same set of symmetric elements.

Density

Amount of mass of a mineral per unit of volume.

Deposit

A natural accumulation of a rock or mineral. If it is located at the site where it formed, the deposit is called primary. Otherwise, it is called secondary.

Diatomite

Light, porous rock. It has a light color, and it is consolidated. Composed exclusively (or almost) of diatoms.

Dolostone

Carbonated sedimentary rock that contains at least 50 percent or more carbonate, of which at least half appears as dolomite.

Earthquake

The sudden and violent release of energy and vibrations in the Earth that generally occurs along the edges of tectonic plates.

Elasticity

Tendency of a mineral to recover its shape after being subjected to flexion or torsion.

Era

Division of time in the Earth's history. Geologists divide eras into periods.

Erosion

Removal and transport of sediment through the action of water, ice, and wind.

Evaporation

Process through which a liquid becomes gas without boiling.

Exfoliation

The tendency for certain minerals to fracture along regular planes within their crystalline structure.

Fault

Fracture involving the shifting of one rock mass with respect to another.

Flexibility

Ability of minerals to bend without fracturing.

Fluorescence

Property of some minerals that enables them to emit a certain level of light when exposed to ultraviolet rays. The fluorescent properties present in a metal can make it look as if it were truly fluorescent.

Fold

Bending and deformation of rock strata due to the compression caused by the movements of tectonic plates.

Fossil

Any trace of an old life-form. It can be the petrified remains of an organism or an impression of an organism left in rock.

Fossil Fuel

Fuel formed from the partially decomposed remains of deceased organisms. These mixtures of organic compounds are extracted from the subsoil with the goal of producing energy through combustion. They are coal, oil, and natural gas.

Fracture

Break of a mineral along an irregular surface. It can be conchoidal, hooked, smooth, or earthy.

Gem

Mineral or other natural material that is valued for its beauty and rarity. It can be polished and cut to produce jewels.

Geode

Spherical, rocky cavity covered with well-formed crystals.

Geology

Study of the Earth, its shape, and its composition. Rocks, minerals, and fossils offer information that helps us reconstruct the history of the planet.

Glacier

A large mass of ice formed through the accumulation of recrystallized and compacted snow occurring either on a mountain or over a large area on a landmass. Ice moves slowly and both excavates rock and carries debris.

Granite

Intrusive igneous rock composed mainly of quartz and feldspar. It can be polished and used in decoration.

Habit

External aspect of a crystal that reflects its predominant shape.

Hardness

Resistance offered by a mineral to scratching and abrasion. One mineral is said to be harder than another if the former can scratch the latter.

Hot Spot

Place within a tectonic plate where active volcanoes form.

Hydrothermal

Process involving the physical and chemical transformations suffered by rocks or minerals through the action of hot fluids (water and gases) associated with a magma body.

Igneous Rocks

Rocks formed directly from the cooling of magma. If they solidify inside the crust, they are said to be plutonic (or intrusive); if they solidify on the surface, they are said to be volcanic (or extrusive).

Impermeable Rock

Rock through which liquids cannot be filtered.

Intrusion

A large mass of rock that forms in empty spaces underground when magma infiltrates strata, cools, and solidifies.

Jade

White or green metamorphic rock formed by a compact and tenacious filter of very fine needles of tremolite. It is a rare rock used in art objects.

Karst Cycle

Formation cycle of caves that lasts a total of about one million years.

Kimberlite

Type of rock usually associated with diamonds and other minerals coming from the depths of the Earth.

Lava

Magma expelled on the surface of the Earth.

Limestone

Rock containing at least 50% calcite. It can also have dolomite, aragonite, and siderite.

Lithosphere

Exterior, rigid layer of the Earth formed by the crust and upper mantle.

Lode

Sub-superficial rock intrusion of tabular-shaped rock.

Luster

Level of light reflection on the surface of a crystal.

Magma

Hot, rocky material from the crust and upper mantle in liquid state that forms crystals as it cools. When magma is expelled at the Earth's surface, it is called lava.

Magmatic Rock

Rock that forms when magma cools off and solidifies. Magmatic intrusive rocks solidify underground, while the extrusive ones solidify on the surface.

Magnetism

Property of some minerals that allows them to be attracted by a magnet and to change the direction of a compass needle.

Malleability

Mechanical property of a mineral that makes it possible for the mineral to be molded and formed into a sheet through repeated blows without breaking.

Mantle

The layer between the crust and external core. It includes the upper mantle and lower mantle.

Marble

Metamorphosed limestone rock composed of compacted calcite and dolomite. It can be polished.

Massive

One of the possible habits of a consistent mineral that refers to the tendency for certain crystals to intertwine and form a solid mass rather than independent crystals.

Metal

Any element that shines, conducts electricity, and is malleable.

Metamorphic Rock

Type of rock resulting from the application of high pressure and temperature on igneous and sedimentary rocks.

Mineral

Inorganic solid of natural origin that has an organized atomic structure.

Mohs Scale

A tool designed to test the hardness of a given mineral by comparing it to 10 known minerals, from the softest to the hardest. Each mineral can be scratched by those following it.

Molecule

Chemical compound formed when one or several types of atoms are joined together.

Native Element

An element that occurs in nature that is not combined with other elements. Sulfur and gold are examples of native elements.

Oceanic Trench

Narrow and deep submarine depression formed when the oceanic crust of one tectonic plate moves beneath another.

Ornamental Stone

It is not a precious stone, but it can be used in jewelry or for other ornamental purposes.

Outcrop

Part of a rock formation devoid of vegetation or soil that stands out from the Earth's surface.

Oxidation Zone

Deposit of minerals with oxidizing properties, formed through the effect of meteorization or weathering.

Petrifaction

Cell-by-cell replacement of organic matter, such as bones or wood, with minerals of the surrounding solutions.

Piezoelectric

Property that some minerals have to produce a difference in potential when subjected to compression, traction, or torsion.

Placer

Mineral concentrations as deposits of placer during time lapses that vary from a few decades up to millions of years.

Pyroelectric

Property that some nonconductor minerals have to create difference in power transmissions from differences in temperature.

Quartzite

Metamorphic rock formed by the consolidation of quartz sandstone. It is extremely hard. Quartzite can also be a sedimentary rock, which is sandstone with a very high content of quartz; it is very hard and it has light color.

Regional Metamorphism

Metamorphism occurring in rock over large areas.

Rock

Natural aggregate of one or more minerals (sometimes including noncrystalline substances) that constitute an independent geologic unit.

Sedimentary Rock

Rock that forms through accumulation of sediments that, when subjected to physical and chemical processes, result in a compacted and consolidated material. Sediment can form on river banks, at the bottom of precipices, in valleys, lakes, and seas. Sedimentary rock accumulates in successive layers, or strata.

Sediments

Rock fragments or remains of plants or animals deposited at the bottom of rivers, lakes, or oceans by water, wind, or ice.

Seismic Waves

Elastic waves that travel through the Earth after an earthquake. They can also be produced artificially through explosions.

Silicates

They make up about 95 percent of the Earth's crust. Their tetrahedral structure, with one silicon and four oxygen ions, creates different types of configurations through the union of the ions. According to their composition, members of this mineral group are differentiated into light and dark.

Slate

Bluish black, fine-grained metamorphic rock. It can be easily divided into sheets.

Solution

Mixture of two or more chemical substances. It can be liquid, solid, or gaseous.

Stalactite

Internal structure of a cave. It is conical and hangs from the cave ceiling.

Stalagmite

Internal structure of a cave. It is conical and rises from the cave floor.

Streak

Characteristic color of the fine dust obtained from a mineral by rubbing it over an unglazed porcelain plate.

Streak Test

A test that involves rubbing a mineral against an unglazed white porcelain sheet to obtain dust. The color of the dust left on the tile can help identify the mineral.

Symmetry Axes

Symmetry element that enables the repetition of crystalline faces to form different shapes.

Syncline

Concave fold of sedimentary rock strata. The younger rocks are located at the center of the concave.

Talus Slope

Accumulation of fragments resulting from the mechanical weathering of rocks. The sediment deposit forms more or less in situ as the result of the transport of materials through gravity over a small distance.

Tectonic Elevation

Rising of rocks as a consequence of the movements of tectonic plates.

Tectonic Plates

Rigid fragments of the lithosphere that move on the asthenosphere.

Tenacity

The level of toughness that a mineral offers to fracture, deformation, crushing, bending, or pulverization.

Transparent

It is said that a mineral is clear when light goes through it without weakening. When only some light passes through, the mineral is called translucent. If no light passes through, it is called opaque.

Vein

Fracture that cuts through rocks and is filled by some mineral.

Volcanic Outcropping

Isolated pile of hard magmatic rocks that remain after the disappearance of the rest of the volcano due to erosion.

Weathering

The breaking down of a material by sustained physical or chemical processes.

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ROCKS AND MINERALS

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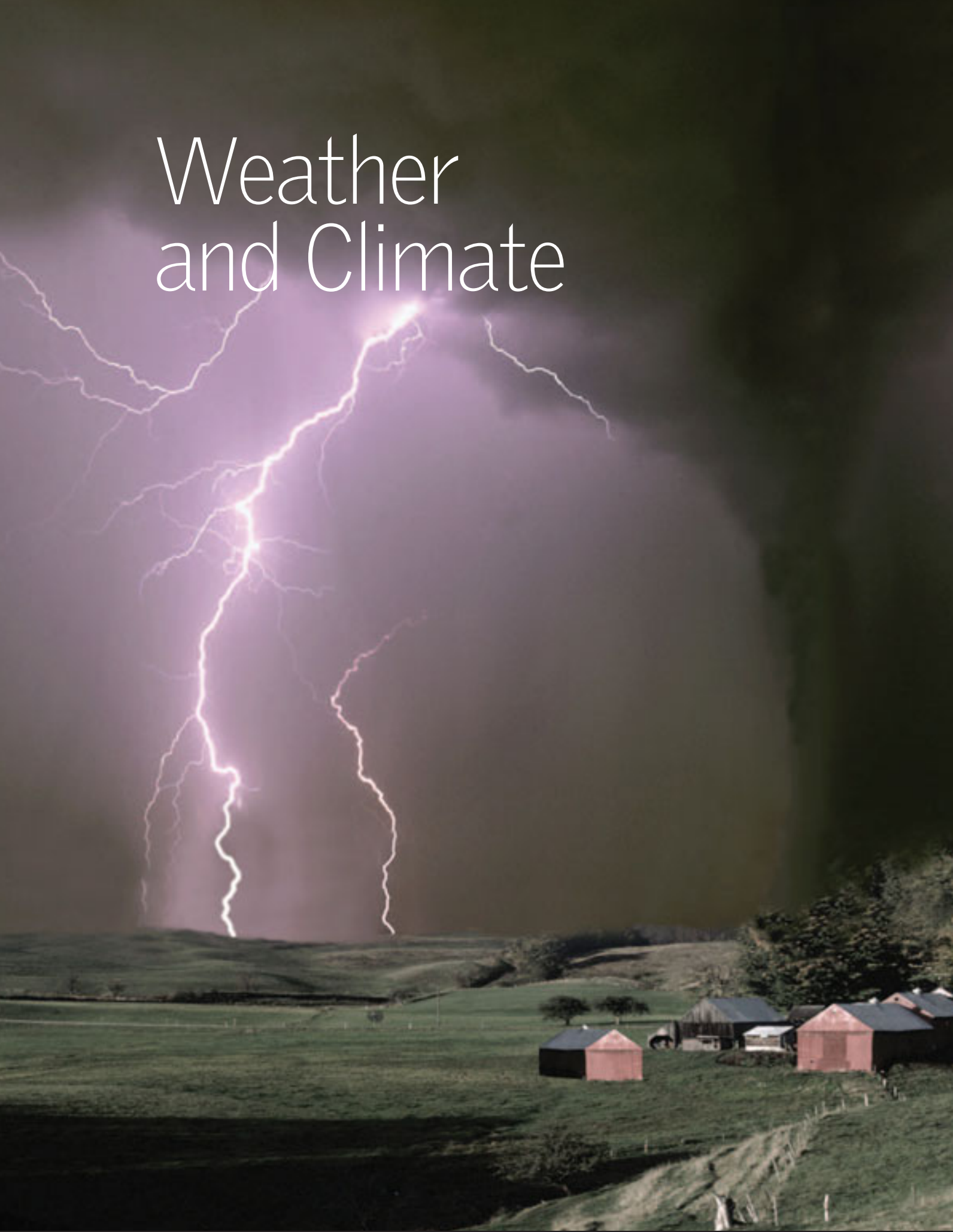
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Tornado during an electrical storm, in Oklahoma, 1973

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A Sum of Factors

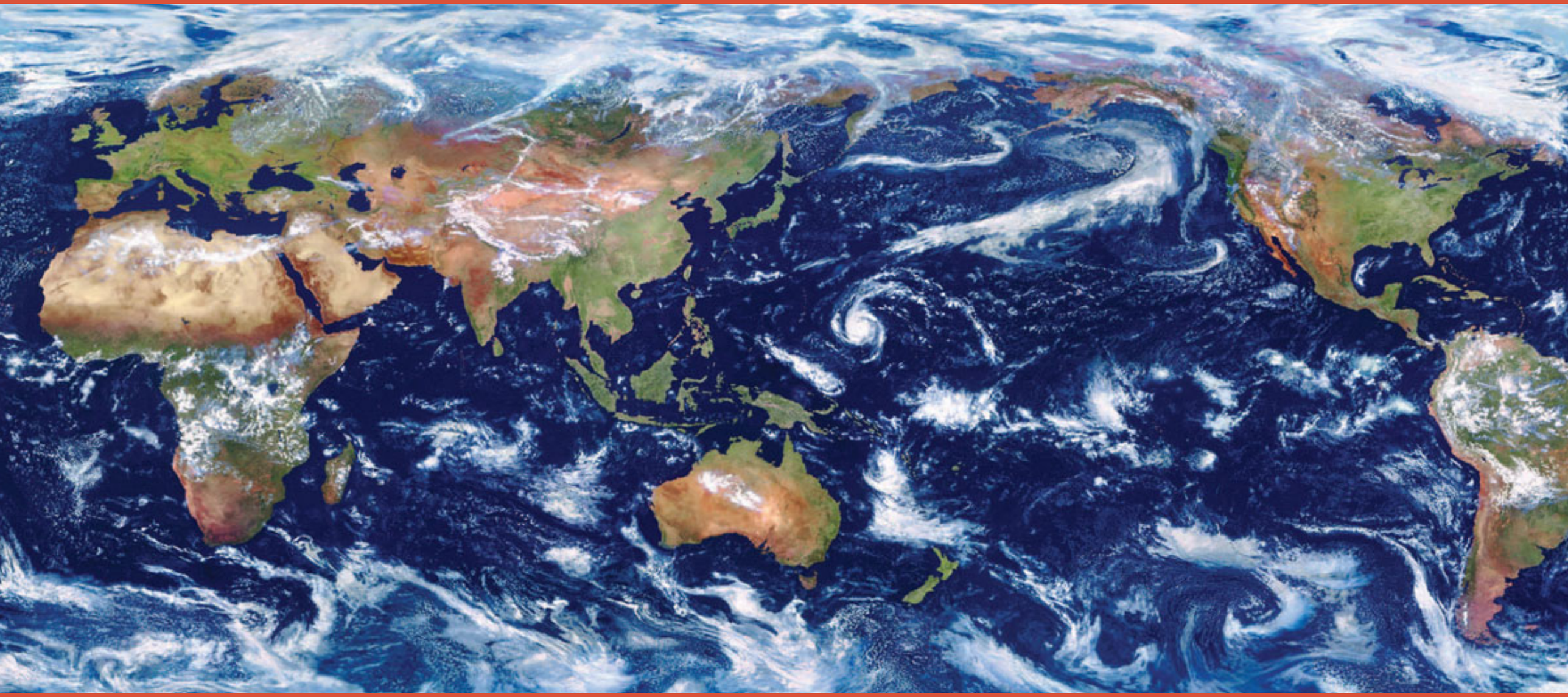
STRONG WINDS AND TORRENTIAL RAINS
Between September 20 and September 25, 1998, Hurricane Georges lashed the Caribbean, leaving thousands of people homeless.

"The flutter of a butterfly's wings in Brazil can unleash a tornado in Florida." That was the conclusion arrived at in 1972 by Edward Lorenz after dedicating himself to the study of meteorology and trying to find a way of predicting meteorological phenomena that might put the lives of people at risk. In effect, the atmosphere is a system so complicated that many scientists define it as chaotic. Any forecast can rapidly deteriorate because of the wind, the appearance of a warm front, or an unexpected storm. Thus, the difference continues to grow geometrically, and the reality of the next day is not the one that was expected but entirely different: when there should have been sunshine, there is rain; people who planned to go to the beach find they have to shut themselves up in the basement until the hurricane passes. All this uncertainty causes many people who live in areas that are besieged by hurricanes or tropical storms to live in fear of what might happen, because they feel very vulnerable to changes in weather. It is also true that natural phenomena, such as tornadoes, hurricanes, and cyclones, do not in themselves cause catastrophes. For example, a hurricane becomes a disaster and causes considerable damage, deaths, and economic losses only because it strikes a populated area or travels over farmland. Yet in society, the idea persists that natural phenomena equate to death and destruction. In fact, experience shows that we have to learn to live with these phenomena and plan ahead for what might happen when they occur. In this book, along with spectacular images, you will find useful information about the factors that determine weather and climate, and you will be able to understand why long-term forecasts are so complicated. What changes are expected if global warming continues to increase? Could the polar ice caps melt and raise sea levels? Could agricultural regions slowly become deserts? All this and much more are found in the pages of the book. We intend to arouse your curiosity about weather and climate, forces that affect everyone.

Climatology

SATELLITE IMAGE
In this image of the Earth, one clearly sees the movement of water and air, which causes, among other things, temperature variations.

GLOBAL EQUILIBRIUM 8-9
PURE AIR 10-11
ATMOSPHERIC DYNAMICS 12-13
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COLORS IN THE SKY 16-17



The constantly moving atmosphere, the oceans, the continents, and the great masses of ice are the principal components of the environment. All these constitute what is called the climatic system; they permanently interact with one another and transport water (as liquid or vapor), electromagnetic radiation, and heat. Within this complex system, one of the fundamental variables is temperature, which experiences the most change and is the most noticeable. The wind is important because it carries heat and moisture into the atmosphere. Water, with all its processes (evaporation, condensation, convection), also plays a fundamental role in Earth's climatic system. ●

Global Equilibrium

The Sun's radiation delivers a large amount of energy, which propels the Earth's extraordinary mechanism called the climatic system. The components of this complex system are the atmosphere, hydrosphere, lithosphere, cryosphere, and biosphere. All these components are constantly interacting with one another via an interchange of materials and energy. Weather and climatic phenomena of the past—as well as of the present and the future—are the combined expression of Earth's climatic system. ●

Atmosphere

Part of the energy received from the Sun is captured by the atmosphere. The other part is absorbed by the Earth or reflected in the form of heat. Greenhouse gases heat up the atmosphere by slowing the release of heat to space.

Biosphere

Living beings (such as plants) influence weather and climate. They form the foundations of ecosystems, which use minerals, water, and other chemical compounds. They contribute materials to other subsystems.

EVAPORATION
The surfaces of water bodies maintain the quantity of water vapor in the atmosphere within normal limits.

about 10%
ALBEDO OF THE TROPICAL FORESTS

WINDS
The atmosphere is always in motion. Heat displaces masses of air, and this leads to the general circulation of the atmosphere.

PRECIPITATION
Water condensing in the atmosphere forms droplets, and gravitational action causes them to fall on different parts of the Earth's surface.

HEAT

HEAT

Night and day, coastal breezes exchange energy between the hydrosphere and the lithosphere.

MARINE CURRENTS

HUMAN ACTIVITY

Hydrosphere

The hydrosphere is the name for all water in liquid form that is part of the climatic system. Most of the lithosphere is covered by liquid water, and some of the water even circulates through it.

3%
ALBEDO OF THE BODIES OF WATER

SOLAR RADIATION
About 50 percent of the solar energy reaches the surface of the Earth, and some of this energy is transferred directly to different layers of the atmosphere. Much of the available solar radiation leaves the air and circulates within the other subsystems. Some of this energy escapes to outer space.

Sun

Essential for climatic activity. The subsystems absorb, exchange, and reflect energy that reaches the Earth's surface. For example, the biosphere incorporates solar energy via photosynthesis and intensifies the activity of the hydrosphere.

ALBEDO
The percentage of solar radiation reflected by the climatic subsystems.

50%
THE ALBEDO OF LIGHT CLOUDS

SUN

Cryosphere

Represents regions of the Earth covered by ice. Permafrost exists where the temperature of the soil or rocks is below zero. These regions reflect almost all the light they receive and play a role in the circulation of the ocean, regulating its temperature and salinity.

80% ALBEDO OF RECENTLY FALLEN SNOW

Lithosphere

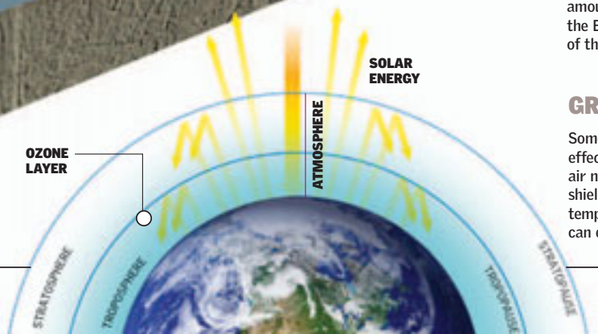
This is the uppermost solid layer of the Earth's surface. Its continual formation and destruction change the surface of the Earth and can have a large impact on weather and climate. For example, a mountain range can act as a geographic barrier to wind and moisture.

SMOKE
Particles that escape into the atmosphere can retain their heat and act as condensation nuclei for precipitation.

RETURN TO THE SEA

UNDERGROUND CIRCULATION
The circulation of water is produced by gravity. Water from the hydrosphere infiltrates the lithosphere and circulates therein until it reaches the large water reservoirs of lakes, rivers, and oceans.

ASHES
Volcanic eruptions bring nutrients to the climatic system where the ashes fertilize the soil. Eruptions also block the rays of the Sun and thus reduce the amount of solar radiation received by the Earth's surface. This causes cooling of the atmosphere.



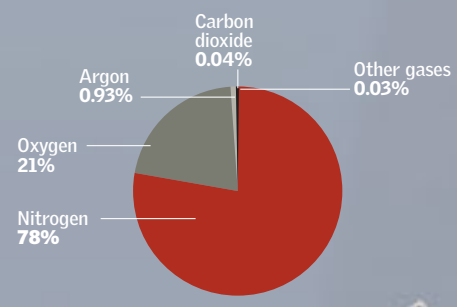
GREENHOUSE EFFECT

Some gases in the atmosphere are very effective at retaining heat. The layer of air near the Earth's surface acts as a shield that establishes a range of temperatures on it, within which life can exist.

Pure Air

The atmosphere is the mass of air that envelops the surface of the Earth. Its composition allows it to regulate the quantity and type of solar energy that reaches the surface of the Earth. The atmosphere, in turn, absorbs energy radiated by the crust of the Earth, the polar ice caps and the oceans, and other surfaces on the planet. Although nitrogen is its principal component, it also contains other gases, such as oxygen, carbon dioxide, ozone, and water vapor. These less abundant gases, along with microscopic particles in the air, have a great influence on the Earth's weather and climate.

GASES IN THE AIR



EXOSPHERE
This layer, which begins at an altitude of about 310 miles (500 km), is the upper limit of the atmosphere. Here material in plasma form escapes from the Earth, because the magnetic forces acting on them are greater than those of gravity.

GREENHOUSE EFFECT
Produced by the absorption of infrared emissions by the greenhouse gases in the atmosphere. This natural phenomenon helps to keep the Earth's surface temperature stable.



DISTANT ORBITS
Polar meteorological satellites orbit in the exosphere.

59° F (15° C)
AVERAGE TEMPERATURE OF THE EARTH'S SURFACE

THERMOSPHERE
Found between an altitude of 55 and 300 miles (90-500 km). The O_2 and the N_2 absorb ultraviolet rays and reach temperatures greater than 1,800° F (1,000° C). These temperatures keep the density of gases in this layer very low.



Auroras
Created in the upper layers of the atmosphere when the solar wind generates electrically charged particles

6%
of solar radiation is reflected by the atmosphere.



Military satellites
Air friction shortens their useful life.



Rocket probes
Used for scientific studies of the higher regions of the atmosphere

19%
of solar radiation is absorbed by the gases in the atmosphere.

Meteors
become superheated by friction with the molecules of the gas in the atmosphere. Particles that skip across the atmosphere are called shooting stars.

Cosmic rays
Come from the Sun and other radiation sources in outer space. When they collide with the molecules of gas in the atmosphere, they produce a rain of particles.



MESOSPHERE
Located between an altitude of 30 to 55 miles (50-90 km), it absorbs very little energy yet emits a large amount of it. This absorption deficit causes the temperatures to decrease from 60° F to -130° F (20° C to -90° C) in the upper boundary of the mesopause.

Noctilucent clouds
The only clouds that exist above the troposphere. They are the objects of intense study.

20%
of solar radiation is reflected by the clouds.

SOLAR RADIATION

Forecasts
Weather balloons are used to make weather forecasts. They record the conditions of the stratosphere.

STRATOSPHERE
Extends from an altitude of 6 miles to 30 miles (10-50 km). The band from 12 to 19 miles (20-30 km) has a high concentration of ozone, which absorbs ultraviolet radiation. A thermal inversion is produced in this layer that is expressed as an abrupt temperature increase beginning at an altitude of 12 miles (20 km).

The Ozone Layer
stops most of the Sun's ultraviolet rays.



Safe flights
The absence of meteorological changes in this region makes it safer for commercial flights.

Tropical storm clouds

TROPOSPHERE
Starts at sea level and goes to an altitude of six miles (10 km). It provides conditions suitable for life to exist. It contains 75 percent of the gases in the atmosphere. Meteorological conditions, such as the formation of clouds and precipitation, depend on its dynamics. It is also the layer that contains pollution generated by human activities.

51%
of solar radiation is absorbed by the Earth's surface.

4%
A small amount of solar radiation is reflected by the oceans and the ground.

High mountains
Any mountains higher than 5 miles (8 km) above sea level. The decrease of oxygen with altitude makes it difficult to breathe above 2.5 miles (4 km).

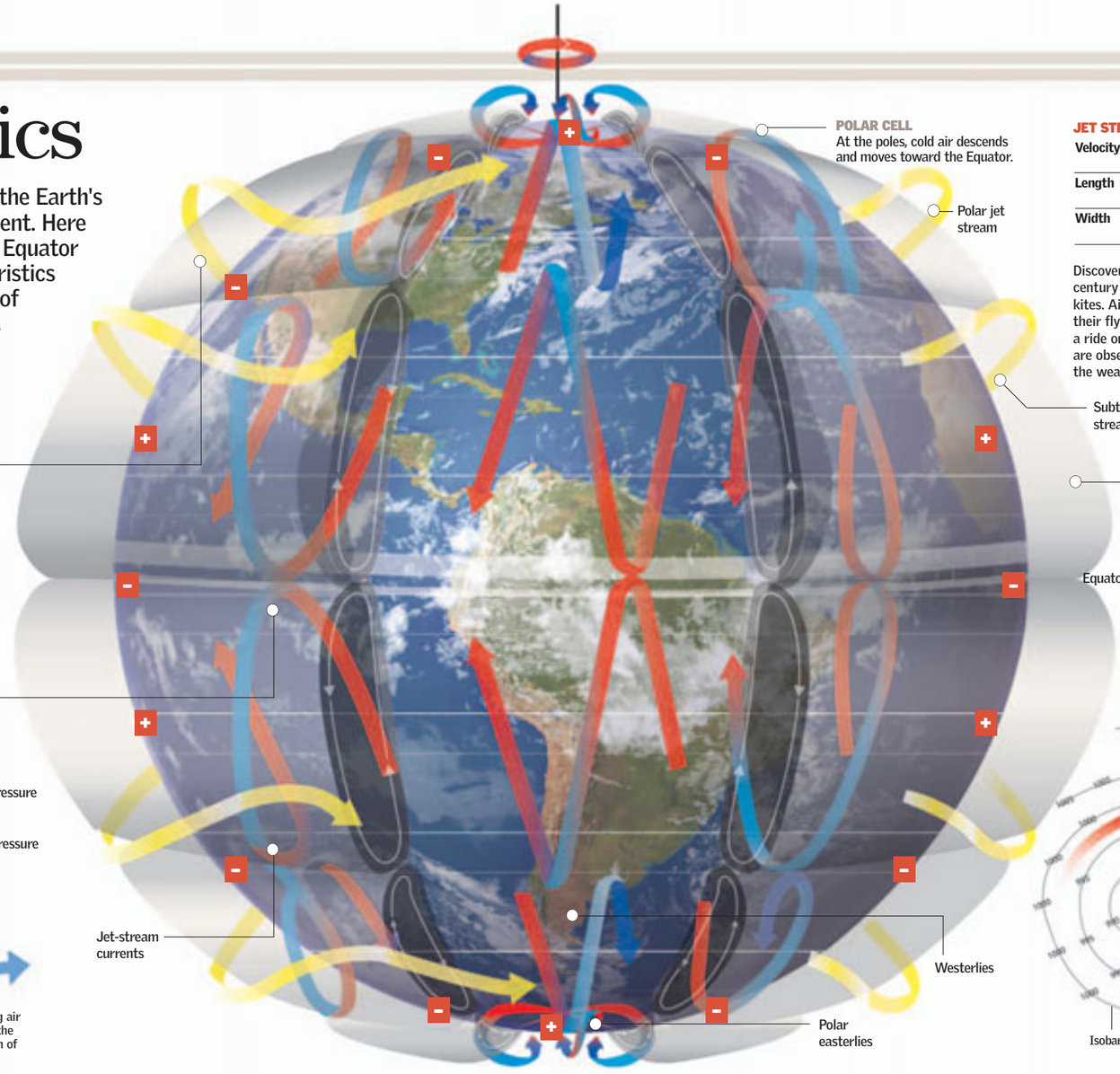
Cirrus

Atmospheric Dynamics

The atmosphere is a dynamic system. Temperature changes and the Earth's motion are responsible for horizontal and vertical air displacement. Here the air of the atmosphere circulates between the poles and the Equator in horizontal bands within different latitudes. Moreover, the characteristics of the Earth's surface alter the path of the moving air, causing zones of differing air densities. The relations that arise among these processes influence the climatic conditions of our planet.



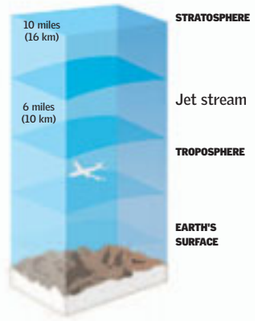
CORIOLIS FORCE
The Coriolis effect is an apparent deflection of the path of an object that moves within a rotating coordinate system. The Coriolis effect appears to deflect the trajectory of the winds that move over the surface of the Earth, because the Earth moves beneath the winds. This apparent deflection is to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. The effect is only noticeable on a large scale because of the rotational velocity of the Earth.



JET STREAM

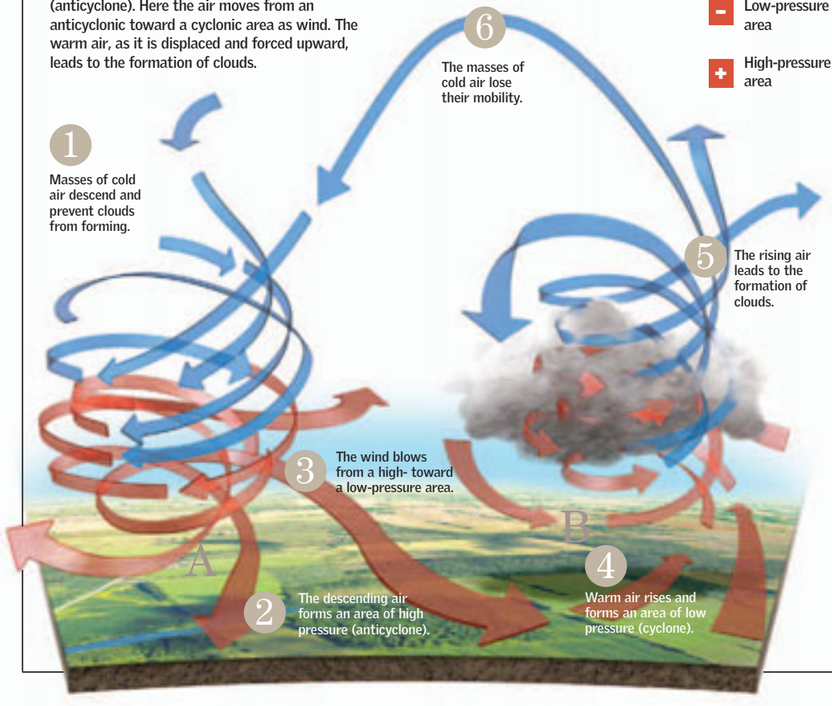
Velocity	55 to 250 miles per hour (90-400 km/h)
Length	1,000 to 3,000 miles (1,610-4,850 km)
Width	1 to 3 miles (1.6-4.8 km)

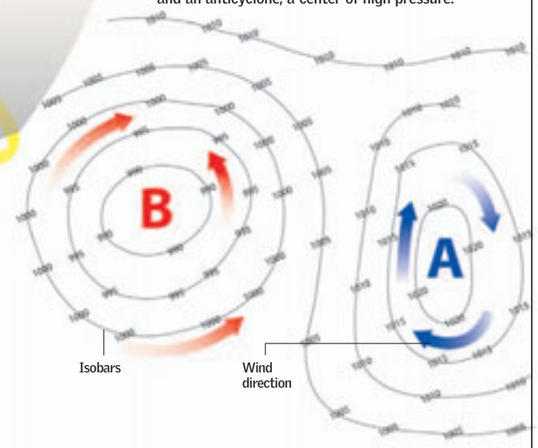
Discovered in the 19th century through the use of kites. Airplanes can shorten their flying time by hitching a ride on them. Their paths are observed to help predict the weather.



High and Low Pressure

Warm air rises and causes a low-pressure area (cyclone) to form beneath it. As the air cools and descends, it forms a high-pressure area (anticyclone). Here the air moves from an anticyclonic toward a cyclonic area as wind. The warm air, as it is displaced and forced upward, leads to the formation of clouds.

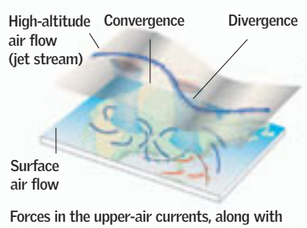




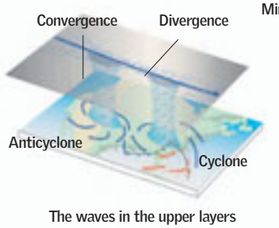
WEATHER SYSTEMS ANALYSIS
The continuous lines are isobars (in this case, in the Southern Hemisphere), imaginary lines that connect points of equal pressure. They show depressions—centers of low pressure relative to the surroundings—and an anticyclone, a center of high pressure.

Changes in Circulation

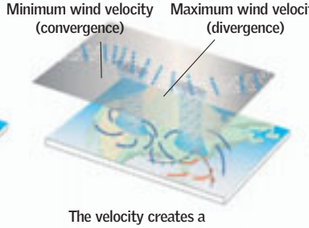
Irregularities in the topography of the surface, abrupt changes in temperature, and the influence of ocean currents can alter the general circulation of the atmosphere. These circumstances can generate waves in the air currents that are, in general, linked to the cyclonic zones. It is in these zones that storms originate, and they are therefore studied with great interest. However, the anticyclone and the cyclone systems must be studied together because cyclones are fed by currents of air coming from anticyclones.



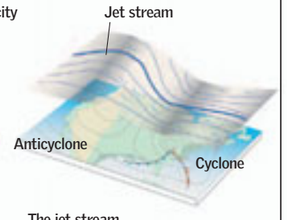
Forces in the upper-air currents, along with surface conditions, may cause air currents to flow together or may split them apart.



The waves in the upper layers are translated into cyclones and anticyclones at ground level.



The velocity creates a difference in air concentration between different systems.



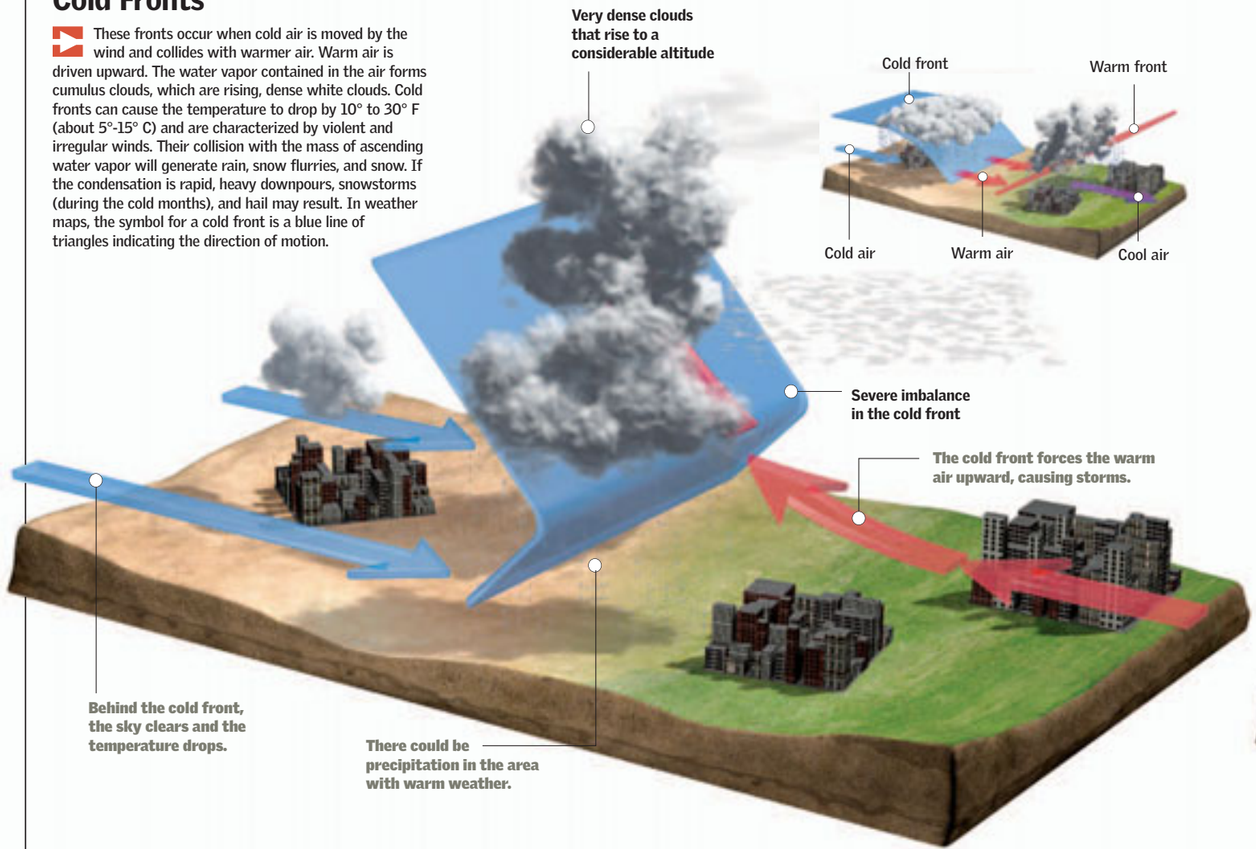
The jet stream generates air rotation, or vorticity.

Collision

When two air masses with different temperatures and moisture content collide, they cause atmospheric disturbances. When the warm air rises, its cooling causes water vapor to condense and the formation of clouds and precipitation. A mass of warm and light air is always forced upward, while the colder and heavier air acts like a wedge. This cold-air wedge undercuts the warmer air mass and forces it to rise more rapidly. This effect can cause variable, sometimes stormy, weather.

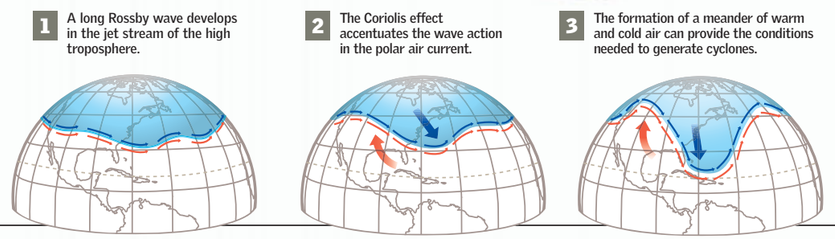
Cold Fronts

These fronts occur when cold air is moved by the wind and collides with warmer air. Warm air is driven upward. The water vapor contained in the air forms cumulus clouds, which are rising, dense white clouds. Cold fronts can cause the temperature to drop by 10° to 30° F (about 5°-15° C) and are characterized by violent and irregular winds. Their collision with the mass of ascending water vapor will generate rain, snow flurries, and snow. If the condensation is rapid, heavy downpours, snowstorms (during the cold months), and hail may result. In weather maps, the symbol for a cold front is a blue line of triangles indicating the direction of motion.



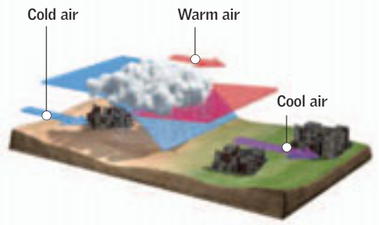
Rossby Waves

Large horizontal atmospheric waves that are associated with the polar-front jet stream. They may appear as large undulations in the path of the jet stream. The dynamics of the climatic system are affected by these waves because they promote the exchange of energy between the low and high latitudes and can even cause cyclones to form.



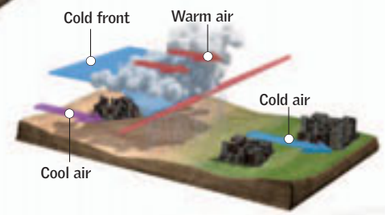
STATIONARY FRONTS

These fronts occur when there is no forward motion of warm or cold air—that is, both masses of air are stationary. This type of condition can last many days and produces only altocumulus clouds. The temperature also remains stable, and there is no wind except for some flow of air parallel to the line of the front. There could be some light precipitation.



OCCLUDED FRONTS

When the cold air replaces the cool air at the surface, with a warm air mass above, a cold occlusion is formed. A warm occlusion occurs when the cool air rises above the cold air. These fronts are associated with rain or snow, cumulus clouds, slight temperature fluctuations, and light winds.



Entire Continents

Fronts stretch over large geographic areas. In this case, a cold front causes storm perturbations in western Europe. But to the east, a warm front, extending over a wide area of Poland, brings light rain. These fronts can gain or lose force as they move over the Earth's surface depending on the global pressure system.

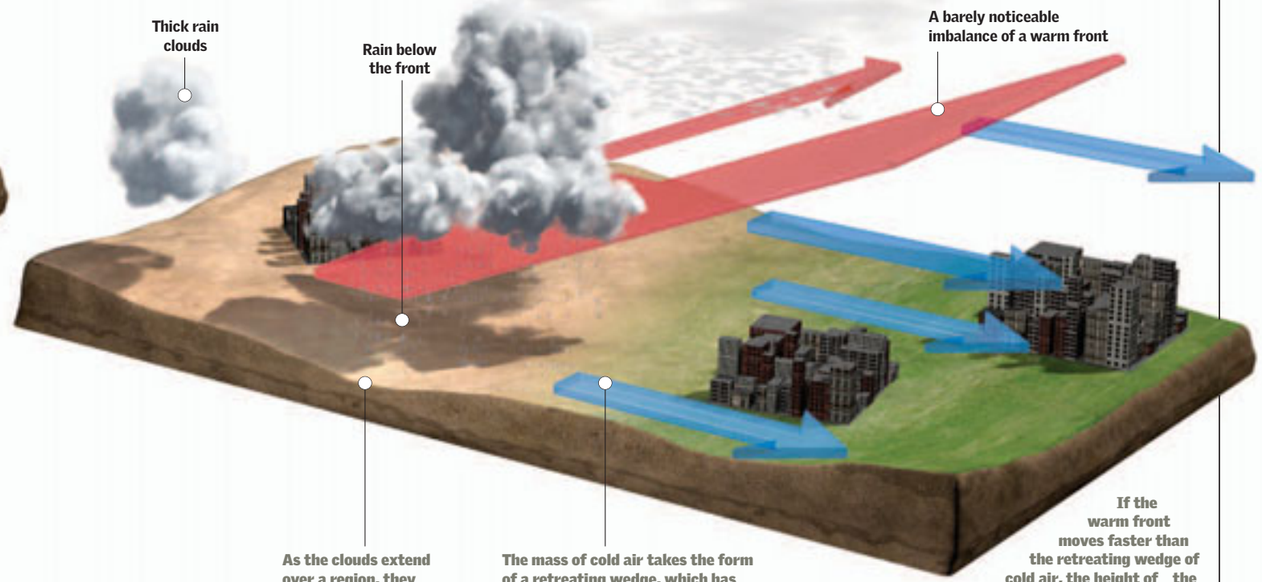


125 miles (200 km)

A warm front can be 125 miles (200 km) long. A cold front usually covers about 60 miles (100 km). In both cases, the altitude is roughly 0.6 mile (1 km).

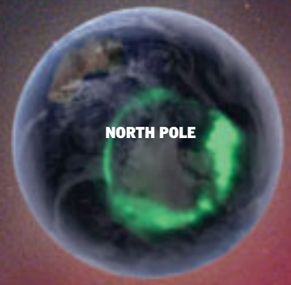
Warm Fronts

These are formed by the action of winds. A mass of warm air occupies a place formerly occupied by a mass of cold air. The speed of the cold air mass, which is heavier, decreases at ground level by friction, through contact with the ground. The warm front ascends and slides above the cold mass. This typically causes precipitation at ground level. Light rain, snow, or sleet are typically produced, with relatively light winds. The first indications of warm fronts are cirrus clouds, some 600 miles (1,000 km) in front of the advancing low pressure center. Next, layers of stratified clouds, such as the cirrostratus, altostratus, and nimbostratus, are formed while the pressure is decreasing.



Colors in the Sky

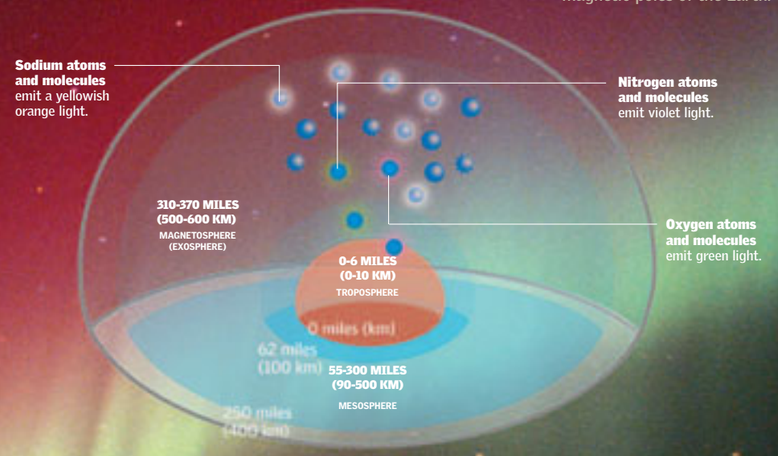
A natural spectacle of incomparable beauty, the auroras are produced around the magnetic poles of the Earth by the activity of the Sun. Solar wind acts on the magnetosphere, which is a part of the exosphere. In general, the greater the solar wind, the more prominent the aurora. Auroras consist of luminous patches and columns of various colors. Depending on whether they appear in the north or south, they are called aurora borealis or aurora australis. The aurora borealis can be seen in Alaska, Canada, and the Scandinavian countries.



A satellite image of the aurora borealis

How They Are Produced

The auroras are the result of the shock produced as ions coming from the Sun make contact with the magnetic field of the Earth. They appear in different colors depending on the altitude at which they are produced. Moreover, they demonstrate the function of the magnetosphere, which protects the planet against solar winds.



1 ELECTRONS COLLIDE WITH MOLECULES
The oxygen and nitrogen molecules receive the impact of the particles from the Sun. This occurs in the magnetosphere (exosphere).

2 THEY BECOME EXCITED
After the shock, the atoms receive a significant additional energetic charge that will be released in the form of photons (light).

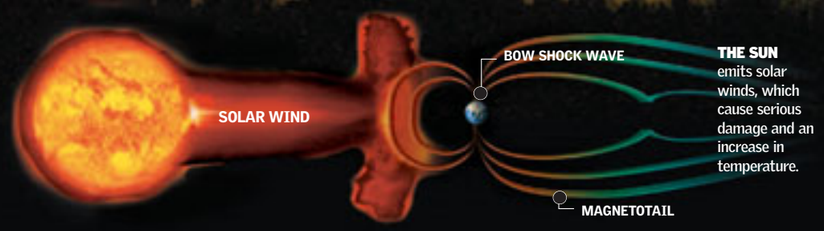
3 THEY GENERATE LIGHT
Depending on the altitude and the velocity where the shock is produced, the aurora displays different colors. Among the possibilities are violet, green, orange, and yellow.

620 miles (1,000 km)

is how long an aurora can be. From space it will look like a circle around one of the magnetic poles of the Earth.

Solar Winds

The Sun emits radiation, continuously and in all directions. This radiation occurs as a flow of charged particles or plasma, which consists mainly of electrons and protons. The plasma particles are guided by the magnetic field of the Sun and form the solar wind, which travels through space at some 275 miles per second (450 km/s). Particles from the solar wind arrive at the Earth within four or five days.



THE SUN
emits solar winds, which cause serious damage and an increase in temperature.



THE EARTH
The Earth's magnetosphere is responsible for protecting the planet from the deadly and harmful solar winds.

THE POLES
The auroras are more noticeable near the poles; they are called aurora borealis in the Northern Hemisphere and aurora australis in the Southern Hemisphere.

10-20 minutes

duration of the phenomenon

The amount of light emitted oscillates between 1 and 10 million megawatts, equivalent to the energy produced by 1,000 to 10,000 large electric power plants.

Surface Factors

VIETNAM, DECEMBER 1991
The intense monsoon rains caused severe flooding in vast regions of Cambodia, Vietnam, Laos, and Thailand.

LIVING WATER 20-21
OCEAN CURRENTS 22-23
AN OBSTACLE COURSE 24-25
THE LAND AND THE OCEAN 26-27
MONSOONS 28-29
GOOD FORTUNE AND CATASTROPHE 30-31
THE ARRIVAL OF EL NIÑO 32-33
THE EFFECTS OF EL NIÑO 34-35



Among meteorological phenomena, rain plays a very important role in the life of humans. Its scarcity causes serious problems, such as droughts, lack of food, and an increase in infant mortality. It is clear that an excess of water, caused by overabundant rain or the effects of gigantic waves, is also cause for alarm and concern. In Southwest Asia, there are frequent typhoons and torrential rains during which millions of people lose their houses and must be relocated to more secure areas; however, they still run the risk of catching contagious diseases such as malaria. The warm current of El Niño also affects the lives and the economy of millions of people. ●

Living Water

The water in the oceans, rivers, clouds, and rain is in constant motion. Surface water evaporates, water in the clouds precipitates, and this precipitation runs along and seeps into the Earth. Nonetheless, the total amount of water on the planet does not change. The circulation and conservation of water is driven by the hydrologic, or water, cycle. This cycle begins with evaporation of water from the Earth's surface. The water vapor humidifies as the air rises. The water vapor in the air cools and condenses onto solid particles as microdroplets. The microdroplets combine to form clouds. When the droplets become large enough, they begin to fall back to Earth, and, depending on the temperature of the atmosphere, they return to the ground as rain, snow, or hail.

WATER AVAILABILITY

(cubic feet [cu m] per capita/year)

- Less than 60,000 cu ft (1,700 cu m)
- 60,000-175,000 cu ft (1,700-5,000 cu m)
- More than 175,000 cu ft (5,000 cu m)

Access to potable water

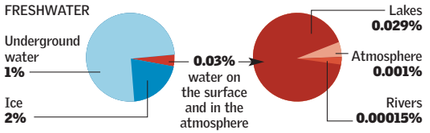
- Less than 50% of the population



WHERE IT IS FOUND

A small percentage is freshwater; most of it is salt water.

FRESHWATER **3%** SALT WATER **97%**



1. EVAPORATION

Thanks to the effects of the Sun, ocean water is warmed and fills the air with water vapor. Evaporation from humid soil and vegetation increases humidity. The result is the formation of clouds.

GASEOUS STATE
The rays of the Sun increase the motion of atmospheric gases. The combination of heat and wind transforms liquid water into water vapor.

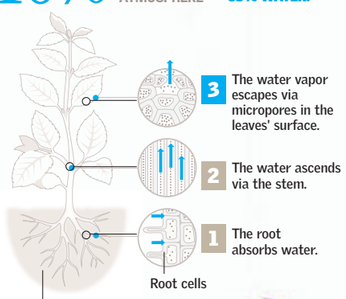
All the molecules of water are freed.

TRANSPIRATION

Perspiration is a natural process that regulates body temperature. When the body temperature rises, the sweat glands are stimulated, causing perspiration.

CONTRIBUTION OF LIVING BEINGS, ESPECIALLY PLANTS, TO **10%** THE WATER IN THE ATMOSPHERE

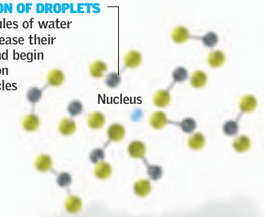
THE HUMAN BODY IS **65% WATER.**



2. CONDENSATION

In order for water vapor to condense and form clouds, the air must contain condensation nuclei, which allow the molecules of water to form microdroplets. For condensation to occur, the water must be cooled.

FORMATION OF DROPLETS
The molecules of water vapor decrease their mobility and begin to collect on solid particles suspended in the air.

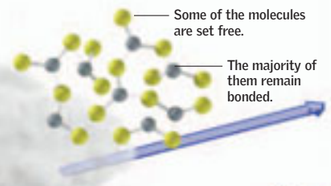


3. PRECIPITATION

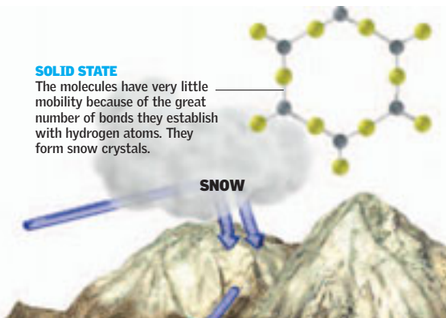
The wind carries the clouds toward the continent. When the humid air cools, it condenses and falls as rain, snow, or hail.

72 cubic miles OF WATER FALL EACH DAY IN THE FORM OF PRECIPITATION.

LIQUID STATE
A rise in temperature increases the kinetic energy of the molecules, which breaks the hydrogen bonds.



SOLID STATE
The molecules have very little mobility because of the great number of bonds they establish with hydrogen atoms. They form snow crystals.



4. RUNOFF

Water in liquid form runs off the surface of the terrain via rivers and valleys. In climates that are not especially dry, this phenomenon is the principal geologic agent of erosion and transport. Runoff is reduced during times of drought.

340 cubic miles OF WATER CIRCULATE IN THE TERRESTRIAL HYDROSPHERE.

5. UNDERGROUND CIRCULATION

There are two kinds, both of which are gravity driven. The first occurs in a shallow zone, in karstic rock such as limestone, and consists of a downward flow. The second occurs in aquifers, where interstitial water fills up the pores of a rock.

300 years THE AVERAGE LENGTH OF TIME THAT A WATER MOLECULE REMAINS IN THE UNDERGROUND AQUIFERS

6. RETURN TO THE OCEAN

The waters return to the ocean, completing the cycle, which can take days for surface waters and years for underground waters.

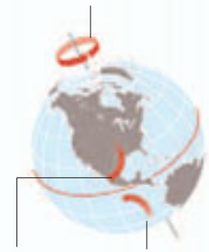
Ocean Currents

Ocean water moves as waves, tides, and currents. There are two types of currents: surface and deep. The surface currents, caused by the wind, are great rivers in the ocean. They can be some 50 miles (80 km) wide. They have a profound effect on the world climate because the water warms up near the Equator, and currents transfer this heat to higher latitudes. Deep currents are caused by differences in water density.

THE INFLUENCE OF THE WINDS

TIDES AND THE CORIOLIS EFFECT

The Coriolis effect, which influences the direction of the winds, drives the displacement of marine currents.

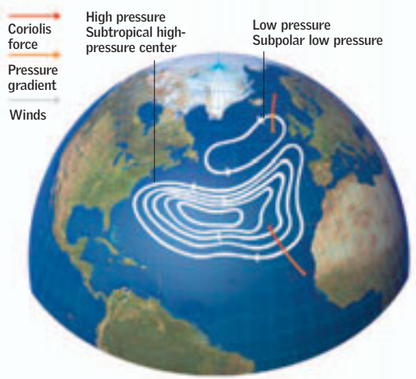


Currents in the Northern Hemisphere travel in a clockwise direction.

In the Southern Hemisphere, the currents travel in a counterclockwise direction.

GEOSTROPHIC BALANCE

The deflection caused by the Coriolis effect on the currents is compensated for by pressure gradients between cyclonic and anticyclonic systems. This effect is called geostrophic balance.

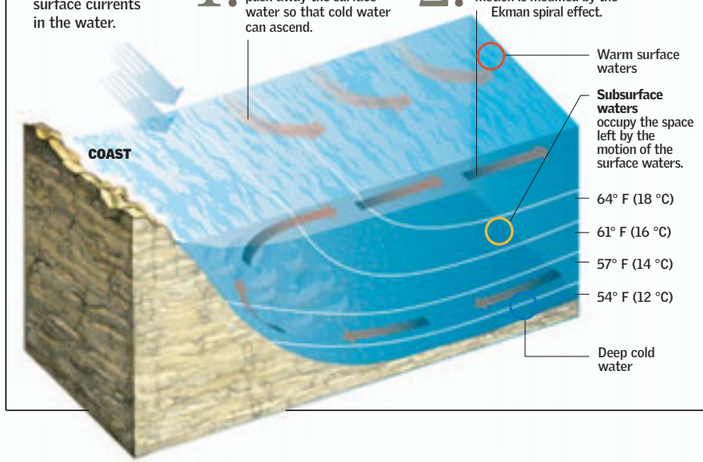


HOW CURRENTS ARE FORMED

Wind and solar energy produce surface currents in the water.

1. In the Southern Hemisphere, coastal winds push away the surface water so that cold water can ascend.

2. This slow ascent of deep water is called a surge. This motion is modified by the Ekman spiral effect.

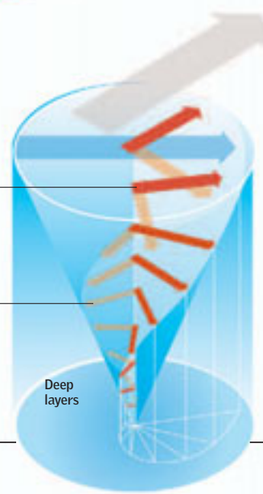


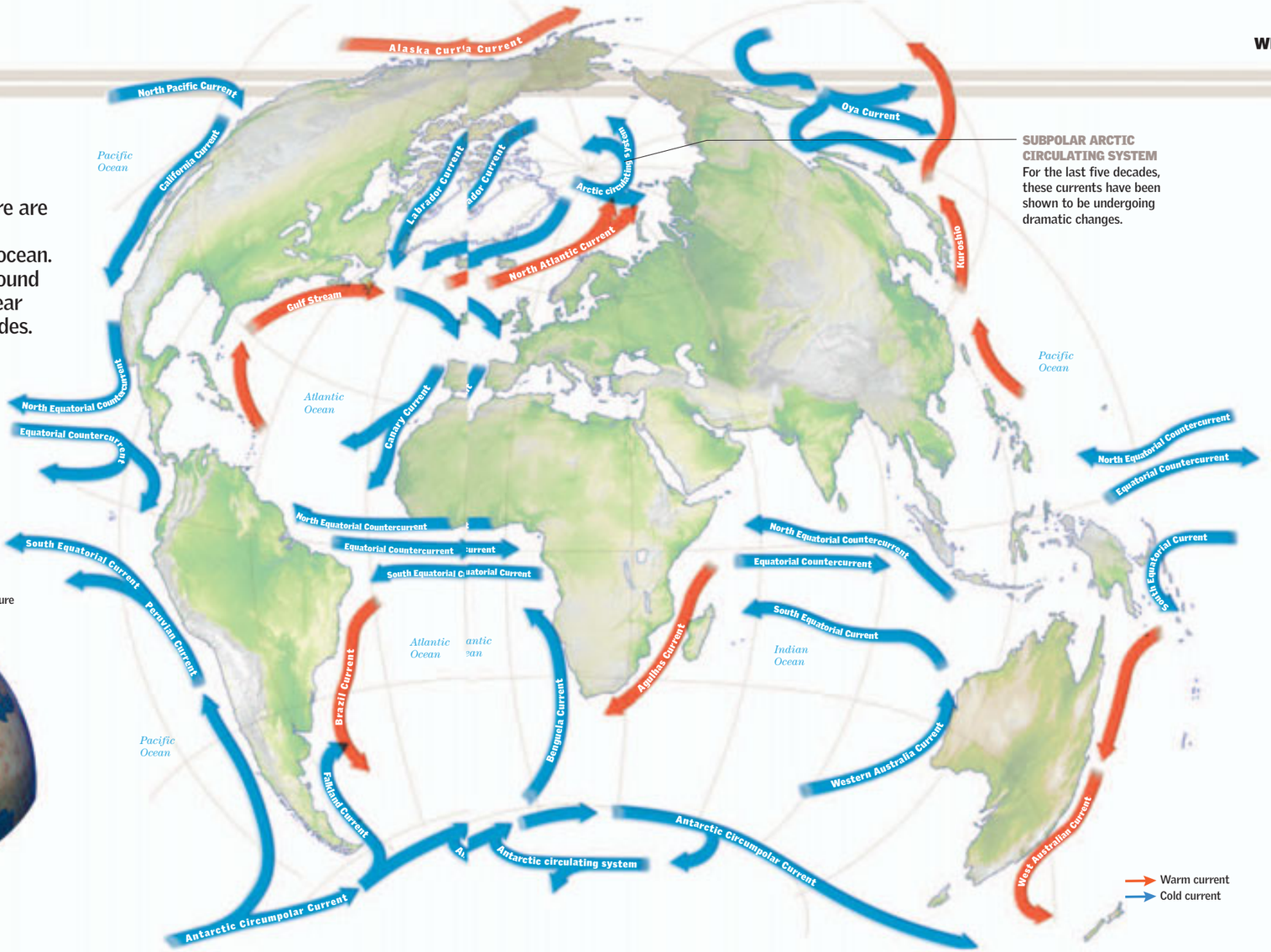
EKMAN SPIRAL

explains why the surface currents and deep currents are opposite in direction.

Wind energy is transferred to the water in **friction layers**. Thus, the velocity of the surface water increases more than that of the deep water.

The Coriolis effect causes the **direction of the currents** to deviate. The surface currents travel in the opposite direction of the deep currents.





SUBPOLAR ARCTIC CIRCULATING SYSTEM

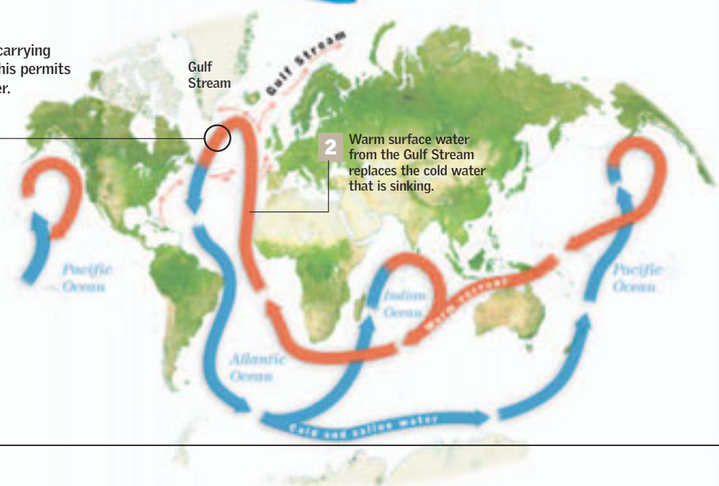
For the last five decades, these currents have been shown to be undergoing dramatic changes.

DEEP CURRENTS

have a vital function of carrying oxygen to deep water. This permits life to exist in deep water.

1 Near Greenland, the North Atlantic water **sinks**, and the **colder and more saline** water is pushed southward.

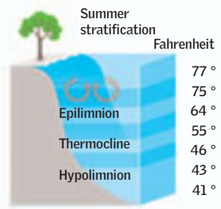
2 Warm surface water from the Gulf Stream replaces the cold water that is sinking.



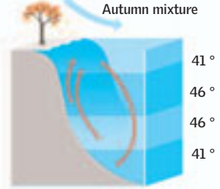
THE FOUR SEASONS OF A LAKE

Because of the physical properties of water, lakes and lagoons have a special seasonal circulation that ensures the survival of living creatures.

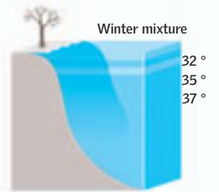
SUMMER
Stable summer temperatures prevent vertical circulation in the body of water of the lagoon.



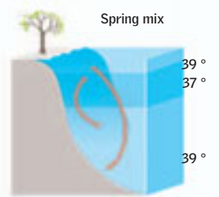
AUTUMN
Temperature decrease and temperature variations generate a mixing of the surface and deep waters.



WINTER
When the water reaches 39° F (4° C), its density increases. That is how strata of solid water on the surface and liquid water underneath are created.



SPRING
The characteristics of water once again initiate vertical circulation in the lake. Spring temperatures lead to this circulation.



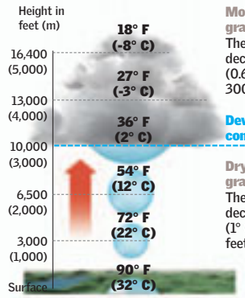
An Obstacle Course

The mountains are geographical features with a great influence on climate. Winds laden with moisture collide with these vertical obstacles and have to rise up their slopes to pass over them. During the ascent, the air discharges water in the form of precipitation on the windward sides, which are humid and have dense vegetation. The air that reaches the leeward slopes is dry, and the vegetation usually consists of sparse grazing land. ●

The Effect of the Andes Mountains

1. HUMID WINDS
In the mountains, the predominant winds are moisture-laden and blow in the direction of the coastal mountains.

2. ASCENT AND CONDENSATION
Condensation occurs when a mass of air cools until it reaches the saturation point (relative humidity 100 percent). The dew point rises when the air becomes saturated as it cools and the pressure is held constant.



Moist adiabatic gradient
The temperature decreases 1° F (0.6° C) for every 300 feet (100 m).

Dew point, or condensation point

Dry adiabatic gradient
The temperature declines 1.8° F (1° C) every 300 feet (100 m).

3. PRECIPITATION
A natural barrier forces the air to ascend and cool. The result is cloud formation and precipitation.

IN THE CLOUD

Temperature (in °F [°C])	Composition
-40 to -4 (-40 to -20)	Ice crystals
-4 to 14 (-20 to -10)	Supercooled water
14 to 32 (-10 to 0)	Microdroplets of water
Greater than 32 (0)	Drops of water

SNOW
Drops of super-cooled water combine to form ice crystals.

The crystals grow in size.

While they are falling, they combine with other crystals.

RAIN
The microdroplets increase in size and fall because of gravity.

When they fall, these drops collide with smaller ones.

Successive collisions increase the size of the drops.

4. DESCENDING WIND
A natural barrier forces the air to descend and warm up.

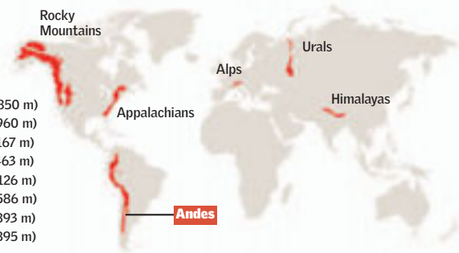
HIGH LEVEL OF POLLUTION IN SANTIAGO
Partly because it is the most urbanized and industrialized city of Chile, the capital, Santiago, faces serious pollution problems. In addition, it is located in a valley with characteristics that do not help disperse the pollution produced by vehicles and factories.

Santiago, Chile
Viña del Mar
Valparaíso
PACIFIC OCEAN
COASTAL MOUNTAIN RANGE
INTERMEDIATE DEPRESSION
CHILE
ARGENTINA

ANDES MOUNTAIN RANGE
has altitudes greater than
19,700 feet
(6,000 m).
It runs parallel to the Pacific Ocean, from Panama to southern Argentina. It is 4,500 miles (7,240 km) long and 150 miles (241 km) wide.

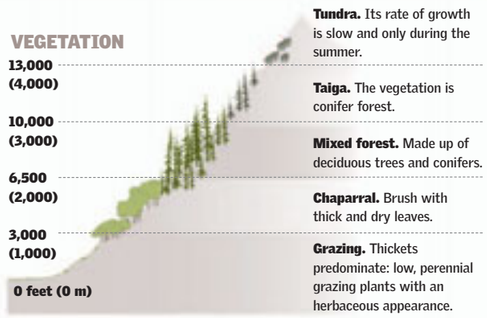
This drawing shows the coast and the Andes near Santiago, Chile, at Uspallata Pass.

MAJOR MOUNTAIN RANGES



Mountain	Elevation
Everest	29,035 feet (8,850 m)
Aconcagua	22,834 feet (6,960 m)
Dhaulagiri	26,795 feet (8,167 m)
Makalu	27,766 feet (8,463 m)
Nanga Parbat	26,660 feet (8,126 m)
Kanchenjunga	28,169 feet (8,586 m)
Ojos del Salado	22,614 feet (6,893 m)
Kilimanjaro	19,340 feet (5,895 m)

VEGETATION



Tundra. Its rate of growth is slow and only during the summer.

Taiga. The vegetation is conifer forest.

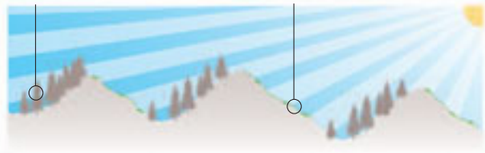
Mixed forest. Made up of deciduous trees and conifers.

Chaparral. Brush with thick and dry leaves.

Grazing. Thickets predominate: low, perennial grazing plants with an herbaceous appearance.

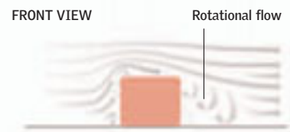
Western slopes
receive most of the moisture, which leads to the growth of pine and other trees of coastal mountain ranges.

Eastern slopes
The rays of the Sun fall directly upon these areas, making them more arid. There is little or no vegetation.



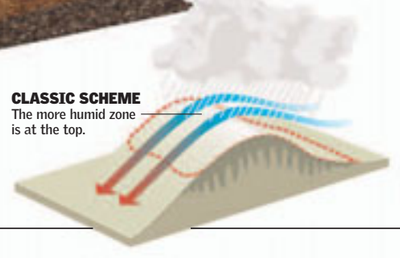
HOW OBSTACLES WORK

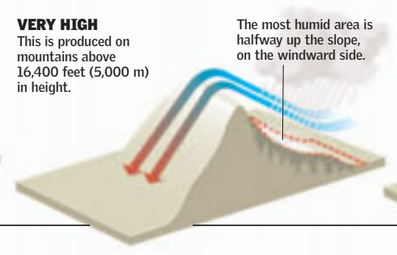
Obstacles, such as buildings, trees, and rock formations, decrease the velocity of the wind significantly and often create turbulence around them.

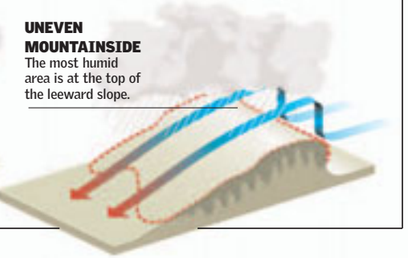


TYPES OF OROGRAPHICAL EFFECTS

DRY Winds
HUMIDS Winds
Area affected by precipitation







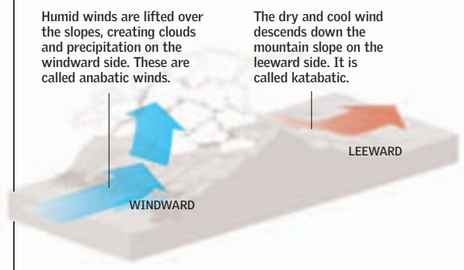
The Land and the Ocean

Temperature distribution and, above all, temperature differences very much depend on the distribution of land and water surface. Differences in specific heat moderate the temperatures of regions close to great masses of water. Water absorbs heat and releases it more slowly than the land does, which is why a body of water can heat or cool the environment. Its influence is unmistakable. Moreover, these differences between the land and the sea are the cause of the coastal winds. In clear weather, the land heats up during the day, which causes the air to rise rapidly and form a low-pressure zone. This zone draws marine breezes.

MOUNTAIN WINDS

Chinook WINDS

These winds are dry and warm, sometimes quite hot, occurring in various places of the world. In the western United States, they are called chinooks and are capable of making snow disappear within minutes.

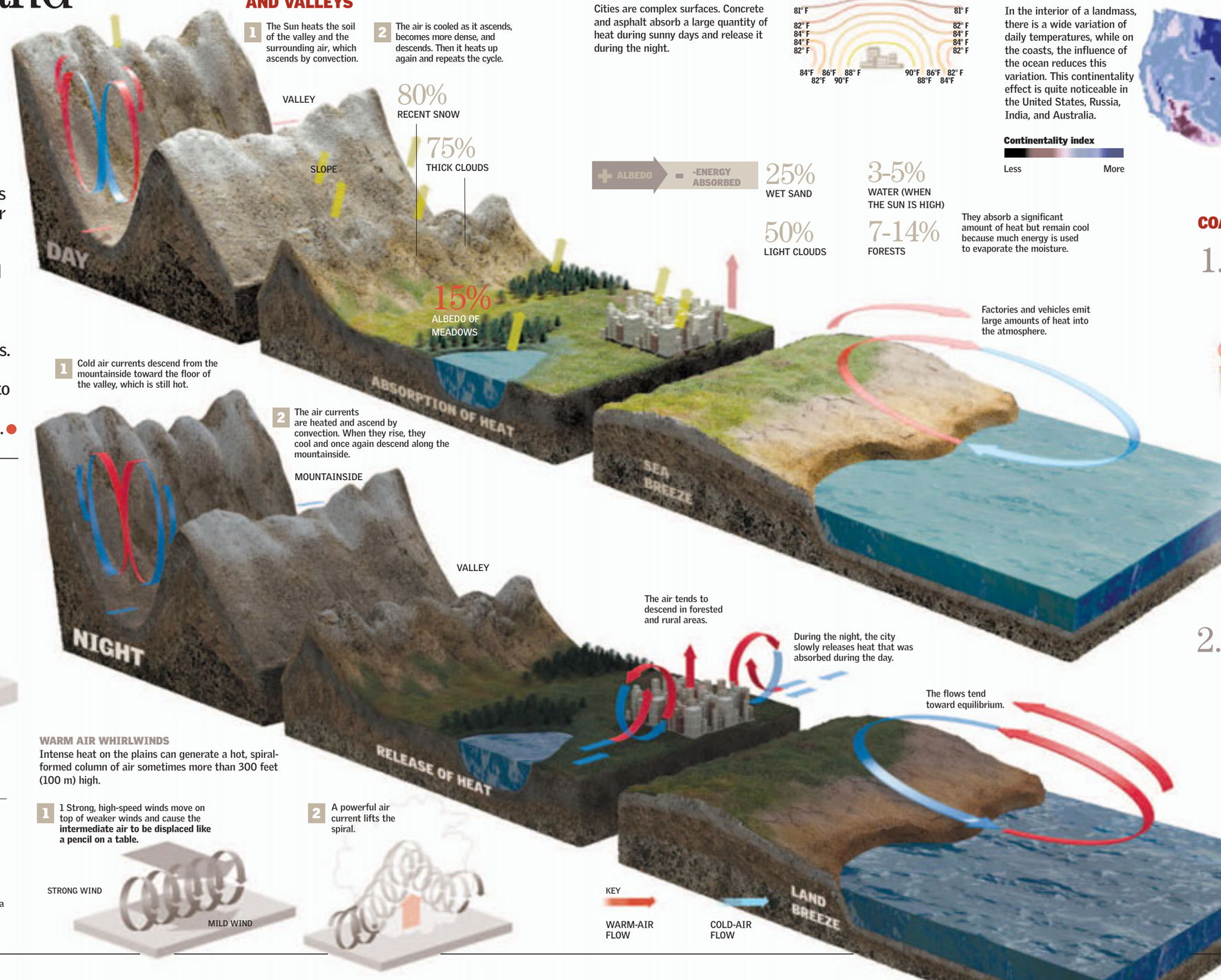


Winds	Characteristics	Location
Autan wind	Dry and mild	Southwestern France
Berg	Dry and warm	South Africa
Bora	Dry and cold	Northeastern Italy
Brickfielder	Dry and hot	Australia
Buran	Dry and cold	Mongolia
Harmattan	Dry and cool	North Africa
Levant	Humid and mild	Mediterranean region
Mistral	Dry and cold	Rhône valley
Santa Ana	Dry and hot	Southern California
Sirocco	Dry and hot	Southern Europe and North Africa
Tramontana	Dry and cold	Northeast Spain
Zonda	Dry and mild	Western Argentina

WINDS OF THE MOUNTAINS AND VALLEYS

1 The Sun heats the soil of the valley and the surrounding air, which ascends by convection.

2 The air is cooled as it ascends, becomes more dense, and descends. Then it heats up again and repeats the cycle.



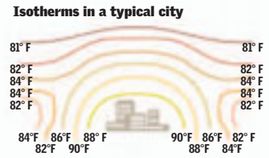
WARM AIR WHIRLWINDS

Intense heat on the plains can generate a hot, spiral-formed column of air sometimes more than 300 feet (100 m) high.

HEAT ISLANDS

Cities are complex surfaces. Concrete and asphalt absorb a large quantity of heat during sunny days and release it during the night.

Isotherms in a typical city



25% WET SAND

3-5% WATER (WHEN THE SUN IS HIGH)

50% LIGHT CLOUDS

7-14% FORESTS

They absorb a significant amount of heat but remain cool because much energy is used to evaporate the moisture.

CONTINENTALITY

In the interior of a landmass, there is a wide variation of daily temperatures, while on the coasts, the influence of the ocean reduces this variation. This continentality effect is quite noticeable in the United States, Russia, India, and Australia.

Continentality index

Daily variation of temperatures in the United States



COASTAL BREEZES

1. **ON THE LAND**
During the day, the land heats up more rapidly than the ocean. The warm air rises and is replaced by cooler air coming from the sea.



Because it is opaque, the heat stays in the **surface layers**, which are heated and cooled rapidly.

IN THE OCEAN
From the coast, the ocean receives air that loses its heat near the water. As a result, the colder air descends toward the sea.



The heat penetrates into **deeper layers** thanks to the transparency of the water. A part of the heat is lost in evaporation of the water.

2. **ON THE LAND**
During the evening, the land radiates away its heat more rapidly than the water. The difference in pressure generated replaces the cold air of the coast with warm air.

When night falls, the land, which was hot, **cools rapidly.**



IN THE OCEAN
The loss of heat from the water is slower.



When night falls, the water is **lukewarm** (barely a degree more than the land).

Monsoons

The strong humid winds that usually affect the tropical zone are called monsoons, an Arabic word meaning "seasonal winds." During summer in the Northern Hemisphere, they blow across Southeast Asia, especially the Indian peninsula. Conditions change in the winter, and the winds reverse and shift toward the northern regions of Australia. This phenomenon, which is also frequent in continental areas of the United States, is part of an annual cycle that, as a result of its intensity and its consequences, affects the lives of many people.

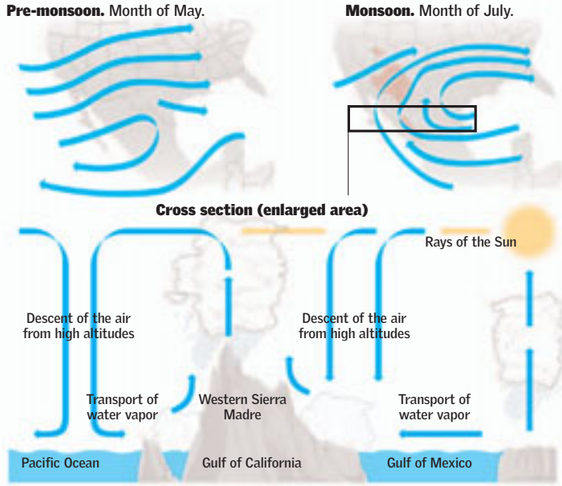
AREAS AFFECTED BY MONSOONS

This phenomenon affects the climates in low latitudes, from West Africa to the western Pacific. In the summer, the monsoon causes the rains in the Amazon region and in northern Argentina. There in the winter rain is usually scarce.

Predominant direction of the winds during the month of July



THE MONSOON OF NORTH AMERICA



How monsoons are created in India

End of the monsoon · Beginning of the monsoon · Cold and dry winds · Cold and humid winds · Cyclone (low pressure) · Anticyclone (high pressure)

1 THE CONTINENT COOLS
After the summer monsoon, the rains stop and temperatures in Central and South Asia begin to drop. Winter begins in the Northern Hemisphere.

Northern Hemisphere
It is winter. The rays of the Sun are oblique, traveling a longer distance through the atmosphere to reach the Earth's surface. Thus they are spread over a larger surface, so the average temperature is lower than in the Southern Hemisphere.

Southern Hemisphere
It is summer. The rays of the Sun strike the surface at a right angle; they are concentrated in a smaller area, so the temperature on average is higher than in the Northern Hemisphere.

Rays of the Sun

N

S

Angle of incidence of the Sun's rays

Cold land

Warm land

Arabian Sea

Bay of Bengal

2 FROM THE CONTINENT TO THE OCEAN
The masses of cold and dry air that predominate on the continent are displaced toward the ocean, whose waters are relatively warmer.

3 OCEAN STORMS
A cyclone located in the ocean draws the cold winds from the continent and lifts the somewhat warmer and more humid air, which returns toward the continent via the upper layers of the atmosphere.

Limit of the Intertropical Convergence Zone (ITCZ)

1 FROM THE OCEAN TO THE CONTINENT
The cool and humid air from the ocean blows toward the continent, which is quite hot and dry.

Limit of the intertropical convergence

3 STORMS ON THE CONTINENT
The climate in India and Bangladesh is very hot and dry. When humid and cool winds come in from the ocean, they cause torrential rains in these regions.

2 BARRIERS
The humid winds are deflected toward the northeast by two mountain chains: the Himalayas and the Ghat mountains. This zone enclosed by the mountains is the main one affected by the monsoons.



INTERTROPICAL INFLUENCE

The circulation of the atmosphere between the tropics influences the formation of monsoon winds. The trade winds that blow toward the Equator from the subtropical zones are pushed by the Hadley cells and deflected in their course by the Coriolis effect. Winds in the tropics occur within a band of low pressure around the Earth called the Intertropical Convergence Zone (ITCZ). When this zone is seasonally displaced in the warm months of the Northern Hemisphere toward the north, a summer monsoon occurs.

THERMAL DIFFERENCE BETWEEN THE LAND AND THE OCEAN

The land is cold, so near the ground the breeze blows toward the ocean.

The sea is a little warmer than the land; therefore, the humid air rises. The cool air colliding with it causes clouds and rain.

The Earth is hot, and therefore the air rises and is replaced in the lower layers by cool breezes that blow in from the sea. The meeting of the two breezes causes clouds and rain on the continent.

The sea is cold because the rays of the Sun heat up the water more slowly than the land. The cool air from the ocean blows toward the coast, toward areas that are warmer.

Good Fortune and Catastrophe

The monsoons are a climatic phenomenon governing the life and the economy of one of the most densely populated regions of the planet, especially India. The arrival of the intense rains is celebrated as the end of a season that might have been extremely dry, but it is also feared. The flooding at times devastates agriculture and housing. The damage is even greater because of the large population of the region. Therefore, anticipating disaster and taking precautions, such as evacuating areas prone to flooding, are part of the organization of agricultural activity, which thrives in periods of heavy rains, even in fields that are flooded.

In June 2006

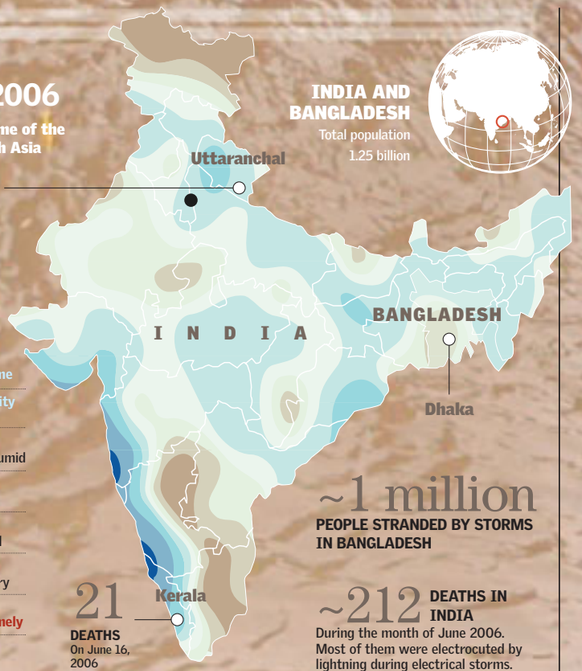
The tragic outcome of the monsoon in South Asia

~49

DEATHS
on June 16, 2006

Precipitation
(in inches [mm])

- 16 (400) Extreme humidity
- 8 (200)
- 4 (100) Very humid
- 2 (50) Humid
- 1 (25) Normal
- 0.4 (10) Very dry
- 0.04 (1) Extremely dry
- 0 (0)



INDIA AND BANGLADESH
Total population
1.25 billion

21

DEATHS
On June 16, 2006

~1 million

PEOPLE STRANDED BY STORMS IN BANGLADESH

~212 **DEATHS IN INDIA**

During the month of June 2006. Most of them were electrocuted by lightning during electrical storms.

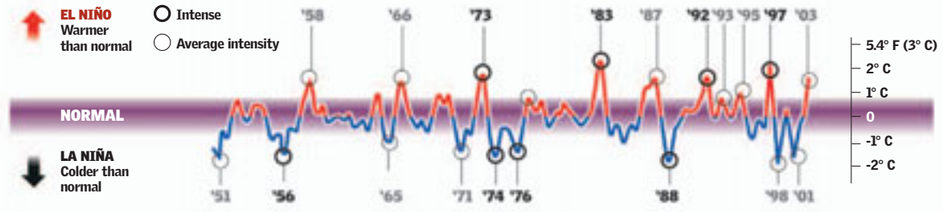
UNDERWATER HARVEST
The mud increases the fertility of the soil, which compensates for the losses. The accumulation of humid sand is later used in the dry season. Rice is a grain that grows in fields that are underwater.

OVERFLOWING RIVERS
The valley that connects the Ganges with the Brahmaputra in Bangladesh is the most afflicted by floods caused by these rains. The rains destroy harvests and property.

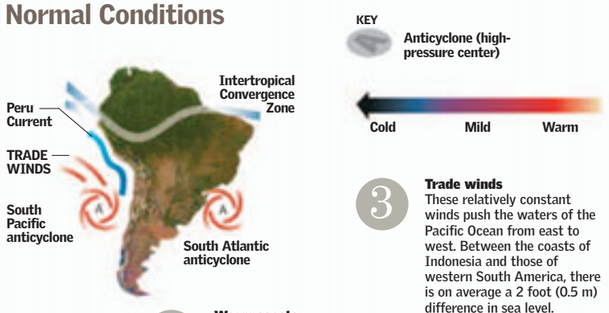
The Arrival of El Niño

The hydrosphere and the atmosphere interact and establish a dynamic thermal equilibrium between the water and the air. If this balance is altered, unusual climatic phenomena occur between the coasts of Peru and Southeast Asia. For example, the phenomenon El Niño or, less frequently, another phenomenon called La Niña are responsible for atypical droughts and floods that every two to seven years affect the routine life of people living on these Pacific Ocean coasts.

SURFACE TEMPERATURE OF THE OCEAN
The graphic shows the temperature variations caused by the Southern Oscillation in the water along the coast of Peru. This graphic illustrates the alternation of the El Niño and La Niña phenomena over the last 50 years.



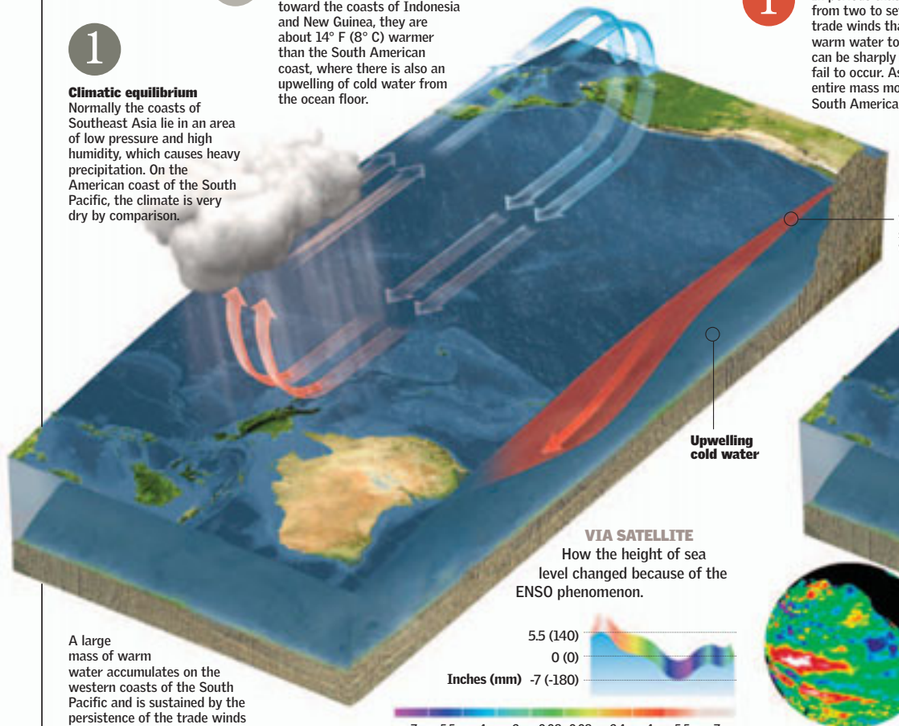
Normal Conditions



3 Trade winds
These relatively constant winds push the waters of the Pacific Ocean from east to west. Between the coasts of Indonesia and those of western South America, there is on average a 2 foot (0.5 m) difference in sea level.

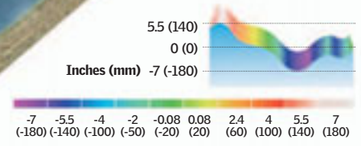
2 Warm coasts
Because great masses of warm water permanently flow toward the coasts of Indonesia and New Guinea, they are about 14° F (8° C) warmer than the South American coast, where there is also an upwelling of cold water from the ocean floor.

1 Climatic equilibrium
Normally the coasts of Southeast Asia lie in an area of low pressure and high humidity, which causes heavy precipitation. On the American coast of the South Pacific, the climate is very dry by comparison.



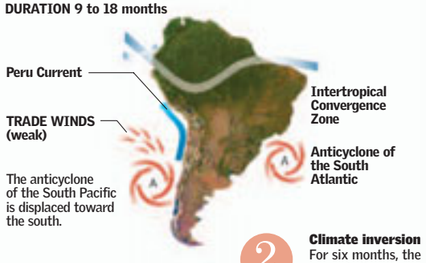
A large mass of warm water accumulates on the western coasts of the South Pacific and is sustained by the persistence of the trade winds at the ocean surface.

VIA SATELLITE
How the height of sea level changed because of the ENSO phenomenon.



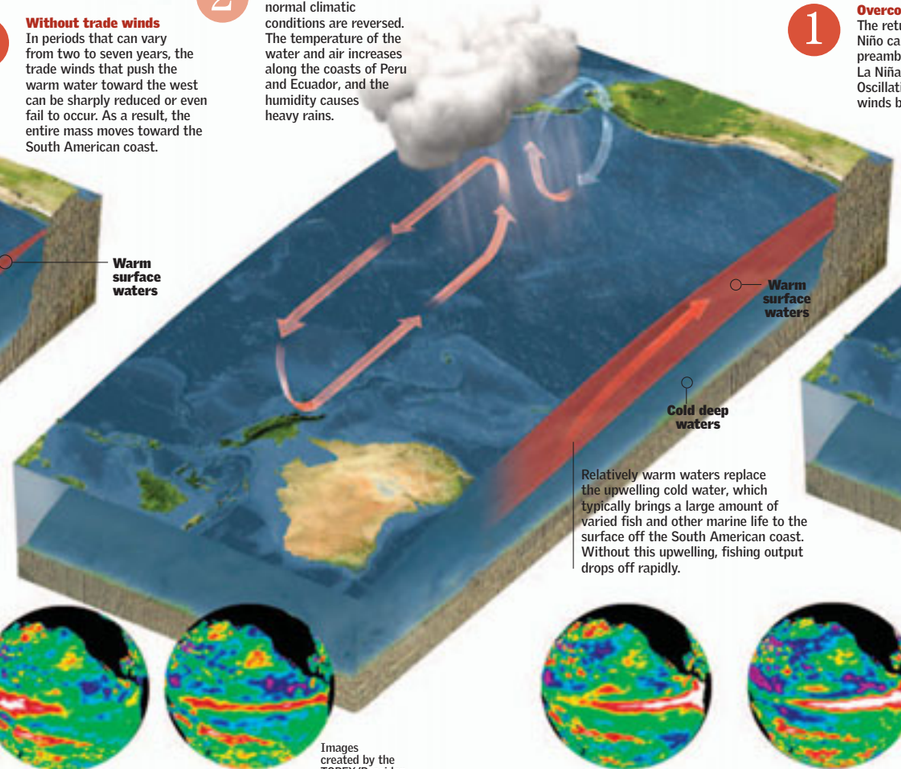
El Niño (the warm phase of El Niño/Southern Oscillation [ENSO])

DURATION 9 to 18 months

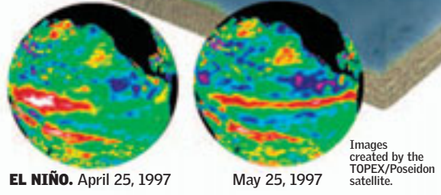


2 Climate inversion
For six months, the normal climatic conditions are reversed. The temperature of the water and air increases along the coasts of Peru and Ecuador, and the humidity causes heavy rains.

1 Without trade winds
In periods that can vary from two to seven years, the trade winds that push the warm water toward the west can be sharply reduced or even fail to occur. As a result, the entire mass moves toward the South American coast.



Relatively warm waters replace the upwelling cold water, which typically brings a large amount of varied fish and other marine life to the surface off the South American coast. Without this upwelling, fishing output drops off rapidly.



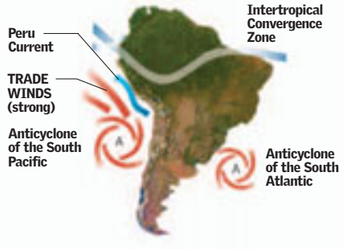
EL NIÑO. April 25, 1997 — May 25, 1997

Images created by the TOPEX/Poseidon satellite.

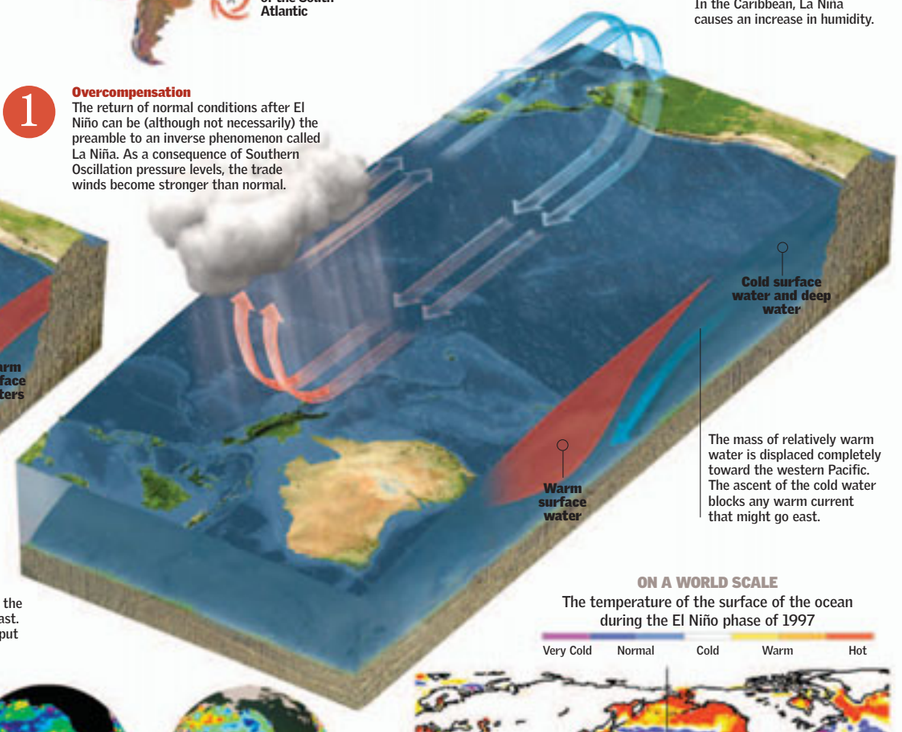
3 El Niño makes itself felt.
Southeast Asia suffers a great drought, an increase of pressure, and a decrease in temperature. On the South American coast, strong winds and storms occur in zones that are usually dry; there is flooding and changes in the flora and fauna.

La Niña (cold ENSO)

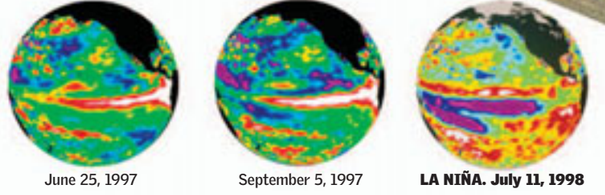
DURATION: 9 to 18 months
FREQUENCY: Every 2 to 7 years



1 Overcompensation
The return of normal conditions after El Niño can be (although not necessarily) the preamble to an inverse phenomenon called La Niña. As a consequence of Southern Oscillation pressure levels, the trade winds become stronger than normal.



The mass of relatively warm water is displaced completely toward the western Pacific. The ascent of the cold water blocks any warm current that might go east.

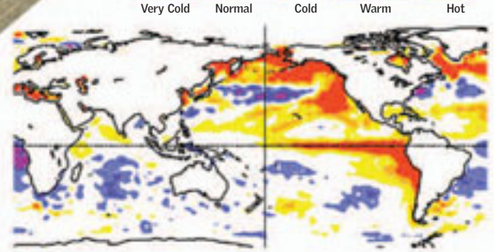


June 25, 1997 — September 5, 1997 — **LA NIÑA. July 11, 1998**

2 A cold current
The total disruption of the masses of warm water off the west coast of South America also generates colder surface temperatures than normal along with high pressure and decreased humidity.

3 Severe drought
The effects of La Niña are less severe than those of El Niño. Also, the shorter its duration, the more intense it is. It typically begins about halfway through the year and intensifies at the end of the year before weakening around the beginning of the new year. In the Caribbean, La Niña causes an increase in humidity.

ON A WORLD SCALE
The temperature of the surface of the ocean during the El Niño phase of 1997



The Effects of El Niño

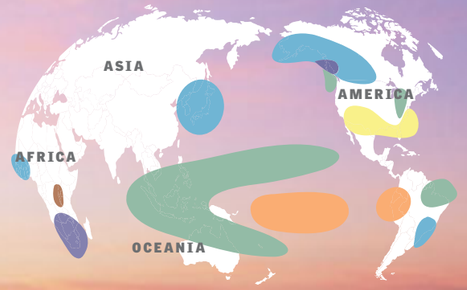
The natural warm phenomenon known as El Niño alters the temperature of the water within the east central zone of the Pacific Ocean along the coasts of Ecuador and Peru. Farmers and fishermen are negatively affected by these changes in temperature and the modification of marine currents. The nutrients normally present in the ocean decrease or disappear from along the coast because of the increase in temperature. As the entire food chain deteriorates, other species also suffer the effects and disappear from the ocean. In contrast, tropical marine species that live in warmer waters can flourish. The phenomenon affects the weather and climate of the entire world. It tends to cause flooding, food shortages, droughts, and fires in various locations.

Areas Affected

EL NIÑO from December to February



LA NIÑA from June to August



KEY
- Humid
- Cold
- Cold Humid
- Warm Humid
- Warm Humid
- Dry
- Dry and cold
- Dry and warm

FLOODING
Abnormal flooding caused by El Niño in the desert regions of Chile and the later evaporation of water leave behind hexagonal deposits of potassium nitrate.

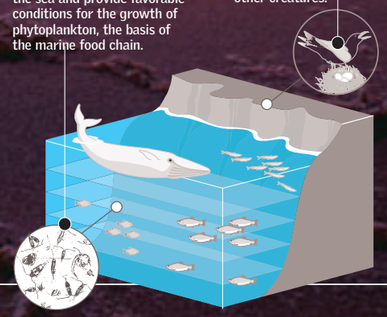


ATACAMA, CHILE
Laguna Blanca Salt Marsh
Latitude 22° 54´ S
Longitude 68° 12´ W

Surface area	**1,200 square miles (3,000 sq km)**
Cause	**Floods caused by El Niño anomalies**
Year	**1999**

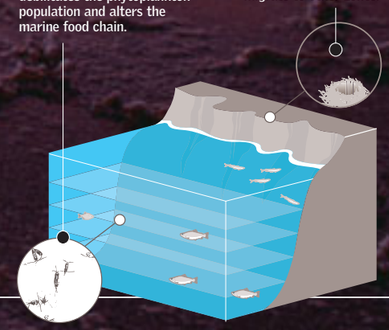
Normal conditions
Cold waters, rich in nutrients, ascend from the bottom of the sea and provide favorable conditions for the growth of phytoplankton, the basis of the marine food chain.

The phytoplankton promote the normal development of microorganisms, fish, and other creatures.



During El Niño,
the scarcity of cold water debilitates the phytoplankton population and alters the marine food chain.

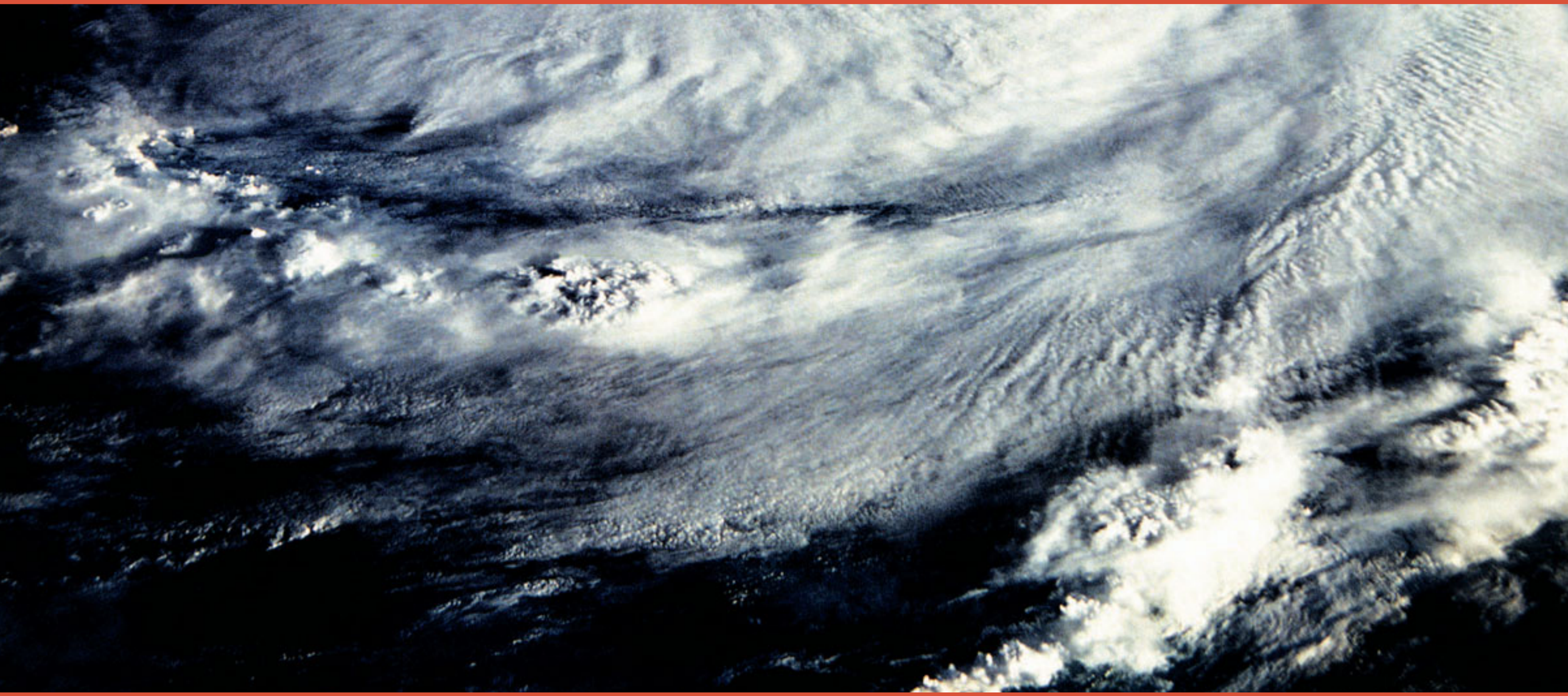
Various marine species die off for lack of food or must migrate to other zones.



Meteorological Phenomena

HURRICANE ALERT
This image of Hurricane Elena, captured by the Space Shuttle on September 1, 1985, allowed meteorologists to evaluate its scope before it reached the Gulf of Mexico.

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Tropical cyclones (called hurricanes, typhoons, or cyclones in different parts of the world) cause serious problems and often destroy everything in their path. They uproot trees, damage buildings, devastate land under cultivation, and cause deaths. The Gulf of Mexico is one of the areas of the planet continually affected by hurricanes. For this reason, the government authorities organize preparedness exercises so that the population knows what to do. To understand how hurricanes function and improve forecasts, investigators require detailed information from the heart of the storm. The use of artificial satellites that send clear pictures has contributed greatly to detecting and tracking strong winds, preventing many disasters. ●

Capricious Forms

Clouds are masses of large drops of water and ice crystals. They form because the water vapor contained in the air condenses or freezes as it rises through the troposphere. How the clouds develop depends on the altitude and the velocity of the rising air. Cloud shapes are divided into three basic types: cirrus, cumulus, and stratus. They are also classified as high, medium, and low depending on the altitude they reach above sea level. They are of meteorological interest because they indicate the behavior of the atmosphere. ●

TYPES OF CLOUDS

NAME	MEANING
CIRRUS	FILAMENT
CUMULUS	AGGLOMERATION
STRATUS	BLANKET
NIMBUS	RAIN

Troposphere

The layer closest to the Earth and in which meteorological phenomena occur, including the formation of clouds



HOW THEY ARE FORMED

Clouds are formed when the rising air cools to the point where it cannot hold the water vapor it contains. In such a circumstance, the air is said to be saturated, and the excess water vapor condenses. Cumulonimbus clouds are storm clouds that can reach a height of 43,000 feet (13,000 m) and contain more than 150,000 tons of water.



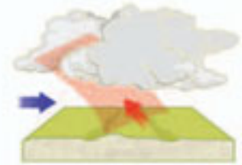
Convection
The heat of the Sun warms the air near the ground, and because it is less dense than the surrounding air, it rises.



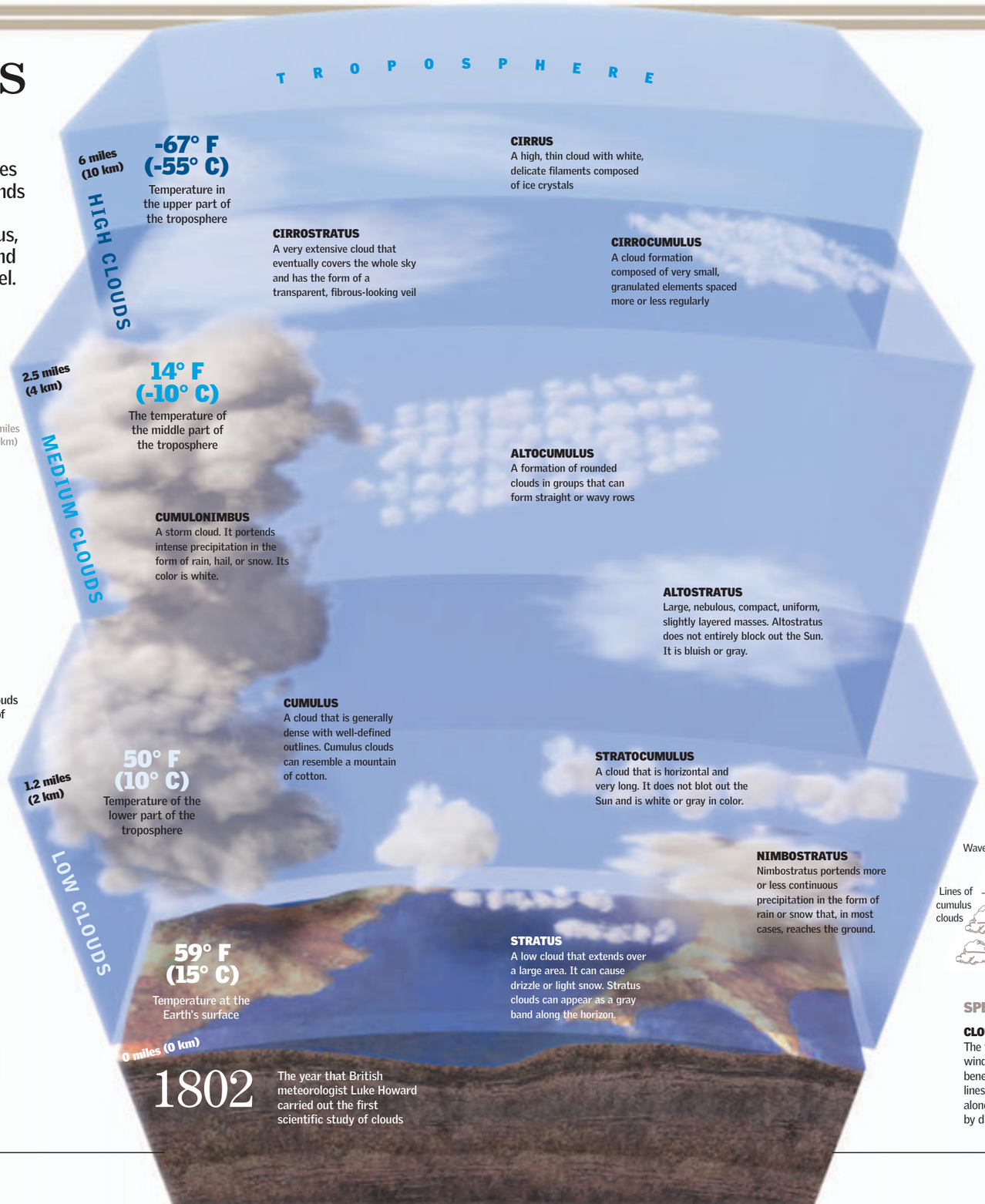
Convergence
When the air coming from one direction meets air from another direction, it is pushed upward.



Geographic elevation
When the air encounters mountains, it is forced to rise. This phenomenon explains why there are often clouds and rain over mountain peaks.



Presence of a front
When two masses of air with different temperatures meet at a front, the warm air rises and clouds are formed.



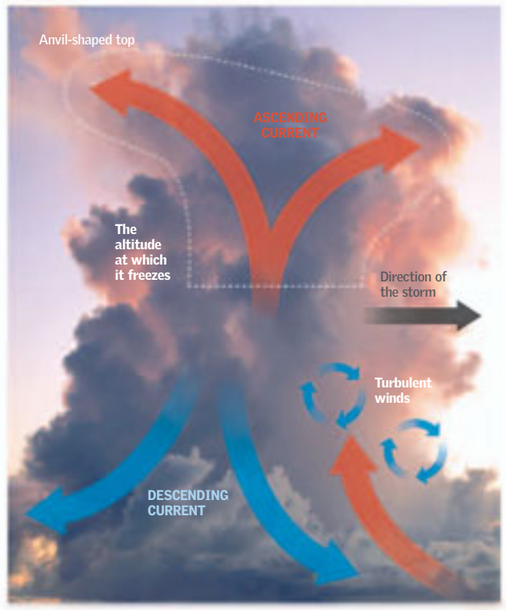
1802
The year that British meteorologist Luke Howard carried out the first scientific study of clouds

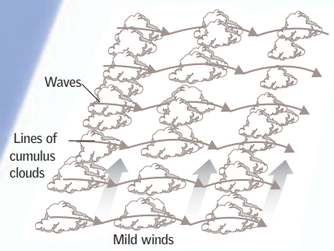
The Inside

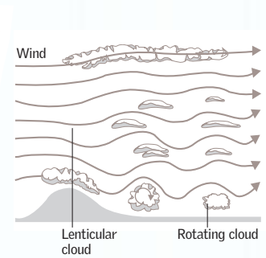
The altitude at which clouds are formed depends on the stability of the air and the humidity. The highest and coldest clouds have ice crystals. The lowest and warmest clouds have drops of water. There are also mixed clouds. There are 10 classes of clouds depending on their height above sea level. The highest clouds begin at a height of 2.5 miles (4 km). The mid-level begins at a height of 1.2 to 2.5 miles (2-4 km) and the lowest at 1.2 miles (2 km) high.

1.2 to 5 miles (2-8 km)
Thickness of a storm cloud

150,000 tons of water
can be contained in a storm cloud.







SPECIAL FORMATIONS

CLOUD STREETS
The form of the clouds depends on the winds and the topography of the terrain beneath them. Light winds usually produce lines of cumulus clouds positioned as if along streets. Such waves can be created by differences in surface heating.

LENTICULAR CLOUDS
Mountains usually create waves in the atmosphere on their lee side, and on the crest of each wave lenticular clouds are formed that are held in place by the waves. Rotating clouds are formed by turbulence near the surface.

The Rain Announces Its Coming

The air inside a cloud is in continuous motion. This process causes the drops of water or the crystals of ice that constitute the cloud to collide and join together. In the process, the drops and crystals become too big to be supported by air currents and they fall to the ground as different kinds of precipitation. A drop of rain has a diameter 100 times greater than a droplet in a cloud. The type of precipitation depends on whether the cloud contains drops of water, ice crystals, or both. Depending on the type of cloud and the temperature, the precipitation can be liquid water (rain) or solid (snow or hail).

1 CONDENSATION NUCLEI
Salt, dust, smoke, and pollen, among other particulates, serve as a surface on which water molecules, ascending by convection, can combine and form water droplets.

2 GROWTH
The smallest clouds adhere to one another to form larger clouds, increasing their size and height.

A Dilatation
The molecules of water are free–water vapor.

Water molecules
Hydrogen
Oxygen

B Condensation
The molecules group themselves around a condensation nucleus.

C Collision-Coalescence
Via this process, molecules collide and join together to form drops.

Sandstorm particulates
Forest fire particulates
Particulates from combustion in factories and vehicles
Volcanic particulates
Rock erosion particulates
Sea-salt particulates

3 MATURATION
Mature clouds have very strong ascending currents, leading to protuberances and rounded formations. Convection occurs.

4 miles (7 km)

-22° F (-30° C)

When the air cools, it descends and is then heated again, repeating the cycle.

0.02 inch (0.5 mm)

The air cools. The water vapor condenses and forms microdroplets of water.

0.6-1.2 miles (1-2 km)

LEVEL OF CONDENSATION

68° F (20° C)
The hot air rises.

0 miles (0 km)

4 RAIN
The upper part of the cloud spreads out like an anvil, and the rain falls from the lower cloud, producing descending currents.

6 miles (10 km)

Anvil-shaped

STORM CLOUD

Coalescence
The microdroplets continue to collide and form bigger drops.

Heavier drops fall onto a lower cloud as fine rain.

0.04 inch (1 mm)

0.07 inch (2 mm)

5 DISSIPATION
The descending currents are stronger than the ascending ones and interrupt the feeding air, causing the cloud to disintegrate.

Low, thin clouds contain tiny droplets of water and therefore produce rain.

0.2 inch (5 mm)

0.04 inch (1 mm)

When they begin to fall, the drops have a size of 0.02 inch (0.5 mm), which is reduced as they fall since they break apart.

26,875 trillion
molecules occupy 1 cubic millimeter under normal atmospheric conditions.

6 SNOW

Tiny ice crystals combine to form a hexagonal star, or snowflake. They form at -4° F (-20° C).

A HOW CRYSTALS ARE FORMED

The drop attaches itself to a nucleus or solid particle.

Drop

Condensation nucleus

Then the surface of the drop freezes.

Nucleus

Periphery

ICE CRYSTAL

3 miles (5 km)

-39° F (-39° C)

SNOWFLAKE

2 miles (3 km)

-9° F (-23° C)

B The ice crystals combine and form snowflakes.

C If the drops crystallize near the freezing level, they fall in the form of sleet.

0.6 mile (1 km)

19° F (-7° C)

ASCENDING WARM CURRENT

SLEET

SNOWFALL

Most snowflakes disintegrate before they reach the ground. They fall as snowflakes only when the air near the ground is very cold.

10 feet (3.11 m)

The record of annual snowfall
Mount Rainier, Washington. From February 19, 1971, to February 18, 1972.



TYPES OF CRYSTALS

Plate

Column

Dendrite

Needle clusters



Most have **six points**.

The flakes measure between **0.04 and 0.8 inch (1 and 20 mm)**.

No two snowflakes are identical to each other.

VARIED FORMS

Snow crystals can have a variety of shapes; most of them have six points, although some have three or 12, and they have hexagonal symmetry in a plane. They can also be cubic crystals, but these form under conditions of extremely low temperature in the highest regions of the troposphere.

A Vertical air currents cause the microdroplets to ascend and descend within the cloud.

B The droplets freeze, and each time they are carried upward in the cloud, they acquire a new layer of ice. This process, called accretion, increases the size of the hailstone.

Very small hail (0.2 inch [5 mm] or less in diameter) is called snow pellets.

C When the hailstones are too heavy to be supported by the ascending air currents, they fall to the ground.

WARM ASCENDING CURRENT

A cloud with a greenish tinge or rain with a whitish color can portend a hailstorm.

7 HAIL

Precipitation in the form of solid lumps of ice. Hail is produced inside storm clouds in which frozen droplets grow in size as they rise and fall within the cloud.

CROSS SECTION OF A HAILSTONE



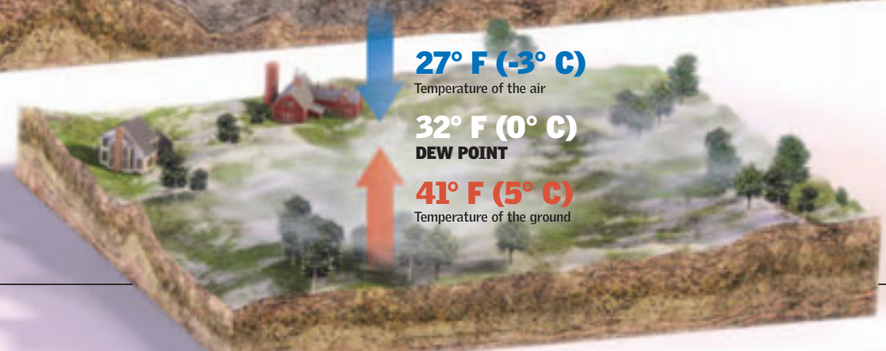
0.2 to 2 inches (5 to 50 mm)
The typical range of hailstone sizes

2 pounds (1 kg)
The heaviest hailstones
that fell on April 14, 1986, in Gopalganj, Bangladesh.

HYDROMETEORS

Drops of condensed or frozen water in the atmosphere are called hydrometeors. These include rain, fog, hail, mist, snow, and frost.

DEW
Water vapor that condenses during the night into very small drops. The condensation forms on surfaces that radiate heat during the night, such as plants, animals, and buildings.



27° F (-3° C)
Temperature of the air

32° F (0° C)
DEW POINT

41° F (5° C)
Temperature of the ground

FROST
Frost forms when the dew point of the air is less than 32° F (0° C), and the water vapor transforms directly into ice when it is deposited on surfaces.

HOAR FROST
Similar to frost but thicker. It usually forms when there is fog.

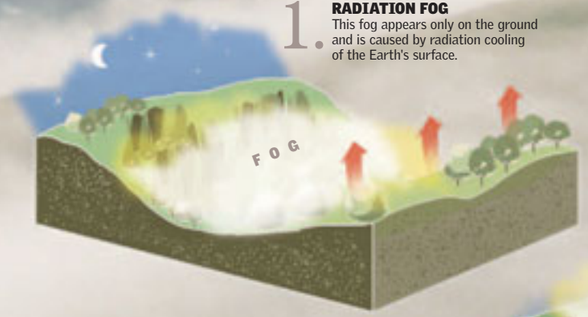
Lost in the Fog

When atmospheric water vapor condenses near the ground, it forms fog and mist. The fog consists of small droplets of water mixed with smoke and dust particles. Physically the fog is a cloud, but the difference between the two lies in their formation. A cloud develops when the air rises and cools, whereas fog forms when the air is in contact with the ground, which cools it and condenses the water vapor. The atmospheric phenomenon of fog decreases visibility to distances of less than 1 mile (1.6 km) and can affect ground, maritime, and air traffic. When the fog is light, it is called mist. In this case, visibility is reduced to 2 miles (3.2 km).

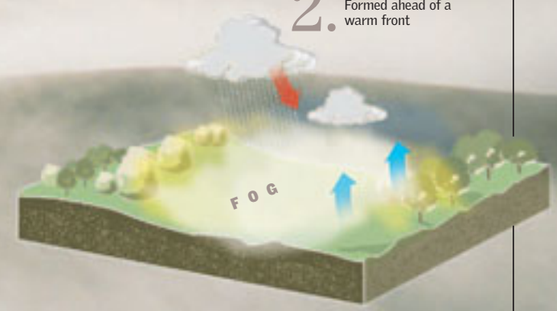
Types of Fog

Radiation fog forms during cold nights when the land loses the heat that was absorbed during the day. Frontal fog forms when water that is falling has a higher temperature than the surrounding air; the drops of rain evaporate, and the air tends to become saturated. These fogs are thick and persistent. Advection fog occurs when humid, warm air flows over a surface so cold that it causes the water vapor from the air to condense.

1. RADIATION FOG
This fog appears only on the ground and is caused by radiation cooling of the Earth's surface.



2. FRONTAL FOG
Formed ahead of a warm front



3. ADVECTION FOG
Formed when a mass of humid and cool air moves over a surface that is colder than the air



Orographic barrier
Fog develops on lee-side mountain slopes at high altitudes and occurs when the air becomes saturated with moisture.

4. OROGRAPHIC FOG

The air becomes saturated as it ascends.

ASCENDING AIR

Dew
The condensation of water vapor on objects that have radiated enough heat to decrease their temperature below the dew point

Mist
Mist consists of salt and other dry particles imperceptible to the naked eye. When the concentration of these particles is very high, the clarity, color, texture, and form of objects we see are diminished.



INVERSION FOG
When a current of warm, humid air flows over the cold water of an ocean or lake, an inversion fog can form. The warm air is cooled by the water, and its moisture condenses into droplets. The warm air traps the cooled air below it, near the surface. High coastal landmasses prevent this type of fog from penetrating very far inland.

160 feet (50 m)

The densest fog affects visibility at this distance and has repercussions on car, boat, and airplane traffic. In many cases, visibility can be zero.

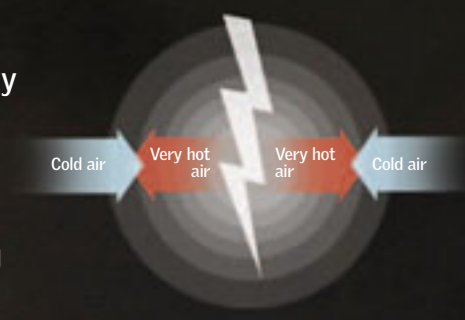
Fog and Visibility

Visibility is defined as a measure of an observer's ability to recognize objects at a distance through the atmosphere. It is expressed in miles and indicates the visual limit imposed by the presence of fog, mist, dust, smoke, or any type of artificial or natural precipitation in the atmosphere. The different degrees of fog density have various effects on maritime, land, and air traffic.



Brief Flash

Electrical storms are produced in large cumulonimbus-type clouds, which typically bring heavy rains in addition to lightning and thunder. The storms form in areas of low pressure, where the air is warm and less dense than the surrounding atmosphere. Inside the cloud, an enormous electrical charge accumulates, which is then discharged with a zigzag flash between the cloud and the ground, between the cloud and the air, or between one cloud and another. This is how the flash of lightning is unleashed. Moreover, the heat that is released during the discharge generates an expansion and contraction of the air that is called thunder.



THUNDER
This is the sound produced by the air when it expands very rapidly, generating shock waves as it is heated.

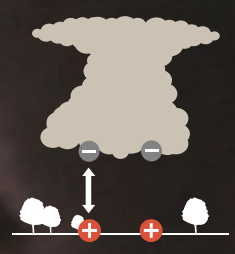


1. **ORIGIN**
Lightning originates within large cumulonimbus storm clouds. Lightning bolts can have negative or positive electric charges.



2. **INSIDE THE CLOUD**
Electrical charges are produced from the collisions between ice or hail crystals. Warm air currents rise, causing the charges in the cloud to shift.

SEPARATION
The charges become separated, with the positive charges accumulating at the top of the cloud and the negative charges at the base.



3. **ELECTRICAL CHARGES**
The cloud's negative charges are attracted to the positive charges of the ground. The difference in electrical potential between the two regions produces the discharge.

INDUCED CHARGE
The negative charge of the base of the cloud induces a positive charge in the ground below it.



4. **DISCHARGE**
The discharge takes place from the cloud toward the ground after the stepped leader, a channel of ionized air, extends down to the ground.

TYPES OF LIGHTNING

Lightning can be distinguished primarily by the path taken by the electrical charges that cause them.



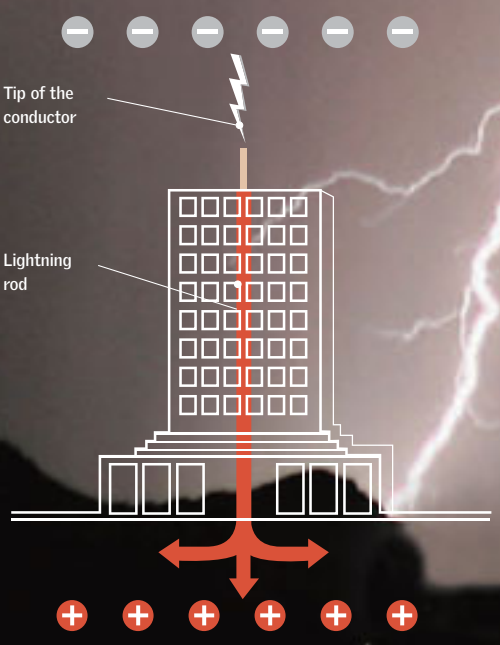
Cloud-to-air
The electricity moves from the cloud toward an air mass of opposite charge.

Cloud-to-cloud
A lightning flash can occur within a cloud or between two oppositely charged areas.

Cloud-to-ground
Negative charges of the cloud are attracted by the positive charges of the ground.

LIGHTNING RODS

The primary function of lightning rods is to facilitate the electrostatic discharge, which follows the path of least electrical resistance.



A lightning rod is an instrument whose purpose is to attract a lightning bolt and channel the electrical discharge to the ground so that it does no harm to buildings or people. A famous experiment by Benjamin Franklin led to the invention of this apparatus. During a lightning storm, he flew a kite into clouds, and it received a strong discharge. That marked the birth of the lightning rod, which consists of an iron rod placed on the highest point of the object to be protected and connected to the ground by a metallic, insulated conductor. The principle of all lightning rods, which terminate in one or more points, is to attract and conduct the lightning bolt to the ground.

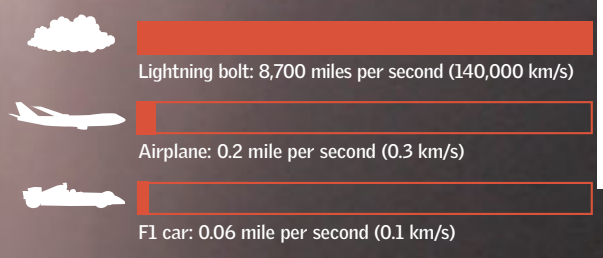


POINT OF IMPACT

65 feet (20 m)

This is the radius of a lightning bolt's effective range on the surface of the Earth.

8,700 miles per second (140,000 km/s) speed



100 million volts

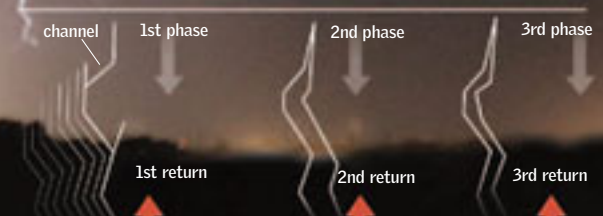
IS THE ELECTRICAL POTENTIAL OF A LIGHTNING BOLT.

A windmill generates 200 volts.

110 volts is consumed by a lamp.

5. **RETURN STROKE** In the final phase, the discharge rises from the Earth to the cloud.

DISCHARGE SEQUENCE



A The lightning bolt propagates through an ionized channel that branches out to reach the ground. Electrical charges run along the same channel in the opposite direction.

B If the cloud has additional electrical charges, they are propagated to the ground through the channel of the first stroke and generate a second return stroke toward the cloud.

C This discharge, as in the second stroke, does not have branches. When the return discharge ceases, the lightning flash sequence comes to an end.

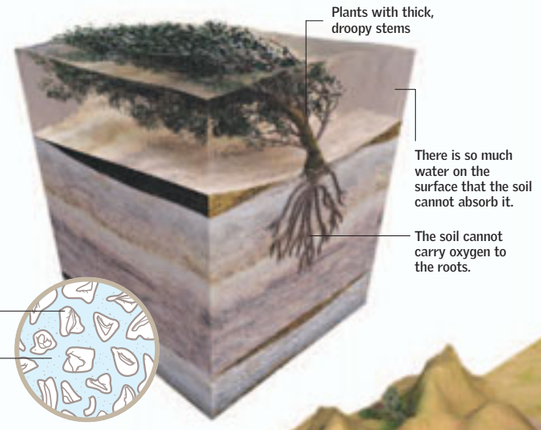
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When Water Accumulates

Water is a vital element for life, but in excess it leads to serious consequences for people and their economic activity. Flooding occurs when certain areas that are normally dry are covered with water for a more or less prolonged period. The most important causes are excessive rains, the overflow of rivers and lakes, and giant waves that wash over the coast. Such waves can be the result of unusually high tides caused by strong surface winds or by submarine earthquakes. Walls, dikes, dams, and embankments are used to help prevent flooding.

Flooded Land

When land is flooded for days or months, the air in the soil is replaced by water, which prevents the buildup of oxygen, thus affecting the biological activity of plants and the soil itself. In the latter case, if the water does not have sufficient salt, the incomplete decomposition of organic matter and the significant washing away of nutrients make the soil more acidic. If the water contains a great deal of salt, the salt will remain in the soil, causing a different problem: salinization.



Reduction

The components of the soil that are oxidized can be reduced and thus change their properties.

Floodplains

Floodplains are areas adjacent to rivers or streams that are subject to recurrent flooding.

Torrential Rains

Caused by low pressure systems, instability of the air mass, and high humidity

Torrential rains raise the level of the water in the rivers and the riverbeds.

Snow increases runoff into the rivers.

Little or no rain penetrates into the valley slopes covered with pines.

Principal river

Tributary river

Low-lying terrain
The main river cannot contain the increased flow of the tributary rivers.

Large rivers cross the plains, which suffer from regular flooding

Houses and trees covered with water

Flood Control

With the construction of dikes and embankments, the flow of rivers prone to flooding is largely contained.

Hydroelectric dam

Natural course of the river

Agriculture is more productive when water can be controlled.

Channeling water via turbines also generates electricity.

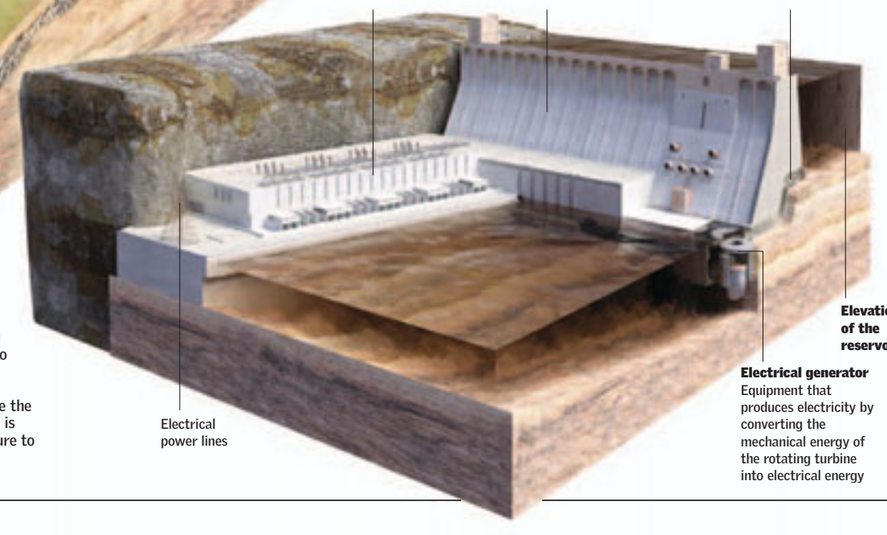
Electrical energy can be made available to houses.

EMBANKMENT
Earthen embankments help contain rivers that tend to overflow and temporarily change course.

STORM DIKES
In areas where the coast is low and exposed to flooding, protective dikes have been constructed against high tides and powerful waves.

Hydroelectric Plants

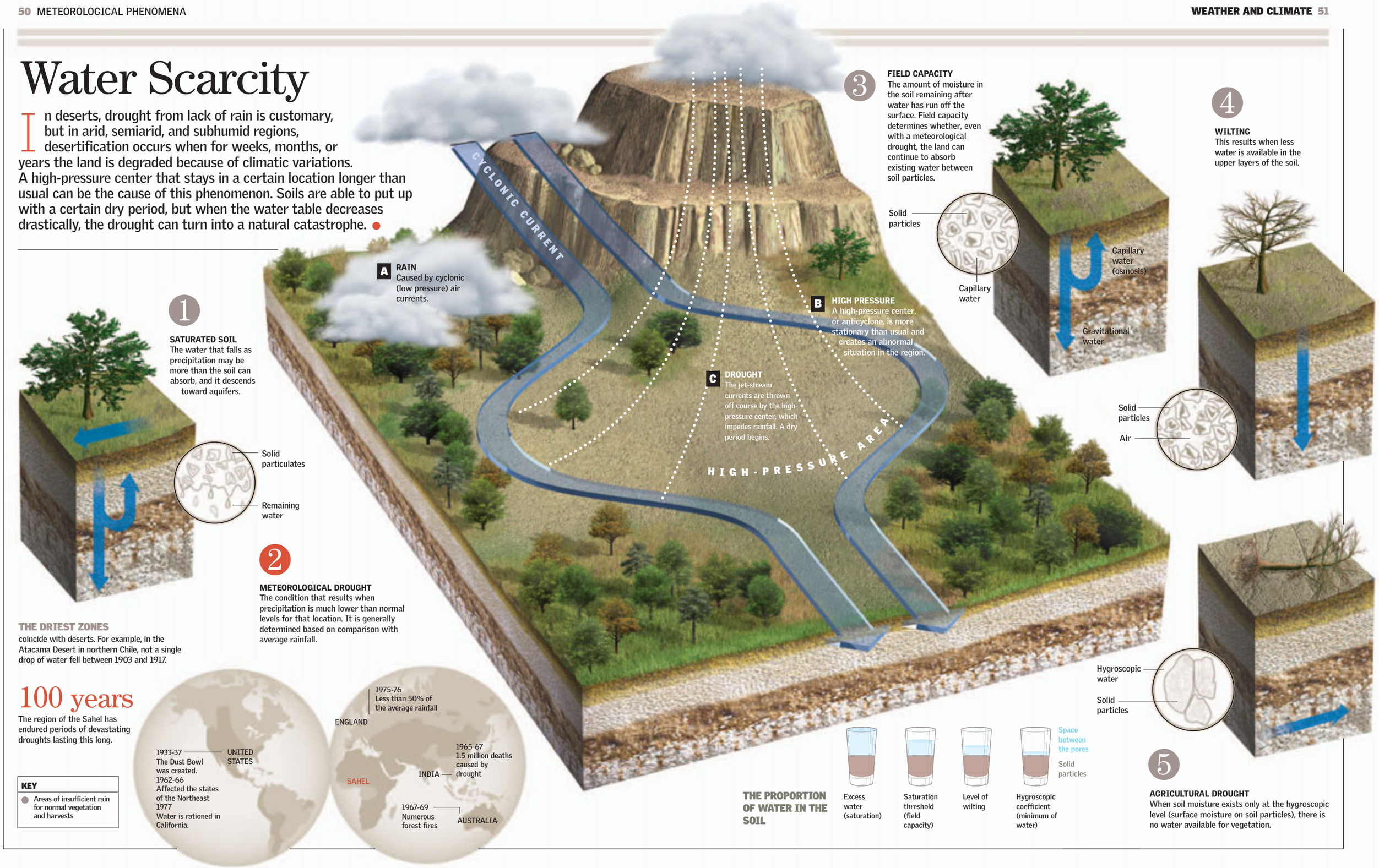
use the force and velocity of running water to turn turbines. There are two types: run-off-river (which uses the natural kinetic energy of the river's running waters) and reservoir (where the water accumulates behind dams and is then released under increased pressure to the power plant).



250,000
Victims of flooding in the Bay of Bengal, Bangladesh, in 1970

Water Scarcity

In deserts, drought from lack of rain is customary, but in arid, semiarid, and subhumid regions, desertification occurs when for weeks, months, or years the land is degraded because of climatic variations. A high-pressure center that stays in a certain location longer than usual can be the cause of this phenomenon. Soils are able to put up with a certain dry period, but when the water table decreases drastically, the drought can turn into a natural catastrophe.



THE DRIEST ZONES

coincide with deserts. For example, in the Atacama Desert in northern Chile, not a single drop of water fell between 1903 and 1917.

100 years

The region of the Sahel has endured periods of devastating droughts lasting this long.

KEY

- Areas of insufficient rain for normal vegetation and harvests

THE PROPORTION OF WATER IN THE SOIL

Lethal Force

Tornadoes are the most violent storms of nature. They are generated by electrical storms (or sometimes as the result of a hurricane), and they take the form of powerful funnel-shaped whirlwinds that extend from the sky to the ground. In these storms, moving air is mixed with soil and other matter rotating at velocities as high as 300 miles per hour (480 km/h). They can uproot trees, destroy buildings, and turn harmless objects into deadly airborne projectiles. A tornado can devastate a whole neighborhood within seconds.

TOP
The top of the tornado remains inside the cloud.

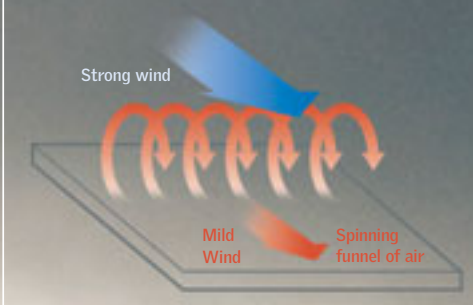
6 miles (10 km)
Maximum height that it can attain



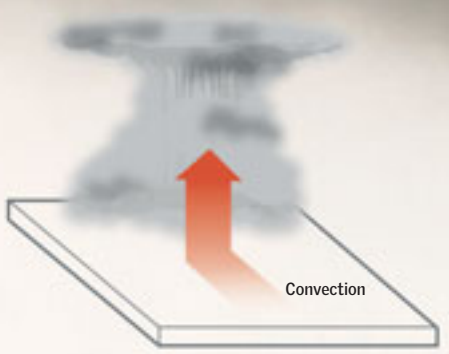
How They Form

Tornadoes begin to form when a current of warm air ascends inside a cumulonimbus cloud and begins to rotate under the influence of winds in the upper part of the cloud. From the base of the column, air is sucked toward the inside of the turning spiral. The air rotates faster as it approaches the center of the column. This increases the force of the ascending current, and the column continues to grow until it stretches from high in the clouds to the ground. Because of their short duration, they are difficult to study and predict.

300 miles per hour (480 km/h)
Maximum velocity the tornado winds can attain



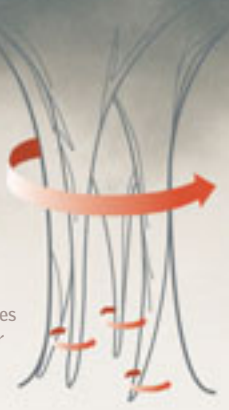
1.
BEGINNING OF A TORNADO
When the winds meet, they cause the air to rotate in a clockwise direction in the Southern Hemisphere and in the reverse direction in the Northern Hemisphere.

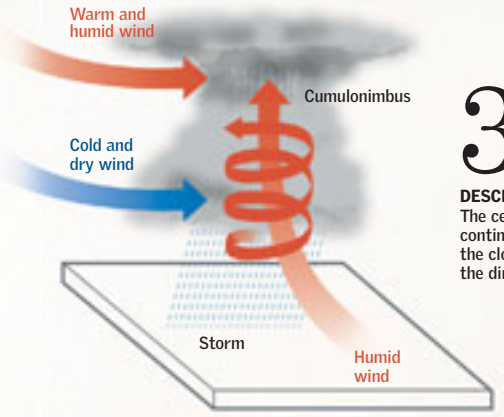


2.
ROTATION
The circulation of the air causes a decrease in pressure at the center of the storm, creating a central column of air.

VORTEX
Column of air that forms the lower part of a tornado; a funnel that generates violent winds and draws in air. It usually acquires the dark color of the dust it sucks up from the ground, but it can be invisible.

MULTIPLE VORTICES
Some tornadoes have a number of vortices.





3.
DESCENT
The central whirling column continues to descend within the cloud, perforating it in the direction of the ground.

4.
THE OUTCOME
The tornado reaches the Earth and depending on its intensity can send the roofs of buildings flying.

Where and When

Most tornadoes occur in agricultural areas. The humidity and heat of the spring and summer are required to feed the storms that produce them. In order to grow, crops require both the humidity and temperature variations associated with the seasons.



1,000
tornadoes are generated on average annually in the United States.

3:00 P.M.-9:00 P.M.
The period of the day with the highest probability of tornado formation

SPIRALING WINDS
First a cloud funnel appears that can then extend to touch the ground.

PATH
Normally the tornado path is no more than 160 to 330 feet (50-100 m) wide.

The tornado generally moves from the southwest to the northeast.

Some tornadoes are so powerful that they can rip the roofs off houses.

125 miles (200 km)
The length of the path along the ground over which a tornado can move

FUJITA SCALE
The Fujita-Pearson scale was created by Theodore Fujita to classify tornadoes according to the damage caused by the wind, from the lightest to the most severe.

	F0	F1	F2	F3	F4	F5
WIND VELOCITY MILES PER HOUR (KM/H)	40-72 (64-116)	73-112 (117-180)	113-157 (181-253)	158-206 (254-332)	207-260 (333-418)	261-320 (420-512)
EFFECTS	Damage to chimneys, tree branches broken	Mobile homes ripped from their foundations	Mobile homes destroyed, trees felled	Roofs and walls demolished, cars and trains overturned	Solidly built walls blown down	Houses uprooted from their foundations and dragged great distances

Death and Destruction

Of the 1,000 tornadoes that annually strike the United States, there is one that has the unfortunate distinction of being one of the worst: the Tri-State tornado, which occurred on March 18, 1925, and caused extreme devastation. It moved across Missouri, Illinois, and Indiana, destroying homes and causing the confirmed deaths of 695 people, although it is believed that the number may have been much higher. The tornado traveled 230 miles (368 km) at an average velocity of 66 miles an hour (105 km/h), and its duration set a record at three hours and 30 minutes. It has been rated on the Fujita scale as an F5 tornado—one of the most damaging—and caused losses to the United States of $17 million.





MISSOURI (U.S.)
Latitude 37° N
Longitude 93° W

Value on the Fujita scale	**F5**
Duration	**3 hours 30 minutes**
Average velocity	**66 miles per hour (105 km/h)**

1:01 P.M.
First contact with the ground

ELLINGTON
First town affected
One dead

REDFORD
Town hit by tornado

ANNAPOLIS AND LEADANNA
Large number of victims
75 injured and 2 dead

90 percent destroyed

BIEHLE
A number of houses destroyed

MURPHYSBORO
Town with the greatest number of fatalities
234 dead

40 percent destroyed

100 percent destroyed

GORHAM
Town in ruins
34 dead

30 percent destroyed

DE SOTO
Partial destruction but a large number of victims
69 dead

90 percent destroyed

PARRISH
Almost total destruction
22 dead

WEST FRANKFORT
Partial destruction
450 wounded and 127 dead

20 percent destroyed

100 percent destroyed

GRIFFIN
150 houses destroyed, and many children killed.

PRINCETON
Half of the town destroyed
65 deaths

50 percent destroyed

OWENSVILLE
Serious damage to houses

4:30 P.M.
Final contact with the ground

230 miles (368 km) TOTAL PATH TRAVELLED

190 miles (307.5 km)

65 miles per hour (104 km/h) Average velocity

38 miles (60.5 km)

9° of rotation

70 miles per hour (115 km/h) Velocity

71 miles per hour (115 km/h)

60 miles per hour (96 km/h)

55 miles per hour (90 km/h)

66 miles per hour (107 km/h)

60 miles per hour (96 km/h)

71 miles per hour (115 km/h)

In **40 minutes, 541 people died.**

Rural area

MISSOURI

ILLINOIS

INDIANA

Tornadoes in the United States

Unlike hurricanes, which are tropical storms primarily affecting the Gulf of Mexico, tornadoes are phenomena that occur between the Great Plains of the United States, the Rocky Mountains, and the Gulf of Mexico and usually appear in the spring and summer.



3:00 P.M. -9:00 P.M.
The period of the day with the highest probability of tornado formation

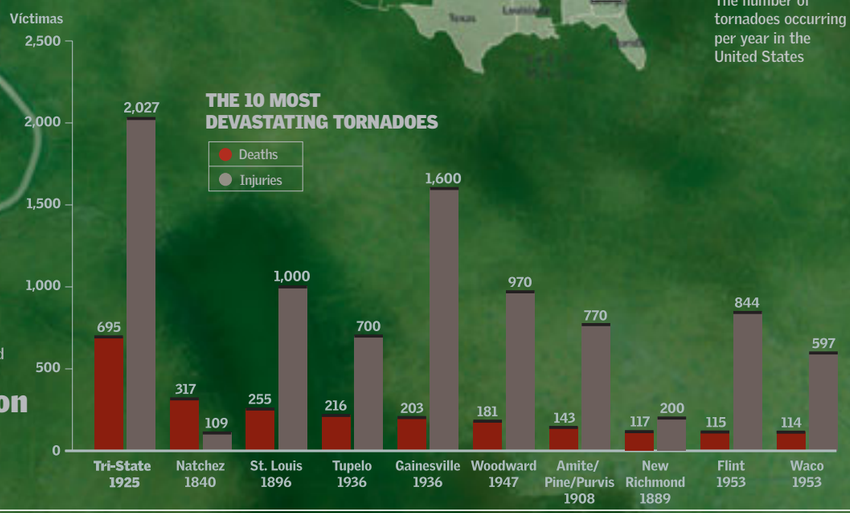
1,000
The number of tornadoes occurring per year in the United States

THE TOWN OF GRIFFIN, IN THE STATE OF INDIANA, WAS LEFT IN RUINS.

15,000
houses destroyed

17 million
dollars in losses

THE 10 MOST DEVASTATING TORNADOES



Anatomy of a Hurricane

A hurricane, with its ferocious winds, banks of clouds, and torrential rains, is the most spectacular meteorological phenomenon of the Earth's weather. It is characterized by an intense low-pressure center surrounded by cloud bands arranged in spiral form; these rotate around the eye of the hurricane in a clockwise direction in the Southern Hemisphere and in the opposite direction in the Northern Hemisphere. While tornadoes are brief and relatively limited, hurricanes are enormous and slow-moving, and their passage usually takes many lives.



NH
Hurricanes in the Northern Hemisphere rotate counterclockwise, and those in the Southern Hemisphere rotate clockwise.

SH



DAY 1
A jumble of clouds is formed.



DAY 2
The clouds begin to rotate.



DAY 3
The spiral form becomes more defined.



DAY 6
Now mature, it displays a visible eye.

DANGER ZONE

The areas that are vulnerable to hurricanes in the United States include the Atlantic coast and the coast along the Gulf of Mexico, from Texas to Maine. The Caribbean and the tropical areas of the western Pacific, including Hawaii, Guam, American Samoa, and Saipan, are also zones frequented by hurricanes.



DAY 12
The hurricane begins to break apart when it makes landfall.

1. BIRTH



Forms over warm seas, aided by winds in opposing directions, high temperatures, humidity, and the rotation of the Earth

2. DEVELOPMENT

Begins to ascend, twisting in a spiral around a low-pressure zone

3. DEATH

As they pass from the sea to the land, they cause enormous damage. Hurricanes gradually dissipate over land from the lack of water vapor.

FRINGES OF STORM CLOUDS
otate violently around the central zone.

THE EYE
Central area, has very low pressure

Descending air currents

The high-altitude winds blow from outside the storm.

The air wraps around the eye.

Cloud bands in the form of a spiral

EYE WALL
The strongest winds are formed.

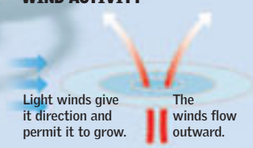
VAPOR
Rises warm from the sea, forming a column of clouds. It rises 3,900 feet (1,200 m) in the center of the storm.

Strong ascendant currents

80° F
(27° C)
is the minimum temperature that water on the surface of the ocean will evaporate at.

The trade winds are pulled toward the storm.

WIND ACTIVITY



Light winds give it direction and permit it to grow.

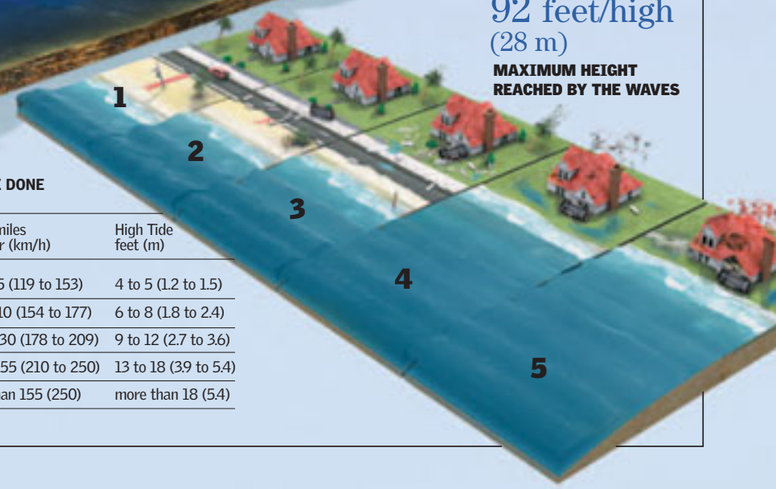
The winds flow outward.

19 miles per hour
(30 km/h)
VELOCITY AT WHICH IT APPROACHES THE COAST

FRICTION
When the hurricane reaches the mainland, it moves more slowly; it is very destructive in this stage, since it is here that populated cities are located.

PATH OF THE HURRICANE

92 feet/high
(28 m)
MAXIMUM HEIGHT REACHED BY THE WAVES



CLASSIFICATION OF DAMAGE DONE
Saffir-Simpson category

Damage		Speed miles per hour (km/h)	High Tide feet (m)
CLASS 1	minimum	74 to 95 (119 to 153)	4 to 5 (1.2 to 1.5)
CLASS 2	moderate	96 to 110 (154 to 177)	6 to 8 (1.8 to 2.4)
CLASS 3	extensive	111 to 130 (178 to 209)	9 to 12 (2.7 to 3.6)
CLASS 4	extreme	131 to 155 (210 to 250)	13 to 18 (3.9 to 5.4)
CLASS 5	catastrophic	more than 155 (250)	more than 18 (5.4)

What Katrina Took Away

Hurricane Katrina lashed the south and the center of the United States in August 2005. The force of the wind razed thousands of houses, buildings, oil installations, highways, and bridges, leaving a vast area of the country without communication and some heavily populated areas without provisions. It resulted in extensive material damage and thousands of deaths in Florida, the Bahamas, Louisiana, and Mississippi. Satellite images reveal the scope of the disaster, considered one of the most devastating in the history of the country. ●

THE WATER
advances toward the city, invading the central regions.

THE WINDS
At 155 miles per hour (250 km/h), they force the water against the protective walls..

LAKE PONTCHARTRAIN

DIKES
were breached by the water and the wind, causing a great flood.

6:00 A.M.
The time when the hurricane made landfall

17TH STREET CANAL

LONDON AVENUE CANAL

ORLEANS AVENUE CANAL

80%
Area of New Orleans affected by flooding

Area most affected by the flood

Areas most affected by the flood

75%
of the inhabitants of this zone were evacuated.

OVER 1,500
Deaths confirmed after Katrina

OVER 75 billion
dollars was the cost of the repairs.

The hurricane winds pushed the water 14 feet (4.3 m) above the normal sea level.

Along with the storm, the backed-up water reaches the dikes of the Mississippi River.



NEW ORLEANS
Latitude 30° N
Longitude 90° W

Area	360 square miles (933 square kilometers)
Number of inhabitants	500,000
Altitude (above sea level)	10 feet (3 m)



AUGUST 23
A tropical depression forms in the Bahamas. It intensifies and becomes tropical storm Katrina. On August 25, it makes landfall in Florida as a category 1 hurricane.

14 Huracanes fueron registrados en 2005.

26 El total de tormentas tropicales registradas en el año 2005.

AUGUST 27
Leaves the Gulf of Mexico and reaches category 3. On August 28, it is transformed from category 3 to category 5 and increases in size.

CATEGORY 5

CATEGORY 3

AUGUST 29
In the early hours, it makes landfall in Louisiana as a category 4 hurricane. A little later, it makes landfall for the third time, in Mississippi.

CATEGORY 4

155 miles per hour (250 km/h)
MAXIMUM WIND SPEED

SEPTEMBER 1
What remains of the hurricane is weakened as it moves north to Canada, where it dissipates.

Direction of the hurricane

Foresight to Prevent Tragedies

Hurricanes usually lash specific regions of the planet, and the population must become aware of the disasters that can strike the community. Each family must know which area of the house is the most secure in case the roof, a door, or a window collapses. They must also know when it is time to go to a shelter or if it is better to remain at home. Another important precaution is to organize and store all family documents and real-estate records in a water- and fireproof strongbox.

1 BEFORE THE HURRICANE

If you live in a hurricane-prone area, it is recommended that you know the emergency plans of the community and that you have a plan of action for your family.

2 DURING THE HURRICANE

The important thing is to remain calm and to stay informed via radio or television about the path of the hurricane. Move away from doors and windows. Do not leave until the authorities announce the danger from the hurricane has ended.

3 AFTER THE HURRICANE

First verify that everyone in the family is well and that there are no injuries. Do not touch loose cables or fallen poles. Call the fire department or the police in case you need food, clothing, or immediate medication.

Secure all the doors and windows to keep them from opening.

Reinforce roof tiles to keep them from being loosened.

Store nonperishable food and potable water.

Keep valuable objects and documents in a waterproof container.

Follow news reports with a battery-powered radio.

Keep the car supplied with a full tank of fuel just in case.

Administer first aid when necessary.

Disconnect all electrical devices and shut off the house circuit breaker.

Use a battery-powered radio to tune into local stations to get information.

Help people who are injured or trapped.

Keep documents confirming your ownership of property close at hand.

Return home only when the authorities say that it is safe.

Do not drink water unless you are sure it is potable.

Use the telephone only for emergency calls.

Verify that there are no natural-gas leaks or damage to the electrical system.

Check the most fire-prone areas.

Do not touch wires or damaged electrical equipment.

Turn off the main water valve and the main gas valve.

When you are on the move, use caution whether on foot or driving.

HOW TO PREPARE EMERGENCY EQUIPMENT

A complete first-aid kit must be prepared and available. Consult a pharmacist or your family physician.

First-aid kit
Check the first-aid kit and replace any expired items.

First-aid course
You should be prepared for dealing with the most common symptoms and injuries.

HOW TO PREPARE DOCUMENTATION

To be prepared for evacuation, keep family documents in good order.

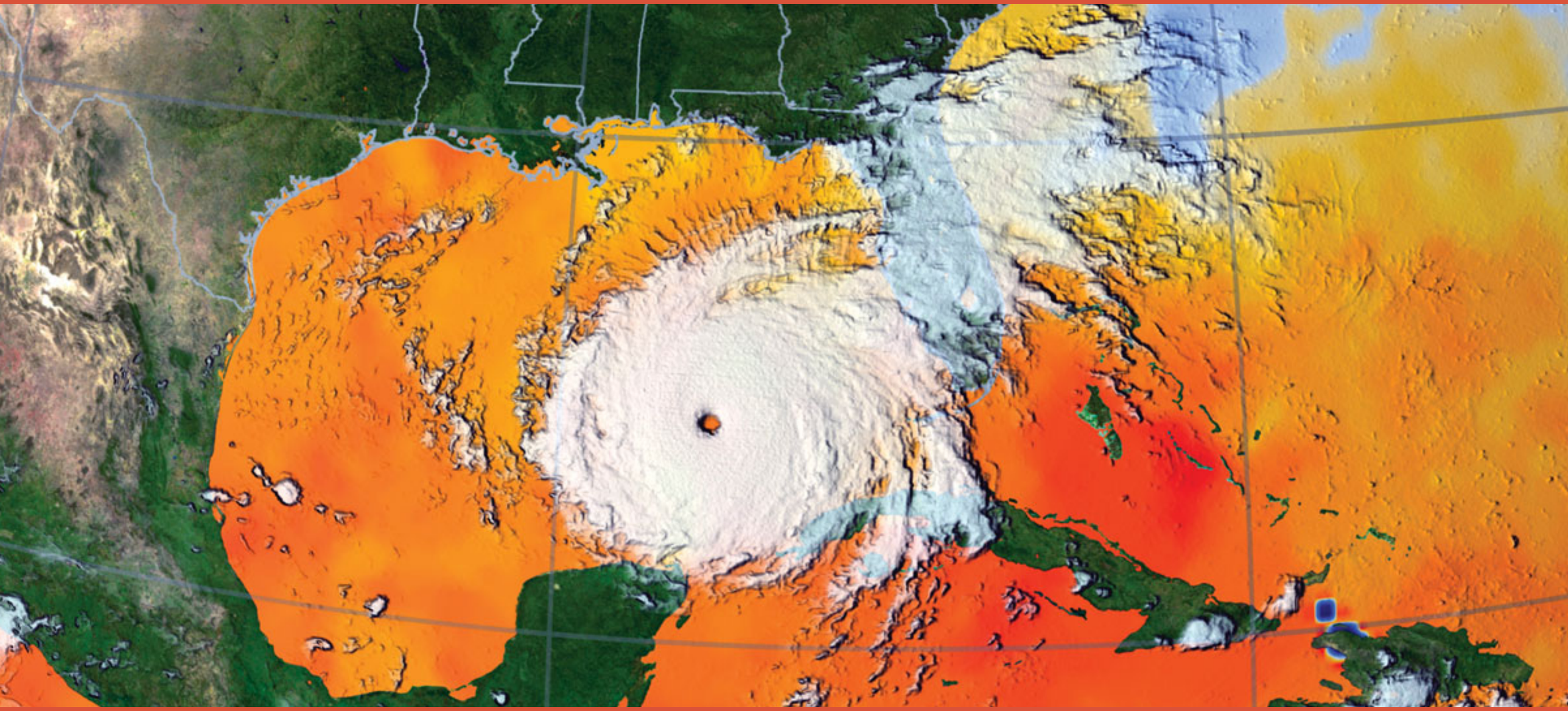
Inventory
Make a complete list of belongings of each person.

Personal ID
It is important for everyone to have an ID card.

Meteorology

RITA, SEPTEMBER 2003
The image from the GOES-12 satellite shows the configuration of Hurricane Rita in the eastern portion of the Gulf of Mexico.

WEATHER FOLKLORE 64-65
COMPILATION OF INFORMATION 66-67
INSTANTANEOUS MAPS 68-69
RAIN, COLD, OR HEAT 70-71
MOBILE SATELLITES 72-73



The use of satellites orbiting the Earth, recording the coming of rain, air currents, and clouds, allows us to know with some hours of advance warning if a severe storm is heading toward a certain point on the planet. Counting on this type of precise information about when and where tropical cyclones will occur, for example, has allowed government officials to coordinate the evacuation of people from the affected zones. The surface of the planet is also monitored by a system of meteorological stations placed hundreds of miles from each other. These collect information from and send information to all areas of the world so that meteorologists can prepare maps, graphics, and predictions to inform the public. ●

Weather Folklore

Before the development of meteorology as we know it today, people observed in nature signs that allowed them to predict rains, floods, or strong winds. All this knowledge has been transmitted over the centuries in the form of proverbs or rhymes. Most of these fragments of meteorological knowledge lack a scientific foundation, but some of them reflect certain principles. Plants and animals play a major role in these observations.

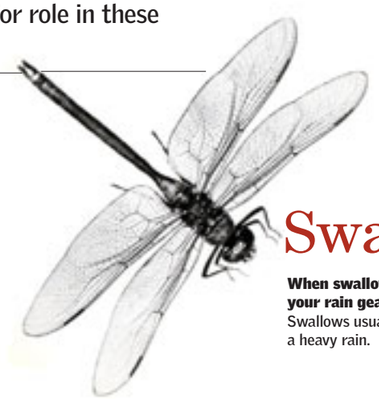
Signs from Plants and Animals

In every rural community, concern for the harvest and dependency on weather resulted in a series of beliefs, with varying degrees of accuracy, taken as prophesies of later events. In any case, even though it is certain that people as well as plants and animals react to the current weather, there is nothing to indicate that this might reveal anything about the weather in the future except to the degree that an incipient change is related to the current weather. For example, some signs accompany the increase in humidity that occurs prior to the passage of a cold front.



Swallow

When swallows fly low, get your rain gear in tow.
Swallows usually appear before a heavy rain.





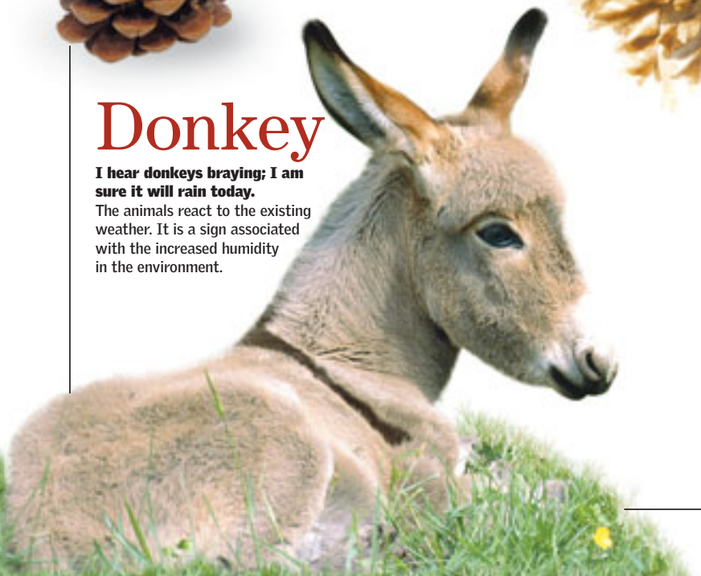
OPEN AND CLOSED PINECONES
Open pinecones mean dry weather; closed pinecones mean humid weather.



DRY SEAWEED
The lower the humidity, the more probable it is that the next day will be dry.

Donkey

I hear donkeys braying; I am sure it will rain today.
The animals react to the existing weather. It is a sign associated with the increase in humidity in the environment.



Toad

When you see a toad walking, it will be a wet spring.
When a toad is swimming in the water, this means it will soon rain. If it stays in the water without moving, the rain will last for some time.





OAK
If the leaves of the oak fall before those of the ash, the summer will be dry.

ASH
If the leaves of the ash fall before those of the oak, the summer will be wet.



Moon

When the Moon has a halo, tomorrow will have wet or bad weather.
Halos occur as a consequence of the refraction of light by ice crystals in cirrostratus clouds covering the Sun or Moon. They portend a warm front, which will be followed by rain.

Almanac Forecasts

In the 16th century, almanacs with weather forecasts were sold throughout Europe. Each month of the year has its own refrain, although this depends on the hemisphere a person lives in. The monthly and annual calendars offered agricultural and medical advice. From the most remote times, there was a general belief that the Moon determined the behavior of the atmosphere and that variations in the weather were caused by changes in the phase of the Moon. Some examples of these popular sayings are: "Sweet April showers do spring May flowers;" "After a dark winter's night, the next day will be bright."

Clouds

Clouds with a fringe or lining—secure your sails well.
This relates to clouds that are carried by winds at high altitudes; these clouds are often a sign that a low-pressure system, or cyclone, is approaching.

WEATHER PREDICTION
There are thousands of refrains that refer to changes in weather conditions. Here are some examples.

WIND
Wind from the east, rain like a beast.



MORNING DEW
Dew and cool in May, bring wine to the vine and hay to the cow.



CLEAR SUNSET
Rainbow at sundown, good weather at dawn.



Snails

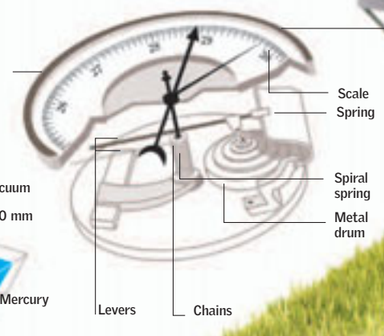
When you see a black slug in your way, rain is not far away.
Snails are usually hidden in the garden. You see them only on humid days, just prior to the rain.

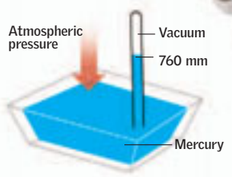


Compilation of Information

Most of the information available regarding climatic data comes from the record that meteorologists everywhere in the world keep regarding cloud cover, temperature, the force and direction of the wind, air pressure, visibility, and precipitation. Then from each meteorological station, the data is sent by radio or satellite, and this makes it possible to make forecasts and maps.

ANEROID BAROMETER
measures atmospheric pressure. Changes are shown by the pointers.





MERCURY BAROMETER
An instrument used to measure atmospheric pressure. It consists of a glass tube full of mercury, with the open end submerged in a reservoir.



BAROGRAPH
measures the atmospheric pressure and records its changes over time.

Workplace

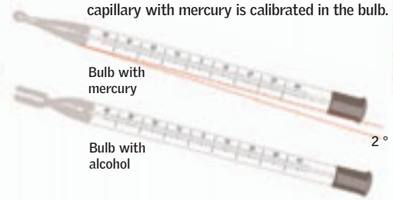
A typical meteorological station checks the temperature, humidity, wind velocity and direction, solar radiation, rain, and barometric pressure. In some places, soil temperature and flow of nearby rivers are also monitored. The compilation of this data makes it possible to predict different meteorological phenomena.

WEATHER VANE
shows which way the wind is blowing. It is a perfectly balanced mechanical system.



ANEMOMETER
measures the speed of the wind. This instrument is activated by the wind, which turns three hemispherical cups mounted on a vertical rod firmly placed in the ground.

MAXIMUM THERMOMETER
shows the highest temperature of the day. The capillary with mercury is calibrated in the bulb.



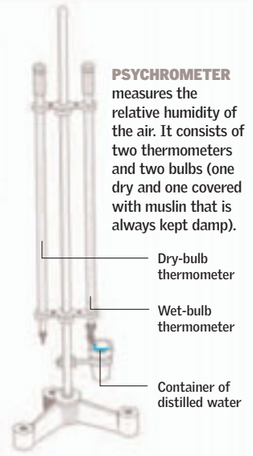
MINIMUM THERMOMETER
indicates the lowest temperature of the day. It has a fork-shaped bulb.

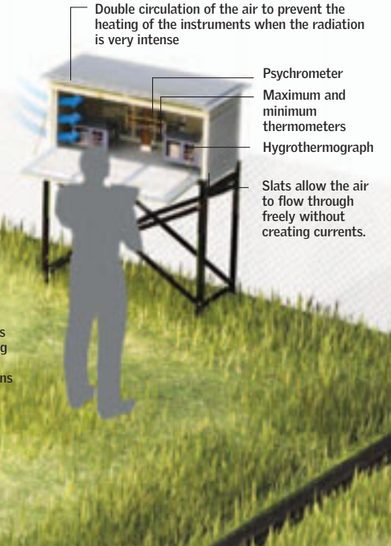


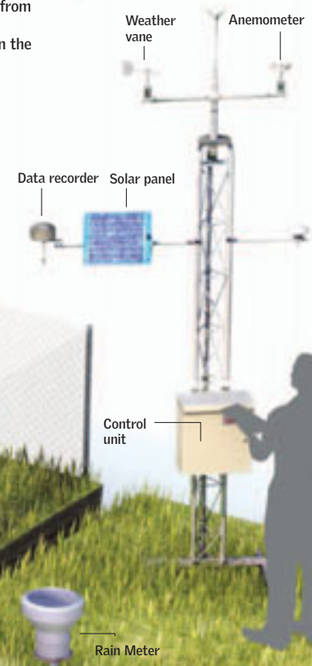
HYGROTHERMOGRAPH
simultaneously records the air temperature and relative humidity. A thermograph and a hygrograph independently make records on paper of the daily variations in temperature and humidity.

METEOROLOGICAL SHELTER
It is built of wood or fiberglass on a base that insulates it from the soil and protects certain instruments (thermometers, psychrometers, and others) from solar radiation. Screens in the windows ensure good ventilation.

PSYCHROMETER
measures the relative humidity of the air. It consists of two thermometers and two bulbs (one dry and one covered with muslin that is always kept damp).



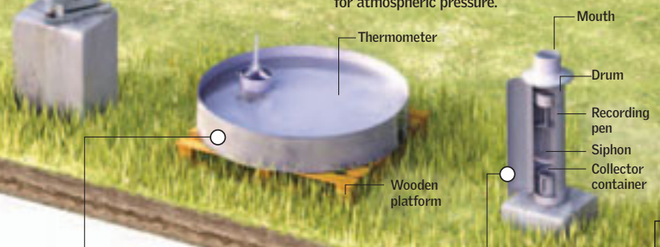




Weather Station

Meteorologists collect data at different heights. They use various instruments at ground level: a thermometer for temperature, a hygrometer for humidity, and a barometer for atmospheric pressure.

In the Northern Hemisphere, the doors should be oriented toward the north to prevent the Sun's rays from striking the instruments when observations are being made.



EVAPORIMETER
As its name indicates, it measures the effective evaporation of water from a mass of liquid in the open air, from its loss from the surface through transformation to water vapor.

RAIN METER
This is used to keep a chronological record of the amount of water falling as rain.

RAIN GAUGE
The precipitation that falls on the ground in the form of rain is collected by the rain gauge.

Automatic Weather Station

An automatic meteorological station uses electrical sensors to record temperature, humidity, wind velocity and direction, atmospheric pressure, and rainfall, among other parameters. The readings are processed by microprocessors and transmitted via an automatic system. This station functions autonomously, 24 hours a day, powered by solar energy (solar panels) or wind energy.



The light strikes and is concentrated as it traverses the sphere.

HELIOPHANOGRAPH
An instrument used to measure the number of hours of sunlight. It consists of a glass sphere that acts as a lens to concentrate sunlight. The light is projected onto a piece of cardboard behind the sphere. The cardboard is burned according to the intensity of the light.

IMPRESSION
The concentrated rays of sunlight burn cardboard placed behind the glass sphere.



Instantaneous Maps

Weather maps represent at any given moment the state of the atmosphere at different altitudes. These maps are made based on the information provided by meteorological stations and are useful for specialists. The data collected by them include various values for pressure and temperature that make it possible to forecast the probability of precipitation, whether the weather will remain stable, or if it will change because a weather front is moving in.

NOMENCLATURE

Every meteorological map carries a label that indicates the date and time it was made.

12 indicates the hour and Z Greenwich Mean Time.

This map is prepared with the initial values of Tuesday, September 2.

It indicates the initial values.



1686
is the year in which English astronomer Edmond Halley made the first meteorological map.

SYMBOLS

There are a number of different symbols to represent different kinds of fronts.

WARM A warm air mass with local storms is advancing.

COLD A cold air mass with rain is advancing.

STATIONARY Moderately bad weather and little change of temperature

OCCLUDED FRONT
It is mixed; it will act first as a warm front and then as a cold front.

Isobar Maps

One of the variables that provides the most information in real time for knowing meteorological conditions is atmospheric pressure, whose values over land (at sea level) are represented on what are called isobar maps, or ground-level weather maps. The isobars, or lines that connect points of equal pressure, make it possible to estimate the velocity and direction of the wind at ground level. This information helps forecast the movement of cold or warm air masses. The letter A indicates an anticyclonic area, which indicates atmospheric stability and that the probability of rain is very low. The letter B indicates a low-pressure area and presages major atmospheric instability with possible rain.

LOW PRESSURE, OR DEPRESSION

In this zone, atmospheric stability will be low given that the air is rising, and there is a high probability of precipitation.

LOW PRESSURE
This is a low-pressure zone. The pressure increases from the internal isobars toward the external isobars.

1000
995
990

ANTICYCLONE

In this area, the atmospheric stability is high, since the downward motion of the air prevents the formation of clouds. There is low probability of rain.

WINDS
They circulate and move away from the area.

WINDS
circulate around the center of the area.

1030
1025
1020
1015

HIGH PRESSURE
This is a high-pressure area. The pressure decreases from the internal isobars toward the external isobars.

ISOBARS
are lines joining points of equal pressure.

OCCLUDED FRONT
indicates the line of collision between a cold front and a warm front. These are usually associated with severe storms.

Upper-air Map

Another type of map, which is used to analyze upper-air weather conditions, is an upper-level, or geopotential, map. On these maps, contour lines connect points located at the same altitude for a certain pressure level (normally 500 hectopascals [hPa]) and correlate with the temperature of the air in the higher layers of the troposphere (at 16,400 feet [5,000 meters] altitude on the 500 hPa map). The temperature is represented in each region of the troposphere by lines called isotherms.

WINDS

The direction and intensity of the winds are indicated by a segment with a circle at its end, which indicates the direction from which the wind is blowing. On this segment, perpendicular lines are traced that indicate the velocity of the wind in knots, where one knot equals 1.2 miles per hour (1.9 km/h).

SYMBOLS
The direction of the wind is represented by these symbols:

POSITION
The line indicates the direction of the wind. It can be north, northeast, east, southeast, south, southwest, west, or northwest.

OVERCAST SKY
A black circle indicates an overcast sky and a white circle a clear sky.

WIND VELOCITY
A short line indicates five knots, a longer line indicates 10 knots, and a terminal triangle indicates more than 40 knots.

BAD WEATHER
Instability and high probability of abundant rain

LOW-PRESSURE TROUGH

This phenomenon increases the probability of bad weather. A low-pressure trough has a low geopotential value.

HIGH-PRESSURE RIDGE

Area of high geopotential values in which the chances of rain are slight

GOOD WEATHER
Atmospheric stability and low expectation of precipitation

LOW-PRESSURE TROUGH AXIS

HIGH-PRESSURE RIDGE AXIS

UPPER-LEVEL MAPS

The contour lines traced in these charts connect points of equal geopotential height, which define high-pressure ridges and low-pressure troughs. The wind direction is parallel to these lines. These charts are used to prepare weather forecasts.

250 hPa	36,100 FEET (11,000 METERS)
500 hPa	18,000 FEET (5,500 METERS)
700 hPa	9,800 FEET (3,000 METERS)
850 hPa	4,900 FEET (1,500 METERS)
SURFACE	0 FEET (0 METERS)

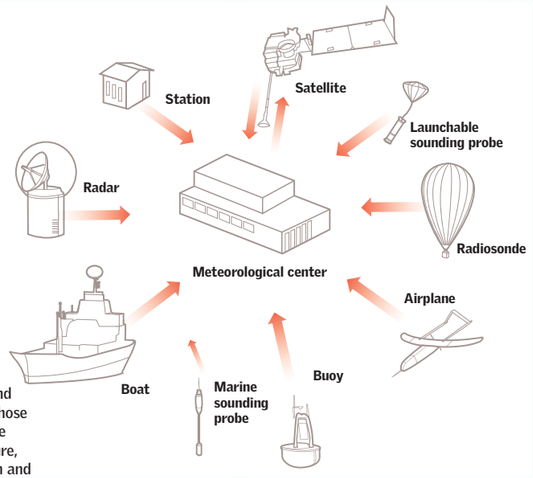
500 HPA
The first pressure value that represents a geopotential of 500 hectopascals (hPa)

600 596 592 588 584 580 576 572 568 564 560 556 552 548 544 540 536 532 528 524 520 516 512 508 504 500 496 492 488 484 480 476

Rain, Cold, or Heat

Knowing ahead of time what the weather will be is sometimes a question of life or death. The damage resulting from a torrential rain or a heavy snowfall can be avoided thanks to the forecasts of meteorologists. The forecasts they make are based on information gathered from many sources, including instruments on the ground, in the air, and at sea. Despite the use of sophisticated information systems, the weather can be forecast only for the next few hours or days. Nonetheless, it is very useful in helping to prevent major catastrophes.

DATA COLLECTION
The World Meteorological Organization acts as a center for receiving and transmitting data coming from various stations located in the air, on the ocean, and on land.



On Land

The observations made at ground level are more numerous than those made at higher altitudes. They include measurements of atmospheric pressure, temperature, humidity, wind direction and velocity, the extent and altitude of cloud cover, visibility, and precipitation.

METEOROLOGICAL STATION
Measurements at ground level permit the collection of partial data. Thermometers measure temperature, the hygrometer measures humidity, and the barometer measures atmospheric pressure.

In the Air

Data can be collected by airplanes, satellites, or sounding probes. One single satellite can cover the entire surface of the Earth. Precise information helps prevent meteorological catastrophes such as hurricanes or flooding.

RADIOSONDE
carries out airborne measurements of temperature, pressure, and relative humidity at different altitudes or atmospheric levels. It also indicates the direction and speed of the wind.

METEOROLOGICAL AIRCRAFT
obtain temperature and humidity data and photograph particles contained in the clouds.

HURRICANE HUNTER P-3 AIRPLANE
Its Doppler radar has a resolution four times greater than the standard Doppler radar in conventional use.

14,000 feet (4,270 m)
is the altitude that can be reached by the P-3 aircraft.

49,200 feet (15,000 m)
is the altitude that a radiosonde can reach.

32,800 feet (10,000 m)
The height at which they fly, near the upper limit of the troposphere

JET G-IV

Doppler radar

Parachutes lengthen the time in the air.

Radiosonde sends information to the base.

1,200 feet (365 m)
is the altitude that can be reached by a radio sounding probe.

AEROSONDE
Pilotless weather aircraft capable of sending meteorological information at intervals of tenths of a second

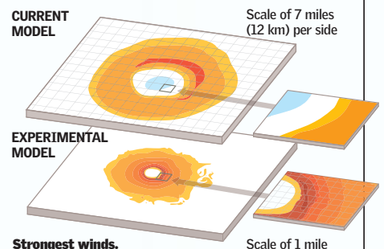
ARTIFICIAL SATELLITES
provide images used for visualizing clouds and water vapor in the atmosphere and for measuring the temperature of land and ocean surfaces.

49,200 feet (13,000 m)
is the altitude that can be reached by the G-IV airplane.

LAUNCHABLE SOUNDING PROBE
is launched from an airplane toward the ground. Its trajectory is followed as it relays information about wind velocity, temperature, humidity, and pressure.

Better Forecasts

New models that measure changes in such variables as humidity, temperature, wind velocity, and cloud displacement may make it possible to improve forecasts by 25 percent over current ones.



Strongest winds. They are not detected by current models.

METEOROLOGICAL CENTERS
They improve worldwide cooperation in meteorological observations, normalize the data obtained in different cities throughout the world, and promote the application of forecasts to various human activities.

OCEANOGRAPHIC SHIP
gathers data on the direction and speed of the wind and the temperature of the air and water, among other things.

Navigation lights
Anemometer
Data transmitter
Solar panel

METEOROLOGICAL BUOY
provides information about conditions of the sea in areas that are not covered by ships. The buoy floats freely with the ocean currents and transmits readings automatically via satellite.

ACOUSTIC SIGNAL
An acoustic depth sounder sends out sound waves to measure the depth of the water.

AUTONOMOUS UNDERWATER VEHICLE
Images related to the physical properties of the ocean water, such as the temperature, salinity, and density, are relayed to operators and its location and depth tracked via the Global Positioning System (GPS).

6,600 feet (2,000 m)
is the depth reached by the vehicle.

MARITIME SOUNDING PROBES
They are dropped from airplanes and then sink.

RADAR STATION
is utilized to measure the intensity with which rain, snow, or ice is falling. The radar sends radio waves that bounce off raindrops, and the return signal is displayed on a receiving screen.

On the Sea

Boats, buoys, and autonomous underwater vehicles help measure water temperature, salinity, density, and reflected sunlight. All the information gathered is sent to a meteorological center.

Mobile Satellites

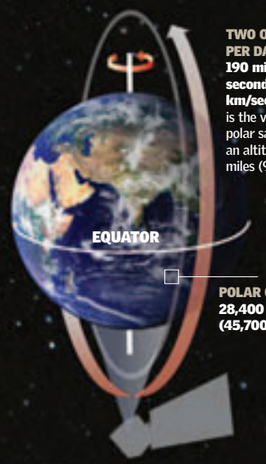
Meteorological satellites, which have been orbiting the Earth for more than 30 years, are an indispensable aid to scientists. Along with the images generated by these instruments, meteorologists receive data that can be used to prepare weather bulletins. These reports, circulated via the mass media, allow people all over the world to know the weather forecast. Moreover, the most advanced satellites are used to study the characteristics of phenomena such as tropical cyclones (hurricanes, cyclones, and typhoons).

Polar Orbit

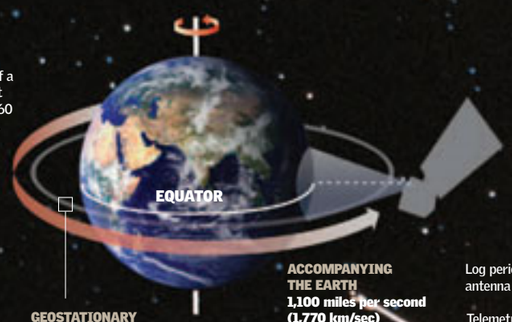
They orbit from pole to pole with a synchronized period. As they move in their orbits, they scan swaths of the Earth's surface. They pass over any given point twice a day. Their operational lifetime is approximately two years.

Geostationary

They orbit the Earth above the Equator and are synchronized with the Earth's rotation—that is, as they orbit the Earth, they are always over the same geographic point on the Earth's surface.



TWO ORBITS PER DAY
190 miles per second (305 km/sec)
is the velocity of a polar satellite at an altitude of 560 miles (900 km).



ACCOMPANYING THE EARTH
1,100 miles per second (1,770 km/sec)
The velocity necessary to remain fixed over one point on the Earth

CHARACTERISTICS

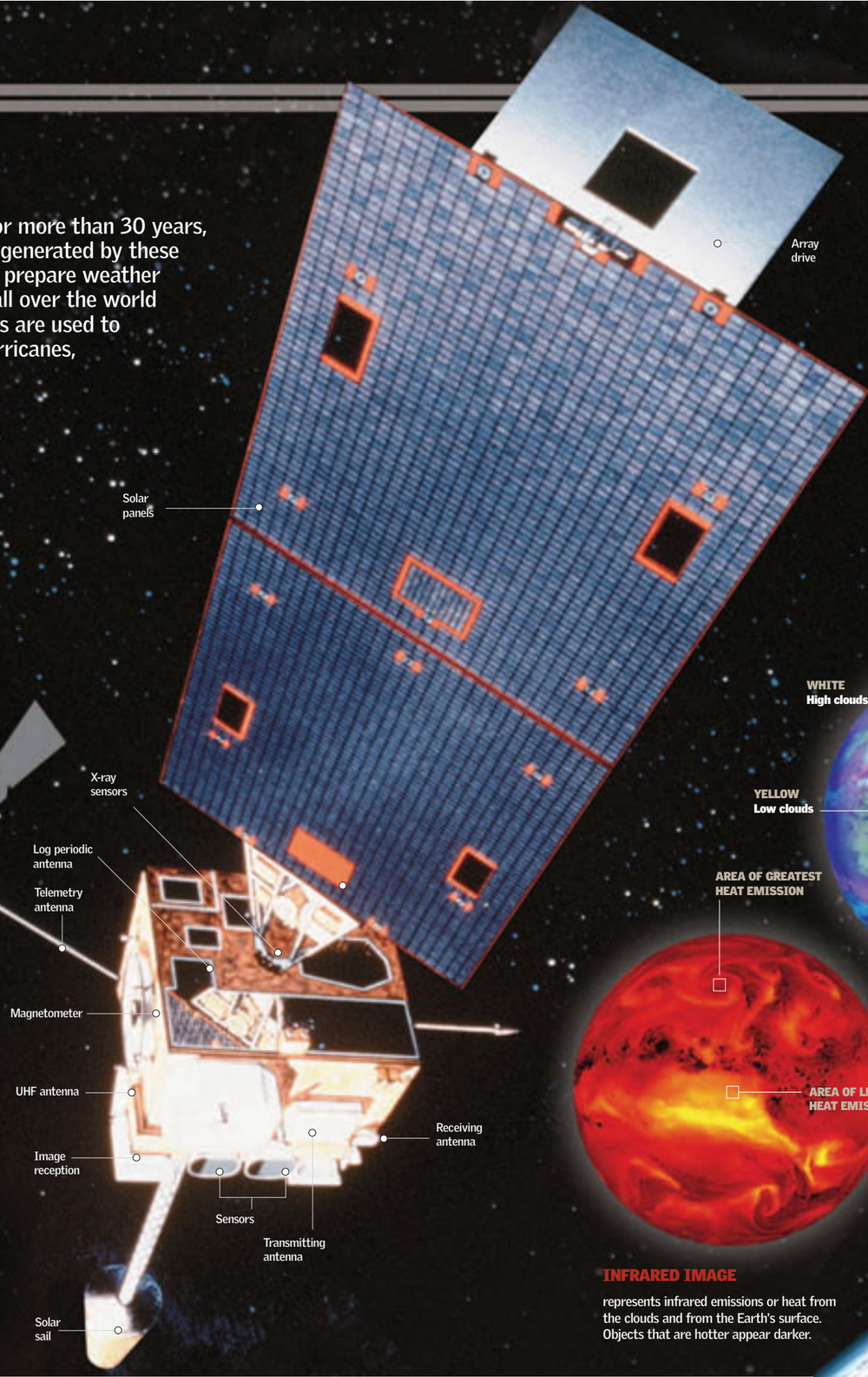
ORBITAL ALTITUDE	22,300 miles (35,900 km)
ROTATIONAL VELOCITY	100 RPM
ORBITAL PERIOD	24 hours

ACTIVE POLAR SATELLITES



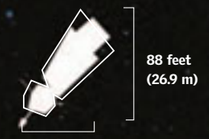
ACTIVE GEOSTATIONARY SATELLITES





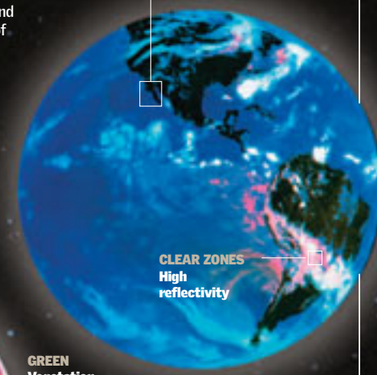
GOES EAST

Orbital altitude	22,370 miles (36,000 km)
Weight	4,850 pounds (2,200 kg)
Launch date	2001
Orbit	75°



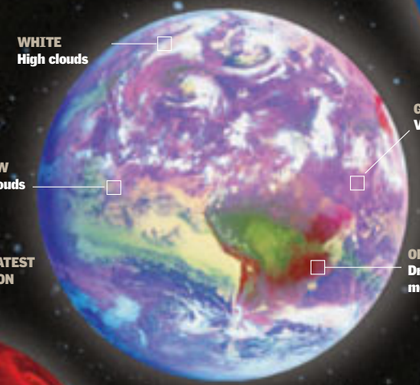
Images, Yesterday and Today

The TIROS satellites (Television and Infra-Red Observation Satellite) of the 1960s provided the first images of cloud systems. The modern GOES satellites (Geostationary Operational Environmental Satellites), which take more precise time and space measurements, provide higher-quality images of clouds, continents, and oceans. They also measure the humidity of the atmosphere and the temperature at ground level.



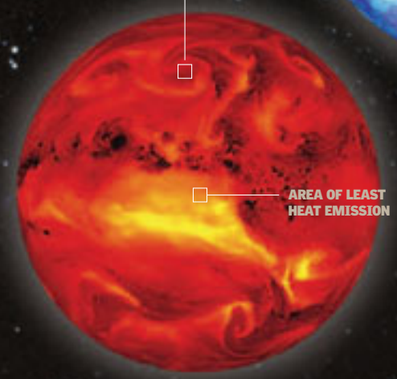
VISIBLE IMAGE

Oceans and continents have low albedo and appear as darker areas. Areas with high albedo, in contrast, are clear and bright.



COMBINED IMAGES

They are composed of infrared images (which permit differentiation of high and low clouds) and visible-light images (which measure the reflectivity of each climatic subsystem).



INFRARED IMAGE

represents infrared emissions or heat from the clouds and from the Earth's surface. Objects that are hotter appear darker.

Climate Change

GLACIERS IN ALASKA
Approximately 5 percent of the land is covered by glaciers, which advance and break up when they reach the ocean, where they form impressive cliffs of ice.

GODS AND RITUALS 76-77
CLIMATE ZONES 78-79
PALEOCLIMATOLOGY 80-81
THE PLANET WARMS UP 82-83
ACCELERATED MELTING 84-85
TOXIC RAIN 86-87
WEAKER AND WEAKER 88-89
CHANGE; EVERYTHING CHANGES 90-91



Mountain glaciers are melting, and this is a threat to the availability of freshwater. It is calculated that 8 cubic miles (35 cu km) of water melts from the glaciers each year, which is the glaciers' major contribution to raising the global sea level; it is thought that the continental ice sheet may play a significantly larger role. The volume of the glaciers in the European Alps and in the Caucasus Mountains has been reduced by half, and in Africa, only 8 percent of the largest glacier of Mount Kenya still exists. If these tendencies continue, by the end of the century, most glaciers will have disappeared completely, including those in Glacier National Park in the United States. That will have powerful repercussions on the water resources of many parts of the world. ●

Gods and Rituals

Predicting the weather was a subject of interest to all the early civilizations that populated the Earth. Greeks, Romans, Egyptians, pre-Columbians, and Orientals venerated the gods of the Sun, the Moon, the heavens, the rain, storms, and the wind for centuries. In their own way, with rituals and praise, they tried to influence the weather to improve the bounty of the harvest.



ZEPHYRUS
The Greek god of the west wind had an important presence. At times he was beneficial, and at other times catastrophic. Though the ancient Greeks were not sure whether the winds were male or female, they did believe the winds had wings.

The Romans

The Romans worshiped many gods because they inherited them from the Greek oracles. The gods of weather were Jupiter (wise and just, who reigned over the earth), Apollo (the god of the sun), Neptune (the god of the sea and storms), and Saturn (the god of agriculture). Each god had a specific function. As a result, any human activity could suffer or benefit from the attitude of the god in charge of that particular function. Thus, the purpose of ritual worship and sacrifice to the gods was to gain their favor.



THE SCEPTER
A symbol of command consisting of ornamented short sticks, the symbol of authority

THE LIGHTNING BOLT
Jupiter reigned over the earth and heaven, and he had the attributes of an eagle, a lightning bolt, and a scepter.

THE EAGLE
Jupiter is the Roman supreme god, represented by the figure of the eagle. He is also first in wisdom and power.

Greeks

The powerful Zeus was the king of the Greek gods and dispenser of divine justice. He was the sovereign of heaven (his brothers Poseidon and Hades governed the ocean and the underworld, respectively). He carried a thunderbolt to represent his power, associated with the weather. Zeus lived on Mount Olympus, from where he could observe and often intervene in the affairs of humans. The Greeks believed that Poseidon, when annoyed, would break up the mountains and throw them into the sea to form islands. Uranus was a personification of heaven for the Greeks, and Apollo was the god of the sun, light, and creation.

Egyptians

As in all ancient civilizations, the gods of weather were very much a part of Egyptian life. Civilization extended along the banks of the Nile, where water was crucial for survival—that is, where cities, temples, pyramids, and the entire economic life of the kingdom were concentrated. The weather influenced the rising of the river and the harvests. Therefore the Egyptians venerated Re (the god of the sun), Nut (the god of heaven), Seth (the god of the storm), and Toth (the god of the moon).



RE
Egyptian sun god, the primordial creator. His center of worship was Heliopolis, or the City of the Sun.



SETH
Egyptian god of the storm, represented by a jackal, a dog, or a wolf. The son of Re and brother of Osiris.

Pre-Columbians

The pre-Columbian population believed water was a gift from the gods. For the Aztecs, Tlaloc was the god of rain, whereas the Incas called him Viracocha. Among the Mayans, he was known as Chac. He was the divinity of the peasants because water was the essential factor for stability and organization for these indigenous peoples. The calendar made it possible to forecast certain astrological events and rainstorms.



CHAC
Mayan god of agriculture. The Mayans performed ceremonies petitioning Chac for rain when drought threatened the harvest.



TLALOC
Venerated by the Aztecs, he was known as the provider because he had the power to bring rain, which made the corn grow.



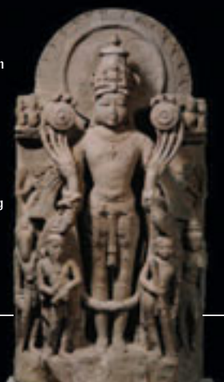
VIRACOCHA
For the Incas, he was all powerful. Creator of the universe and of all the earth, he was linked with rays of light, thunder, lightning, and snow.



FUJIN
Japanese god of wind. Drawn as a dark monster, covered with leopard skin, he carried a bag of wind on his shoulders.

The Orient

Hinduism has various weather-related gods. The most popular is Surya (god of the sun). Next come Chandra (god of the moon), Indra (the god who governs heaven), and Parjanya (god of rain). Japanese mythology emphasizes the following: Fujin (god of wind), Amaterasu (goddess of the sun), Tsukiyomi (god of the moon), Amatsu-kami (god of heaven), Susanoo (god of storms), and Aji-Suki-Taka-Hi-Kone (god of thunder).



SURYA
Hindu god of the sun. In India the sun personified as Surya was considered to be harmful by the Dravidians of the south but benevolent by the peoples of central regions. These peoples attributed great healing power to the god.

Climate Zones

Different places in the world, even if far removed from each other, can be grouped into climate zones—that is, into regions that are homogeneous relative to climatic elements, such as temperature, pressure, rain, and humidity. There is some disagreement among climatologists about the number and description of each of these regions, but the illustrations given on this map are generally accepted.

Ice cap

Hudson Bay

NORTH AMERICA

Rocky Mountains

Appalachian Mountains

CENTRAL AMERICA

Pacific Ocean

Atlantic Ocean

SOUTH AMERICA

Cordillera de los Andes

Amazon basin

Pampas region

Patagonia

EUROPE

East European Plain

Alps

Black Sea

Caspian Sea

Siberia

Plains of Siberia

ASIA

Himalayas

Sahara

Arabian Peninsula

Congo basin

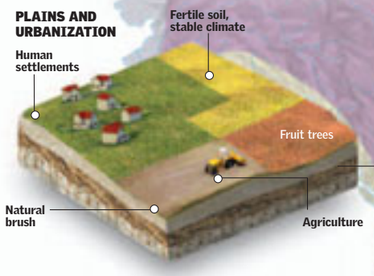
AFRICA

Indian Ocean

OCEANIA

Gibson Desert

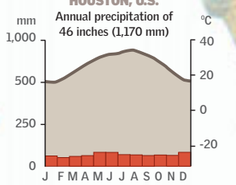
PLAINS AND URBANIZATION



TEMPERATE

Characterized by pleasant temperatures and moderate rains throughout the year. Winters are mild, with long, frost-free periods. Temperate regions are ideal for most agricultural products.

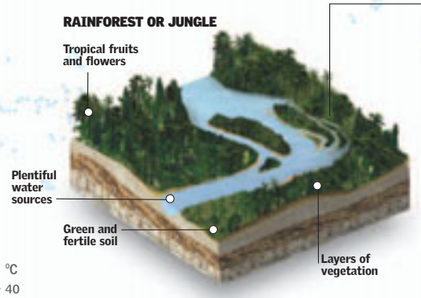
HOUSTON, U.S.
Annual precipitation of 46 inches (1,170 mm)



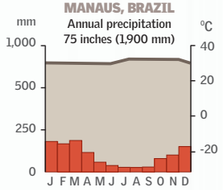
TROPICAL

High temperatures throughout the year, combined with heavy rains, are typical for this climate. About half of the world's population lives in regions with a tropical climate. Vegetation is abundant, and humidity is high because the water vapor in the air is not readily absorbed.

RAINFOREST OR JUNGLE



MANAUS, BRAZIL
Annual precipitation 75 inches (1,900 mm)

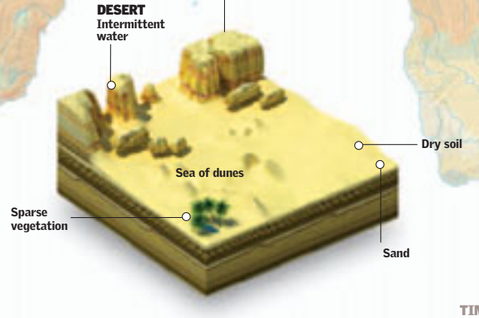


Temperature and Rains

The temperature of the Earth depends on the energy from the Sun, which is not distributed equally at all latitudes. Only 5 percent of sunlight reaches the surface at the poles, whereas this figure rises to 75 percent at the Equator. Rain is an atmospheric phenomenon. Clouds contain millions of drops of water, which collide to form larger drops. The size of the drops increases until they are too heavy to be supported by air currents, and they fall as rain.

59° F (15° C)
is the average annual temperature of the Earth.

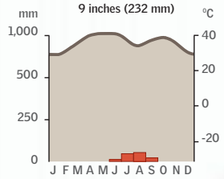
DESERT
Intermittent water



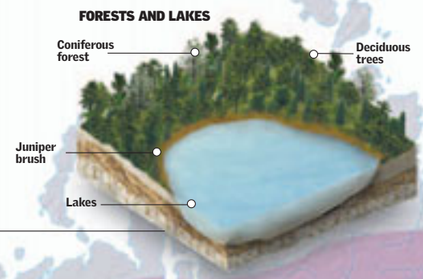
DRY

Lack of rain controls the arid climate in desert or semidesert regions, the result of the atmospheric circulation of air. In these regions, dry air descends, leaving the sky clear, with many hours of burning Sun.

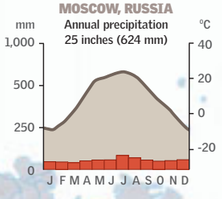
TIMBUKTU, MALI
Annual precipitation 9 inches (232 mm)



FORESTS AND LAKES



MOSCOW, RUSSIA
Annual precipitation 25 inches (624 mm)



COLD

Very cold winters, with frequent freezing at night, are typical of these regions. In these zones, the climate changes more often than anywhere else. In most cold climate regions, the landscape is covered by natural vegetation.

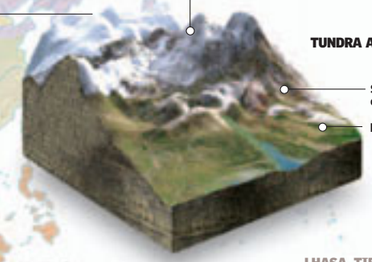
12° F (6.5° C)
is the temperature decrease for every 3,300 feet (1,000 m) of increase in elevation.

POLAR MOUNTAINOUS CLIMATE

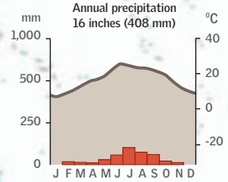
Mountains create their own climate that is somewhat independent of their location. Near the poles, the polar climate is dominated by very low temperatures, strong and irregular winds, and almost perpetual snow. The mountain peaks lack vegetation.

Eternal snow on the mountains

TUNDRA AND TAIGA

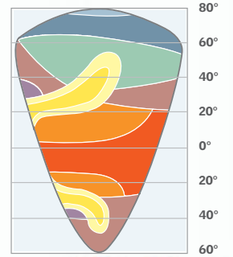


LHASA, TIBET
Annual precipitation 16 inches (408 mm)



Köppen Climate Classification

In 1936 Russian-born climatologist Wladimir Köppen presented a climatological classification based on temperature and precipitation. The table provides a broad overview of the approximate distribution of climates on the terrestrial globe. Köppen classification does not discuss climatic regions but rather the type of climate found in a given location according to specific parameters.



KEY

- Tropical forests, without a dry season
- Tropical savanna, with a dry winter
- Steppes (semiarid)
- Desert (arid)
- Temperate humid, without a dry season
- Temperate, with a dry winter
- Temperate, with a dry summer
- Tundra
- Glacial
- Mountain climate
- Temperate cold continental (hot summer)
- Temperate cold continental (cold summer)
- Temperate cold continental (subarctic)

Paleoclimatology

The climate of the planet is constantly changing. In approximately two million years, the Earth has gone through very cold periods, or glaciations, that lasted thousands of years, alternating with warm periods. Today we live in an interglacial period that began some 10,000 years ago with an increase in average global temperature. These climatic changes can be analyzed over time periods that exceed hundreds of thousands of years. Paleoclimatology uses records derived from fossils, tree rings, corals, glaciers, and historical documents to study the climates of the past.



VOSTOK

Latitude 77° S

Longitude 105° E

Surface area of the lake	**5,405 square miles (14,000 sq km)**
Inhabitants	**Only scientists**
Year of founding	**1957**
Temperature	**-67° F (-55° C)**
Surface	**95% ice**

Gas Measurement

Vertical ice cores (or samples) allow scientists to study the climate of the past. The nearly 12-foot-long (3.6-m) ice sample taken at the Russian Vostok station contains climatic data going back 420,000 years, including the concentration of carbon dioxide, methane, and other greenhouse gases in the atmosphere.

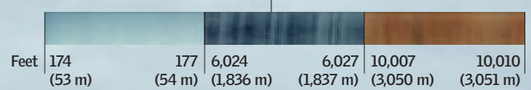


SAMPLES
The zones marked on the map are places where scientists have gathered samples of ice, which were analyzed in the laboratories.

KEY
- Drillings
- Ice sheets

CLOTHES
protect the scientists from the weather and prevent the contamination of samples.

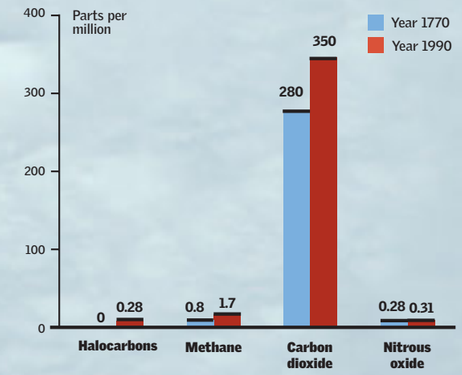
ICE CORES
Samples are taken at different depths. The surface snow becomes more compact in the lower layers. In the last layer, there are rocks and sand.



Human Activity

Climate can be divided into before and after the Industrial Revolution. This graphic shows the progressive increase of halocarbon gases, methane, carbon dioxide, and nitrous oxide between 1770 and 1990. It is clear that humans have contributed to the contamination of the planet.

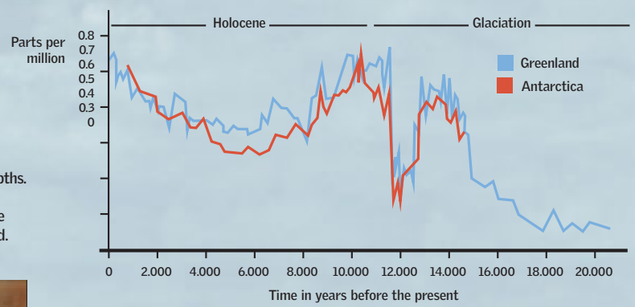
EVALUATION OF GREENHOUSE GASES



Composition

The lower graphic shows the change in concentration of methane in the atmosphere in the last 20,000 years until the end of the preindustrial era. The information collected was estimated on the basis of ice probes in Greenland and Antarctica.

METHANE CONCENTRATION



Chronology

During the history of the Earth, climate has changed greatly, which has had a large effect not only on the appearance of the Earth's surface but also on animal and plant life. This timeline shows the planet's major climate changes and their consequences.

B.Y.A. = billions of years ago M.Y.A. = millions of years ago Y.A. = years ago

4.5 B.Y.A.
In the beginning, there was heat. Life produces oxygen and cools the climate.

2.7-1.8 B.Y.A.
Ice covers very extensive areas.

544 M.Y.A.
Glacial climate in a changing geography. Extinction of 70 percent of marine species.

330 M.Y.A.
Beginning of a long period of glaciation. Ice covers different geographic areas.

245 M.Y.A.
Drought and heat at the beginning. Abrupt cooling at the end of the period. Appearance of the dinosaurs.

65 M.Y.A.
Paleocene and beginning Eocene: very warm climate. Middle Eocene: cooling begins.

2 M.Y.A.
The cold continues; glaciation occurs every 100,000 years.

1.6 M.Y.A.
Interglacial. The beginning of a two-million-year period.

18,000 Y.A.
begins the last deglaciation. Increase in temperature; melting of ice.

1,300-700 Y.A.
Medieval warm period; in some places warmer than today. Vikings arrive in Greenland..

550-150 Y.A.
Little Ice Age. Alpine glaciers advance; more severe winters.

The Planet Warms Up

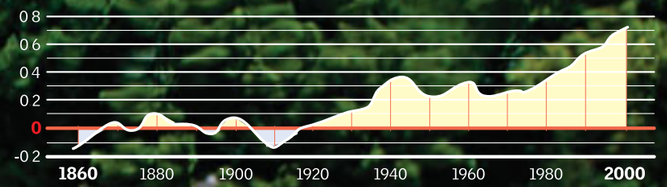
The increase in average temperature of the Earth's atmosphere and oceans is the result of global warming. The main cause is an increase in carbon dioxide emissions by industrialized nations during the past 200 years. This phenomenon has increased the greenhouse effect. It is estimated that the average global temperature has increased more than 1.1° F (0.6° C) between the end of the 19th century and the year 2000. The consequences of this are already beginning to be noticed. Changes are observed in the global distribution of precipitation: there are regions where there is an increase of rain, and there are other regions where rain is diminishing. This generates, among other things, a redistribution of fauna and flora, changes in ecosystems, and changes in human activities.

Product of Human Activity

Our planet is going through an accelerated process of global warming because of the accumulation in the atmosphere of a series of gases generated by human activity. These gases not only absorb the energy emitted by the surface of the Earth when it is heated by radiation coming from the Sun, but they also strengthen the naturally occurring greenhouse effect, whose purpose is to trap heat. One of the primary agents responsible for the growth of the greenhouse effect is CO_2 (carbon dioxide), which is artificially produced by burning fossil fuels (coal, petroleum, and natural gas). Because of the intensive use of these fuels, there has been a notable increase in the quantity of both carbon and nitrogen oxides and carbon dioxide released into the atmosphere. Other aggravating human activities, such as deforestation, have limited the regenerative capacity of the atmosphere to eliminate carbon dioxide through photosynthesis. These changes have caused a slow increase in the average annual temperature of the Earth. Global warming, in turn, causes numerous environmental problems: desertification and droughts (which cause famines), deforestation (which further increases climate change), floods, and the destruction of ecosystems. Because all these variables contribute to global warming in complex ways, it is very difficult to predict with precision everything that will happen in the future.

THE TEMPERATURE OF THE EARTH THROUGH THE YEARS

The effects of global warming are already noticeable. It is estimated that the average global temperature has increased more than 1.1° F (0.6° C) between the end of the 19th century and the year 2000.





GREAT BARRIER REEF

Latitude 18°S

Longitude 147°E

Surface	1,430 miles (2,300 km)
Types of reefs	3,000
Age	300 million years
Discovery	1770, by James Cook

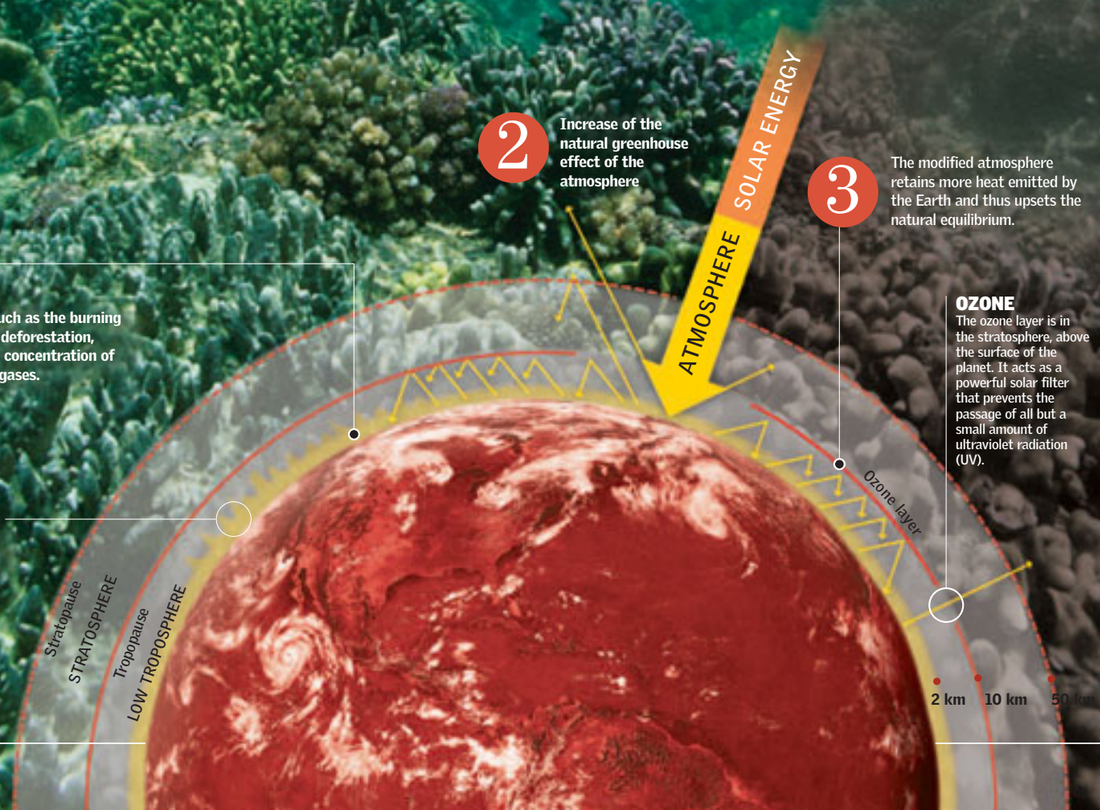
84° F
(29° C)

The discoloration of coral occurs when the temperature exceeds 84° F (29° C). Algae are lost, the coral weakens, and the color of the coral fades.

1.1° F
(0.6° C)

APPROXIMATE INCREASE

Of the Earth's global average temperature from 1860



A Different World

With the changing patterns of precipitation and the shifting of air-pressure systems, some regions will become more humid, and others will suffer droughts. One of the areas that will become drier will be the western part of North America, where desertification is already affecting agriculture. According to current forecasts, areas in high latitudes, closer to the poles, will go through a rapid warming in the next 40 years. Populations of animals will be forced to emigrate from their habitat to avoid extinction, and other animals, such as the polar bear and emperor penguin, will have trouble subsisting as their habitats disappear. Ocean levels are rising between 0.4 and 0.8 inch (1 and 2 cm) per decade. Some Pacific island nations such as Tuvalu have contingency plans for evacuation. Another affected region is the Great Barrier Reef of Australia. The coral is very sensitive to changes in temperature. At temperatures above a normal 84° F [29 ° C], the coral begin to expel the algae on which they depend for food, and then they die.

Accelerated Melting

The climate is changing at a disconcerting speed. Glaciers are retreating, and sea level is rising because of a phenomenon known as thermal expansion. Scientists evaluating the planet's health deduce that this is the consequence of the Earth warming too rapidly. Human activity—in particular, the burning of fossil fuels and the consequent accumulation of greenhouse gases in the atmosphere—has increased this trend.



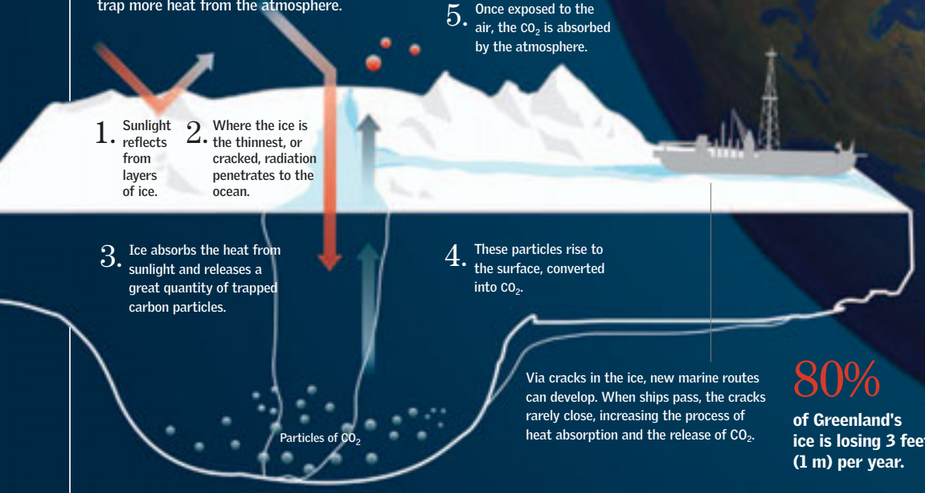
ARCTIC
Latitude 66° N
Longitude 0°

Surface area	5,444,040 square miles (14,100,000 sq km)
Depth	13,100 to 6,600 feet (4,000 to 2,000 m)
Temperature	-58° F (-50° C) in winter

Why It Happens

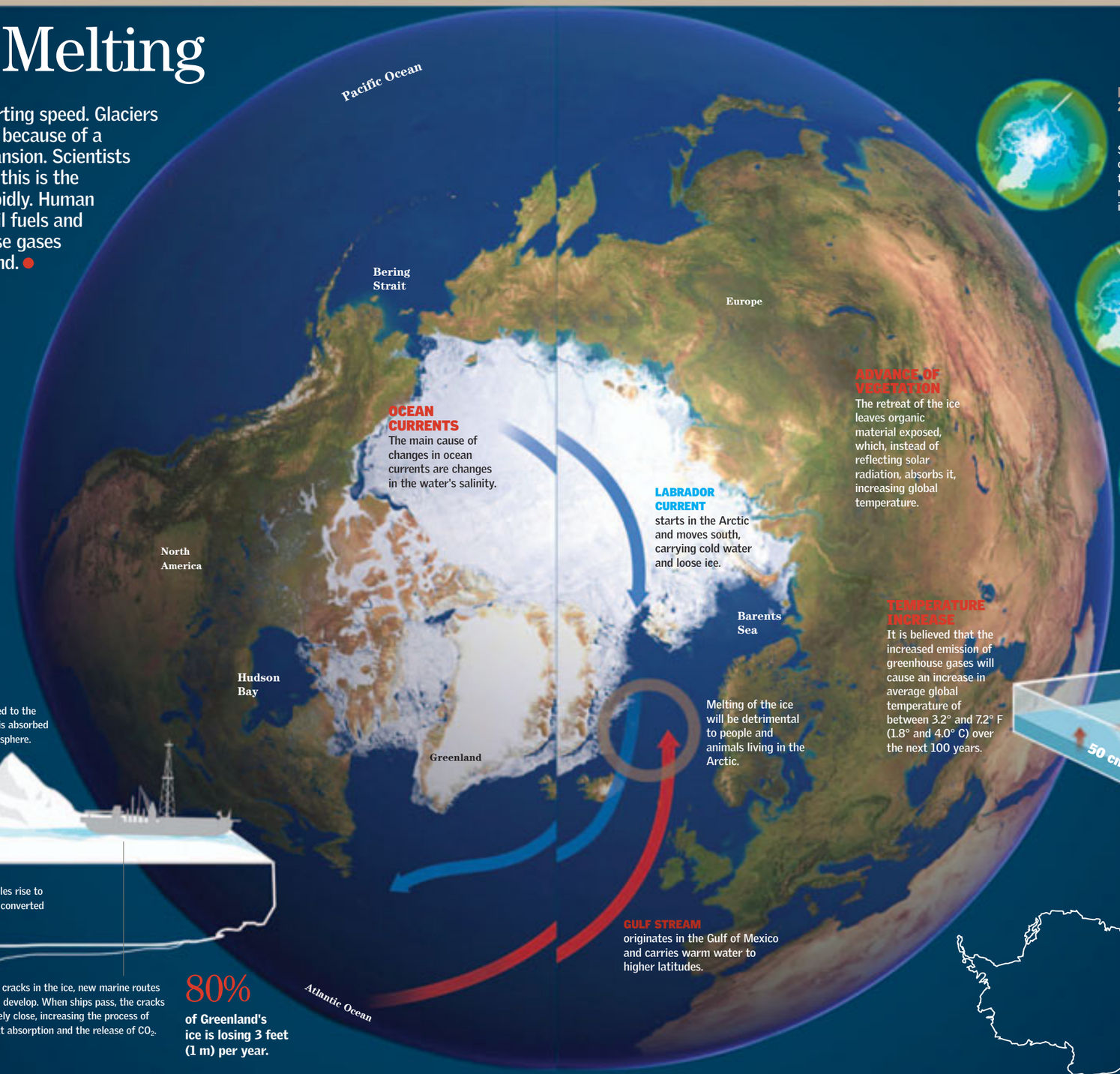
The thawing at the poles is, in part, caused by the increase of greenhouse gases. They absorb the radiation emitted by the Earth and heat up the atmosphere, further increasing the Earth's temperature. The melting of glaciers puts more water in the oceans.

EFFECT
The Arctic heats up more rapidly than the global average because of the darkness of the soil and the water, which, once exposed, trap more heat from the atmosphere.



Via cracks in the ice, new marine routes can develop. When ships pass, the cracks rarely close, increasing the process of heat absorption and the release of CO_2.

80%
of Greenland's ice is losing 3 feet (1 m) per year.



OCEAN CURRENTS
The main cause of changes in ocean currents are changes in the water's salinity.

LABRADOR CURRENT
starts in the Arctic and moves south, carrying cold water and loose ice.

GULF STREAM
originates in the Gulf of Mexico and carries warm water to higher latitudes.

ADVANCE OF VEGETATION
The retreat of the ice leaves organic material exposed, which, instead of reflecting solar radiation, absorbs it, increasing global temperature.

TEMPERATURE INCREASE
It is believed that the increased emission of greenhouse gases will cause an increase in average global temperature of between 3.2° and 7.2° F (1.8° and 4.0° C) over the next 100 years.

Melting of the ice will be detrimental to people and animals living in the Arctic.

PROJECTIONS 2010-30

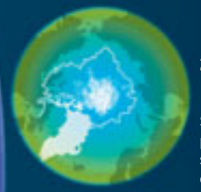
Summer sea ice, currently in decline, tends to diminish more and more rapidly in the future.

2040-60



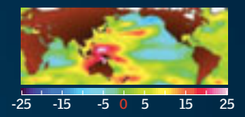
As the century progresses, sea ice continues to melt more and more along the coasts of the Arctic Ocean.

2070-90



Some scientific models project that summer sea ice will be virtually eliminated during this century.

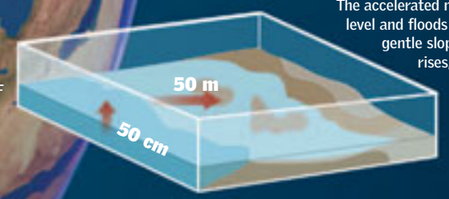
POSSIBLE FLOOD ZONES



In the period between 1993 and 2003, some coastlines were reduced by the rise in sea level.

ADVANCING WATERS

The accelerated melting raises sea level and floods coasts that have a gentle slope. As the sea level rises, the width of coastal areas diminishes.



164 feet (50 m)
The amount of coastal area lost when sea level rises 20 inches (50 cm)

70%
of the freshwater in the world is in Antarctica.



Antarctica

The Antarctic loses 36 cubic miles (152 cu km) of ice per year, and the western ice sheet is becoming thinner at an accelerating pace. This is contributing to increases in sea level. Over the long term, the effect on the climate could be disastrous for many regions of the planet.

Toxic Rain

Burning fossil fuel releases into the air chemicals that mix with water vapor and produce acid rain. The excess of sulfur dioxides and nitrogen dioxides in bodies of water makes the development of aquatic life more difficult, substantially increasing the mortality rate of fish. Likewise, it affects vegetation on land, causing significant damage in forested areas by contaminating animals and destroying substances vital for the soil. Moreover, acidic sedimentation can increase the levels of toxic metals, such as aluminum, copper, and mercury, that are deposited in untreated drinking-water reservoirs.

1 GAS EMISSIONS

Generated by burning fuels and the eruption of volcanoes

CO_2 SO_2 CH_4 H_2S CO NO_2

Petroleum refineries

Chemical industry

Waste incinerator

2 GAS MIXTURES

The molecules of various gases rise and mix with water in the air.

3 PHOTOCHEMICAL REACTION

Sunlight increases the speed at which chemical reactions occur. Thus, sulfur dioxide and atmospheric gases rapidly produce sulfur trioxide.

Atmospheric circulation enhances the dispersal of contaminants over great distances.

4 ACID RAIN

falls in the form of water, fog, or dew and leaves the acids formed in the atmosphere on the ground.

pH:5 Acid rain

pH:6 Normal rain

AREAS AFFECTED BY ACID RAIN



The regions most vulnerable to this phenomenon are Mexico, Beijing, Cairo, Jakarta (Indonesia), and Los Angeles.

WHAT IS pH?

pH acid

pH neutral

The degree of acidity of an aqueous solution. It indicates the concentration of hydrogen ions.

TYPES OF GASES EMITTED

Petroleum refinery	CO_2 (carbon dioxide) SO_2 (sulfur dioxide) CH_4 (methane)
Chemical industry	CO_2, SO_2, H_2S (hydrogen sulfide)
Waste incinerator	CO_2, SO_2, CH_4, CO (carbon monoxide) NO_2 (nitrogen dioxide)

The leaves lose their wax layer.

Destruction of chlorophyll

Defoliation

Root damage

CONSEQUENCES FOR PLANTS

Acid rain acts via certain mechanisms that weaken plants, making them more vulnerable to the effects of wind, cold, drought, disease, and parasites.

CONSEQUENCES FOR AGRICULTURE

Areas under cultivation are not as vulnerable because they are generally improved by fertilizers that restore nutrients to the soil and neutralize acidity.

Melting water carries acidic particles that come from the rain.

EFFECTS ON THE WATER

The acidity of rainwater changes the neutral pH of bodies of water.

pH 7 (neutral) → pH 4.3 (acid)

SOIL CONSEQUENCES

SILICATE SOIL
The effect of acidity increases because of the lack of buffering minerals.

CALCAREOUS SOIL
The effect is neutralized by the presence of bicarbonate.

In mountainous areas, fog and snow contribute significant quantities of the gases in question.

1972 The year when the phenomenon of acid rain was recorded for the first time

MOST-THREATENED SPECIES

Fir Beech Oak

LEAVES
This rain damages their surface, causing small lesions that alter the action of photosynthesis.

Seriously affected species are lettuce and tobacco, especially because their leaves, destined for human consumption, must be of high quality.

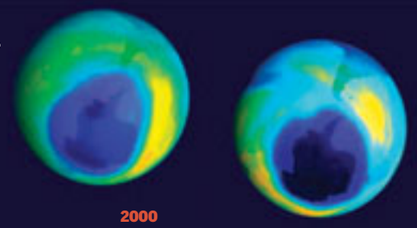
pH 4.3 LEVEL AT WHICH FISH DO NOT SURVIVE IN THE WATER

MOST-AFFECTED SPECIES

Trout Perch Frogs

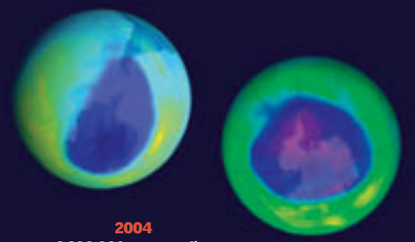
Weaker and Weaker

Artificial substances are destroying the ozone layer, which provides protection against ultraviolet rays. This phenomenon is observed every year in polar regions (primarily in the Antarctic) between August and October. Because of this, the Earth is receiving more harmful rays, which perhaps explains the appearance of certain illnesses: an increase in skin cancer cases, damage to vision, and weakening of the immune system.



2000
11,000,000 square miles
(28,000,000 sq km)

2001
10,000,000 square miles
(26,000,000 sq km)



2004
9,300,000 square miles
(24,200,000 sq km)

2005
10,400,000 square miles
(27,000,000 sq km)

THE SOUTHERN OZONE HOLE

The thinning of the ozone layer over the Antarctic is the result of a series of phenomena, including the action of chlorine radicals, which cause the destruction of ozone.

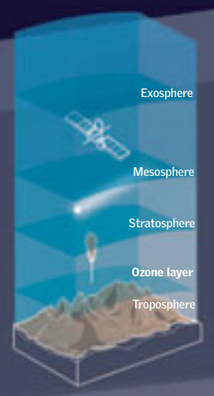
UV RADIATION

Ultraviolet radiation (UV) is a radiant form of energy that comes from the Sun. The various forms of radiation are classified according to the average wavelength measured in nanometers (nm), equivalent to one millionth of a millimeter. The shorter the wavelength, the greater the energy of the radiation.

UV-A
These rays easily penetrate the ozone layer. They cause skin wrinkling and aging.

UV-B
are almost all absorbed by the ozone layer. They are harmful and cause various types of skin cancer.

UV-C
These are the most damaging rays, but they are totally filtered by the upper part of the ozone layer.



OZONE LAYER

At an altitude of 12 to 19 miles (20 to 30 km), the Earth is surrounded by a stratospheric ozone layer that is of vital importance for life on the surface. The layer is formed from oxygen molecules through the absorption of ultraviolet light from the Sun. This reaction is reversible, that is, the ozone can return to its natural state, oxygen. This oxygen is reconverted into ozone, beginning a continuous process of formation and destruction of these components.

It is popularly called the ozone hole—a decrease or abnormal thinning that occurs in the ozone layer.

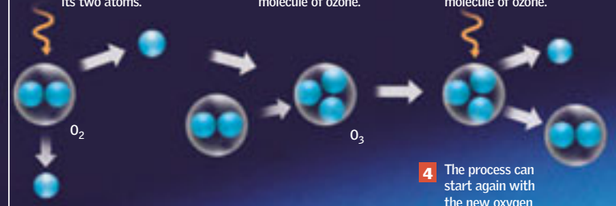
11,000,000 square miles (28,000,000 sq km) is the size of the area of attenuated ozone reached in 2000.

The ozone layer functions as a natural filter, absorbing UV rays.

75% OF SKIN CANCER IS ATTRIBUTED TO UV-B RADIATION.

HOW OZONE IS FORMED

1. Ultraviolet rays strike a molecule of oxygen which breaks up and releases its two atoms.
2. One of the released atoms combines with a molecule of oxygen. Together they form a molecule of ozone.
3. One of the released atoms combines with a molecule of oxygen. Together they form a molecule of ozone.
4. The process can start again with the new oxygen molecule.



HOW IT DETERIORATES

1. Ultraviolet radiation strikes a molecule of CFC gas.
2. An atom of chlorine is released.
3. Chlorine atoms combine with a molecule of ozone, destroy it, and form one chloromonoxide and one oxygen atom.
4. The chloromonoxide combines with an atom of free oxygen and releases the chlorine atom.
5. This atom, once again free, combines with another molecule of ozone.



CFC GASES

are a family of gases with multiple applications. They are used in refrigeration systems, air-conditioning equipment, and aerosols.



WHEN? WHO? HOW?

In 1974, it was discovered that industrial chlorofluorocarbons (CFCs) affect the ozone layer. Chemists Mario Molina and F. Sherwood Rowland demonstrated that industrial CFCs are the gases that weaken the ozone layer by destroying the ozone molecules.

50 to 100 THE NUMBER OF YEARS THAT CFC GASES SURVIVE IN THE ATMOSPHERE



HUMAN BEINGS
Skin cancer. Damage to vision. Weakening of the immune system. Severe burns. Skin aging.

PLANTS
Destruction of phytoplankton. Inhibition of the photosynthesis process. Changes in growth. Reduced harvest yields.

ANIMALS
Diseases among farm animals. Destruction of links in the food chain. Increase of skin cancer.

Change; Everything Changes

The Most Responsible

The climate of the planet is constantly changing. At present, the average global temperature is approximately 59° F (15° C). Geologic and other types of evidence suggest that in the past the average could have been as low as 45° F (7° C) and as high as 81° F (27° C). Climate change is, in large part, caused by human activities, which cause an increase in the concentration of greenhouse gases. These gases include carbon dioxide, methane, and nitrogen dioxide and are released by modern industry, by agriculture, and by the burning of coal, petroleum, and natural gas. Its atmospheric concentration is increasing: atmospheric carbon-dioxide content alone has grown by more than 20 percent since 1960. Investigators indicate that this warming can have grave implications for the stability of the climate, on which most of the life on the planet depends.

NORTH AMERICA

CENTRAL AMERICA

Pacific Ocean

Atlantic Ocean

EUROPE

ASIA

AFRICA

SOUTH AMERICA

Indian Ocean

OCEANIA

More than 10.8° F (6° C)

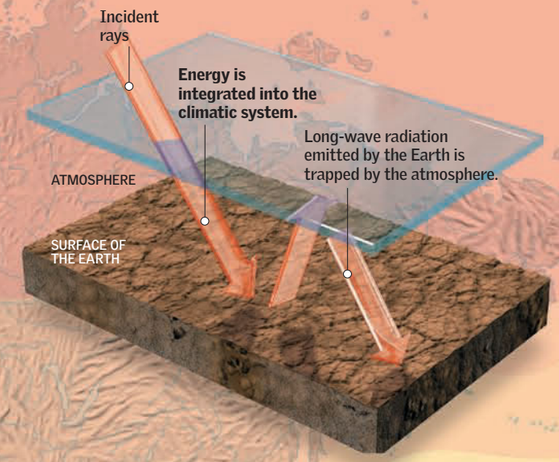
From 9° to 10.8° F (5° to 6° C)

From 7.2° to 9° F (4° to 5° C)

From 5.4° to 7.2° F (3° to 4° C)

From 3.6° to 5.4° F (2° to 3° C)

From 1.8° to 3.6° F (1° to 2° C)

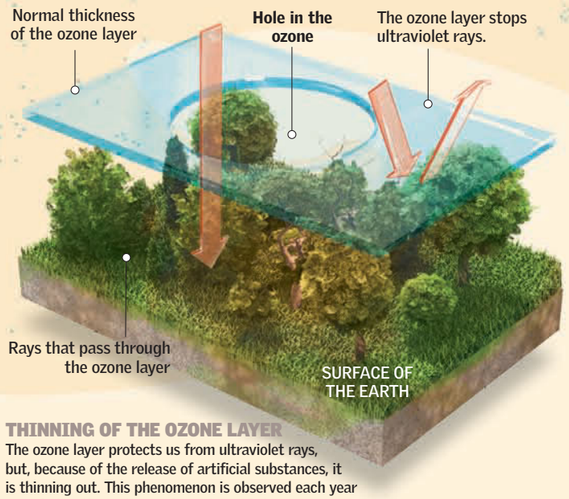


ACCELERATION OF THE GREENHOUSE EFFECT

Ice reflects solar radiation, whereas the soil of jungles, forests, and steppes absorbs the energy and radiates it as sensible heat. This artificially increases the greenhouse effect and contributes to global warming.

THE RISE IN TEMPERATURE

In Alaska and western Canada winter temperatures have increased between 5.4° and 7.2° F (3° and 4° C) in the past 50 years. It has been projected that in the next 100 years the Earth's average temperature will increase between 3.2° and 7.2° F (1.8° and 4.0° C).

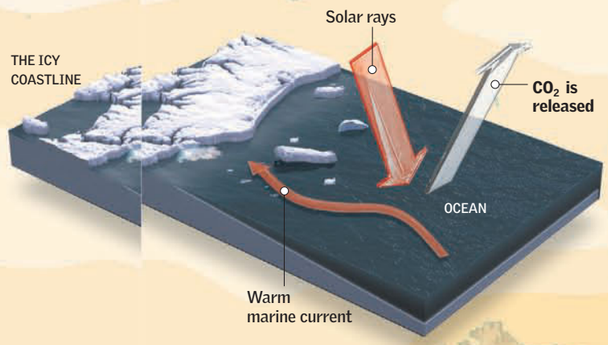


THINNING OF THE OZONE LAYER

The ozone layer protects us from ultraviolet rays, but, because of the release of artificial substances, it is thinning out. This phenomenon is observed each year over Antarctica between August and October and over the North Pole between October and May. Moreover, there is evidence that greater amounts of UV rays at the Earth's surface are destroying or altering vegetable cells and decreasing the production of oxygen.

THE EFFECT OF POLAR MELTING

The snow-covered sea ice reflects between 85 and 90 percent of the sunlight that strikes it, whereas sea water reflects only 10 percent. For that reason, as the ice and snow melt, many of today's coastlines will become submerged under water, which will cause yet more ice to melt.



Cause and Effect

The burning of fossil fuels and the indiscriminate cutting of deciduous forests and rainforests cause an increase in the concentration of carbon dioxide, methane, and other greenhouse gases. They trap heat and increase the greenhouse effect. That is how the Arctic is warming up; the density of the ice is decreased by melting, and freshwater flows into the ocean, changing its salinity.

100 years is the length of time it takes for a deciduous forest to return to its natural state after it has been laid to waste.

Glossary

Accretion

Growth of an ice crystal in the atmosphere by direct capture of water droplets when the temperature is below 32° F (0° C).

Acid Rain

Rain resulting from the mixture of water vapor in the air with chemical substances typically released by the combustion of fossil fuels.

Aerosol

Aerosols are very small (liquid or solid) particles suspended in the atmosphere, with varied chemical composition. Aerosols play an essential role in the formation of clouds by acting as condensation nuclei. They are also important to the Earth's radiation balance since they help to increase the reflection and dispersion of radiation coming from the Sun.

Air Mass

Extensive volume in the atmosphere whose physical properties, in particular the temperature and humidity in a horizontal plane, show only small and gradual differences. An air mass can cover an area of a few million square miles and can have a thickness of several miles.

Albedo

A measure of the percentage of radiation reflected by a surface.

Altitude

Height relative to sea level.

Anemometer

Instrument for measuring wind velocity.

Anticyclone

Region where the atmospheric pressure is relatively high compared with neighboring regions. Normally the air above an anticyclone descends, which prevents clouds from forming at medium and high levels of the atmosphere. Hence an anticyclonic system is associated with good weather.

Atmosphere

The gaseous envelope that surrounds the Earth.

Atmospheric Pressure

The pressure or weight exerted by the atmosphere at a specific point. Its measurement can be expressed in various units: hectopascals, millibars, inches, or millimeters of mercury (Hg). It is also called barometric pressure.

Aurora

A phenomenon that is produced in the higher layers of the atmosphere at polar latitudes. An aurora occurs when there is a collision between the electrically charged particles emitted by the Sun and the magnetic field of the Earth. In the Northern Hemisphere, the phenomenon is called the aurora borealis, and in the Southern Hemisphere, it is known as the aurora australis.

Avalanche

A large mass of snow that flows down the side of a mountain.

Barometer

An instrument for measuring atmospheric pressure. A decrease in pressure usually means that storms are on the way. Increasing pressure indicates good weather.

Beaufort Scale

A scale invented at the beginning of the 19th century by a British sailor, Francis Beaufort, for estimating and reporting wind velocity. It is based on the different shapes taken by water waves at different wind velocities, and its graduation goes from 0 to 12. There is also a Beaufort scale for application on land based on observations of the wind's effect on trees and other objects.

Carbon Dioxide

An odorless, colorless gas emitted in the engine exhaust of automobiles, trucks, and buses. It is also produced by the combustion of coal and other organic material. Too much carbon dioxide in the atmosphere contributes to global warming.

Chlorofluorocarbons

Artificial chemical substances often contained in aerosols, refrigerants, and air conditioners. These chemicals are largely responsible for the damage to the ozone layer.

Cirrus

Wispy cloud formations at altitudes greater than 16,400 feet (5,000 m).

Climate

The average state of the meteorological conditions of a location considered over a long period of time. The climate of a location is determined by climatological factors: latitude, longitude, altitude, topography, and continentality.

Cloud

A visible mass of small particles, such as droplets of water and/or crystals of ice, suspended in the air. A cloud is formed in the atmosphere because of the condensation of water vapor onto solid particles of smoke, dust, ashes, and other elements called condensation nuclei.

Coalescence

The process of growth of drops of water in a cloud. Two drops collide and remain joined after the collision, constituting a bigger drop. This is one of the mechanisms that explains the growth of the size of drops in a cloud until precipitation (rain) is produced.

Cold Wave

A rapid drop in temperature to the point requiring special protective measures in agriculture, industry, commerce, or social activities.

Condensation

The process by which water vapor is transformed into liquid by the effect of cooling.

Conduction

The transfer of heat through a substance by molecular action or from one substance to another it is in contact with.

Continentality

The tendency of the interior regions of the continents to have more extreme temperature changes than coastal zones.

Convection

The process by which a heated surface transfers energy to the material (air, water, etc.) above it. This material becomes less dense and rises. Cooler material descends to fill in the void. Air rising as a result of the heating of the ground by the Sun's rays.

Coriolis Force

A fictitious or apparent force that applies when the Earth is used as a reference frame for motion. It depends upon the latitude and the velocity of the object in motion. In the Northern Hemisphere, the air is deflected toward the right side of its path, and in the Southern Hemisphere, the air is deflected toward the left side of its path. This force is strongest at the poles and does not exist at the Equator.

Cyclone

A climatic low-pressure system.

Desert

A hot or cold zone where annual precipitation is less than 1 inch (25 mm).

Desertification

A process that converts fertile land to desert through a reduction in precipitation.

Dew

Condensation in the form of small drops of water formed on grass and other small objects near the ground when the temperature has dropped to the dew point. This generally happens during the night.

Dike

An earthwork for containing or channeling a river or for protection against the sea.

Drizzle

A type of light liquid precipitation composed of small drops with diameters between 0.007 and 0.019 inch (0.2 and 0.5 mm). Usually drizzle falls from stratus-type clouds that are found at low altitudes and can be accompanied by fog, which significantly decreases visibility.

Drought

An abnormally dry climatic condition in a specific area where the lack of water is prolonged and which causes a serious hydrological imbalance.

El Niño

The anomalous appearance, every few years, of unusually warm ocean conditions along the tropical west coast of South America.

Erosion

Action in which the ground is worn down by moving water, glaciers, wind, or waves.

Evaporation

Physical process by which a liquid (such as water) is transformed into its gaseous state (such as water vapor). The reverse process is called condensation.

Exosphere

The outermost layer of the Earth's atmosphere.

Flash Flood

Sudden flooding caused by the passage of a large quantity of water through a narrow space, such as a canyon or a valley.

Fog

Visible manifestation of drops of water suspended in the atmosphere at or near ground level; this reduces the horizontal visibility to less than a mile. It originates when the temperature of the air is near the dew point, and sufficient numbers of condensation nuclei are present.

Forecast

A statement about future events. The weather forecast includes the use of objective models based on a number of atmospheric parameters combined with the ability and experience of the meteorologist. It is also called weather prediction.

Front

The transition or contact zone between two masses of air with different meteorological characteristics, which almost always implies different temperatures. For example, a front occurs at the area of convergence between warm humid air and dry cold air.

Frontogenesis

The process of formation or intensification of a front. This happens when wind forces two adjacent masses of air of different densities and temperatures together, creating a front. It can occur when one of the masses of air, or both, move over a surface that reinforces their original properties. This is common on the east coast of North America or Asia, when a mass of air moving toward the ocean has a weak or undefined boundary. It is the opposite of frontolysis.

Frost

A covering of ice crystals on a cold object.

Global Warming

The heating of the atmosphere caused by increased concentrations of greenhouse gases due to human activities.

Greenhouse Effect

A phenomenon explained by the presence of certain components in the atmosphere (primarily carbon dioxide [CO_2], water vapor, and ozone) that absorb a portion of the infrared radiation emitted by the surface of the Earth and simultaneously reflect radiative energy back to the surface. This process contributes to the increase in the average temperature near the surface.

Gust

A rapid and significant increase in wind velocity. The maximum velocity of the wind must reach at least 16 knots (18 miles per hour [30 km/h]), and the difference between the peaks and calm must be at least 10 knots (12 miles per hour [18 km/h]). It generally lasts less than 20 seconds.

Hail

Precipitation that originates in convective clouds, such as the cumulonimbus, in the form of masses or irregular pieces of ice. Typically hail has a diameter of 0.2 to 2 inches (5 to 50 mm) but may grow significantly larger. The smallest ice fragments—whose diameter is 0.2 inch (5 mm) or less—are called small hailstones, or graupel. Strong upward currents are required inside the clouds for hail to be produced.

Heat Wave

A period of abnormally hot and uncomfortable weather. It can last from a few days to a number of weeks.

Hectopascal

A pressure unit equal to 100 pascals and equivalent to 1 millibar—a millibar being equivalent to 0.031 inch (0.8 mm) of ordinary mercury. The millibar (mb) was the technical unit used to measure pressure until recently, when the hectopascal was adopted. The pascal is the unit for pressure in the MKS system, corresponding to the pressure exerted by the unit force (1 newton) on a unit surface (1 square meter—11 square feet); 1,000 hPa = 1,000 mb = 1 bar = 14.5 pounds per square inch.

High

A prefix describing cloud formations at an altitude between 6,560 and 16,400 feet (2,000 and 5,000 m).

Humidity

The amount of water vapor contained in the air.

Hurricane

The name for a tropical cyclone with sustained winds of 64 knots (74 miles per hour [119 km/h]) or more, which develops in the North Atlantic, the Caribbean, the Gulf of Mexico, and the Pacific Northeast. This storm is called a typhoon in the western Pacific and a cyclone in the Indian Ocean.

Hygrometer

An instrument used to measure humidity.

Ice

The solid state of water. It is found in the atmosphere in the form of ice crystals, snow, or hail.

Jet Streams

Air currents high in the troposphere (about 6 miles [10 km] above sea level), where the wind velocity can be up to 90 meters per second (200 miles per hour). This type of structure is seen in subtropical latitudes in both hemispheres, where the flow is toward the east, reaching its maximum intensity during the winter.

Latitude

A system of imaginary parallel lines that encircle the globe north and south of the Equator. The poles are located at 90° latitude north and south and the Equator at 0° latitude.

Lightning

A discharge of the atmosphere's static electricity occurring between a cloud and the ground.

Mesosphere

The layer of the Earth's atmosphere that lies above the stratosphere.

METAR

The name of the format airport meteorological bulletins are reported in. This includes data on wind, visibility, temperature, dew point, and atmospheric pressure, among other variables.

Meteorology

The science and study of atmospheric phenomena. Some of the subdivisions of meteorology are agrometeorology, climatology, hydrometeorology, and physical, dynamic, and synoptic meteorology.

Microbarometer

A very sensitive barometer that records pressure variations using a magnified scale.

Mist

Microscopic drops of water suspended in the air, or humid hygroscopic particles, which reduce visibility at ground level.

Monsoon

A seasonal wind that causes heavy rains in tropical and subtropical regions.

Normal

The standard value accepted for a meteorological element as calculated for a specific location over a specific number of years. The normal values refer to the distribution of data within the limits of the common occurrence. The parameters can include temperature (high, low, and divergences), pressure, precipitation (rain, snow, etc.), winds (velocity and direction), storms, cloud cover, percentage of relative humidity, and so on.

Ocean Current

The movement of water in the ocean caused by the system of planetary winds. Ocean currents transport warm or cold water over long distances around the planet.

Orographic Rain

Rain that results from the cooling of humid air as it crosses over a mountain range.

Ozone Layer

A layer of the atmosphere situated 20 to 30 miles (30 to 50 km) above the Earth's surface between the troposphere and the stratosphere. It acts as a filtering mechanism for ultraviolet radiation.

Polar Front

An almost permanent and very large front of the middle latitudes that separates the relatively cold polar air and the relatively warm subtropical air.

Precipitation

A liquid or solid, crystallized or amorphous particle that falls from a cloud or system of clouds and reaches the ground.

Radiation

The process by which energy propagates through a specific medium (or a vacuum) via wave phenomena or motion. Electromagnetic radiation, which emits heat and light, is one form of radiation. Other forms are sound waves.

Seaquake

An earthquake at the bottom of the ocean, causing a violent agitation of ocean waves, which in some cases reach coastal areas and cause flooding.

Snow

Precipitation in the form of white or transparent frozen ice crystals, often in the form of complex hexagons. In general, snow falls from stratiform clouds, but it can also fall from cumulus clouds, usually in the form of snowflakes.

Stratosphere

The layer of the atmosphere situated above the troposphere.

Stratus

Low clouds that form layers. They often produce drizzle.

Synoptic Map

A map that shows weather conditions of the Earth's surface at a certain time and place.

Thermal Inversion

An inversion of the normal reduction in temperature with an increase in altitude.

Thermometer

An instrument for measuring temperature. The different scales used in meteorology are Celsius, Fahrenheit, and Kelvin (or absolute).

Tornado

A column of air that rotates with great violence, stretching between a convective cloud and the surface of the Earth. It is the most destructive phenomenon in the atmosphere. Tornadoes can occur, under the right conditions, anywhere on Earth, but they appear most frequently in the central United States, between the Rocky Mountains and the Appalachian Mountains.

Tropical Cyclone

A cyclone without fronts, it develops over tropical waters and has a surface circulation organized and defined in a counterclockwise direction. A cyclone is classified, according to the intensity of its winds, as a tropical disturbance (light ground-level winds), tropical depression (maximum ground-level winds of 38 miles per hour [61 km/h]), tropical storm (maximum winds in the range of 39 to 73 miles per hour [62 to 112 km/h]), or hurricane (maximum ground-level winds exceeding 74 miles per hour [119 km/h]).

Troposphere

The layer of the atmosphere closest to the ground, its name means "changing sphere," and this layer is where most changes in weather take place. This is also where most of the phenomena of interest in meteorology occur.

Turbulence

Disorderly motion of air composed of small whirlwinds that move within air currents. Atmospheric turbulence is produced by air in a state of continuous change. It can be caused by thermal or convective currents, by differences in terrain and in the velocity of the wind, by conditions along a frontal zone, or by a change in temperature and pressure.

Weather

The state of the atmosphere at a given moment, as it relates to its effects on human activity. This process involves short-term changes in the atmosphere in contrast to the great climatic changes that imply more long-term changes. The terms used to define weather include cloudiness, humidity, precipitation, temperature, visibility, and wind.

Windward

The direction from which the wind is blowing.

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WEATHER AND CLIMATE

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VOLCANOES AND EARTHQUAKES

Britannica Illustrated Science Library

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VOLCANOES AND EARTHQUAKES



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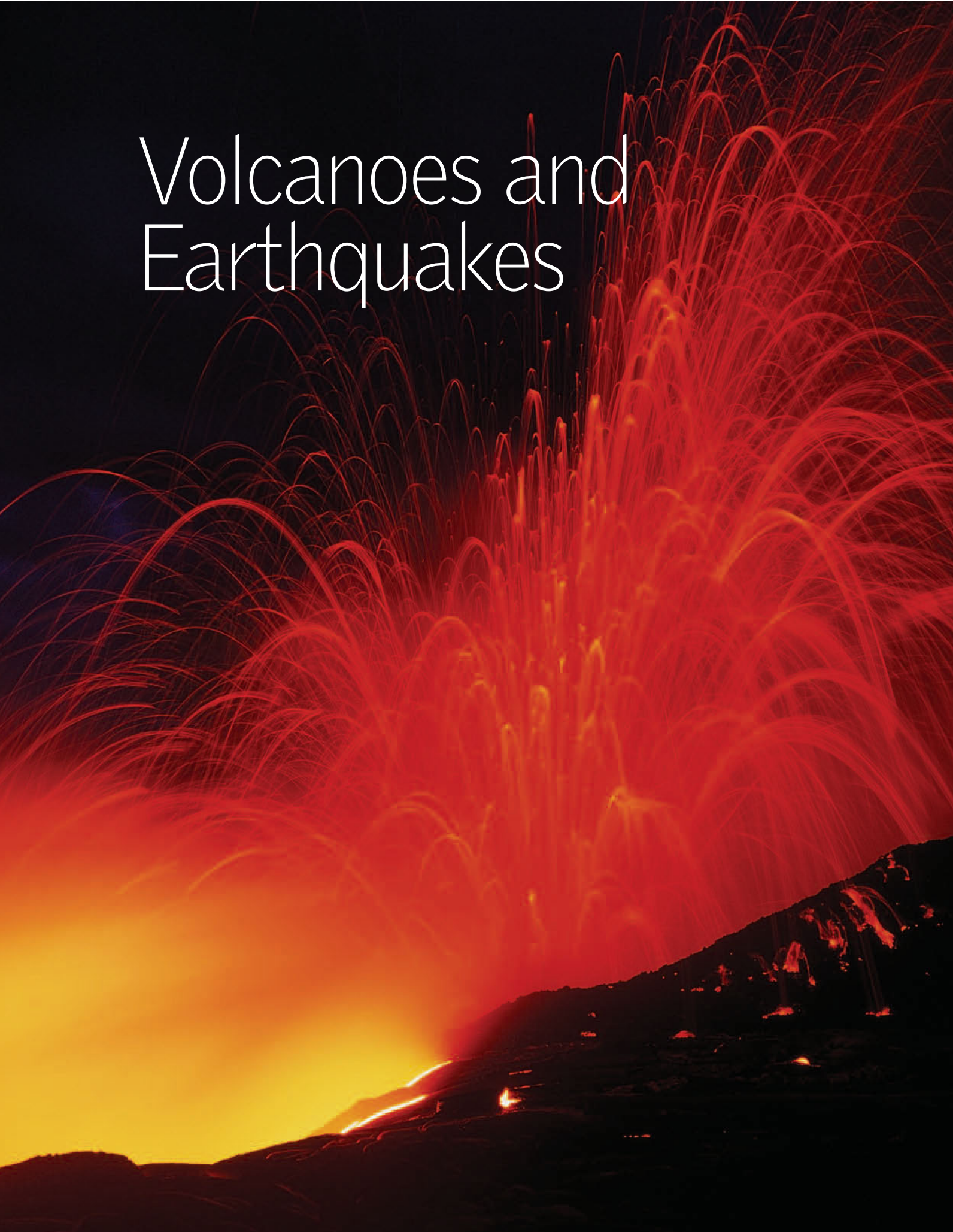
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Volcanoes and Earthquakes



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Kashmir, 2005
Farmer Farid Hussain, 50, grasps the hand of his wife, Akthar Fatma, after the earthquake that rocked the Himalayas on the Indian subcontinent. Eighty thousand people were killed, and thousands of families were left homeless.

The Power of Nature

Some photos speak for themselves. Some gestures communicate more than words ever could, like these clasped hands, which seek comfort in the face of fear of the unknown. The picture was taken Oct. 8, 2005, when aftershocks were still being felt from the strongest earthquake ever to strike Kashmir, in northern India. Those clasped hands symbolize terror and panic; they speak of fragility and helplessness, of endurance in the face of chaos. Unlike storms and volcanic eruptions, earthquakes are unpredictable, unleashed within seconds, and without warning. They spread destruction and death, forcing millions to flee from their homes. The day after the catastrophe revealed a terrifying scene: debris everywhere, a number of people injured and dead, others wandering desperately, children crying, and over three million survivors seeking help after losing everything. Throughout history Earth has been shaken by earthquakes of greater or lesser violence. These earthquakes have caused great harm. One of the most famous is the earthquake that rocked San Francisco in 1906. Registering 8.3 on the Richter scale, the temblor left nearly three thousand dead and was felt as far away as Oregon to the north, and Los Angeles in southern California.

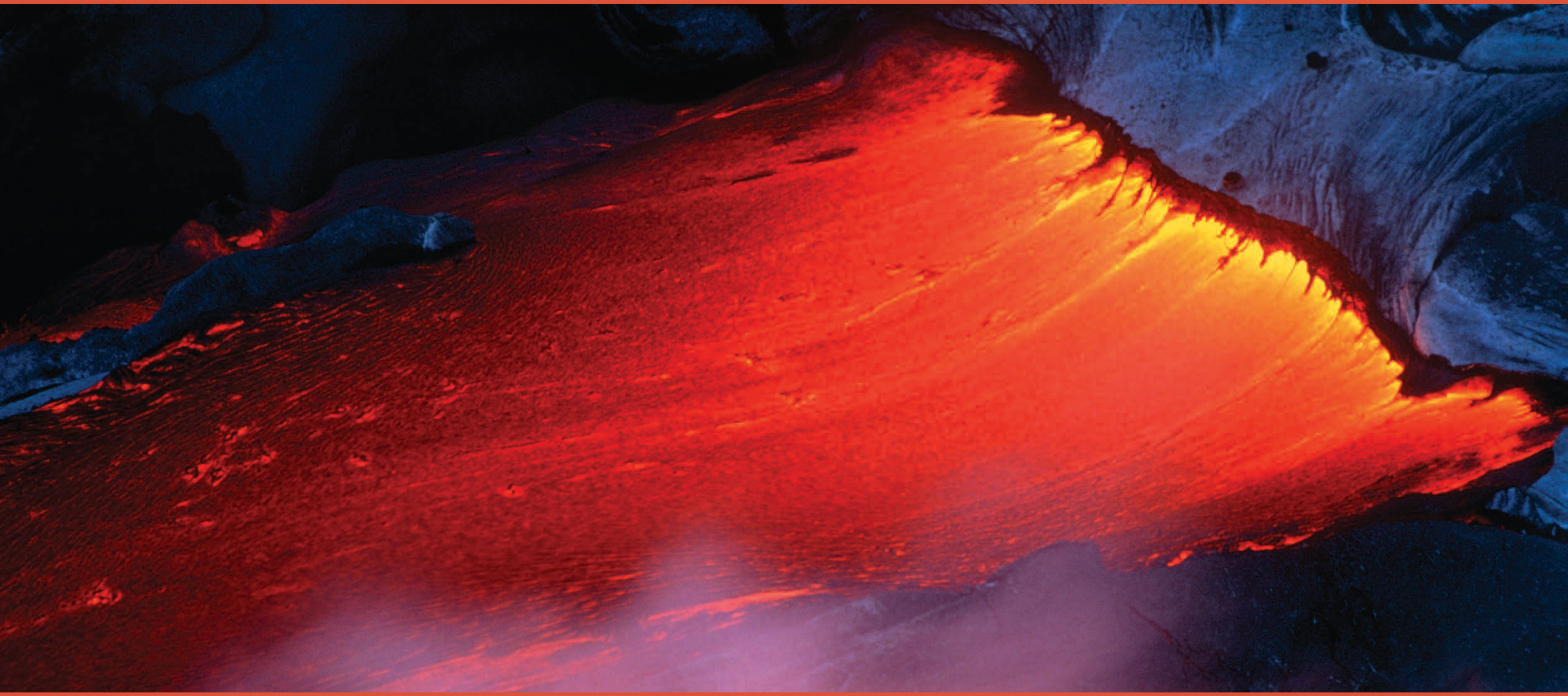
The purpose of this book is to help you better understand the causes of fractures and the magnitude and violence of the forces deep within the earth. The full-color, illustrated book you hold in your hands contains shocking scenes of cities convulsed by earthquakes and volcanoes, natural phenomena that, in mere seconds, unleash rivers of fire, destroy buildings, highways and bridges, and gas and water lines and leave entire cities without electricity or phone service. If fires cannot be put out quickly, the results are even more devastating. Earthquakes near coastlands can cause tsunamis, waves that spread across the ocean with the speed of an airplane. A tsunami that reaches a coast can be more destructive than the earthquake itself. On Dec. 26, 2004, the world witnessed one of the most impressive natural disasters ever. An undersea quake with a magnitude of 9 on the Richter scale shook the eastern Indian Ocean, causing tsunamis that reached the coastal areas of eight Asian nations, causing about 230,000 deaths. The earthquake was the fifth strongest since the invention of the seismograph. Satellite images show the region before and after the catastrophe.

Throughout history, nearly all ancient peoples and large societies have thought of volcanoes as dwelling places of gods or other supernatural beings to explain the mountains' fury. Hawaiian mythology, for instance, spoke of Pele, the goddess of volcanoes, who threw out fire to cleanse the earth and fertilize the soil. She was believed to be a creative force. Nowadays, specialists try to find out when a volcano might start to erupt, because within hours after an eruption begins, lava flows can change a lush landscape into a barren wilderness. Not only does hot lava destroy everything in its path, but gas and ash expelled in the explosion also replace oxygen in the air, poisoning people, animals, and plants. Amazingly, life reemerges once again from such scenes of destruction. After a time, lava and ash break down, making the soil unusually fertile. For this reason many farmers and others continue to live near these "smoking mountains," in spite of the latent danger. Perhaps by living so close to the danger zone, they have learned that no one can control the forces of nature, and the only thing left to do is to simply live.

Continuous Movement

PAHOEHOE LAVA
A type of Hawaiian lava that flows down the slopes of Mt. Kilauea to the sea.

SCORCHING FLOW 8-9
THE LONG HISTORY OF THE EARTH 10-11
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THE JOURNEY OF THE PLATES 14-15
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In the volatile landscape of Volcano National Park in Hawaii, the beginning and end of life seem to go hand in hand. Outpourings of lava often reach the sea. When the molten rock enters the water, the lava quickly cools and hardens into rock that becomes part of the coastline. By this process, volcanic islands grow constantly, and nothing stays the same from one moment to another. One day rivers of lava blaze down the volcano's slopes, and the next day there are new, silver-colored rocks. The ongoing investigation of lava samples under the microscope helps volcanologists discover the rock's mineral composition and offers clues about how the volcano may behave.●

Scorching Flow

Most of the Earth's interior is in a liquid and incandescent state at extremely high temperatures. This vast mass of molten rock contains dissolved crystals and water vapor, among other gases, and it is known as magma. When part of the magma rises toward the Earth's surface, mainly through volcanic activity, it is called lava. As soon as it reaches the surface of the Earth or the ocean floor, the lava starts to cool and solidify into different types of rock, according to its original chemical composition. This is the basic process that formed the surface of our planet, and it is the reason the Earth's surface is in constant flux. Scientists study lava to understand our planet better.

Streams of Fire

Lava is at the heart of every volcanic eruption. The characteristics of lava vary, depending on the gases it contains and its chemical composition. Lava from an eruption is loaded with water vapor and gases such as carbon dioxide, hydrogen, carbon monoxide, and sulfur dioxide. As these gases are expelled, they burst into the atmosphere, where they create a turbulent cloud that sometimes discharges heavy rains. Fragments of lava expelled and scattered by the volcano are classified as bombs, cinders, and ash. Some large fragments fall back into the crater. The speed at which lava travels depends to a great extent on the steepness of the sides of the volcano. Some lava flows can reach 90 miles (145 km) in length and attain speeds of up to 30 miles per hour (50 km/hr).

INTENSE HEAT
Lava can reach temperatures above 2,200º F (1,200º C). The hotter the lava, the more fluid it is. When lava is released in great quantities, it forms rivers of fire. The lava's advance is slowed down as the lava cools and hardens.

Rock Cycle

Once it cools, lava forms igneous rock. This rock, subjected to weathering and natural processes such as metamorphism and sedimentation, will form other types of rocks that, when they sink back into the Earth's interior, again become molten rock. This process takes millions of years and is known as the rock cycle.

SEDIMENTARY ROCK
Rock formed by eroded and compacted materials.

METAMORPHIC ROCKS
Their original structure is changed by heat and pressure.

TURNS BACK INTO LAVA

TURNS BACK INTO LAVA

2. IGNEOUS ROCK
Rock formed when lava solidifies. Basalt and granite are good examples of igneous rocks.

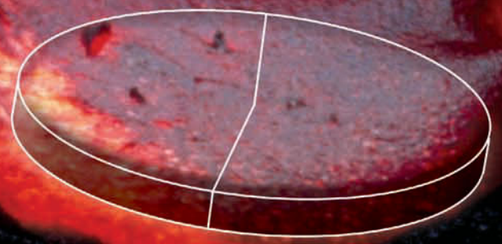
1. LAVA
The state in which magma flows to the Earth's outer crust, either reaching the surface or getting trapped within the crust.

SOLID LAVA
Lava solidifies at temperatures below 1,700º F (900º C). The most viscous type of lava forms a rough landscape, littered with sharp rocks; more fluid lava, however, tends to form flatter and smoother rocks.

1,800º F
(1,000º C)
is the average temperature of liquid lava.

Mineral Composition

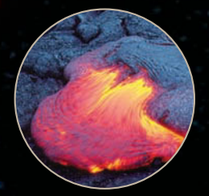
Lava contains a high level of silicates, light rocky minerals that make up 95 percent of the Earth's crust. The second most abundant substance in lava is water vapor. Silicates determine lava's viscosity, that is, its capacity to flow. Variations in viscosity have resulted in one of the most commonly used classification systems of lava: basaltic, andesitic, and rhyolitic, in order from least to greatest silicate content. Basaltic lava forms long rivers, such as those that occur in typical Hawaiian volcanic eruptions, whereas rhyolitic lava tends to erupt explosively because of its poor fluidity. Andesitic lava, named after the Andes mountains, where it is commonly found, is an intermediate type of lava of medium viscosity.



52% Silicates

48% Other Content

TYPES OF LAVA
Basaltic lava is found mainly in islands and in mid-ocean ridges; it is so fluid that it tends to spread as it flows. Andesitic lava forms layers that can be up to 130 feet (40 m) thick and that flow very slowly, whereas rhyolitic lava is so viscous that it forms solid fragments before reaching the surface.



Andesitic Lava

Silicates	63%
Other Content	37%



Rhyolitic Lava

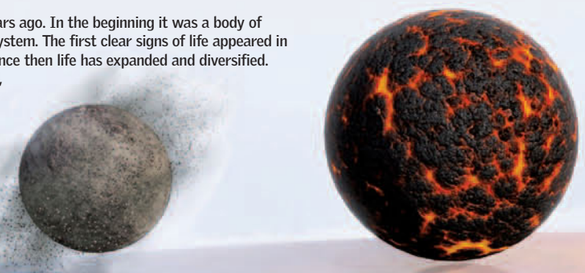
Silicates	68%
Other Content	32%

The Long History of the Earth

The nebular hypothesis developed by astronomers suggests that the Earth was formed in the same way and at the same time as the rest of the planets and the Sun. It all began with an immense cloud of helium and hydrogen and a small portion of heavier materials 4.6 billion years ago. Earth emerged from one of these "small" revolving clouds, where the particles constantly collided with one another, producing very high temperatures. Later, a series of processes took place that gave the planet its present shape.

From Chaos to Today's Earth

Earth was formed 4.6 billion years ago. In the beginning it was a body of incandescent rock in the solar system. The first clear signs of life appeared in the oceans 3.6 billion years ago, and since then life has expanded and diversified. The changes have been unceasing, and, according to experts, there will be many more changes in the future.



4.6 BILLION YEARS AGO

FORMATION

The accumulation of matter into solid bodies, a process called accretion, ended, and the Earth stopped increasing in volume.

4.5 BILLION YEARS AGO

COOLING

The first crust formed as it was exposed to space and cooled. Earth's layers became differentiated by their density.

4 BILLION YEARS AGO

METEORITE COLLISION

Meteorite collisions, at a rate 150 times as great as that of today, evaporated the primitive ocean and resulted in the rise of all known forms of life.

The oldest rocks appeared.

3.8 BILLION YEARS AGO

ARCHEAN EON

STABILIZATION

The processes that formed the atmosphere, the oceans, and protolife intensified. At the same time, the crust stabilized, and the first plates of Earth's crust appeared. Because of their weight, they sank into Earth's mantle, making way for new plates, a process that continues today.

When the first crust cooled, intense volcanic activity freed gases from the interior of the planet, and those gases formed the atmosphere and the oceans.

THE AGE OF THE SUPER VOLCANOES

Indications of komatite, a type of igneous rock that no longer exists.

2.3 BILLION YEARS AGO

"SNOWBALL" EARTH

Hypothesis of a first, great glaciation.

2.2 BILLION YEARS AGO

WARMING

Earth warmed again, and the glaciers retreated, giving way to the oceans, in which new organisms would be born. The ozone layer began to form.

1.8 BILLION YEARS AGO

PROTEROZOIC EON

CONTINENTS

The first continents, made of light rocks, appeared. In Laurentia (now North America) and in the Baltic, there are large rocky areas that date back to that time.

1.0 BILLION YEARS AGO

SUPERCONTINENTS

Rodinia, the first supercontinent, formed, but it completely disappeared about 650 million years ago.

540 MILLION YEARS AGO

PALEOZOIC ERA

FRAGMENTATION

The great landmass formed that would later fragment to provide the origin of the continents we have today. The oceans reached their greatest rate of expansion.

60 MILLION YEARS AGO

FOLDING IN THE TERTIARY PERIOD

The folding began that would produce the highest mountains that we now have (the Alps, the Andes, and the Himalayas) and that continues to generate earthquakes even today.

Stacked Layers

Every 110 feet (33 m) below the Earth's surface, the temperature increases by 1.8 degrees Fahrenheit (1 degree Celsius). To reach the Earth's center—which, in spite of temperatures above 12,000° F (6,700° C), is assumed to be solid because of the enormous pressure exerted on it—a person would have to burrow through four well-defined layers. The gases that cover the Earth's surface are also divided into layers with different compositions. Forces act on the Earth's crust from above and below to sculpt and permanently alter it.

Earth's crust

Earth's crust is its solid outer layer, with a thickness of 3 to 9 miles (4 to 15 km) under the oceans and up to 44 miles (70 km) under mountain ranges. Volcanoes on land and volcanic activity in the mid-ocean ridges generate new rock, which becomes part of the crust. The rocks at the bottom of the crust tend to melt back into the rocky mantle.

KEY Sedimentary Rock · Igneous Rock · Metamorphic Rock

THE SOLID EXTERIOR
The crust is made up of igneous, sedimentary, and metamorphic rock, of various typical compositions, according to the terrain.

MOUNTAIN RANGES
Made up of the three types of rock in about equal parts.

THE CONTINENTAL SHELF
In the area where the oceanic crust comes in contact with a continent, igneous rock is transformed into metamorphic rock by heat and pressure.

THE MID-OCEAN RIDGES
The ocean floor is regenerated with new basaltic rock formed by magma that solidifies in the rifts that run along mid-ocean ridges.

OCEANIC ISLANDS
Some sedimentary rocks are added to the predominantly igneous rock composition.

GRANITIC BATHOLITHS
Plutons can solidify underground as masses of granite.

PLUTONS
Masses of rising magma trapped within the Earth's crust. Their name is derived from Pluto, the Roman god of the underworld.

INTERNAL ROCK
The inside of a mountain range consists of igneous rock (mostly granite) and metamorphic rock.

COASTAL ROCK
Lithified layers of sediments, usually clay and pebbles, that come from the erosion of high mountains.

CRUST
3-44 miles
(5-70 km)

The Gaseous Envelope

The air and most of the weather events that affect our lives occur only in the lower layer of the Earth's atmosphere. This relatively thin layer, called the troposphere, is up to 10 miles (16 km) thick at the equator but only 4 miles (7 km) thick at the poles. Each layer of the atmosphere has a distinct composition.

Less than
6 miles
(10 km)
TROPOSPHERE
Contains 75 percent of the gas and almost all of the water vapor in the atmosphere.

Less than
31 miles
(50 km)
STRATOSPHERE
Very dry; water vapor freezes and falls out of this layer, which contains the ozone layer.

Less than
62 miles
(100 km)
MESOSPHERE
The temperature is -130º F (-90° C), but it increases gradually above this layer.

Less than
310 miles
(500 km)
THERMOSPHERE
Very low density. Below 155 miles (250 km) it is made up mostly of nitrogen; above that level it is mostly oxygen.

Greater than
310 miles
(500 km)
EXOSPHERE
No fixed outer limit. It contains lighter gases such as hydrogen and helium, mostly ionized.

UPPER MANTLE
370 miles
(600 km)

LITHOSPHERE
Includes the solid outer part of the upper mantle, as well as the crust.
93 miles (150 km)

LOWER MANTLE
1,430 miles
(2,300 km)
Composition similar to that of the crust, but in a liquid state and under great pressure, between 1,830° and 8,130° F (1,000° and 4,500° C).

ASTHENOSPHERE
Underneath is the asthenosphere, made up of partially molten rock.
280 miles (450 km)

OUTER CORE
1,410 miles
(2,270 km)
Composed mainly of molten iron and nickel among other metals at temperatures above 8,500º F (4,700° C).

INNER CORE
756 miles
(1,216 km)
The inner core behaves as a solid because it is under enormous pressure.

The Journey of the Plates

When geophysicist Alfred Wegener suggested in 1910 that the continents were moving, the idea seemed fantastic. There was no way to explain the idea. Only a half-century later, plate tectonic theory was able to offer an explanation of the phenomenon. Volcanic activity on the ocean floor, convection currents, and the melting of rock in the mantle power the continental drift that is still molding the planet's surface today.

Continental Drift

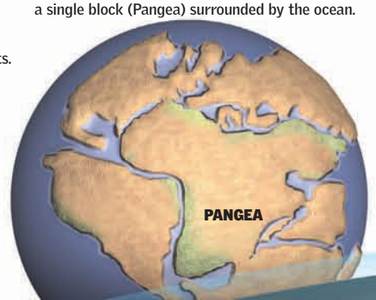
The first ideas on continental drift proposed that the continents floated on the ocean. That idea proved inaccurate. The seven tectonic plates contain portions of ocean beds and continents. They drift atop the molten mantle like sections of a giant shell. Depending on the direction in which they move, their boundaries can converge (when they tend to come together), diverge (when they tend to separate), or slide horizontally past each other (along a transform fault).

The Hidden Motor

Convection currents of molten rock propel the crust. Rising magma forms new sections of crust at divergent boundaries. At convergent boundaries, the crust melts into the mantle. Thus, the tectonic plates act like a conveyor belt on which the continents travel.

250 MILLION YEARS AGO

The landmass today's continents come from was a single block (Pangea) surrounded by the ocean.



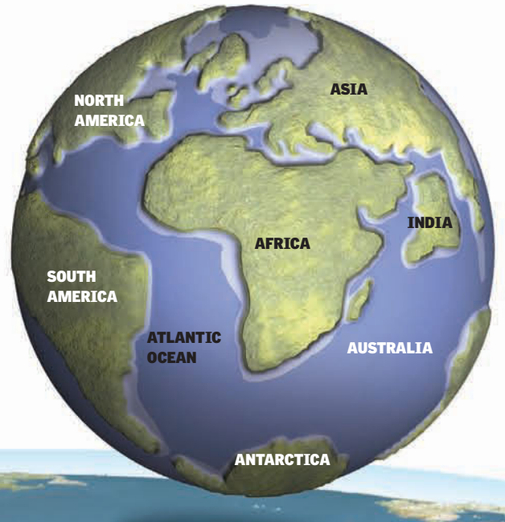
...180 MILLION YEARS AGO

The North American Plate has separated, as has the Antarctic Plate. The supercontinent Gondwana (South America and Africa) has started to divide and form the South Atlantic. India is separating from Africa.



...100 MILLION YEARS AGO

The Atlantic Ocean has formed. India is headed toward Asia, and when the two masses collide, the Himalayas will rise. Australia is separating from Antarctica.



... 60 MILLION YEARS AGO

The continents are near their current location. India is beginning to collide with Asia. The Mediterranean is opening, and the folding is already taking place that will give rise to the highest mountain ranges of today.



250 MILLION YEARS

The number of years it will take for the continents to drift together again.

2 inches (5 cm)

Typical distance the plates travel in a year.

CONVERGENT BOUNDARY

When two plates collide, one sinks below the other, forming a subduction zone. This causes folding in the crust and volcanic activity.

DIVERGENT BOUNDARY

When two plates separate, a rift is formed between them. Magma exerts great pressure, and it renews the ocean floor as it solidifies. The Atlantic Ocean was formed in this way.

CONVECTION CURRENTS

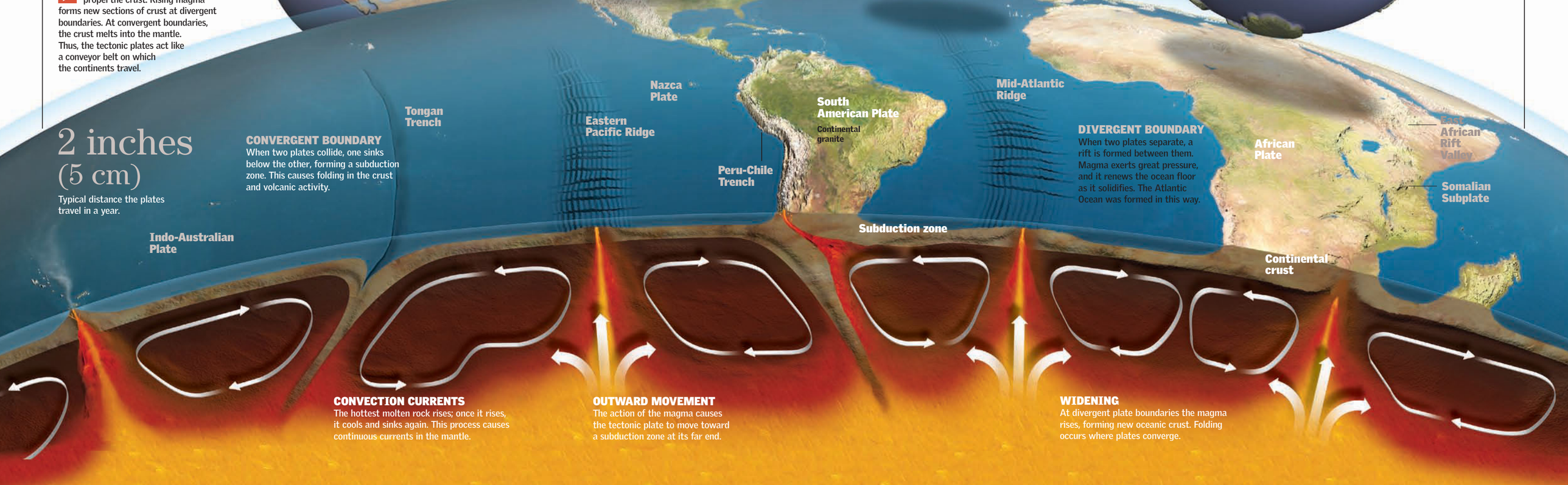
The hottest molten rock rises; once it rises, it cools and sinks again. This process causes continuous currents in the mantle.

OUTWARD MOVEMENT

The action of the magma causes the tectonic plate to move toward a subduction zone at its far end.

WIDENING

At divergent plate boundaries the magma rises, forming new oceanic crust. Folding occurs where plates converge.



Cracks in the Ocean Floor

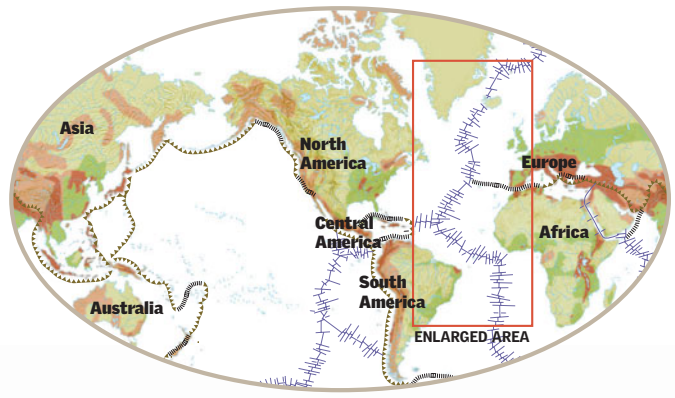
The concept that the ocean floor is spreading was studied for many years: new crust constantly forms at the bottom of the ocean. The ocean floor has deep trenches, plains, and mountain ranges. The mountain ranges are higher than those found on the continents but with different characteristics. The spines of these great mountain ranges, called mid-ocean ridges, exhibit incredible volcanic activity in rift zones. The rift zones are fissures in relatively narrow regions of the crust, along which the crust splits and spreads. One hundred eighty million years ago, the paleocontinent Gondwana broke apart, forming a rift from which the Atlantic Ocean grew, and is still growing.

The Crust Under the Oceans

The constant generation of new ocean crust along rift zones powers a seemingly endless process that generates new lithosphere that is carried from the crest of the ridges, as if on a conveyor belt. Because of this, scientists have calculated that in about 250 million years, the continents will again join and form a new Pangea as they are pushed by the continually expanding ocean floor. Ocean plates are in contact with land plates at the active boundaries of subduction zones or at passive continental boundaries (continental shelves and slopes). Undersea subduction zones, called ocean trenches, also occur between oceanic plates: these are the deepest places on the planet.

HEIGHTS AND DEPTHS

Deep-ocean basins cover 30 percent of the Earth's surface. The depth of the ocean trenches is greater than the height of the greatest mountain ranges, as shown in the graphic below at left.



29,035 feet (8,850 m)
Highest point
(Mount Everest)

Inside and Outside the Ridge

The abyssal (deep-ocean) plains of the Atlantic are the flattest surfaces on Earth; for thousands of miles, the elevation varies by only about 10 feet (3 m). The plains are made mostly of sediment. Variations in the ocean's depth are mainly the result of volcanic activity, not just within the mid-Atlantic Ridge but elsewhere as well.

1 ATOLLS
Also called coral reefs, atolls are formations of coral deposited around a volcanic cone in warm seas. They form ring-shaped islands.

EUROPE

AFRICA

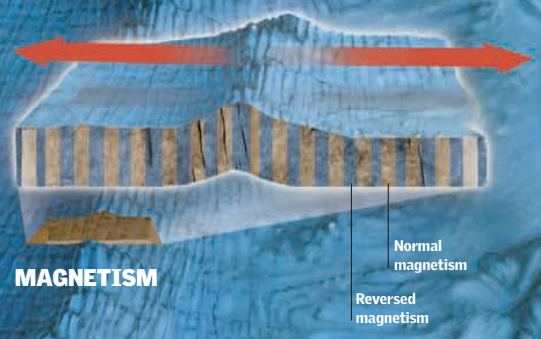
SOUTH AMERICA

2,900 feet (870 m)
Average land elevation

0 feet (0 m)
Sea level

Magnetic Reversals

The Earth's magnetic field changes direction periodically. The magnetic north pole changes places with the magnetic south pole. Rock that solidified during a period of magnetic polarity reversal was magnetized with a polarity opposite that of newly forming rocks. Rocks whose magnetism corresponds to the present direction of the Earth's magnetic field are said to have normal polarity, whereas those with the opposite magnetic polarity are said to have reversed polarity.



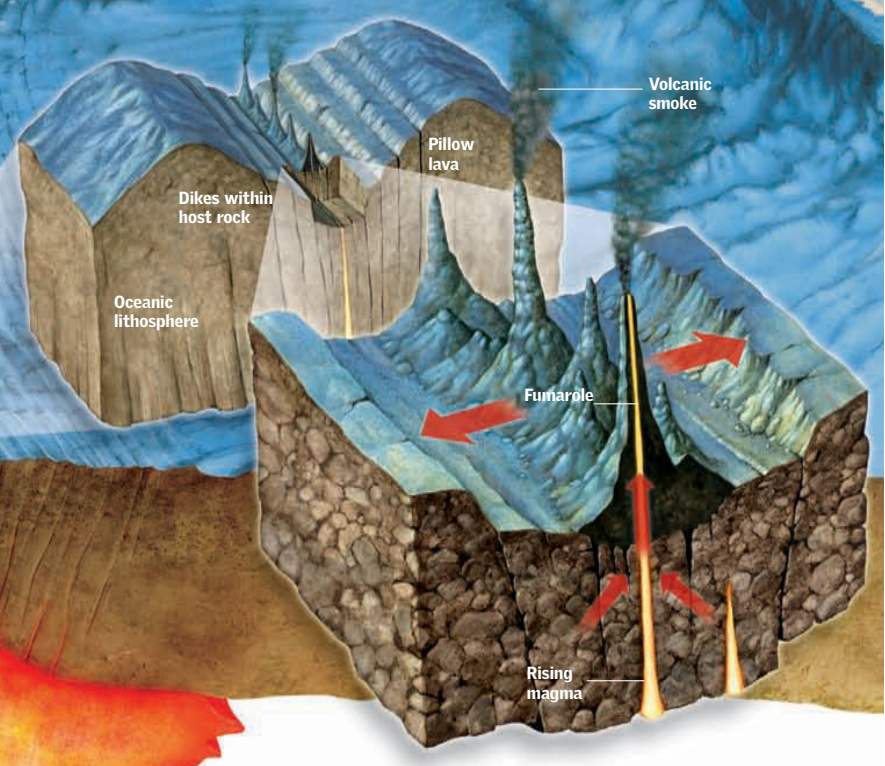
7,900 feet (2,400 m)
Earth's average elevation

12,240 feet (3,730 m)
Average depth

2 OCEAN MOUNTS
Isolated volcanic cones. Some rise above the ocean's surface to become islands, such as the Azores.

How the Mid-Ocean Ridge Was Formed

A spongy layer of rock several dozen miles wide rises above the rift. As the layer fractures and moves away from the fissure, it solidifies into angled blocks that are parallel to the fissure and separated by dikes. Thus the ocean widens as the ridge spreads. The magma exists in a fluid form 2 miles (3.5 km) below the crest of the ridge.



Asthenosphere

Greatest depth
(Mariana Trench)
About 36,000 feet (11,000 m)

Folding in the Earth's Crust

The movement of tectonic plates causes distortions and breaks in the Earth's crust, especially in convergent plate boundaries. Over millions of years, these distortions produce larger features called folds, which become mountain ranges. Certain characteristic types of terrain give clues about the great folding processes in Earth's geological history.

Distortions of the Crust

The crust is composed of layers of solid rock. Tectonic forces, resulting from the differences in speed and direction between plates, make these layers stretch elastically, flow, or break. Mountains are formed in processes requiring millions of years. Then external forces, such as erosion from wind, ice, and water, come into play. If slippage releases rock from the pressure that is deforming it elastically, the rock tends to return to its former state and can cause earthquakes.

1 A portion of the crust subjected to a sustained horizontal tectonic force is met by resistance, and the rock layers become deformed.



2 The outer rock layers, which are often more rigid, fracture and form a fault. If one rock boundary slips underneath another, a thrust fault is formed.



3 The composition of rock layers shows the origin of the folding, despite the effects of erosion.



The Three Greatest Folding Events

The Earth's geological history has included three major mountain-building processes, called "orogenies." The mountains created during the first two orogenies (the Caledonian and the Hercynian) are much lower today because they have undergone millions of years of erosion.



MATERIALS Mudstone, slate, and sandstone, in lithified layers.



Trilobites



MATERIALS Mostly granite, slate, amphibolite, gneiss, quartzite, and schist.



Brachiopods

430 Million Years

CALEDONIAN OROGENY

Formed the Caledonian range. Remnants can be seen in Scotland, the Scandinavian Peninsula, and Canada (which all collided at that time).

300 Million Years

HERCYNIAN OROGENY

Took place between the late Devonic and the early Permian periods. It was more important than the Caledonian Orogeny. It shaped central and western Europe and produced large veins of iron ore and coal. This orogeny gave rise to the Ural Mountains, the Appalachian range in North America, part of the Andes, and Tasmania.

Formation of the Himalayas

The highest mountains on Earth were formed following the collision of India and Eurasia. The Indian Plate is sliding horizontally underneath the Asiatic Plate. A sedimentary block trapped between the plates is cutting the upper part of the Asiatic Plate into segments that are piling on top of each other. This folding process gave rise to the Himalayan range, which includes the highest mountain on the planet, Mount Everest (29,035 feet [8,850 m]). This deeply fractured section of the old plate is called an accretion prism. At that time, the Asian landmass bent, and the plate doubled in thickness, forming the Tibetan plateau.





Amonites



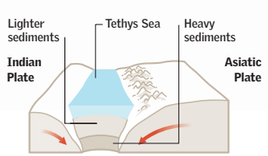
60 MILLION YEARS

ALPINE OROGENY

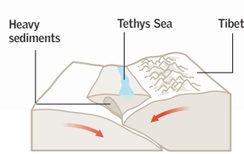
Began in the Cenozoic Era and continues today. This orogeny raised the entire system of mountain ranges that includes the Pyrenees, the Alps, the Caucasus, and even the Himalayas. It also gave the American Rockies and the Andes Mountains their current shape.

MATERIALS
High proportions of sediment in Nepal, batholiths in the Asiatic Plate, and intrusions of new granite: iron, tin, and tungsten.

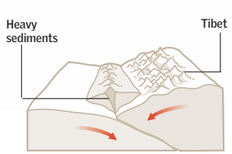
A COLLISION OF CONTINENTS



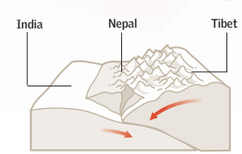
60 MILLION YEARS AGO
The Tethys Sea gives way as the plates approach. Layers of sediment begin to rise.



40 MILLION YEARS AGO
As the two plates approach each other, a subduction zone begins to form.



20 MILLION YEARS AGO
The Tibetan plateau is pushed up by pressure from settling layers of sediment.



THE HIMALAYAS TODAY
The movement of the plates continues to fold the crust, and the land of Nepal is slowly disappearing.

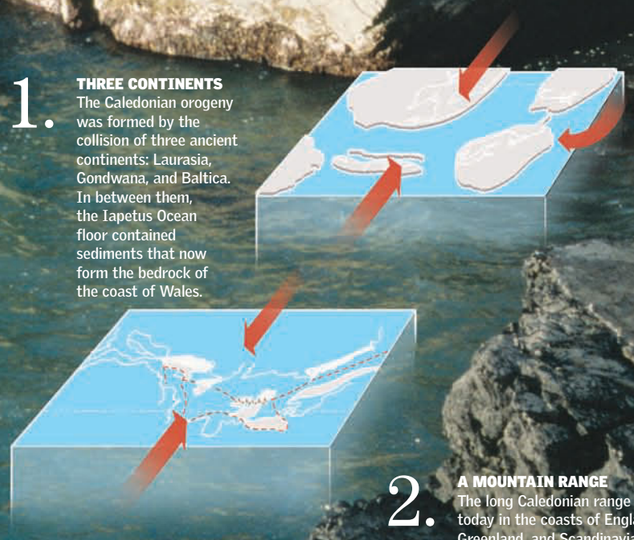
Folds

The force that forms the mountains also molds the rocks within them. As the result of millions of years of pressure, the layers of crust fold into strange shapes. The Caledonian Orogeny, which began 450 million years ago, created a long mountain range that joined the Appalachian mountains of the United States to the Scandinavian peninsula. All of northern England was lifted up during this process. The ancient Iapetus Ocean once lay between the colliding continents. Sedimentary rocks from the bed of this ocean were lifted up, and they have kept the same forms they had in the past.

Silurian

The name of the geological period in which this folding occurred.

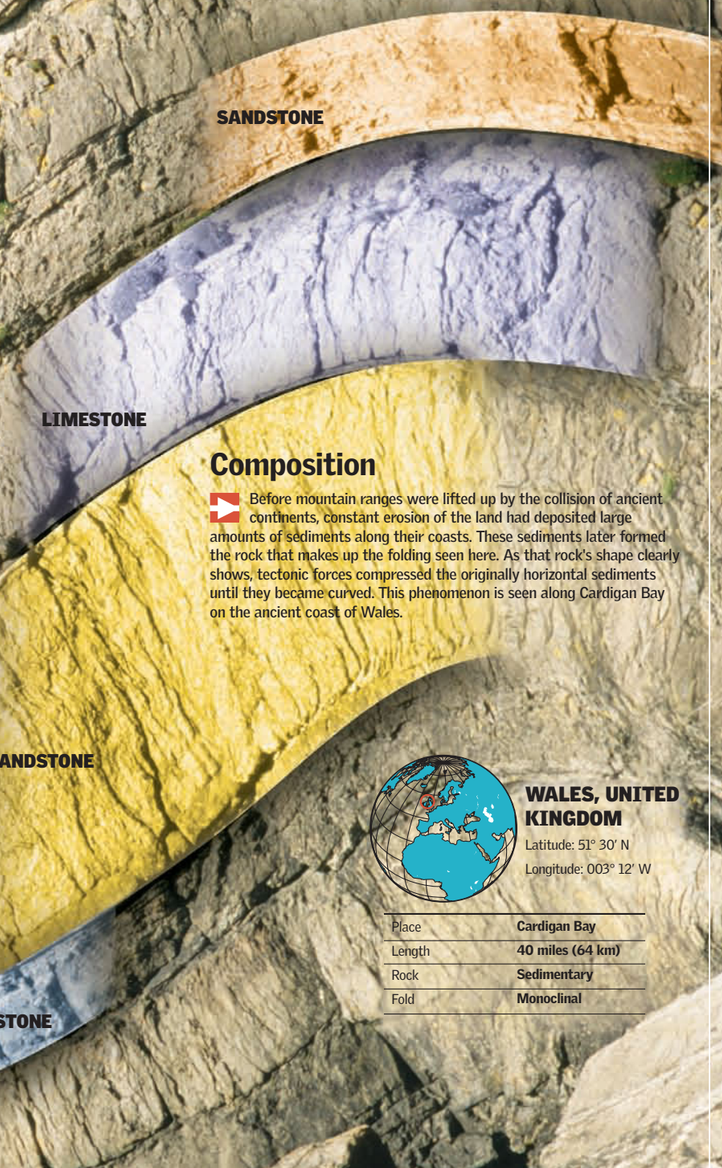
1. THREE CONTINENTS
The Caledonian orogeny was formed by the collision of three ancient continents: Laurasia, Gondwana, and Baltica. In between them, the Iapetus Ocean floor contained sediments that now form the bedrock of the coast of Wales.



440 MILLION YEARS

395 MILLION YEARS

2. A MOUNTAIN RANGE
The long Caledonian range is seen today in the coasts of England, Greenland, and Scandinavia. Since the tectonic movements that created them have ended, they are being worn away and sculpted by constant erosion.



Composition

Before mountain ranges were lifted up by the collision of ancient continents, constant erosion of the land had deposited large amounts of sediments along their coasts. These sediments later formed the rock that makes up the folding seen here. As that rock's shape clearly shows, tectonic forces compressed the originally horizontal sediments until they became curved. This phenomenon is seen along Cardigan Bay on the ancient coast of Wales.

WALES, UNITED KINGDOM
Latitude: 51° 30′ N
Longitude: 003° 12′ W

Place	**Cardigan Bay**
Length	**40 miles (64 km)**
Rock	**Sedimentary**
Fold	**Monoclinal**

When the Faults Resound

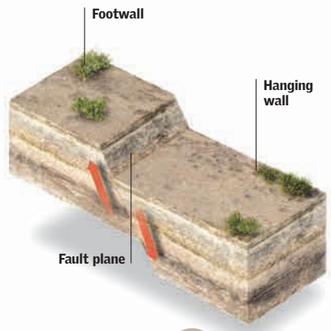
Faults are small breaks that are produced along the Earth's crust. Many, such as the San Andreas fault, which runs through the state of California, can be seen readily. Others, however, are hidden within the crust. When a fault fractures suddenly, an earthquake results. Sometimes fault lines can allow magma from lower layers to break through to the surface at certain points, forming a volcano.

Relative Movement Along Fault Lines

Fault borders do not usually form straight lines or right angles; their direction along the surface changes. The angle of vertical inclination is called "dip." The classification of a fault depends on how the fault was formed and on the relative movement of the two plates that form it. When tectonic forces compress the crust horizontally, a break causes one section of the ground to push above the other. In contrast, when the two sides of the fault are under tension (pulled apart), one side of the fault will slip down the slope formed by the other side of the fault.

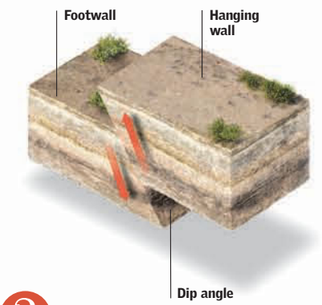
1 Normal Fault

This fault is the product of horizontal tension. The movement is mostly vertical, with an overlying block (the hanging wall) moving downward relative to an underlying block (the footwall). The fault plane typically has an angle of 60 degrees from the horizontal.



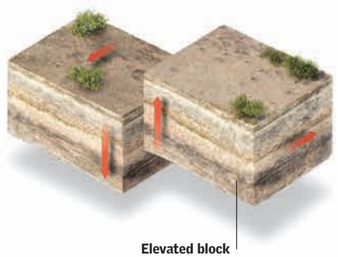
2 Reverse Fault

This fault is caused by a horizontal force that compresses the ground. A fracture causes one portion of the crust (the hanging wall) to slide over the other (the footwall). Thrust faults (see pages 18-19), are a common form of reverse fault that can extend up to hundreds of miles. However, reverse faults with a dip greater than 45° are usually only a few yards long.



3 Oblique-Slip Fault

This fault has horizontal as well as vertical movements. Thus, the relative displacement between the edges of the fault can be diagonal. In the oldest faults, erosion usually smoothes the differences in the surrounding terrain, but in more recent faults, cliffs are formed. Transform faults that displace mid-ocean ridges are a specific example of oblique-slip faults.



350 miles (566 km)

The distance that the opposite sides of the fault have slipped past each other, throughout their history.



OPPOSITE DIRECTIONS
The northwestward movement of the Pacific Plate and the southeastward movement of the North American Plate cause folds and fissures throughout the region.

Strike-Slip Fault

In this fault the relative movement of the plates is mainly horizontal, along the Earth's surface, parallel to the direction of the fracture but not parallel to the fault plane. Transform faults between plates are usually of this type. Rather than a single fracture, they are generally made up of a system of smaller fractures, slanted from a centerline and more or less parallel to each other. The system can be several miles wide.

PAST AND FUTURE
Some 30 million years ago, the Peninsula of California was west of the present coast of Mexico. Thirty million years from now, it is possible that it may be some distance off the coast of Canada.

Streambeds Diverted by Tectonic Movement

Through friction and surface cracking, a transform fault creates transverse faults and, at the same time, alters them with its movement. Rivers and streams distorted by the San Andreas fault have three characteristic forms: streambeds with tectonic displacement, diverted streambeds, and streambeds with an orientation that is nearly oblique to the fault.

1



Diverted Streambed
The stream changes course as a result of the break.

2



Displaced Streambed
The streambed looks "broken" along its fault line.



WEST COAST OF THE UNITED STATES

Length of California	**770 miles (1,240 km)**
Length of fault	**800 miles (1,300 km)**
Maximum width of fault	**60 miles (100 km)**
Greatest displacement (1906)	**20 feet (6 m)**

140 years

The average interval between major ruptures that have taken place along the fault. The interval can vary between 20 and 300 years.

Fatal Crack

The great San Andreas fault in the western United States is the backbone of a system of faults. Following the great earthquake that leveled San Francisco in 1906, this system has been studied more than any other on Earth. It is basically a horizontal transform fault that forms the boundary between the Pacific and North American tectonic plates. The system contains many complex lesser faults, and it has a total length of 800 miles (1,300 km). If both plates were able to slide past each other smoothly, no earthquakes would result. However, the borders of the plates are in contact with each other. When the solid rock cannot withstand the growing strain, it breaks and unleashes an earthquake.

Volcanoes

MOUNT ETNA
With a height of 10,810 feet (3,295 m), Etna is the largest and most active volcano in Europe.

FLAMING FURNACE 26-27
CLASSIFICATION 28-29
FLASH OF FIRE 30-31
MOUNT ST. HELENS 32-33
KRAKATOA 34-35
AFTERMATH OF FURY 36-37
JETS OF WATER 38-39
RINGS OF CORAL 40-41
FROZEN FLAME 42-43



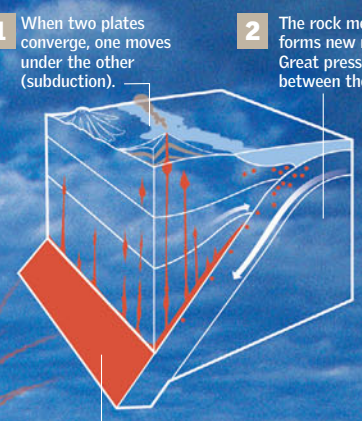
Mount Etna has always been an active volcano, as seen from the references to its activity that have been made throughout history. It could be said that the volcano has not given the beautiful island of Sicily a moment's rest. The Greek philosopher Plato was the first to study Mount Etna. He traveled to Italy especially to see it up close, and he subsequently described how the lava cooled. Today Etna's periodic eruptions continue to draw hundreds of thousands of tourists, who enjoy the spectacular fireworks produced by its red-hot explosions. This phenomenon is visible from the entire east coast of Sicily because of the region's favorable weather conditions and the constant strong winds. ●

Flaming Furnace

Volcanoes are among the most powerful manifestations of our planet's dynamic interior. The magma they release at the Earth's surface can cause phenomena that devastate surrounding areas: explosions, enormous flows of molten rock, fire and ash that rain from the sky, floods, and mudslides. Since ancient times, human beings have feared volcanoes, even seeing their smoking craters as an entrance to the underworld. Every volcano has a life cycle, during which it can modify the topography and the climate and after which it becomes extinct.

MOUNTAIN-RANGE VOLCANOES

Many volcanoes are caused by phenomena occurring in subduction zones along convergent plate boundaries.



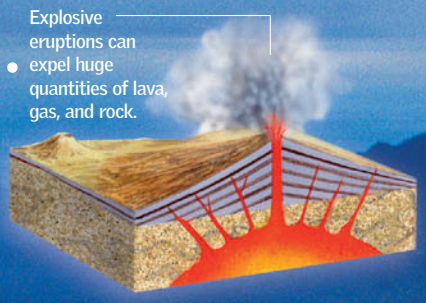
1 When two plates converge, one moves under the other (subduction).

2 The rock melts and forms new magma. Great pressure builds up between the plates.

3 The heat and pressure in the crust force the magma to seep through cracks in the rock and rise to the surface, causing volcanic eruptions.

LIFE AND DEATH OF A VOLCANO: THE FORMATION OF A CALDERA

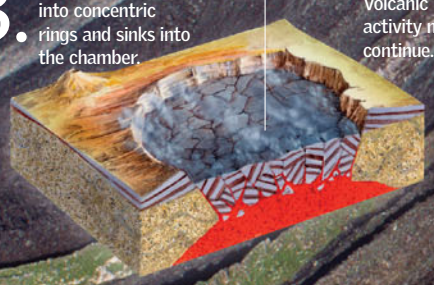
1. Explosive eruptions can expel huge quantities of lava, gas, and rock.



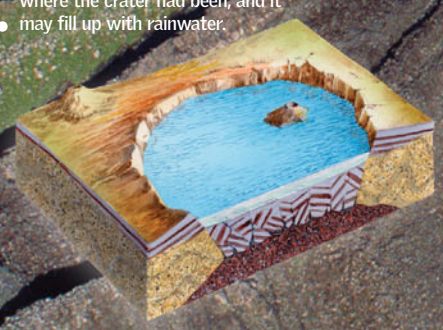
2. A void is left in the conduit and in the internal chamber.



3. The cone breaks up into concentric rings and sinks into the chamber. Volcanic activity may continue.



4. A depression, or caldera, forms where the crater had been, and it may fill up with rainwater.



ERUPTION OF LAVA

CLOUD OF ASH

CRATER
Depression or hollow from which eruptions expel magmatic materials (lava, gas, steam, ash, etc.)

STREAMS OF LAVA flow down the flanks of the volcano.

PARASITIC VOLCANO
Composite volcanic cones have more than one crater.

SECONDARY CONDUIT

VOLCANIC CONE
Made of layers of igneous rock, formed from previous eruptions. Each lava flow adds a new layer.

MAIN CONDUIT
The pipe through which magma rises. It connects the magma chamber with the surface.

SEEPAGE OF GROUNDWATER

EXTINCT CONDUIT

INTRUSION OF MAGMA



Magma can reach the surface, or it can stay below ground and exert pressure between the layers of rock. These seepages of magma have various names.

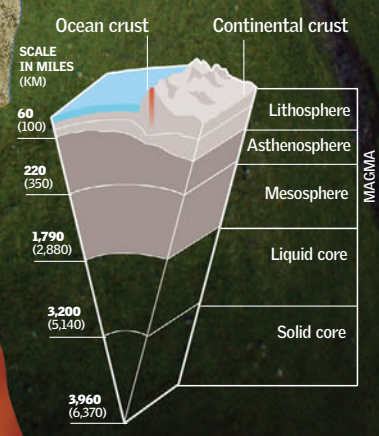
MAGMA CHAMBER
Mass of molten rock at temperatures that may exceed

2,000° F
(1,100° C)

In an active volcano, magma in the chamber is in constant motion because of fluctuations of temperature and pressure (convection currents).

UNDER THE VOLCANO

In its ascent to the surface, the magma may be blocked in various chambers at different levels of the lithosphere.



Classification

No two volcanoes on Earth are exactly alike, although they have characteristics that permit them to be studied according to six basic types: shield volcanoes, cinder cones, stratovolcanoes, lava cones, fissure volcanoes, and calderas. A volcano's shape depends on its origin, how the eruption began, processes that accompany the volcanic activity, and the degree of danger the volcano poses to life in surrounding areas.

THE MOST COMMON
Stratovolcanoes, or composite cones, are strung along the edges of the Pacific Plate in the region known as the "Ring of Fire."

IGNEOUS INTRUSIONS: A PECULIAR PROFILE

1 FORMATION OF THE VOLCANIC PLUG
Extinct volcano
Lava solidifies and forms resistant rock.

2 INITIAL EROSION
Erosion of the cone
The plug is not affected.

3 THE NECK FORMS.
The surrounding terrain is flat.
The volcanic neck remains.

CHAPEL OF ST. MICHAEL
Built in Le Puy, France, on top of a volcanic neck of hard rock that once sealed the conduit of a volcano. The volcano's cone has long since been worn away by erosion; the lava plug remains.

262
FEET (80 M)
The height of the plug, from base to peak.

Caldera that contains a lake
Plug of extinct volcano
Crater of Stratovolcano
Main Conduit
River of Lava
Parasitic Volcano
Branch Pipe
Sill
Lava slope
Formation of new cone
Shock wave
Magma chamber
Dike
Convex Sides
Layers of ash

LAVA DOME
The sides are formed by the accumulation of "hard" lava, made viscous by its high silicon content. Instead of flowing, it quickly hardens in place.

CINDER CONE
Cone-shaped, circular mounds up to 980 feet (300 m) high. They are formed when falling debris or ash accumulates near the crater. These volcanic cones have gently sloping sides, with an angle between 30° and 40°.

SHIELD VOLCANO
The diameter of these volcanoes is much greater than their height. They are formed by the accumulation of highly fluid lava flows, so they are low, with gently sloping sides, and they are nearly flat on top.

STRATOVOLCANO (COMPOSITE VOLCANO)
Nearly symmetrical in appearance, formed by layers of fragmented material (ash and pyroclasts) between lava flows. A stratovolcano is structured around a main conduit, although it may also have several branch pipes. This is usually the most violent type of volcano.

CALDERA VOLCANO
Large basins, similar to craters but greater than 0.8 mile (1 km) across, are called calderas. They are found at the summit of extinct or inactive volcanoes, and they are typically filled with deep lakes. Some calderas were formed after cataclysmic explosions that completely destroyed the volcano. Others were formed when, after successive eruptions, the empty cone could no longer hold up the walls, which then collapsed.

FISSURE VOLCANOES
Long, narrow openings found mainly in mid-ocean ridges. They emit enormous amounts of highly fluid material and form wide slopes of stratified basaltic stone. Some, such as that of the Deccan Plateau in India, cover more than 380,000 square miles (1 million sq km).

MOUNT ILAMATEPEC
Cinder cone located 45 miles (65 km) west of the capital of El Salvador. Its last recorded eruption was in October 2005.



MOUNT KILAUEA
Shield volcano in Hawaii. One of the most active shield volcanoes on Earth.



MOUNT FUJI
Composite volcano 12,400 feet (3,776 m) high, the highest in Japan. Its last eruption was in 1707.



CALDERA BLANCA
Located on Lanzarote, Canary Islands, in the fissure zone known as the Montañas de Fuego (Fire Mountains).



MAUNA ULU
Fissure volcano, about 5 miles (8 km) from the top of Kilauea (Hawaii). This is one of the most active volcanoes in the central Pacific.



Flash of Fire

A volcanic eruption is a process that can last from a few hours to several decades. Some are devastating, but others are mild. The severity of the eruption depends on the dynamics between the magma, dissolved gas, and rocks within the volcano. The most potent explosions often result from thousands of years of accumulation of magma and gas, as pressure builds up inside the chamber. Other volcanoes, such as Stromboli and Etna, reach an explosive point every few months and have frequent emissions.

HOW IT HAPPENS

3. THE ESCAPE

When the mounting pressure of the magma becomes greater than the materials between the magma and the floor of the volcano's crater can bear, these materials are ejected.

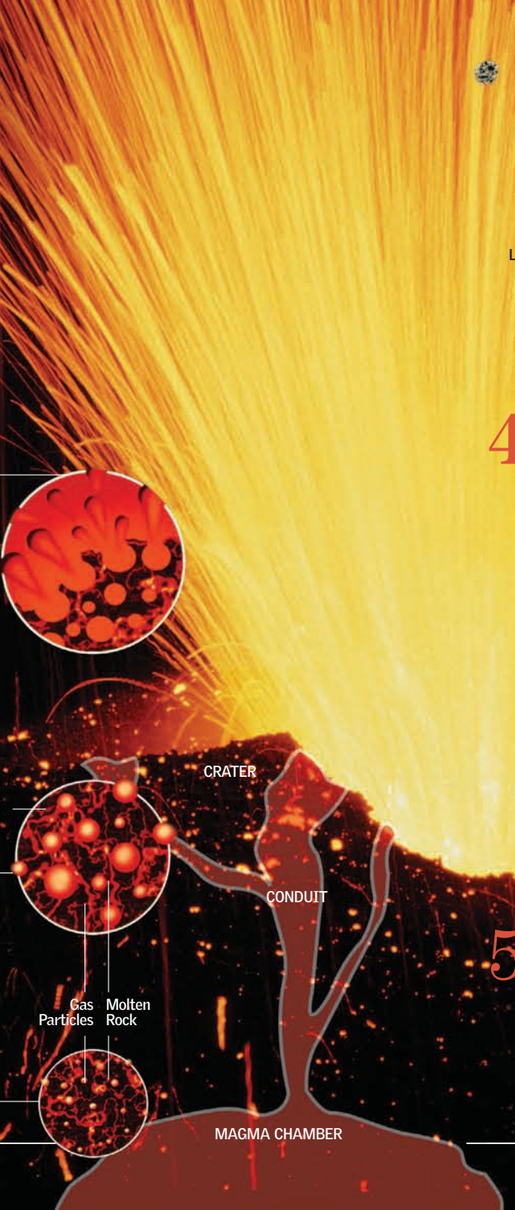


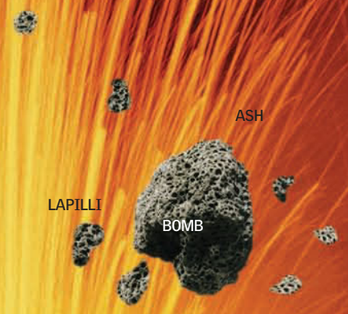
2. IN THE CONDUIT

A solid layer of fragmented materials blocks the magma that contains the volatile gases. As the magma rises and mixes with volatile gases and water vapor, the pockets of gases and steam that form give the magma its explosive power.

1. IN THE CHAMBER

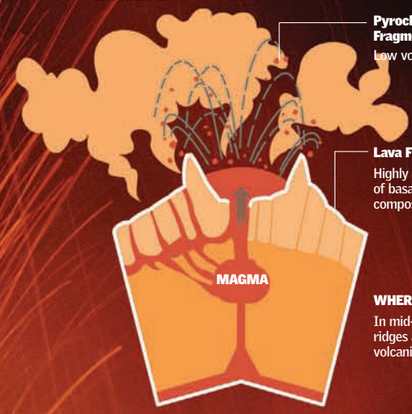
There is a level at which liquefaction takes place and at which rising magma, under pressure, mixes with gases in the ground. The rising currents of magma increase the pressure, hastening the mixing.





EFFUSIVE ACTIVITY

Mild eruptions with a low frequency of explosions. The lava has a low gas content, and it flows out of openings and fissures.



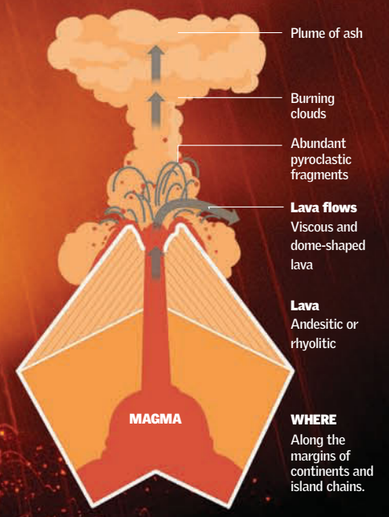
EXPLOSIVE ACTIVITY

Comes from the combination of high levels of gas with relatively viscous lava, which can produce pyroclasts and build up great pressure. Different types of explosions are distinguished based on their size and volume. The greatest explosions can raise ash into a column several miles high.

4. PYROCLASTIC PRODUCTS

In addition to lava, an eruption can eject solid materials called pyroclasts. Volcanic ash consists of pyroclastic material less than 0.08 inch (2 mm) in size. An explosion can even expel granite blocks.

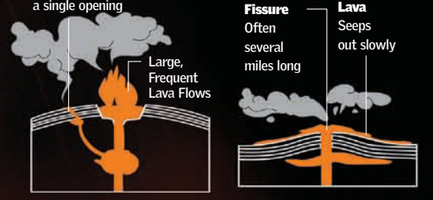
BOMB	2.5 inches (64 mm) and up
LAPILLI	0.08 to 2.5 inches (2 mm to 64 mm)
ASH	Up to 0.08 inch (2 mm)



5. LAVA FLOWS

On the volcanic island of Hawaii, nonerupting flows of lava abound. Local terms for lava include "aa," viscous lava flows that sweep away sediments, and "pahoehoe," more fluid lava that solidifies in soft waves.

TYPES OF EFFUSIVE ERUPTION



HAWAIIAN

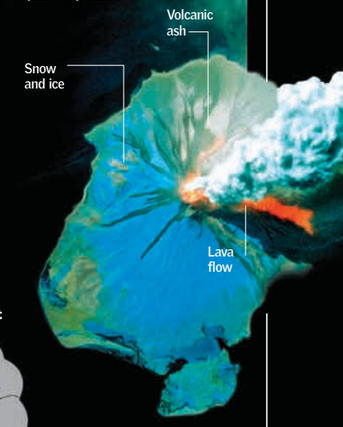
Volcanoes such as Mauna Loa and Kilauea expel large amounts of basaltic lava with a low gas content, so their eruptions are very mild. They sometimes emit vertical streams of bright lava ("fountains of fire") that can reach up to 330 feet (100 m) in height.

FISSURE

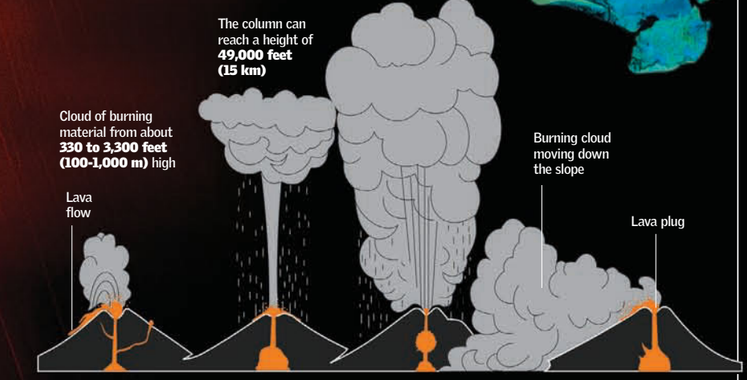
Typical in ocean rift zones, fissures are also found on the sides of composite cones such as Etna (Italy) or near shield volcanoes (Hawaii). The greatest eruption of this type was that of Laki, Iceland, in 1783: 2.9 cubic miles (12 cu km) of lava was expelled from a crack 16 miles (25 km) long.

FROM OUTER SPACE

A photo of the eruption of Mt. Augustine in Alaska, taken by the Landsat 5 satellite hours after the March 27, 1986, eruption.



TYPES OF EXPLOSIVE ERUPTION



STROMBOLIAN

The volcano Stromboli in Sicily, Italy, gave its name to these high-frequency eruptions. The relatively low volume of expelled pyroclasts allows these eruptions to occur approximately every five years.

VULCANIAN

Named after Vulcano in Sicily. As eruptions eject more material and become more explosive, they become less frequent. The 1985 eruption of Nevado del Ruiz expelled tens of thousands of cubic yards of lava and ash.

VESUVIAN

Also called Plinian, the most violent explosions raise columns of smoke and ash that can reach into the stratosphere and last up to two years, as in the case of Krakatoa (1883).

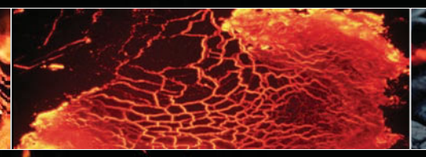
PELEAN

A plug of lava blocks the crater and diverts the column to one side after a large explosion. As with Mt. Pelée in 1902, the pyroclastic flow and lava are violently expelled down the slope in a burning cloud that sweeps away everything in its path.

LAVA FLOW MT. KILAUEA, HAWAII



LAKE OF LAVA MAKA-O-PUHL, HAWAII



COOLED LAVA (PAHOEHOE) MT. KILAUEA, HAWAII



Mount St. Helens

Within the territory of the United States, active volcanoes are not limited to exotic regions such as Alaska or Hawaii. One of the most explosive volcanoes in North America is in Washington state. Mount St. Helens, after a long period of calm, had an eruption of ash and vapor on May 18, 1980. The effects were devastating: 57 people were killed, and lava flows destroyed trees over an area of 232 square miles (600 sq km). The lake overflowed, causing mudslides that destroyed houses and roads. The area will need a century to recover.



Cut Top
Like the cork in a bottle of champagne, the top of the mountain burst off because of pressure from the magma.

In the eruption Mount St. Helens lost its conical stratovolcano shape and became a caldera.



BEFORE THE ERUPTION
The symmetrical cone, surrounded by forest and prairies, was admired as the American Fuji. The eruption left a horseshoe-shaped caldera, surrounded by devastation.

DURING THE EXPLOSION
The energy released was the equivalent of 500 nuclear bombs. The top of the mountain flew off like the cap of a shaken bottle of soda.

OLYMPIA WASHINGTON STATE

Type of Volcano	Stratovolcano
Size of Base	5.9 mi (9.5 km)
Type of Activity	Explosive
Type of Eruption	Plinian
Most Recent Eruptions	1980, 1998, 2004
Fatalities	57

Warning Signs

Two months before the great explosion, Mount St. Helens gave several warning signs: a series of seismic movements, small explosions, and a swelling of the mountain's north slope, caused by magma rising toward the surface. Finally on May 18, an earthquake caused a landslide that carried away the top of the volcano. Later, several collapses at the base of the column caused numerous pyroclastic flows with temperatures of nearly 1,300° F (700° C).

8 miles
13 km

Pulverized and incinerated by the force of the lava and the pyroclastic flow. Temperatures rose above 1,110° F (600° C).

232 SQUARE MILES
600 sq km

SURFACE DESTRUCTION
The effects were devastating: 250 houses, 47 bridges, rail lines, and 190 miles (300 km) of highway were lost.

15 miles
24 km

Range of the shock wave from the pyroclastic flow. The heat and ash left acres of forest completely destroyed.



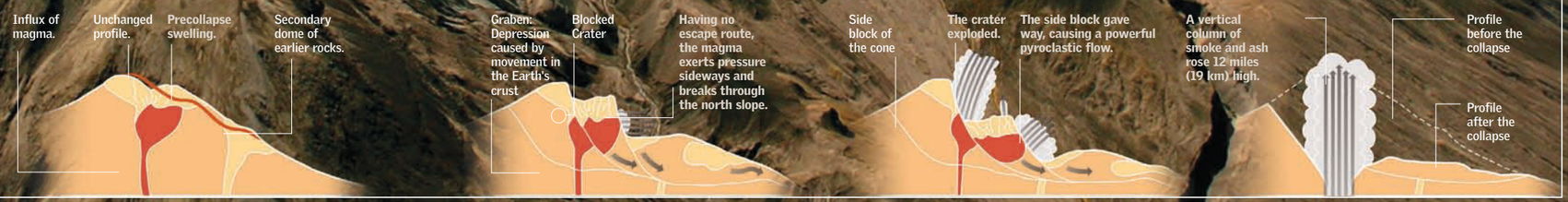
The Forest
Burned trees covered with ash, several miles from the volcano

1. SWELLING — 00:00
The uninterrupted flow of magma toward the volcano's surface caused the north slope of the mountain to swell, and later collapse in an avalanche.

2. PRESSURE ON THE NORTH SLOPE — 00:40
The swelling of the mountain was no doubt caused by the first eruption, almost two months before the final explosion.

3. INITIAL ERUPTIONS — 00:50
The north slope gave way to the great pressure of the magma in an explosive eruption. The lava traveled 16 miles (25 km) at 246 feet (75 m) per second.

4. EXPLOSION AND VERTICAL COLLAPSE — 00:60
At the foot of the volcano, a valley 640 feet (195 m) deep was buried in volcanic material. Over 10 million trees were destroyed.

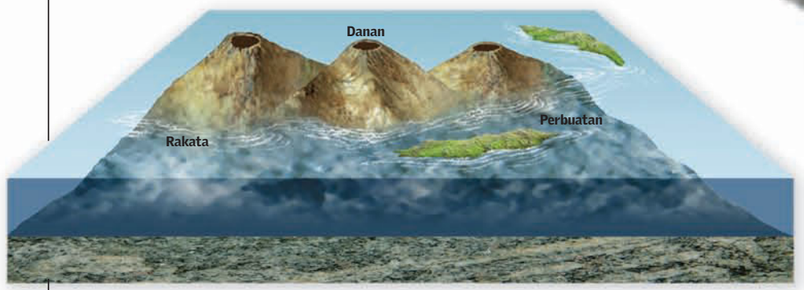


Krakatoa

In early 1883, Krakatoa was just one of many volcanic islands on Earth. It was located in the Straits of Sundra, between Java and Sumatra in the Dutch East Indies, now known as Indonesia. It had an area of 10.8 square miles (28 sq km) and a central peak with a height of 2,690 feet (820 m). In August 1883, the volcano exploded, and the island was shattered in the largest natural explosion in history. ●

The Island That Exploded

Krakatoa was near the subduction zone between the Indo-Australian and Eurasian plates. The island's inhabitants were unconcerned about the volcano because the most recent previous eruption had been in 1681. Some even thought the volcano was extinct. On the morning of Aug. 27, 1883, the island exploded. The explosion was heard as far away as Madagascar. The sky was darkened, and the tsunamis that followed the explosion were up to 130 feet (40 m) high.



1 BEFORE
In May the volcano began showing signs in the form of small quakes and spouting vapor, smoke, and ash. None of this served to warn of the terrible explosion to come, and some even took trips to see the volcano's "pyrotechnics."

2 DURING
At 5:30 a.m. the island burst from the accumulated pressure, opening a crater 820 feet (250 m) deep. Water immediately rushed in, causing a gigantic tsunami.

34 miles (55 km)
The height of the column of ash.

PYROCLASTICS
The pyroclastic flows were so violent that, according to the descriptions of sailors, they reached up to 37 miles (80 km) from the island.

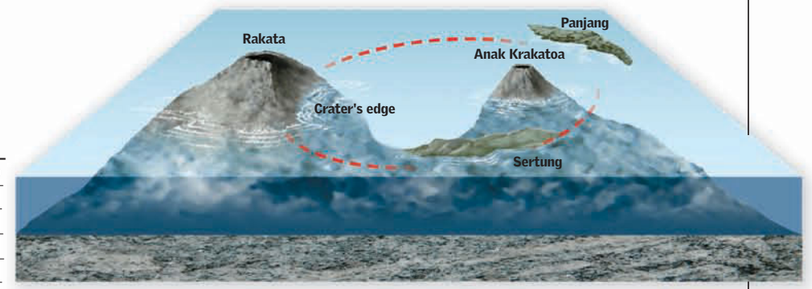
130 feet (40 m)
The height of the tsunami waves, which traveled at 700 miles per hour (1,120 km/h).

500
MEGATONS
The energy released, equivalent to 25,000 atomic bombs such as the one dropped on Hiroshima.



KRAKATOA
Latitude 6° 06´ S
Longitude 105° 25´ E

Surface Area	**10.8 square miles (28 sq km)**
Remaining Surface Area	**3 square miles (8 sq km)**
Range of the Explosion	**2,900 miles (4,600 km)**
Range of Debris	**1,550 miles (2,500 km)**
Tsunami Victims	**36,000**



3 AFTER
A crater nearly 4 miles (6.4 km) in diameter was left where the volcano had been. About 1927, new volcanic activity was observed in the area. In 1930, a cone emerged. Anak Krakatoa ("daughter of Krakatoa") appeared in 1952; it grows at a rate of nearly 15 feet (4.5 m) per year.

FRACTION
Two thirds of the island was destroyed, and only a part of Rakata survived the explosion.

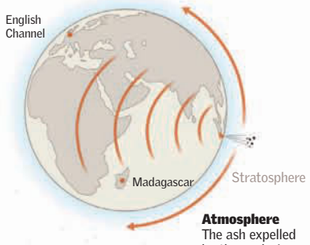
Aftereffects

The ash released into the atmosphere left enough particles suspended in the air to give the Moon a blue tinge for years afterward. The Earth's average temperature also decreased.

Long-Term Effects

WATER LEVEL
The water level fluctuated as far away as the English Channel.

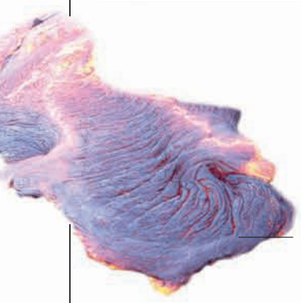
PRESSURE WAVE
The atmospheric pressure wave went around the world seven times.



Atmosphere
The ash expelled by the explosion lingered for years

Aftermath of Fury

When a volcano becomes active and explodes, it sets in motion a chain of events beyond the mere danger of the burning lava that flows down its slopes. Gas and ash are expelled into the atmosphere and affect the local climate. At times they interfere with the global climate, with more devastating effects. The overflow of lakes can also cause mudslides called lahars, which bury whole cities. In coastal areas, lahars can cause tsunamis. ●



LAVA FLOWS

In volcanoes with calderas, low-viscosity lava can flow without erupting, as with the Laki fissures in 1783. Low-viscosity lava drips with the consistency of clear honey. Viscous lava is thick and sticky, like crystallized honey.

LAVA IN VOLCANO NATIONAL PARK, HAWAII



CINDER CONE

Cone with walls of hardened lava.

As the lava flows upward, the cone explodes.

MOLDS OF TREES

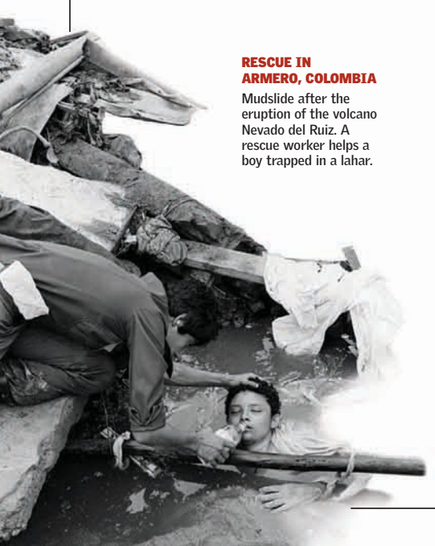
Burned tree underneath cooled lava.

The petrified mold forms a minivolcano.

LAVA TUBES

Outer layer of hardened lava.

Inside, the lava stays hot and fluid.



RESCUE IN ARMERO, COLOMBIA

Mudslide after the eruption of the volcano Nevado del Ruiz. A rescue worker helps a boy trapped in a lahar.

MUDSLIDES OR LAHARS

Rain mixed with snow and melted by the heat, along with tremors and overflowing lakes, can cause mudslides called "lahars." These can be even more destructive than the eruption itself, destroying everything in their path as they flow downhill. They occur frequently on high volcanoes that have glaciers on their summit.



ARMERO FROM ABOVE

On Nov. 13, 1985, the city of Armero, Colombia, was devastated by mudslides from the eruption of the volcano Nevado del Ruiz.

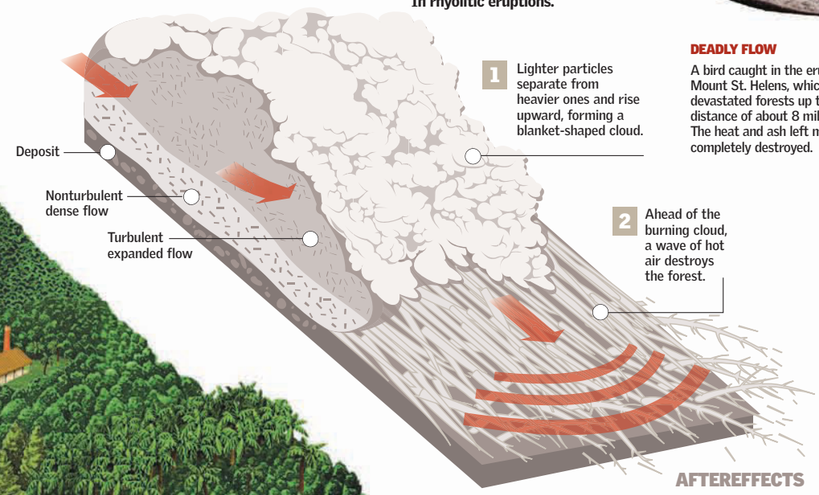
PYROCLASTIC FLOW

Incandescent masses of ash, gas, and rock fragments that come from sudden explosive eruptions flow downhill at high temperature, burning and sweeping away everything in their path.

SPEED
61-132 miles per hour (100-200 km/h)

TEMPERATURE
930-1830° F (500-1000° C)

RANGE
30-61 miles per hour (50-100 km/h)
In rhyolitic eruptions.





DEADLY FLOW

A bird caught in the eruption of Mount St. Helens, which devastated forests up to a distance of about 8 miles (13 km). The heat and ash left many acres completely destroyed.

AFTEREFFECTS



OPTICAL EFFECTS

Particles of volcanic ash intensify yellow and red colors. After the eruption of Tambora in Indonesia in 1815, unusually colorful sunrises were seen worldwide.

RISING RIVERS

QUAKES

The underground action of magma and gas creates pressure that, in turn, causes movement in the Earth's crust. The quakes can be warning signs of an impending eruption.

GRAPHICAL RECONSTRUCTION

Aerial photo of a small fishing village on San Vicente Island, covered in volcanic ash. This eruption had no victims.

Jets of Water

Geysers are intermittent spurts of hot water that can shoot up dozens of yards into the sky. Geysers form in the few regions of the planet with favorable hydrogeology, where the energy of past volcanic activity has left water trapped in subterranean rocks. Days or weeks may pass between eruptions. Most of these spectacular phenomena are found in Yellowstone National Park (U.S.) and in northern New Zealand. ●

The eruptive cycle

5. THE CYCLE REPEATS
When the water pressure in the chambers is relieved, the spurt of water abates, and the cycle repeats. Water builds up again in cracks of the rock and in permeable layers.

On average, a geyser can expel up to
7,900 gallons
(30,000 l) OF WATER

4. SPURTING SPRAY
The water spurts out of the cone at irregular intervals. The lapse between spurts depends on the time it takes for the chambers to fill up with water, come to a boil, and produce steam.

The average height reached of the spurt of water is about
148 feet
(45 m)

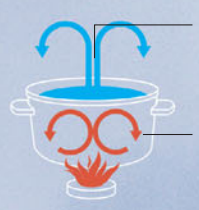
3. BURSTING FORTH
The water rises by convection and spurts out the main vent to the chimney or cone. The deepest water becomes steam and explodes outward.

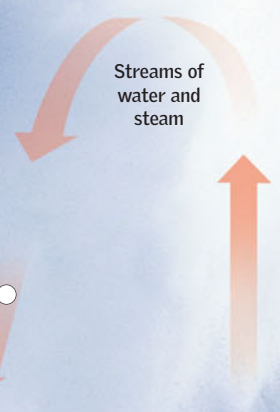
2. MOUNTING PRESSURE
The underground chambers fill with water, steam, and gas at high temperatures, and these are then expelled through secondary conduits to the main vent.

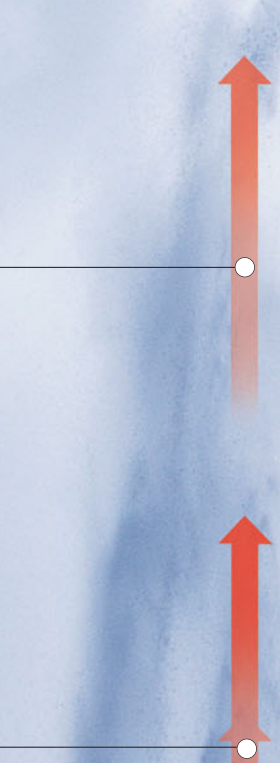
1. HEATED WATER
Thousands of years after the eruption of a volcano, the area beneath it is still hot. The heat rising from the magma chambers warms water that filters down from the soil. In the subsoil, the water can reach temperatures of up to 518° F (270° C), but pressure from cooler water above keeps it from boiling.

Temperatures up to
194°F
(90° C)

CONVECTION FORCES
This is a phenomenon equivalent to boiling water.







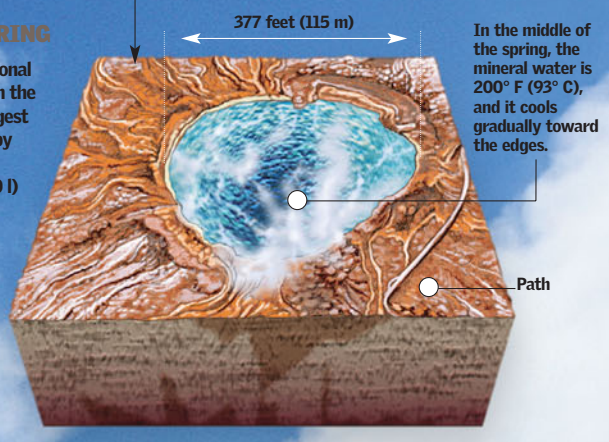
PRINCIPAL GEOTHERMAL FIELDS

There are some 1,000 geysers worldwide, and 50 percent are in Yellowstone National Park (U.S.).



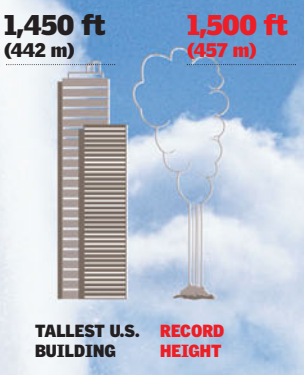
GRAND PRISMATIC SPRING

This spring, in Yellowstone National Park, is the largest hot spring in the United States and the third largest in the world. It measures 246 by 377 feet (75 by 115 m), and it emits about 530 gallons (2,000 l) of water per minute. It has a unique color: red mixed with yellow and green.



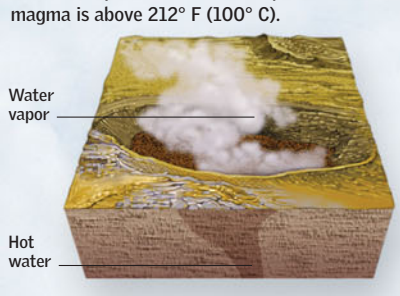
DISCHARGE
530 gallons
(2,000 l)
OF WATER PER MINUTE

RECORD HEIGHT
In 1904, New Zealand's Waimangu geyser (now inactive) emitted a record-setting spurt of water. In 1903, four tourists lost their lives when they unknowingly came too close to the geyser.



OTHER POSTVOLCANIC ACTIVITY

FUMAROLE
This is a place where there is a constant emission of water vapor because the temperature of the magma is above 212° F (100° C).

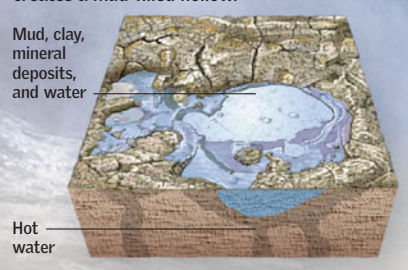


SOLFATARA
The thermal layers emit sulfur and sulfurous anhydride.



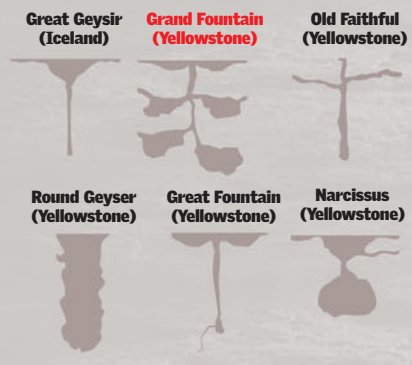
TERRACES
These are shallow, quickly drying pools with stair-step sides.

MUD BASIN
These basins produce their own mud; sulfuric acid corrodes the rocks on the surface and creates a mud-filled hollow.



MORPHOLOGY OF THE CHAMBERS

The heat of a magma chamber warms water in the cavity, the chamber fills, and the water rises to the surface. The pressure in the cavity is released, and the water suddenly boils and spurts out.



MINERAL SPRINGS

Their water contains many minerals, known since antiquity for their curative properties. Among other substances, they include sodium, potassium, calcium, magnesium, silicon oxide, chlorine, sulfates (SO4), and carbonates (HCO3). They are very helpful for rheumatic illnesses.

Steam Energy
In Iceland, geothermic steam is used not only in thermal spas but also to power turbines that generate most of the country's electricity.

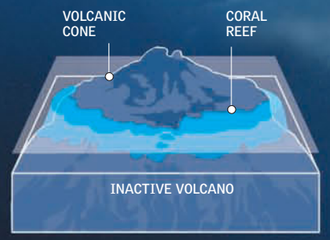


Rings of Coral

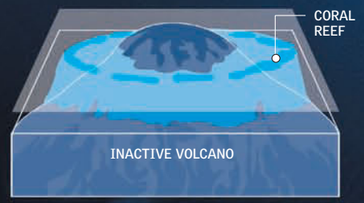
In the middle of the ocean, in the tropics, there are round, ring-shaped islands called atolls. They are formed from coral reefs that grew along the sides of ancient volcanoes that are now submerged. As the coral grows, it forms a barrier of reefs that surround the island like a fort. How does the process work? Gradually, volcanic islands sink, and the reefs around them form a barrier. Finally, the volcano is completely submerged; no longer visible, it is replaced by an atoll.

FORMATION OF AN ATOLL

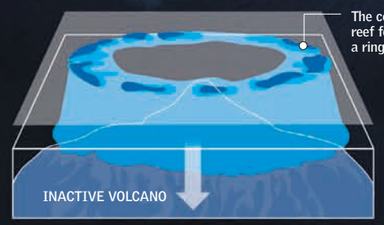
1. THE BEGINNING OF AN ATOLL. The undersea flanks of an extinct volcano are colonized by corals, which continue to grow.



2. THE CORALS GAIN GROUND. As the surrounding reef settles and continues to expand, it becomes a barrier reef that surrounds the summit of the ancient volcano, now inactive.



3. THE ATOLL SOLIDIFIES. Eventually the island will be completely covered and will sink below the water, leaving a ring of growing coral with a shallow lagoon in the middle.



ATOLLS AND VOLCANIC ISLANDS AROUND THE WORLD

Coral reefs are found in the world's oceans, usually between the Tropic of Cancer and the Tropic of Capricorn.





OPTIMAL CONDITIONS

Coral is mainly found in the photic zone (less than 165 feet [50 m] deep), where sunlight reaches the bottom and provides sufficient energy. For reefs to grow, the water temperature should be between 68° and 82° F (20-28° C).



Country	Republic of Kiribati
Ocean	North Pacific
Archipelago	Gilbert Islands
Surface area	10.8 square miles (28 sq km)
Altitude	6.9 ft (2.1 m)

LEGEND
● Town ✪ Capital

REEF LEVELS

CREST Barrier that protects the shore from waves. Deep grooves and tunnels let seawater inside the reef.

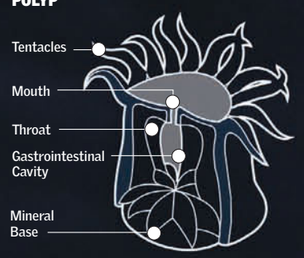
FACE Branching corals grow here, though colonies can break loose because of the steep slope.

HAWAIIAN ARCHIPELAGO

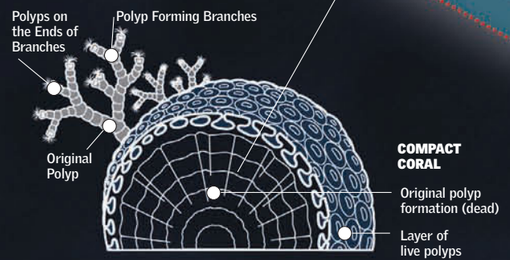
WHAT ARE CORALS?

Corals are formed from the exoskeletons of a group of Cnidarian species. These marine invertebrates have a sexual phase, called a medusa, and an asexual phase, called a polyp. The polyps secrete an outer skeleton composed of calcium carbonate, and they live in symbiosis with one-celled algae.

HARD CORAL POLYP



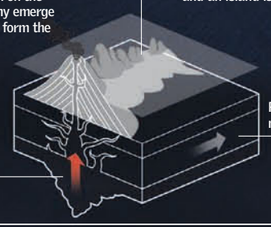
BRANCHING CORAL

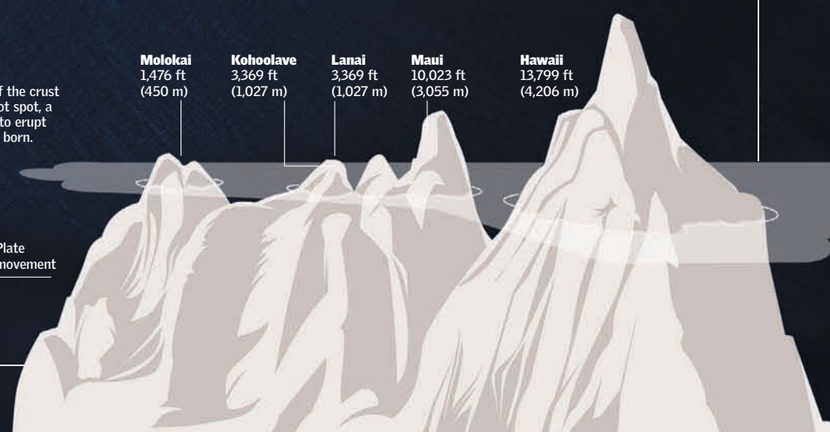


FORMATION OF A VOLCANIC ISLAND

A Volcanoes form when magma rises from deep within the Earth. Thousands of volcanoes form on the seafloor, and many emerge from the sea and form the base of islands.

B When a plate of the crust moves over a hot spot, a volcano begins to erupt and an island is born.





Frozen Flame

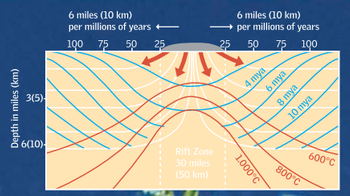
It is known as the land of ice and fire. Under Iceland's frozen surface there smolders a volcanic fire that at times breaks free and causes disasters. The island is located over a hot spot on the Central Atlantic Ridge. In this area the ocean bed is expanding, and large quantities of lava flow from vents, fissures, and craters.



ICELAND
Latitude 64° 6′ N
Longitude -21° 54′ E

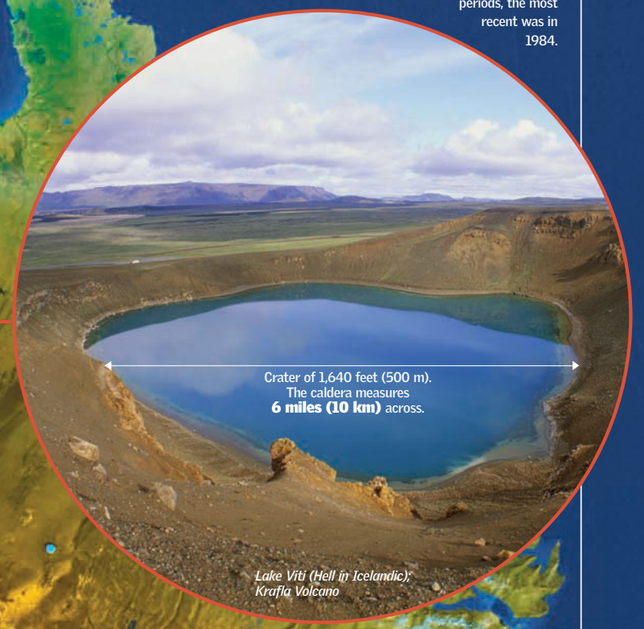
Surface Area	39,768 sq miles (103,000 sq km)
Population	293,577
Population density	1 per sq mile (2.8 per sq km)
Area of lakes	1,064 sq miles (2,757 sq km)
Glaciers	4,603 sq miles (11,922 sq km)

1/5
of all the lava that has emerged on the Earth's surface since 1500 has come from Iceland.



RIFT ZONE
If the rift zone that crosses the island from southwest to north were cut in two, different ages of the Earth would be revealed according to the segment being analyzed. For example, the rock 60 miles (100 km) from the rift is six million years old.

KAFLA VOLCANIC CRATER
This volcano has been very active throughout history. Of its 29 active periods, the most recent was in 1984.



Lake Viti (Hell in Icelandic); Krafla Volcano

ENERGY
The islanders use geothermal (steam) energy from volcanoes and geysers for heat, hot water, and electric energy.

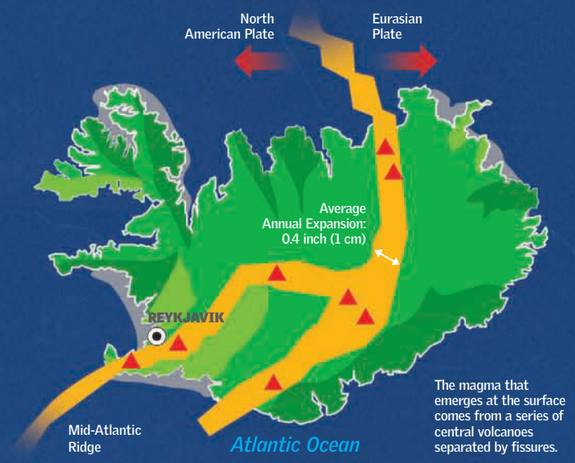
REYKJAVIK
The capital of Iceland is the northernmost capital in the world.

ERUPTION UNDER THE ICE
In 1996 a fissure opened up between Grimsvötn and Bardarbunga. The lava made a hole 590 feet (180 m) deep in the ice and released a column of ash and steam. The eruption lasted 13 days.



Split Down the Middle

Part of Iceland rests on the North American Plate, which is drifting westward. The rest of Iceland is on the Eurasian Plate, drifting eastward. As tectonic forces pull on the plates, the island is slowly splitting in two and forming a fault. The edges of the two plates are marked by gorges and cliffs. Thus, the ocean bed is growing at the surface.



The magma that emerges at the surface comes from a series of central volcanoes separated by fissures.

Birth of an Island

On Nov. 15, 1963, an undersea volcanic eruption off the southern coast of Iceland gave rise to the island of Surtsey, the newest landmass on the planet. The eruption began with a large column of ash and smoke. Later, heat and pressure deep within the Earth pushed part of the Mid-Atlantic Ridge to the surface. The island kept growing for several months, and today it has a surface area of 1.0 square mile (2.6 sq km). The island was named after Surtur, a fire giant from Icelandic mythology.



1 The first eruptions were caused by the interaction of magma and water. The explosions were infrequent, and rocks were thrown only a few yards from the volcano.



2 Repeated eruptions expelled vapor and ash into the air, forming a column over 6 miles (10 km) high. The island was formed from volcanic blocks and masses of lava.



3 The entire process lasted three-and-a-half years. Over 0.25 cubic mile (1 cu km) of lava and ash was expelled, with only 9 percent of it appearing above sea level.

Study and Prevention

INCANDESCENT ROCK
A river of lava from Mt. Kilauea flows constantly, forming surface wrinkles that deform under the lightest step.

LATENT DANGER 46-47

LEARN MORE 48-49

PREPARATIONS FOR DISASTER 50-51

BURIED IN A DAY 52-55

ERUPTIONS THROUGH TIME 56-57



Large eruptions often give warning signs months in advance. These signs consist of any observable manifestation on the exterior of the Earth's crust. They may include emissions of steam, gases, or ash and rising temperatures in the lake that typically forms in the crater. This is why volcanic seismology is considered one of the most useful tools for protecting nearby towns. Several seismic recording stations are typically placed around the cone of an active volcano. Among other things, the readings scientists get give them a clear view of the varying depths of the volcano's tremors-extremely important data for estimating the probability of a major eruption. ●

Latent Danger

Some locations have a greater propensity for volcanic activity. Most of these areas are found where tectonic plates meet, whether they are approaching or moving away from each other. The largest concentration of volcanoes is found in a region of the Pacific known as the "Ring of Fire." Volcanoes are also found in the Mediterranean Sea, in Africa, and in the Atlantic Ocean.

Arctic Ocean

AVACHINSKY
Russia
This is a young, active cone inside an old caldera, on the Kamchatka peninsula.

NOVARUPTA
Alaska, U.S.
It is in the Valley of Ten Thousand Smokes.

MOUNT ST. HELENS
Washington, U.S.
It had an unexpected, violent eruption in 1980.

The Pacific "Ring of Fire"

Formed by the edges of the Pacific tectonic plate, where most of the world's volcanoes are found.

ASIA

FUJIYAMA
Japan
This sacred mountain is the country's largest volcano.

PINATUBO
Philippines
In 1991 it had the second most violent eruption of the 20th century.

50 Volcanoes

Indonesia has the highest concentration of volcanoes in the world. Java alone has 50 active volcanoes.

MAUNA LOA
Hawaii, U.S.
The largest active volcano on Earth is rooted in the ocean floor and takes up nearly half of the island.

KILAUEA
Hawaii, U.S.
The most active shield volcano, its lava flows have covered more than 40 square miles (100 sq km) since 1983.

KRAKATOA
Indonesia
Its 1883 eruption destroyed an entire island.

TAMBORA
Indonesia
In 1815 it produced 35 cubic miles (150 cu km) of ash. It was the largest recorded eruption in human history.

OCEANIA

Pacific Ocean

EAST EPI
Vanuatu
This is an undersea caldera with slow eruptions lasting for months.

Subduction

Most volcanoes in the western United States were formed by subduction of the Pacific Plate.

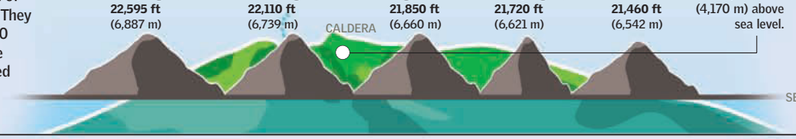
Indian Ocean

AUSTRALIAN PLATE

PACIFIC PLATE

The tallest

These are found in the middle of the Andes range, which forms part of the Pacific Ring of Fire. They were most active 10,000 years ago, and many are now extinct or dampened by fumarolic action.



The "top five" list changes when the volcanoes are measured from the base rather than from their altitude above sea level.

60

volcanoes erupt per year.

EURASIAN PLATE

Iceland

The western half of Iceland lies on the North American Plate, but the eastern half is on the Eurasian Plate.

ELDFELL
Iceland
During one eruption, it expelled 3,500 cubic feet (100 cu m) of lava per second.

ASIA

VESUVIUS
Italy
Erupted twice during the 20th century.

EUROPE

NORTH AMERICA

NORTH AMERICAN PLATE

The Antilles

The Lesser Antilles is a volcanically active region.

ETNA
Italy
10,990 feet (3,350 m) high; has been active for thousands of years.

CENTRAL AMERICA

Atlantic Ocean

AFRICA

MT. PELÉE
Martinique
Its eruption completely destroyed the city of Saint-Pierre and its port in 1902.

Indian Ocean

NAZCAN PLATE

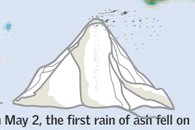
SOUTH AMERICA

OJOS DEL SALADO
Chile/Argentina
The tallest volcano in the world, its last eruption was in 1956.

SOUTH AMERICAN PLATE

AFRICAN PLATE

1



On May 2, the first rain of ash fell on Saint-Pierre. The sky around the island was darkened for several days.

2



On May 5, near the summit, the caldera Etang Sec ruptured, releasing the water that it contained. A large lahar formed.

3



On May 8, Saint-Pierre was destroyed by a burning cloud that devastated an area of 22 square miles (58 sq km), killing all 28,000 inhabitants.

ANTARCTIC PLATE

Danger

The most dangerous volcanoes are those located near densely populated areas, such as in Indonesia, the Philippines, Japan, Mexico, and Central America.

Increasing Knowledge

Volcanology is the scientific study of volcanoes. Volcanologists study eruptions from airplanes and satellites, and they film volcanic activity from far off. However, to study the inner workings of a volcano up close, they must scale near-vertical cliffs and face the dangers of lava, gas, and mudslides. Only then can they take samples and set up equipment to detect tremors and sounds.

SAMPLING OF VOLCANIC GASES
Gas and water vapor dissolved in magma provides the energy that powers eruptions. Visible emissions, such as sulfur and steam, are measured, as are invisible gases. Analyzing the gases' composition makes it possible to predict the beginning and end of an eruption.

GAS MASK

VACUUM TUBE

TITANIUM TUBE

Volcanologists Taking Gas Samples from a Fumarole on Lipari Island, Italy

Field Measurements

Monitoring a volcano includes gathering and analyzing samples and measuring various phenomena. Seismic movements, varying compositions of gases, deformations in the rock, and changes in electromagnetic fields induced by the movement of underground magma can all provide clues to predict volcanic activity.

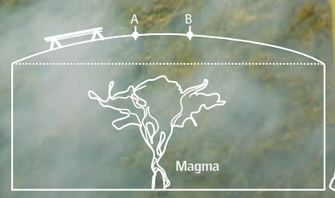
FUMAROLE

GAS ESCAPING FROM CRACK

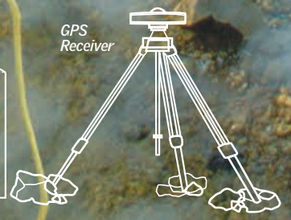


Thermopar

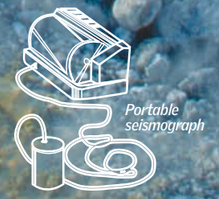
LAVA TEMPERATURE
is measured with a thermometer called a Thermopar; glass thermometers would melt from the heat. Temperatures of water and of nearby rocks are other variables to take into account.



TILTOMETERS
These are placed on the slopes of a volcano to record soil changes that precede an eruption. Points are determined (A-B) to monitor how pressure from the magma deforms the surface between them.



GLOBAL POSITIONING SYSTEM (GPS)
Movements in the magma cause hundreds of cracks in the cone. A GPS system records images continuously and analyzes the deformation over a period of time.



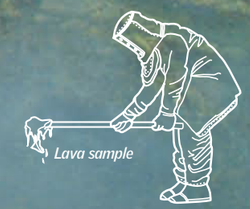
TEMBLORS OR EARTHQUAKES
Portable seismographs are used to detect movements in the ground within 6 miles (10 km) of the volcano that is being studied. These tremors can give clues about the movements of the magma.



THE SIZE OF THE CRATER
The widening of the crater caused by volcanic activity and the growth of the solid lava domes are measured. This growth implies certain risks for the proximity of an eruption.



HYDROLOGICAL MONITORING
Mudslides, or lahars, can bury large areas. Monitoring the volume of water in the area makes it possible to alert and evacuate the population when the amount of water passes critical points.



LAVA COLLECTION
The study of lava can determine its mineral composition and its origin. Lava deposits are also analyzed because the history of a volcano's eruptions can give clues about a future eruption.

Preparations for Disaster

Volcanic eruptions are dangerous to surrounding populations for two basic reasons. One danger is posed by the volcanic material that flows down the sides of the volcano (lava flows and mudslides), and the other danger is from the volcano's pyroclastic material, especially ash. Ash fallout can bury entire cities. Experts have developed an effective series of prevention and safety measures for people living in volcanic areas. These measures greatly reduce the highest risks.

Before an Eruption

It is best to get informed about safety measures, evacuation routes, safe areas, and alarm systems before a volcanic eruption. Other safety measures include stocking up on nonperishable food, obtaining gas masks and potable water, and checking the load-bearing capacity of roofs.

Do not carry more than **44 pounds (20 kg)** OF PROVISIONS.

Evacuation of Nearby Areas

In the immediate area (within 12 miles [20 km]) of the volcano, evacuation is the only possible safety measure. Returning home will be possible only when permission is given. Keep in mind that it takes a long time for life to return to normal after an evacuation.

MEDICAL PRECAUTIONS
Keep a first-aid kit and essential medications on hand, and keep vaccinations up to date.

SHUT OFF UTILITIES
Before leaving a house, shut off the electricity, gas, and water. Tape doors and windows shut.

PROVISIONS
Water and food are indispensable, especially if you evacuate the area on your own.

CIVIL DEFENSE
Follow all recommendations, be alert to official information, and do not spread rumors.

RIVERS AND STREAMS
Large volumes of water pose a threat of mudslides. Avoid these areas.

MAIN ROUTES
These usually cross low-lying areas. They can be a potential path for flows of lava or mud.

BRIDGES
When possible, do not use for your evacuation route because they might collapse.

HIGHER ELEVATIONS
These are the preferred sites for evacuations from volcanic eruptions. High ground is safe from lahars and lava flows, and if there is shelter there, it is also safe from rains of ash.

12 miles (20 km)

60 miles (100 km)

LAHARS AND PYROCLASTIC FLOWS
Lahars (mudflows) can form from rainwater or melting snow. Volcanic danger zones often have strategies to divert rivers and reduce the volume of water in dams and reservoirs.

12 miles (20 km)
Considered to be the critical distance from a volcano in emergency relief efforts.

WIND AND RAIN
Wind is a risk factor that spreads volatile ash over a large area so that settlements at a distance greater than 60 miles (100 km) can be affected. The greatest danger posed by falling ash is that it can mix with rain falling on the roofs of houses and form a heavy mass that will collapse the buildings.

Areas of Falling Ash

Most of the population lives outside the volcano's range, but ash from an eruption can become highly volatile and fall over wide areas. Wind can carry ash to other areas, so the best preventive efforts are focused on warning people about what to do in case of falling ash.

ALTERNATIVE ROUTES
Roads running through higher elevations are preferred because they cannot be reached by lava and mudflows.

WATER TANK
Roof-mounted water tanks should be disconnected and covered until the roof has been cleared of ashes.

AT HOME
It is best to stay indoors during an ashfall. One of the main precautions is to provide for potable drinking water, because the usual water supply will be interrupted because of pollution risks, especially if the water supply comes from lakes or rivers in the area.

ASH ON THE ROOF
Ash should be removed immediately (before it rains) so the roof does not collapse.

AIR CONDITIONING
Air conditioners and large clothes dryers should not be used during an eruption.

MASKS
Use masks and special ash-protective clothing when outdoors.

DOORS AND WINDOWS
It is best to always leave doors and windows shut tightly, as airtight as possible, for as long as the ashfall continues.

STAY CALM
To breathe, cover your face with a handkerchief soaked in water and vinegar.

INFORMATION
Listen to the radio at all times.

DO NOT WASH WITH WATER.
After the ashfall, washing with water will form a sticky and heavy paste that will be very hard to remove.

CHILDREN
If children are at school, do not go to pick them up: they will be safe there.

AVOID DRIVING
If you must drive, do so slowly and turn on your headlights. It is best to leave the car parked in an enclosed space or under cover.

Buried in One Day

At noon on Aug. 24, AD 79, Mount Vesuvius erupted near the coast of Naples Bay. The Roman cities of Pompeii and Herculaneum were completely buried in ashes and pyroclasts, in what would become one of the worst natural tragedies of ancient times. Many details from that day have reached us thanks to the narrative of Pliny the Younger. His well-known description of the eruption column as "shaped like a pine" caused this type of eruption to be named after him: a "Plinian eruption."

10 A.M.

1 AN ALMOST NORMAL DAY
Tremors and earthquakes had been felt in the city for four days. Hanging lamps swayed, furniture moved, and some door frames had even cracked. Because these things happened about once a year without any consequences, the inhabitants of Pompeii continued with their normal lives. The public forum was filled with people. The festivities of Isis were celebrated in the temple of Apollo.

POMPEII'S FORUM
This was the political, religious, and commercial heart of the city. Every day the forum was alive with Pompeii's citizens, as it was on August 24.

1 P.M.

2 THE ERUPTION.
Suddenly Vesuvius spewed out a huge column of smoke, lava, and ash that formed a pyroclastic flow moving toward Pompeii. People ran in all directions seeking refuge in houses. The roughness of the sea made escape by water impossible.

RICHES
Several precious objects such as this gold bracelet have been unearthed.

RAIN OF STONES
Moments after the eruption, incandescent pumice stones fell from the sky.

23 feet (7 m)
The maximum depth of the ashes.

The Violent Awakening

Mount Vesuvius had been inactive for more than 800 years, until the pressure that had accumulated inside produced its explosion in the year 79. Most of the deaths during this tragedy were originally blamed on the ash that buried parts of the neighboring settlements (Herculaneum and Stabiae, as well as Pompeii). Now, though, the eruption is believed to have produced the typical "burning clouds" of a Plinian eruption: Flames of incandescent ash and gases were expelled at high speeds by the eruptive pressure. Suspended moist particles charged the air with electricity, causing an intense electric storm, whose flashes of lightning would have been the only source of light under the ashfall. Since then Vesuvius has had a dozen other important eruptions. The worst killed 4,000 people in 1631. The first volcanology observatory in the world was installed at Vesuvius in 1841.



POMPEII, ITALY
Latitude 40° 49′ N
Longitude 14° 26′ E

Distance from Vesuvius	6 miles (10 km)
Population in the year AD 79	20,000 people
Current population	27,000 people
Ash dispersion (79)	60 miles (100 km) (SE)
Last Eruption of Vesuvius	1944

9 P.M.

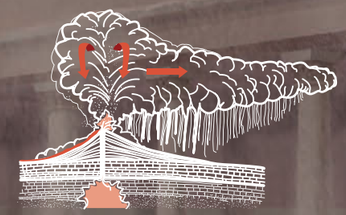
3 A TWO-DAY NIGHT
The tongues of lava from the volcano were seen better at night. The next morning the Sun's light could not be seen through the ash cloud. Pliny's narrative mentions a constant rain of pyroclasts, continuing on the following morning, and emissions of sulfuric gases that killed many people. Many sought shelter on the beaches. Only on August 26 did the ashfall begin to disperse.

SEQUENCE OF THE ERUPTION

For more than 20 hours (the time the eruption lasted), the ash column rose and then fell on the surrounding area.



1 After the first explosion, the column of smoke began its vertical climb. The wind blew it toward the southeast.



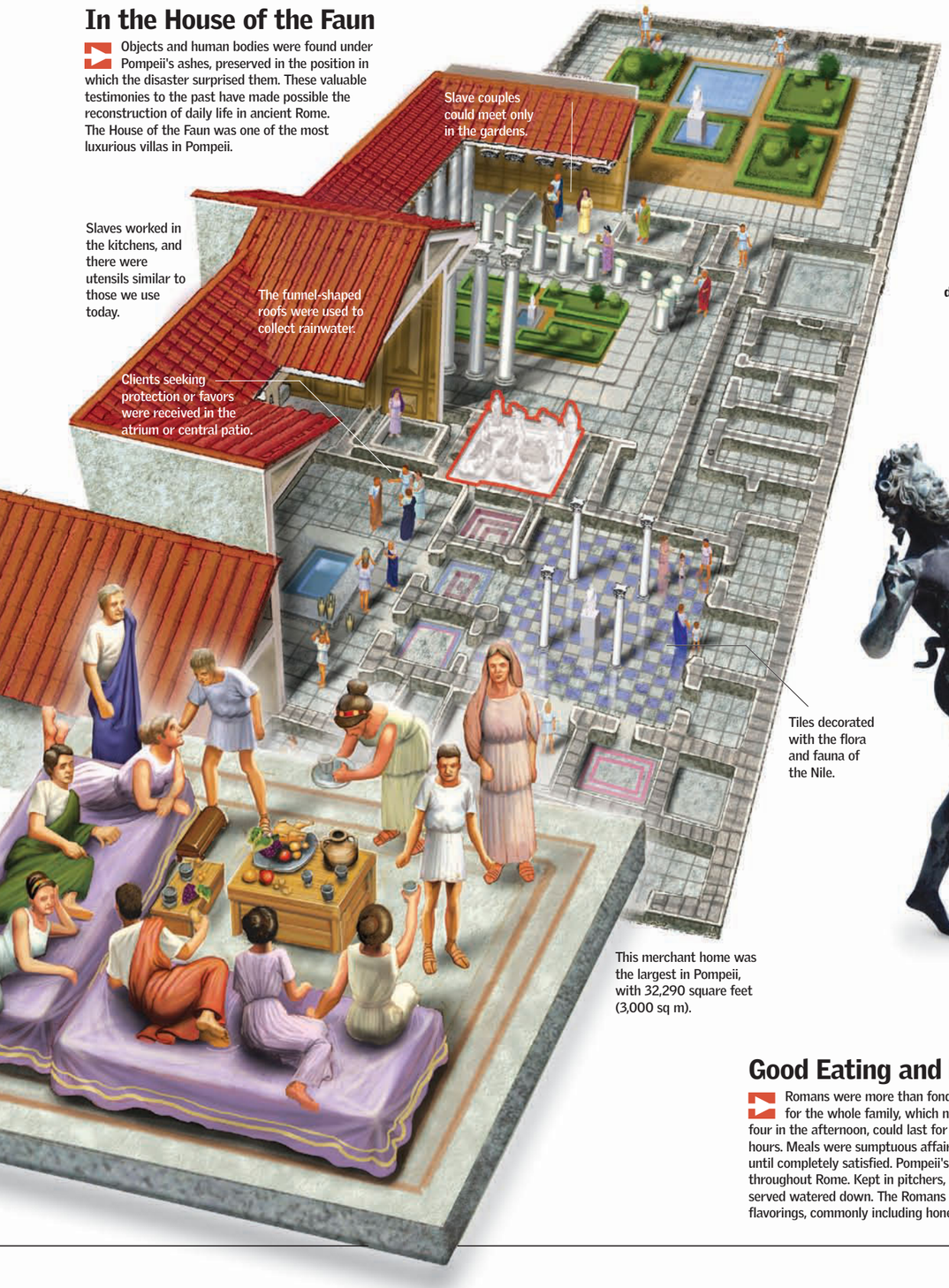
2 The cloud spread nearly 60 miles (100 km) from side to side, and ash fell on the city for a whole day.



3 By 7:30 A.M. on August 25, the pyroclastic flows reached Pompeii. These flows are estimated to have reached temperatures of 1,022° F (550° C).

In the House of the Faun

Objects and human bodies were found under Pompeii's ashes, preserved in the position in which the disaster surprised them. These valuable testimonies to the past have made possible the reconstruction of daily life in ancient Rome. The House of the Faun was one of the most luxurious villas in Pompeii.



This merchant home was the largest in Pompeii, with 32,290 square feet (3,000 sq m).



BRONZE FAUN
The name given to the house is from this statue found in the villa's atrium. The faun was considered a wild deity, with the ability to predict the future.

Good Eating and Drinking

Romans were more than fond of feasts. A dinner for the whole family, which normally began at four in the afternoon, could last for more than four hours. Meals were sumptuous affairs, and no one left until completely satisfied. Pompeii's wine was famous throughout Rome. Kept in pitchers, it was always served watered down. The Romans sometimes added flavorings, commonly including honey and pepper.



As in That Moment

In 1709, some of Pompeii's artifacts were found buried under volcanic ash, and that started a treasure hunt. It was not until 1864, though, that reconstruction and conservation of materials began with the work of Giuseppe Fiorelli. The exhibits that are the most fascinating to people who visit Pompeii's ruins today (about two million people every year) are his reconstructions of the bodies.

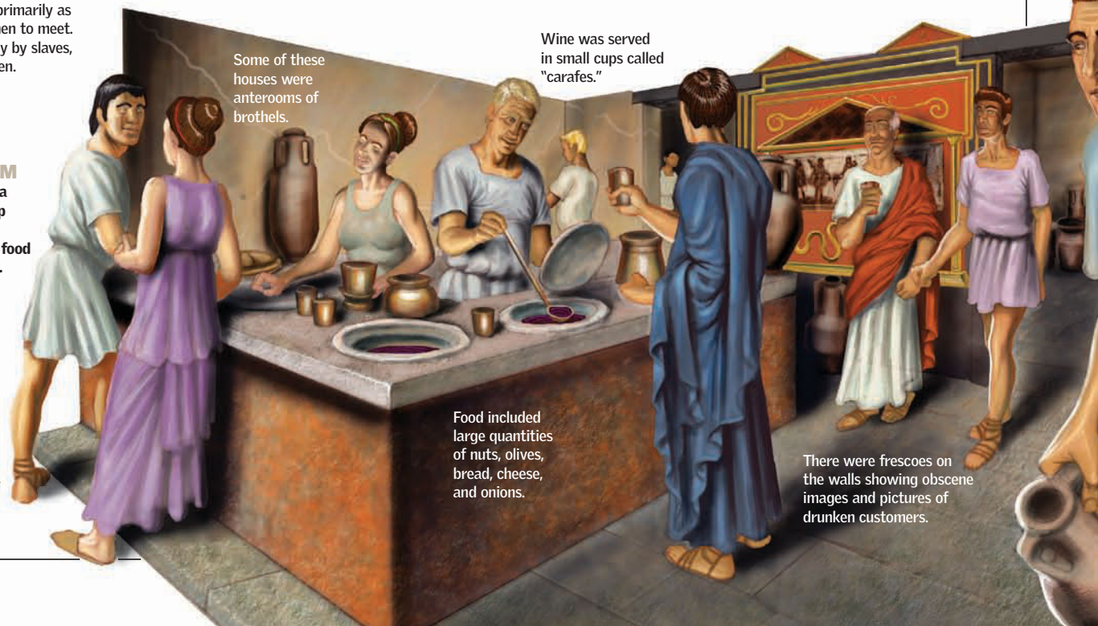


In a Pompeii Bar

There were several types of food and drink establishments in Pompeii, from food vendors in the streets to luxury services. These food places served many different social purposes but acted primarily as places for businessmen to meet. They were run mostly by slaves, men as well as women.

THE THERMOPOLIUM
The typical bar had a long marble tabletop with embedded containers in which food could be kept warm.

200
was the approximate number of places of this type in the city.



1 THE CATASTROPHE
Several corpses were covered by volcanic ash, which had accumulated in layers and later hardened. The bodies had decomposed, but their forms were molded in the volcanic rock.

2 RECONSTRUCTION
The work of Fiorelli was to fill these natural "tombs" (ash molds) with plaster. When the plaster hardened, the surrounding layers of ash were removed, leaving the outlines or molds of the bodies.



3 THE FORM, UNTOUCHED
Making plaster casts allowed precise reconstructions of the people's postures at the time of the disaster, and we have been able to learn details such as the hairstyles and dress of these people. Animal forms and other organic objects have also been reconstructed. Today the use of resins and silicones makes it possible to obtain even greater detail.

Historic Eruptions

The lava falls and flows, sweeping away everything in its path. This happens in a slow, uninterrupted way, and the lava destroys entire cities, towns, and forests and claims thousands of human lives. One of the most famous examples was the eruption of Mount Vesuvius in AD 79, which wiped out two cities and two cultures, those of Pompeii and Herculaneum. In the 20th century, the eruption of Mount Pelée destroyed the city of Saint-Pierre in Martinique in a few minutes and instantly killed almost its entire population. Volcanic activity also seems to be closely related to changes in climate.

AD 79

MOUNT VESUVIUS
Naples, Italy

Volume of ejected ash in cubic feet (cu m)	**141,000 (4,000)**
Victims	**2,200**
Characteristics	**Active**

The cities of Pompeii and Herculaneum were destroyed in AD 79 when Mount Vesuvius erupted. Until that day, it was not known that the mountain was a volcano because it had been inactive for over 300 years. This was one of the first eruptions to be recorded: Pliny the Younger stated in one of his manuscripts that he had seen how the mountain exploded. He described the gas and ash cloud rising above Vesuvius and how thick, hot lava fell. Many people died because they inhaled the poisonous gases.

Volcanoes and Climate

There is a strongly supported theory that relates climate changes to volcanic eruptions. The idea of linking the two phenomena is based on the fact that explosive eruptions spew huge amounts of gases and fine particles high into the stratosphere, where they spread around the Earth and remain for years. The volcanic material blocks a portion of solar radiation, reducing air temperatures around the world. Perhaps the most notable cold period related to volcanic activity was the one that followed the eruption of Tambora in 1815. Some areas of North America and Europe had an especially harsh winter.

KALAPANA. After the Kilauea volcano (Hawaii) erupted in 1991, a lava flow advanced on the city, covering everything in its path.

1783

LAKI VOLCANO
Iceland

Volume of ejected ash in cubic feet (cu m)	**490 billion (14 billion)**
Victims	**10,000**
Characteristics	**Very active**

In spite of the fact that the eruptions are related to conic forms, most of the volcanic material comes out through fractures in the crust, called "fissures." The fissure eruptions of Laki were the greatest in Iceland; they created more than 20 vents in a distance of 15 miles (25 km). The gases ruined grasslands and killed livestock. The subsequent famine took the lives of 10,000 people.

1815

TAMBORA VOLCANO
Indonesia

Volume of ejected ash in cubic feet (cu m)	**100 billion (3 billion)**
Victims	**10,000**
Characteristics	**Stratovolcano**

After giving off fumes for seven months, Tambora erupted, and the ensuing catastrophe was felt around the globe. The ash cloud expanded to more than 370 miles (600 km) away from the epicenter of the eruption, and it was so thick that it hid the Sun for two days. The ashfall covered an area of 193,051 square miles (500,000 sq km). It is considered to be the most destructive volcanic explosion that ever took place. More than 10,000 people died during the eruption, and 82,000 died of illness and starvation after the eruption.

1883

KRAKATOA VOLCANO
Java, Indonesia

Volume of ejected ash in cubic feet (cu m)	**670 billion (19 billion)**
Victims	**36,000**
Characteristics	**Active**

Even though Krakatoa began to announce its forthcoming eruption with clouds of vapor and smoke, these signs, instead of preventing a disaster, became a tourist attraction. When the explosion took place, it destroyed two thirds of the island. Stones shot from the volcano reached a height of 34 miles (55 km)-beyond the stratosphere. A crater 4 miles (6.4 km) in diameter opened a chasm 820 feet (250 m) deep. Land and islands were swept bare.

1902

MOUNT PELÉE
Martinique, Antilles

Volume of ejected ash in cubic feet (cu m)	**No figures available**
Victims	**30,000**
Characteristics	**Stratovolcano**

A burning cloud and a thick mass of ash and hot lava were shot from this small volcano that completely destroyed the port city of Saint-Pierre. Most striking is the fact that this destruction took place in only a few minutes. The energy released was so great that trees were uprooted. Almost the entire population died, and only three people survived, one of them because he was trapped in the city jail.

1944

MOUNT VESUVIUS
Naples, Italy

Volume of ejected ash in cubic feet (cu m)	**No figures available**
Victims	**2,000**
Characteristics	**End of a cycle**

With this last activity, the Vesuvius volcano ended the cycle of eruptions it began in 1631. This explosion, along with the previous one in 1906, caused severe material damage. The eruptions were responsible for more than 2,000 deaths from avalanches and lava bombs. Additionally, the 1944 eruption took place during World War II and caused as much damage as the eruption at the beginning of the 20th century had, because it flooded Somma, Atrio de Cevallo, Massa, and San Sebastiano.

1973

ELDFELL VOLCANO
Heimaey Islands, Iceland

Volume of ejected ash in cubic feet (cu m)	**No figures available**
Victims	**0**
Characteristics	**656 feet (200 m)**

The lava advanced, and it appeared that it would take everything in its path. Volcanologists decided that Heimaey Island, south of Iceland, should be evacuated. But a physics professor proposed watering the lava with seawater to solidify or harden it. Forty-seven pumps were used, and, after three months and 6.5 million tons (6 million metric tons) of water, the lava was stopped, and the port was saved. The eruption began on January 23 and ended on June 28.

1980

MOUNT ST. HELENS
State of Washington, U.S.

Volume of ejected ash in cubic feet (cu m)	**35 billion (1 billion)**
Victims	**57**
Characteristics	**Active**

Also known as the Mount Fuji of the American continent. During the 1980 explosion, 1,315 feet (401 m) of the mountain's top gave way through a fault on its side. A few minutes after the volcano began its eruption, rivers of lava flowed down its sides, carrying away the trees, houses, and bridges in their path. The eruption destroyed whole forests, and the volcanic debris devastated entire communities.

1982

EL CHICHÓN VOLCANO
Mexico

Volume of ejected ash in cubic feet (cu m)	**No figures available**
Victims	**2,000**
Characteristics	**Active**

On Sunday, March 28, after 100 years of inactivity, this volcano became active again and unleashed an eruption on April 4. The eruption caused the deaths of about 2,000 people who lived in the surrounding area, and it destroyed nine settlements. It was the worst volcanic disaster in Mexico's history.

Earthquakes

LOMA PRIETA
On Oct. 18, 1989, an earthquake measuring 7.0 on the Richter scale, with its epicenter in Loma Prieta, 52 miles (85 km) south of San Francisco, caused great damage, including the collapse of a section of the Bay Bridge.

DEEP RUPTURE 60-61
ELASTIC WAVES 62-63
BURSTS OF ENERGY 64-65
MEASURING AN EARTHQUAKE 66-67
VIOLENT SEAS 68-69
AFTER THE CATASTROPHE 70-71
CAUSE AND EFFECT 72-73



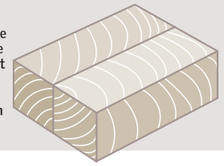
Earthquakes shake the ground in all directions, even though the effects of a quake depend on the magnitude, depth, and distance from its point of origin. Often the waves are so strong that the Earth buckles, causing the collapse of houses and buildings, as happened in Loma Prieta. In mountainous regions earthquakes can be followed by landslides and mudslides, whereas in the oceans, tsunamis may form; these walls of water strike the coast with enough force to destroy whole cities, as occurred in Indonesia in December 2004. Thailand recorded the highest number of tourist deaths, and 80 percent of tourist areas were destroyed. ●

Deep Rupture

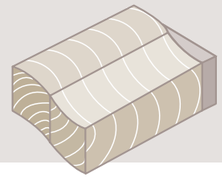
Earthquakes take place because tectonic plates are in constant motion, and therefore they collide with, slide past, and in some cases even slip on top of each other. The Earth's crust does not give outward signs of all the movement within it. Rather energy builds up from these movements within its rocks until the tension is more than the rock can bear. At this point the energy is released at the weakest parts of the crust. This causes the ground to move suddenly, unleashing an earthquake.

ORIGIN OF AN EARTHQUAKE

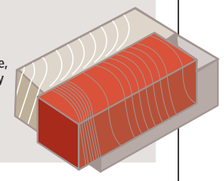
1
Tension Is Generated
The plates move in opposite directions, sliding along the fault line. At a certain point along the fault, they catch on each other. Tension begins to increase between the plates.



2
Tension Versus Resistance
Because the force of displacement is still active even when the plates are not moving, the tension grows. Rock layers near the boundary are distorted and crack.



3
Earthquake
When the rock's resistance is overcome, it breaks and suddenly shifts, causing an earthquake typical of a transform-fault boundary.



1 FORESHOCK
Small tremor that can anticipate an earthquake by days or even years. It could be strong enough to move a parked car.

2 AFTERSHOCK
New seismic movement that can take place after an earthquake. At times it can be even more destructive than the earthquake itself.

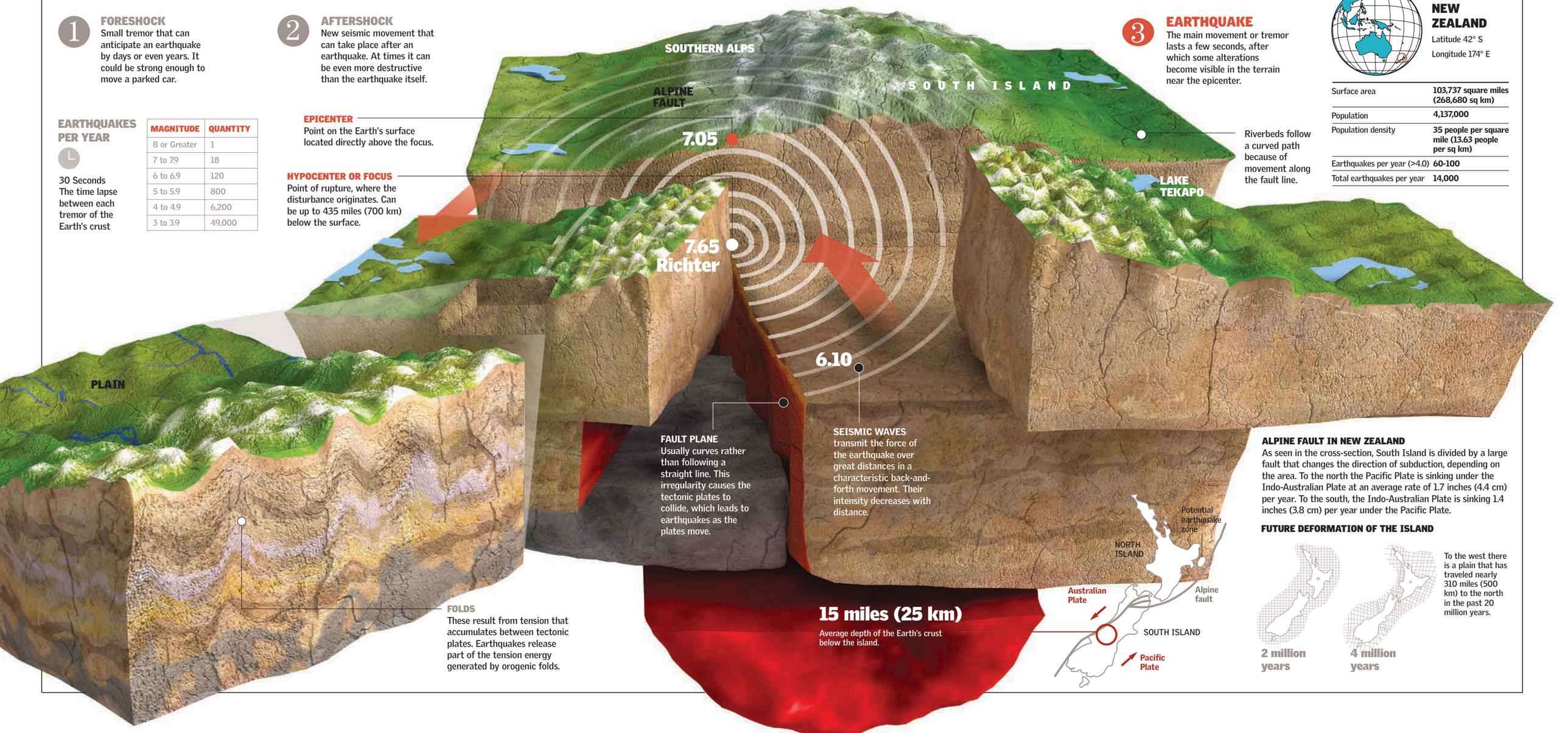
EARTHQUAKES PER YEAR

MAGNITUDE	QUANTITY
8 or Greater	1
7 to 7.9	18
6 to 6.9	120
5 to 5.9	800
4 to 4.9	6,200
3 to 3.9	49,000

30 Seconds
The time lapse between each tremor of the Earth's crust

EPICENTER
Point on the Earth's surface located directly above the focus.

HYPOCENTER OR FOCUS
Point of rupture, where the disturbance originates. Can be up to 435 miles (700 km) below the surface.



3 EARTHQUAKE
The main movement or tremor lasts a few seconds, after which some alterations become visible in the terrain near the epicenter.

Riverbeds follow a curved path because of movement along the fault line.

FAULT PLANE
Usually curves rather than following a straight line. This irregularity causes the tectonic plates to collide, which leads to earthquakes as the plates move.

SEISMIC WAVES
transmit the force of the earthquake over great distances in a characteristic back-and-forth movement. Their intensity decreases with distance.

FOLDS
These result from tension that accumulates between tectonic plates. Earthquakes release part of the tension energy generated by orogenic folds.

15 miles (25 km)
Average depth of the Earth's crust below the island.



NEW ZEALAND
Latitude 42° S
Longitude 174° E

Surface area	103,737 square miles (268,680 sq km)
Population	4,137,000
Population density	35 people per square mile (13.63 people per sq km)
Earthquakes per year (>4.0)	60-100
Total earthquakes per year	14,000

ALPINE FAULT IN NEW ZEALAND
As seen in the cross-section, South Island is divided by a large fault that changes the direction of subduction, depending on the area. To the north the Pacific Plate is sinking under the Indo-Australian Plate at an average rate of 1.7 inches (4.4 cm) per year. To the south, the Indo-Australian Plate is sinking 1.4 inches (3.8 cm) per year under the Pacific Plate.

FUTURE DEFORMATION OF THE ISLAND

2 million years

4 million years

To the west there is a plain that has traveled nearly 310 miles (500 km) to the north in the past 20 million years.

Elastic Waves

Seismic energy is a wave phenomenon, similar to the effect of a stone dropped into a pool of water. Seismic waves radiate out in all directions from the earthquake's hypocenter, or focus. The waves travel faster through hard rock and more slowly through loose sediment and through water. The forces produced by these waves can be broken down into simpler wave types to study their effects.



Focus
Vibrations travel outward from the focus, shaking the rock.

Different Types of Waves

There are basically two types of waves: body waves and surface waves. The body waves travel inside the Earth and transmit foreshocks that have little destructive power. They are divided into primary (P) waves and secondary (S) waves. Surface waves travel only along the Earth's surface, but, because of the tremors they produce in all directions, they cause the most destruction.

Direction of seismic waves

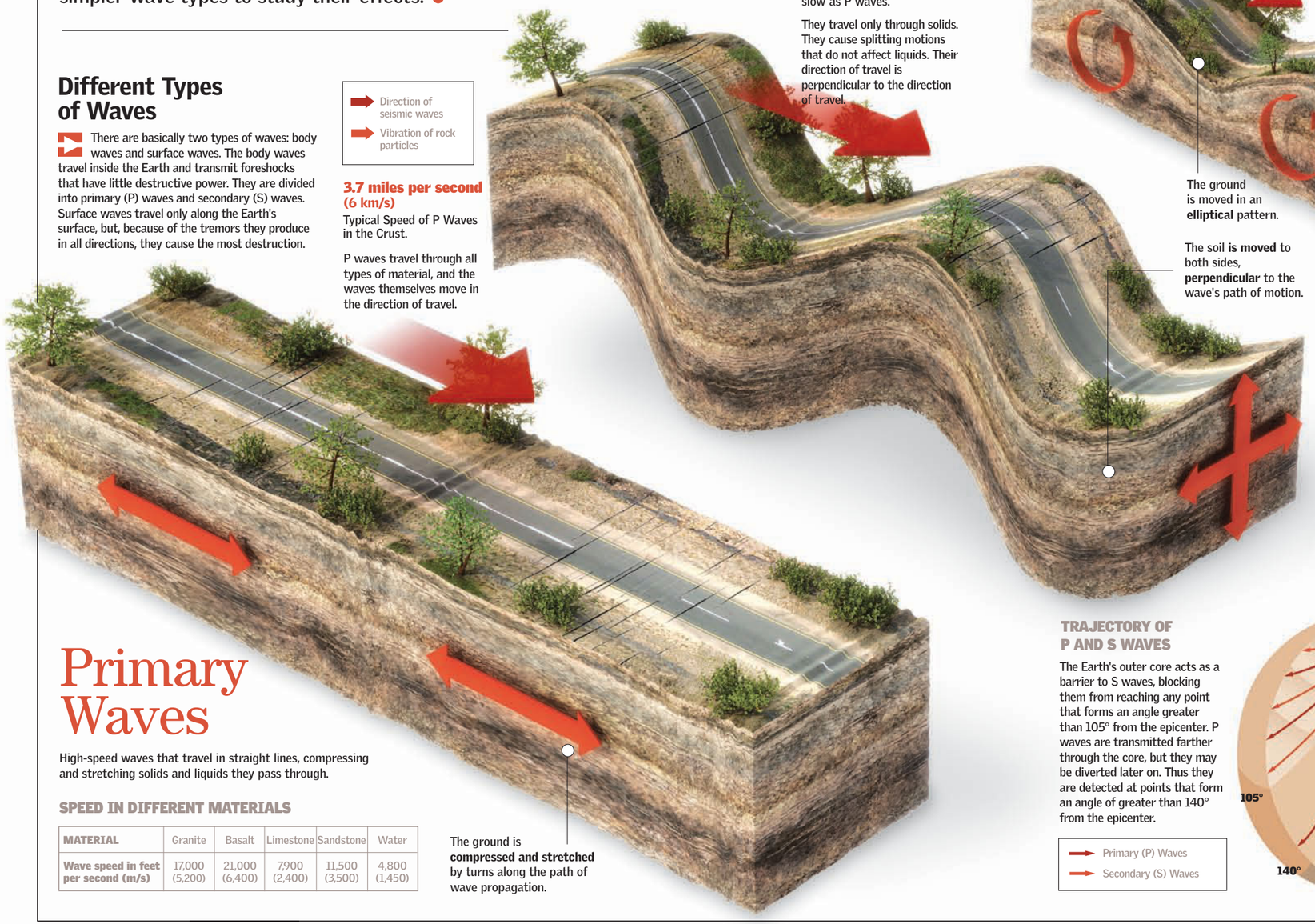
Vibration of rock particles

3.7 miles per second (6 km/s)
Typical Speed of P Waves in the Crust.

P waves travel through all types of material, and the waves themselves move in the direction of travel.

2.2 miles per second (3.6 km/s)
S waves are 1.7 times as slow as P waves.

They travel only through solids. They cause splitting motions that do not affect liquids. Their direction of travel is perpendicular to the direction of travel.



The soil **is moved** to both sides, **perpendicular** to the wave's path of motion.

The ground is **compressed and stretched** by turns along the path of wave propagation.

Primary Waves

High-speed waves that travel in straight lines, compressing and stretching solids and liquids they pass through.

SPEED IN DIFFERENT MATERIALS

MATERIAL	Granite	Basalt	Limestone	Sandstone	Water
Wave speed in feet per second (m/s)	17,000 (5,200)	21,000 (6,400)	7,900 (2,400)	11,500 (3,500)	4,800 (1,450)

Surface Waves

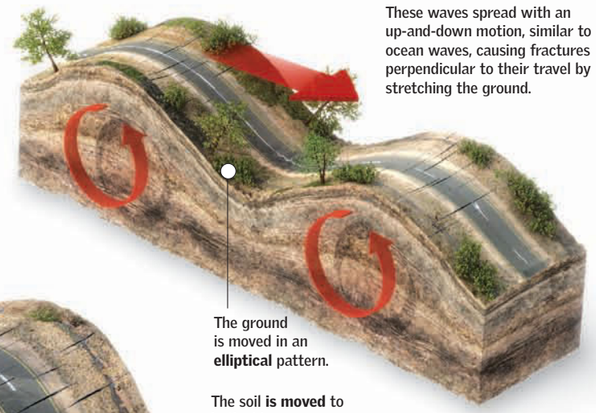
appear on the surface after the P and S waves reach the epicenter. Having a lower frequency, surface waves have a greater effect on solids, which makes them more destructive.

1.9 miles per second (3.2 km/s)
Speed of surface waves in the same medium.

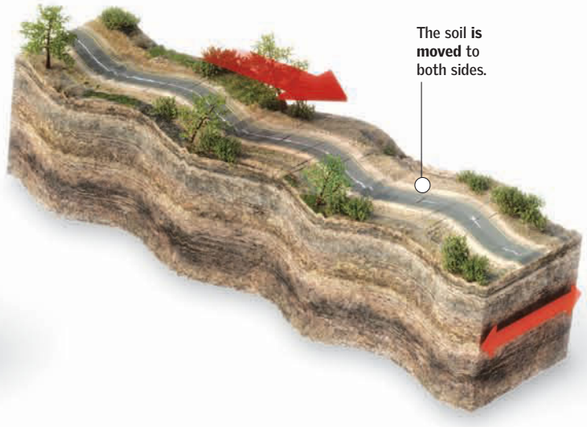
These waves travel only along the surface, at 90 percent of the speed of S waves.

RAYLEIGH WAVES

These waves spread with an up-and-down motion, similar to ocean waves, causing fractures perpendicular to their travel by stretching the ground.



The ground is moved in an **elliptical** pattern.



The soil **is moved** to both sides.

LOVE WAVES

These move like horizontal S waves, trapped at the surface, but they are somewhat slower and make cuts parallel to their direction.

Secondary Waves

Body waves that shake the rock up and down and side to side as they move.

SPEED IN DIFFERENT MATERIALS

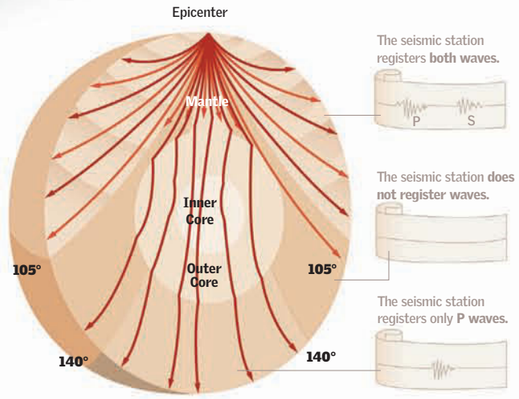
MATERIAL	Granite	Basalt	Limestone	Sandstone
Wave speed in feet per second (m/s)	9,800 (3,000)	1,500 (3,200)	4,430 (1,350)	7,050 (2,150)

TRAJECTORY OF P AND S WAVES

The Earth's outer core acts as a barrier to S waves, blocking them from reaching any point that forms an angle greater than 105° from the epicenter. P waves are transmitted farther through the core, but they may be diverted later on. Thus they are detected at points that form an angle of greater than 140° from the epicenter.

Primary (P) Waves

Secondary (S) Waves



Types of Earthquakes

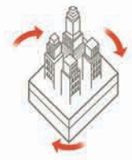
Although earthquakes generally cause all types of waves, some kinds of waves may predominate. This fact leads to a classification that depends on whether vertical or horizontal vibration causes the most movement. The depth of the epicenter can also affect its destructiveness.

BASED ON TYPE OF MOVEMENT



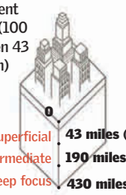
Trepidatory
Located near the epicenter, where the vertical component of the movement is greater than the horizontal.

Oscillatory
When a wave reaches soft soil, the horizontal movement is amplified, and the movement is said to be oscillating.



BASED ON FOCUS DEPTH

Earthquakes originate at points between 3 and 430 miles (5 and 700 km) underground. Ninety percent originate in the first 62 miles (100 km). Those originating between 43 and 190 miles (70 and 300 km) are considered intermediate. Superficial earthquakes (often of higher magnitude) occur above that level, and deep-focus earthquakes occur below it.





OAKLAND, CALIFORNIA

Latitude 37° 46′ N

Longitude 122° 13′ W

Surface area of state	**156,100 square miles (404,298 sq km)**
Range of Damages	**68 miles (110 km)**
State population	**36,132,147**
Earthquakes per year (>4.0)	**15-20**
Earthquake victims	**63**
Magnitude on Richter scale	**7.1**

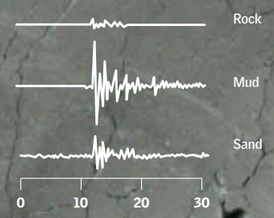
Bursts of tension

Seismic energy can even be compared to the power of nuclear bombs. In addition, the interaction between seismic waves and soil materials also causes a series of physical phenomena that can intensify its destructive capacity. An example of such an effect occurred when a section of an interstate highway plummeted to the ground during the 1989 earthquake in Loma Prieta, California.

THE HIGHWAY

Each soil type responds differently to an earthquake. The figure shows how the same quake can produce waves of different strengths in different soils of different composition. The 0.86-mile (1.4-km) collapsed section of Interstate 880 was built on the mud of San Francisco Bay.

SEISMOGRAPH READOUT

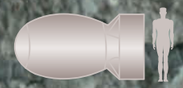


FACTORS THAT DETERMINE THE EFFECTS OF AN EARTHQUAKE

INTRINSIC
- Magnitude
- Type of wave
- Depth

GEOLOGIC
- Distance
- Wave direction
- Topography
- Groundwater saturation

SOCIAL
- Quality of construction
- Preparedness of the population
- Time of day



4 = 1,000 tons

Magnitude Energy released by TNT

The energy released by an earthquake of magnitude 4 on the Richter scale is equal to the energy released by a low-power atomic bomb.



7 = 32 million tons

Magnitude Energy released by TNT

The energy released by an earthquake of magnitude 7 on the Richter scale, such as the 1995 earthquake in Hyogo-Ken Nanbu, Japan, is equal to the energy released by a high-powered thermonuclear bomb (32 megatons).



12 = 160 quadrillion tons

Magnitude Energy released by TNT

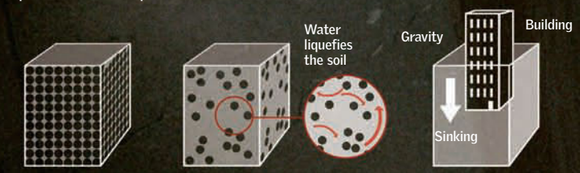
The energy released by a hypothetical earthquake of magnitude 12 on the Richter scale (the greatest known earthquake was 9.5) would be equal to the energy released if the Earth were to split in half.

DIRECT AND INDIRECT EFFECTS

Direct effects are felt in the fault zone and are rarely seen at the surface. Indirect effects stem from the spread of seismic waves. In the Kobe earthquake, the fault caused a fissure in the island of Awaji up to 10 feet (3 m) deep. The indirect effects had to do with liquefaction.

Liquefaction

Seismic tremors apply a force to muddy or water-saturated soils, filling the empty spaces between grains of sand. Solid particles become suspended in the liquid, the soil loses its load-bearing capacity, and buildings sink as if the ground were quicksand. That displaces some of the water, which rises to the surface.



1 The soil is compact, even though it contains water.

2 During the earthquake, the water causes the solid particles to shake.

3 Solid structures sink, and water rises.

Measuring an Earthquake

Earthquakes can be measured in terms of force, duration, and location. Many scientific instruments and comparative scales have been developed to take these measurements. Seismographs measure all three parameters. The Richter scale describes the force or intensity of an earthquake. Naturally, the destruction caused by earthquakes can be measured in many other ways: numbers of people left injured, dead, or homeless, damage and reconstruction costs, government and business expenditures, insurance costs, school days lost, and in many more ways.



CHARLES RICHTER

American seismologist (1900-85) who developed the scale of magnitude that bears his name.



GIUSEPPE MERCALLI

Italian volcanologist (1850-1914) who developed the first scale for measuring the intensity of an earthquake.



EMS 98 SCALE

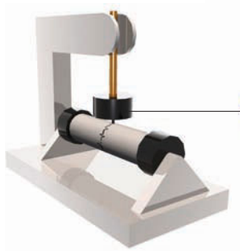
In use since 1998 throughout the European Union and other countries that use the protocol, including those of northern Africa. This scale describes the intensity of earthquakes in European contexts, where the most modern construction may be found side by side with ancient buildings. Earthquakes there can have widely varying effects. The scale has 12 points that combine magnitude readings with levels of destruction.

Intensity

Concept of the destruction caused by an earthquake.

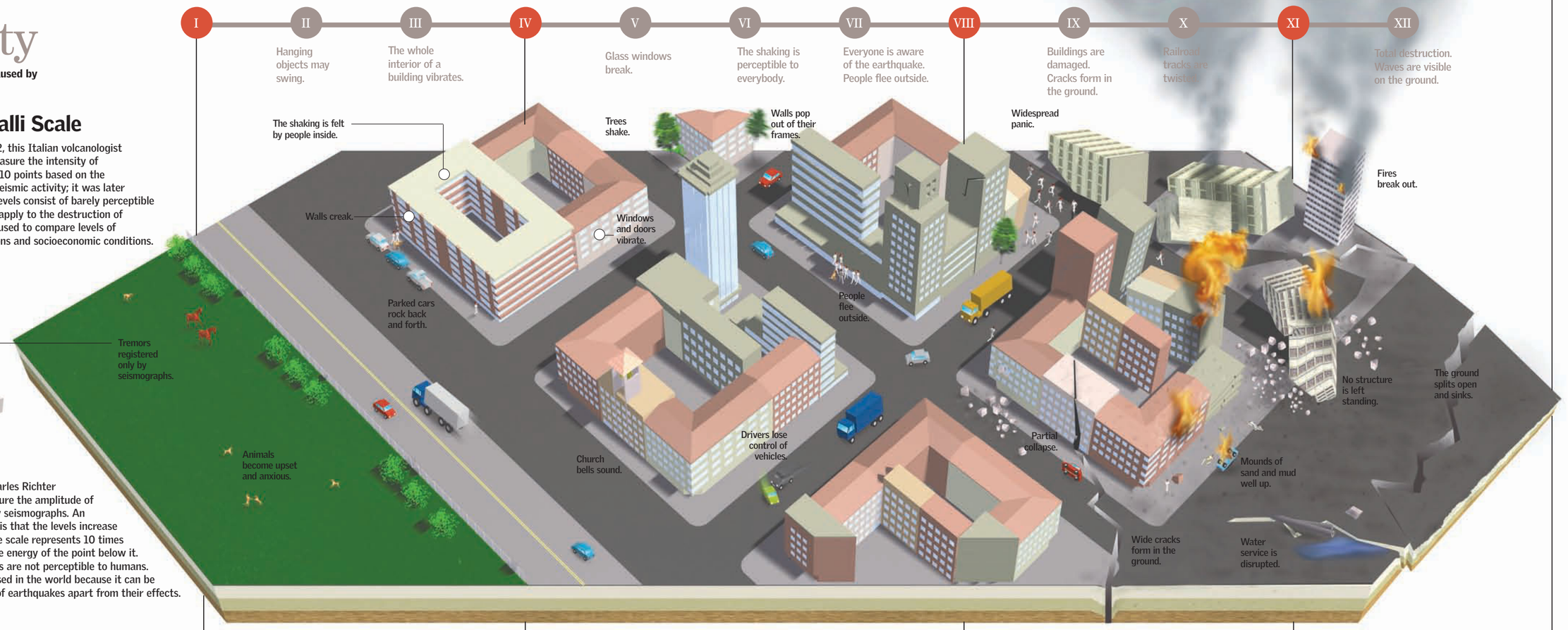
Modified Mercalli Scale

Between 1883 and 1902, this Italian volcanologist developed a scale to measure the intensity of earthquakes. It originally had 10 points based on the observation of the effects of seismic activity; it was later modified to 12. The first few levels consist of barely perceptible sensations. The highest levels apply to the destruction of buildings. This scale is widely used to compare levels of damage among different regions and socioeconomic conditions.



Richter Scale

In 1935, seismologist Charles Richter designed a scale to measure the amplitude of the largest waves registered by seismographs. An important feature of this scale is that the levels increase exponentially. Each point on the scale represents 10 times the movement and 30 times the energy of the point below it. Temblors of magnitude 2 or less are not perceptible to humans. This scale is the most widely used in the world because it can be used to compare the strength of earthquakes apart from their effects.



Magnitude

The energy released in a seismic event.

2	2.5	3.5	4.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0
Registered only by seismographs.	Very few people feel the tremor.	The tremor is felt. Only minor damages.	Most people perceive the quake.	Some buildings are lightly damaged.	May cause severe damage.	Unstable buildings are destroyed.	May cause heavy damage in populated areas.	Major earthquake. Causes extensive damage.	Considered a great earthquake.	Causes very extensive damage.	Very great earthquake. Total destruction.

Violent Seas

A large earthquake or volcanic eruption can cause a tsunami, which means "wave in the harbor" in Japanese. Tsunamis travel very fast, up to 500 miles per hour (800 km/h). On reaching shallow water, they decrease in speed but increase in height. A tsunami can become a wall of water more than 33 feet (10 m) high on approaching the shore. The height depends partly on the shape of the beach and the depth of coastal waters. If the wave reaches dry land, it can inundate vast areas and cause considerable damage. A 1960 earthquake off the coast of Chile caused a tsunami that swept away communities along 500 miles (800 km) of the coast of South America. Twenty-two hours later the waves reached the coast of Japan, where they damaged coastal towns.

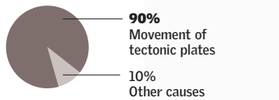
津 波

The word tsunami comes from Japanese

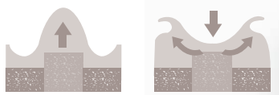
TSU Harbor **NAMI** Wave

How It Happens

A tremor that generates vibrations on the ocean water's surface can be caused by seismic movement on the seafloor. Most of the time the tremor is caused by the upward or downward movement of a block of oceanic crust that moves a mass of ocean water. A volcanic eruption, meteorite impact, or nuclear explosion can also cause a tsunami.



RISING PLATE



Water level rises | Water level drops

SINKING PLATE



The displaced water tends to level out, generating the force that causes waves.

7.5

Only earthquakes above this magnitude on the Richter scale can produce a tsunami strong enough to cause damage.

1 THE EARTHQUAKE
A movement of the ocean floor displaces an enormous mass of water upward.

2 THE WAVES ARE FORMED
As this mass of water drops, the water begins to vibrate. The waves, however, are barely 1.5 feet (0.5 m) high, and a boat may cross over them without the crew even noticing.

3 THE WAVES ADVANCE
Waves may travel thousands of miles without weakening. As the sea becomes shallower near the coast, the waves become closer together, but they grow higher.

4 TSUNAMI
On reaching the coast, the waves find their path blocked. The coast, like a ramp, diverts all the force of the waves upward.

Displacement of the plate.

CREST

TROUGH

CREST

LENGTH OF THE WAVE
From 62 to 430 miles (100 to 700 km) on the open sea, measured from crest to crest.

Float
System of glass spheres.

Chain

Detection device.
Located at a depth of 16,000 feet (5,000 m).

518 miles/hour
(835 km/h)
Speed of the tsunami

18,000 feet
(5,500 m)

210 miles/hour
(340 km/h)
Speed of the tsunami

3,000 feet
(900 m)

OCEAN FLOOR

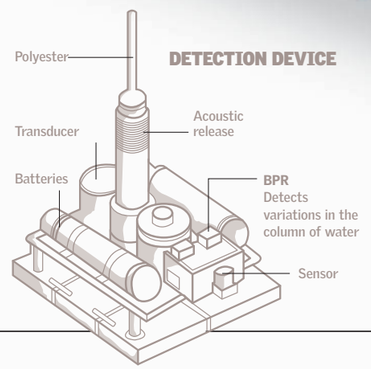
31 miles per hour
(50 km/h)
Speed of the Tsunami

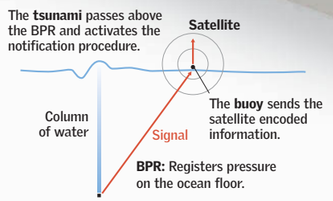
65 feet
(20 m)

Between 5 and 30 minutes before the tsunami arrives, the sea level suddenly drops.

Buildings on the coast may be damaged or destroyed.

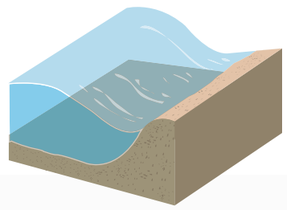
DETECTION DEVICE



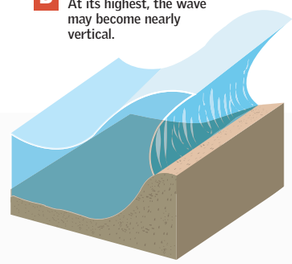


WHEN THE WAVE HITS THE COAST

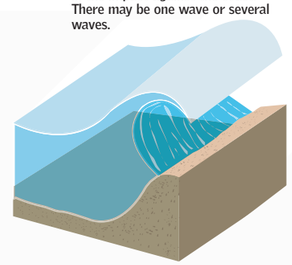
A **Sea level drops abnormally low.** Water is "sucked" away from the coast by the growing wave.



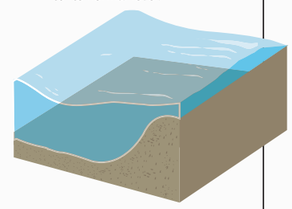
B **The giant wave forms.** At its highest, the wave may become nearly vertical.



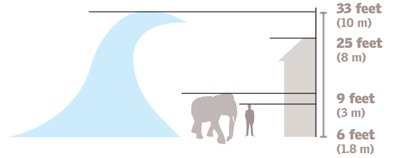
C **The wave breaks along the coast.** The force of the wave is released in the impact against the coast. There may be one wave or several waves.



D **The land is flooded.** The water may take several hours or even days to return to its normal level.



COMPARISON OF THE SIZE OF THE WAVE



33 feet (10 m)
Typical height a major tsunami can reach.

After a catastrophe

The illustration shows a satellite image of Khao Lak, in the coastal province of Phang Nga in southwestern Thailand. The picture was taken three days after the great tsunami of Dec. 26, 2004, that was caused by the colliding Eurasian and Australian plates near Indonesia. This was the greatest undersea earthquake in 40 years. Below, the area as it looked two years earlier.

Everything swept away by the wave was left piled up on the beach.

Coastline before the tsunami

The coastline was devastated.

Bamboo Orchid Resort

CAPE PANKARANG

The tropical forests along the beach of Cape Pankarang were wiped out.

Palm Galleria Resort

Pankarang Beach Cottage

South Sea Pankarang

River levels rose after the catastrophe.

Blue Village Pankarang Resort

The river's mouth was completely flooded.

Dec. 29, 2004

The hypothetical line shows how far inland the tsunami reached. Over half a mile (1 km) of the coast was swept away by the tidal wave. Eighty percent of the surface in Khao Lak's tourist area was destroyed.

1,000

Deaths caused by the tsunami in this area alone.

Thailand had the greatest number of tourist deaths.



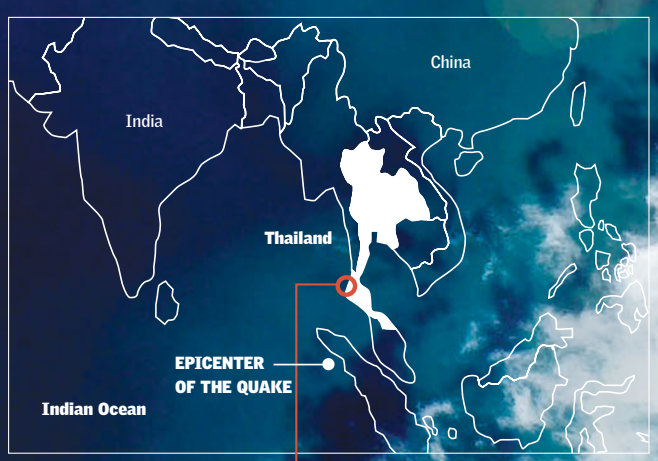
THAILAND

Latitude 16° N

Longitude 100° E

Surface area	198,114 square miles (513,115 sq km)
Population	63,100,000
Population density	289 people per square mile (112.9 people/sq km)
Tsunami-related deaths	5,248
Persons missing in tsunami	4,499

ANDAMAN SEA



Area flooded by the wave

3,300-4,900 feet (1,000-1,500 m)

Khuk Khak Beach

Many beaches lost all their sand.

Sofitel Magic Lagoon Resort

Grand Diamond Resort and Spa

Theptaro Lagoon Resort

Meteorological center

0 feet (m) 1,650 (500)



Jan. 13, 2003

Nearly two years before the tragedy. Wide areas of lush vegetation, fine, white sand beaches, and many buildings enhanced the natural attractions of this tourism center.

10:00 a.m.

Time when the wave hit the beach.



INDIAN OCEAN

Surface area	28.3 million square miles (73.4 million sq km)
Percentage of Earth's surface	14%
Percentage of total volume of the oceans	20%
Length of plate boundaries (in focus)	745 miles (1,200 km)
Countries affected in 2004	21

Cause and Effect

On Dec. 26, 2004, an earthquake occurred that measured 9.0 on the Richter scale, the fifth greatest on record. The epicenter was 100 miles (160 km) off the west coast of Sumatra, Indonesia. This quake generated a tsunami that pummeled all the coasts of the Indian Ocean. The islands of Sumatra and Sri Lanka suffered the worst effects. India, Thailand, and the Maldives also suffered damage, and there were victims as far away as Kenya, Tanzania, and Somalia, in Africa.

7:58
Local time when the tsunami was unleashed (00:58 universal time)

THE VICTIMS
On this map, the number of confirmed deaths and the number of missing persons in each country are added together, giving an estimated total death toll. In addition, 1,600,000 persons had to be evacuated.

Duration

The tremor lasted between 8 and 10 minutes, one of the longest on record. The waves took six hours to reach Africa, over 5,000 miles (8,000 km) away.

LEGEND
- Most-affected areas
- Plate movements at different speeds
- 6h — Time it took the wave to reach the indicated dotted line.
- Movement of the wave.

ARABIAN PLATE
AFRICA
INDIAN PLATE
AFRICAN PLATE
EURASIAN PLATE
ASIA
PHILIPPINE PLATE
PACIFIC PLATE
Indian Ocean
Pacific Ocean
GULF OF BENGAL
SUMATRA

SOMALIA
Pop. 8,863,338
289 dead

KENYA
Pop. 34,707,817
1 dead

TANZANIA
Pop. 37,445,392
13 dead

MALDIVES
Pop. 339,330
108 dead

INDIA
Pop. 1.065 billion
18,045 dead

SRI LANKA
Pop. 19,905,165
35,322 dead

BANGLADESH
Pop. 141,340,476
2 dead

MYANMAR
Pop. 42,720,196
600 dead

THAILAND
Pop. 64,865,523
8,212 estimated dead

MALAYSIA
Pop. 23,522,482
74 dead

INDONESIA
Pop. 238,452,952
167,736 dead

Dhaka
Calcutta
Mandalay
Rangoon (Yangon)
Bangkok
Phuket
Banda Aceh
Vishakhapatnam
Bangalore
Madras
Cochin
Pulmoddal
Batticaloa
Colombo
Matara

0.4 inches per year (1 cm/year)
4 inches per year (10 cm/year)
0.4 inches per year (1.0 cm/yr)
0.4 inches per year (1.0 cm/yr)

1h
2h
3h
4h
5h
6h

EPICENTER
3° 18′ N
95° 47′ E

Magnitude 9

Multiple aftershocks of up to magnitude 7.3.

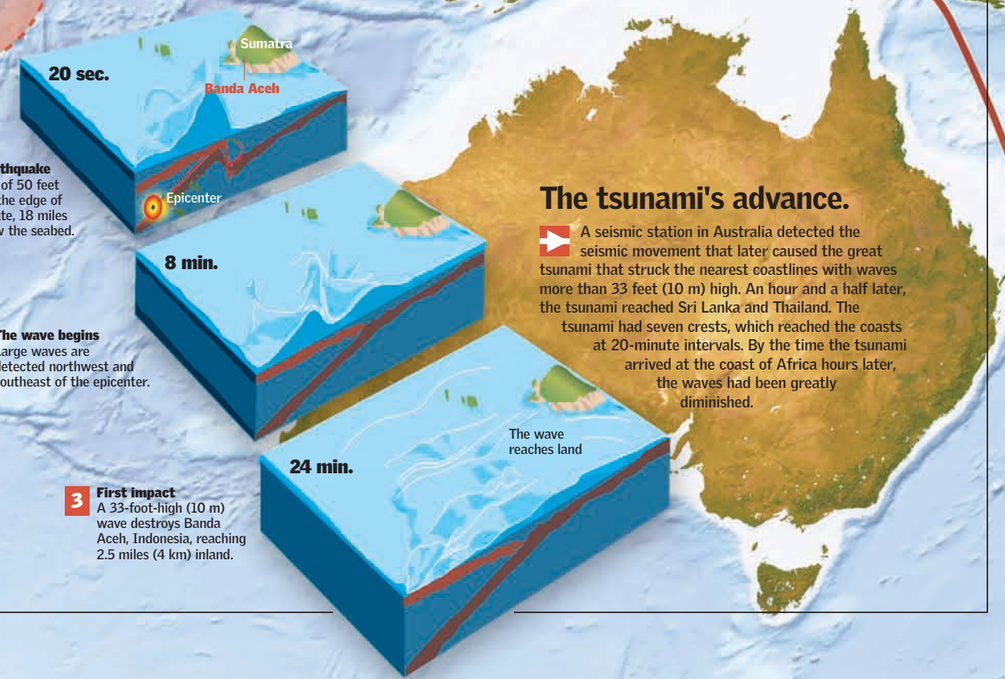
500 miles per hour (800 km/h)
Speed of the first wave

230,507

Estimated dead



30 percent were children



1 Undersea earthquake
Displacement of 50 feet (15 m) along the edge of the Indian Plate, 18 miles (30 km) below the seabed.

2 The wave begins
Large waves are detected northwest and southeast of the epicenter.

3 First impact
A 33-foot-high (10 m) wave destroys Banda Aceh, Indonesia, reaching 2.5 miles (4 km) inland.

The tsunami's advance.

A seismic station in Australia detected the seismic movement that later caused the great tsunami that struck the nearest coastlines with waves more than 33 feet (10 m) high. An hour and a half later, the tsunami reached Sri Lanka and Thailand. The tsunami had seven crests, which reached the coasts at 20-minute intervals. By the time the tsunami arrived at the coast of Africa hours later, the waves had been greatly diminished.

Study and Prevention

NORTHRIDGE
The 1994 earthquake in this California city measured 6.7 on the Richter scale and caused approximately 60 deaths and damage estimated at a value of $40,000,000,000.

RISK AREAS 76-77
PRECISION INSTRUMENTS 78-79
CONTINUOUS MONITORING 80-81
STABLE BUILDINGS 82-83
ON GUARD 84-85
SAN FRANCISCO IN FLAMES 86-89
HISTORIC EARTHQUAKES 90-91



Predicting earthquakes is very difficult because of a large number of variables, because no two fault systems are alike. That is why populations that have settled in areas with high seismic risk have developed a number of strategies to help everyone know how to act should the earth begin to shake. California and Japan are examples of densely populated regions whose buildings, now designed according to a stable construction model, have saved many lives. There children are trained periodically at their schools: they do practice drills, and they know where to look for cover. Experts have learned many things about earthquakes in their attempt to understand the causes of these tremors, but they still are not able to predict when an earthquake will take place. ●

Risk Areas

A seismic area is found wherever there is an active fault, and these faults are very numerous throughout the world. These fractures are especially common near mountain ranges and mid-ocean ridges. Unfortunately, many population centers were built up in regions near these dangerous places, and, when an earthquake occurs, they become disaster areas. Where the tectonic plates collide, the risk is even greater.

Most-vulnerable regions

They are unpredictable, and among the most destructive of natural phenomena. Earthquakes shake the earth. They open and move it, and, within a few seconds, they can turn a peaceful city into the worst disaster area, an area in which seismic activity and a high population density coincide. But in the open country, where earthquakes have much less effect, we can conclude that it is not earthquakes, but buildings, that kill people.

Arctic Ocean

ASIA

8.7
Assam, 1897
More than 1,600 people died in northwest India.

6.8
Kobe, 1995
The city of Kobe and nearby villages were destroyed in only 30 seconds.

Indo-Australian Plate

Mountain

Trench

Pacific Plate

Subduction zone

Pacific Ocean

9.2
Alaska, 1964
Lasted between three and five minutes and caused a tsunami responsible for 122 deaths.

8.3
San Francisco, 1906
Major fires contributed to the devastation of the city.

Rocky Mountains

PACIFIC PLATE

8.1
Mexico, 1985
Two days later there was a 7.6 aftershock. More than 11,000 people died.

Himalayas

INDO-AUSTRALIAN PLATE

9.0
Sumatra, 2004
Tsunami in Asia
An earthquake near the island of Sumatra created 33-foot (10-m) waves and a human tragedy.

PACIFIC PLATE

MARIANA TRENCH
The deepest marine trench on the planet, with a depth of 35,872 feet (10,934 m) below sea level. It is on the western side of the north Pacific and east of the Mariana Islands.

Pacific Ocean

COCOS AND CARIBBEAN PLATES
Contact between these two plates is of the convergent type: the Cocos Plate moves under the Caribbean Plate, a phenomenon known as subduction. This causes a great number of tremors and volcanoes.

Cocos Plate

Caribbean Plate

Indian Ocean

AUSTRALIAN PLATE

FIJI PLATE

Fiji Plate

NEW ZEALAND FAULT
A large fault that moves horizontally, crosses the lithosphere, accommodating the movement between two large crust plates; it is a special type of directional plate called a transforming plate.

Pacific Plate

ANTARCTIC PLATE

NORTH AMERICA

NORTH AMERICAN PLATE

CENTRAL AMERICA

CARIBBEAN PLATE

COCOS PLATE

Atlantic Ocean

NAZCA PLATE

Andes Mountains

SOUTH AMERICA

SOUTH AMERICAN PLATE

9.5
Chile, 1960
The most powerful earthquake ever registered: 5,700 people died and two million were left homeless.

Mid-ocean ridges

Trench

Mid-ocean ridges

South American Plate

Asthenosphere

African Plate

ANTARCTIC PLATE

SCOTIA PLATE

MID-OCEAN RIDGE
A submarine mountain range formed by the displacement of tectonic plates, these are active formations. These mountain systems are the longest in the world.

EURASIAN PLATE

ASIA

Ural Mountains

8.7
Lisbon, Portugal, 1755
More than 60,000 people died, and a tsunami followed the earthquake.

EUROPE

Alps

6.8
Armenia, 1988
Destroyed the city of Spitak and took more than 25,000 lives.

7.6
Kashmir, 2005
80,000 fatalities and losses valued at $653,170,000.

Caucasus

Himalayas

7.5
Iran, 1990
More than 60,000 dead. This was the worst disaster in Iran in the 20th century.

AFRICA

AFRICAN PLATE

African Plate

Arabian Plate

ARABIAN PLATE

INDIAN PLATE

Indian Ocean

AFRICAN AND ARABIAN PLATES
The African Plate includes part of the Atlantic, Indian, and Antarctic oceans. To the north it borders with the Arabian Plate. When these two plates separated, they formed the Red Sea, which is still widening.

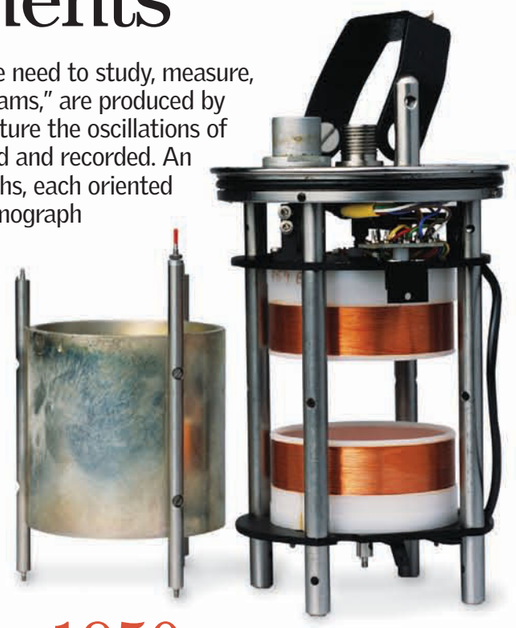
SOUTH AMERICAN PLATE

ANTARCTIC PLATE

KEY
- Convergent boundary and direction
- Oceanic fault
- Transform fault
- Movement and direction of the oceanic fault
- Movement and direction of fault
- Epicenter
- Important earthquake
- Seismic area
- Disaster area

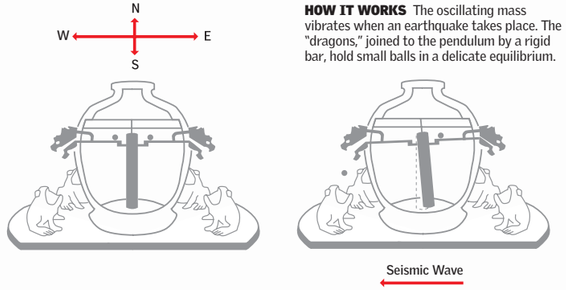
Precision Instruments

The destructive potential of earthquakes gave rise to the need to study, measure, and record them. Earthquake records, called "seismograms," are produced by instruments called "seismographs," which basically capture the oscillations of a mass and transform them into signals that can be measured and recorded. An earthquake is usually analyzed by means of three seismographs, each oriented in a unique direction at a given location. In this way one seismograph detects the vibrations produced from north to south, another records those from east to west, and a third detects vertical vibrations, those that go up and down. With these three instruments, a seismic event can be reconstructed.



Seismometers in History

Modern seismometers have digital mechanisms that provide maximum precision. The sensors are still based on seismic energy moving a mechanical part, however, and that is essentially the same principle that operated the first instrument used to evaluate earthquakes. It was invented by a Chinese mathematician almost 2,000 years ago. Beginning with his invention, the mechanism has been perfected to what it is today.



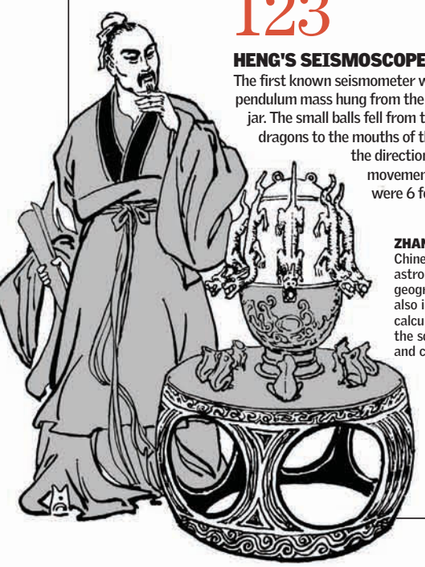
HOW IT WORKS The oscillating mass vibrates when an earthquake takes place. The "dragons," joined to the pendulum by a rigid bar, hold small balls in a delicate equilibrium.

Seismic Wave

123

HENG'S SEISMOSCOPE

The first known seismometer was Chinese. The metallic pendulum mass hung from the cover of a large bronze jar. The small balls fell from the mouths of the dragons to the mouths of the frogs, depending on the direction of the seismic movement. Some of these models were 6 feet (2 m) tall.



ZHANG HENG
Chinese mathematician, astronomer, and geographer (AD 78-139), also invented the odometer, calculated the number pi as the square root of 10 (3.16), and corrected the calendar.

1906

BOSCH-OMORI SEISMOMETER

Is a horizontal pendulum with a pen that makes a mark directly on a paper roll. With it, Omori, a Japanese scientist, registered the 1906 earthquake in San Francisco.



1950

PORTABLE SEISMOMETER

Their strong structure allowed these seismometers to be installed in the field. This model translated movement to electric impulses so the signal could be transmitted over some distance.

1980

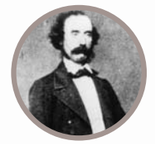
WILMORE PORTABLE SEISMOMETER

A sensitive mass vibrates and moves to the rhythm of the seismic energy inside this tube-shaped mechanism. An electromagnet translates this vibration to electric signals, which are transmitted to a computer that records the data.



Pioneers of seismology

The defining principle of modern seismology emerged from relating earthquakes to the movement of the continents, but that did not take place until well into the 20th century. Starting in the 19th century, however, many scholars contributed elements that would be indispensable.



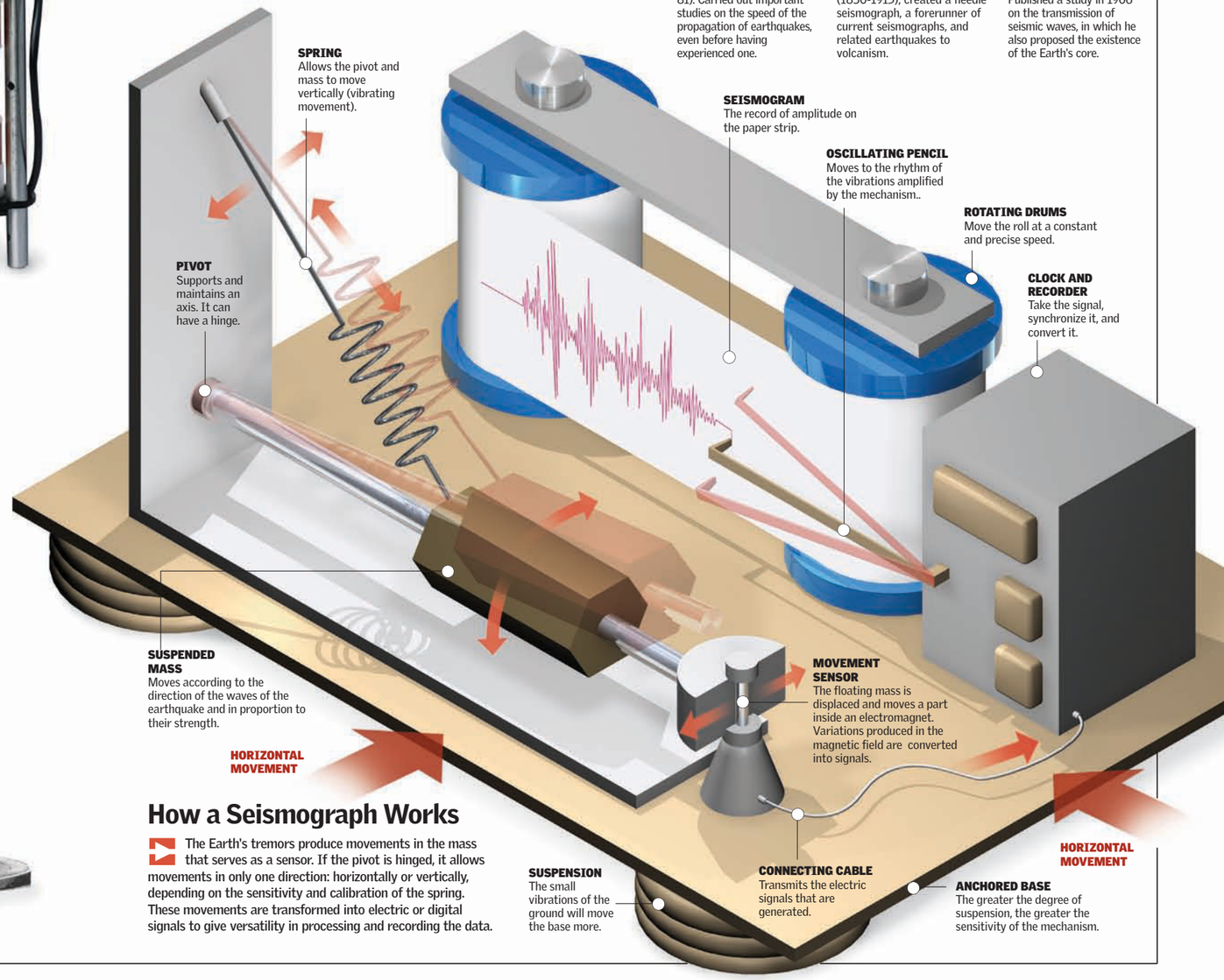
ROBERT MALLET
From Dublin, Ireland (1810-81). Carried out important studies on the speed of the propagation of earthquakes, even before having experienced one.



JOHN MILNE
British geologist and engineer (1850-1913), created a needle seismograph, a forerunner of current seismographs, and related earthquakes to volcanism.



RICHARD OLDHAM
British (1858-1936). Published a study in 1906 on the transmission of seismic waves, in which he also proposed the existence of the Earth's core.



How a Seismograph Works

The Earth's tremors produce movements in the mass that serves as a sensor. If the pivot is hinged, it allows movements in only one direction: horizontally or vertically, depending on the sensitivity and calibration of the spring. These movements are transformed into electric or digital signals to give versatility in processing and recording the data.

Continuous Movement

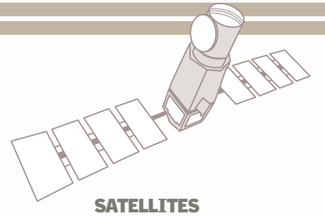
Humankind has tried throughout history to find a way to predict earthquakes. Today, this is done through the installation of seismic observatories and of various field instruments that gather information and compare it to the data sent by scientists from other locations. Based on these records, it is possible to evaluate the chances that a great earthquake is developing and act accordingly.

Seismologic Networks

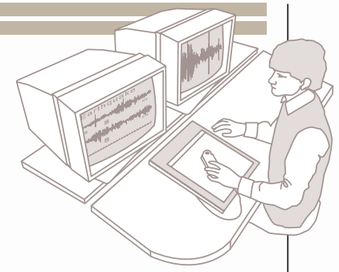
Installing complex detection systems would not be of much use if the systems worked in an isolated manner and were not able to share the information they generated. There are national and international seismologic networks that, by means of communications technology, send their observations to other areas that might be affected.



NETWORK OF NETWORKS
Findings in an area can have repercussions at a great distance. The immediate availability of data allows for linked work.



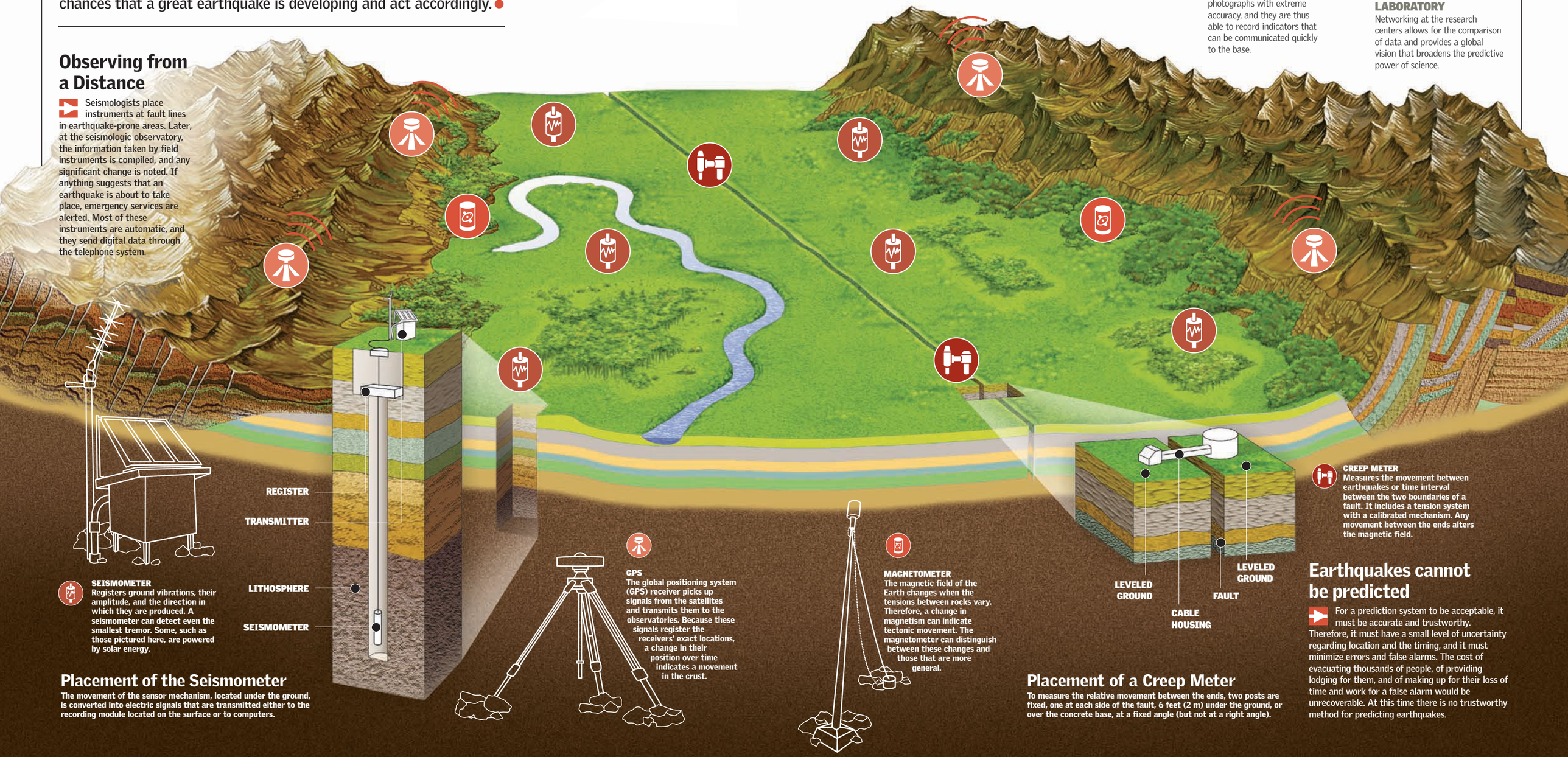
SATELLITES
Some are used by the GPS systems, but others are critical because they take photographs with extreme accuracy, and they are thus able to record indicators that can be communicated quickly to the base.



LABORATORY
Networking at the research centers allows for the comparison of data and provides a global vision that broadens the predictive power of science.

Observing from a Distance

Seismologists place instruments at fault lines in earthquake-prone areas. Later, at the seismologic observatory, the information taken by field instruments is compiled, and any significant change is noted. If anything suggests that an earthquake is about to take place, emergency services are alerted. Most of these instruments are automatic, and they send digital data through the telephone system.



SEISMOMETER
Registers ground vibrations, their amplitude, and the direction in which they are produced. A seismometer can detect even the smallest tremor. Some, such as those pictured here, are powered by solar energy.

GPS
The global positioning system (GPS) receiver picks up signals from the satellites and transmits them to the observatories. Because these signals register the receivers' exact locations, a change in their position over time indicates a movement in the crust.

MAGNETOMETER
The magnetic field of the Earth changes when the tensions between rocks vary. Therefore, a change in magnetism can indicate tectonic movement. The magnetometer can distinguish between these changes and those that are more general.

CREEP METER
Measures the movement between earthquakes or time interval between the two boundaries of a fault. It includes a tension system with a calibrated mechanism. Any movement between the ends alters the magnetic field.

Placement of the Seismometer

The movement of the sensor mechanism, located under the ground, is converted into electric signals that are transmitted either to the recording module located on the surface or to computers.

Placement of a Creep Meter

To measure the relative movement between the ends, two posts are fixed, one at each side of the fault, 6 feet (2 m) under the ground, or over the concrete base, at a fixed angle (but not at a right angle).

Earthquakes cannot be predicted

For a prediction system to be acceptable, it must be accurate and trustworthy. Therefore, it must have a small level of uncertainty regarding location and the timing, and it must minimize errors and false alarms. The cost of evacuating thousands of people, of providing lodging for them, and of making up for their loss of time and work for a false alarm would be unrecoverable. At this time there is no trustworthy method for predicting earthquakes.

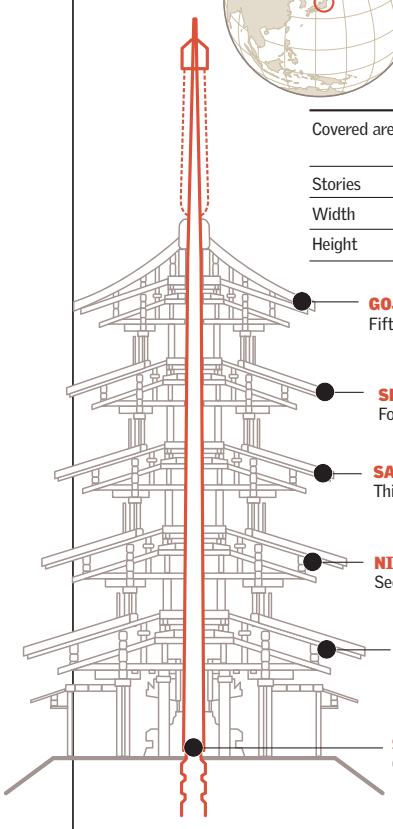
Stable Buildings

In cities located in seismic areas, buildings must be designed and constructed with an earthquake-resistant structure that can adequately withstand the movements caused by an earthquake. Foundations are built with damping so that they can absorb the force of the seismic movement. Other buildings have a large metallic axis, around which the stories of the building can oscillate without falling. Currently the amount of knowledge on the effect of earthquakes on structures, as well as knowledge on the behavior of different materials, allows for the construction of less-vulnerable buildings.



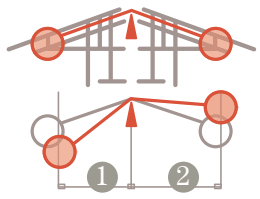
ROPPONGI HILLS
TOKYO, JAPAN
Latitude 36° N
Longitude 140° E

Covered area	**4,089,930 square feet (380.105 sq m)**
Stories	**54 (+6 underground)**
Width	**275 feet (84 m)**
Height	**780 feet (238 m)**

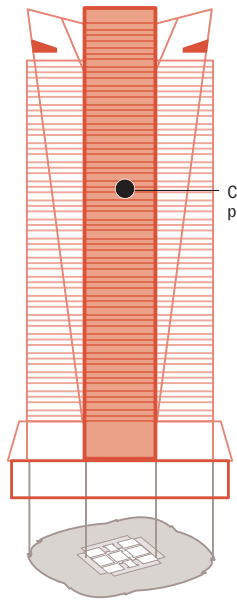


Why Pagodas in Japan Do Not Fall

Japanese pagodas have survived centuries of earthquakes. They are five stories tall, and higher sections of the building are smaller than lower parts. The pagodas are held up by a central pillar that acts as the only support for the building. During a quake, each floor balances independently, without transmitting the oscillating force to the other floors.



Swaying Principle
Each floor also has a symmetric structure. During an earthquake, the ends opposite the eaves act as a counterbalance to achieve equilibrium.



ROPPONGI HILLS TOWER
Located in Tokyo, its structure consists of simple geometric bodies, symmetrically placed, without any irregularities in shape. The tower is formed by a massive central framework and a lightweight and flexible exterior framework.



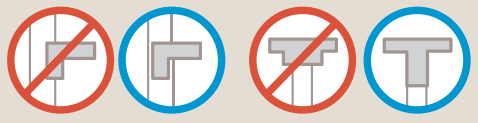
Earthquake-Resistant Architecture

There are many ways to design an earthquake-resistant structure: the distribution of walls, the joints between beams and columns, and geometric simplicity. There are also earthquake simulators, large platforms that shake a structure to test it. The simulators are used to test materials and study the forces that act on them. A building's true earthquake resistance, though, can be proven only when it has been built and has survived actual earthquakes.

STRUCTURE
To avoid imbalances, the upper elements of a structure must be located over only a few axes, without any isolated vertical segments.

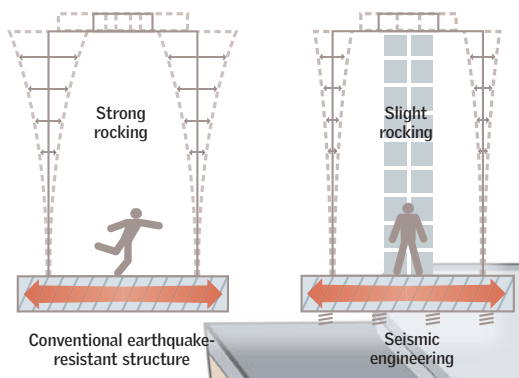


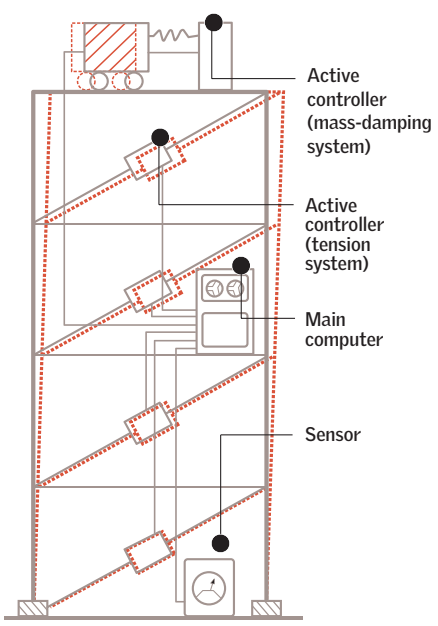
AVOIDANCE OF OFF-CENTER JOINTS
If the beam remains still when the wall moves, the joint breaks. Forces spread out over an axis with flexible material.



Suspension System

So that a building will suffer only small oscillations during an earthquake, it is isolated and built in a large trench, separated by special devices. In addition, because the higher floors move more than the lower ones, mechanical dampers are emplaced diagonally so as to be more highly tensioned on top than on the bottom. This makes the structure as a whole more flexible, but it also offers resistance to sudden variations.





THE INTELLIGENT BUILDING
When an earthquake is detected, a computer-controlled system provides variable compression to the dampers, which absorb the movements according to the height of the floor and the intensity of the vibrations.

On Guard

When the earth shakes, nothing can stop it. Disaster seems inevitable, but, though it is inevitable, much can be done to diminish the extent of the catastrophe. Residents of earthquake-prone areas have incorporated a series of preventive measures to avoid being surprised and to help them act appropriately at home, at the office, or outdoors. These are basic rules of behavior that will help you survive.

Prevention

If you live in an earthquake-prone area, familiarize yourself with the emergency plans for the community where you live, plan how your family will behave in the event of an earthquake, know first aid, and know how to extinguish fires.



FIRST-AID KIT
Keep a first-aid kit, and keep your vaccinations up to date.



LIGHTS
Have emergency lighting, flashlights, a transistor radio, and batteries on hand.



SECURING OBJECTS
Secure heavy objects such as furniture, shelves, and gas appliances to the wall or to the floor.



BREAKERS
Have a breaker installed, and know how to shut off the electricity and the gas supply.



FOOD AND WATER
Store drinking water and nonperishable food.



FIRST AID
Learn first aid, and participate in community earthquake-response training.

During an earthquake

As soon as you feel the earth under your feet begin to move, look for a safe place, such as beneath a doorframe or under a table, to take cover. If you happen to be on a street, head to an open space such as a square or park. It is important to remain calm and to not be influenced by people who panic.

AT HOME

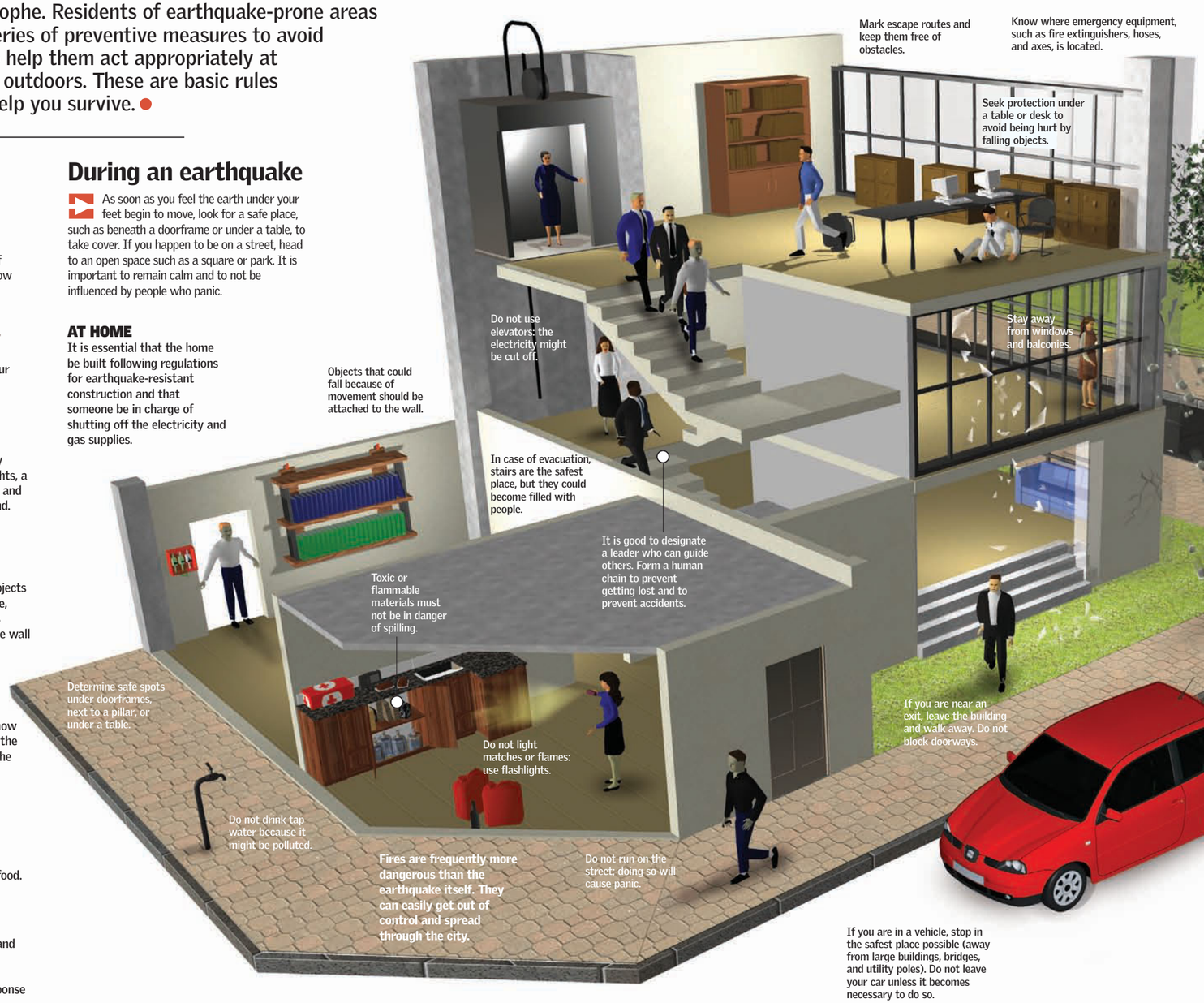
It is essential that the home be built following regulations for earthquake-resistant construction and that someone be in charge of shutting off the electricity and gas supplies.

AT THE OFFICE

Offices are usually located in areas conducive to bringing large groups of people together. Thus it is recommended that you remain where you are and not rush to the exits. When people panic, there is a greater probability of their being crushed by a crowd than by a building, especially in buildings that contain a lot of people.

IN PUBLIC PLACES

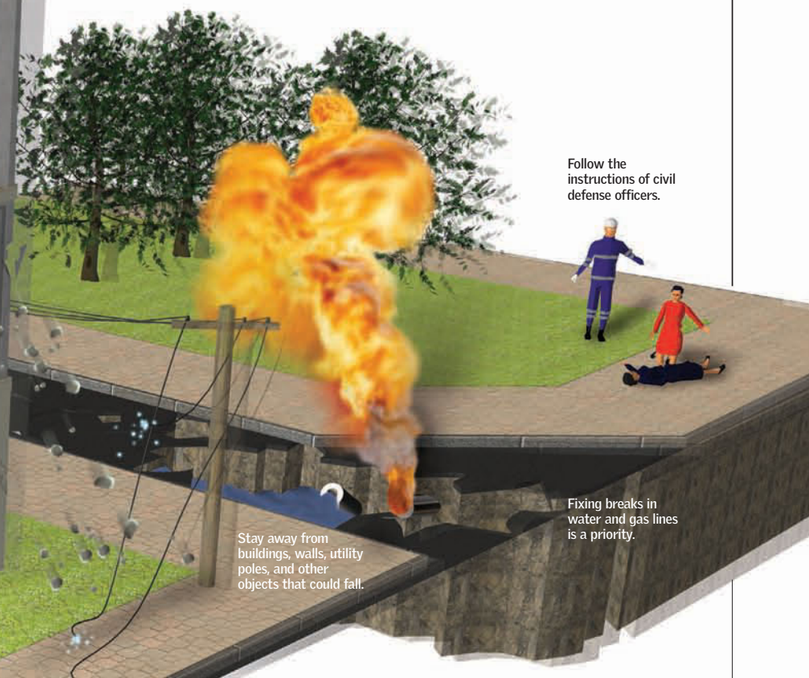
When you are outside, it is important to keep away from tall buildings, light poles, and other objects that could fall. The safest course of action is to head to a park or other open space. If the earthquake takes you by surprise while you are driving, stop and remain in the car, but make sure you are not close to any bridges.



Coastlines

Head toward open spaces such as squares and parks, and move away from any trees to the extent possible.

Do not approach the coastline because of the possibility of a tsunami. Also avoid rivers, which could develop strong currents.



Rescue Tasks

Once the earthquake ends, rescue tasks must begin. At this stage it is imperative to determine whether anyone is injured and to apply first aid. Do not move injured people who have fractures, and do not drink water from open containers.

RESCUERS
The first priority after an earthquake is to search for survivors..

DOGS
Specially trained animals with protective helmets and masks can search for people under the rubble.

TRANSPORTATION
It is important to keep access routes to affected areas open to ensure entry by emergency teams.







San Francisco in Flames

The earthquake that shook San Francisco on April 18, 1906, was a major event: in only a few seconds, a large part of one of the most vital cities of the United States was reduced to rubble. Suddenly, centuries of pent-up energy was released when the earthquake, measuring 8.3 on the Richter scale, devastated the city. Though the earthquake destroyed many buildings, the worst damage was caused by the fires that destroyed the city in the course of three days, forcing people to flee their homes.

April 18

1 EVERYTHING STARTED LIKE THIS.
On April 18, 1906, at 5:12 a.m., the Pacific Plate experienced movement of approximately 19 feet (6 m) along its 267-mile (430-km) length along the northern San Andreas fault. The earthquake's epicenter lay 39 miles (64 km) north of San Francisco. In seconds, the earth began to move, and the majority of the city's buildings collapsed. The trolleys and carriages that were moving through the cobblestoned streets of the city were reduced to rubble.

CITY HALL
The facade was crowned by a dome that was supported by a system of columns on a steel structure. It was considered one of the city's most beautiful buildings.

History of City Hall

Until the earthquake struck, City Hall had been the seat of city government and the symbol of the city. Built in the second half of the 19th century, it represented a time of accelerated growth, powered by the gold riches of the state of California. Construction began on Feb. 22, 1870, and ended 27 years later, after many revisions to architect Auguste Laver's original project. While it stood, City Hall was said to have been constructed with bricks held together with corruption, typical of a time of easy money and weak institutions. The total cost of the work rose to a little more than $6,000,000 of that time, and, according to current calculations, it is estimated that it was prepared to withstand an earthquake up to a magnitude of 6.6. Only the dome and the metal structure were left standing. The remnants of the building were demolished in 1909.

THE FACE OF THE BUILDING COLLAPSED.
The facade collapsed completely on top of the rotunda at its base.

UNITED STATES
SAN FRANCISCO, CALIFORNIA
Latitude 42° 40′ N
Longitude 122° 18′ W

Surface area	46 square miles (120 sq km)
Population	739,426
Population density	16,000 people per square mile (6,200 people/sq km)
Perceptible earthquakes felt annually	100 - 150
Total earthquakes per year	~ 10,000

April 20

3 THE GREAT FIRE
Two days later, what had begun as a localized fire had become an inferno that consumed the city. There were mass evacuations of people to distant areas, while the army dynamited some buildings. Firefighters had to control the flames using seawater.

GAS LIGHTING
Gas lighting was one of the signs of progress that gave prominence to the city.

5:12 a.m.

2 THE EARTHQUAKE
Not only was the earthquake extremely violent, but it oscillated in every direction for 40 seconds. People left their houses and ran down the streets, completely stunned and blinded by fear. Many buildings split open, and others became piles of rubble. A post office employee related that "The walls were thrown into the middle of the rooms, destroying the furniture and covering everything with dust."

3 years

4 REBUILDING
The city reemerged from the ashes, powered by its wealth and economic importance. Losses are estimated to have reached $5,000,000,000 in present-day dollars, and, until Hurricane Katrina struck in 2005, the 1906 earthquake was the greatest natural disaster the United States had experienced.

Clearing the Rubble

It is calculated that some 3,000 people died in the 1906 catastrophe, trapped in their destroyed homes or burned by the fire the earthquake started. In the following weeks, the army, firefighters, and other workers deposited the rubble in the bay, forming new land, which is today known as the Marina District. Little by little, traffic resumed in the major streets, and the trolley system was reestablished. Six weeks after the earthquake, banks and stores opened for business.



Workers pose while they demolish a house.

WORKERS

By Saturday, April 21, some 300 plumbers had entered the city to reestablish services, mainly the water system. During the following weeks, thousands of workers tore down unstable buildings, prepared the streets for traffic, and cleared the city of rubble. Nearly 15,000 horses were used to haul rubble.



FIELD LUNCH

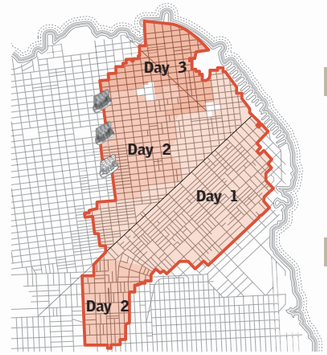
The army set up kitchens in the camps. There was always food in these field kitchens, and there was even a free ration of tobacco for every person.

Three Days of Fire

The great fire that followed the earthquake expanded quickly. Firefighters, in a desperate attempt to block the spread of the fire, used explosives to make firebreaks because there was no water supply available. The army evacuated the area, and people could not take anything with them. During the three days when the city burned, it is speculated that many homeowners burned their houses that had been partially destroyed by the earthquake, in order to be able to collect insurance money. Other things that contributed to the fire were the intentional explosions that, at first badly implemented, spread the fire. By the fourth day, the center of the city was reduced to ashes.

1 The fire began in the Market Street area, south of the city in the worker's district, where many houses were made of wood.

2 On the second day, the fire spread west. About 300,000 people were evacuated from the bay in ferries.



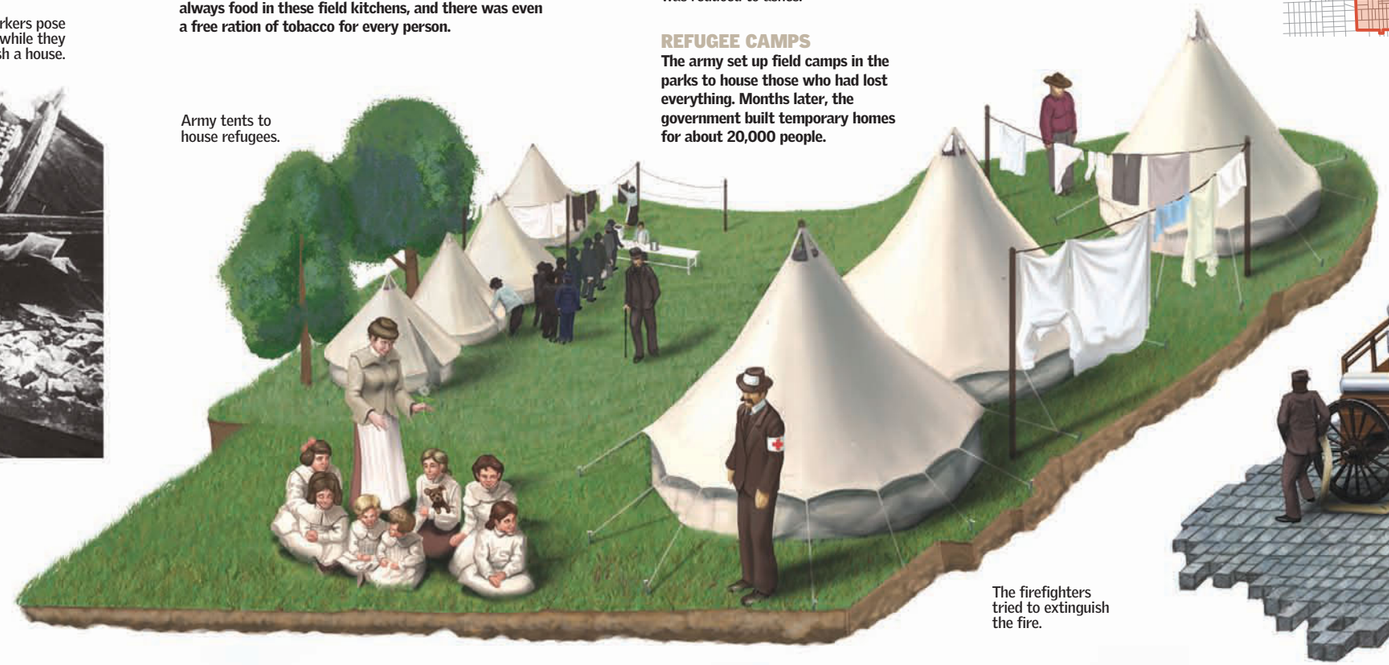
3 During the third day, the fire swept through Chinatown and North Beach, causing heavy damage to the Victorian homes on North Beach hill.

4 Once the fire was extinguished, Russian Hill and Telegraph Hill (shown as white spots) were still intact, as was the port.

REFUGEE CAMPS

The army set up field camps in the parks to house those who had lost everything. Months later, the government built temporary homes for about 20,000 people.

Army tents to house refugees.





The firefighters tried to extinguish the fire.

SHORTLY AFTERWARD

This panoramic photograph shows the destruction of the city. Despite the destruction, many buildings were left standing.

SAINT MARY'S CHURCH

CHINATOWN
Was completely destroyed by the fire.

18,000

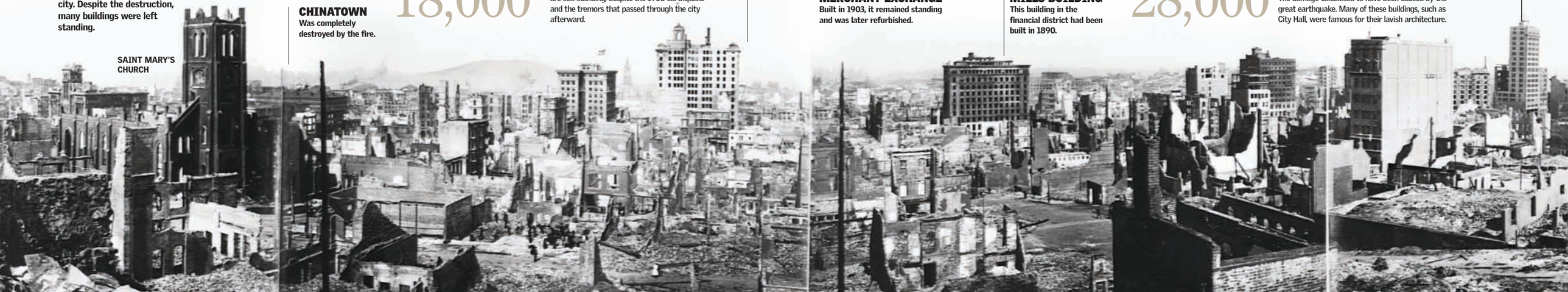
BUILDINGS OF THAT PERIOD
are still standing, despite the 1906 earthquake and the tremors that passed through the city afterward.

MERCHANT EXCHANGE
Built in 1903, it remained standing and was later refurbished.

MILLS BUILDING
This building in the financial district had been built in 1890.

28,000

BUILDINGS DEMOLISHED
The damage calculated to have been caused by the great earthquake. Many of these buildings, such as City Hall, were famous for their lavish architecture.



Historic Earthquakes

The Earth is alive. It moves, it shifts, it crashes and quakes, and it has done so since its origin. Earthquakes vary from a soft vibration to violent and terrorizing movements. Many earthquakes have gone down in history as the worst natural catastrophes ever survived by humanity. Lisbon, Portugal, 1755; Valdivia, Chile, 1960; and Kashmir, Pakistan, 2005, are only three examples of the physical, material, and emotional devastation in which an earthquake can leave a population. ●

1995



KOBE, JAPAN

Magnitude	6.8 (Richter)
Fatalities	6,433
Material losses	$100 billion

AN INFERNO

The great earthquake of Hanshin that occurred on Jan. 17, 1995, in Kobe, a Japanese port, left behind more than 6,000 dead, 38,000 injured, and 319,000 people who had to be housed in more than 1,200 emergency shelters. The Nagata District was one of the hardest-hit areas. Almost 80 percent of the victims died because the old wooden homes crumbled in the generalized fires that followed the earthquake.

1755



LISBON, PORTUGAL

Magnitude	8.7 (Richter)
Fatalities	62,000
Material losses	unknown

It was the Day of the Dead, and, at 9:20 in the morning, almost the entire population of Lisbon was at church. While mass was celebrated, the earth quaked, and this earthquake would be one of the most destructive and lethal in history. The earthquake unleashed a tsunami that was felt from Norway to North America and that took the lives of those who had sought shelter in the river.

1906



SAN FRANCISCO, U.S.

Magnitude	8.3 (Richter)
Fatalities	3,000
Material losses	$5 billion

The city was swept by the earthquake and by the fires that followed it. The quake was the result of the rupture of more than 40 miles of the San Andreas fault. It is the greatest earthquake in the history of the United States: 300,000 people were left homeless, and property losses reached millions in 1906 dollars. Buildings collapsed, the fires spread for three days, and the water lines were destroyed.

2004



SUMATRA, INDONESIA

Magnitude	9.0 (Richter)
Fatalities	230,507
Material losses	incalculable

An earthquake whose epicenter crossed the island of Sumatra, Indonesia, took place on December 26. This earthquake generated a tsunami that affected the entire Indian Ocean, primarily the islands of Sumatra and Sri Lanka, and reached the coasts of India, Thailand, the Maldives, and even Kenya and Somalia. This was a true human tragedy, and the economic damages were incalculable.

1960



VALDIVIA, CHILE

Magnitude	9.5 (Richter)
Fatalities	5,700
Material losses	$500 million

Known as the Great Chilean Earthquake, this was the strongest earthquake of the 20th century. The surface waves produced were so strong that they were still being registered by seismometers 60 hours after the earthquake. The earthquake was felt in various parts of the planet, and a huge tsunami spread through the Pacific Ocean, killing more than 60 people in Hawaii. One of the most powerful earthquakes in memory, its aftershocks lasted for more than a week. More than 5,000 people died, and nearly two million people suffered damage and loss.

1985



MEXICO CITY, MEXICO

Magnitude	8.1 (Richter)
Fatalities	11,000
Material losses	$1 billion

The city shook on September 19. Two days later, there was an aftershock measuring 7.6 on the Richter scale. In addition to 11,000 deaths, there were 30,000 injured, and 95,000 people were left homeless. As the Cocos Plate slid under the North American Plate, the North American Plate fractured, or split, 12 miles (20 km) inside the mantle. The vibrations of the ocean floor off the southwestern coast of Mexico provoked a tsunami and produced energy 1,000 times as great as that of an atomic bomb. Strong seismic waves reached as far east as Mexico City, a distance of 220 miles (350 km).

2005



KASHMIR, PAKISTAN

Magnitude	7.6 (Richter)
Fatalities	80,000
Material losses	$595 million

Also known as the Indian Subcontinent Earthquake, the North Pakistan Earthquake, and the South Asian Earthquake. It occurred on Oct. 8, 2005, in the Kashmir region between India and Pakistan. Because schools were in session when the earthquake struck (9:20 a.m.), many of the victims were children, who died when their school buildings collapsed. It was the strongest earthquake experienced by the region for a century. Three million people lost their homes. The most-heavily affected areas lost all their cattle. Entire fields disappeared under earth and rock. The epicenter was located near Islamabad, in the mountains of Kashmir, in an area governed by Pakistan.

AFTER THE HORROR. The world was shaken, looking at the horrendous images of how Kobe, the city by the sea, had been painfully broken to pieces.

Glossary

Aa

Type of lava flow that presents sharp projections on its surface when it hardens.

Abrasion

Modification of rock surfaces by friction and by the impact of other particles transported by wind, water, and ice.

Active Volcano

Volcano that erupts lava and gas at regular intervals.

Aerosol

Small particles and drops of liquid scattered in the air by volcanic gases.

Aftershock

Small temblor or quake produced as rock settles into place after a major earthquake.

Aseismic

The characteristic of a building designed to withstand oscillations, or of areas with no seismic activity.

Aseismic Region

Tectonically stable region of the Earth, where there are almost no earthquakes. For example, the Arctic region is aseismic.

Ashfall

Phenomenon in which gravity causes ash (or other pyroclastic material) to fall from a smoke column after an eruption. The distribution of the ash is a function of wind direction.

Asthenosphere

Internal layer of the Earth that forms part of the mantle.

Avalanche

Rapid movement of enormous volumes of rock and other materials caused by instability on the flanks of the volcano. The instability can be caused by the intrusion of magma into the structure of the volcano, by a large earthquake, or by the weakening of the volcano's structure by hydrothermal variation, for example.

Ballistic (Fragment)

A lump of rock expelled forcefully by a volcanic eruption and that follows a ballistic or elliptical trajectory.

Baltic

Of or pertaining to the Baltic Sea, or to the territories along it.

Batholith

Massive body of magma that results from an intrusion between preexisting layers.

Caldera

Large, round depression left when a volcano collapses onto its magma chamber.

Convection Currents

Vertical and circular movement of rock material in the mantle but found exclusively in the mantle.

Convergent Boundary

Border between two colliding tectonic plates.

Core

Central part of the Earth, with an outer boundary 1,800 miles (2,900 km) below the Earth's surface. The core is believed to be composed of iron and nickel—with a liquid outer layer and a solid inner core.

Crater

Depression on the peak of a volcano, or produced by the impact of a meteorite.

Crust

Outermost, rigid part of the Earth, made up mostly of basaltic rocks (underneath the oceans) and of rocks with a higher silicate content (in the continents).

Density

Ratio of a body's mass to its volume. Liquid water has a density of 62.4 pounds per cubic foot (1 g/cu cm).

Dike

Tabular igneous intrusion that crosses through layers of surrounding rock.

Dome

Cup-shaped bulge with very steep sides, formed by the accumulation of viscous lava. Usually a dome is formed by andesitic, dacitic, or rhyolitic lava, and the dome can reach a height of many hundreds of feet.

Duration of Earthquake

Time during which the shaking or tremor of an earthquake is perceptible to humans. This period is always less than that registered by a seismograph.

Earthquake

Vibration of the Earth caused by the release of energy.

Eon

The largest unit of time on the geologic scale, of an order of magnitude greater than an era.

Epicenter

Point on the Earth's surface located directly above the focus of an earthquake.

Epicentral Area

Region around the epicenter of an earthquake, usually characterized by being the area where the shaking is most intense and the earthquake damage is greatest.

Epicentral Distance

Distance along the Earth's surface from the point where an earthquake is observed to the epicenter.

Extinct Volcano

Volcano that shows no signs of activity for a long period of time, considered to have a very low probability of erupting.

Fault Displacement

Slow, gradual movement produced along a fault. It is characterized by not generating an earthquake or tremor.

Focus

Internal zone of the Earth, where seismic waves are released, carrying the energy held by rocks under pressure.

Fumarole

Emission of steam and gas, usually at high temperatures, from fractures or cracks in the surface of a volcano or from a region with volcanic activity. Most of the gas emitted is steam, but fumarole emissions can include gases such as CO2, CO, SO2, H2S, CH4, HCl, among others.

Geothermal Energy

Naturally heated steam used to generate energy.

Geyser

Spring that periodically expels hot water from the ground.

Gondwana

Southern portion of Pangea, which at one time included South America, Africa, Australia, India, and Antarctica.

Hot Spot

Point of concentrated heat in the mantle capable of producing magma that shoots up to the Earth's surface.

Hydrothermal Alteration

Chemical change in rocks and minerals, produced by an aqueous solution that is rich in volatile chemical elements found at high temperature and that rises from a magma body.

Igneous Activity

Geologic activity involving magma and volcanic activity.

Incandescent

A property of metal that has turned red or white because of heat.

Lahar

Mudflows produced on the slopes of volcanoes when unstable layers of ash and debris become saturated with water and flow downhill.

Lapilli

Fragments of rock with a diameter between 0.06 and 1.3 inches (2 and 32 mm) expelled during a volcanic eruption.

Lava

Magma, or molten rock, that reaches the Earth's surface.

Lava Bombs

Masses of lava that a volcano expels, which have a diameter equal to or greater than 1.2 inches (3.2 cm).

Lava Flow

River of lava that flows out of a volcano and runs along the ground.

Liquefaction

Transformation of ground from solid to fluid state through the action of an earthquake.

Lithosphere

Rigid part of the outer layer of the Earth, formed by the crust and the outer layer of the mantle. This is the layer that is destroyed in subduction zones and that grows in mid-ocean ridges.

Magma

Mass of molten rock deep below the surface, which includes dissolved gas and crystals. When magma has lost its gases and reaches the surface, it is called lava. If magma cools within the Earth's crust, it forms plutonic rocks.

Magma Chamber

Section within a volcano where incandescent magma is found.

Mantle

Layer between the Earth's crust and the outer core. Its lower part, the asthenosphere, is partially molten. The more superficial and less-fluid outer part is called the lithosphere.

Mid-Ocean Ridge

An elongated mountain range on the ocean floor, which varies between 300 and 3,000 miles (500 and 5,000 km) in breadth.

Neck

Column of lava that has solidified inside a volcano.

Normal Fault

Fracture in rock layers where the ground is being stretched, which generally causes the upper edge to sink relative to the lower part.

Ocean Trench

Long, narrow, extremely deep area of the ocean floor formed where the edge of an oceanic tectonic plate sinks beneath another plate.

Pahoehoe Lava

Lava with a smooth surface that has a ropelike form.

Pelean Eruption

Type of volcanic eruption with a growing dome of viscous lava that may be destroyed when it collapses because of gravity or brief explosions. Pelean eruptions produce pyroclastic flows or burning clouds. The term comes from Mount Pelée in Martinique.

Permeable Layers

Strata of the Earth's crust that allow water to reach deeper layers.

Plate Tectonics

Theory that the Earth's outer layer consists of separate plates that interact in various ways, causing earthquakes and forming volcanoes, mountains, and the crust itself.

Plinian Eruption

Extremely violent and explosive type of volcanic eruption that continuously expels large quantities of ash and other pyroclastic materials into the atmosphere, forming an eruption column typically 5 to 25 miles (8 to 40 km) high. The term honors Pliny the Younger, who observed the eruption of Mount Vesuvius (Italy) in AD 79.

Plume

Column of hot rock that rises from within the mantle, inside of which the rock may melt.

Primary (P) Wave

Seismic wave that alternately compresses and stretches the ground along its direction of travel.

Pumice

Pale volcanic rock full of holes, which give it a low density. Its composition is usually acidic (rhyolitic). The holes are formed by volcanic gases that expand as volcanic material rises to the surface.

Pyroclastic Flow

Dense, hot mix of volcanic gas, ash, and rock fragments that flows rapidly down the sides of a volcano.

Reverse Fault

Fractures in rock layers where the ground is being compressed, which generally causes the upper edge to rise above the lower part in a plane inclined between 45 and 90 degrees from the horizontal.

Richter Scale

Measures the magnitude of an earthquake or of the energy it releases. The scale is logarithmic, such that an earthquake of magnitude 8 releases 10 times as much energy as a magnitude 7 quake. An earthquake's magnitude is estimated based on measurements taken by seismic instruments.

Rift Zone

Area where the crust is splitting and stretching, as shown by cracks in the rock. Such areas are produced by the separation of tectonic plates, and their presence causes earthquakes and recurrent volcanic activity.

Scale of Intensity

Scale used to measure the severity of movement of the ground produced by an earthquake. Degrees of intensity are assigned subjectively depending on how the tremor is perceived and according to the damage caused to buildings. A widely used scale is the Mercalli scale.

Secondary (S) Wave

Transverse or cross-section wave with motion perpendicular to the direction of its travel.

Seismic Event

Shaking of the ground caused by an abrupt and violent movement of a mass of rock along a fault, or fracture, in the crust. Active volcanoes cause a wide variety of seismic events.

Seismic Gap

Fault zone, or zone of a segment at the boundary between tectonic plates, with a known seismic history and activity, which records a period of prolonged calm, or of seismic inactivity, during which large amounts of elastic energy of deformation accumulate, and that, therefore, presents a greater probability of rupture and occurrence of a seismic event.

Seismic Hazard Calculation

Process of determining the seismic risk of various sites in order to define areas with similar levels of risk.

Seismic Risk

The probability that the economic and social effects of a seismic event will exceed certain preestablished values during a given period, for example, a certain number of victims, an amount of building damage, economic losses, etc. Also defined as the comparative seismic hazard of one site relative to another.

Seismic Wave

Wavelike movement that travels through the Earth as a result of an earthquake or an explosion.

Seismic Zone

Limited geographic area within a seismic region, with similar seismic hazard, seismic risk, and earthquake-resistant design standards.

Seismograph

Instrument that registers seismic waves or tremors in the Earth's surface during an earthquake.

Seismology

Branch of geology that studies tremors in the Earth, be they natural or artificial.

Shield Volcano

Large volcano with gently sloping flanks formed by fluid basaltic lava.

Silicon

One of the most common materials, and a component of many minerals.

Subduction

Process by which the oceanic lithosphere sinks into the mantle along a convergence boundary. The Nazca Plate is undergoing subduction beneath the South American Plate.

Subduction Zone

Long, narrow region where one plate of the crust is slipping beneath another.

Surface Wave

Seismic wave that travels along the Earth's surface. It is perceived after the primary and secondary waves.

Swarm of Earthquakes

Sequence of small earthquakes that occur in the same area within a short time period, with a low magnitude in comparison to other earthquakes.

Symmetry

Correspondence that exists in an object with respect to a center, an axis, or a plane that divides it into parts of equal proportions.

Tectonic Plates

Large, rigid sections of the Earth's outer layer. These plates sit on top of a more ductile and plastic layer of the mantle, the asthenosphere, and they drift slowly at an average rate of 1 inch (2.4 cm) or more per year.

Thrust Fault

A fracture in rock layers that is characterized by one boundary that slips above another at an angle of less than 45 degrees.

Transform Fault

Fault in which plate boundaries cause friction by sliding past each other in opposite directions.

Tremor

Seismic event perceived on the Earth's surface as a vibration or shaking of the ground, without causing damage or destruction.

Tsunami

Word of Japanese origin that denotes a large ocean wave caused by an earthquake.

Viscous

Measure of a material's resistance to flow in response to a force acting on it. The higher the silicon content, the higher the viscosity.

Volcanic Glass

Natural glass formed when molten lava cools rapidly without crystallizing. A solid-like substance made of atoms with no regular structure.

Volcanic Ring

Chain of mountains or islands located near the edges of the tectonic plates and that is formed as a result of magma activity associated with subduction zones.

Volcano

Mountain formed by lava, pyroclastic materials, or both.

Volcanology (Vulcanology)

Branch of geology that studies the form and activity of volcanoes.

Vulcanian Eruption

Type of volcanic eruption characterized by the occurrence of explosive events of brief duration that expel material into the atmosphere to heights of about 49,000 feet (15 km). This type of activity is usually linked to the interaction of groundwater and magma (phreatomagmatic eruption).

Water Spring

Natural source of water that flows out of the crust. The water comes from rainwater that seeps into the ground in one place and comes to the surface in another, usually at a lower elevation. Because the water is not confined in waterproof chambers, it can be heated by contact with igneous rock. This causes it to rise to the surface as hot springs.

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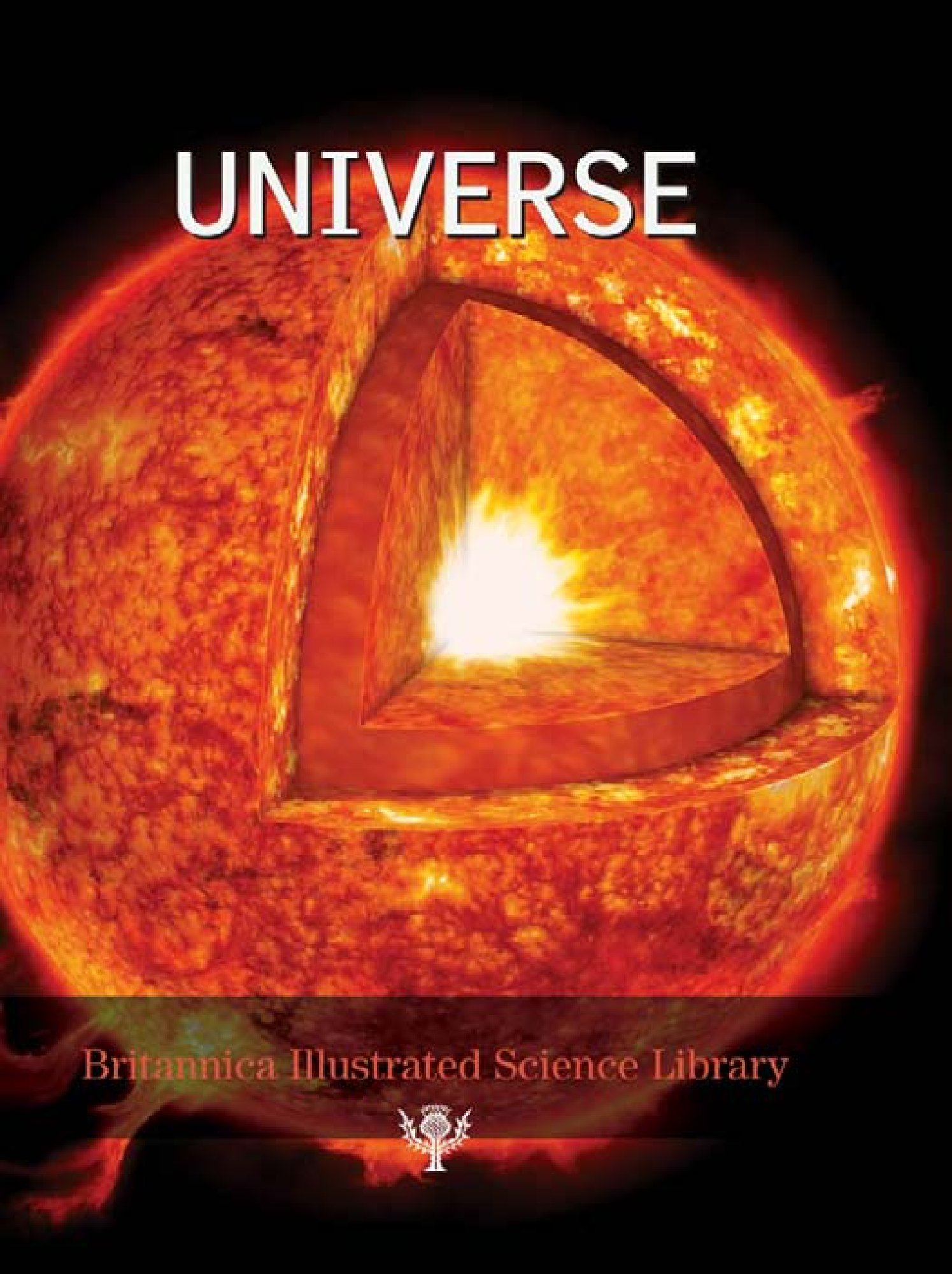
VOLCANOES AND EARTHQUAKES

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Universe



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PICTURE ON PAGE 1
Image of a planetary nebula. Planetary nebulae are among the most photogenic objects in astronomy.

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The Solar System

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The Earth and the Moon

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Observing the Universe

Page 80

CONE NEBULA
This nebula got its name from its cone shape, as shown in the image.

The Secrets of the Universe

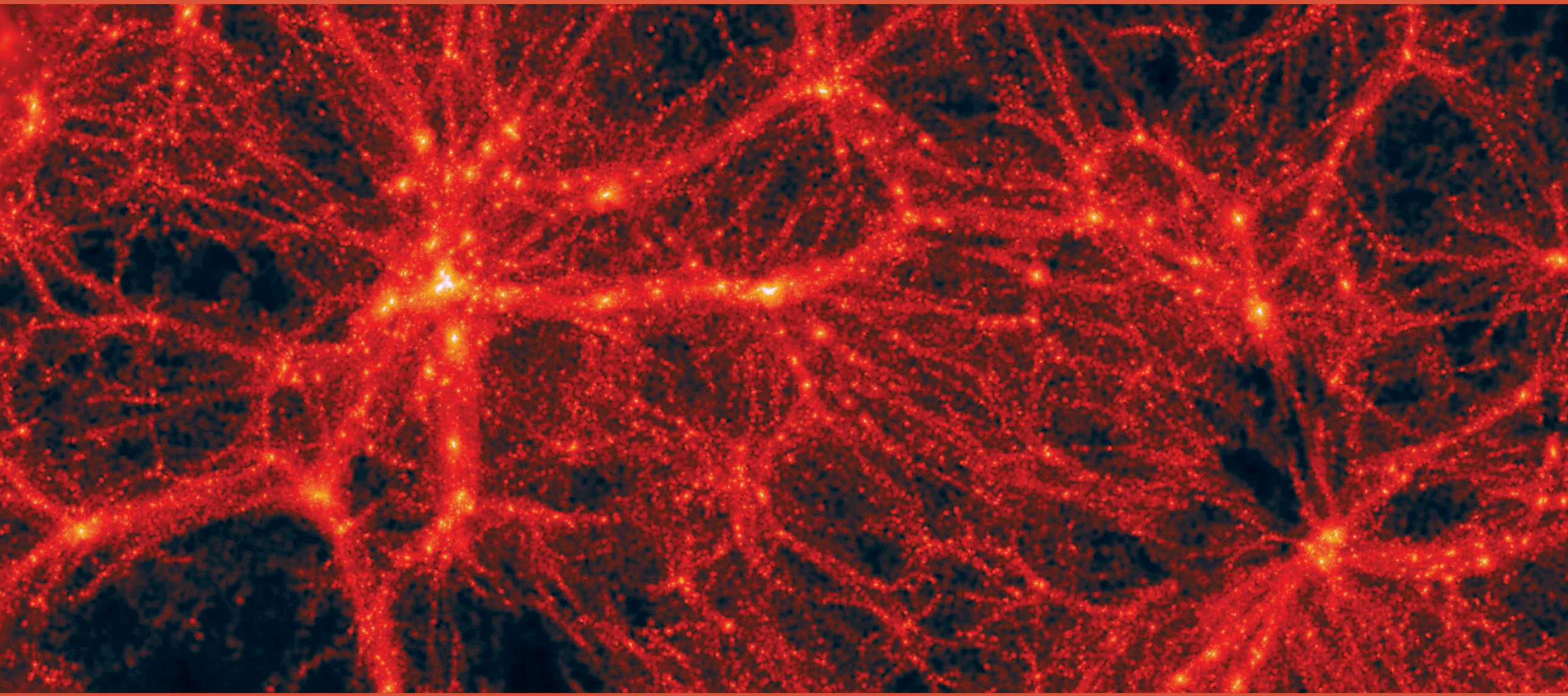
There was a time when people believed that the stars were bonfires lit by other tribes in the sky, that the universe was a flat plate resting on the shell of a giant turtle, and that the Earth, according to the Greek astronomer Ptolemy, was at the center of the universe. From the most remote of times, people have been curious about what lies hidden beyond the celestial sphere. This curiosity has led them to build telescopes that show with clarity otherwise blurry and distant objects. In this book you will find the history of the cosmos illustrated with spectacular images that show in detail how the cosmos was formed, the nature of the many points of light that adorn the night sky, and what lies ahead. You will also discover how the suns that inhabit space live and die, what dark matter and black holes are, and what our place is in this vastness. Certainly, the opportunity to compare the destiny of other worlds similar to ours will help us understand that for the time being there is no better place than the Earth to live. At least for now.

In the Milky Way—according to mathematical and physical calculations—there are more than 100 billion stars, and such a multitude leads to the question: Is it possible that our Sun is the only star that possesses an inhabited planet? Astronomers are more convinced than ever of the possibility of life in other worlds. We just need to find them. Reading this book will let you become better acquainted with our neighbors in the solar system—the other planets—and the most important characteristics that distinguish them. All this information that explores the mysteries of space is accompanied by recent images captured by the newest telescopes. They reveal many details about the planets and their satellites, such as the volcanoes and craters found on the surface of some of them. You will also learn more about the asteroids and comets that orbit the Sun and about Pluto, a dwarf planet, which is to be visited by a space probe for the first time. Less than a decade ago, astronomers began observing frozen worlds, much smaller than a planet, in a region of the solar system called the Kuiper belt. We invite you to explore all of this. The images and illustrations that accompany the text will prove very helpful in studying and understanding the structure of all the visible and invisible objects (such as dark matter) that form part of the universe. There are stellar maps showing the constellations, the groups of stars that since ancient times have served as a guide for navigation and for the development of calendars. There is also a review through history: from Ptolemy, who thought the planets orbited around the Earth, and Copernicus, who put the Sun in the center, and Galileo, the first to aim a telescope skyward, up to the most recent astronomical theories, such as those of Stephen Hawking, the genius of space and time who continues to amaze with his discoveries about the greatest mysteries of the cosmos. You will find these and many more topics no matter where you look in this fantastic book that puts the universe and its secrets in your hands.

What Is the Universe?

DARK MATTER
Evidence exists that dark matter, though invisible to telescopes, betrays itself by the gravitational pull it exerts over other heavenly bodies.

X-RAY OF THE COSMOS 8-9
THE INSTANT OF CREATION 10-13
EVERYTHING COMES TO AN END 14-15
THE FORCES OF THE UNIVERSE 16-17



The universe is everything that exists, from the smallest particles to the largest ones, together with all matter and energy. The universe includes visible and invisible things, such as dark matter, the great, secret component of the cosmos. The search for dark matter is currently one of the most important tasks of cosmology. Dark matter may literally determine the density of all of space, as well as decide the destiny of the universe. Did you know that, second by second, the universe grows and grows? The question that astronomers are asking—the question that concerns them the most—is how much longer the universe can continue to expand like a balloon before turning into something cold and dark. ●

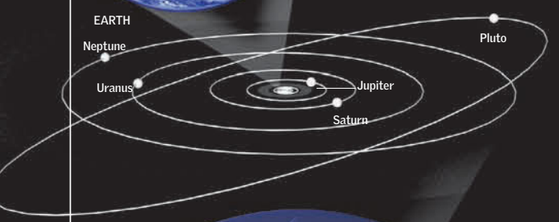
X-Ray of the Cosmos

The universe, marvelous in its majesty, is an ensemble of a hundred billion galaxies. Each of these galaxies (which tend to be found in large groups) has billions of stars. These galactic concentrations surround empty spaces, called cosmic voids. The immensity of the cosmos can be better grasped by realizing that the size of our fragile planet Earth, or even that of the Milky Way, is insignificant compared to the size of the remainder of the cosmos.



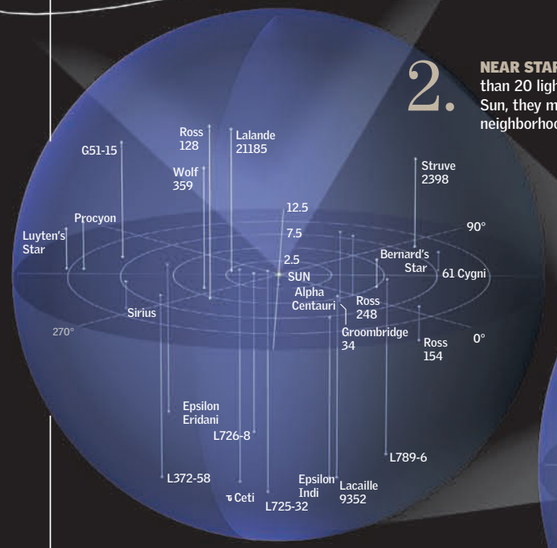
1.

EARTH Originated, together with the solar system, when the universe was already 9.1 billion years old. It is the only known planet that is home to life.



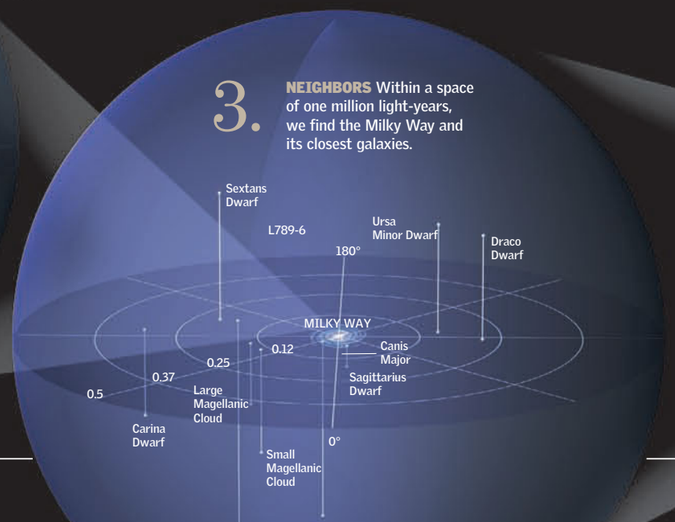
The Universe

Originating nearly 14 billion years ago in an immense explosion, the universe today is too large to be able to conceive. The innumerable stars and galaxies that populate it promise to continue expanding for a long time. Though it might sound strange today, for many years, astronomers thought that the Milky Way, where the Earth is located, constituted the entire universe. Only recently—in the 20th century—was outer space recognized as not only much vaster than previously thought but also as being in a state of ongoing expansion.



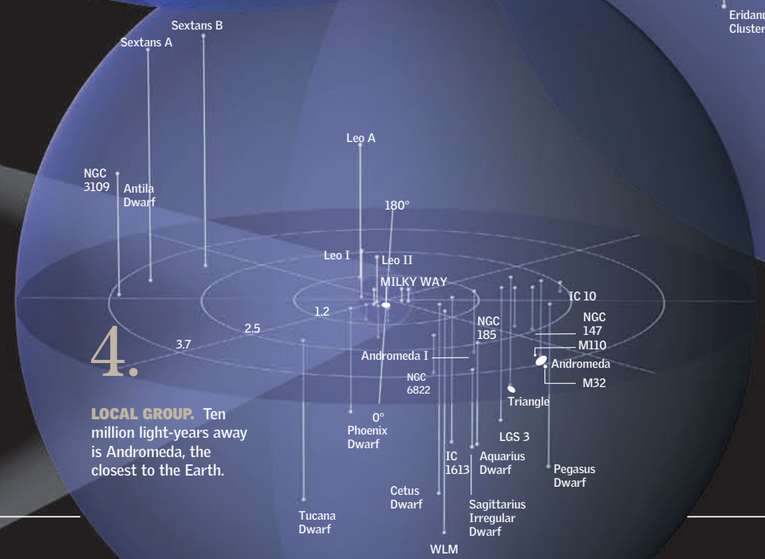
2.

NEAR STARS Found closer than 20 light-years from the Sun, they make up our solar neighborhood.



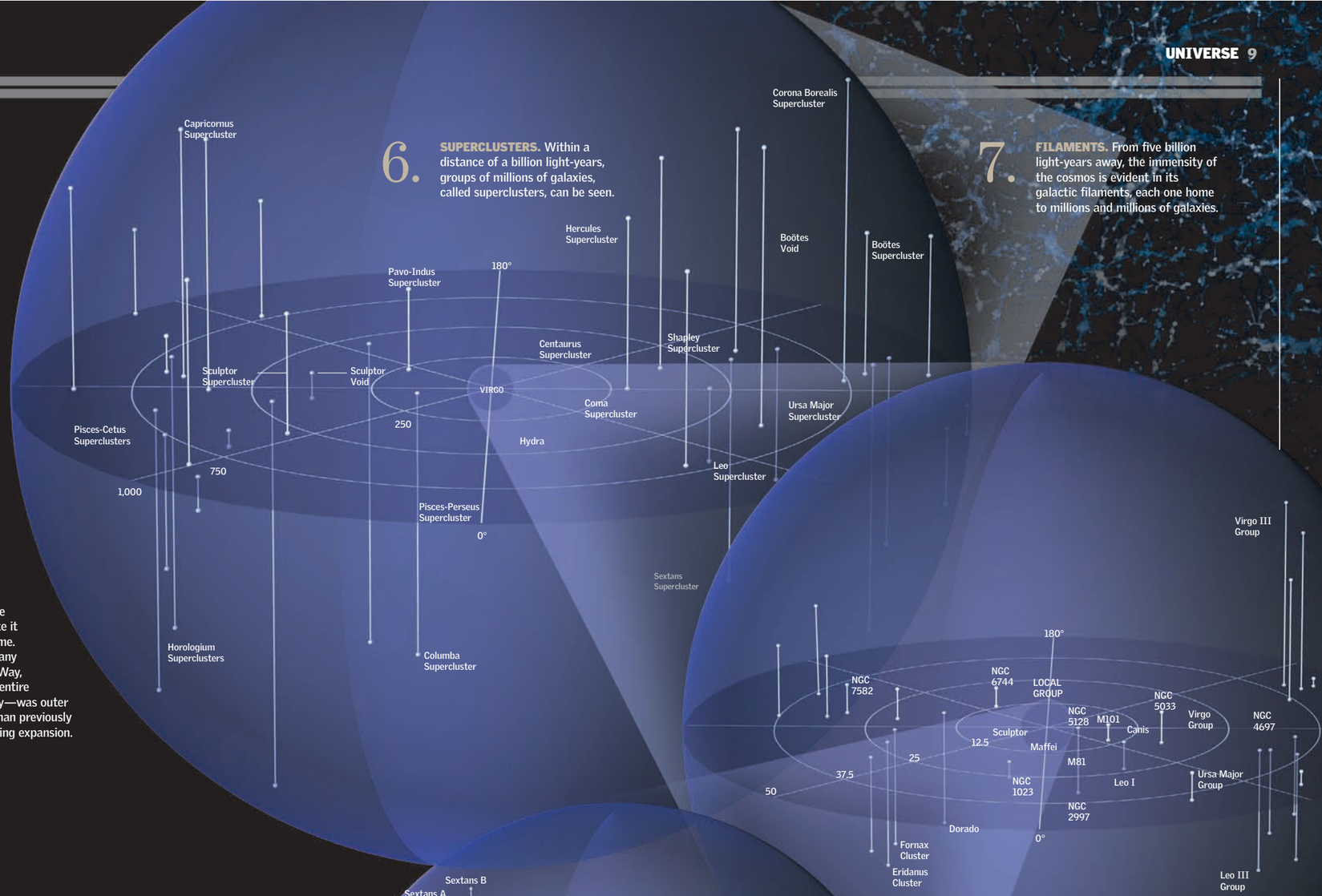
3.

NEIGHBORS Within a space of one million light-years, we find the Milky Way and its closest galaxies.



4.

LOCAL GROUP. Ten million light-years away is Andromeda, the closest to the Earth.



6.

SUPERCLUSTERS. Within a distance of a billion light-years, groups of millions of galaxies, called superclusters, can be seen.

7.

FILAMENTS. From five billion light-years away, the immensity of the cosmos is evident in its galactic filaments, each one home to millions and millions of galaxies.

5.

NEAREST GALAXIES. At a scale of one hundred million light-years, the galactic clusters nearest to the Milky Way can be seen.

100 BILLION

The total number of galaxies that exist, indicating that the universe is both larger and older than was previously thought

The Instant of Creation

It is impossible to know precisely how, out of nothing, the universe began to exist. According to the big bang theory—the theory most widely accepted in the scientific community—in the beginning, there appeared an infinitely small and dense burning ball that gave rise to space, matter, and energy. This happened 13.7 billion years ago. The great, unanswered question is what caused a small dot of light—filled with concentrated energy from which matter and antimatter were created—to arise from nothingness. In very little time, the young universe began to expand and cool. Several billion years later, it acquired the form we know today.

Energetic Radiation

The burning ball that gave rise to the universe remained a source of permanent radiation. Subatomic particles and antiparticles annihilated each other. The ball's high density spontaneously produced matter and destroyed it. Had this state of affairs continued, the universe would never have undergone the growth that scientists believe followed cosmic inflation.

HOW IT GREW

Cosmic inflation was an expansion of the entire universe. The Earth's galactic neighborhood appears fairly uniform. Everywhere you look, the types of galaxies and the background temperature are essentially the same.

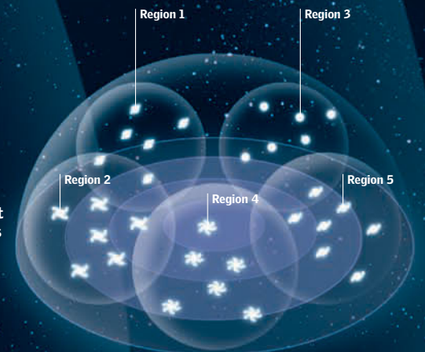


Cosmic Inflation Theory

Although big bang theorists understood the universe as originating in an extremely small, hot, and condensed ball, they could not understand the reason for its staggering growth. In 1981, physicist Alan Guth proposed a solution to the problem with his inflationary theory. In an extremely short period of time (less than a thousandth of a second), the universe grew more than a trillion trillion trillion times. Near the end of this period of expansion, the temperature approached absolute zero.

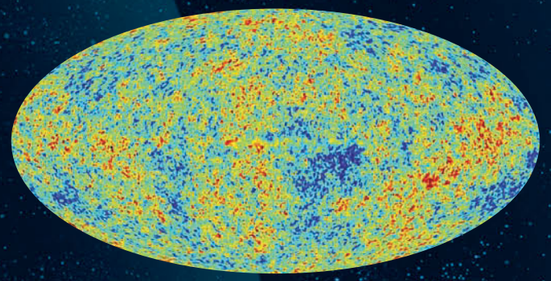
HOW IT DID NOT GROW

Had the universe not undergone inflation, it would be a collection of different regions, each with its own particular types of galaxies and each clearly distinguishable from the others.



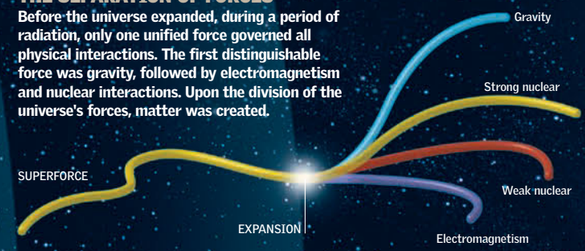
WMAP (WILKINSON MICROWAVE ANISOTROPY PROBE)

NASA's WMAP project maps the background radiation of the universe. In the image, hotter (red-yellow) regions and colder (blue-green) regions can be observed. WMAP makes it possible to determine the amount of dark matter.



THE SEPARATION OF FORCES

Before the universe expanded, during a period of radiation, only one unified force governed all physical interactions. The first distinguishable force was gravity, followed by electromagnetism and nuclear interactions. Upon the division of the universe's forces, matter was created.



TIME 0

TEMPERATURE -

1 Scientists theorize that, from nothing, something infinitely small, dense, and hot appeared. All that exists today was compressed into a ball smaller than the nucleus of an atom.

10^{-43} sec

10^{32} ° F (and C)

2 At the closest moment to zero time, which physics has been able to reach, the temperature is extremely high. Before the universe's inflation, a superforce governed everything.

10^{-38} sec

10^{29} ° F (and C)

3 The universe is unstable. Only 10^{-38} seconds after the big bang, the universe increases in size more than a trillion trillion trillion times. The expansion of the universe and the division of its forces begin.

10^{-12} sec

10^{15} ° F (and C)

4 The universe experiences a gigantic cooldown. Gravity has already become distinguishable, and the electromagnetic force and the strong and weak nuclear interactions appear.

10^{-4} sec

10^{12} ° F (and C)

5 Protons and neutrons appear, formed by three quarks apiece. Because all light is trapped within the web of particles, the universe is still dark.

5 sec

$9x10^{9}$ ° F ($5x10^{9}$ ° C)

6 The electrons and their antiparticles, positrons, annihilate each other until the positrons disappear. The remaining electrons form atoms.

3 min

$2x10^{9}$ ° F ($1x10^{9}$ ° C)

7 The nuclei of the lightest elements, hydrogen and helium, form. Protons and neutrons unite to form the nuclei of atoms.

ELEMENTARY PARTICLES

In its beginnings, the universe was a soup of particles that interacted with each other because of high levels of radiation. Later, as the universe expanded, quarks formed the nuclei of the elements and then joined with electrons to form atoms.



1 sec

The neutrinos separate from the initial particle soup through the disintegration of neutrons. Though having extremely little mass, the neutrinos might nevertheless form the greatest part of the universe's dark matter.

FROM PARTICLES TO MATTER

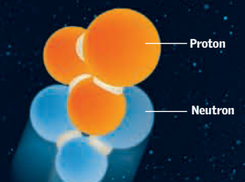
The quarks, among the oldest particles, interact with each other by forces transmitted through gluons. Later protons and neutrons will join to form nuclei.



1 A gluon interacts with a quark.



2 Quarks join by means of gluons to form protons and neutrons.



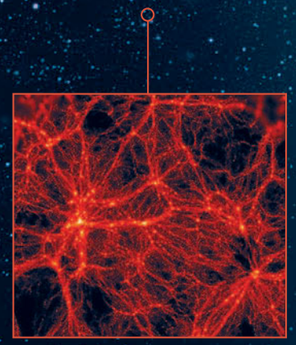
3 Protons and neutrons unite to create nuclei.

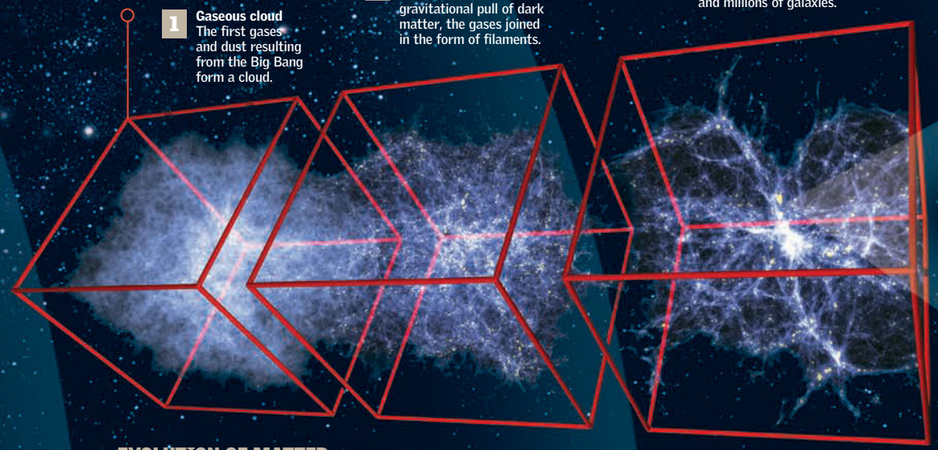
The Transparent Universe

With the creation of atoms and overall cooling, the once opaque and dense universe became transparent. Electrons were attracted by the protons of hydrogen and helium nuclei, and together they formed atoms. Photons (massless particles of light) could now pass freely through the universe. With the cooling, radiation remained abundant but was no longer the sole governing factor of the universe. Matter, through gravitational force, could now direct its own destiny. The gaseous lumps that were present in this process grew larger and larger. After 100 million years, they formed even larger objects. Their shapes not yet defined, they constituted protogalaxies. Gravitation gave shape to the first galaxies some 500 million years after the big bang, and the first stars began to shine in the densest regions of these galaxies. One mystery that could not be solved was why galaxies were distributed and shaped the way they were. The solution that astronomers have been able to find through indirect evidence is that there exists material called dark matter whose presence would have played a role in galaxy formation.

DARK MATTER

The visible objects in the cosmos represent only a small fraction of the total matter within the universe. Most of it is invisible even to the most powerful telescopes. Galaxies and their stars move as they do because of the gravitational forces exerted by this material, which astronomers call dark matter.





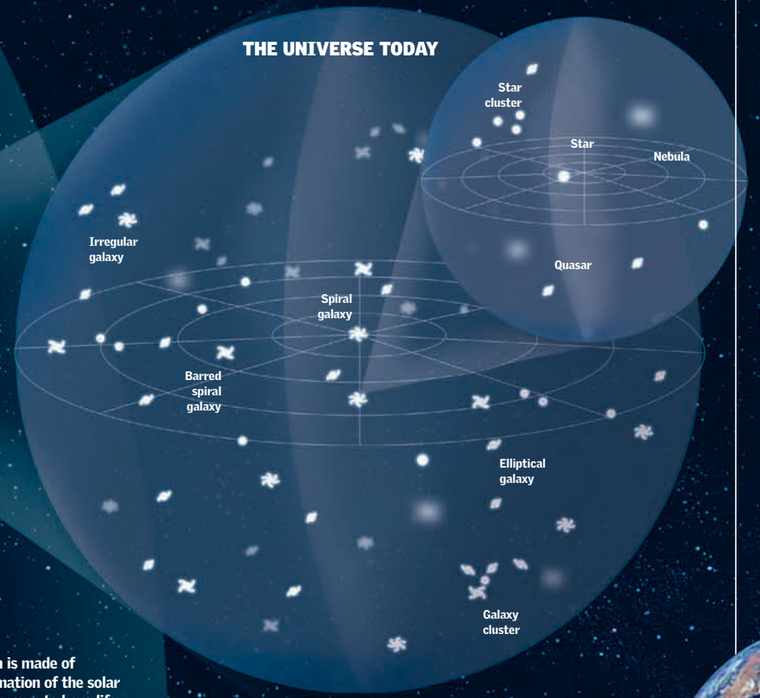
1 Gaseous cloud
The first gases and dust resulting from the Big Bang form a cloud.

2 First filaments
Because of the gravitational pull of dark matter, the gases joined in the form of filaments.

3 Filament networks
The universe has large-scale filaments that contain millions and millions of galaxies.

EVOLUTION OF MATTER

What can be observed in the universe today is a great quantity of matter grouped into galaxies. But that was not the original form of the universe. What the big bang initially produced was a cloud of uniformly dispersed gas. Just three million years later, the gas began to organize itself into filaments. Today the universe can be seen as a network of galactic filaments with enormous voids between them.



9.1 billion

THE EARTH IS CREATED

Like the rest of the planets, the Earth is made of material that remained after the formation of the solar system. The Earth is the only planet known to have life.



TIME (in years)

TEMPERATURE

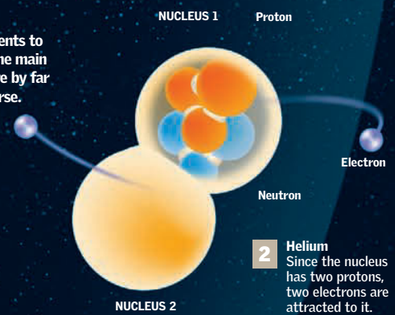
380,000

4,900° F (2,700° C)

8 380,000 years after the big bang, atoms form. Electrons orbit the nuclei, attracted by the protons. The universe becomes transparent. Photons travel through space.

FIRST ATOMS

Hydrogen and helium were the first elements to be formed at the atomic level. They are the main components of stars and planets. They are by far the most abundant elements in the universe.



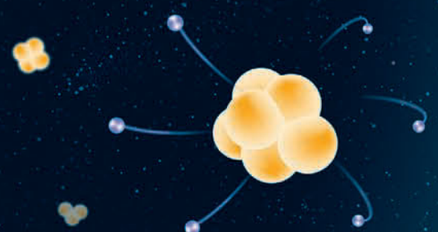
1 Hydrogen
An electron is attracted by and orbits the nucleus, which has a proton and a neutron.

2 Helium
Since the nucleus has two protons, two electrons are attracted to it.

500 million

-405° F (-243° C)

9 Galaxies acquire their definitive shape: islands of millions and millions of stars and masses of gases and dust. The stars explode as supernovas and disperse heavier elements, such as carbon.



3 Carbon
With time, heavier and more complex elements were formed. Carbon, the key to human life, has six protons in its nucleus and six electrons orbiting it.

9 billion

-432° F (-258° C)

10 Nine billion years after the big bang, the solar system emerged. A mass of gas and dust collapsed until it gave rise to the Sun. Later the planetary system was formed from the leftover material.

13.7 billion

-454° F (-270° C)

11 The universe continues to expand. Countless galaxies are surrounded by dark matter, which represents 22 percent of the mass and energy in the universe. The ordinary matter, of which stars and planets are made, represents just 4 percent of the total. The predominant form of energy is also of an unknown type. Called dark energy, it constitutes 74 percent of the total mass and energy.

TIMESCALE

The vast span of time related to the history of the universe can be readily understood if it is scaled to correspond to a single year—a year that spans the beginning of the universe, the appearance of humans on the Earth, and the voyage of Columbus to America. On January 1 of this imaginary year—at midnight—the big bang takes place. *Homo sapiens* appears at 11:56 P.M. on December 31, and Columbus sets sail on the last second of the last day of the year. One second on this timescale is equivalent to 500 true years.

BIG BANG
occurs on the first second of the first day of the year.

JANUARY

THE SOLAR SYSTEM
is created on August 24 of this timescale.

COLUMBUS'S ARRIVAL
takes place on the last second of December 31.

DECEMBER



Everything Comes to an End

The big bang theory helped solve the enigma of the early moments of the universe. What has yet to be resolved is the mystery surrounding the future that awaits. To unravel this mystery, the total mass of the universe must be known, but that figure has not yet been reliably determined. The most recent observations have removed some of this uncertainty. It seems that the mass of the universe is far too little to stop its expansion. If this is this case, the universe's present growth is merely the last step before its total death in complete darkness.

DISCOVERIES
The key discovery that led to the big bang theory was made in the early 1920s by Edwin Hubble, who discovered that galaxies were moving away from each other. In the 1940s, George Gamow developed the idea that the universe began with a primordial explosion. A consequence of such an event would be the existence of background radiation, which Arno Penzias and Robert Wilson accidentally detected in the mid-1960s.



1920s
GALACTIC EXPANSION
By noting a redshift toward the red end of the spectrum, Hubble was able to demonstrate that galaxies were moving away from each other.



1940s
GAMOW'S SUSPICION
Gamow first hypothesized the big bang, holding that the early universe was a "cauldron" of particles.

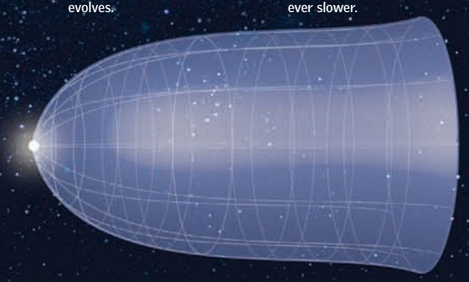


1965
BACKGROUND RADIATION
Penzias and Wilson detected radio signals that came from across the entire sky—the uniform signal of background radiation.

Flat Universe

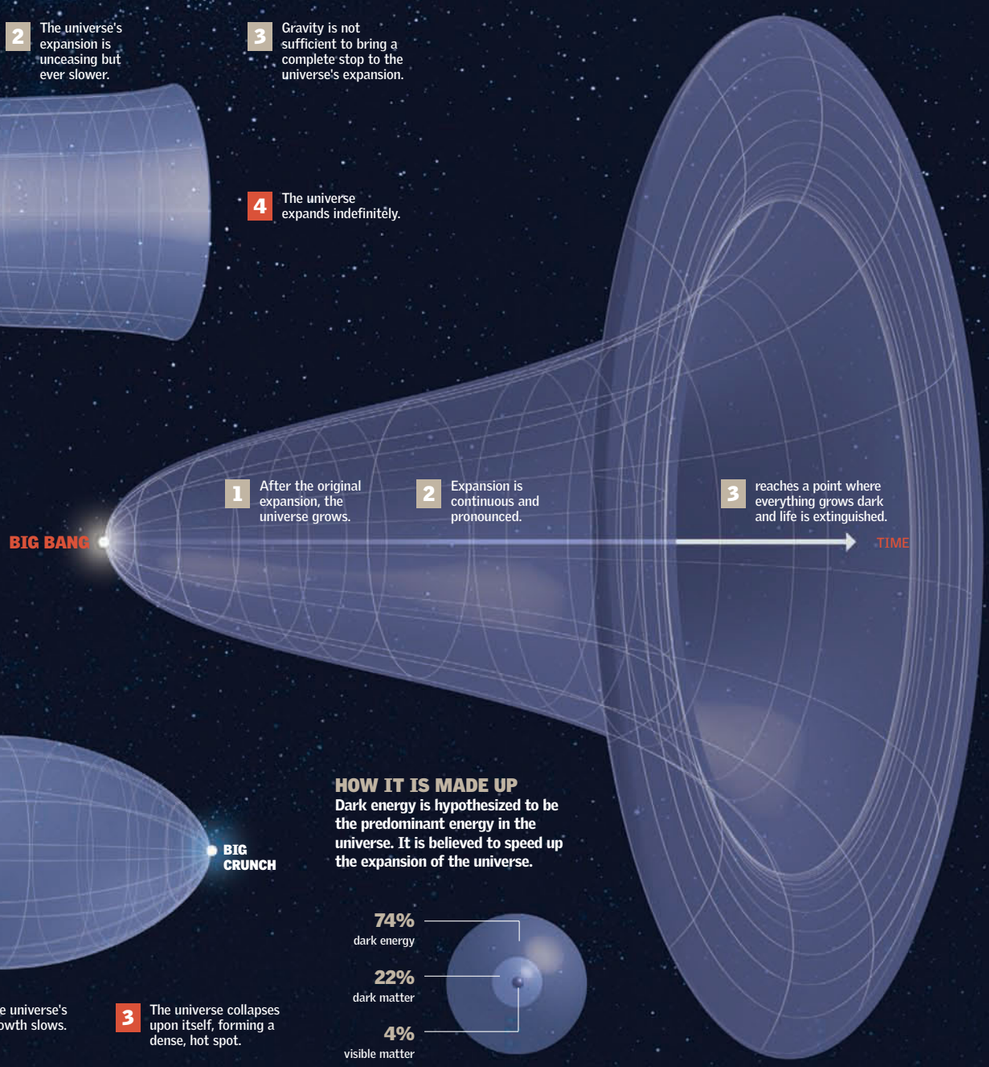
1 There is a critical amount of mass for which the universe would expand at a declining rate without ever totally stopping. The result of this eternal expansion would be the existence of an ever-increasing number of galaxies and stars. If the universe were flat, we could talk about a cosmos born from an explosion, but it would be a universe continuing outward forever. It is difficult to think about a universe with these characteristics.





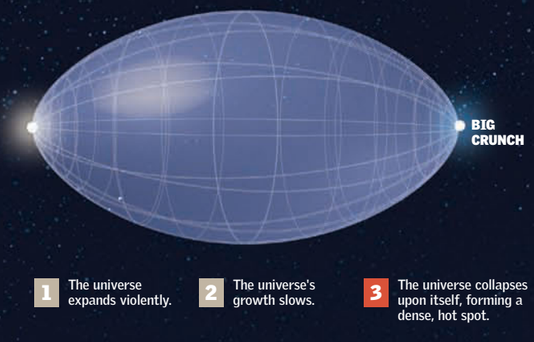
THE HAWKING UNIVERSE
The universe was composed originally of four spatial dimensions without the dimension of time. Since there is no change without time, one of these dimensions, according to Hawking, transformed spontaneously on a small scale into a temporal dimension, and the universe began to expand.





Closed Universe

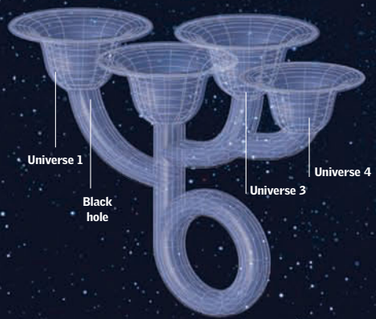
2 If the universe had more than critical mass, it would expand until reaching a point where gravity stopped the expansion. Then, the universe would contract in the Big Crunch, a total collapse culminating in an infinitely small, dense, and hot spot similar to the one from which the universe was formed. Gravity's pull on the universe's excess matter would stop the expansion and reverse the process.



HOW IT IS MADE UP
Dark energy is hypothesized to be the predominant energy in the universe. It is believed to speed up the expansion of the universe.

Self-generated Universes

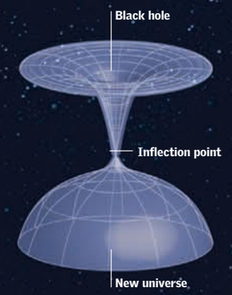
3 A less widely accepted theory about the nature of the universe suggests that universes generate themselves. If this is the case, universes would be created continuously like the branches of a tree, and they might be linked by supermassive black holes.

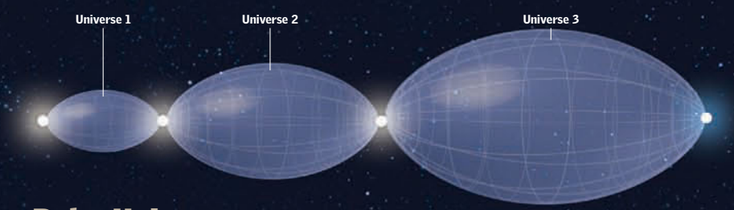


Open Universe

4 The most accepted theory about the future of the cosmos says that the universe possesses a mass smaller than the critical value. The latest measurements seem to indicate that the present time is just a phase before the death of the universe, in which it goes completely dark.

BLACK HOLES
Some theorists believe that, by entering a black hole, travel through space to other universes might be possible because of antigravitational effects.





Baby Universes

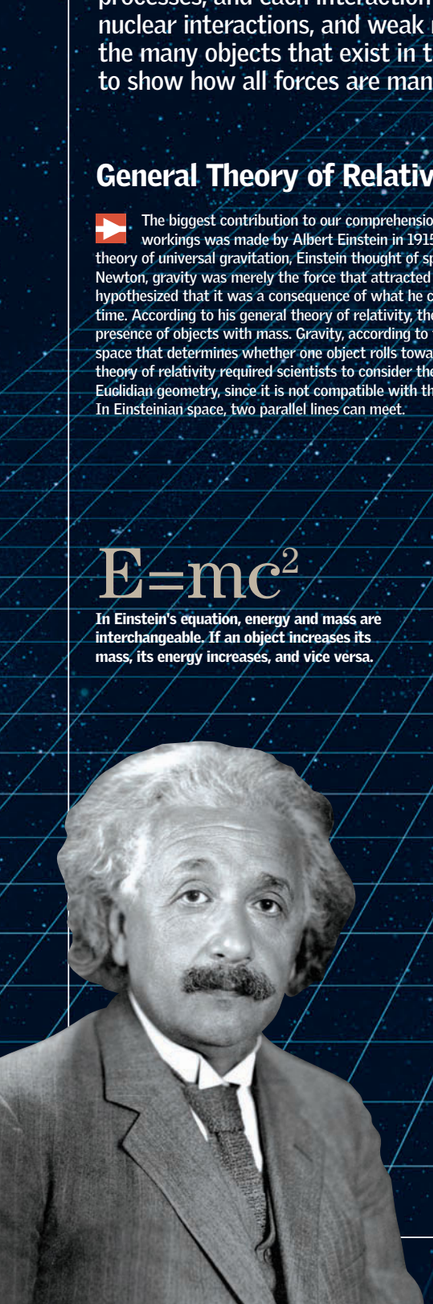
5 According to this theory, universes continuously sprout other universes. But in this case, one universe would be created from the death or disappearance of another. Each dead universe in a final collapse, or Big Crunch, would give rise to a supermassive black hole, from which another universe would be born. This process could repeat itself indefinitely, making the number of universes impossible to determine.

The Forces of the Universe

The four fundamental forces of nature are those that are not derived from basic forces. Physicists believe that, at one time, all physical forces functioned as a single force and that during the expansion of the universe, they became distinct from each other. Each force now governs different processes, and each interaction affects different types of particles. Gravity, electromagnetism, strong nuclear interactions, and weak nuclear interactions are essential to our understanding of the behavior of the many objects that exist in the universe. In recent years, many scientists have tried with little success to show how all forces are manifestations of a single type of exchange.

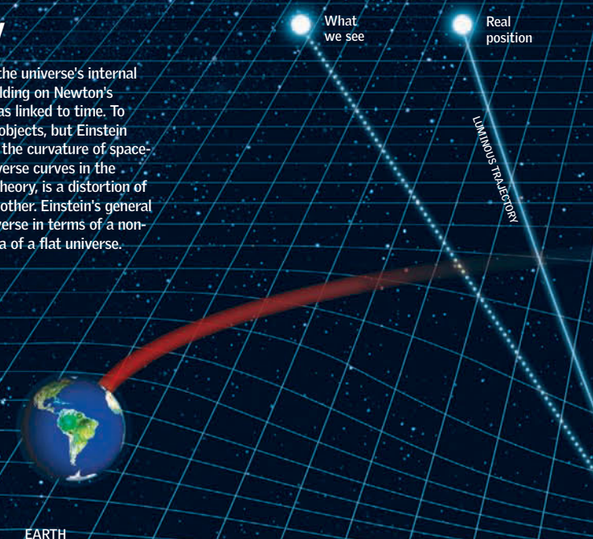
General Theory of Relativity

The biggest contribution to our comprehension of the universe's internal workings was made by Albert Einstein in 1915. Building on Newton's theory of universal gravitation, Einstein thought of space as linked to time. To Newton, gravity was merely the force that attracted two objects, but Einstejn hypothesized that it was a consequence of what he called the curvature of space-time. According to his general theory of relativity, the universe curves in the presence of objects with mass. Gravity, according to this theory, is a distortion of space that determines whether one object rolls toward another. Einstein's general theory of relativity required scientists to consider the universe in terms of a non-Euclidian geometry, since it is not compatible with the idea of a flat universe. In Einsteinian space, two parallel lines can meet.



$E=mc^2$

In Einstein's equation, energy and mass are interchangeable. If an object increases its mass, its energy increases, and vice versa.

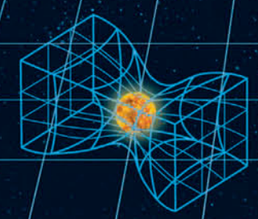


Gravity

1 Gravity was the first force to become distinguishable from the original superforce. Today scientists understand gravity in Einstein's terms as an effect of the curvature of space-time. If the universe were thought of as a cube, the presence of any object with mass in space would deform the cube. Gravity can act at great distances (just as electromagnetism can) and always exerts a force of attraction. Despite the many attempts to find antigravity (which could counteract the effects of black holes), it has yet to be found.



The universe, if it were empty, could be pictured in this way.



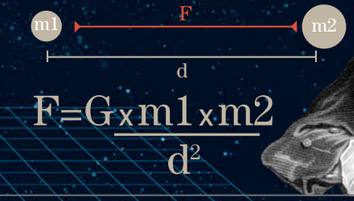
The universe is deformed by the mass of the objects it contains.

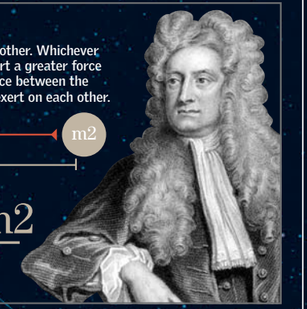
UNIVERSAL GRAVITATION

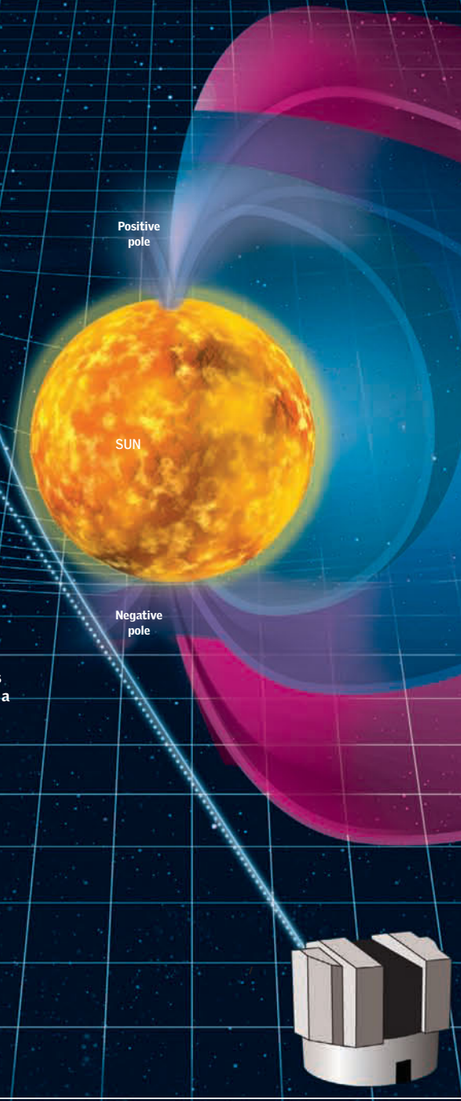
The gravitation proposed by Newton is the mutual attraction between bodies having mass. The equation developed by Newton to calculate this force states that the attraction experienced by two bodies is directly proportional to the product of their masses and inversely proportional to the square of the distance between them. Newton represented the constant of proportionality resulting from this interaction as G. The shortcoming of Newton's law, an accepted paradigm until Einstein's theory of general relativity, lies in its failure to make time an essential component in the interaction between objects. According to Newton, the gravitational attraction between two objects with mass did not depend on the properties of space but was an intrinsic property of the objects themselves. Nevertheless, Newton's law of universal gravitation was a foundation for Einstein's theory.

NEWTON'S EQUATION

Two bodies with mass attract each other. Whichever body has the greatest mass will exert a greater force on the other. The greater the distance between the objects, the smaller the force they exert on each other.

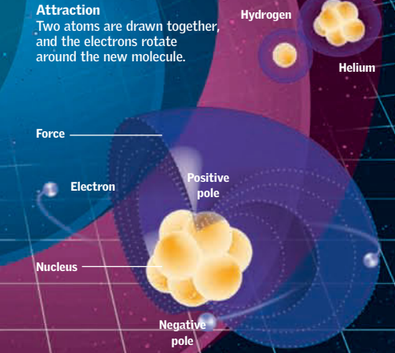






Electromagnetism

2 Electromagnetism is the force that affects electrically charged bodies. It is involved in the chemical and physical transformations of the atoms and molecules of the various elements. The electromagnetic force can be one of attraction or repulsion, with two types of charges or poles.



MOLECULAR MAGNETISM

In atoms and molecules, the electromagnetic force is dominant. It is the force that causes the attraction between protons and electrons in an atom and the attraction or repulsion between ionized atoms.

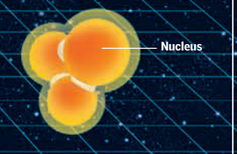
BENDING LIGHT

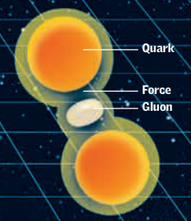
Light also bends because of the curvature of space-time. When seen from a telescope, the real position of an object is distorted. What is perceived through the telescope is a false location, generated by the curvature of the light. It is not possible to see the actual position of the object.

Strong Nuclear Force

3 The strong nuclear force holds the protons and neutrons of atomic nuclei together. Both protons and neutrons are subject to this force. Gluons are particles that carry the strong nuclear force, and they bind quarks together to form protons and neutrons. Atomic nuclei are held together by residual forces in the interaction between quarks and gluons.

1 **Quarks and gluons**
The strong nuclear interaction takes place when the gluon interacts with quarks.





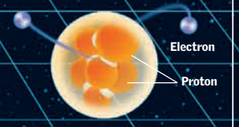
2 **Union**
Quarks join and form nuclear protons and neutrons.

Weak Nuclear Force

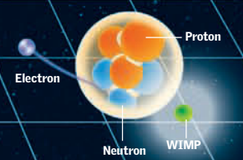
4 The weak nuclear force is not as strong as the other forces. The weak nuclear interaction influences the beta decay of a neutron, which releases a proton and a neutrino that later transforms into an electron. This force takes part in the natural radioactive phenomena associated with certain types of atoms.

1 **Hydrogen**
A hydrogen atom interacts with a weak, light particle (WIMP). A neutron's bottom quark transforms into a top quark.

HELIUM ISOTOPE



HYDROGEN ATOM

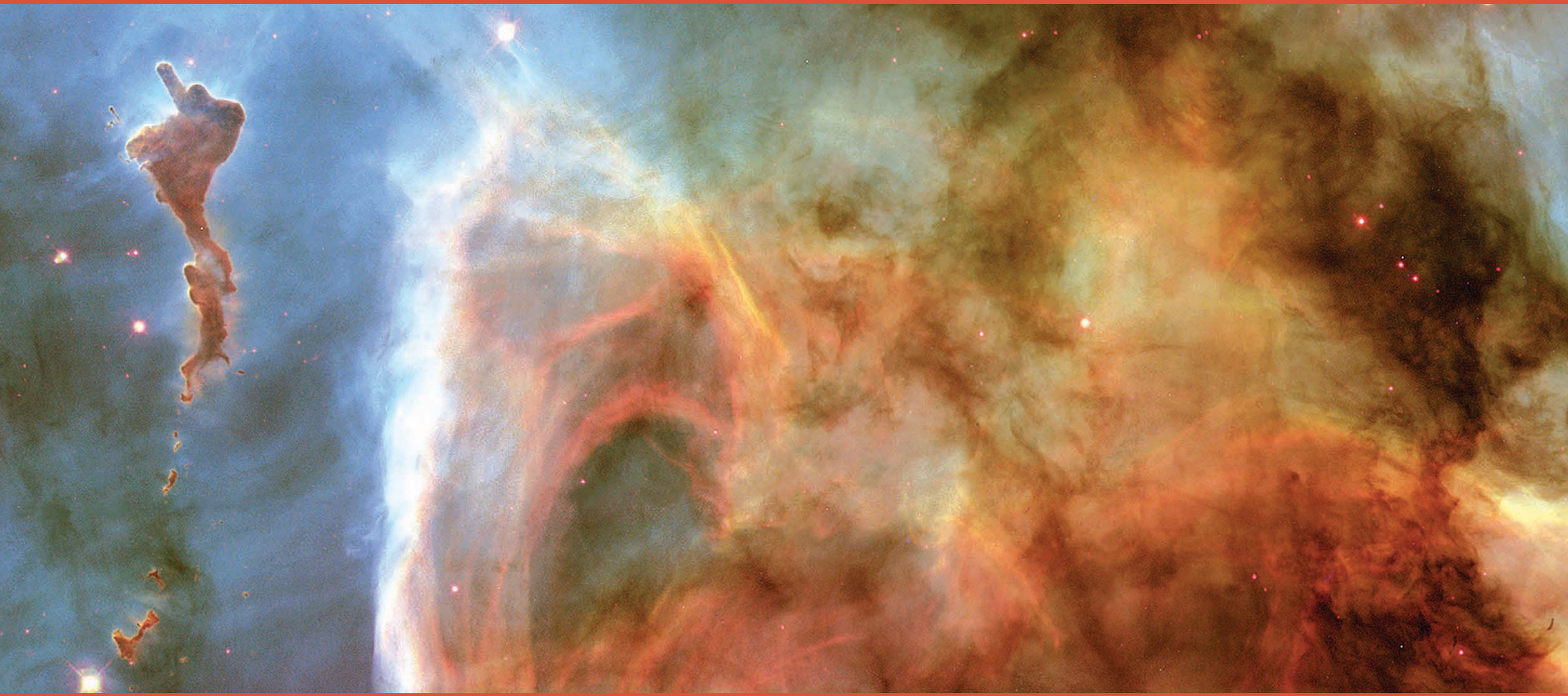


2 **Helium**
The neutron transforms into a proton. An electron is released, and the helium isotope that is formed has no nuclear neutrons.

What Is in the Universe?

ETA CARINAE NEBULA
With a diameter of more than 200 light-years, it is one of biggest and brightest nebulae of our galaxy. This young, supermassive star is expected to become a supernova in the near future.

LUMINOUS 20-21
STELLAR EVOLUTION 22-23
RED, DANGER, AND DEATH 24-25
GAS SHELLS 26-27
SUPERNOVAE 28-29
THE FINAL DARKNESS 30-31
ANATOMY OF GALAXIES 32-33
ACTIVE GALAXIES 34-35
STELLAR METROPOLIS 36-37



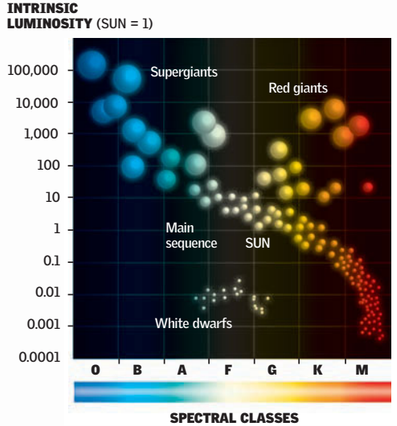
The universe is populated on a grand scale by strands of superclusters surrounding vacant areas. Sometimes the galaxies collide with each other, triggering the formation of stars. In the vast cosmos, there are also quasars, pulsars, and black holes. Thanks to current technology, we can enjoy the displays of light and shadow that make up, for example, the Eta Carinae Nebula (shown), which is composed of jets of hot, fluorescent gases. Although not all the objects in the universe are known, it can be said without a doubt that most of the atoms that make up our bodies have been born in the interior of stars.●

Luminous

For a long time stars were a mystery to humans, and it was only as recently as the 19th century that astronomers began to understand the true nature of stars. Today we know that they are gigantic spheres of incandescent gas—mostly hydrogen, with a smaller proportion of helium. As a star radiates light, astronomers can precisely measure its brightness, color, and temperature. Because of their enormous distance from the Earth, stars beyond the Sun only appear as points of light, and even the most powerful telescopes do not reveal any surface features.

Hertzsprung-Russell (H-R) Diagram

The H-R diagram plots the intrinsic luminosity of stars against their spectral class, which corresponds to their temperature or the wavelengths of light they emit. The most massive stars are those with greatest intrinsic luminosity. They include blue stars, red giants, and red supergiants. Stars spend 90 percent of their lives in what is known as the main sequence.



TYPE O 52,000-72,000° F (29,000-40,000° C)

TYPE B 17,500-52,000° F (9,700-29,000° C)

TYPE A 13,000-17,500° F (7,200-9,700° C)

TYPE F 10,500-13,000° F (5,800-7,200° C)

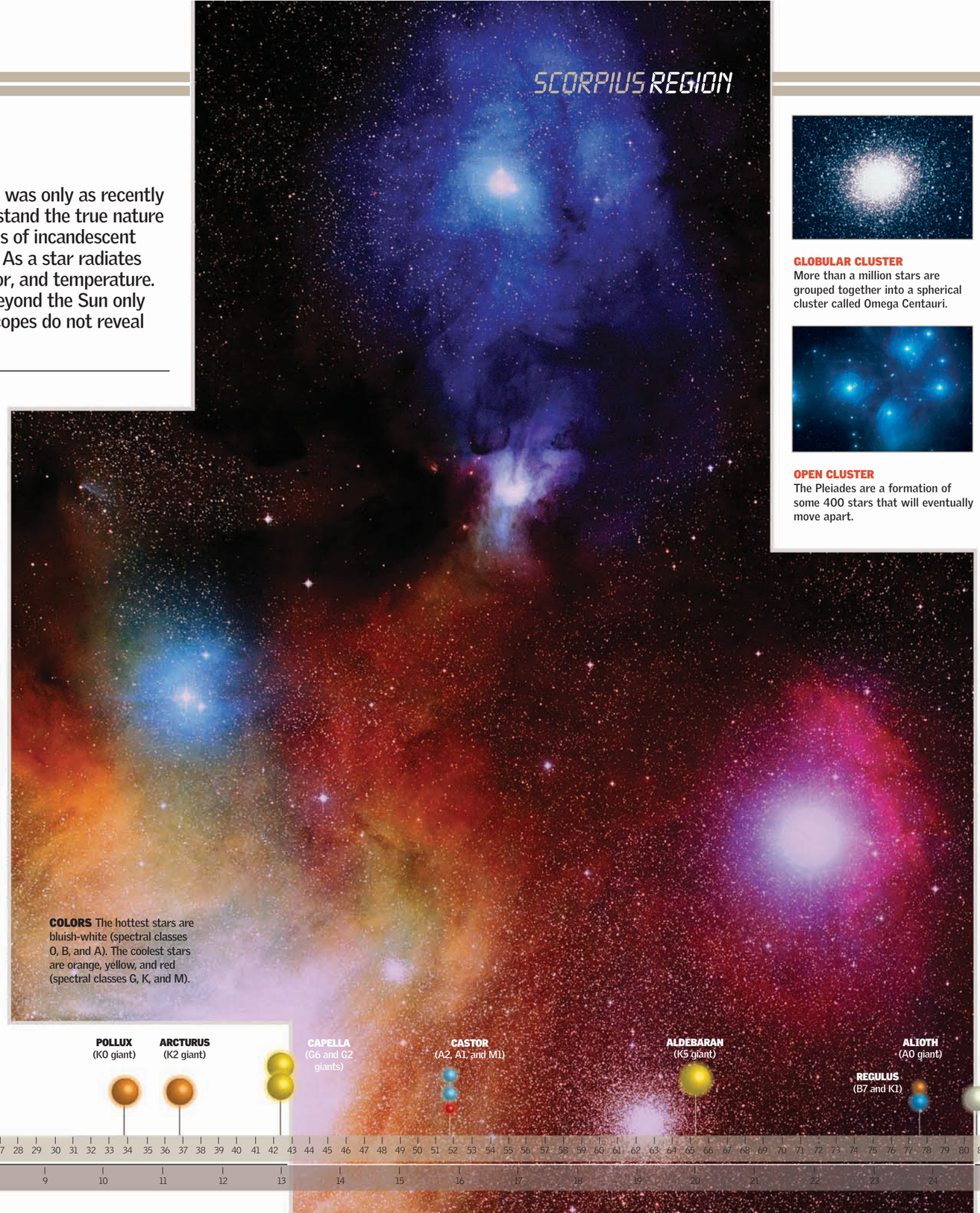
TYPE G 8,500-10,500° F (4,700-5,800° C)

TYPE K 6,000-8,500° F (3,300-4,700° C)

TYPE M 4,000-6,000° F (2,100-3,300° C)

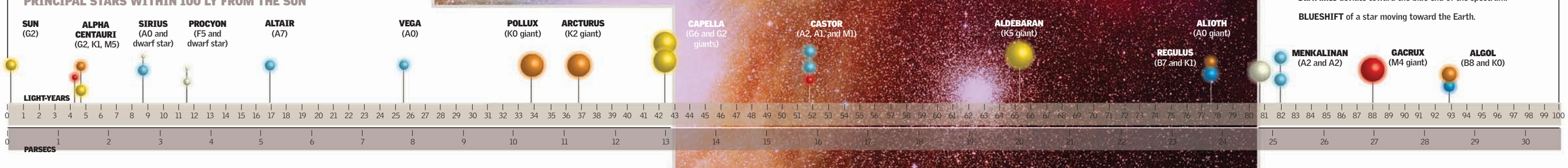
Light-years and Parsecs

In measuring the great distances between stars, both light-years (ly) and parsecs (pc) are used. A light-year is the distance that light travels in a year—5.9 trillion miles (10 trillion km). A light-year is a unit of distance, not time. A parsec is equivalent to the distance between the star and the Earth if the parallax angle is of one second arc. A pc is equal to 3.26 light-years, or 19 trillion miles (31 trillion km).



COLORS The hottest stars are bluish-white (spectral classes O, B, and A). The coolest stars are orange, yellow, and red (spectral classes G, K, and M).

PRINCIPAL STARS WITHIN 100 LY FROM THE SUN

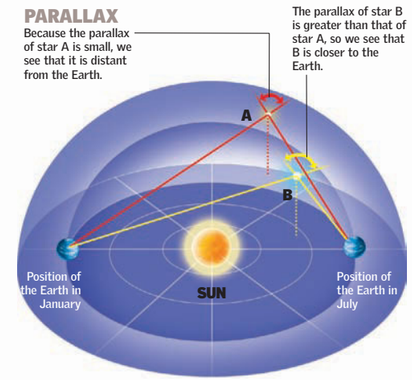


GLOBULAR CLUSTER
More than a million stars are grouped together into a spherical cluster called Omega Centauri.

OPEN CLUSTER
The Pleiades are a formation of some 400 stars that will eventually move apart.

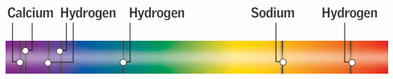
Measuring Distance

When the Earth orbits the Sun, the closest stars appear to move in front of a background of more distant stars. The angle described by the movement of a star in a six-month period of the Earth's rotation is called its parallax. The parallax of the most distant stars are too small to measure. The closer a star is to the Earth, the greater its parallax.



Spectral Analysis

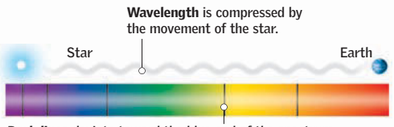
The electromagnetic waves that make up light have different wavelengths. When light from a hot object, such as a star, is split into its different wavelengths, a band of colors, or spectrum, is obtained. Patterns of dark lines typically appear in the spectrum of a star. These patterns can be studied to determine the elements that make up the star.



Wavelength longest on the red side

DOPPLER EFFECT

When a star moves toward or away from an observer, its wavelengths of light shift, a phenomenon called the Doppler effect. If the star is approaching the Earth, the dark lines in its spectrum experience a blueshift. If it moves away from the Earth, the lines experience a redshift.



Dark lines deviate toward the blue end of the spectrum.

BLUESHIFT of a star moving toward the Earth.

Stellar Evolution

Stars are born in nebulae, which are giant clouds of gas (mainly hydrogen) and dust that float in space. Stars can have a life span of millions, or even billions, of years. The biggest stars have the shortest lives, because they consume their nuclear fuel (hydrogen) at a very accelerated rate. Other stars, like the Sun, burn fuel at a slower rate and may live some 10 billion years. Many times, a star's size indicates its age. Smaller stars are the youngest, and bigger stars are approaching their end, either through cooling or by exploding as a supernova.

Massive star

More than 8 solar masses

Nebula

A CLOUD OF GAS AND DUST collapses because of gravitational forces. In doing so it heats up and divides into smaller clouds. Each one of these clouds will form a protostar.

Small star

Less than 8 solar masses

1. PROTOSTAR
A protostar has a dense, gaseous core surrounded by a cloud of dust.

2. STAR
A star is finally born. It fuses hydrogen to form helium and lies along the main sequence.

3. RED SUPERGIANT
The star swells and heats up. Through nuclear reactions, a heavy core of iron is formed.

4. SUPERNOVA
When the star can no longer fuse any more elements, its core collapses, causing a strong emission of energy.

5. BLACK HOLE
If the star's initial mass is 20 solar masses or more, its nucleus is denser and it turns into a black hole, whose gravitational force is extremely strong.

5. NEUTRON STAR
If the star's initial mass is between eight and 20 solar masses, it ends up as a neutron star.

6. BLACK DWARF
If a white dwarf fades out completely, it becomes a black dwarf.

5. WHITE DWARF
The star remains surrounded by gases and is dim.

3. RED GIANT
The star continues to expand, but its mass remains constant and its core heats up. When the star's helium is depleted, it fuses carbon and oxygen.

4. PLANETARY NEBULA
When the star's fuel is depleted, its core condenses, and its outer layers detach, expelling gases in an expanding shell of gases.

Life Cycle of a Star

The evolution of a star depends on its mass. The smallest ones, like the Sun, have relatively long and modest lives. Such a star begins to burn helium when its hydrogen is depleted. In this way, its external layers begin to swell until the star turns into a red giant. It ends its life as white dwarfs, eventually fading away completely, ejecting remaining outer layers, and forming a planetary nebula. A massive star, because of its higher density, can form elements heavier than helium from its nuclear reactions. In the final stage of its life, its core collapses and the star explodes. All that remains is a hyperdense remnant, a neutron star. The most massive stars end by forming black holes.

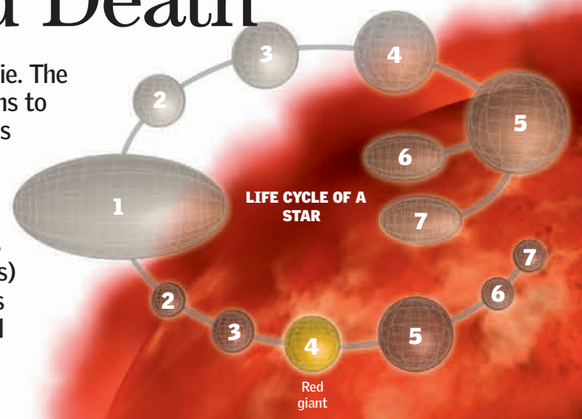
1. PROTOSTAR
A protostar is formed by the separation of gas and dust. Gravitational effects cause its core to rotate.

2. STAR
The star shines and slowly consumes its hydrogen. It begins to fuse helium as its size increases.

95% of stars end their lives as white dwarfs. Other (larger) stars explode as supernovae, illuminating galaxies for weeks, although their brightness is often obscured by the gases and dust.

Red, Danger, and Death

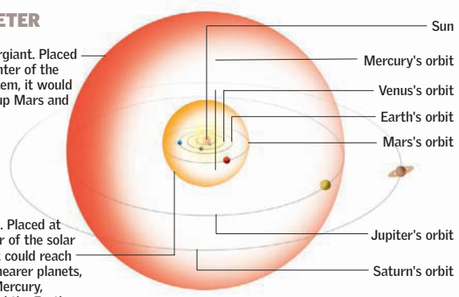
When a star exhausts its hydrogen, it begins to die. The helium that now makes up the star's core begins to undergo nuclear reactions, and the star remains bright. When the star's helium is depleted, fusion of carbon and oxygen begins, which causes the star's core to contract. The star continues to live, though its surface layers begin to expand and cool as the star turns into a red giant. Stars similar to the Sun (solar-type stars) follow this process. After billions of years, they end up as white dwarfs. When they are fully extinguished, they will be black dwarfs, invisible in space. ●



Red Giant

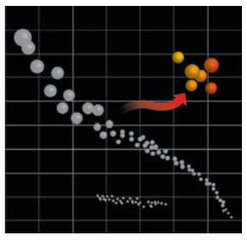
All stars go through a red-giant stage. Depending on a star's mass, it may collapse or it may simply die enveloped in gaseous layers. The core of a red giant is 10 times smaller than it was originally since it shrinks from a lack of hydrogen. A supergiant star (one with an initial mass greater than eight solar masses) lives a much shorter life. Because of the high density attained by its core, it eventually collapses in on itself and explodes.

DIAMETER

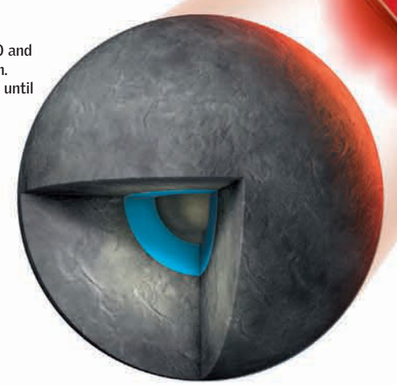


SPECTACULAR DIMENSIONS

On leaving the main sequence, the star enlarges to 200 times the size of the Sun. When the star begins to burn helium, its size decreases to between 10 and 100 times the size of the Sun. The star then remains stable until it becomes a white dwarf.



HERTZSPRUNG-RUSSELL
When the star exhausts its hydrogen, it leaves the main sequence and burns helium as a red giant (or a supergiant). The smallest stars take billions of years to leave the main sequences. The color of a red giant is caused by its relatively cool surface temperature of 3,600° F (2,000° C).



REGION OF THE CORE

1 HYDROGEN
Hydrogen continues undergoing nuclear fusion in the exterior of the core even when the inner core has run out of hydrogen.

2 HELIUM
Helium is produced by the fusion of hydrogen during the main sequence.

3 CARBON AND OXYGEN
Carbon and oxygen are produced by the fusion of helium within the core of the red giant.

4 TEMPERATURE
As the helium undergoes fusion, the temperature of the core reaches millions of degrees Fahrenheit (millions of degrees Celsius).

Convection Cells

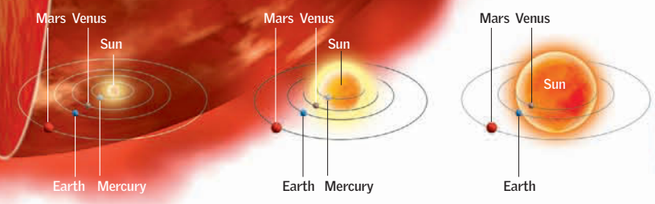
Convection cells carry heat toward the surface of a star. The ascending currents of gas eventually reach the surface of the star, carrying with them a few elements that formed in the star's core.

Hot Spots

Hot spots appear when large jets of incandescent gas reach the star's surface. They can be detected on the surface of red giants.

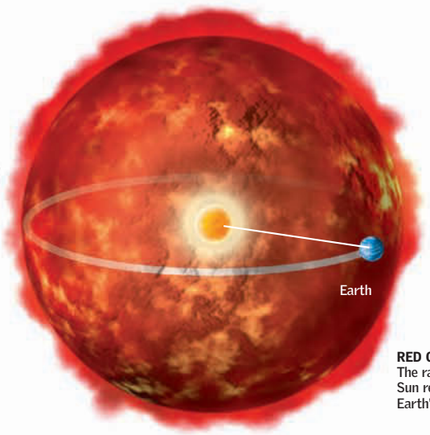
Dust Grains

Dust grains condense in the star's outer atmosphere and later disperse in the form of stellar winds. The dust acquires a dark appearance and is swept into interstellar space, where new generations of stars will form. The outer layer of the star may extend across several light-years of interstellar space.



THE FUTURE OF THE SUN

Like any typical star, the Sun burns hydrogen during its main sequence. After taking approximately five billion years to exhaust its supply of hydrogen, it will begin its transformation into a red giant, doubling in brightness and expanding until it swallows Mercury. At its maximum size, it may even envelop the Earth. Once it has stabilized, it will continue as a red giant for two billion years and then become a white dwarf.

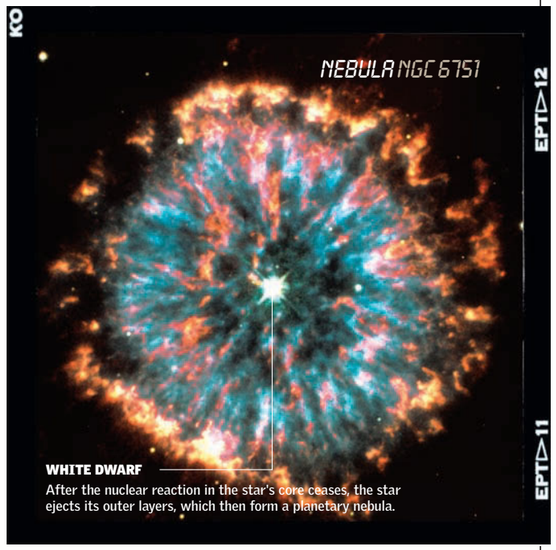


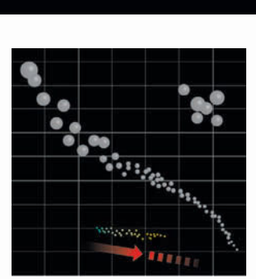
RED GIANT
The radius of the Sun reaches the Earth's orbit.

SUN 1%
The scale of the diameter of the Sun to the diameter of a typical red giant.

White Dwarf

After going through the red-giant stage, a solar-type star loses its outer layers, giving rise to a planetary nebula. In its center remains a white dwarf—a relatively small, very hot (360,000° F [200,000° C]), dense star. After cooling for millions of years, it shuts down completely and becomes a black dwarf.

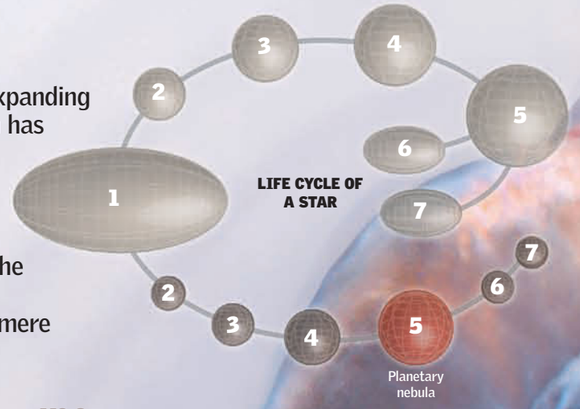


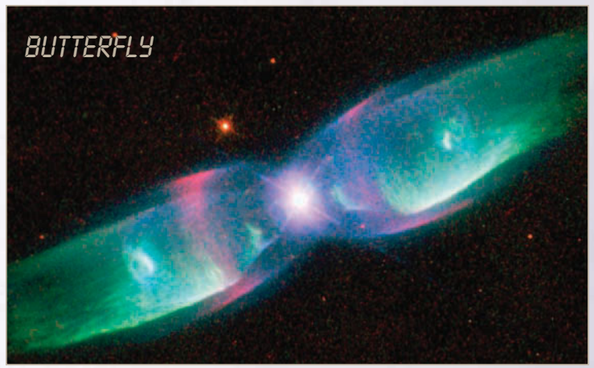


HERTZSPRUNG-RUSSELL
When a white dwarf leaves the red-giant stage, it occupies the lower-left corner of the H-R diagram. Its temperature may be double that of a typical red giant. A massive white dwarf can collapse in on itself and end its life as a neutron star.

Gas Shells

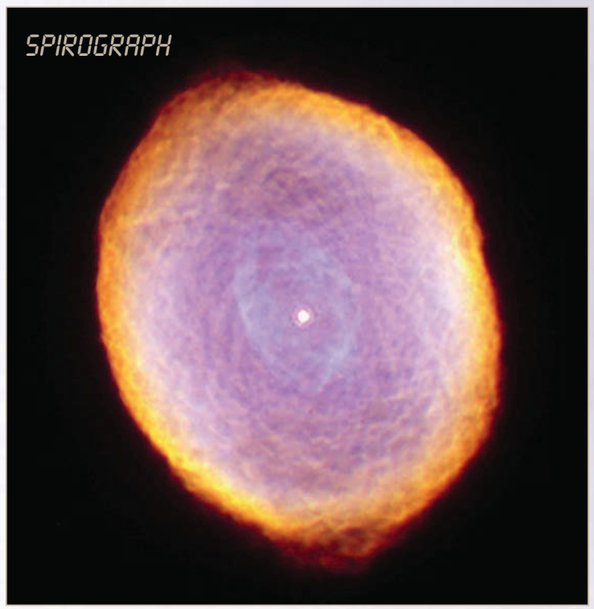
When a small star dies, all that remains is an expanding gas shell known as a planetary nebula, which has nothing to do with the planets. In general, planetary nebulae are symmetrical or spherical objects. Although it has not been possible to determine why they exist in such diversity, the reason may be related to the effects of the magnetic field of the dying central star. Viewed through a telescope, several nebulae can be seen to contain a central dwarf star, a mere remnant of its precursor star. ●





◄ **M2-9**
The Butterfly Nebula contains a star in addition to a white dwarf. Each orbits the other inside a gas disk that is 10 times larger than Pluto's orbit. The Butterfly Nebula is located 2,100 light-years from Earth.

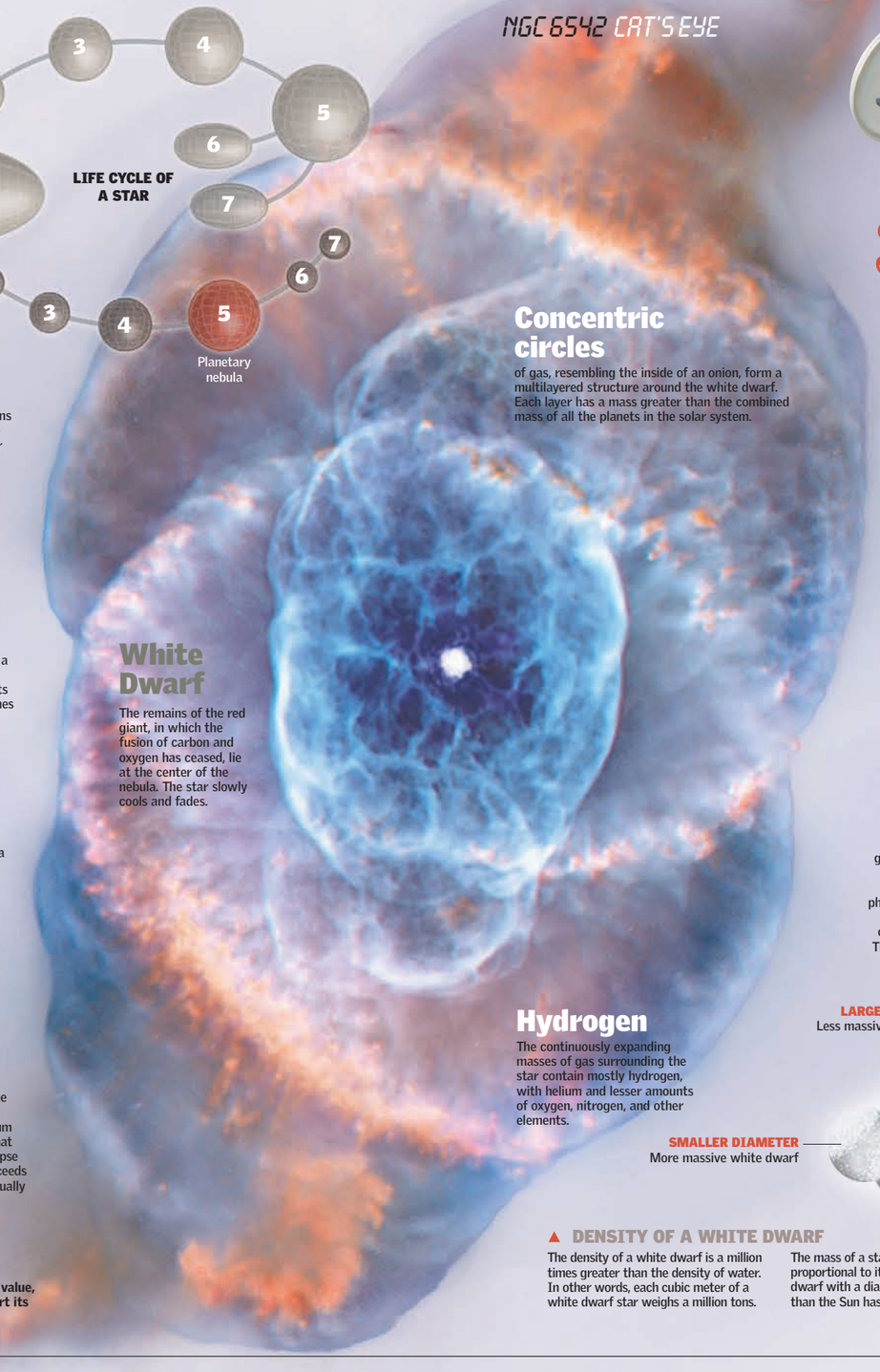
TWICE THE TEMPERATURE OF THE SUN
is reached at the surface of a white dwarf, causing it to appear white even though its luminosity is a thousand times less than that of the Sun.



◄ **IC 418**
The Spirograph Nebula has a hot, luminous core that excites nearby atoms, causing them to glow. The Spirograph Nebula is about 0.1 light-year wide and is located 2,000 light-years from Earth.

CHANDRASEKHAR LIMIT
The astrophysicist Subrahmanyan Chandrasekhar, winner of the Nobel Prize for Physics in 1983, calculated the maximum mass a star could have so that it would not eventually collapse on itself. If a star's mass exceeds this limit, the star will eventually explode in a supernova.

1.44 SOLAR MASSES
is the limit Chandrasekhar obtained. In excess of this value, a dwarf star cannot support its own gravity and collapses.



Concentric circles
of gas, resembling the inside of an onion, form a multilayered structure around the white dwarf. Each layer has a mass greater than the combined mass of all the planets in the solar system.

White Dwarf
The remains of the red giant, in which the fusion of carbon and oxygen has ceased, lie at the center of the nebula. The star slowly cools and fades.

Hydrogen
The continuously expanding masses of gas surrounding the star contain mostly hydrogen, with helium and lesser amounts of oxygen, nitrogen, and other elements.



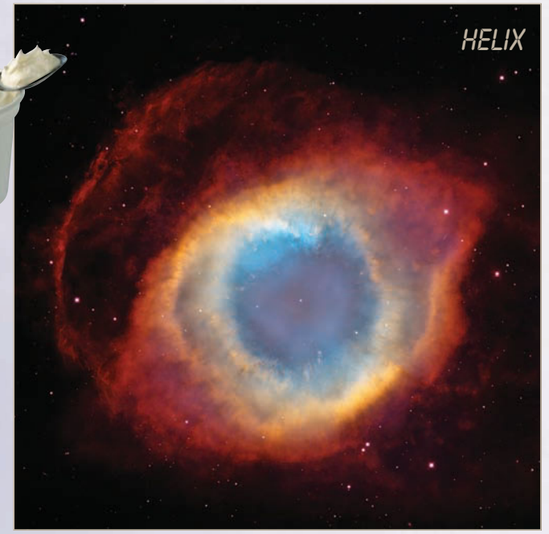
▲ **DENSITY OF A WHITE DWARF**
The density of a white dwarf is a million times greater than the density of water. In other words, each cubic meter of a white dwarf star weighs a million tons.

The mass of a star is indirectly proportional to its diameter. A white dwarf with a diameter 100 times smaller than the Sun has a mass 70 times greater.



3 tons
is the weight of a single tablespoon of a white dwarf. A white dwarf is very massive in spite of the fact that its diameter of 9,300 miles (or 15,000 km) is comparable to the Earth's.

NGC 7293 ►
The Helix is a planetary nebula that was created at the end of the life of a solar-type star. It is 650 light-years from the Earth and is located in the constellation Aquarius.

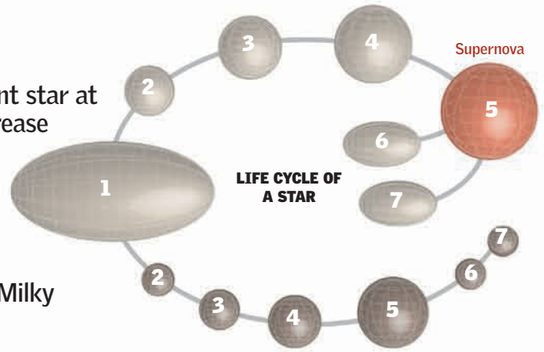


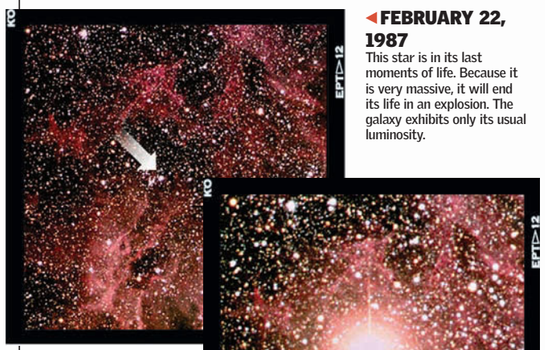


MYCN 18 ►
The two rings of colored gas form the silhouette of this hourglass-shaped nebula. The red in the photograph corresponds to nitrogen, and the green corresponds to hydrogen. This nebula is 8,000 light-years from the Earth.

Supernovae

A supernova is an extraordinary explosion of a giant star at the end of its life, accompanied by a sudden increase in brightness and the release of a great amount of energy. In 10 seconds, a supernova releases 100 times more energy than the Sun will release in its entire life. After the explosion of the star that gives rise to a supernova, the gaseous remnant expands and shines for millions of years. It is estimated that, in our Milky Way galaxy, two supernovae occur per century. ●





◂FEBRUARY 22, 1987
This star is in its last moments of life. Because it is very massive, it will end its life in an explosion. The galaxy exhibits only its usual luminosity.



FEBRUARY 23, 1987 ▸
After the supernova explosion, increased brightness is observed in the region near the star.

BEFORE AND AFTER
The image at left shows a sector of the Large Magellanic Cloud, an irregular galaxy located 170,000 light-years from the Earth, depicted before the explosion of supernova 1987A. The image at right shows the supernova.

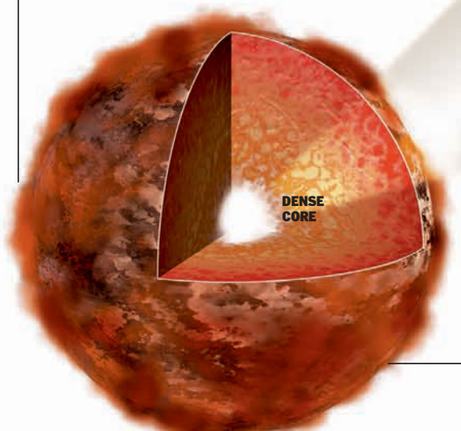
The Twilight of a Star

The explosion that marks the end of a supergiant's life occurs because the star's extremely heavy core has become incapable of supporting its own gravity any longer. In the absence of fusion in its interior, the star falls in upon itself, expelling its remaining gases, which will expand and shine for hundreds—or even thousands—of years. The explosion of the star injects new material into interstellar space and contributes heavy atoms that can give rise to new generations of stars.

Core

A star's core can be seen to be separated into distinct layers that correspond to the different elements created during nuclear fusion. The last element created before the star's collapse is iron.

FUSION
The nuclear reactions in a dying star occur at a faster rate than they do in a red giant.

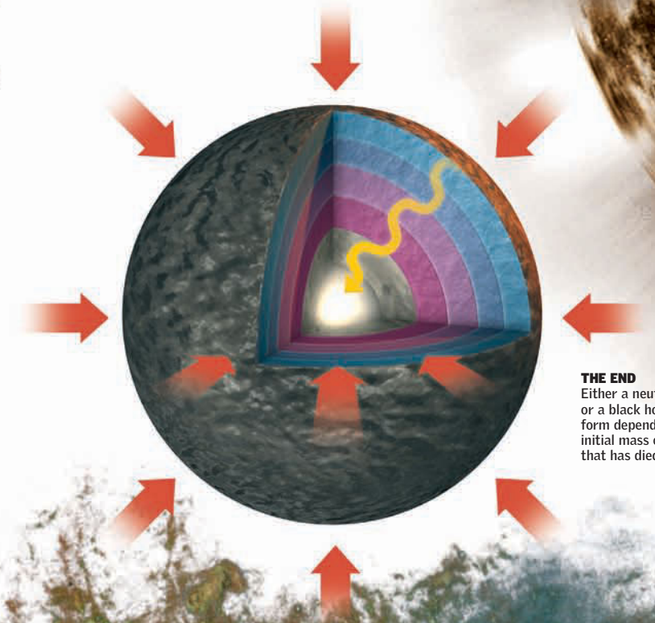


Supergiant

The diameter of the star may increase to more than 1,000 times that of the Sun. Through nuclear fusion, the star can produce elements even heavier than carbon and oxygen.

Other Elements

When a star's iron core increases in density to 1.44 solar masses, the star can no longer support its own weight and it collapses upon itself. The resulting explosion causes the formation of elements that are heavier than iron, such as gold and uranium.



THE END
Either a neutron star or a black hole may form depending on the initial mass of the star that has died.



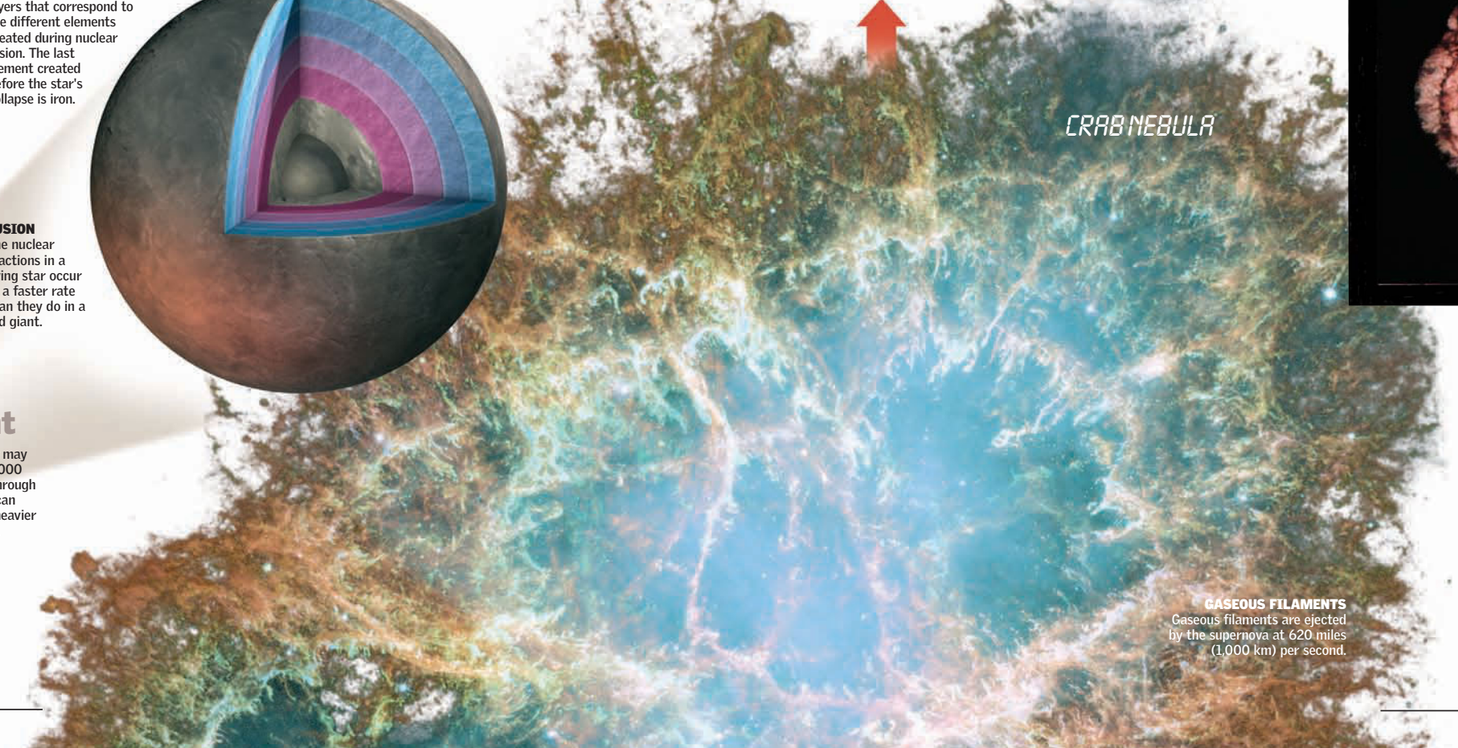
Explosion

The star's life ends in an immense explosion. During the weeks following the explosion, great quantities of energy are radiated that are sometimes greater than the energy emitted by the star's parent galaxy. A supernova may illuminate its galaxy for weeks.



SUPERMASSIVE
The mass of Eta Carinae is 100 times greater than that of the Sun. Astronomers believe that Eta Carinae is about to explode, but no one knows when.

GAS AND DUST
Gas and dust that have accumulated in the two visible lobes absorb the blue light and ultraviolet rays emitted from its center.



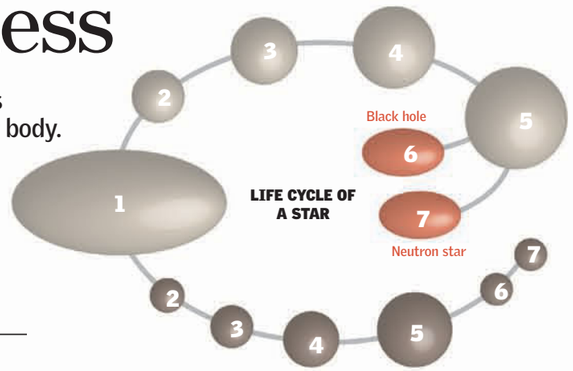
GASEOUS FILAMENTS
Gaseous filaments are ejected by the supernova at 620 miles (1,000 km) per second.

Stellar Remnant

When the star explodes as a supernova, it leaves as a legacy in space the heavy elements (such as carbon, oxygen, and iron) that were in the star's nucleus before its collapse. The Crab Nebula (M1) was created by a supernova seen in 1054 by Chinese astronomers. The Crab Nebula is located 6.5 light-years from Earth and has a diameter of six light-years. The star that gave rise to the Crab Nebula may have had an initial mass close to 10 solar masses. In 1969, a pulsar radiating X-rays and rotating 33 times per second was discovered at the center of the nebula, making the Crab Nebula a very powerful source of radiation.

The Final Darkness

The last stage in the evolution of a star's core is its transformation into a very dense, compact stellar body. Its particulars depend upon the amount of mass involved in its collapse. The largest stars become black holes, their density so great that their gravitational forces capture even light. The only way to detect these dead stars is by searching for the effects of their gravitation.

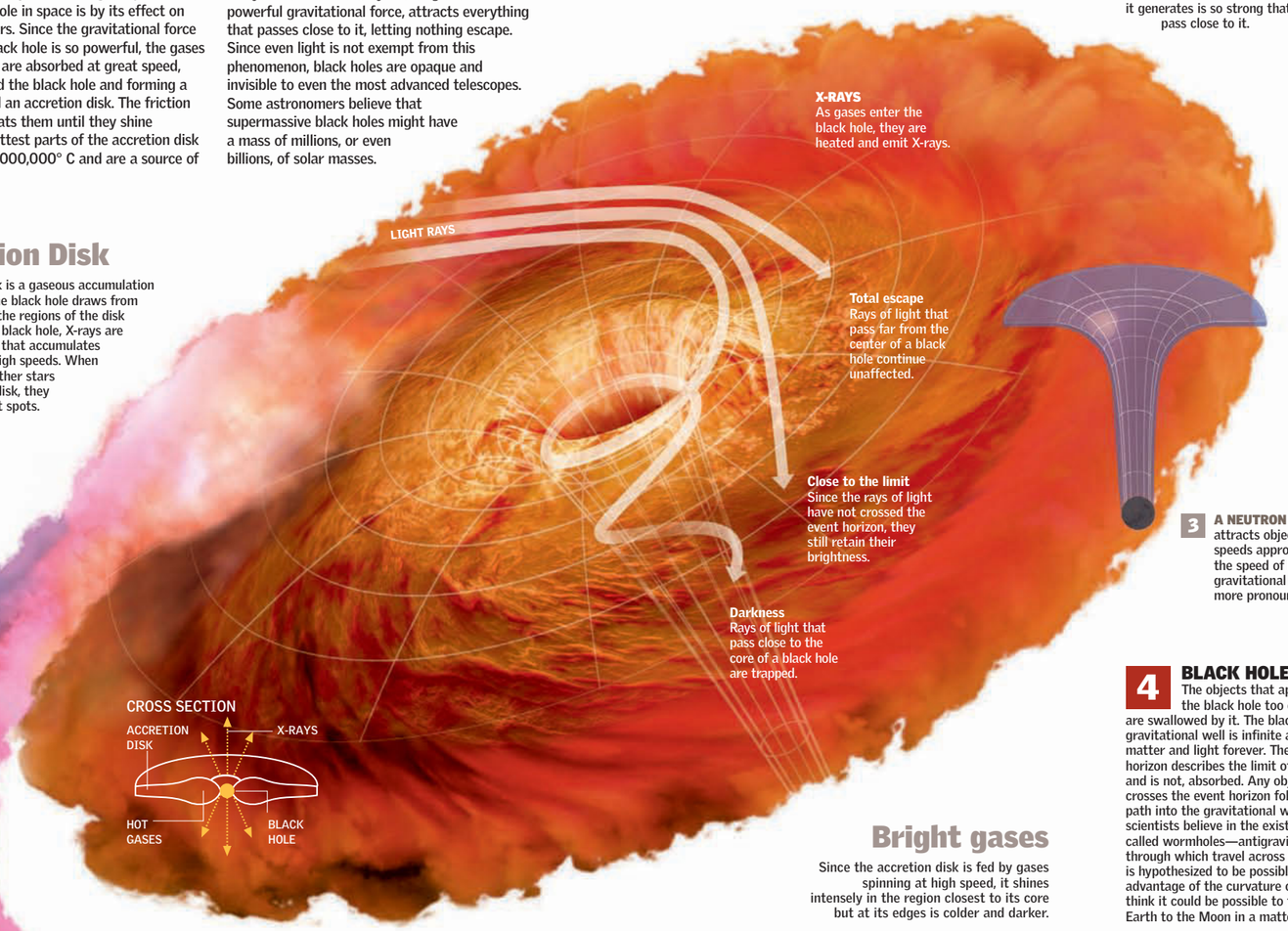


Discovery of Black Holes

The only way of detecting the presence of a black hole in space is by its effect on neighboring stars. Since the gravitational force exerted by a black hole is so powerful, the gases of nearby stars are absorbed at great speed, spiraling toward the black hole and forming a structure called an accretion disk. The friction of the gases heats them until they shine brightly. The hottest parts of the accretion disk may reach 100,000,000° C and are a source of X-rays. The black hole, by exerting such powerful gravitational force, attracts everything that passes close to it, letting nothing escape. Since even light is not exempt from this phenomenon, black holes are opaque and invisible to even the most advanced telescopes. Some astronomers believe that supermassive black holes might have a mass of millions, or even billions, of solar masses.

Accretion Disk

An accretion disk is a gaseous accumulation of matter that the black hole draws from nearby stars. In the regions of the disk very close to the black hole, X-rays are emitted. The gas that accumulates rotates at very high speeds. When the gases from other stars collide with the disk, they create bright, hot spots.



Bright gases

Since the accretion disk is fed by gases spinning at high speed, it shines intensely in the region closest to its core but at its edges is colder and darker.

Neutron Star

When a star's initial mass is between 10 and 20 solar masses, its final mass will be larger than the mass of the Sun. Despite losing great quantities of matter during nuclear reactions, the star finishes with a very dense core. Because of its intense magnetic and gravitational fields, a neutron star can end up as a pulsar. A pulsar is a rapidly spinning neutron star that gives off a beam of radio waves or other radiation. As the beam sweeps around the object, the radiation is observed in very regular pulses.

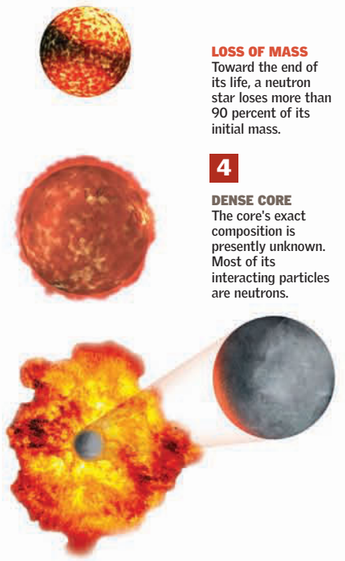
Strong Gravitational Attraction

The gravitational force of the black hole attracts gases from a neighboring star. This gas forms a large spiral that swirls faster and faster as it gets closer to the black hole. The gravitation field that it generates is so strong that it traps objects that pass close to it.

1 RED GIANT
A red giant leaves the main sequence. Its diameter is 100 times greater than the Sun's.

2 SUPERGIANT
A supergiant grows and rapidly fuses heavier chemical elements, forming carbon, oxygen, and finally iron.

3 EXPLOSION
The star's iron core collapses. Protons and electrons annihilate each other and form neutrons.



LOSS OF MASS
Toward the end of its life, a neutron star loses more than 90 percent of its initial mass.

4 DENSE CORE
The core's exact composition is presently unknown. Most of its interacting particles are neutrons.

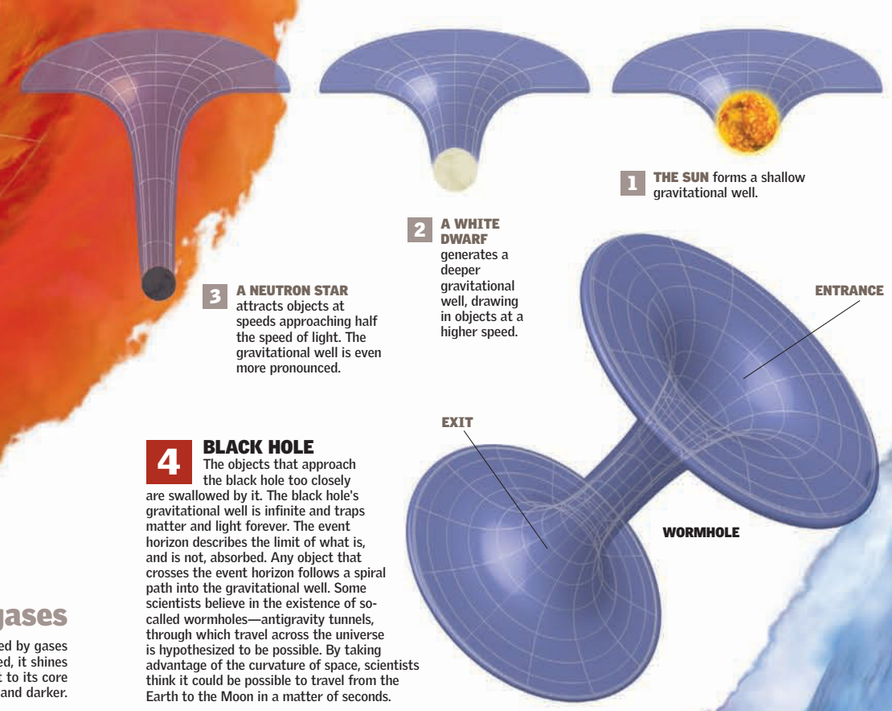


1 billion

tons is what one tablespoon of a neutron star would weigh. Its small diameter causes the star to have a compact, dense core accompanied by intense gravitational effects.

CURVED SPACE

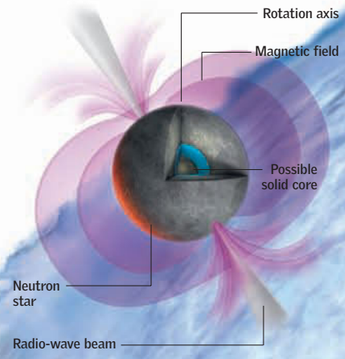
The theory of relativity suggests that gravity is not a force but a distortion of space. This distortion creates a gravitational well, the depth of which depends on the mass of the object. Objects are attracted to other objects through the curvature of space.



Pulsars

The first pulsar (a neutron star radiating radio waves) was discovered in 1967. Pulsars rotate approximately 30 times per second and have very intense magnetic fields. Pulsars emit radio waves from their two magnetic poles when they rotate. If a pulsar absorbs gas from a neighboring star, a hot spot that radiates X-rays is produced on the pulsar's surface.

STRUCTURE OF A PULSAR



Devouring gas from a supergiant

Located within a binary system, the pulsar can follow the same process as a black hole. The pulsar's gravitational force causes it to absorb the gas of smaller, neighboring stars, heating up the pulsar's surface and causing it to emit X-rays.

Anatomy of Galaxies

Galaxies are rotating groups of stars, gas, and dust. More than 200 years ago, philosopher Immanuel Kant postulated that nebulae were island-universes of distant stars. Even though astronomers now know that galaxies are held together by gravitational force, they have not been able to decipher what reasons might be behind galaxies' many shapes. The various types of galaxies range from ovals of old stars to spirals with arms of young stars and bright gases. The center of a galaxy has the greatest accumulation of stars. The Milky Way Galaxy is now known to be so big that rays of light, which travel at 186,000 miles (300,000 km) per second, take 100,000 years to cross from one end to the other.

MILKY WAY
Seen from its side, the Milky Way looks like a flattened disk, swollen at the center. Around the disk is a spherical region, called a halo, containing dark matter and globular clusters of stars. From June to September, the Milky Way is especially bright, something that would make it more visible viewed from above than from the side.



CLASSIFYING GALAXIES ACCORDING TO HUBBLE



ELLIPTICAL
These galaxies are elliptical in shape and have little dust and gas. Their masses fall within a wide range.

SPIRAL
In a spiral galaxy, a nucleus of old stars is surrounded by a flat disk of stars and two or more spiral arms.

IRREGULAR
Irregular galaxies have no defined shape and cannot be classified. They contain a large amount of gases and dust clouds.

SUBCLASSIFICATIONS



SUBCLASSIFICATIONS
Galaxies are subdivided into different categories according to their tendency toward round shape (in the case of elliptical galaxies), as well as by the presence of an axis and the length of their arms (in the case of spiral and barred spiral galaxies). An E0 galaxy is elliptical but almost circular, and an E7 galaxy is a flattened oval. An Sa galaxy has a large central axis and coiled arms, and an Sc galaxy has a thinner axis and more extended arms.



Galactic Clusters

Galaxies are objects that tend to form groups or clusters. Acting in response to gravitational force, they can form clusters of galaxies of anywhere from two to thousands of galaxies. These clusters have various shapes and are thought to expand when they join together. The Hercules cluster, shown here, was discovered by Edmond Halley in 1714 and is located approximately 25,100 light-years from Earth. Each dot represents a galaxy that includes billions of stars.

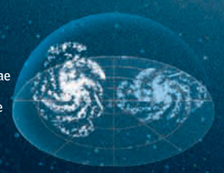
Star Cities

The first galaxies formed 100 million years after the big bang. Billions of these great conglomerates of stars can be found throughout space. The two most important discoveries concerning galaxies are attributed to the astronomer Edwin Hubble. In 1926, he pointed out that the spots, or patches, of light visible in the night sky were actually distant galaxies. Hubble's discovery put an end to the view held by astronomers at the time that the Milky Way constituted the universe. In 1929, as a result of various observations of the spectrum of light radiated by the stars in the galaxies, Hubble noted that the light from the galaxies showed a redshift (Doppler effect). This effect indicated that the galaxies were moving away from the Milky Way Galaxy. Hubble concluded that the universe is expanding. But the expansion of the universe does not imply that galaxies are growing in numbers. On the contrary, galaxies can collide and merge. When two galaxies collide, they can distort each other in various ways. Over time, there are fewer and fewer galaxies. Some galaxies exhibit very peculiar shapes. The Sombrero Galaxy, shown in the center of the page, has a bright white core surrounded by thin spiral arms.

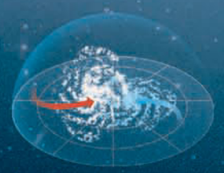
COLLISION
300 million light-years from the Earth, these two colliding galaxies form a pair. Together they are called "The Mice" for the large tail of stars emanating from each galaxy. With time, these galaxies will fuse into a single, larger one. It is believed that in the future the universe will consist of a few giant stars.



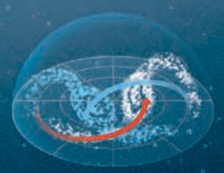
1
1.2 BILLION YEARS
ago, the Antennae (NGC 4038 and NGC 4039) were two separate spiral galaxies.



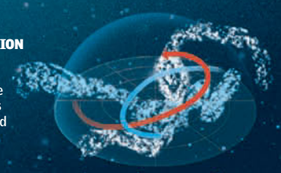
2
300 MILLION YEARS
later, the galaxies collided at great speed.



3
300 MILLION YEARS
go by until the collision takes place and the shapes of the galaxies are distorted.



4
300 MILLION YEARS
later, the stars in the spiral arms are expelled from both galaxies.



5
NOW
two jets of expelled stars stretch far from the original galaxies.



Active Galaxies

A small number of galaxies differ from the rest by emitting high amounts of energy. The energy emission might be caused by the presence of black holes in its core that were formed through the gravitational collapse accompanying the death of supermassive stars. During their first billion years, the galaxies might have accumulated surrounding gaseous disks with their corresponding emissions of radiation. It is possible that the cores of the first galaxies are the quasars that are now observed at very great distances. ●

Energetic Activity

Astronomers believe that active galaxies are a direct legacy from the beginning of the universe. After the big bang, these galaxies would have retained very energetic levels of radiation. Quasars, the brightest and most ancient objects in the universe, make up the core of this type of galaxy. In some cases, they emit X-rays or radio waves. The existence of this high-energy activity helps support the theory that galaxies could be born from a supermassive black hole with a quasar that became inactive as stars formed and it was left without gas to feed it. This process of formation might be common to many galaxies. Today quasars represent the limit of what it is possible to see, even with specialized telescopes. Quasars are small, dense, and bright.

GAS
As two jets are expelled from the core, radio waves are emitted. If the waves collide with clouds of intergalactic gas, they swell and form gigantic clouds that can emit radio waves or X-rays.

CENTRAL RING
The core of an active galaxy is obscured by a ring of dust and gas that is dark on the outside and bright within. It is a powerful source of energy.

CLASSIFICATION
The classification of an active galaxy depends upon its distance from Earth and the perspective from which it is seen. Quasars, radio galaxies, and blazars are members of the same family of objects and differ only in the way they are perceived.

QUASARS The most powerful objects in the universe, quasars are so distant from Earth that they appear to us as diffuse stars. They are the bright cores of remote galaxies.

RADIO GALAXIES Radio galaxies are the largest objects in the universe. Jets of gases come out from their centers that extend thousands of light-years. The cores of radio galaxies cannot be seen.

BLAZARS Blazars may be active galaxies with jets of gas that are aimed directly toward Earth. The brightness of a blazar varies from day to day.

INCREASING GRAVITY

1 Dark clouds of gas and dust on the outer edge of a black hole are gradually swallowed up.

2 As the gases move inward, their temperature increases.

3 The strong gravitational force of the disk attracts and destroys stars.

4 The center of the black hole radiates charged particles.

GASEOUS CLOUDS
Gaseous clouds appeared from the gravitational collapse of immense masses of gas during the early stages of the universe. Later, in the clouds' interior, stars began to form.

Galaxy Formation

A theory of galaxy formation associated with active galaxies holds that many galaxies, possibly including the Milky Way, were formed from the gradual calming of a quasar at their core. As the surrounding gases consolidated in the formation of stars, the quasars, having no more gases to absorb, lost their energetic fury and became inactive. According to this theory, there is a natural progression from quasars to active galaxies to the common galaxies of today. In 1994, astronomers studying the center of the Milky Way discovered a region that may contain a black hole and could be left over from early galactic activity.

1

The Force of Gravity

Gravitational force begins to unite vast quantities of hot, gaseous clouds. The clouds attract one another and collide, forming stars. A large amount of gas accumulates at the center of the galaxy, intensifying gravitational forces until a massive black hole comes into being in the galaxy's core.

2

The Quasar in the Core

The quasar in the core ejects two jets of particles that reach speeds approaching the speed of light. The quasar stage is thought to have been the most violent stage in the formation of galaxies. The gases and stars arising from the jets are introduced as spirals into the black hole, forming a type of accretion disk known as a quasar.

3

Black Hole

A black hole swallows the gas that begins to surround it. A hot, gaseous spiral forms, emitting high-speed jets. The magnetic field pours charged particles into the region around the black hole, and the exterior of the disk absorbs interstellar gas.

ACCRETION DISK
Formed by interstellar gas and star remnants, the accretion disk can radiate X-rays because of the extreme temperature of its center.

PARTICLES
ejected from the black hole have intense magnetic fields. The jets of particles travel at speeds approaching the speed of light when they leave the core.

100
MILLION DEGREES
Celsius is the temperature that the core of a black hole can reach.

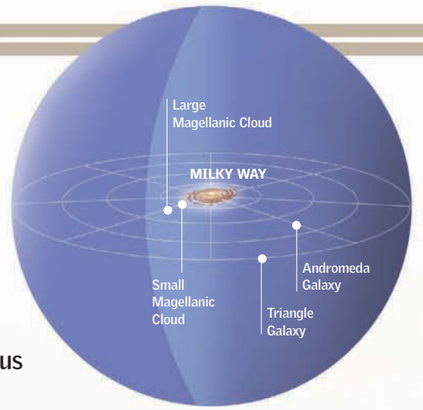
4

Stable Galaxy

Nine billion years after its formation, with a supermassive black hole at its core, the galaxy drastically slows its energetic activity, forming a low-energy core. The stabilization of the galaxy allowed the formation of stars and other heavenly bodies.

Stellar Metropolis

For a long time, our galaxy (called the Milky Way because of its resemblance to a stream of milk in the night sky) was a true enigma. It was Galileo Galilei who, in 1610, first pointed a telescope at the Milky Way and saw that the weak whitish strip was composed of thousands and thousands of stars that appeared to almost touch each other. Little by little, astronomers began to realize that all these stars, like our own Sun, were part of the enormous ensemble—the galaxy that is our stellar metropolis. ●



Structure of the Milky Way

The Milky Way, containing more than 100 billion stars, has two spiral arms rotating around its core. The Sagittarius arm, located between the Orion arm and the center of the Milky Way, holds one of the most luminous stars in the galaxy, Eta Carinae. The Perseus arm, the main outer arm of the Milky Way, contains young stars and nebulae. The Orion arm, extending between Perseus and Sagittarius, houses the solar system within its inner border. The Orion arm of the Milky Way is a veritable star factory, where gaseous interstellar material can give birth to billions of stars. Remnants of stars can also be found within it.

ROTATION
The speeds of the rotation of the various parts of the Milky Way vary according to those parts' distances from the core of the galaxy. The greatest number of stars is concentrated in the region between the Milky Way's core and its border. Here the speed of rotation is much greater because of the attraction that the objects in this region feel from the billions of stars within it.

120 miles per hour (200 km/h)
140 miles per hour (220 km/h)
150 miles per hour (240 km/h)
155 miles per hour (250 km/h)
0°
30°
60°
90°
120°
150°
180°
210°
240°
270°
360°
Central protuberance
PERSEUS ARM
ORION ARM
SAGITTARIUS ARM
3KPC ARM
NORMA ARM
CARINA ARM
OUTER ARM
Eagle Nebula
Eta Carinae
SOLAR SYSTEM
Orion Nebula
6,000 light-years
Cassiopeia A
Crab Nebula

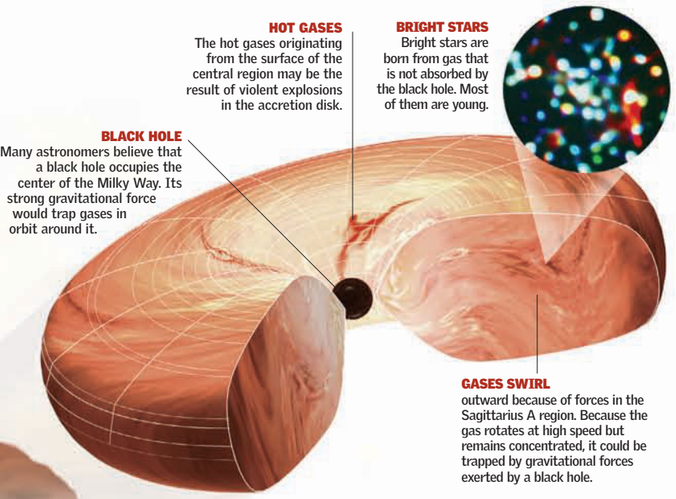
Central Region

Because the Milky Way is full of clouds of dust and rock particles, its center cannot be seen from outside the galaxy. The Milky Way's center can be seen only through telescopes that record infrared light, radio waves, or X-rays, which can pass through the material that blocks visible light. The central axis of the Milky Way contains ancient stars, some 14 billion years old, and exhibits intense activity within its interior, where two clouds of hot gas have been found: Sagittarius A and B. In the central region, but outside the core, a giant dark cloud contains 70 different types of molecules. These gas clouds are associated with violent activity in the center of our galaxy and contain the heart of the Milky Way within their depths. In general, the stars in this region are cold and range in color from red to orange.

SAGITTARIUS B2
The largest dark cloud in the central region of the Milky Way, Sagittarius B2 contains enough alcohol to cover the entire Earth.

MAGNETISM
The center of the Milky Way is surrounded by strong magnetic fields, perhaps from a rotating black hole.

OUTER RING
A ring of dark clouds of dust and molecules that is expanding as a result of a giant explosion. It is suspected that a small object in the central region of the Milky Way might be its source.



The Exact Center

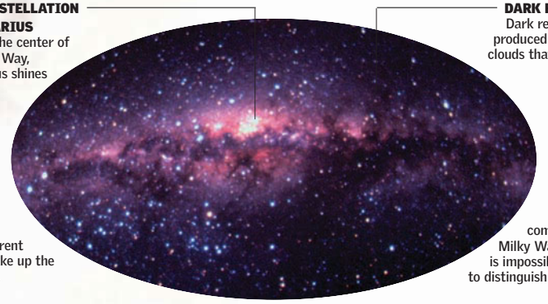
The core of the Milky Way galaxy is marked by very intense radio-wave activity that might be produced by an accretion disk made up of incandescent gas surrounding a massive black hole. The region of Sagittarius A, discovered in 1994, is a gas ring that rotates at very high speed, swirling within several light-years of the center of the galaxy. The speed of its rotation is an indication of the powerful gravitational force exerted from the center of the Milky Way, a force stronger than would be produced by the stars located in the region. The hot, blue stars that shine in the center of the Milky Way may have been born from gas not yet absorbed by the black hole.

A Diverse Galaxy

The brightest portion of the Milky Way that appears in photographs taken with optical lenses (using visible light) is in the constellation Sagittarius, which appears to lie in the direction of the center of the Milky Way. The bright band in the nighttime sky is made up of stars so numerous that it is almost impossible to count them. In some cases, stars are obscured by dense dust clouds that make some regions of the Milky Way seem truly dark. The objects that can be found in the Milky Way are not all of one type. Some, such as those known as the halo population, are old and are distributed within a sphere around the galaxy. Other objects form a more flattened structure called the disk population. In the spiral arm population, we find the youngest objects in the Milky Way. In these arms, gas and interstellar dust abound.

100,000
LIGHT-YEARS
The diameter of the Milky Way is large in comparison with other galaxies but not gigantic.

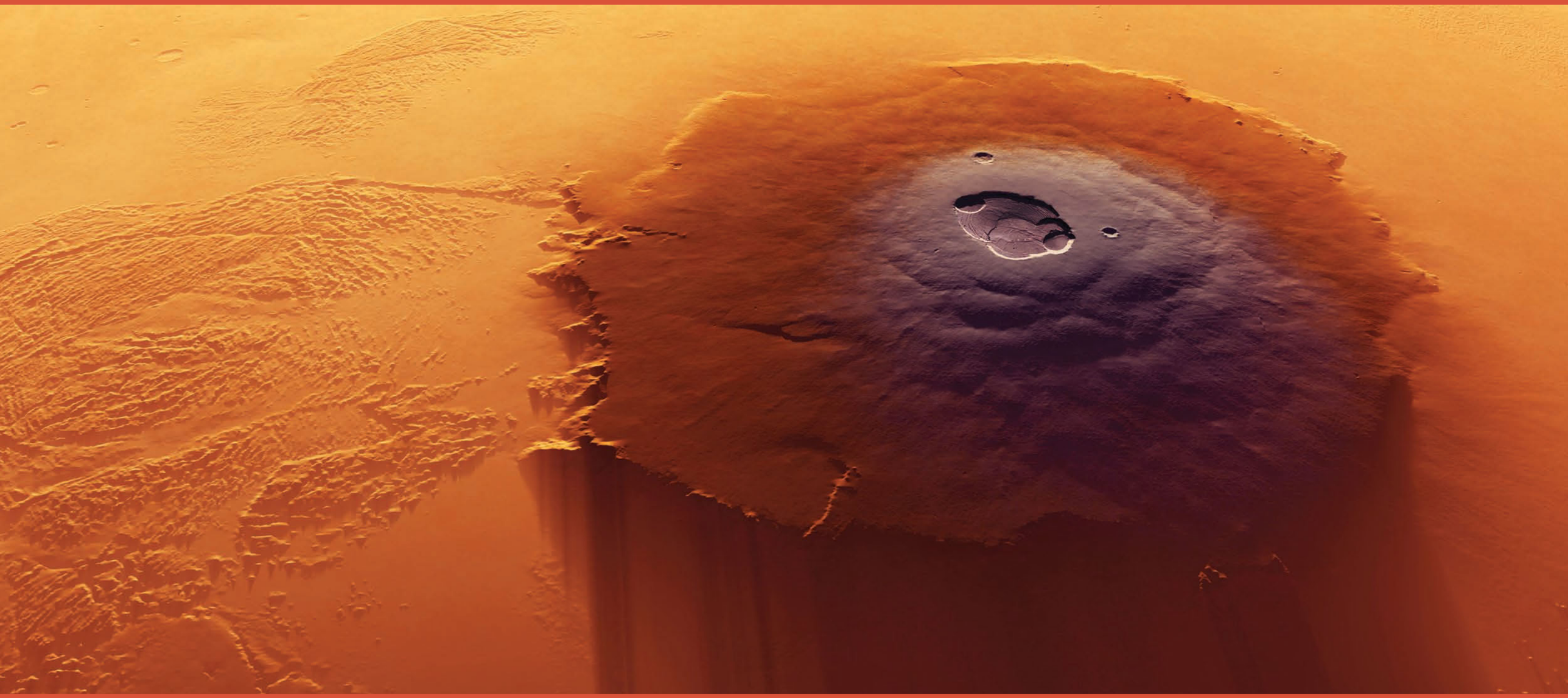
THE MILKY WAY IN VISIBLE LIGHT



The Solar System

OLYMPUS MONS, ON MARS
Olympus Mons is the largest volcano of the solar system. It is about two-and-a-half times as high as Mount Everest.

ATTRACTED BY A STAR 40-41
A VERY WARM HEART 42-43
MERCURY, AN INFERNO 44-45
VENUS, OUR NEIGHBOR 46-47
RED AND FASCINATING 48-49
JUPITER, GAS GIANT 50-51
THE LORD OF THE RINGS 52-53
URANUS WITHOUT SECRETS 54-55
NEPTUNE: DEEP BLUE 56-57
PLUTO: NOW A DWARF 58-59
DISTANT WORLDS 60-61
CONSTRUCTION DEBRIS: ASTEROIDS AND METEORITES 62-63
THOSE WITH A TAIL 64-65



Among the millions and millions of stars that form the Milky Way galaxy, there is a medium-sized one located in one of the galaxy's arms—the Sun. To ancient peoples, the Sun was a god; to us, it is the central source of energy that generates heat, helping life exist. This star, together with the planets and other bodies that spin in orbits around it, make up the solar system, which formed about 4.6 billion years ago. The planets that rotate around it do not produce their own light. Instead, they reflect sunlight. After the Earth, Mars is the most explored planet. Here we see a photo of Olympus Mons, the largest volcano in the entire solar system. It is almost two-and-a-half times as high as the tallest peak on the Earth, Mount Everest.

Attracted by a Star

Planets and their satellites, asteroids and other rocky objects, and an incalculable number of cometlike objects, some more than 1 trillion miles (1.6 trillion km) from the Sun, make up the solar system. In the 17th century, astronomer Johannes Kepler proposed a model to interpret the dynamic properties of the bodies of the solar system. According to this interpretation, the planets complete elliptical trajectories, called orbits, around the Sun. In every case, the movement is produced by the influence of the gravitational field of the Sun. Today, as part of a rapidly developing field of astronomy, it is known that planet or planetlike bodies also orbit other stars.

Outer Planets

Planets located outside the asteroid belt. They are enormous gas spheres with small solid cores. They have very low temperatures because of their great distance from the Sun. The presence of ring systems is exclusive to these planets. The greatest of them is Jupiter: 1,300 Earths could fit inside of it. Its mass is 2.5 times as great as that of the rest of the planets combined.

NEPTUNE

DIAMETER **30,775 MILES (49,528 KM)**
MOONS **13**

Triton Proteus Nereid

URANUS

DIAMETER **31,763 MILES (51,118 KM)**
MOONS **27**

Titania Oberon Umbriel Ariel Miranda Puck

SATURN

DIAMETER **74,898 MILES (120,536 KM)**
MOONS **50+**

Titan Rhea Iapetus Tethys

JUPITER

DIAMETER **88,846 MILES (142,984 KM)**
MOONS **60+**

Ganymede Callisto Io Europa

Asteroid Belt

The border between the outer and inner planets is marked by millions of rocky fragments of various sizes that form a band called the asteroid belt. Their orbits are influenced by the gravitational pull exerted on them by the giant planet Jupiter. This effect also keeps them from merging and forming a planet.

Inner Planets

Planets located inside the asteroid belt. They are solid bodies in which internal geologic phenomena, such as volcanism, which can modify their surfaces, are produced. Almost all of them have an appreciable atmosphere of some degree of thickness, according to individual circumstances, which plays a key role in the surface temperatures of each planet.

Phobos Deimos

MARS

DIAMETER **4,217 MILES (6,786 KM)**
MOONS **2**

MOON

EARTH

DIAMETER **7,926 MILES (12,756 KM)**
MOONS **1**

VENUS

DIAMETER **7,520 MILES (12,103 KM)**
MOONS **0**

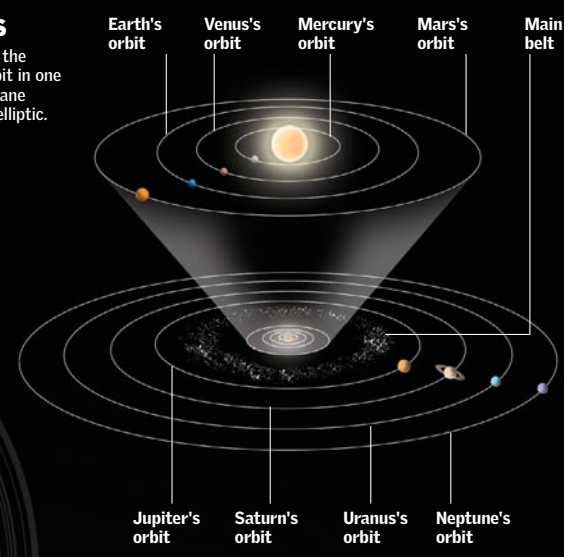
MERCURY

DIAMETER **3,031 MILES (4,878 KM)**
MOONS **0**

S U N

ORBITS

In general, the planets orbit in one common plane called the elliptic.



The rotation of most planets around their own axes is in counterclockwise direction. Venus and Uranus, however, revolve clockwise.

BUILDING PLANETS

Early ideas suggested that the planets formed gradually, beginning with the binding of hot dust particles. Today scientists suggest that the planets originated from the collision and melding of larger-sized bodies called planetesimals.

1

ORIGIN
Remains from the formation of the Sun created a disk of gas and dust around it, from which the planetesimals formed.



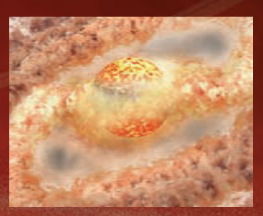
2

COLLISION
Through collisions among themselves, planetesimals of different sizes joined together to become more massive objects.



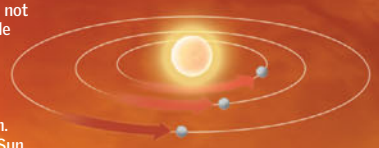
3

HEAT
The collisions produced a large amount of heat that accumulated in the interior of the planets, according to their distance from the Sun.



SOLAR GRAVITY

The gravitational pull of the Sun upon the planets not only keeps them inside the solar system but also influences the speed with which they revolve in their orbits around the Sun. Those closest to the Sun revolve in their orbits much faster than those farther from it.



A Very Warm Heart

The Sun at the center of the solar system is a source of light and heat. This energy is produced by the fusion of atomic hydrogen nuclei, which generate helium nuclei. The energy that emanates from the Sun travels through space and initially encounters the bodies that populate the solar system. The Sun shines thanks to thermonuclear fusion, and it will continue to shine until its supply of hydrogen runs out in about six or seven billion years.

Very Gassy

The Sun is a giant ball of gases with very high density and temperature. Its main components are hydrogen (90%) and helium (9%). The balance of its mass is made up of trace elements, such as carbon, nitrogen, and oxygen, among others. Because of the conditions of extreme temperature and pressure on the Sun, these elements are in a plasma state.

CHARACTERISTICS

CONVENTIONAL PLANET SYMBOL

ESSENTIAL DATA

Average distance from Earth	93 million miles (150 million km)
Equatorial diameter	864,000 miles (1,391,000 km)
Orbital speed	7,456 miles per second (12,000 km/s)
Mass*	332,900
Gravity*	28
Density	0.81 ounce per cubic inch (1.4 g per cu cm)
Average temperature	9,932° F (5,500° C)
Atmosphere	Dense
Moons	None

*In both cases, Earth = 1

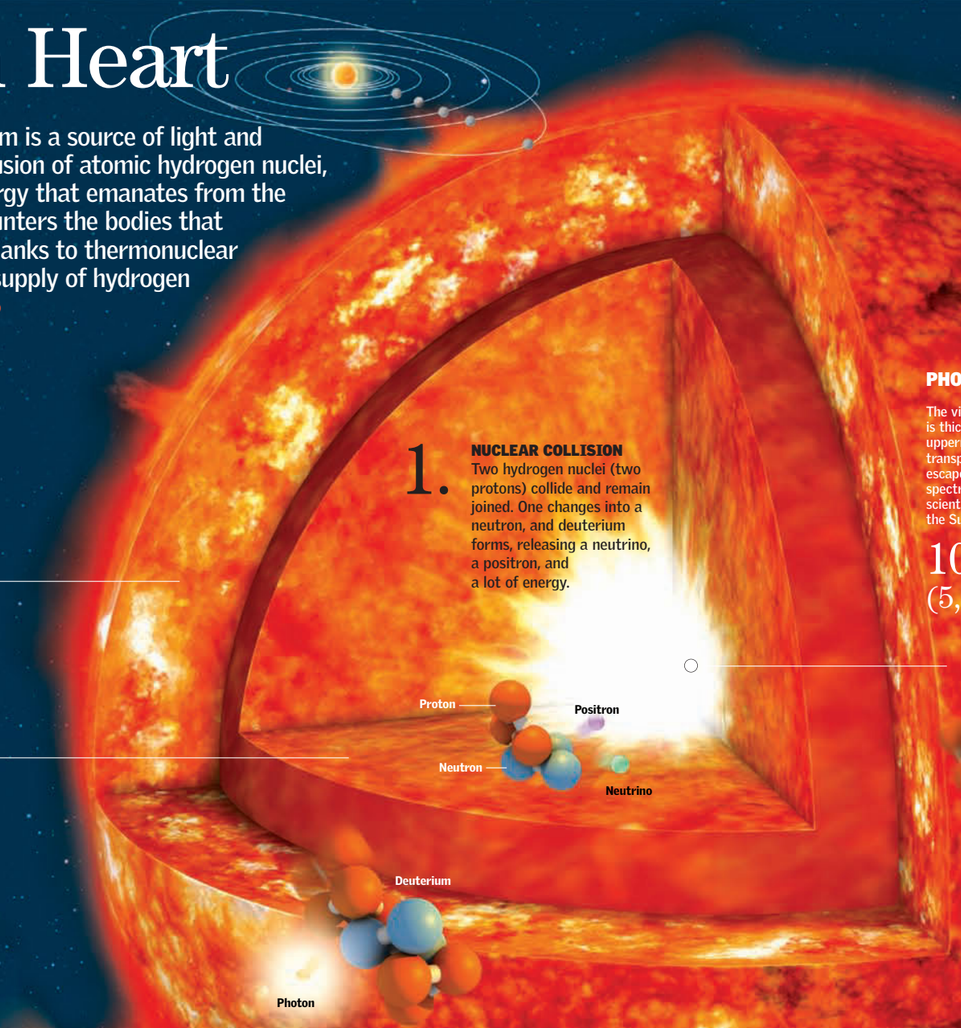
CONVECTIVE ZONE
extends from the base of the photosphere down to a depth of 15 percent of the solar radius. Here energy is transported up toward the surface by gas currents (through convection).

RADIATIVE ZONE
This portion of the Sun is traversed by particles coming from the core. A proton can take a million years to cross this zone.

14,400,000° F
(8,000,000° C)

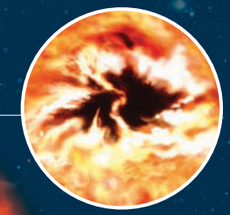
NUCLEAR FUSION OF HYDROGEN

The extraordinary temperature of the nuclear core helps the hydrogen nuclei join. Under conditions of lower energy, they repel each other, but the conditions at the center of the Sun can overcome the repulsive forces, and nuclear fusion occurs. For every four hydrogen nuclei, a series of nuclear reactions produce one helium nucleus.



Surface and Atmosphere

The visible portion of the Sun is a sphere of light, or photosphere, made of boiling gases emanating from the solar core. The gas flares form plasma, which passes through this layer. Later the gas flares enter a vast gas layer called the solar atmosphere. The density of this layer decreases toward its outermost region. Above the photosphere lies the solar atmosphere—the chromosphere and the corona. The energy generated at the core moves through the surface of the photosphere and solar atmosphere for thousands of years in search of an exit into space.



SUNSPOTS
are regions of gases that are generally colder (7,232° F [4,000° C]) than the photosphere (10,112° F [5,600° C]). For that reason, they appear dark.

UMBRA
Central region. It is the coldest and darkest part.

PENUMBRA
Peripheral region. It is the hottest and brightest part of the Sun.



PHOTOSPHERE
The visible surface of the Sun, a boiling tide, is thick with gases in a plasma state. In its uppermost layer, its density decreases and its transparency increases, and the solar radiation escapes from the Sun as light. The spectrographic study of this layer has allowed scientists to confirm that the main components of the Sun are hydrogen and helium.

10,112° F
(5,600° C)

CHROMOSPHERE
Above the photosphere, and of less density, lies the chromosphere, a layer 3,110 miles (5,000 km) thick. Its temperature ranges from 8,100° F (4,500° C) to 900,000° F (500,000° C) with increasing altitude. The temperature of the corona can reach 1,800,000° F (1,000,000° C).

900,000° F
(500,000° C)
MAXIMUM TEMPERATURE OF THE CHROMOSPHERE

CORE
The core occupies only 2 percent of the total volume of the Sun, but in it is concentrated about half the total mass of the Sun. The great pressures and temperatures in the core produce thermonuclear fusion.

27,000,000° F
(15,000,000° C)

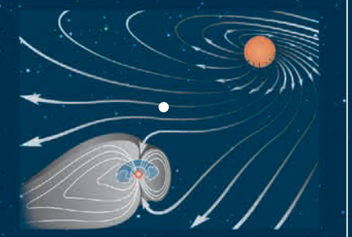
SPICULES
Vertical jets of gas that spew from the chromosphere, usually reaching 6,200 miles (10,000 km) in height. They originate in upper convection cells and can rise as high as the corona.

MACROSPICULES
This type of vertical eruption is similar to a spicule, but it usually reaches up to 25,000 miles (40,000 km) in height.

CORONA
Located above the chromosphere, it extends millions of miles into space and reaches temperatures nearing 1,800,000° F (1,000,000° C). It has some holes, or low-density regions, through which gases flow into the solar wind.

1,800,000° F
(1,000,000° C)
THE TEMPERATURE IN THE CORONA

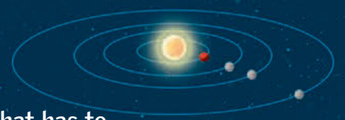
SOLAR WIND
Consists of a flux of ions emitted by the solar atmosphere. The composition is similar to that of the corona. The Sun loses approximately 1,800 pounds (800 kg) of matter per second in the form of solar wind.



SOLAR PROMINENCES
Clouds and layers of gas from the chromosphere travel thousands of miles until they reach the corona, where the influence of magnetic fields causes them to take on the shape of an arc or wave.

SOLAR FLARES
These eruptions come out of the solar atmosphere and can interfere with radio communications on Earth.

Mercury, an Inferno



Mercury is the planet nearest to the Sun and is therefore the one that has to withstand the harshest of the Sun's effects. Due to its proximity to the Sun, Mercury moves at great speed in its solar orbit, completing an orbit every 88 days. It has almost no atmosphere, and its surface is dry and rugged, covered with craters caused by the impact of numerous meteorites; this makes it resemble the Moon. Numerous faults, formed during the cooling of the planet when it was young, are also visible on the surface. Constantly baked by its neighbor, the Sun, Mercury has an average surface temperature of 333° F (167° C).

A Scar-Covered Surface

The surface of Mercury is very similar to that of the Moon. It is possible to find craters of varying sizes. The largest one has a diameter of some 810 miles (1,300 km). There are also hills and valleys. In 1991, radio telescopes were able to detect possible evidence of the presence of frozen water in Mercury's polar regions, information that Mariner 10 had been unable to gather. Mariner 10, the only mission sent to Mercury, flew by the planet three times between 1974 and 1975. The polar ice was found at the bottom of very deep craters, which limit the ice's exposure to the Sun's rays. The spacecraft Messenger, launched in 2004, is scheduled to orbit the planet Mercury in 2011 and is expected to provide new information about Mercury's surface and magnetic field.

CALORIS CRATER
The largest impact crater in the solar system, it has a diameter of 810 miles (1,300 km).

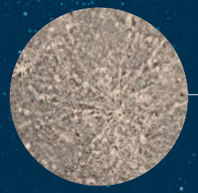


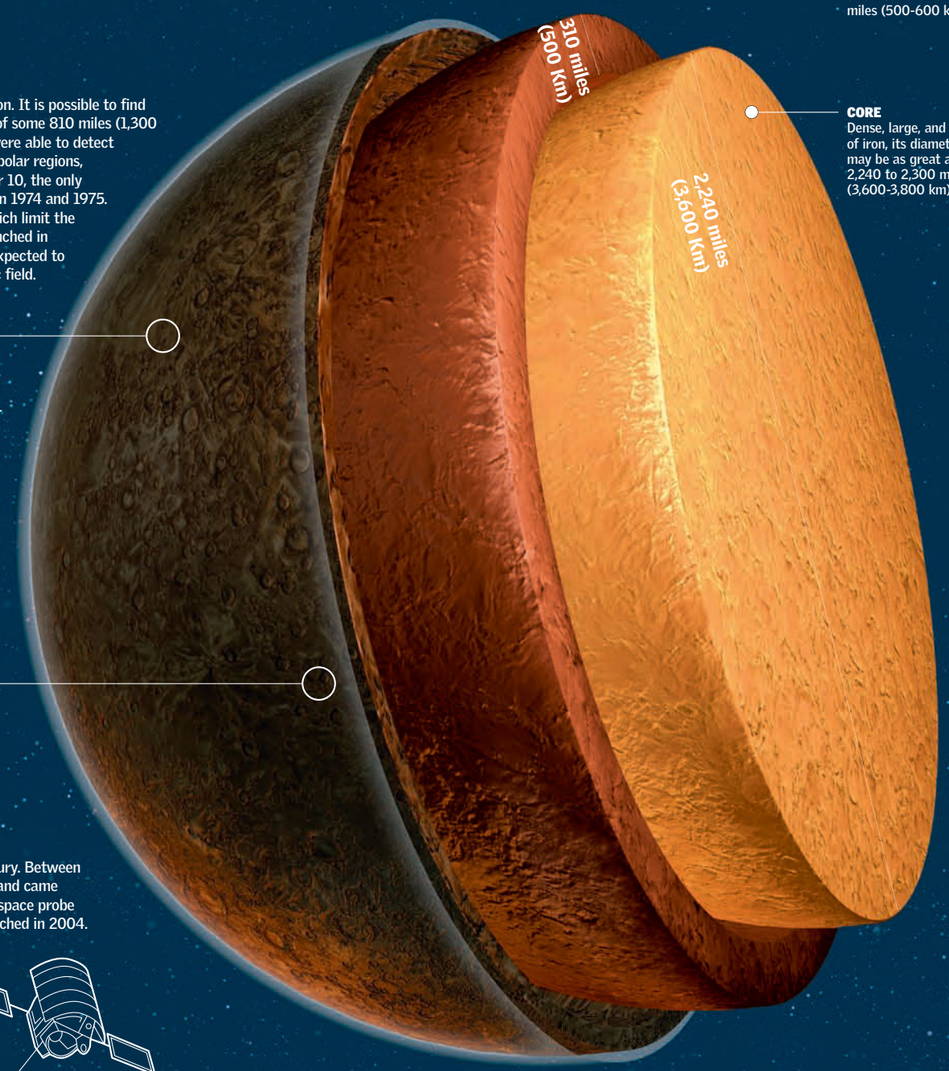


The crater was flooded with lava.

When the projectile that formed the crater struck, Mercury was still forming. The extensive waves that extended from the site of impact formed hills and mountains ranges.

BEETHOVEN
is the second largest crater on Mercury. It is 400 miles (643 km) in diameter. Its floor was flooded by lava and later marked by meteorite impacts.





CRUST
Made of silicate rocks, Mercury's crust is similar to the crust and mantle of the Earth. It has a thickness of 310 to 370 miles (500-600 km).

CORE
Dense, large, and made of iron, its diameter may be as great as 2,240 to 2,300 miles (3,600-3,800 km).

MANTLE
Made up mostly of silica-based rocks

Missions to Mercury

The space probe Mariner 10 was the first to reach Mercury. Between 1974 and 1975, the craft flew by the planet three times and came within about 200 miles (320 km) of the surface. Messenger, a space probe scheduled to study Mercury between 2008 and 2011, was launched in 2004.

Mariner 10



Messenger

The probe will pass by Mercury twice in 2008 and once again in 2009 before beginning to orbit the planet.



Composition and Magnetic Field

Like the Earth, Mercury has a magnetic field, although a much weaker one. The magnetism results from its enormous core made of solid iron. The mantle that surrounds the core is believed to be a fine layer of iron and sulfur.



29% Sodium

22% Hydrogen

6% Helium

43% Others

EXTREMELY THIN ATMOSPHERE
Mercury's atmosphere is almost nonexistent and consists of a very thin layer that cannot protect the planet either from the Sun or from meteorites. During the day, when Mercury is closer to the Sun, the planet's temperature can surpass 842° F (450° C). At night, temperatures can plummet to -297° F (-183° C).

During the night, the heat of Mercury's rocks is lost rapidly, and the planet's temperature drops.



During the day, the Sun directly heats the rock.

-297° F (-183° C)

883° F (473° C)



333° F (167° C)

Baked by its neighbor the Sun, Mercury is the planet with the greatest thermal fluctuations in the solar system. Its average temperature is 333° F (167° C), but when it gets closer to the Sun, the temperature can climb to 842° F (450° C). At night, it drops to -297° F (-183° C).

CHARACTERISTICS

CONVENTIONAL PLANET SYMBOL



ESSENTIAL DATA

Average distance from the Sun	36,000,000 miles (57,900,000 km)
Solar orbit (Mercurian year)	88 days 00 hours
Equatorial diameter	3,032 miles (4,880 km)
Orbital speed	29.75 miles per second (47.87 km/s)
Mass*	0.06
Gravity*	0.38
Density	3.14 ounces per cubic inch (5.43 g/cu cm)
Average temperature	332° F (167° C)
Atmosphere	Almost nonexistent
Lunas	

*In both cases, Earth = 1

AXIS INCLINATION

0.1°

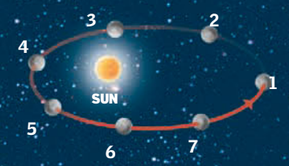
One rotation lasts 59 days.



Rotation and Orbit

Mercury rotates slowly on its axis and takes approximately 59 Earth days to complete a turn, but it only needs 88 days to travel in its orbit. To an observer in Mercury, these two combined motions would give a combined interval of 176 days between two sunrises. A person observing the sunrise from position 1 would have to wait for the planet to make two orbits around the Sun and make three rotations on its own axis before seeing the next sunrise.

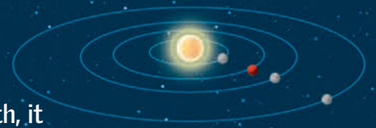
ORBIT OF MERCURY AROUND THE SUN



Each number corresponds to a position of the Sun in the sky as seen from Mercury.

VIEW FROM MERCURY

Venus, Our Neighbor



Venus is the second closest planet to the Sun. Similar in size to the Earth, it has a volcanic surface, as well as a hostile atmosphere governed by the effects of carbon dioxide. Although about four billion years ago the atmospheres of the Earth and Venus were similar, the mass of Venus's atmosphere today is 100 times greater than the Earth's. Its thick clouds of sulfuric acid and dust are so dense that stars are invisible from the planet's surface. Viewed from the Earth, Venus can be bright enough to be visible during day and second only to the moon in brightness at night. Because of this, the movements of Venus were well-known by most ancient civilizations.

CHARACTERISTICS

CONVENTIONAL PLANET SYMBOL

ESSENTIAL DATA

Average distance from the Sun	67,000,000 miles (108,000,000 km)
Solar orbit (Venusian year)	224 days 17 hours
Equatorial diameter	7,520 miles (12,100 km)
Orbital speed	22 miles per second (35 km/s)
Mass*	0.8
Gravity*	0.9
Density	3.03 ounces per cubic inch (5.25 g/cu cm)
Average temperature	860° F (460° C)
Atmosphere	Very thick
Moons	None

*In both cases, Earth = 1

AXIS INCLINATION

117°

Rotates on its own axis every 243 days



Composition

The overwhelming presence of carbon dioxide in the Venusian atmosphere induces a greenhouse effect, increasing the surface temperature to 864º F (462° C). Because of this, Venus is hotter than Mercury, even though Venus is farther from the Sun and reflects all but 20 percent of the Sun's light. The surface temperature of Venus is relatively constant, averaging 860° F (460° C). The atmospheric pressure on Venus is 90 times greater than that on the Earth.

ATMOSPHERE
Venus's glowing appearance is caused by the planet's thick, suffocating atmosphere, which is made up of carbon dioxide and sulfuric clouds that reflect sunlight.

50 miles (80 km) IS THE THICKNESS OF THE ATMOSPHERE.

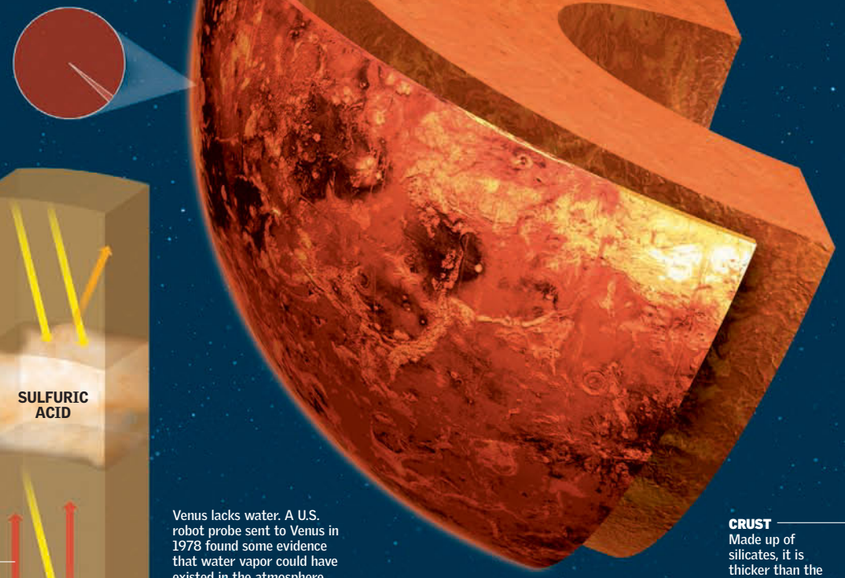
MANTLE
Made of molten rock, it constitutes most of the planet. It traps the solar radiation and is between 37 and 62 miles (60 and 100 km) thick.

CORE
It is believed that Venus's core is similar to the Earth's, containing metallic elements (iron and nickel) and silicates. Venus has no magnetic field—possibly because of its slow axial rotation.

14,400º F (8,000º C)

Carbon dioxide 97%

Nitrogen and traces of other gases 3%



GREENHOUSE EFFECT
Only 20 percent of the Sun's light reaches the surface of Venus. The thick clouds of dust, sulfuric acid, and carbon dioxide that constitute Venus's atmosphere reflect the remaining light, leaving Venus in permanent darkness.

SOLAR RADIATION
Venus is kept hot by its thick atmosphere, which retains the energy of the Sun's rays.

864º F (462º C)

INFRARED RAYS
The surface of Venus radiates infrared radiation. Only 20 percent of the Sun's rays pass through Venus's thick clouds of sulfuric acid.

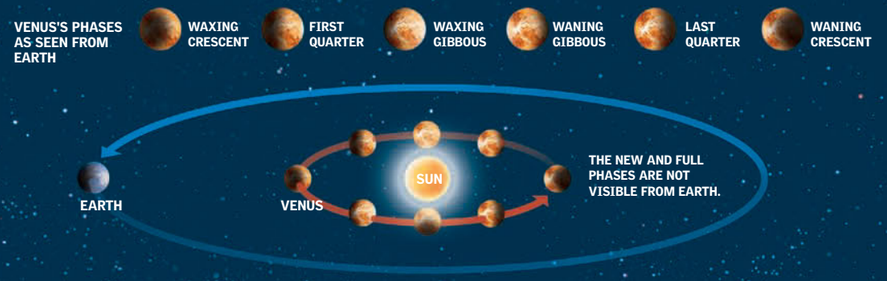


Venus lacks water. A U.S. robot probe sent to Venus in 1978 found some evidence that water vapor could have existed in the atmosphere hundreds of millions of years ago, but today no trace of water remains.

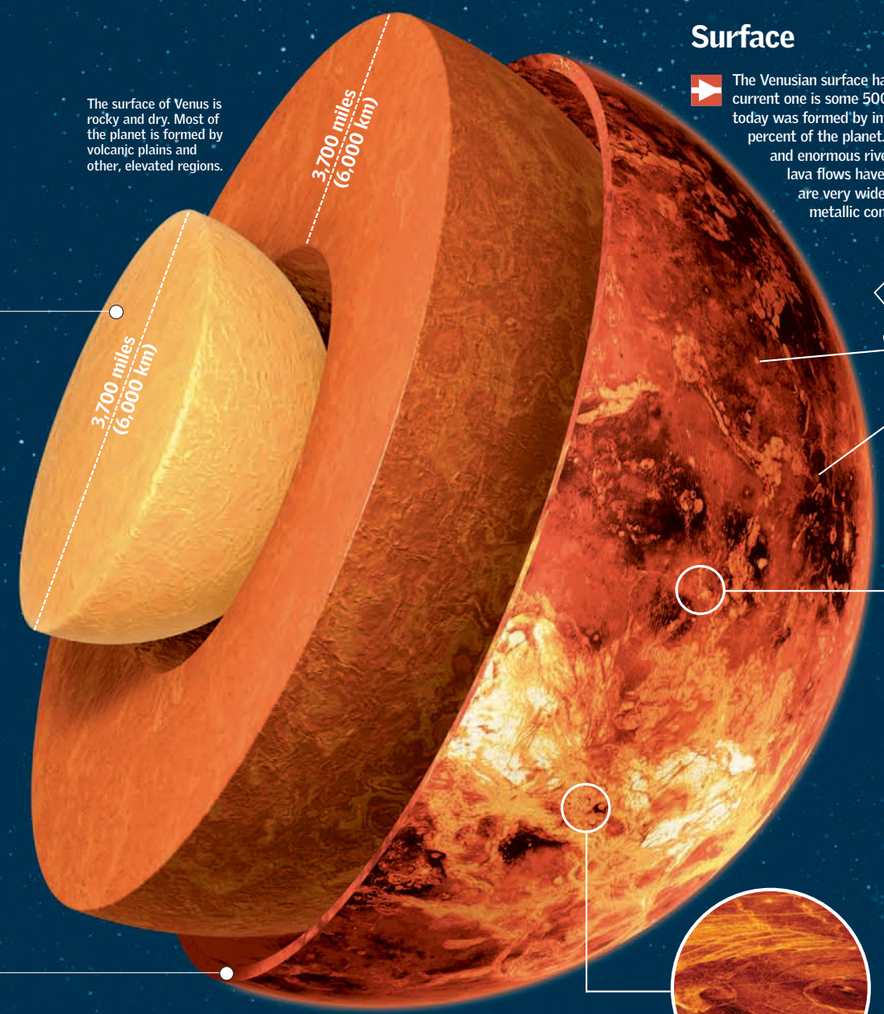
CRUST
Made up of silicates, it is thicker than the Earth's crust.

VENUS'S PHASES

As Venus revolves around the Sun, its solar illumination varies as is seen from the Earth depending upon its position in relation to the Sun and the Earth. Thus Venus has phases similar to the Moon's. During its elongations, when Venus is farthest from the Sun in the sky, Venus appears at its brightest.



The surface of Venus is rocky and dry. Most of the planet is formed by volcanic plains and other, elevated regions.

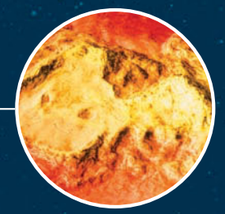


Surface

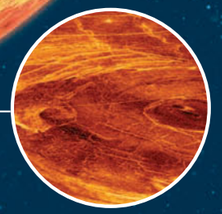
The Venusian surface has not remained the same throughout its life. The current one is some 500 million years old, but the rocky landscape visible today was formed by intense volcanic activity. Volcanic rock covers 85 percent of the planet. The entire planet is crisscrossed by vast plains and enormous rivers of lava, as well as a number of mountains. The lava flows have created a great number of grooves, some of which are very wide. The brightness of Venus's surface is the result of metallic compounds.



MAGELLAN
Venus was explored by the Magellan spacecraft between 1990 and 1994. The probe was equipped with a radar system to observe the surface through its dense atmosphere.

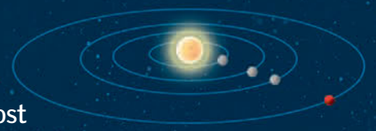


ISHTAR TERRA
One of the raised plateaus of Venus, it is similar in size to Australia and is located close to Venus's north pole. It has four main rocky mountain ranges called Maxwell Montes, Freyja Montes, Akna Montes, and Dam Montes.



APHRODITE TERRA
Larger than Ishtar Terra, it is the size of South America. Aphrodite Terra lies near the equator and consists mostly of mountainous regions to the east and west, which are separated by a low-lying region.

Red and Fascinating



Mars is the fourth planet from the Sun. Of all the planets, Mars most closely resembles the Earth. It has polar ice caps, and the tilt of its axis, period of rotation, and internal structure are similar to those of the Earth. Known as the Red Planet because of the reddish iron oxide that covers its surface, Mars has a thin atmosphere composed essentially of carbon dioxide. Mars does not have water, though it did in the past, and there is evidence some water might exist underground. Many spacecraft have been sent to explore Mars, in part because it is the planet other than Earth most likely to have developed some form of life, and it will probably be the first planet humans leave the Earth to visit.

Martian Orbit

Because Mars's orbit is more elliptical than that of Earth, Mars's distance from the Sun varies widely. At its perihelion, or closest approach to the Sun, Mars receives 45 percent more solar radiation than at its aphelion, or farthest point. Temperatures on Mars range from -220° F to 62° F (-140° C to 17° C).



Moons

Mars has two moons, Phobos and Deimos. Both have a lower density than Mars and are pitted with craters. Phobos has a diameter of 17 miles (27 km), and Deimos has a diameter of nine miles (15 km). Deimos orbits Mars in 30 hours at an altitude of 14,627 miles (23,540 km), and Phobos orbits Mars in eight hours at an altitude of 5,840 miles (9,400 km). Astronomers believe that the moons are asteroids that were captured by Mars's gravity.

DEIMOS



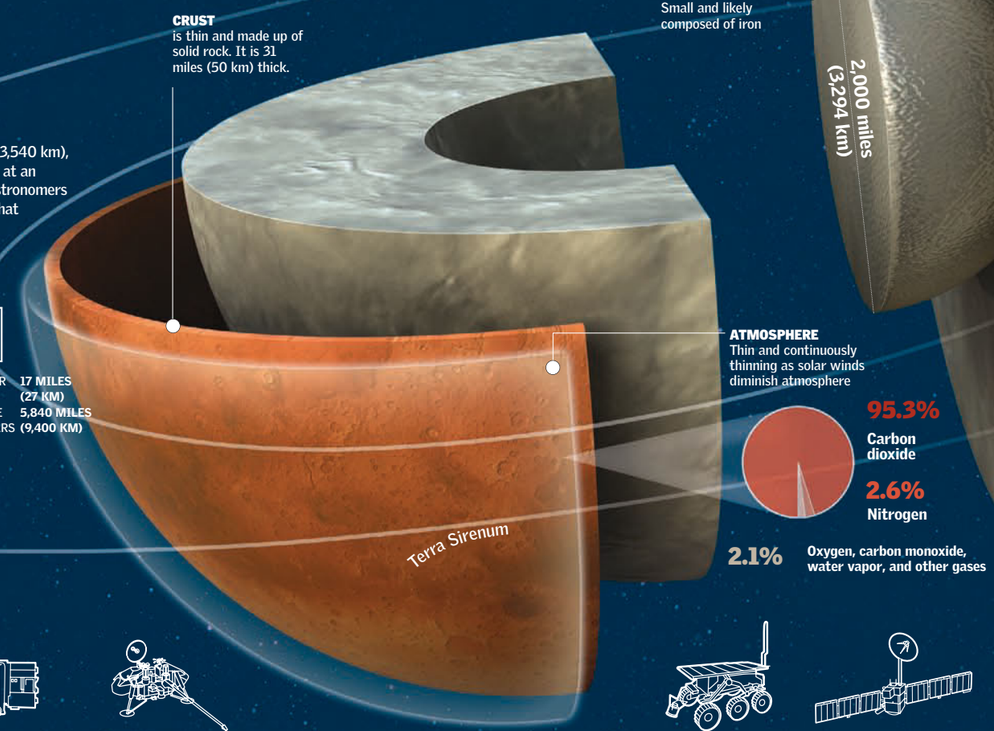
DIAMETER 9 MILES (15 KM)
DISTANCE FROM MARS 14,627 MILES (23,540 KM)

PHOBOS

DIAMETER 17 MILES (27 KM)
DISTANCE FROM MARS 5,840 MILES (9,400 KM)

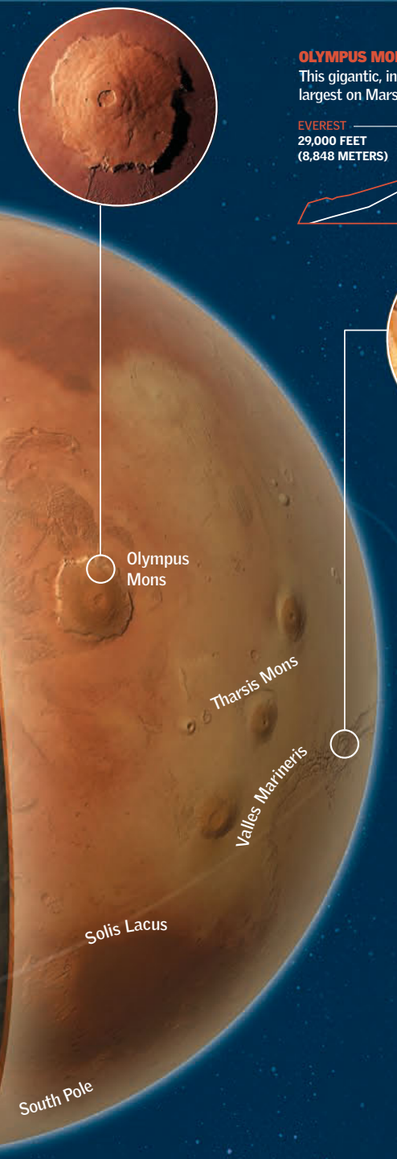
Composition

Mars, a rocky planet, has an iron-rich core. Mars is almost half the size of the Earth and has a similar period of rotation, as well as clearly evident clouds, winds, and other weather phenomena. Its thin atmosphere is made up of carbon dioxide, and its red color comes from its soil, which is rich in iron oxide.



Surface

It is a place of geologic extremes, shaped by volcanic activity, meteorite bombardment, windstorms, and floods (though there is little or no water on Mars today). Mountains dominate the southern hemisphere, but lowlands are common in the northern hemisphere.



OLYMPUS MONS
This gigantic, inactive volcano is not only the largest on Mars but also in the solar system.





VALLES MARINERIS

The canyon system of the Valles Marineris was likely caused naturally, primarily by water erosion.

CHARACTERISTICS

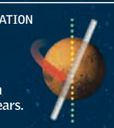
CONVENTIONAL PLANET SYMBOL ♂

ESSENTIAL DATA

Average distance from the Sun	141,600,000 miles (227,900,000 km)
Solar orbit (Martian year)	1.88 years
Equatorial diameter	4,222 miles (6,794 km)
Orbital speed	15 miles per second (24 km/s)
Mass*	0.107
Gravity*	0.38
Density	2.27 ounces per cubic inch (3.93 g/cu cm)
Average temperature	-81° F (-63° C)
Atmosphere	Very thin
Moons	2

*In both cases, Earth = 1

AXIS INCLINATION



25.2°

One rotation lasts 1.88 years.

MISSIONS TO MARS

After our own Moon, Mars has been a more attractive target for exploratory missions than any other object in the solar system.



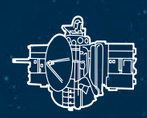
1965 MARINER 4
The first mission sent to Mars, it made only brief flyovers.



1969 MARINER 6 AND 7 studied the southern hemisphere and equator of Mars.



1971 MARINER 9 photographed the Olympus volcano for the first time.



1973 MARS 4, MARS 5, MARS 6, AND MARS 7
Russian spacecraft successfully sent to Mars

1976 VIKING 1 AND 2 searched for traces of life. They were the first spacecraft to land on Martian soil.

1997 MARS PATHFINDER was the third successful Mars landing.

1997 MARS GLOBAL SURVEYOR took more than 100,000 photos of the planet.



2001 MARS ODYSSEY mapped the mineralogy and morphology of Mars's surface.



2003 MARS EXPRESS
Orbiting probe. First spacecraft sent by the European Space Agency.

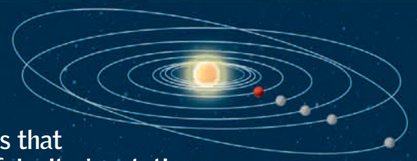


2004 SPIRIT AND OPPORTUNITY surveyed many square miles of the surface.



2006 MARS RECONNAISSANCE ORBITER made a detailed study of the Martian surface while orbiting the planet.

Jupiter, Gas Giant



Jupiter is the largest planet in the solar system. Its diameter is 11 times that of the Earth, and its mass is 300 times as great. Because the speed of Jupiter's rotation flattens the planet at its poles, its equatorial diameter is greater than its polar diameter. Jupiter rotates at 25,000 miles per hour (40,000 km/hr). One of the most distinctive elements of Jupiter's atmosphere is its so-called Great Red Spot, a giant high-pressure region of turbulence that has been observed from the Earth for more than 300 years. The planet is orbited by numerous satellites and has a wide, faint ring of particles.

Composition

Jupiter is a giant ball of hydrogen and helium that have been compressed into liquid in the planet's interior and into metallic rock in its core. Not much is known about Jupiter's core, but it is believed to be bigger than the Earth's core.

ATMOSPHERE
measures 620 miles (1,000 km).

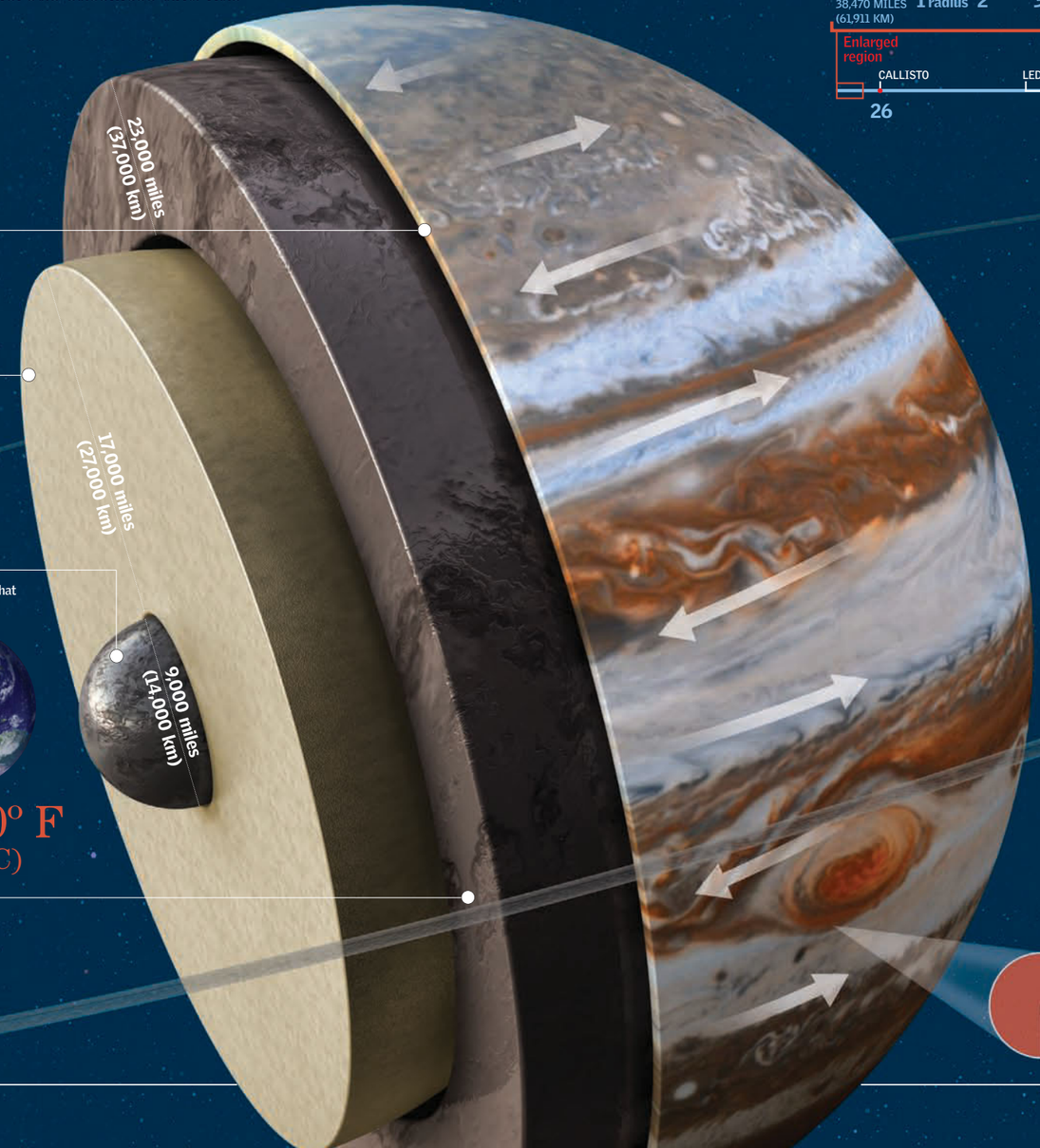
INNER MANTLE
Surrounds the core. It is made of liquid metallic hydrogen, an element only found under hot, high-pressure conditions. The inner mantle is a soup of electrons and nuclei.

CORE
Its size is similar to that of the Earth's core.



54,000° F
(30,000° C)

OUTER MANTLE
Made of liquid molecular hydrogen. The outer mantle merges with the atmosphere.



CHARACTERISTICS

CONVENTIONAL PLANET SYMBOL



ESSENTIAL DATA

Average distance from the Sun	483,000,000 miles (778,000,000 km)
Solar orbit (Jovian year)	11 years 312 days
Equatorial diameter	88,700 miles (142,800 km)
Orbital speed	8 miles per second (13 km/s)
Mass*	318
Gravity*	2.36
Density	0.77 ounce per cubic inch (1.33 g/cu cm)
Average temperature	-184° F (-120° C)
Atmosphere	Very dense
Moons	More than 60

*In both cases, Earth = 1

AXIS INCLINATION

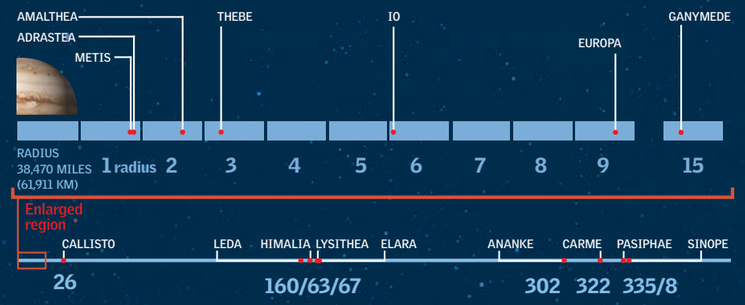
3.1°

One rotation lasts 9 hours and 55 minutes.



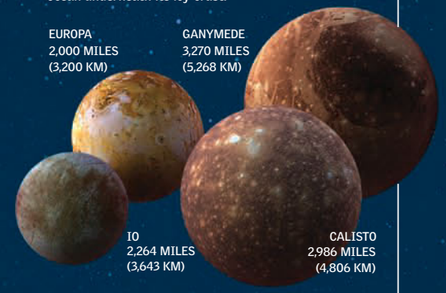
The Moons of Jupiter

Jupiter has more than 60 moons. Many of them have not been officially confirmed and do not even have names. Jupiter's rotation is gradually slowing because of the moons' tidal effects.



GALILEAN MOONS

Of Jupiter's 63 moons, four are visible from Earth with binoculars. These are called the Galilean moons in honor of their discoverer, Galileo Galilei. Astronomers believe that Io has active volcanoes and that Europa has an ocean underneath its icy crust.



Winds

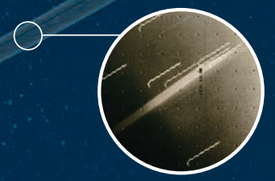
The winds on Jupiter blow in contiguous bands and opposing directions. The bands' small differences in temperature and chemical composition give the planet its multicolored appearance. Jupiter's inclement environment, in which winds blow at more than 370 miles per hour (600 km/h), can cause large storms, such as the Great Red Spot in the southern hemisphere of the planet. The Great Red Spot, which is 16,155 miles (26,000 km) long, is believed to be composed mainly of ammonia gas and clouds of ice.

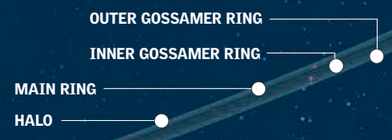


16,160 miles
(26,000 km)
GREAT RED SPOT

RINGS

Jupiter's rings are made of dust from the planet's four inner moons. These rings were first seen in 1979 by the space probe Voyager 1 and later by Voyager 2.





ATMOSPHERE

surrounds the inner liquid layers and the solid core. It is 620 miles thick (1,000 km).

89.8%
Hydrogen

10.2%
Helium
With traces of methane and ammonia

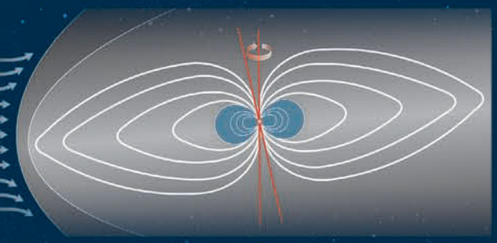


JUPITER'S MAGNETISM

Jupiter's magnetic field is 20,000 times stronger than the Earth's. Astronomers believe the field is caused by the electrical currents that are created by the rapid rotation of metallic hydrogen. Jupiter is surrounded by a huge magnetic bubble, the magnetosphere. The magnetosphere's tail reaches more than 370,000,000 miles (600,000,000 km)—beyond the orbit of Saturn.

Jupiter's magnetosphere is the largest object in the solar system. It varies in size and shape in response to the solar wind, which is composed of the particles continuously radiated from the Sun.

400,000,000 miles
(650,000,000 km)



The Lord of the Rings

Saturn is the solar system's second largest planet. Like Jupiter, it is a large ball of gas surrounding a small, solid core. Saturn was the most distant planet discovered before the invention of the telescope. To the naked eye, it looks like a yellowish star, but with the help of a telescope, its rings are clearly visible. Ten times farther from the Sun than the Earth, Saturn is the least dense planet. If an ocean could be found large enough to hold it, Saturn would float.

Rings

Saturn's rings, the brightest rings in the solar system, are made of rock and ice and orbit Saturn's equator. The rings are probably remains of destroyed comets that were trapped by Saturn's gravitational field.

RINGS G AND E

ENCKE DIVISION
A small gap that separates ring A into two parts

F RING
The farthest visible ring

A RING
Saturn's outer ring

CASSINI DIVISION
3,100 miles (5,000 km) wide, it is located between the A and B rings.

B RING
Saturn's brightest and widest ring

C RING
Saturn's only transparent ring

D RING
The closest ring to the surface of Saturn—so near that it almost touches the planet

310 miles (500 km)

9,100 miles (14,600 km)

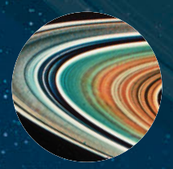
15,800 miles (25,500 km)

10,900 miles (17,500 km)

5,300 miles (8,500 km)

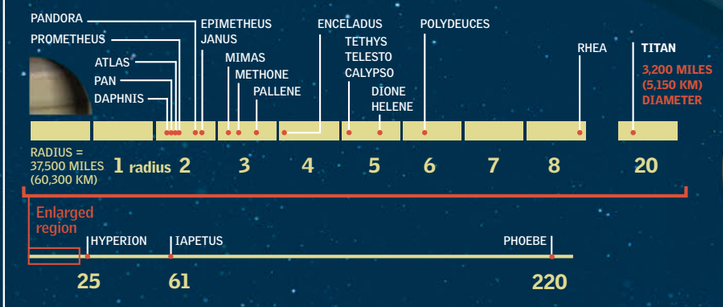
2,200 miles (3,500 km)

THICKNESS AND WIDTH
Although Saturn's rings are very wide, their thickness is sometimes less than 33 feet (10 m).



The Moons of Saturn

Saturn has more than 45 moons, making Saturn's family of moons one of the largest in the solar system. The sizes of the moons vary from Titan's 3,200 miles (5,150 km) to tiny Calypso's 10 miles (16 km).

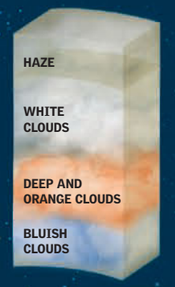




Titan has a larger diameter than Mercury. It has an atmosphere that is mostly made of nitrogen.

Surface

Like Jupiter, Saturn has a surface of clouds that form bands because of the planet's rotation. Saturn's clouds are less turbulent and less colorful than Jupiter's. The higher, white clouds reach temperatures of -220° F (-140° C). A layer of haze extends above the clouds.



WINDS
Saturn's winds generally reach speeds of about 220 miles per hour (360 km/h), causing strong storms.

Gaseous Exterior

Saturn and Jupiter differ very little in their composition. Both are gaseous balls surrounding solid cores. What sets Saturn apart are its rings, formed by clustered pieces of ice that range in size from small particles to large chunks. Each particle in a ring is a satellite orbiting Saturn. From the Earth, the massed debris seems to form large structures, but each discrete piece actually has its own orbit.

ATMOSPHERE

<1% Sulfur gives it a yellowish appearance.

2% Helium

97% Hydrogen

COMPONENTS

The main components of Saturn's atmosphere are hydrogen (97%) and helium (2%). The rest is composed of sulfur, methane, and other gases.

15,500 miles (25,000 km)

9,300 miles (15,000 km)

9,300 miles (15,000 km)

OUTER MANTLE
This layer is formed by liquid molecular hydrogen.

ATMOSPHERE
Mainly hydrogen and helium

INNER MANTLE
It is made up of liquid metallic hydrogen.

CORE
Composed of rock and metallic elements, such as silicates and iron

21,600°F (12,000° C)

CHARACTERISTICS

CONVENTIONAL PLANET SYMBOL

ESSENTIAL DATA

Average distance from the Sun	887,000,000 miles (1,427,000,000 km)
Solar orbit (Saturnine year)	29 years 154 days
Equatorial diameter	74,940 miles (120,600 km)
Orbital speed	6 miles per second (10 km/s)
Mass*	95
Gravity*	0.92
Density	0.4 ounce per cubic inch (0.7 g/cu cm)
Average temperature	-193° F (-125° C)
Atmosphere	Very dense
Moons	More than 45

*In both cases, Earth = 1

AXIS INCLINATION

26.7°
One rotation lasts 10 hours and 39 minutes.

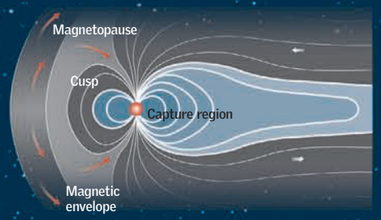


Uranus Without Secrets

To the unaided eye, Uranus looks like a star at the limit of visibility. It is the seventh farthest planet from the Sun and the third largest planet in the solar system. One peculiarity distinguishing it from the other planets is its anomalous axis of rotation, tilted nearly 98 degrees around the plane of its orbit, so that one or the other of Uranus's poles points toward the Sun. Astronomers speculate that, during its formation, Uranus may have suffered an impact with a protoplanet, which could have altered Uranus's tilt. Uranus's orbit is so large that the planet takes 84 years to completely orbit the Sun. Uranus's period of rotation is 17 hours and 14 minutes.

MAGNETIC FIELD

Uranus generates a magnetic field 50 times more powerful than Earth's. This field is not centered on the planet, but is offset and tilted 60 degrees from Uranus's axis. If this were the case on Earth, the magnetic north pole would be located in Morocco. Unlike other planets, Uranus's magnetic field originates in the planet's mantle, not its core.



Some scientists suggest that Uranus's anomalous magnetic field may indicate that the convection of Uranus's core has stopped because of cooling—or, perhaps, that the planet is currently undergoing a magnetic inversion, as has happened on the Earth.

Composition

Uranus's core is made of abundant amounts of silicates and ice. The planet is almost four times larger than the Earth, and its atmosphere is made up of hydrogen, helium, and methane. Uranus has an almost horizontal tilt, causing it to have very long seasons.

CHARACTERISTICS

CONVENTIONAL PLANET SYMBOL

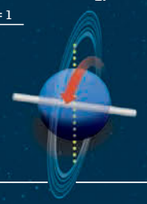
ESSENTIAL DATA	
Average distance from the Sun	1,780,000,000 miles (2,870,000,000 km)
Solar orbit (Uranian year)	84 years 4 days
Equatorial diameter	32,200 miles (51,800 km)
Orbital speed	4 miles per second (7 km/s)
Mass*	14.5
Gravity*	0.89
Density	0.8 ounce per cubic inch (1.3 g/cu cm)
Average temperature	-346° F (-210° C)
Atmosphere	Less dense
Moons	27

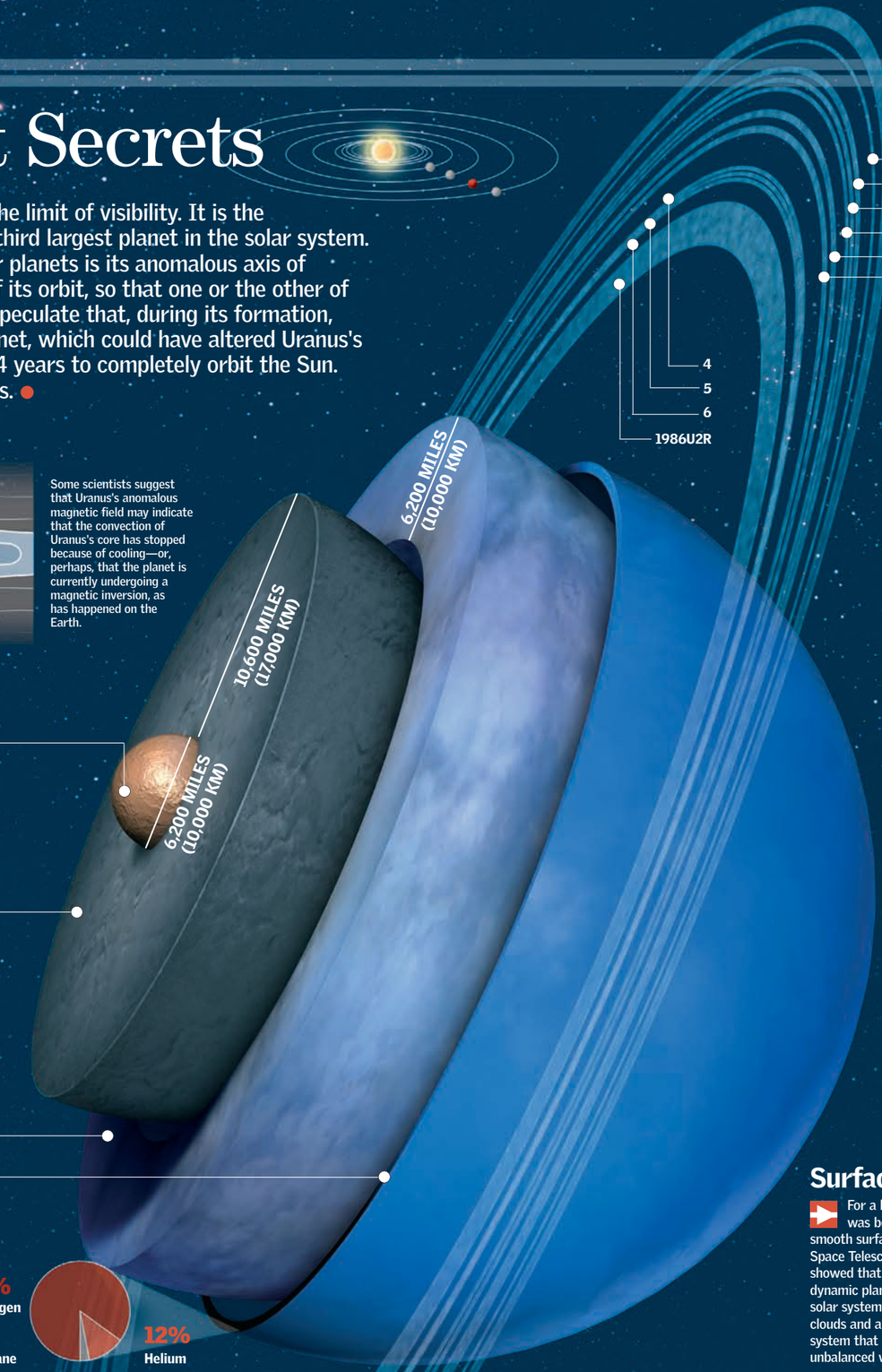
* In both cases, Earth = 1

AXIS INCLINATION

97.9°

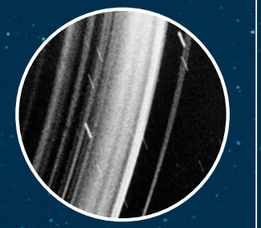
One rotation lasts 17 hours and 14 minutes.





Rings

Like all giant planets of the solar system, Uranus has a ring system, but it is much darker than Saturn's and more difficult to see. The planet's 11 rings, which orbit the planet's equator, were discovered in 1977. In 1986, they were explored by Voyager 2.



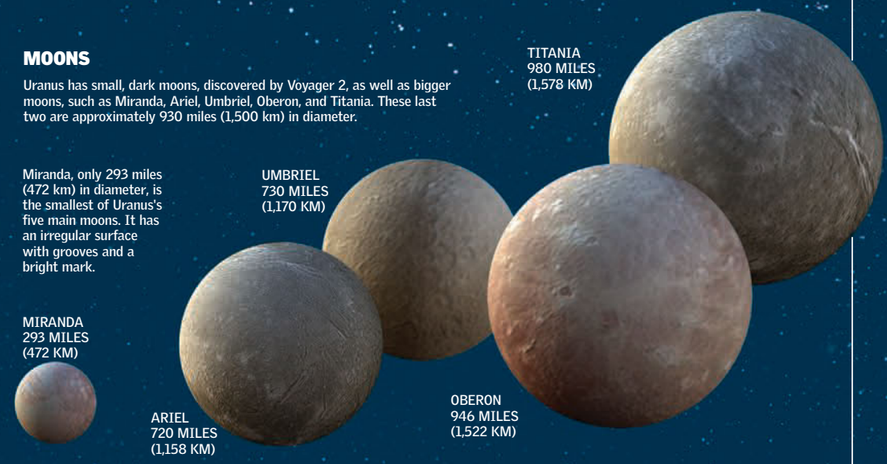
Satellites

Uranus has 27 moons. The first four were discovered in 1787, and another 10 were identified in 1986 by the space probe Voyager 2. Uranus's moons were named in honor of characters from the works of William Shakespeare and Alexander Pope, a naming convention that distinguishes them from the other moons in the solar system. Some of Uranus's moons are large, but most measure only dozens of miles.



MOONS

Uranus has small, dark moons, discovered by Voyager 2, as well as bigger moons, such as Miranda, Ariel, Umbriel, Oberon, and Titania. These last two are approximately 930 miles (1,500 km) in diameter.



Surface

For a long time, Uranus was believed to have a smooth surface. The Hubble Space Telescope, however, showed that Uranus is a dynamic planet that has the solar system's brightest clouds and a fragile ring system that wobbles like an unbalanced wheel.

REFRACTION OF RAYS

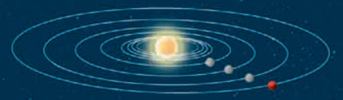
1. In Uranus, sunlight is reflected by a curtain of clouds that lie underneath a layer of methane.



2. When sunlight passes through this layer, the methane absorbs the red light waves and lets the blue light waves pass through, producing the planet's hue.



Neptune: Deep Blue



Seen from our planet, Neptune appears as a faint, blue point invisible to the naked eye. Images sent to Earth by Voyager 2 show the planet as a remarkably blue sphere, an effect produced by the presence of methane in the outer part of Neptune's atmosphere. The farthest of the gaseous planets, Neptune is 30 times farther from the Sun than the Earth is. Its rings and impressive clouds are noteworthy, as is its resemblance to Uranus. Neptune is of special interest to astronomers because, before its discovery, its existence and location were predicted on the basis of mathematical calculations.

Moons

Neptune has 13 natural satellites, nine of which are named. Triton and Nereid were the first moons observed by telescope from Earth. The 11 remaining moons were observed from space by the U.S. space probe Voyager 2. All the names of Neptune's satellites correspond to ancient Greek marine deities.



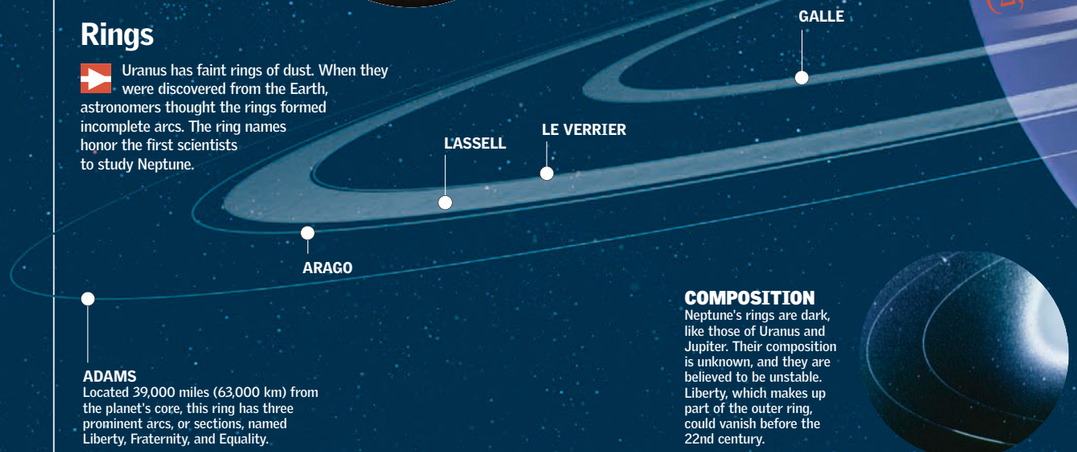


TRITON
Its diameter is 1,681 miles (2,706 km). Triton orbits Neptune in a direction opposite that of the other moons. Its surface has dark stripes formed by the material spewed from its geysers and volcanoes.

-391° F
(-235° C)
is its temperature, making Triton one of the coldest bodies in the solar system.

Rings

Uranus has faint rings of dust. When they were discovered from the Earth, astronomers thought the rings formed incomplete arcs. The ring names honor the first scientists to study Neptune.

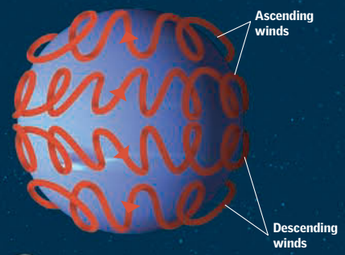


ADAMS
Located 39,000 miles (63,000 km) from the planet's core, this ring has three prominent arcs, or sections, named Liberty, Fraternity, and Equality.

COMPOSITION
Neptune's rings are dark, like those of Uranus and Jupiter. Their composition is unknown, and they are believed to be unstable. Liberty, which makes up part of the outer ring, could vanish before the 22nd century.

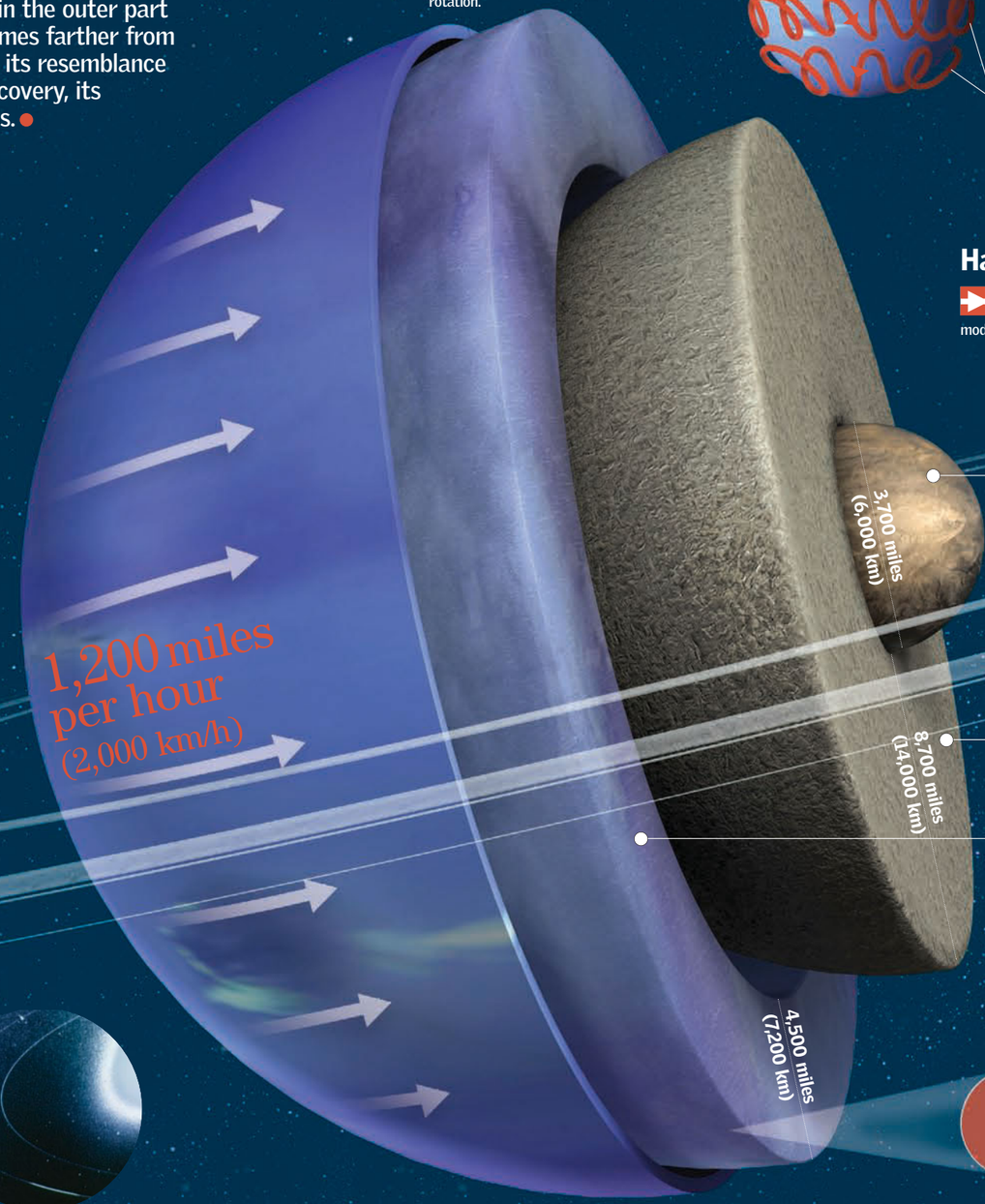
Surface

White methane clouds surround Neptune, circulating at some of the fastest speeds in the solar system. Neptune's winds reach 1,200 miles per hour (2,000 km/h) from east to west, swirling against the direction of the planet's rotation.



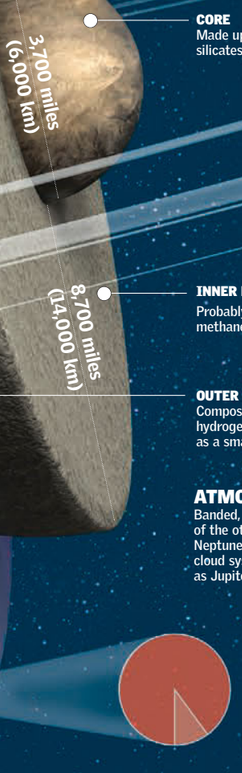
THE GREAT SPOT
This giant storm, called the Great Dark Spot, was first seen on the surface of Neptune in 1989 and was as large as the Earth. By 1994, it had disappeared.





Hard Heart

According to some models, Neptune has a rocky silicate core, covered by a mantle of icy water, ammonia, hydrogen, and methane. According to some models, however, the materials of the mantle and core do not form layers.



CORE
Made up of silicates and ice

INNER MANTLE
Probably icy water, methane, and ammonia

OUTER MANTLE
Composed primarily of hydrogen and helium, as well as a small amount of methane

ATMOSPHERE
Banded, like the atmospheres of the other gas giants, Neptune's atmosphere forms a cloud system at least as active as Jupiter's.

89.8%
Hydrogen

10.2%
Helium

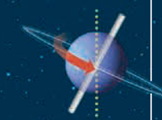
CHARACTERISTICS

CONVENTIONAL PLANET SYMBOL

ESSENTIAL DATA	
Average distance from the Sun	2,800,000,000 miles (4,500,000,000 km)
Solar orbit (Neptunian year)	164 years 264 days
Equatorial diameter	30,800 miles (49,500 km)
Orbital speed	3.4 miles per second (5.5 km/s)
Mass*	17.2
Gravity*	1.12
Density	1 ounce per cubic inch (1.6 g/cu cm)
Average temperature	-330° F (-200° C)
Atmosphere	Dense
Moons	13

*In both cases, Earth = 1

AXIS INCLINATION
28.3°
One rotation lasts 16 hours and 36 minutes.



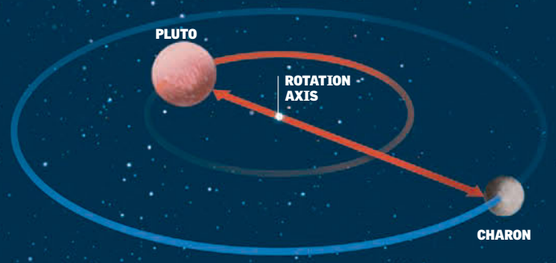
Pluto: Now a Dwarf



Pluto stopped being the ninth planet of the solar system in 2006 when the International Astronomical Union decided to change the classification of cold, distant Pluto to that of dwarf planet. This tiny body in our solar system has never had an imposing profile, and it has not yet been possible to study it closely. All that is known about Pluto comes through observations made from the Earth or Earth orbit, such as those made by the Hubble Space Telescope. Despite the lack of information gathered about Pluto, it is notable for its unique orbit, the tilt of its axis, and its location within the Kuiper belt. All these characteristics make Pluto especially intriguing.

A Double World

Pluto and its largest satellite, Charon, have a very special relationship. They have been called double planets—the diameter of Charon is about that of Pluto. One theory hypothesizes that Charon was formed from ice that was torn from Pluto when another object collided with the dwarf planet.



SYNCHRONIZED ORBITS

The orbital arrangement of Pluto and Charon is unique. Each always faces the other, making the two seem connected by an invisible bar. The synchronization of the two bodies is such that an observer on one side of Pluto would be able to see Charon, but another observer standing on the other side of the planet could not see this moon due to the curvature of the planet.



Surface

Only a little is known about Pluto, but the Hubble Space Telescope showed a surface covered by a frozen mixture of nitrogen and methane. The presence of solid methane indicates that its temperature is less than -333° F (-203° C), but the dwarf planet's temperature varies according to its place in orbit, ranging between 30 and 50 astronomical units from the Sun.



BEST VIEW OF PLUTO AVAILABLE

Moons

In addition to Charon, which was discovered in 1978, Pluto is orbited by two additional moons, Nix and Hydra, first observed in 2005. Unlike the surface of Pluto, which is made of frozen nitrogen, methane, and carbon dioxide, Charon appears to be covered with ice, methane, and carbon dioxide. One theory holds that the matter that formed this satellite was ejected from Pluto as a result of a collision, an origin similar to that ascribed to Earth's moon.



DENSITY
Charon's density is between 0.7 and 0.8 ounce per cubic inch (1.2 and 1.3 g/cu cm), indicating that its composition does not include much rock.

730 miles (1,172 km)
Charon's diameter—half of Pluto's

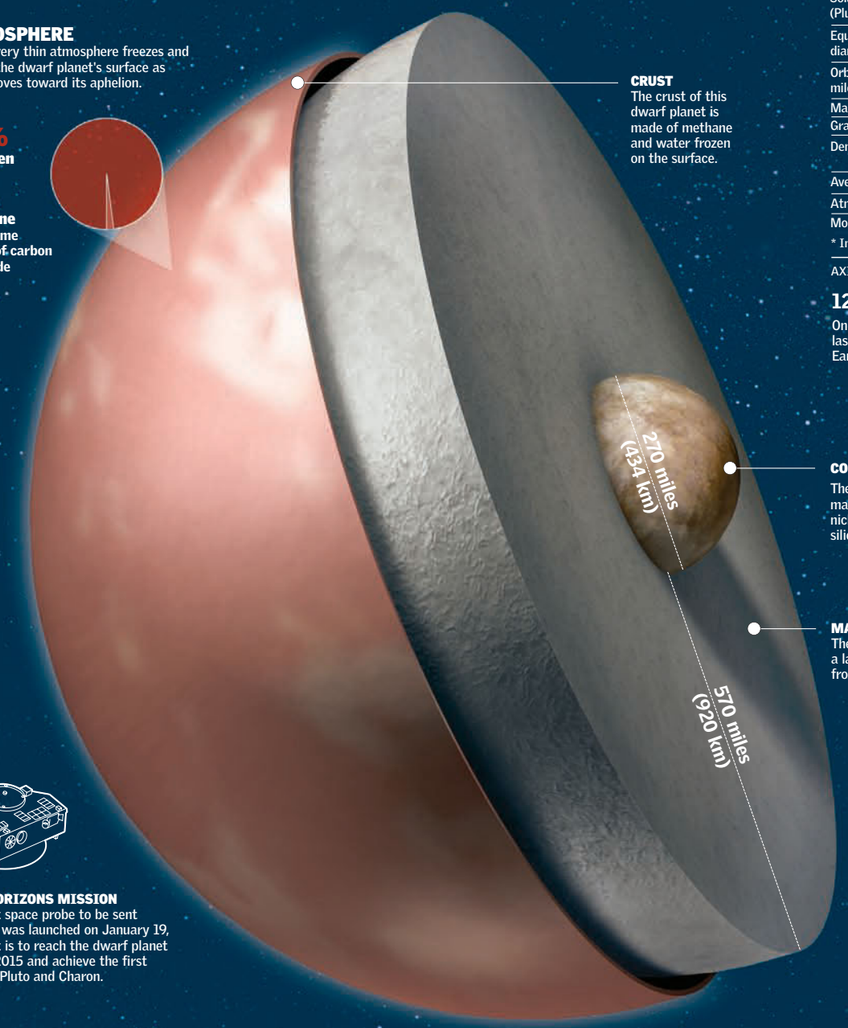
Composition

Scientific calculations have deduced that 75 percent of Pluto consists of a mixture of rocks and ice. This frozen surface is made up of 98 percent nitrogen, as well as traces of solidified carbon monoxide and methane. Recently scientists have concluded that Pluto is an object that belongs to the Kuiper belt, a group of objects left over from the formation of the outer planets. In addition to large amounts of frozen nitrogen, Pluto has simple molecules containing hydrogen and oxygen, the building blocks of life.

ATMOSPHERE
Pluto's very thin atmosphere freezes and falls to the dwarf planet's surface as Pluto moves toward its aphelion.

98%
Nitrogen

2%
Methane
With some traces of carbon monoxide



CRUST
The crust of this dwarf planet is made of methane and water frozen on the surface.

CORE
The core is made of iron, nickel, and silicates.

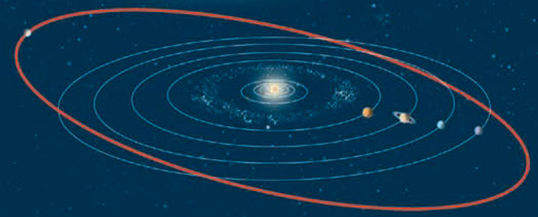
MANTLE
The mantle is a layer of frozen water.



NEW HORIZONS MISSION
The first space probe to be sent to Pluto was launched on January 19, 2006. It is to reach the dwarf planet in July 2015 and achieve the first flyby of Pluto and Charon.

A PECULIAR ORBIT

Pluto's orbit is noticeably elliptical, and it is tilted 17° from the plane of the planets' orbits. The distance between Pluto and the Sun varies from 2,500,000,000 to 4,300,000,000 miles (4,000,000,000 to 7,000,000,000 km). During each 248-year orbit, Pluto orbits closer to the Sun than Neptune for nearly 20 years. Although Pluto appears to cross paths with Neptune, it is impossible for them to collide.



6,387
terrestrial days is the time Pluto takes to complete one rotation.

CHARACTERISTICS

CONVENTIONAL PLANET SYMBOL: P

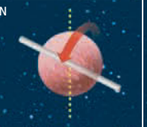
ESSENTIAL DATA

Average distance from the Sun	3,700,000,000 miles (5,900,000,000 km)
Solar orbit (Plutonian year)	247.9 years
Equatorial diameter	1,400 miles (2,247 km)
Orbital speed 3 miles per second	(4.8 km/s)
Mass*	0.002
Gravity*	0.067
Density	1.2 ounces per cubic inch (2.05 g/cu cm)
Average temperature	-380° F (-230° C)
Atmosphere	Very thin
Moons	3

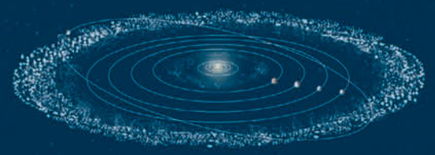
* In both cases, Earth = 1

AXIS INCLINATION

122°
One rotation lasts 6.387 Earth days.



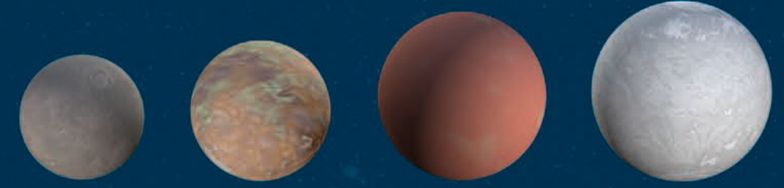
Distant Worlds



Farther even than Neptune, the eighth planet, we find frozen bodies smaller than the Earth's Moon—the more than 100,000 objects forming the Kuiper belt, the frozen boundary of our solar system. Recently astronomers of the International Astronomical Union decided to reclassify Pluto as a dwarf planet because of its size and eccentric orbit. Periodic comets (comets that appear at regular intervals) originate in the Kuiper belt. Nonperiodic comets, on the other hand, come from the Oort cloud, a gigantic sphere surrounding the entire solar system.

Comparable Sizes

The discovery of Quaoar in 2002 allowed scientists to find the link they had long looked for between the Kuiper belt and the origin of the solar system. Quaoar's almost circular orbit helped prove that some objects both belong to the Kuiper belt and orbit the Sun. At the official meeting of the International Astronomical Union, on August 24, 2006, Pluto was reclassified from a planet to a dwarf planet. For the time being, any further objects discovered in the Kuiper belt will be classified in the same category.



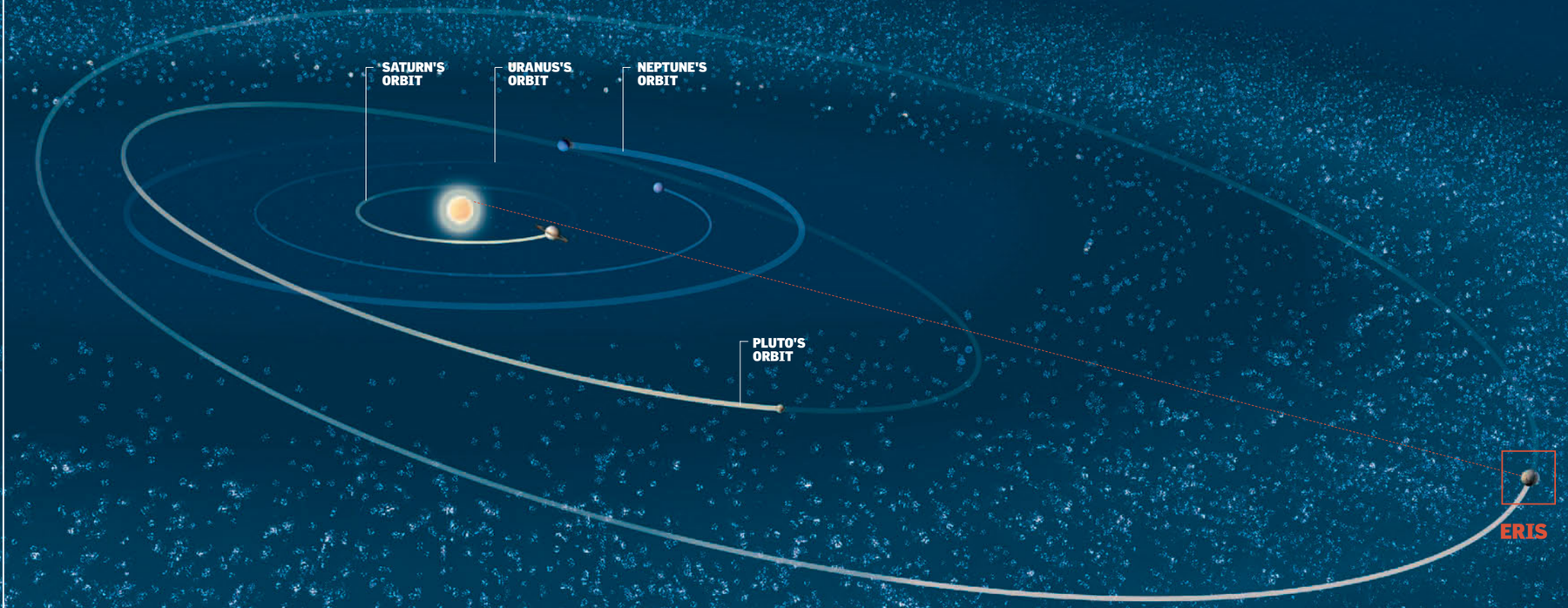
QUAOAR has a diameter of 810 miles (1,300 km).

SEDNA Its diameter is estimated at 1,000 miles (1,600 km).

PLUTO possesses a diameter of 1,400 miles (2,300 km).

ERIS Larger than Pluto, its diameter is about 1,900 miles (3,000 km).

200 OR MORE, POSSIBLE EXTRASOLAR PLANETS HAVE BEEN DETECTED.



Kuiper Belt

Extending outward from the orbit of Neptune are many frozen worlds similar in some ways to planets but much smaller. They are located in the Kuiper belt, the frozen boundary of our solar system. So far, almost a thousand objects have been cataloged, including Quaoar, which has a diameter of 810 miles (1,300 km). The Kuiper belt, estimated to contain more than 100,000 bodies of ice and rock larger than 60 miles (100 km) in diameter (including Pluto), spreads out in the shape of a wide ring. Many of the comets that approach the Sun come from the Kuiper belt.

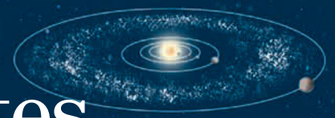
1,410 miles (2,274 km) is the diameter of Pluto—750 miles (1,200 km) smaller than the Earth's Moon. Because of its size and orbit, Pluto is considered a dwarf planet instead of a planet.

THE FARTHEST ONE

Eris is 97 astronomical units (9,040,000,000 miles [14,550,000,000 km]) from the Sun, making it the most distant object observed in the solar system. This dwarf planet follows an oval, eccentric orbit that takes 560 years to complete. The dwarf planet measures about 1,900 miles (3,000 km) in diameter, and traces of methane ice have been detected on its surface.



Construction Debris: Asteroids and Meteorites



Ever since the formation of the solar system, the melting, collision, and rupture of various materials played an essential role in the formation of the planets. Remnants of this process remain in the form of rock debris, which serves as witnesses to the formation of the solar system. These objects are also associated with episodes that influenced subsequent evolutionary processes on Earth. They are a possible cause of the mass extinction of dinosaurs more than 60 million years ago.

Extraterrestrial

One of the main goals of scientist who study meteorites is to understand their nature. Meteoric material holds extraterrestrial solids and gases. Scientific tests have confirmed that some meteorites are from the Moon or Mars, but most meteorites are associated with asteroids. The samples obtained from meteorites are analyzed and classified by their composition.



TYPES OF METEORITES

STONY
meteorites contain silicate minerals. They are subdivided into chondrites and achondrites.



IRON
meteorites contain a high percentage of iron and nickel compounds. They are created in the rupture of asteroids.

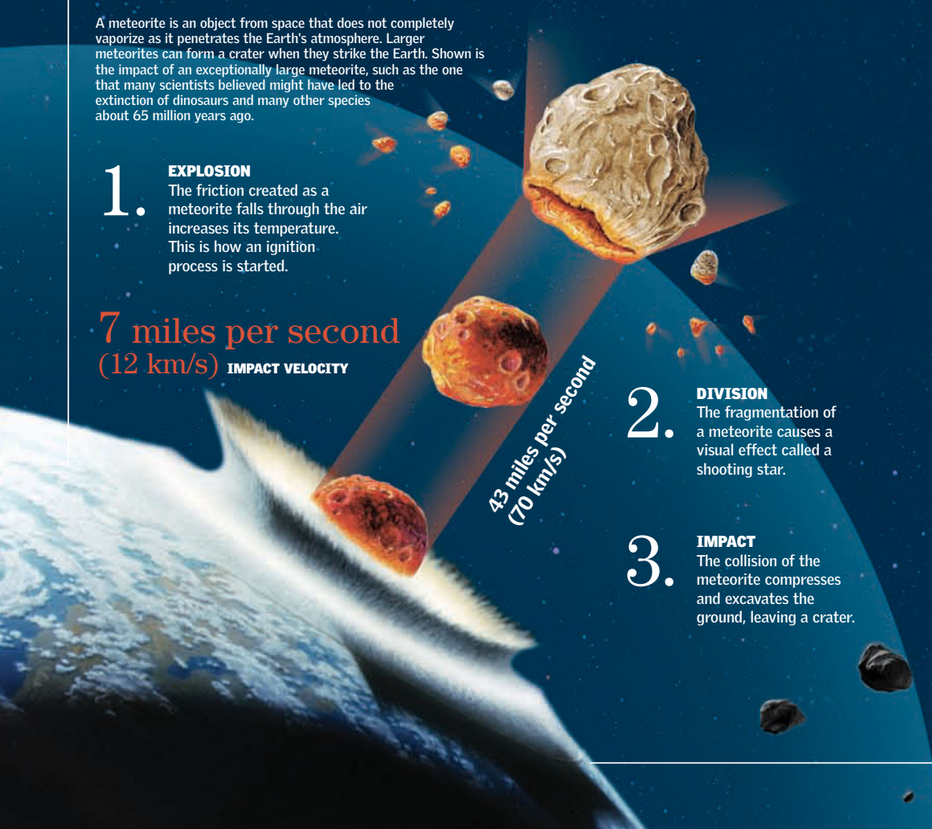


MESOSIDERITES
contain similar quantities of iron, nickel, and silicates.



A HUGE METEORITE STRIKES

A meteorite is an object from space that does not completely vaporize as it penetrates the Earth's atmosphere. Larger meteorites can form a crater when they strike the Earth. Shown is the impact of an exceptionally large meteorite, such as the one that many scientists believed might have led to the extinction of dinosaurs and many other species about 65 million years ago.



1. EXPLOSION
The friction created as a meteorite falls through the air increases its temperature. This is how an ignition process is started.

7 miles per second (12 km/s) IMPACT VELOCITY

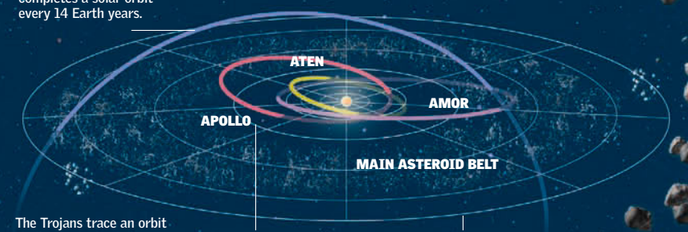
2. DIVISION
The fragmentation of a meteorite causes a visual effect called a shooting star.

3. IMPACT
The collision of the meteorite compresses and excavates the ground, leaving a crater.

Asteroids

Also called minor planets, they are the millions of rock and metal fragments of various shapes and sizes that orbit the Sun. They are mostly located in a belt between the orbits of Mars and Jupiter, but a few, such as those that belong to the Amor, Apollo, and Aten asteroid groups, orbit closer to Earth.

HIDALGO
completes a solar orbit every 14 Earth years.



The Trojans trace an orbit similar to Jupiter's, one group in front of the planet and another behind it.

TYPES OF ASTEROIDS

Despite a great variety in size and shape, three types of minor planets, or asteroids, are known. Classified by their composition, they are grouped as siliceous, carbonaceous, and metallic.

IDA
An asteroid 35 miles (56 km) long, its surface is marked by collisions with other bodies.



Ferrous-type rocks dominate its composition.

15%
The percentage of the total mass of the asteroids compared with the mass of the Moon

Tighten Your Belt

More than a million asteroids at least a mile in diameter are distributed in the main asteroid belt. Ceres was the first asteroid discovered (in 1801). It is the largest known asteroid, with a diameter of 580 miles (932 km).

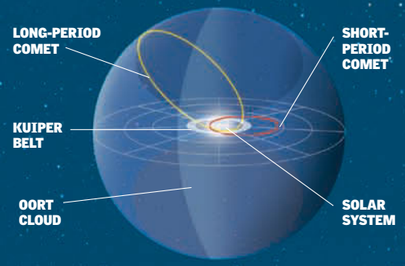
KIRKWOOD
The Kirkwood gaps are the open areas in the main asteroid belt that are devoid of asteroids.

Those with a Tail

Comets are small, deformed objects a few miles in diameter that are normally frozen and dark. Made of dust, rock, gases, and organic molecules rich in carbon, comets are usually found in orbits beyond that of Neptune in the Kuiper belt or in the Oort cloud. Occasionally a comet, such as Halley's comet, veers toward the interior of the solar system, where its ice is heated and sublimates, forming a head and long, spectacular tails of gases and dust.

Types of Comets

Comets with short periods have orbits around the Sun that are shorter than 200 years. Those with a period of more than 200 years travel tens or hundreds of times farther from the Sun than Pluto.



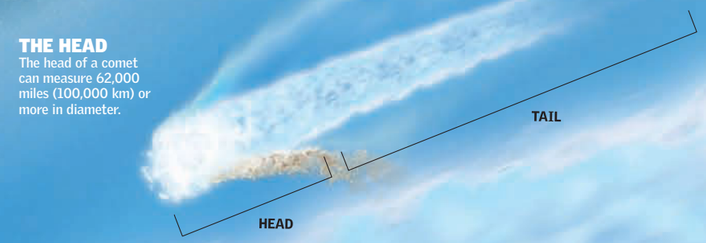
Periodic comets

Comets that leave their original orbits and approach the Sun generally settle into new trajectories. Halley's comet, for example, completes its elongated orbit in 76 years.

HEAD
Formed by the nucleus and the coma. The front part is called the impact front.

COMA
Envelops the nucleus. It is formed by the gases and dust that it releases.

NUCLEUS
Frozen water, methane, carbon dioxide, ammonia, rock, and dust

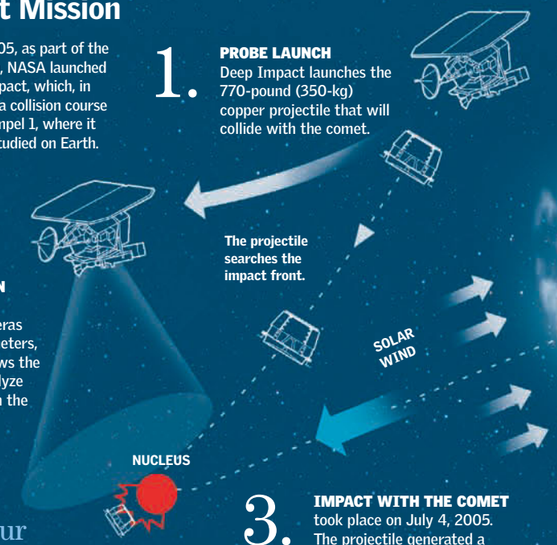


ION TAIL
The trail of suspended gases generates a low-intensity, luminous region with a bluish color. The gas molecules lose an electron and therefore have an electrical charge.

DUST TAIL
The suspended dust particles trail behind the comet, reflecting sunlight and making the luminous tail visible.

Deep Impact Mission

On January 12, 2005, as part of the Discovery program, NASA launched the space probe Deep Impact, which, in turn, sent a projectile on a collision course toward the comet 9P/Tempel 1, where it obtained samples to be studied on Earth.



22,370 miles per hour (36,000 km/h)
VELOCITY OF THE COMET IMPACT

PREVIOUS MISSIONS

NASA has sent other unmanned missions to comets. The first was the international craft ISEE-3/ICE. Launched in 1978, its mission ended after crossing the tail of the Giacobini-Zinner comet in September 1985.

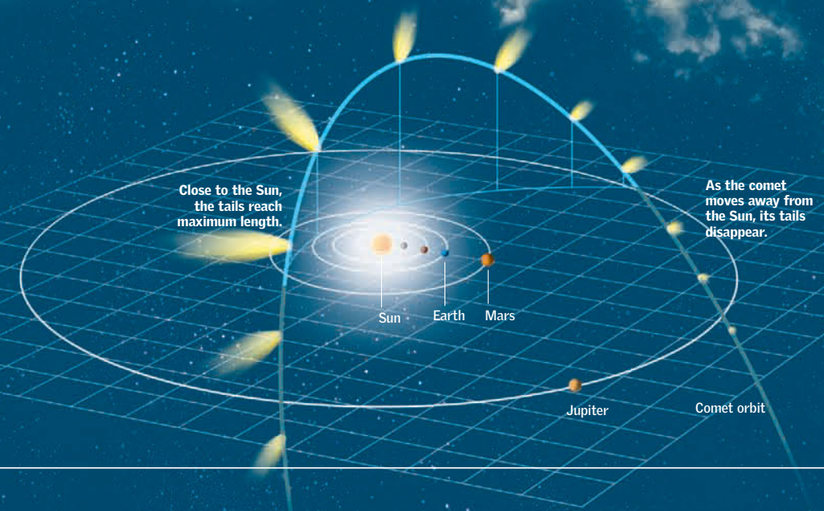
GIOTTO
Launched in 1986, it passed the nucleus of Halley's comet at a distance of 310 miles (500 km) in 1992.

DEEP SPACE
The NASA spacecraft approached the comet Borrelly in 2001.

STARDUST
In 2004, it took samples of the comet Wild 2 and sent them to Earth.

FORMATION OF THE TAIL AND HEAD

Because of the effects of solar radiation and the solar wind, gases and dust are released from an accelerating comet. The dust particles tend to form a curving trail, which is less sensitive to the pressure of the solar wind. As the comet leaves the confines of the solar system, its tails coincide once more, but they disappear as the nucleus cools down and ceases releasing gases.



The Earth and the Moon

AERIAL VIEW OF THE EARTH
In this partial image of the Earth, we can see Bora-Bora, an island that forms part of the Leeward Islands, located in French Polynesia.

THE BLUE PLANET 68-69
JOURNEY TO THE CENTER OF THE EARTH 70-71
ONCE UPON A TIME 72-73
MOVEMENTS AND COORDINATES 74-75
THE MOON AND TIDES 76-77
ECLIPSES 78-79



In the beginning, the Earth was an incandescent mass that slowly began to cool, allowing the continents to emerge and acquire their current form. Although many drastic changes took place during these early eras, our blue planet has still not stopped changing. It must be recognized that life on Earth would be impossible without the presence of the atmosphere—the colorless, odorless, invisible layer of gases that surrounds us, giving us air to breathe and protecting us from the Sun's harmful radiation. Although the atmosphere is approximately 435 miles (700 km) thick, it has no clear boundary and fades into space until it finally disappears. ●

The Blue Planet

The Earth is known as the blue planet because of the color of the oceans that cover two thirds of its surface. This planet, the third planet from the Sun, is the only one where the right conditions exist to sustain life, something that makes the Earth special. It has liquid water in abundance, a mild temperature, and an atmosphere that protects it from objects that fall from outer space. The atmosphere also filters solar radiation thanks to its ozone layer. Slightly flattened at its poles and wider at its equator, the Earth takes 24 hours to revolve once on its axis.

The Phenomenon of Life

Water, in liquid form, makes it possible for life to exist on the Earth, the only planet where temperatures vary from 32° F to 212° F (0° C to 100° C), allowing water to exist as a liquid. The Earth's average distance from the Sun, along with certain other factors, allowed life to develop 3.8 billion years ago.

70%

of the Earth's surface is water. From space, the planet looks blue.



-76° F
(-60° C)

ONLY ICE
Mars is so far from the Sun that all its water is frozen.



32° to 212° F
(0° to 100° C)

3 STATES
On the Earth, water is found in all three of its possible states.

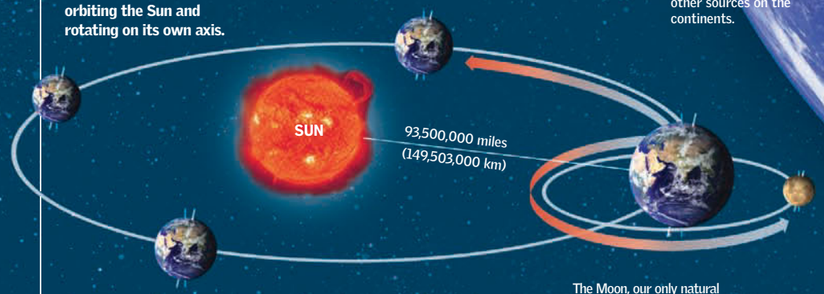


Above 212° F
(100° C)

ONLY STEAM
On Mercury or Venus, which are very close to the Sun, water would evaporate.

EARTH MOVEMENTS

The Earth moves, orbiting the Sun and rotating on its own axis.



ROTATION: The Earth revolves on its axis in 23 hours and 56 minutes.

REVOLUTION: It takes the Earth 365 days, 5 hours, and 57 minutes to travel once around the Sun.

The Moon, our only natural satellite, is four times smaller than the Earth and takes 27.32 days to orbit the Earth.



1. EVAPORATION
Because of the Sun's energy, the water evaporates, entering the atmosphere from oceans and, to a lesser extent, from lakes, rivers, and other sources on the continents.

2. CONDENSATION
The Earth's winds transport moisture-laden air until weather conditions cause the water vapor to condense into clouds and eventually fall to the ground as rain or other forms of precipitation.

3. PRECIPITATION
The atmosphere loses water through condensation. Gravity causes rain, snow, and hail. Dew and frost directly alter the state of the surface they cover.

23.5°

This is the inclination of the Earth's axis from the vertical. As the Earth orbits the Sun, different regions gradually receive more or less sunlight, causing the four seasons.

CHARACTERISTICS

CONVENTIONAL PLANET SYMBOL

ESSENTIAL DATA

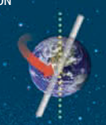
Average distance to the Sun	93 million miles (150 million km)
Revolution around the Sun (Earth year)	365.25 days
Diameter at the equator	7,930 miles (12,756 km)
Orbiting speed	17 miles per second (27.79 km/s.)
Mass*	1
Gravity*	1
Density	3.2 ounces per cubic inch (5.52 g/cu cm)
Average temperature	59° F (15° C)

*In both cases, Earth = 1

AXIS INCLINATION

23.5°

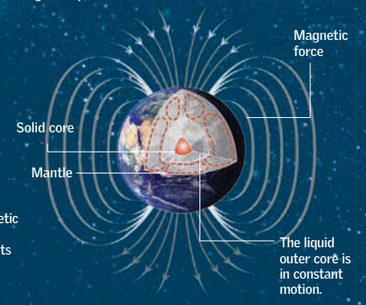
One rotation lasts 23.56 hours.



Magnetism and Gravity

The Earth's magnetic field originates in the planet's outer core, where turbulent currents of molten iron generate both electric and magnetic fields. The orientation of the Earth's magnetism varies over time, causing the magnetic poles to fluctuate.

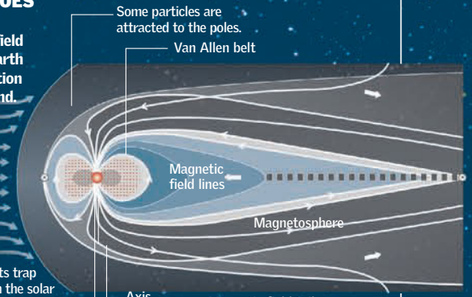
The Earth's core works as a magnet.



The Earth's magnetic field is created by convective currents in its outer core.

WHAT IT DOES

The magnetic field protects the Earth from the radiation of the solar wind.



The Van Allen belts trap the particles from the solar wind, causing phenomena like the auroras.

GRAVITY AND WEIGHT

Weight is the force of the gravity that acts on a body.

24 pounds (11 kg)

ON THE MOON
The Moon has less mass than the Earth and, as a result, less gravity.



154 pounds (70 kg)

ON EARTH
The object is drawn toward the Earth's center.



390 pounds (177 kg)

ON JÚPITER
Jupiter has 300 times more mass than the Earth and therefore more gravity.

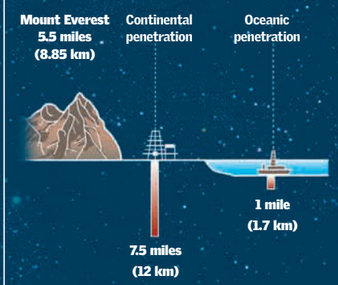
Journey to the Center of the Earth

We live on the Earth, but do we know what we are standing on? The planet is made up of layers of various materials, such as solid and molten rock, which in turn are composed of such elements as iron, nickel, and silicon. Our atmosphere is the layer of gases surrounding our planet. One of these gases, oxygen, does a very special job—it permits life to exist.

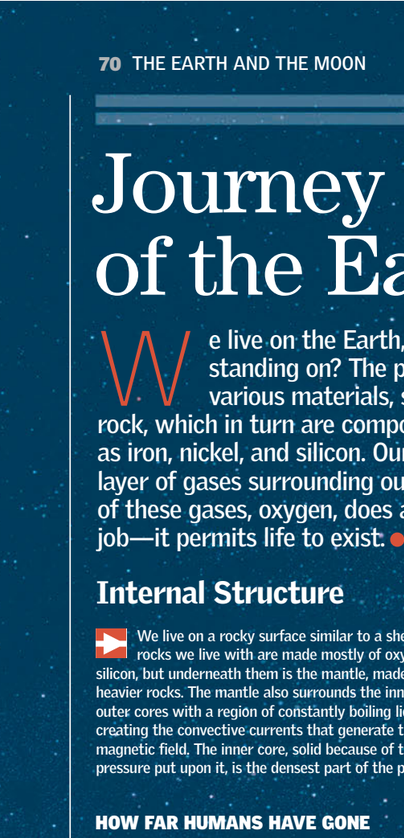
Internal Structure

We live on a rocky surface similar to a shell. The rocks we live with are made mostly of oxygen and silicon, but underneath them is the mantle, made of much heavier rocks. The mantle also surrounds the inner and outer cores with a region of constantly boiling liquid metals, creating the convective currents that generate the Earth's magnetic field. The inner core, solid because of the great pressure put upon it, is the densest part of the planet.

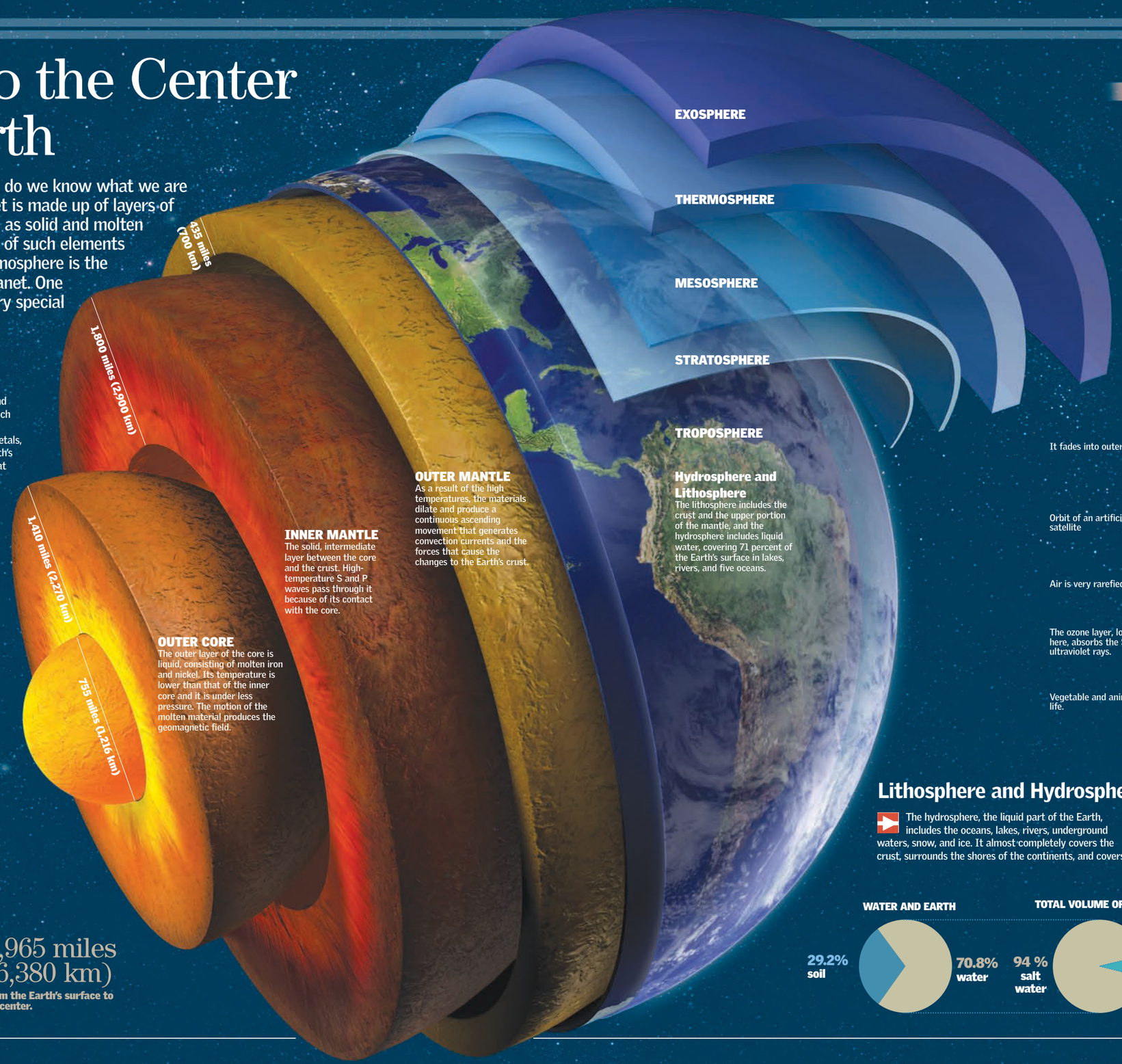
HOW FAR HUMANS HAVE GONE



INNER CORE
is made of the same metals as the outer core, but, despite its high temperature, its center is solid because of the enormous pressure that compresses it.



3,965 miles (6,380 km)
from the Earth's surface to its center.



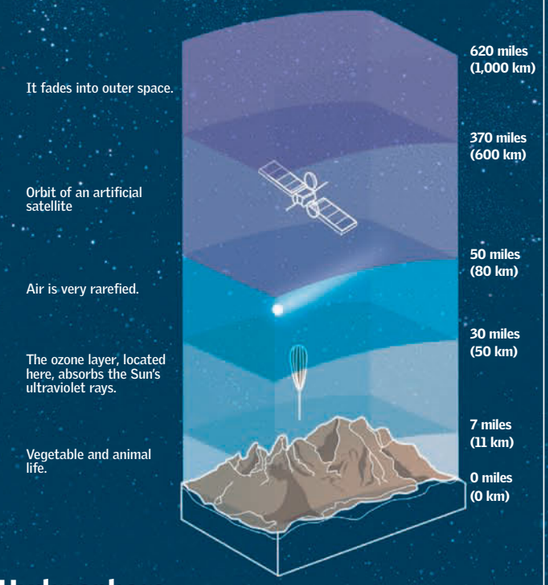


WITH ATMOSPHERE
The sunlight filters into the atmosphere. Winds distribute the heat, cooling the tropics and warming the poles.

WITHOUT ATMOSPHERE
Direct solar radiation. Differences in temperature between the equator and the poles would be far more pronounced.

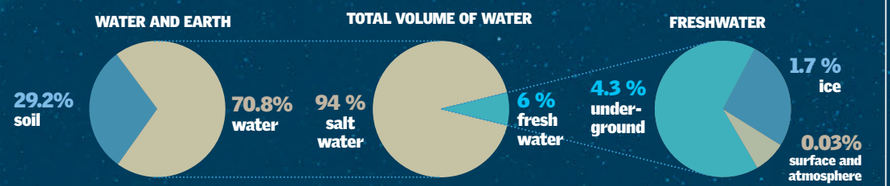
Above the Surface

The existence of life on our planet would be impossible without the atmosphere that provides the air we breathe and the water we drink; it also protects us from the Sun's harmful radiation, while simultaneously maintaining mild temperatures by retaining the Sun's warmth. The atmosphere is about 435 miles thick (700 km) but lacks defined limits.



Lithosphere and Hydrosphere

The hydrosphere, the liquid part of the Earth, includes the oceans, lakes, rivers, underground waters, snow, and ice. It almost completely covers the crust, surrounds the shores of the continents, and covers 71 percent of the Earth's surface. The lithosphere is a superficial, elastic region that is 4 to 7 miles (6 to 11 km) thick under the oceans and up to 43 miles (70 km) thick under mountain ranges.



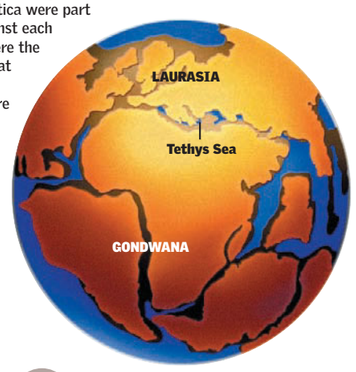
Once Upon a Time

The Earth probably formed from material in the solar nebula—the cloud of gas and dust that led to the formation of the Sun. This material gradually grew into a larger and larger body that became a red-hot ball of rock and metal. Later the rocky crust formed, its surface cooling enough to allow the continents to appear. Even later the oceans arrived, as well as the tiny organisms that released oxygen into the atmosphere. Although much of this gas was initially consumed in chemical reactions, over time, it allowed the development of multicellular organisms and an explosion of life that took place at the start of the Paleozoic Era, 542 million years ago. ●

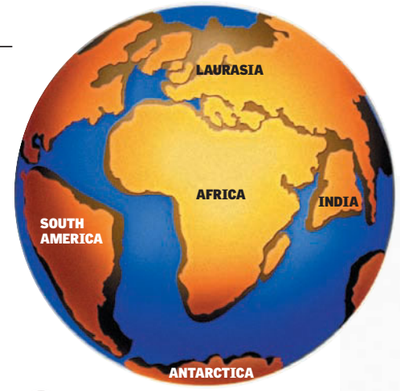
Continental Drift

We live on the continents, which are part of movable plates that drift across the Earth's surface at the rate a fingernail grows. 250 million years ago, India, Africa, Australia, and Antarctica were part of the same continent. When tectonic plates rub against each other, land and oceanic crust earthquakes occur. Where the plates separate, a rift forms. The mid-ocean ridges that run beneath the oceans are formed by lava that emerges from the rifts between tectonic plates. Where plates collide, a process called subduction takes place, in which the rocks of the oceanic floor are drawn under the continent and melt, reemerging in the form of volcanoes.

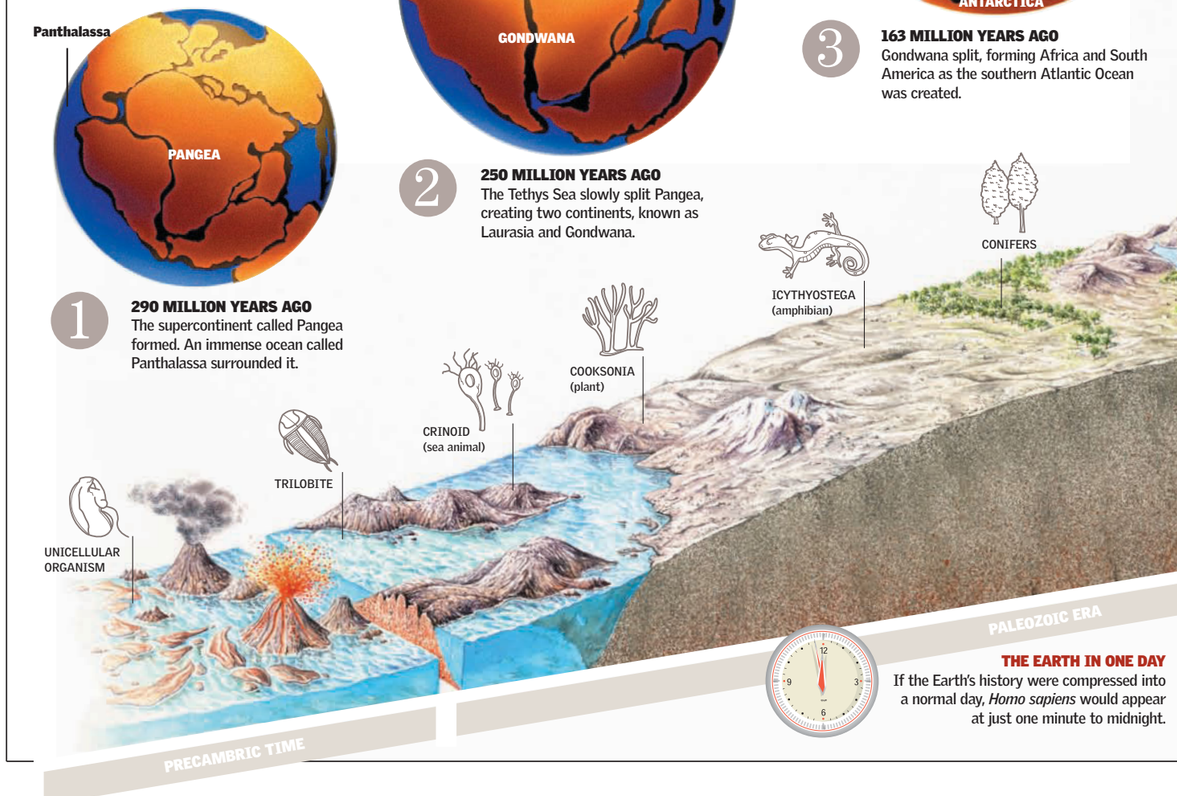
1 290 MILLION YEARS AGO
The supercontinent called Pangea formed. An immense ocean called Panthalassa surrounded it.



2 250 MILLION YEARS AGO
The Tethys Sea slowly split Pangea, creating two continents, known as Laurasia and Gondwana.



3 163 MILLION YEARS AGO
Gondwana split, forming Africa and South America as the southern Atlantic Ocean was created.



Origin of the Earth

The Earth was formed 4.6 billion years ago from a cloud of dust and gas. In the beginning, it was a molten, constantly active, mass. As time passed, the Earth began to cool, and the atmosphere began to clear as rain fell, creating the oceans.



A Ball of fire The Earth was created from small particles that coalesced in the solar nebula.

B The planet cooled The atmosphere was created as the planet cooled and began to emit gases and steam.

C The crust forms Lava poured across the surface of the Earth. As it cooled, it formed the Earth's crust.

D Water appeared on the Earth 3.9 billion years ago. Water-rich Earth is the only planet in the solar system known to have life.



4 60 MILLION YEARS AGO
The northern Atlantic Ocean slowly separated, completing the formation of Europe and North Africa.

Chronology

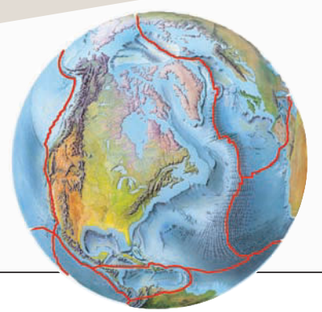
Geology is the study of rocks in the Earth's crust. It divides the Earth's history into different eras, periods, and epochs lasting millions of years. Geology also helps us catalog the processes of evolution—changes in generations as species adapt to their environment and their competitors.

Through the study of fossils—remains of creatures buried in the Earth's various sedimentary layers and consequently at different times in the past–geology helps us trace the timeline of evolutionary history.

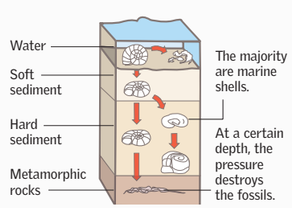
THE EARTH IN ONE DAY
If the Earth's history were compressed into a normal day, *Homo sapiens* would appear at just one minute to midnight.

Tectonic Plates

The surface of the Earth is shaped by tectonic plates. There are eight major plates, some of which even encompass entire continents. The plates' borders are marked by ocean trenches, cliffs, chains of volcanoes, and earthquake zones.



FOSSILS
are remains of living beings preserved in the rocks as a record of the Earth's history.



Movements and Coordinates

Yes, it moves. The Earth rotates on its axis while simultaneously orbiting the Sun. The natural phenomena of night and day, seasons, and years are caused by these movements. To track the passage of time, calendars, clocks, and time zones were invented. Time zones are divided by meridians and assigned a reference hour according to their location. When traveling east, an hour is added with each time zone. An hour is subtracted during west-bound travel.

The Earth's Movements

Night and day, summer and winter, new year and old year result from the Earth's various movements during its orbit of the Sun. The most important motions are the Earth's daily rotation from west to east on its own axis and its revolution around the Sun. (The Earth follows an elliptical orbit that has the Sun at one of the foci of the ellipse, so the distance to the Sun varies slightly over the course of a year.)



ROTATION
1 DAY
The Earth revolves once on its axis in 23 hours and 56 minutes. We see this as day and night.



REVOLUTION
1 YEAR
The Earth's orbit around the Sun lasts 365 days, 5 hours, and 57 minutes.



NUTATION
18.6 YEARS
is a sort of nod made by the Earth, causing the displacement of the geographic poles by nine arc seconds.



PRECESSION
25,800 YEARS
A slow turning of the direction of the Earth's axis (similar to that of a top), caused by the Earth's nonspherical shape and the gravitational forces of the Sun and the Moon

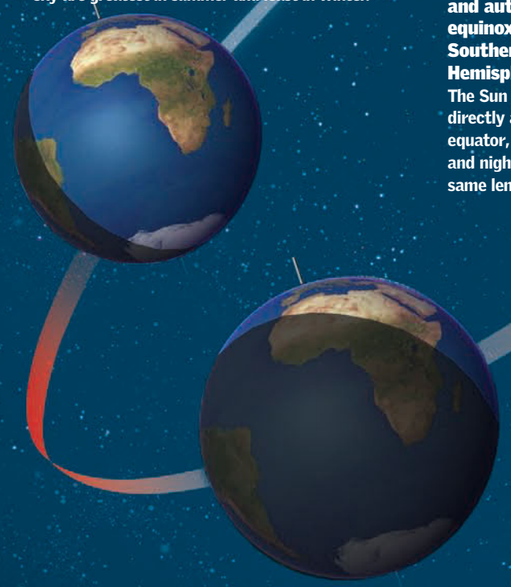
Equinox and Solstice

Every year, around June 21, the Northern Hemisphere reaches its maximum inclination toward the Sun (a phenomenon referred to as the summer solstice in the Northern Hemisphere and the winter solstice in the Southern Hemisphere). The North Pole receives sunlight all day, while the South Pole is covered in darkness. Between one solstice and another the equinoxes appear, which is when the axis of the Earth points toward the Sun and the periods of daylight and darkness are the same all over our planet.



June 20 or 21

Summer solstice in the Northern Hemisphere and winter solstice in the Southern Hemisphere. Solstices exist because of the tilt of the Earth's axis. The length of the day and the height of the Sun in the sky are greatest in summer and least in winter.



March 20 or 21

Spring equinox in the Northern Hemisphere and autumn equinox in the Southern Hemisphere. The Sun passes directly above the equator, and day and night have the same length.



September 21 or 22

Autumn equinox in the Northern Hemisphere and spring equinox in the Southern Hemisphere. The Sun passes directly above the equator, and day and night have the same length.

PERIHELION
The point where the orbiting Earth most closely approaches the Sun (91 million miles [147 million km])

MEASUREMENT OF TIME
Months and days are charted by calendars and clocks, but the measurement of these units of time is neither a cultural nor an arbitrary construct. Instead, it is derived from the natural movements of the Earth.

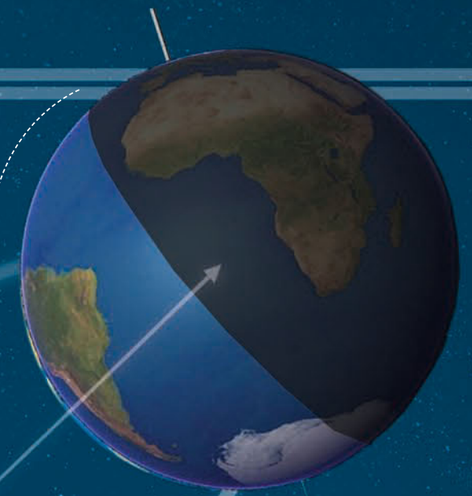
23.5º

TILT OF THE EARTH'S AXIS

93

MILLION MILES

(149 MILLION KM)



THE EARTH'S ORBIT
About 365 days

1 day

THE DAYS
Period of time it takes the Earth to rotate on its axis

About 30 days

THE MONTHS
Each period of time, between 28 and 31 days, into which a year is divided

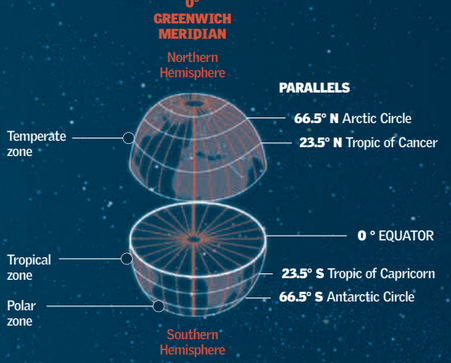
December 21 or 22

Winter solstice in the Northern Hemisphere and summer solstice in the Southern Hemisphere. Solstices exist because of the tilt of the Earth's axis. The length of the day and the height of the Sun in the sky are greatest in summer and least in winter.

APHELION
The point in the Earth's orbit where it is farthest from the Sun (94 million miles [152 million km]). This occurs at the beginning of July.

Geographic Coordinates

Thanks to the grid formed by the lines of latitude and longitude, the position of any object on the Earth's surface can be easily located by using the intersection of the Earth's equator and the Greenwich meridian (longitude 0°) as a reference point. This intersection marks the midpoint between the Earth's poles.

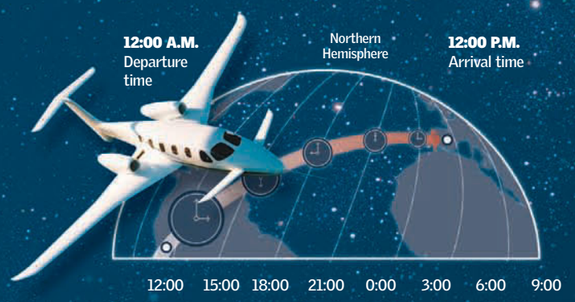


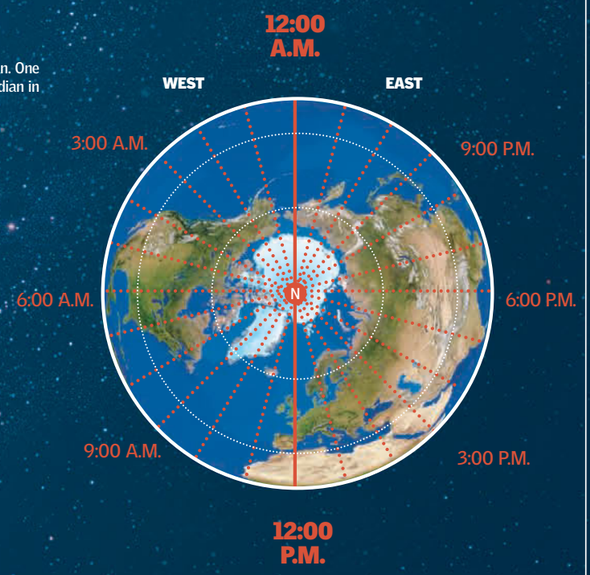
Time Zones

The Earth is divided into 24 areas, or time zones, each one of which corresponds to an hour assigned according to the Coordinated Universal Time (UTC), using the Greenwich, England, meridian as the base meridian. One hour is added when crossing the meridian in an easterly direction, and one hour is subtracted when traveling west.

JET LAG

The human body's biological clock responds to the rhythms of light and dark based on the passage of night and day. Long air flights east or west interrupt and disorient the body's clock, causing a disorder known as jet lag. It can cause fatigue, irritability, nausea, headaches, and difficulty sleeping at night.





The Moon and Tides

Romance and terror, mystery and superstition–all these emotions are responses to the Moon, the Earth's one natural satellite, which always hides one of its two faces. However, whatever symbolic meanings are attributed to the Moon, its gravitational pull has a concrete effect on the Earth—it is a cause of the tides. Depending on the distance of the Moon from the Earth, the gravitational pull exerted by the Moon varies in strength and so can high tides and low tides. To reach full height, tides need large open areas of ocean. For this reason, tides in closed or small bodies of water are much lower.

THE MOON'S MOVEMENTS

As the Moon orbits the Earth, it revolves on its own axis in such a way that it always shows the Earth the same side.

LUNAR MONTH
It takes 29.53 days to complete its phases.

SIDEREAL MONTH
It takes 27.32 days to orbit the Earth.



HIDDEN FACE
Invisible from the Earth, this side of the Moon was a mystery until 1959, when the Russian probe Luna 3 managed to photograph the hidden zone. Because of the greater thickness of the Moon's crust on this side, it has fewer seas.

ORIGIN OF THE MOON
The most widely accepted theory of the Moon's origin suggests that an object the size of Mars collided with the Earth during its formation.

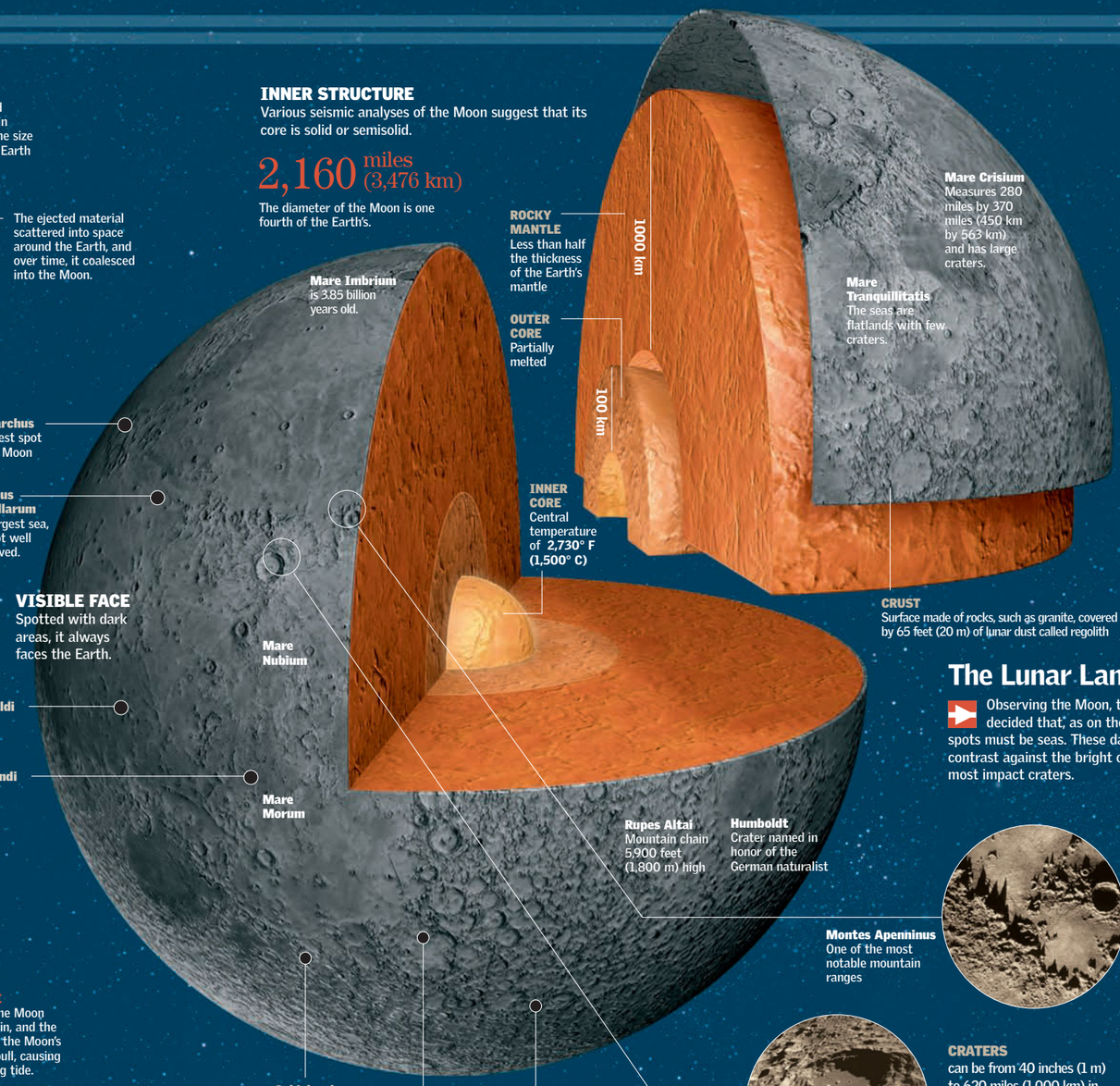


The ejected material scattered into space around the Earth, and over time, it coalesced into the Moon.

INNER STRUCTURE

Various seismic analyses of the Moon suggest that its core is solid or semisolid.

2,160 miles (3,476 km)
The diameter of the Moon is one fourth of the Earth's.



Mare Imbrium
is 3.85 billion years old.

Aristarchus
Brightest spot on the Moon

Oceanus Procellarum
The largest sea, it is not well preserved.

VISIBLE FACE
Spotted with dark areas, it always faces the Earth.

Grimaldi

Gassendi

Mare Nubium

Mare Morum

Rupes Altai
Mountain chain 5,900 feet (1,800 m) high

Humboldt
Crater named in honor of the German naturalist

Montes Apenninus
One of the most notable mountain ranges

Schickard

Tycho
100 million years old

Maguinus

Copernicus
60 miles (93 km) in diameter

CHARACTERISTICS

CONVENTIONAL PLANET SYMBOL

ESSENTIAL DATA	
Average distance from the Earth	226,400 miles (364,400 km)
Revolution around the Earth	27.3 days
Diameter at the equator	2,160 miles (3,476 km)
Orbiting speed	0.6 miles per second (1.02 km/s)
Mass*	0,01
Gravity*	0,17
Density	2 ounces per cubic inch (3.34 g/cu cm)
Temperature	302° F (150° C) (day) -148° F (-100° C) (night)
Volume*	0.02

*Earth = 1

AXIS INCLINATION

5.14°

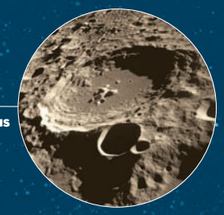
One rotation lasts 27,32 Earth days.



The Lunar Landscape

Observing the Moon, the ancient astronomers decided that, as on the Earth, its plainly visible dark spots must be seas. These dark regions of the Moon contrast against the bright ones, the highlands with the most impact craters.

MOUNTAIN RANGES
When a meteorite strikes the lunar surface, a mountain range forms from the material ejected during the cratering process.



CRATERS
can be from 40 inches (1 m) to 620 miles (1,000 km) in diameter and are formed by meteorites that strike the Moon's surface with incredible force.

SEAS
cover almost 16 percent of the Moon's surface and were formed by flowing lava. Today the Moon has no volcanic activity.

The Tides

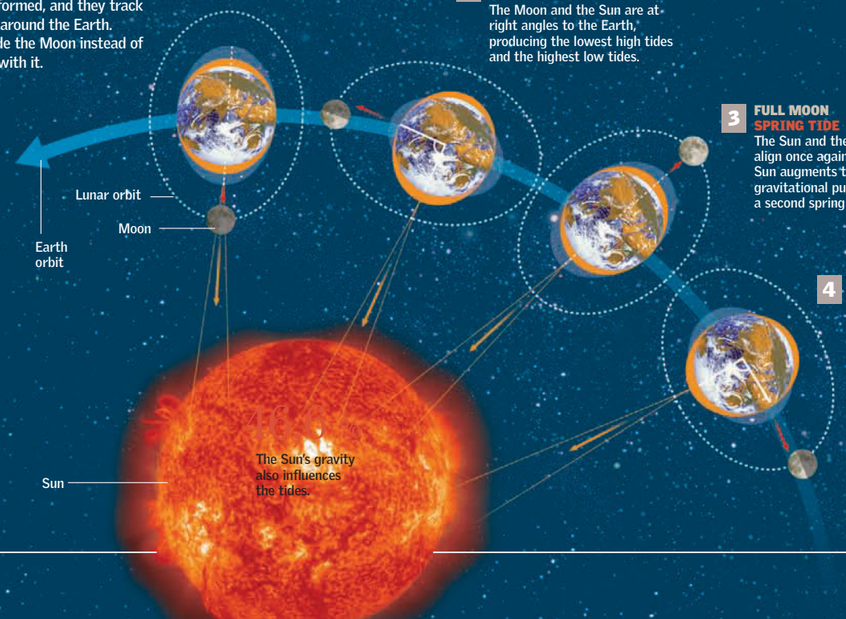
The water on the side of the Earth closest to the Moon feels the Moon's gravitational pull most intensely, and vice versa. Two tides are formed, and they track the Moon in its orbit around the Earth. However, they precede the Moon instead of being directly in line with it.

1 NEW MOON
SPRING TIDE
When the Sun and the Moon are aligned, the highest high tides and lowest low tides are produced.

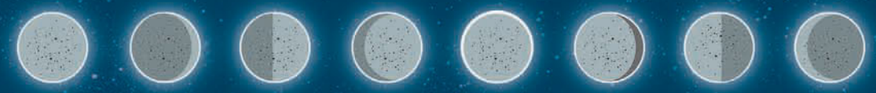
2 FIRST QUARTER
NEAP TIDE
The Moon and the Sun are at right angles to the Earth, producing the lowest high tides and the highest low tides.

3 FULL MOON
SPRING TIDE
The Sun and the Moon align once again, and the Sun augments the Moon's gravitational pull, causing a second spring tide.

4 THIRD QUARTER
NEAP TIDE
The Moon and the Sun again form a right angle, causing a second neap tide.



THE PHASES OF THE MOON



Unique
The Moon is the Earth's only natural satellite.

Eclipses

Typically four times a year, during the full or new moon, the centers of the Moon, the Sun, and the Earth become aligned, causing one of the most marvelous celestial phenomena: an eclipse. At these times, the Moon either passes in front of the Sun or passes through the Earth's shadow. The Sun—even during an eclipse—is not safe to look at directly, since it can cause irreparable damage to the eyes, such as burns on the retina. Special high-quality filters or indirect viewing by projecting the Sun's image on a sheet of paper are some of the ways in which this celestial wonder can be watched. Solar eclipses provide, in addition, a good opportunity for astronomers to conduct scientific research.



TOTAL LUNAR ECLIPSE, SEEN FROM THE EARTH

The orange color comes from sunlight that has been refracted and colored by the Earth's atmosphere.



ANNUAL ECLIPSE OF THE SUN, SEEN FROM THE EARTH

Lunar Eclipse

When the Earth passes directly between the full Moon and the Sun, a lunar eclipse (which could be total, partial, or penumbral) occurs. Without the Earth's atmosphere, during each lunar eclipse, the Moon would become completely invisible (something that never happens). The totally eclipsed Moon's characteristic reddish color is caused by light refracted by the Earth's atmosphere. During a partial eclipse, on the other hand, part of the Moon falls in the shadow cone, while the rest is in the penumbra, the outermost, palest part. It is not dangerous to look at a lunar eclipse directly.

ALIGNMENT



During an eclipse, the Moon is not completely black-but appears reddish.

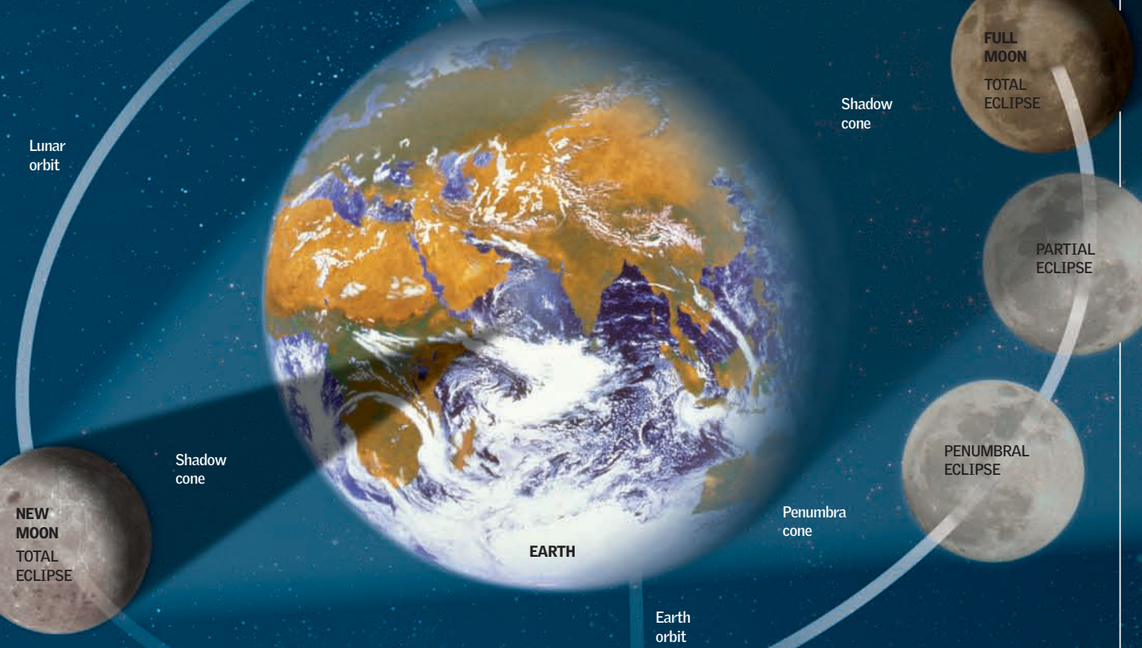
TYPES OF ECLIPSES



TOTAL
The Moon is completely in the shadow cone.

PARTIAL
The Moon is only partially inside the shadow cone.

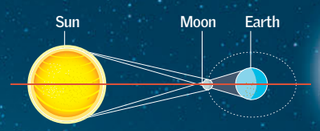
PENUMBRAL
The Moon is in the penumbral cone.



Solar Eclipse

Solar eclipses occur when the Moon passes directly between the Sun and the Earth, casting a shadow along a path on the Earth's surface. The central cone of the shadow is called the umbra, and the area of partial shadow around it is called the penumbra. Viewers in the regions where the umbra falls on the Earth's surface see the Moon's disk completely obscure the Sun—a total solar eclipse. Those watching from the surrounding areas that are located in the penumbra see the Moon's disk cover only part of the Sun—a partial solar eclipse.

ALIGNMENT



During a solar eclipse, astronomers take advantage of the blocked view of the Sun in order to use devices designed to study the Sun's atmosphere.

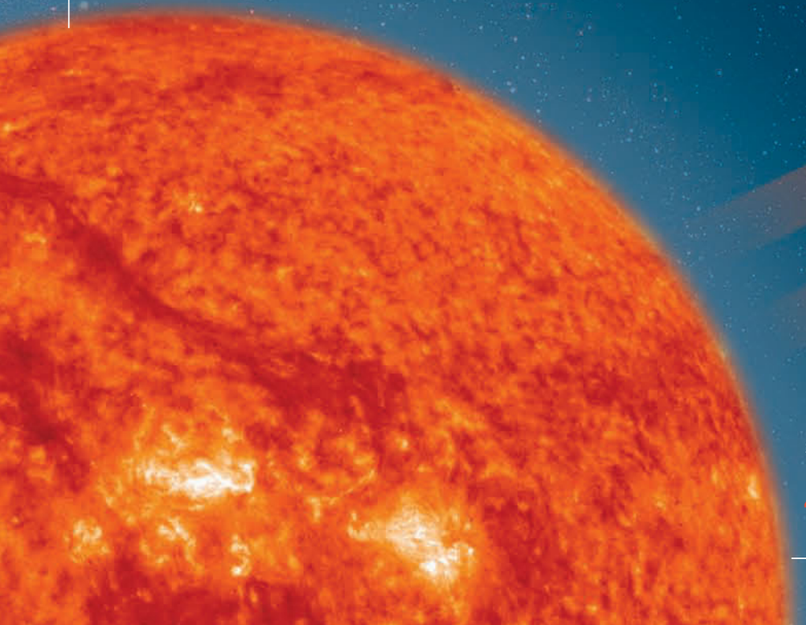
TYPES OF ECLIPSES

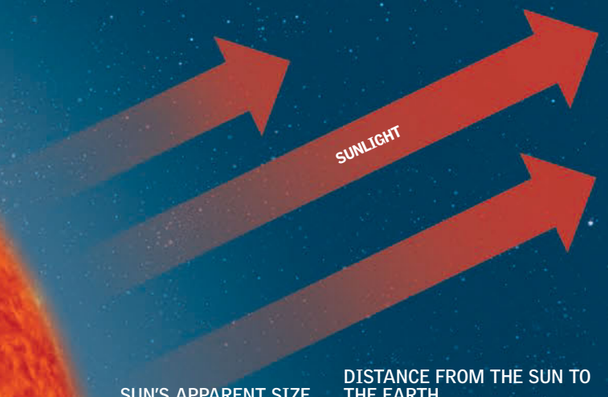


TOTAL
The Moon is between the Sun and the Earth and creates a cone-shaped shadow.

ANNULAR
The Sun appears larger than the Moon, and it remains visible around it.

PARTIAL
The Moon does not cover the Sun completely, so the Sun appears as a crescent.





SUN'S APPARENT SIZE

400 times larger than the Moon

DISTANCE FROM THE SUN TO THE EARTH

400 times greater than the distance from the Earth to the Moon

THE ECLIPSE CYCLE

Eclipses repeat every 223 lunations—18 years and 11 days. These are called Saros periods.

ECLIPSES IN A YEAR			ECLIPSES IN A SAROS		
2	7	4	41	29	70
Minimum	Maximum	Average	of the Sun	of the Moon	Total

OBSERVATION FROM EARTH

A black, polymer filter, with an optical density of 5.0, produces a clear orange image of the Sun.

Prevents retinal burns



SOLAR ECLIPSES

are different for each local observer.

MAXIMUM DURATION
8 minutes

LUNAR ECLIPSES

are the same for all observers.

MAXIMUM DURATION
100 minutes

ECLIPSES IN 2006 AND BEYOND

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
OF THE SUN	3/29 Total	9/22 Total	3/19 Partial	9/11 Partial	2/07 Total	1/26 Total	7/22 Total	1/15 Total	7/11 Total	1/4 Partial	11/25 Partial	5/20 Annular	11/13 Annular	5/10 Annular	11/3 Hybrid	4/29 Annular	10/23 Partial	3/20 Total	9/13 Partial
OF THE MOON	3/14 Partial	9/07 Partial	3/03 Total	8/28 Total	2/21 Total	8/16 Partial	2/9 Partial	7/7 Partial	6/26 Partial	12/21 Total	6/15 Total	12/10 Total	6/4 Partial	12/28 Partial	4/25 Partial	10/18 Partial	4/15 Total	10/08 Total	4/4 Total	9/28 Total

Observing the Universe

STONEHENGE
Located in Wiltshire (England), it was built in several phases over some 600 years—between 2200 and 1600 BC. The placement of most of its large stones has a relationship to the Moon and the Sun.

ASTRONOMICAL THEORIES 82-83
SPRINKLED WITH STARS 84-85
CELESTIAL CARTOGRAPHY 86-87
FROM THE HOME GARDEN 88-89
A FOUR-EYED GIANT 90-91



Astronomy was born out of humankind's need to measure time and seasons, marking the best times to plant. In ancient times, the study of the stars was mixed with superstition and ritual. The megalithic monument Stonehenge, found in southern England, is an example of this. Today, thanks to advances in new technologies, such as the giant telescopes installed in various locations around the planet, we have discovered many new things about the universe. The VLT (Very Large Telescope), astronomy's new monster telescope located in Chile, is part of an attempt to find planets beyond the solar system, because many astronomers suspect that life is not exclusive to the Earth. ●

Astronomical Theories

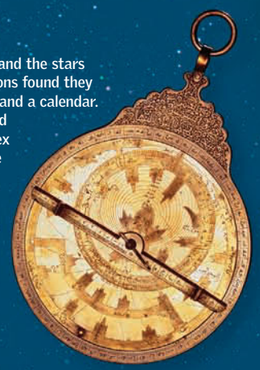
For a long time, it was believed that the Earth was stationary. The Sun, the Moon, and the planets were thought to orbit it. To study the sky and calculate its movements, people began to build instruments, such as the astrolabe, armillary sphere, and telescope. The telescope revolutionized the conception of the universe. Instead of the Earth being at the center of the universe, it was suggested that the Earth and other planets travel around the Sun. The Roman Catholic Church opposed the idea and, for a time, persecuted dissident astronomers and banned their theories.

Geocentric Model

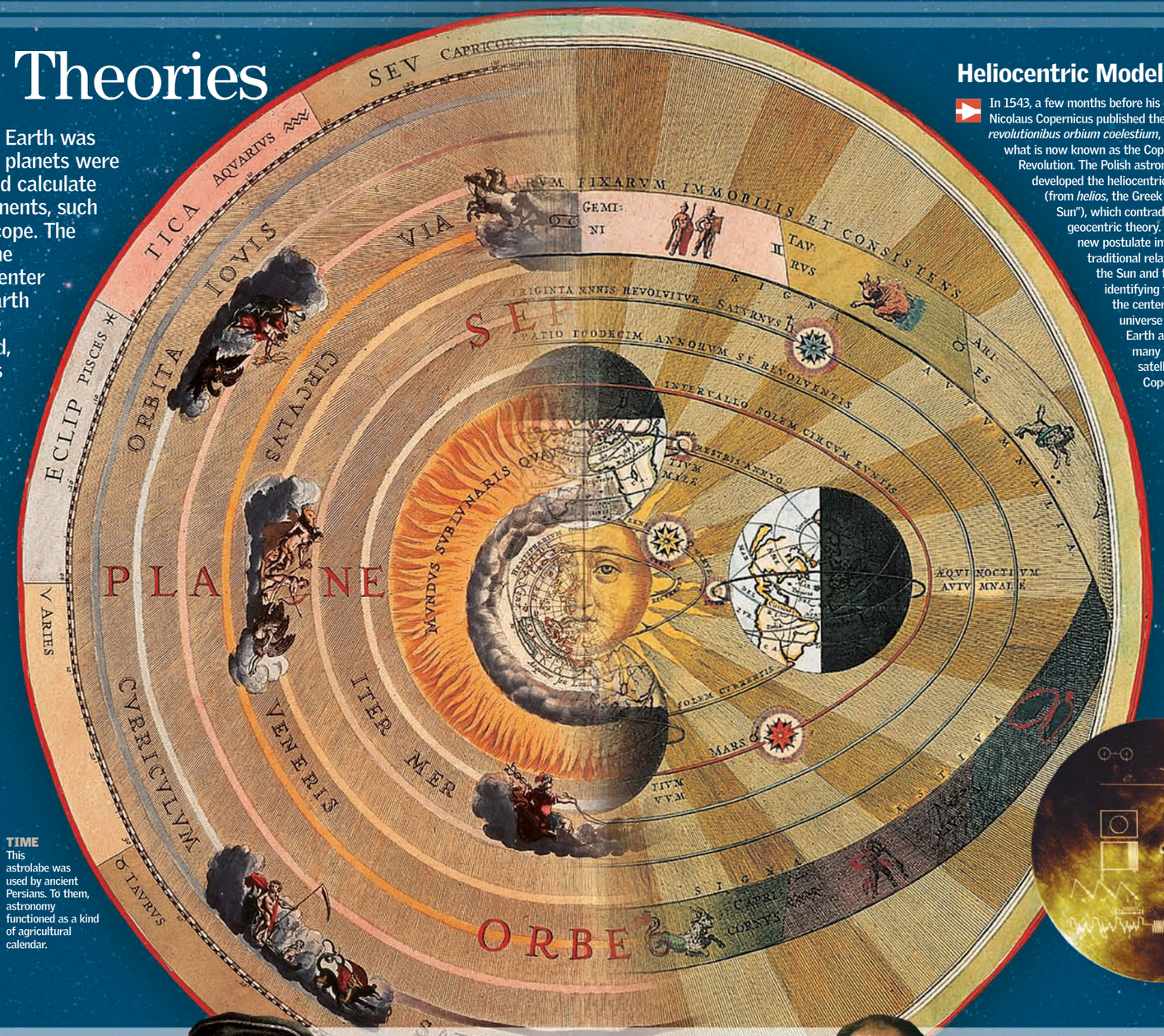
Before telescopes, binoculars, and modern observatories existed, little was known about the Earth. Many believed that the Earth was fixed and that the Sun, the Moon, and the five known planets orbited it in circles. This geocentric model was promoted by the Egyptian astronomer Claudius Ptolemy, who in the 2nd century AD compiled the astronomical ideas of the ancient Greek astronomers (in particular, those of Aristotle, who had proposed the Earth as the center of the universe, with the celestial objects revolving around it). Although other ancient astronomers, such as Aristarchus of Samus, proposed that the Earth was round and rotated around the Sun, Aristotle's ideas were accepted as true for 16 centuries, and at times Aristotle's ideas were defended and preserved by the Roman Catholic Church.

MEASUREMENTS

Noticing that the Sun, the Moon, and the stars moved in cycles, ancient civilizations found they could use the sky as both a clock and a calendar. However, ancient astronomers had difficulties performing the complex calculations needed to predict the positions of stars accurately enough to create a truly precise calendar. A useful tool developed to perform this task was the astrolabe. Its engraved plates reproduce the celestial sphere in two dimensions, allowing the elevations of the celestial bodies to be measured.



TIME
This astrolabe was used by ancient Persians. To them, astronomy functioned as a kind of agricultural calendar.

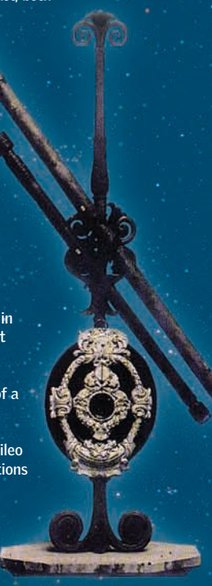


Heliocentric Model

In 1543, a few months before his death, Nicolaus Copernicus published the book *De revolutionibus orbium coelestium*, inaugurating what is now known as the Copernican Revolution. The Polish astronomer developed the heliocentric theory (from *helios*, the Greek word for "the Sun"), which contradicted the geocentric theory. Copernicus's new postulate inverted the traditional relationship of the Sun and the Earth, identifying the Sun as the center of the universe and the Earth as one of many solar satellites. Copernicus argued that spheres moved in endless, circular orbits. Since the universe and all the celestial bodies were thought to be spherical, he argued that their movements must also be circular and uniform (the Ptolemaic system considered the planets' circuits to be irregular). Copernicus reasoned that, since the movements of the planets appeared to be irregular, the Earth must not be the center of the universe. These discoveries were contrary to the views promulgated by the Roman Catholic Church. In fact, both Roman Catholics and Protestants suppressed any writings advocating these beliefs. When Galileo Galilei was brought to trial by the Roman Catholic Church for advocating the Copernican theory, he was forced to renounce his views.

GALILEO'S TELESCOPE

The telescope is thought to have been invented in 1609 by the Dutch optician Hans Lippershey but had no real scientific application until Galileo Galilei improved and adapted it to observe celestial bodies. Galileo's first telescope, made of a leather tube covered by a lens at each end (one lens convex and the other concave), magnified objects up to 30 times. Using the telescope, Galileo discovered that the Sun's surface had imperfections (sunspots), that the Moon had mountains and craters, and that there were four moons, or satellites, that traveled around Jupiter.





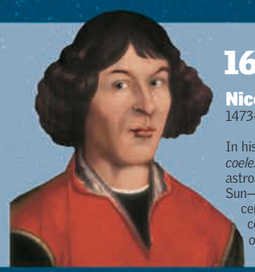
THE TRAVELERS

After many years and great advancements in technology, scientists decided that space observation conducted only from the Earth's surface was insufficient. In 1959, the first space probe was launched, an automatic vehicle that flew to the Moon and photographed its hidden face. The space probes Voyager 1 and 2 explored the planets Jupiter, Saturn, Uranus, and Neptune, a milestone in space exploration. In 2005, Voyager 1 reached the region called Termination Shock, the frontier of the solar system, representing the farthest region explored by humanity. Both probes carried with them golden discs, named Sounds of Earth, containing sounds and images portraying the diversity of life on Earth.

COSMIC CHARACTERS



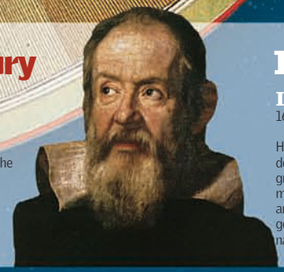
2nd Century
Claudius Ptolemy
100-170
Resurrected and compiled the works of great Greek astronomers into two books. His postulates held undisputed authority for centuries.



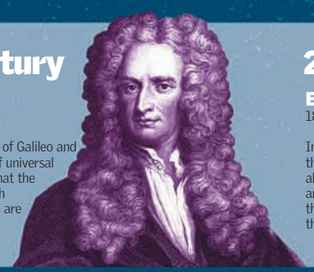
16th Century
Nicolaus Copernicus
1473-1543
In his *De revolutionibus orbium coelestium*, the Polish astronomer postulated that the Sun—not the Earth—was the center of the universe. This concept is the foundation of our own astronomy..



17th Century
Johannes Kepler
1571-1630
The German astronomer, believer in Copernicus's heliocentric model, formulated three famous laws of planetary movement, which encouraged Galileo to publish his research.



17th Century
Galileo Galilei
1564-1642
Built the first telescope, a primitive device with which he discovered sunspots, four of Jupiter's moons, the phases of Venus, and craters on the Moon's surface.



17th Century
Isaac Newton
1642-1727
He built upon the ideas of Galileo and developed the theory of universal gravitation, asserting that the movements of the Earth and the celestial bodies are governed by the same natural laws.



20th Century
Edwin Hubble
1889-1953
In 1929, he began to investigate the expansion of the galaxies, allowing scientists to obtain an idea of the true scale of the universe as well as refine the big bang theory.

Sprinkled with Stars

Constellations are groups of stars thought to represent different animals, mythological characters, and other figures. Constellations were invented by ancient civilizations to serve as reference points in the Earth's sky. There are 88 of these collections of stars. Although each star in a constellation appears related to the others, it is actually very far from them. Not all the constellations are visible at the same time from any one place on the Earth.



ORIGIN

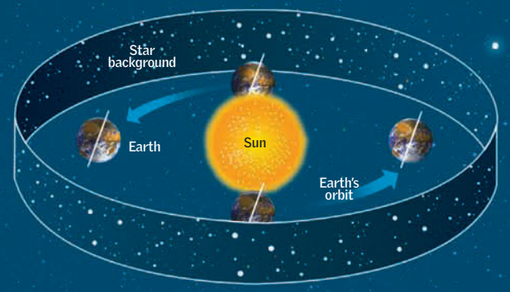
The history of western culture's constellations begins with the first astronomical observations made by ancient Mesopotamian peoples. Because we inherited the constellations from Greco-Roman culture, most of the constellations are named after figures in classical mythology. All of the earliest constellations were named by the 16th century. Constellations discovered more recently bear names drawn from science or technology or from exotic fauna discovered in various places across the globe.

88
constellations



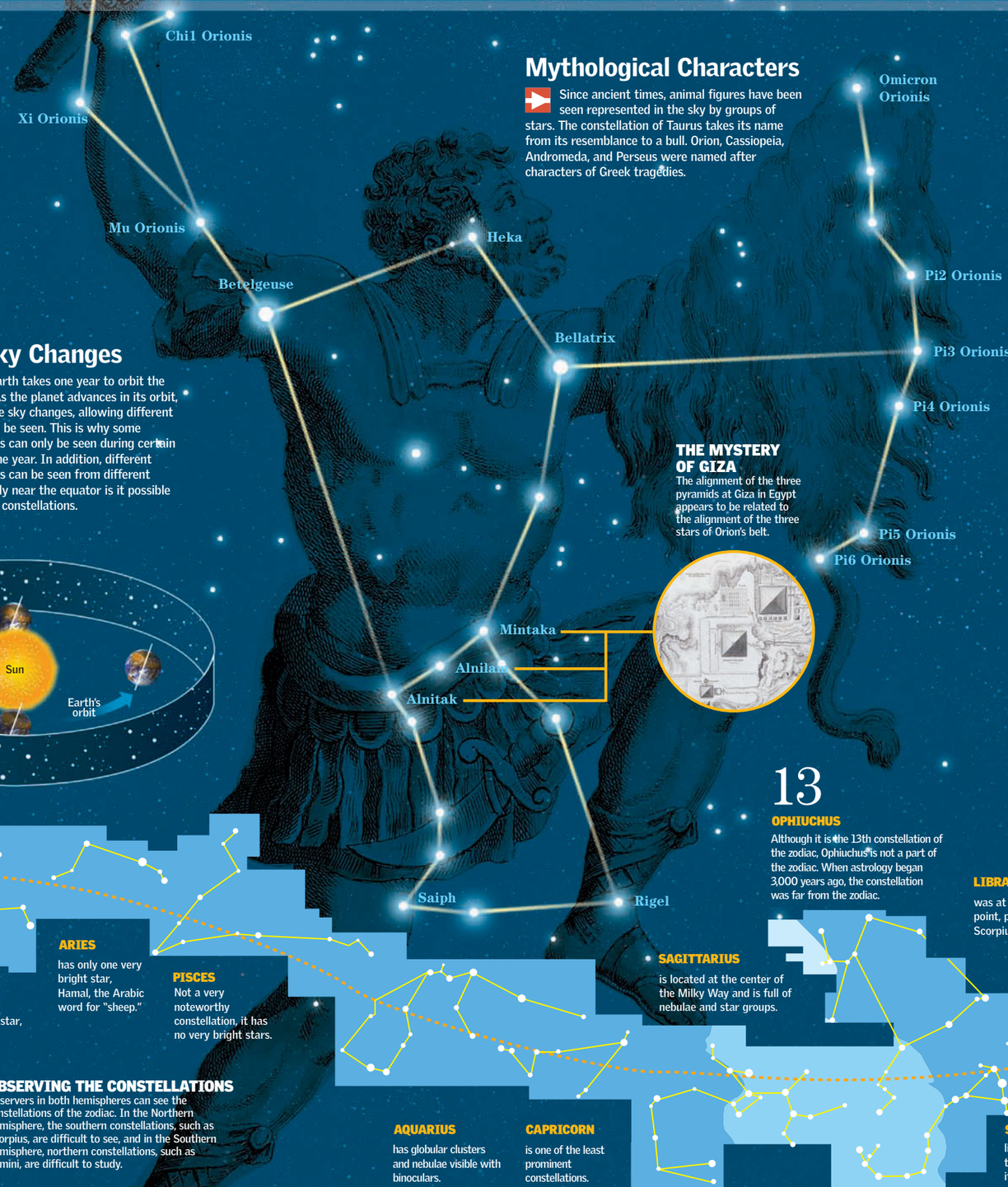
The Sky Changes

The Earth takes one year to orbit the Sun. As the planet advances in its orbit, the nighttime sky changes, allowing different parts of it to be seen. This is why some constellations can only be seen during certain seasons of the year. In addition, different constellations can be seen from different latitudes. Only near the equator is it possible to see all 88 constellations.



Mythological Characters

Since ancient times, animal figures have been seen represented in the sky by groups of stars. The constellation of Taurus takes its name from its resemblance to a bull. Orion, Cassiopeia, Andromeda, and Perseus were named after characters of Greek tragedies.



THE MYSTERY OF GIZA

The alignment of the three pyramids at Giza in Egypt appears to be related to the alignment of the three stars of Orion's belt.

Different Cultures

In antiquity, each culture recognized certain constellations that other civilizations did not. The Chinese see smaller, more detailed patterns in the stars, allowing for more precise positional information. Various cultures also tend to use varied names for the same constellation. Scorpius is recognized by the people of Mesopotamia, Greece, Rome, Mesoamerica, and Oceania—under different names.

SCORPIUS

In Greco-Roman mythology, Orion and Scorpius are closely linked. Orion is the giant, handsome, seductive hunter.



URSA MAJOR

The bear represented by this constellation is unusual because of its long tail. The constellations' shapes rarely agree perfectly with their namesakes.



THE CENTAUR

is a creature from Greek mythology, half man and half horse. The centaur accompanied Orion during his quest to recover his sight.

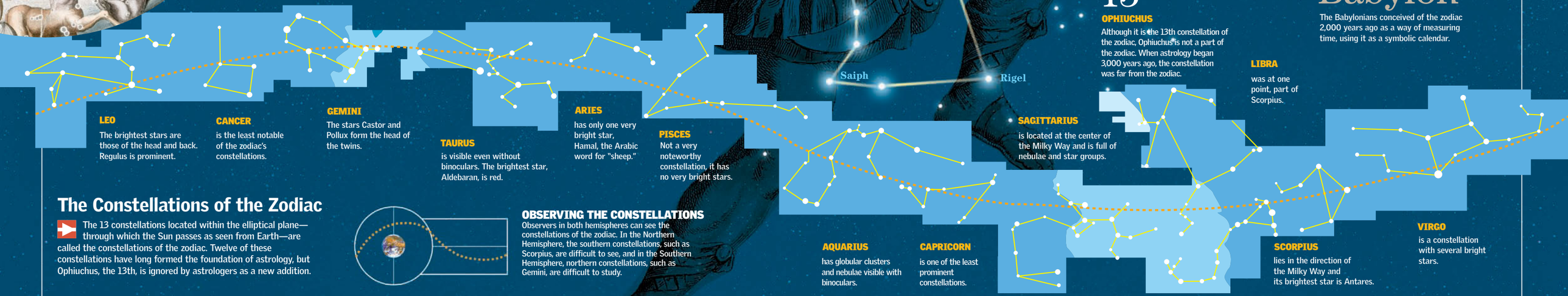


The Constellations of the Zodiac

The 13 constellations located within the elliptical plane—through which the Sun passes as seen from Earth—are called the constellations of the zodiac. Twelve of these constellations have long formed the foundation of astrology, but Ophiuchus, the 13th, is ignored by astrologers as a new addition.

OBSERVING THE CONSTELLATIONS

Observers in both hemispheres can see the constellations of the zodiac. In the Northern Hemisphere, the southern constellations, such as Scorpius, are difficult to see, and in the Southern Hemisphere, northern constellations, such as Gemini, are difficult to study.



LEO

The brightest stars are those of the head and back. Regulus is prominent.

CANCER

is the least notable of the zodiac's constellations.

GEMINI

The stars Castor and Pollux form the head of the twins.

TAURUS

is visible even without binoculars. The brightest star, Aldebaran, is red.

ARIES

has only one very bright star, Hamal, the Arabic word for "sheep."

PISCES

Not a very noteworthy constellation, it has no very bright stars.

AQUARIUS

has globular clusters and nebulae visible with binoculars.

CAPRICORN

is one of the least prominent constellations.

SAGITTARIUS

is located at the center of the Milky Way and is full of nebulae and star groups.

13

OPHIUCHUS

Although it is the 13th constellation of the zodiac, Ophiuchus is not a part of the zodiac. When astrology began 3,000 years ago, the constellation was far from the zodiac.

LIBRA

was at one point, part of Scorpius.

SCORPIUS

lies in the direction of the Milky Way and its brightest star is Antares.

VIRGO

is a constellation with several bright stars.

Babylon

The Babylonians conceived of the zodiac 2,000 years ago as a way of measuring time, using it as a symbolic calendar.

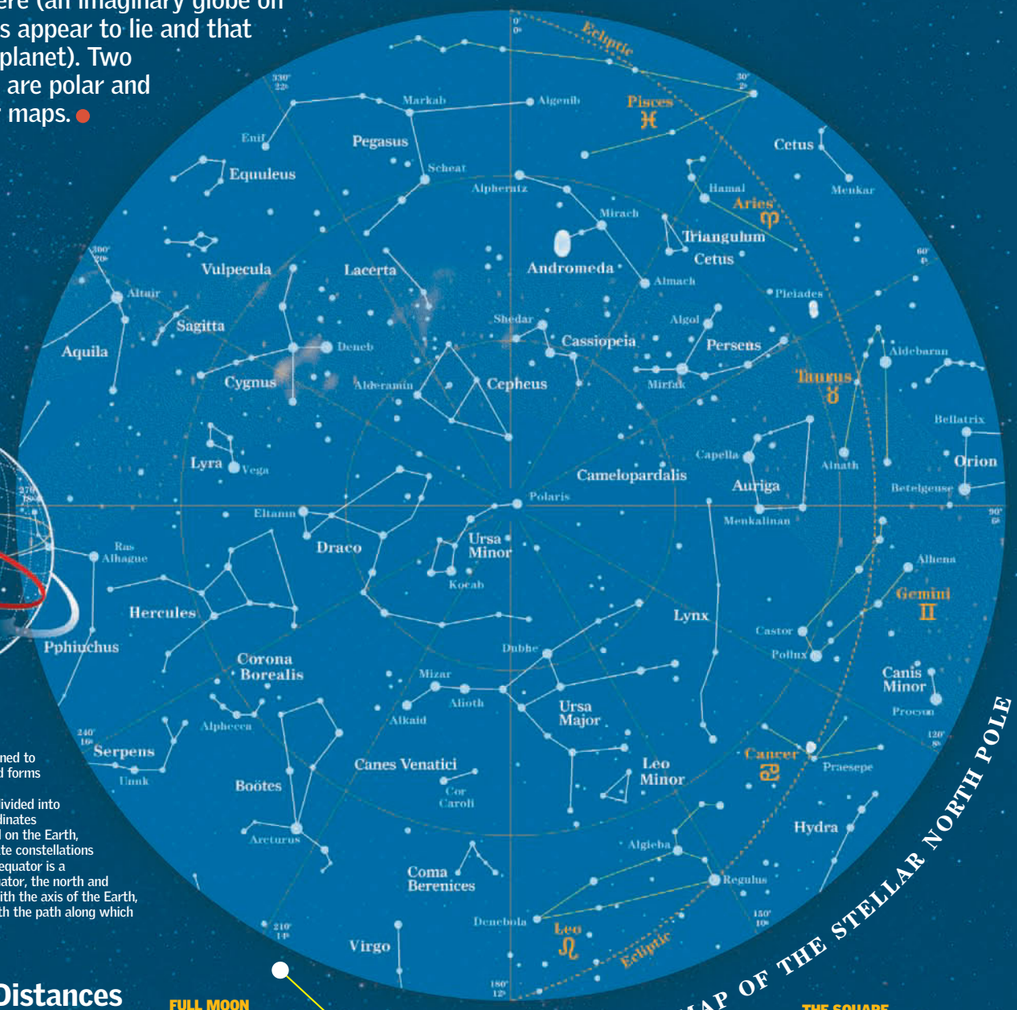
Celestial Cartography

As on the Earth, so in heaven. Just as terrestrial maps help us find locations on the surface of the planet, star charts use a similar coordinate system to indicate various celestial bodies and locations. Planispheres, or star wheels, are based on the idea of a celestial sphere (an imaginary globe on which the stars appear to lie and that surrounds the planet). Two common types are polar and bimonthly star maps.



THE CELESTIAL SPHERE

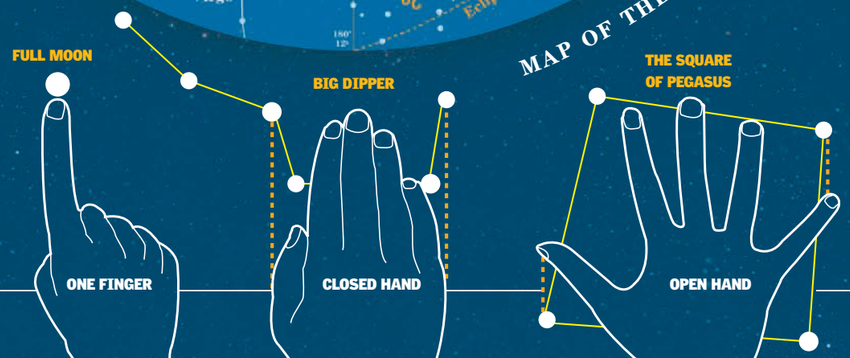
The celestial sphere is imagined to extend around the Earth and forms the basis for modern star cartography. The sphere is divided into a network of lines and coordinates corresponding to those used on the Earth, allowing an observer to locate constellations on the sphere. The celestial equator is a projection of the Earth's equator, the north and south celestial poles align with the axis of the Earth, and the elliptic coincides with the path along which the Sun appears to move.



MAP OF THE STELLAR NORTH POLE

Measuring Distances

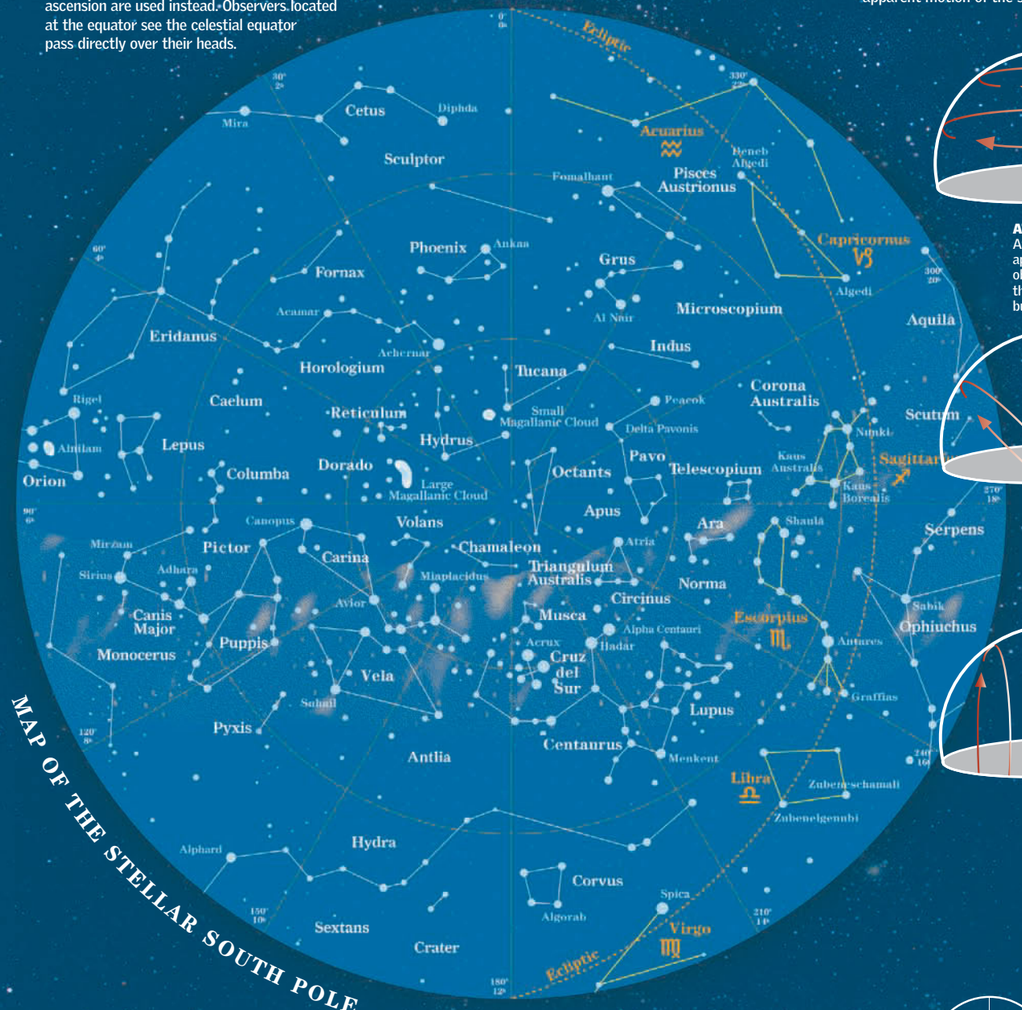
Once a star or constellation has been located in the sky, hands and arms can serve as simple measuring tools. A single extended finger, shown in the first illustration, can form a one-degree angle from the observer's line of sight and is useful for measuring short distances between stars. The closed palm of the hand forms a 10° angle, and the open hand measures 20°.



HOW TO READ A MAP OF THE SKY

Astronomers divide the celestial sphere into sections, allowing them to study the sky in detailed, systematic ways. These maps can show a particular region observed from a certain place at a certain time, or they can merely concentrate on a specific location. To specify the position of a point on the surface of the Earth, the geographic coordinates called latitude and longitude are used. With the celestial sphere, declination and right ascension are used instead. Observers located at the equator see the celestial equator pass directly over their heads.

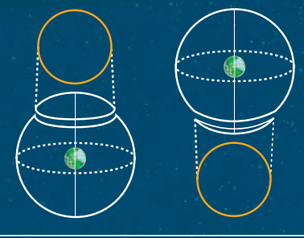




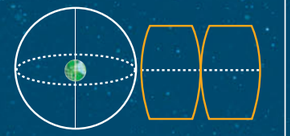
MAP OF THE STELLAR SOUTH POLE

Different Types of Charts

Throughout the year, different constellations are visible because the Earth moves along its orbit. As the Earth's place in its orbit changes, the night side of the planet faces different regions of space. To compensate for this shifting perspective, there are various kinds of planispheres: north and south polar maps and bimonthly equatorial maps.



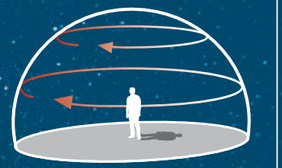
POLAR
The celestial sphere is generally divided into two polar maps: north and south.



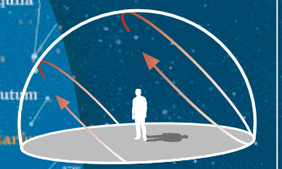
EQUATORIAL
Six bimonthly maps depict all 88 constellations, which can be seen over the course of the year.

Stellar Movements

The visible regions of the celestial sphere and the ways in which stars move through the sky depend upon the observer's latitude. As an observer moves north or south, the visible portion of the celestial sphere will change. The elevation of the north or south celestial pole above the horizon determines the apparent motion of the stars in the sky.



AT THE POLES
At the North Pole, the stars appear to rotate around the observer's head. The effect is the same at the South Pole but in the opposite direction.



IN MIDDLE LATITUDES
some stars can be seen all year long, but others are only visible during certain months.



AT THE EQUATOR
stars can be seen throughout the year, rising in the east and setting in the west.

From the Home Garden

Stargazing is not difficult. After learning to locate celestial objects, many people find the hobby very gratifying. With the aid of a star map, you can recognize galaxies, nebulae, star clusters, planets, and other objects. Some of these treasures of the universe are visible with the unaided eye, but others require binoculars or even more sophisticated telescopes. Familiarity with the night sky is useful in many ways.

Basics

Before stepping out to observe the night sky, make sure you have everything you need. If you collect all your supplies beforehand, you will avoid having to expose your eyes to bright light once they have adjusted to darkness. In addition to binoculars, star maps, and a notebook, you should bring warm clothes, a comfortable seat, and something to drink.



Planisphere



Compass



Flashlight with red cellophane

How to Look at the Moon

Under various degrees of magnification, the Moon and stars take on different appearances. In some cases, you can make observations of the Moon with the unaided eye as well as with binoculars or a telescope.



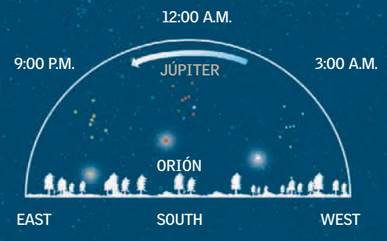
Normal view

View with binoculars

View with telescope

THE MOTION OF CONSTELLATIONS

The Earth's rotation makes the planets and stars appear to move through the nighttime sky in a general east-to-west direction. When the southern constellation Orion, visible from November through March, is viewed from the Northern Hemisphere, it appears to move from left to right.





Observable Objects

The sky is a very busy place. Not only are there stars and planets, but there are also satellites, airplanes, comets, and meteorites. Fortunately all become recognizable by their appearance as well as their movement.

VENUS
can generally be seen above the horizon at dusk or dawn.

SHOOTING STARS
Very short flashes of light lasting only a fraction of a second

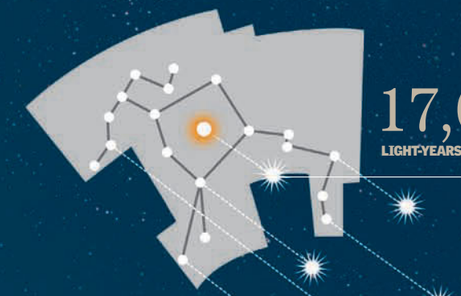
MOON
The illuminated face of the Moon can always be seen at some time during the night, at least partially, except around the new moon.

SATELLITES
The bigger ones are brighter than some stars. Some take a while to cross the sky.

COMETS
visible to the naked eye appear every one to two years and are visible for weeks or even months.

Flat Perspective

A constellation is a group of stars that, when viewed from a certain angle, seem to assume a specific shape. However, these stars that seem closely joined together are, in fact, separated by great distances.



17,000
LIGHT-YEARS FROM EARTH
OMEGA

4.2
LIGHT-YEARS FROM EARTH
CENTAURI



Measurement methods

A planisphere is a circular star chart that is used to locate celestial bodies in the celestial sphere. To identify a particular object, your own arms and body can be used to measure its direction and altitude in relation to the horizon.

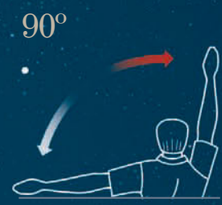
MEASUREMENT OF ELEVATION

Starting at the horizon, extend one of your arms until it is perpendicular to the other.



To measure a 45° angle, move your arm halfway up from the horizon.

MEASURING DIRECTION



The planisphere indicates the principal direction of a star. Place the arms at 90°, using north or south as the base.



A star to the southwest could be located with your arms at 45°. Combine the directional angles with your hand measurements for elevation.

A Four-Eyed Giant

The Paranal Observatory, one of the most advanced in the world, is located in the region of Antofagasta, Chile. It uses four identical telescopes to obtain enough light-gathering power that it could see the flame of a candle on the surface of the Moon. This sophisticated collection of digital cameras, reflecting mirrors, and other instruments is mounted in the interior of four metallic structures weighing hundreds of tons. The Very Large Telescope (VLT) is operated by a scientific consortium drawn from eight European countries. One of their stated objectives is to discover new worlds orbiting other stars.

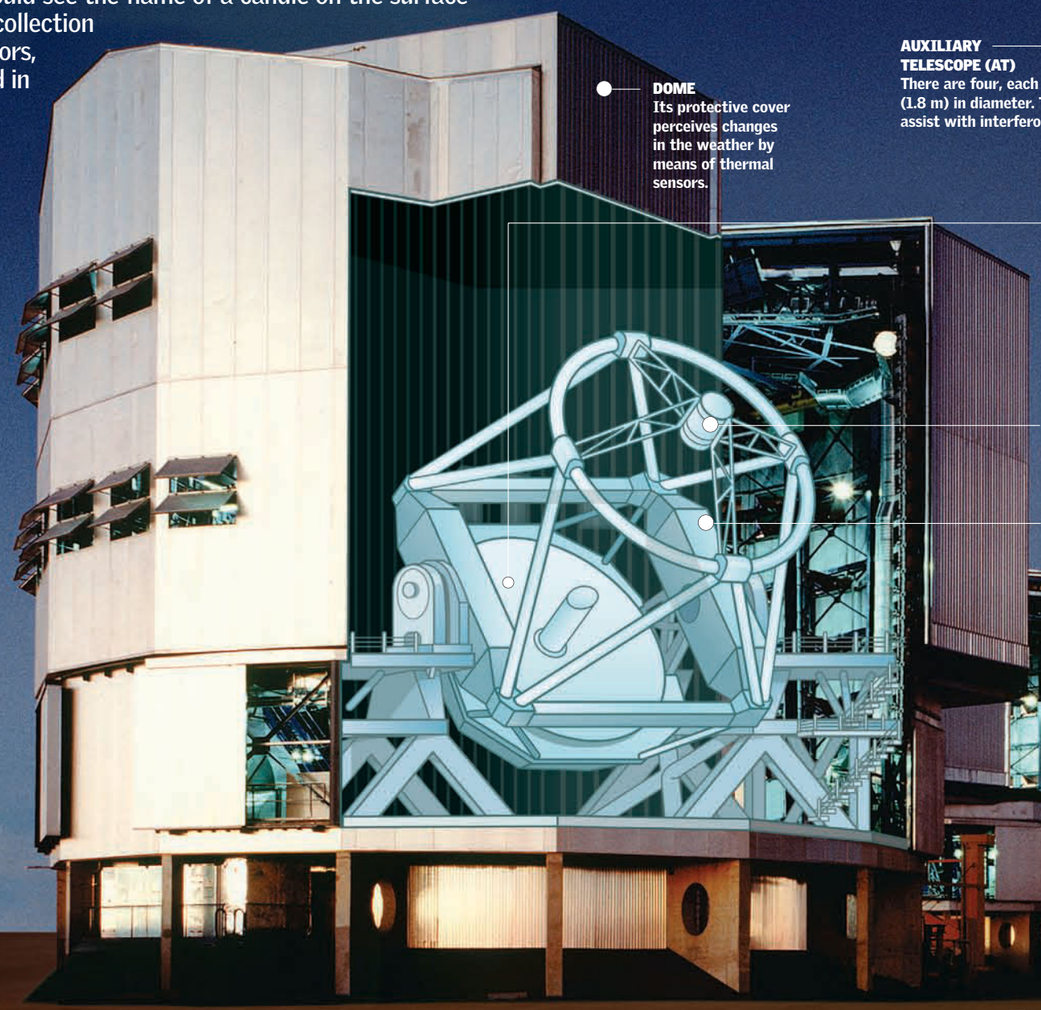
CLIMATIC CONDITIONS
Cerro Paranal is located in the driest part of the Atacama desert, where the conditions for astronomical observation are extraordinarily favorable. It is an 8,645-foot- (2,635-m-) tall mountain that has about 350 cloudless nights a year.

10.9 (750)
LB PER SQ IN (MBAR)
Air pressure

0.06 (0.96)
LB PER CU FT (KG/M3)
Air density

18–77° (-8–25°)
FAHRENHEIT (CELSIUS)
Average temperature

5 to 20
PERCENT
Humidity

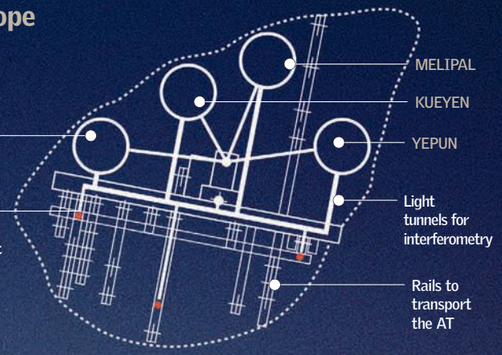


DOME
Its protective cover perceives changes in the weather by means of thermal sensors.

3.9-foot- (1.2-m-) diameter secondary mirror

Mechanical structure

Telescope units

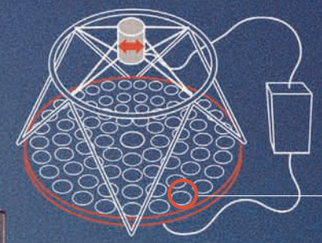


AUXILIARY TELESCOPE (AT)
There are four, each 5.9 feet (1.8 m) in diameter. They assist with interferometry.

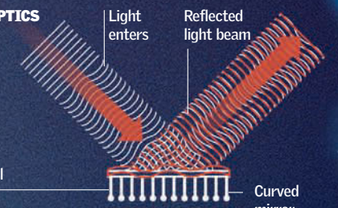
The Telescope

The main feature of the VLT is its revolutionary optical design. By using adaptive and active optics, it achieves resolution similar to that possible from space.

ACTIVE OPTICS



ADAPTIVE OPTICS



Cerro Paranal Observatory

The ESO's Very Large Telescope is located to the north of the Atacama desert, on Cerro Paranal. Completed in 2006, it has four 26.9-foot- (8.2-m-) wide reflector telescopes capable of observing objects four billion times fainter than those visible to the unaided eye. It also has three 5.9-foot- (1.8-m-) wide movable auxiliary telescopes that are used in conjunction with the larger ones to simulate the light-gathering power of a 52-foot- (16-m-) wide mirror (with the resolution of a 656-foot- [200-m-] long telescope). This is enough to see an astronaut on the Moon. The above technique is called interferometry.

215,000 SQ FT
(20,000 SQ M) TOTAL SURFACE

7,759 FEET
(2,365 M) ABOVE SEA LEVEL

ADAPTIVE OPTICS
To prevent the primary mirror from deforming because of gravitational effects, the VLT has an adaptive optics system that maintains the mirror in optimal shape, with 150 supporting pistons that continually adjust the shape of the mirror.

VLT
ACRONYM FOR
Very Large Telescope



ARMILLARY SPHERE
Invented by Eratosthenes in the year 225 BC, it was used as a teaching aid and became especially popular in the Middle Ages thanks to Danish astronomer Tycho Brahe.



2500–2000 BC
STONEHENGE
Located in Wiltshire, England, it is an observatory temple dating from the Neolithic Period.



435–455 BC
CARACOL
It is located in the ruins of the Mayan city of Chichén Itzá. The structure was used for venerating the Sun, the Moon, and Venus.



1726
JAIPUR
Located in India, it was built by the maharajah Sawai Jai Singh and has a large sextant and a meridional chamber.



1888
LICK
Located on 4,265-foot- (1,300-m-) high Mount Hamilton. It was the first observatory to be located on a mountain.



1897
YERKES
Located in Wisconsin, it contains the largest refracting telescope in the world.



1979
MAUNA KEA
An international complex located in Hawaii, with large British, French-American, and American observatories

Glossary

Annihilation

Total destruction of matter in a burst of energy, as when it encounters antimatter.

Antigravity

Hypothesized force, equal to gravity and diametrically opposed to it.

Antimatter

Matter formed from subatomic particles with shared properties. Its electrical charge is opposite that of normal matter.

Aperture

Diameter of the main mirror of a telescope or eyepiece. The larger the aperture, the more light the device receives.

Aphelion

The point in a celestial body's orbit farthest from the Sun. The Earth reaches aphelion on or about July 4, when it is 95,000,000 miles (152, 600,000 km) from the Sun.

Apogee

The farthest position from the Earth reached by the Moon or any of the artificial satellites that orbit the planet.

Asteroids

Minor bodies of the solar system, formed by rock, metal, or a mixture of both. Most asteroids orbit the Sun between the orbits of Mars and Jupiter. Their size ranges from dozens of feet to hundreds of miles.

Astrolabe

Ancient astronomical instrument for measuring both the positions and the movements of celestial objects.

Astronomy

Science that studies the universe. It is concerned with the physical characteristics, movements, distances, formation, and interactions of galaxies, stars, planets, moons, comets, asteroids, and other celestial bodies.

Atmosphere

Layer of gas retained around a planet by its gravity. It is also the outer layer of matter in a star, where the energy produced in the star's interior is emitted in the form of radiation.

Atom

The smallest part of an element that partakes of all the element's properties. It is generally composed of three subatomic particles: the neutron, the proton, and the electron.

Aurora

Luminous phenomenon, with red and green layers, visible in the skies of the polar regions. The auroras are caused by the collision of solar particles with the Earth's atmosphere.

Austral

Related to the Southern Hemisphere.

Big Bang

Cosmological theory asserting that the universe began to exist as a result of a great explosion that occurred some 14 billion years ago.

Big Crunch

Cosmological theory asserting that the universe would undergo a final, complete collapse if it were to begin to contract.

Black Hole

Celestial body so dense that not even light can escape its gravity.

Black Hole, Stellar-Mass

Black hole produced by the explosion of a massive star as a supernova. Its mass is typically about 10 times that of the Sun.

Black Hole, Supermassive

Black hole located at the center of a galaxy and formed by material that falls into the central region of the galaxy. Its mass can be a billion times that of the Sun.

Carbon

One of the most common elements in the universe, produced by stars. All known life is carbon-based.

Chromosphere

The lowest layer of the Sun's atmosphere. It emits a pinkish-red light that can be seen only when the brighter photosphere is obscured during a total eclipse.

Circumpolar Star

Any star always visible to an observer on the Earth as it rotates about the celestial pole.

Comet

Object made of ice and rock dust. When a comet approaches the Sun, the growing heat causes the ice to evaporate, forming a gaseous head and a tail of dust and gas pointing away from the Sun.

Constellation

Group of stars in the sky. Constellations tend to bear the names of mythological characters or creatures. To astronomers, the constellations demarcate regions of the sky.

Core

In a planet, a solid, high-pressure central mass; in a star, the central region undergoing nuclear fusion; in a galaxy, the innermost light-years.

Corona

Upper atmosphere of the Sun. It is visible as a pearly halo during a total solar eclipse.

Cosmos

Another name for the universe.

Crater

Circular depression formed by the impact of a meteorite on the surface of a natural satellite or a planet.

Crust

Rocky layer of the surface of a planet or natural satellite.

Curvature of Light

Distortion of light rays when passing through regions with strong gravitation.

Decay

Process by which radioactive elements and unstable particles become stable substances. Also the way in which black holes eventually disappear.

Density

Degree of solidity of a body (its mass divided by its volume).

Eclipse

Visual concealment of one celestial body by another. A lunar eclipse occurs when the Moon passes into the Earth's shadow, and a solar eclipse takes place when the Earth passes into the Moon's shadow.

Ecliptic

Imaginary line around the sky along which the Sun moves during the year. The orbits of the Earth and the other planets generally lie along the ecliptic.

Electrical Charge

Property of particles causing them to either attract or repel each other because of electrical forces. Electrical charges are either positive or negative.

Electromagnetic Radiation

Radiation composed of magnetic and electric fields moving at the speed of light. It encompasses radio waves (long wavelengths), visible light, and gamma rays (very short wavelengths).

Element

A basic substance of nature that cannot be diminished without losing its chemical properties. Each element (such as hydrogen, helium, carbon, oxygen) has its own characteristics.

Elliptical Orbit

Orbit shaped like a flattened circle. All orbits are elliptical. A circle is a special form of an ellipse.

Energy

The capacity to do work.

Event Horizon

The edge of a black hole.

Extraterrestrial

Foreign to the Earth.

Force

Something that changes the motion or shape of a body.

Galactic Filament

Structure formed by superclusters of galaxies stretching out through great portions of space. Filaments are the largest structures in the universe and are separated by great voids.

Galaxy

Collection of billions of stars, nebulae, dust, and interstellar gas held together by gravity.

Galaxy Cluster

Group of galaxies linked together by gravity.

Gamma Rays

Form of electromagnetic radiation with greatest energy and shortest wavelength. It is generated by only the most powerful phenomena in the universe, such as supernovae or the fusion of neutron stars.

General Relativity

Theory formulated by Albert Einstein in 1915. In part, it holds that gravity is a natural consequence of the curvature of space-time caused by the presence of a massive body. In general relativity, the phenomena of classical mechanics (such as the orbit of a planet or the fall of an object) are caused by gravity and are represented as inertial movements within space-time.

Gravitational Wave

Waves in space that travel at the speed of light and are produced by the movements of very massive bodies.

Gravity

Attractive force between bodies, such as between the Earth and the Moon.

Greenhouse Effect

Temperature increase caused by gases (such as carbon dioxide and methane) that prevent the surface heat of a planet from escaping into space.

Heliosphere

The region of space around the Sun in which its effects are evident. It extends some 100 astronomical units around the Sun.

Helium

The second most common and second lightest element in the universe. It is a product of the big bang and of nuclear fusion of stars.

Hubble Constant

Number that measures the rate of expansion of the universe. It is expressed in kilometers per second per millions of parsecs. It is currently estimated at 70 km/s/Mpc.

Hydrogen

The most common and lightest element in the universe; the main component of stars and galaxies.

Hypernova

Destruction of a massive star, which emits a wave of gamma rays extending great distances across the universe.

Implosion

Collapse of a body upon itself in response to great external pressure.

Infrared Radiation

Heat radiation, with a wavelength between visible light and radio waves.

Intergalactic Space

Space between galaxies.

Interstellar Space

Space between the stars.

Ionosphere

Region of the Earth's atmosphere that is electrically charged and is located between 30 and 370 miles (50 and 600 km) from the Earth's surface.

Kuiper Belt

Region of the solar system that is home to millions of frozen objects, such as comets. It stretches from the orbit of Neptune to the inner limit of the Oort cloud.

Light

Electromagnetic radiation with a wavelength visible to the human eye.

Light Pollution

Brightness of the sky originating in street illumination and other artificial lighting, which impedes the observation of dim celestial objects.

Light-Year

Standard astronomical measurement unit equivalent to the distance traveled by light, or any form of electromagnetic radiation, in one year. Equivalent to 6,000,000,000,000 miles (10,000,000,000,000 km).

Lunar Mare

The large, dark regions of the surface of the Moon. They were originally thought to be seas, but they are actually great depressions covered by lava.

Magnetic Field

The area near a magnetic body, electric current, or changing electric field. Planets, stars, and galaxies have magnetic fields that extend into space.

Magnetosphere

Sphere that surrounds a planet with a magnetic field strong enough to protect the planet from the solar wind.

Mantle

Layer that lies between the crust and the core of a planet.

Mass

Measure of the amount of matter in an object.

Matter

The substance of a physical object, it occupies a portion of space.

Meteorite

Rocky or metallic object that strikes the surface of a planet or satellite, where it can form a crater.

Milky Way

The galaxy to which the Sun and the solar system belong. It is visible as a pale band of light that crosses our night sky.

Molecule

Smallest unit of a pure substance that has the composition and chemical properties of the substance. It is formed by one or more atoms.

Moon

The Earth's natural satellite is called the Moon. The natural satellites of other planets are commonly known as moons and have their own proper names.

Nebulae

Clouds of gas and dust in space. Nebulae can be seen when they reflect starlight or when they obstruct light from sources behind them.

Neutron

Electrically neutral subatomic particle. It makes up part of an atom's nucleus (with the exception of ordinary hydrogen).

Neutron Star

Collapsed star consisting mostly of neutrons.

Nova

Star that increases greatly in brightness for several days or weeks and then slowly fades. Most novae probably occur in binary-star systems in which a white dwarf draws in matter from its companion star.

Nuclear Fusion

Nuclear reaction in which relatively light elements (such as hydrogen) form heavier elements (such as helium). Nuclear fusion is the source of energy that makes stars shine.

Oxygen

Chemical element vital to life and to the expansion of the universe. Oxygen makes up 21 percent of the Earth's atmosphere.

Particle

In particle physics, a tiny, individual component of matter with characteristic mass, electrical charge, and other properties.

Perihelion

The point in a celestial body's orbit closest to the Sun. The Earth reaches perihelion on or about January 4, when it is 92,000,000 miles (147,500,000 km) from the Sun.

Photon

Elemental particle responsible for electromagnetic radiation. Photons are the most common particles in the universe.

Planet

Roughly spherical object made of rocks or gas orbiting a star. A planet cannot generate its own light but reflects the light of its parent star.

Polestar

Polaris, a star that lies near the celestial north pole. Polaris is commonly called the North Star. Over thousands of years, other stars will become the polestar.

Proton

Subatomic particle with positive electrical charge. It forms part of the nucleus of an atom.

Radio Galaxy

Active galaxy emitting energy as both radio waves and light. Most of the radio emission originates at the core of the galaxy.

Solar Flare

Immense explosion produced on the surface of the Sun by the collision of two loops of the solar magnetic field.

Solar Mass

Standard unit of mass against which other objects in the universe can be compared. The Sun has 333,000 times as much mass as the Earth.

Space

The medium through which all celestial bodies move.

Space-Time

Four-dimensional conception of the universe in which length, width, and height constitute three dimensions and time acts as the fourth.

Spectral Analysis

Study of spectral lines that provide information about the composition of stars or galaxies and their redshifts.

Spectrum

The result of dispersing the electromagnetic radiation of an object so that the wavelengths of which it is composed can be seen. Dark lines that originate from elements that are present and punctuate the spectrum at specific wavelengths reveal the composition of the object.

Speed of Light

The distance traveled by light in a vacuum in one second (approximately 186,000 miles, or 300,000 km). No object can move faster than the speed of light.

Star

Enormous sphere of gas (generally hydrogen) that radiates light and heat. The Sun is a star.

Star Cluster

Group of stars linked together by gravity. Open clusters are scattered groups of several hundred stars. Globular clusters are dense spheres of several million old stars.

Sunspots

Dark, relatively cool spots on the surface of the Sun. They tend to be located on either side of the solar equator and are created by the solar magnetic field.

Supernova

Explosion of a massive star at the end of its life.

Tide

The effect of the gravitational pull of one astronomical object upon the surface of another. Ocean tides on Earth are an example.

Unstable

Tendency to change from one state into another less energetic one. Radioactive elements decay into more stable elements.

Vacuum

Space occupied by little or no matter.

Van Allen Belt

Radiation zone surrounding the Earth, where the Earth's magnetic field traps solar particles.

Wavelength

Distance between the peaks of any wave of electromagnetic radiation. Radiation with a short wavelength (such as X-rays) has more energy than radiation with a longer wavelength (such as radio waves).

Zenith

Point in the sky 90° above the horizon (that is, immediately above an observer).

Zodiac

Twelve constellations through which the Sun, the Moon, and the planets appear to move.

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