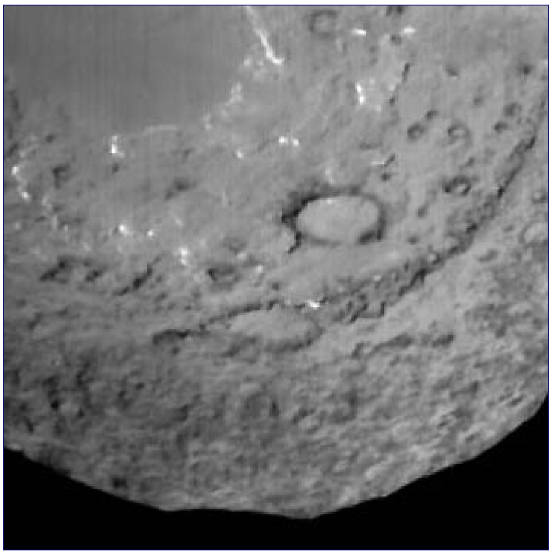
Deep Impact and Stardust: Are Comets Made of the Same Stuff?

"We were hoping to see an exact agreement between Stardust and Deep Impact and we don't have that exact agreement right now." - Carey Lisse, Ph.D., Deep Impact Chemist

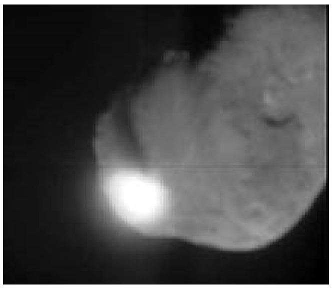
December 1 , 2006 Laurel, Maryland - This week, the European Space Agency's office in Paris announced that one of its spacecraft called "Rosetta" is preparing to swing-by Mars in a couple of months in February 2007. Since its launch in March 2004, Rosetta has been on a trajectory that will eventually lead it to its landing on a comet in the first half of 2014. After landing, Rosetta will burrow into Comet 67P Churyumov-Gerasimenko, named after two Russian scientists who discovered the 2-mile-diameter comet in 1969. The Rosetta spacecraft is heavy and needs to use three gravity assists from Earth and one from Mars in February 2007 to get to Comet 67P seven years from now.

This is the third human effort since 2000 to get close to comets. On July 4, 2005, the NASA Deep Impact mission slammed into Comet Tempel I with cameras and spectroscopes operating. Back on Earth, the largest infrared telescope ever launched into space, Spitzer, and other instruments were also watching. Behind these scientific efforts are the questions: what exactly are comets made of? And did comets bring water and seeds of life to Earth long ago?



Actual cratered surface of Comet Tempel I ninety seconds before the impactor smashed into the fluffy ice at 23,000 mph. Photograph courtesy NASA.

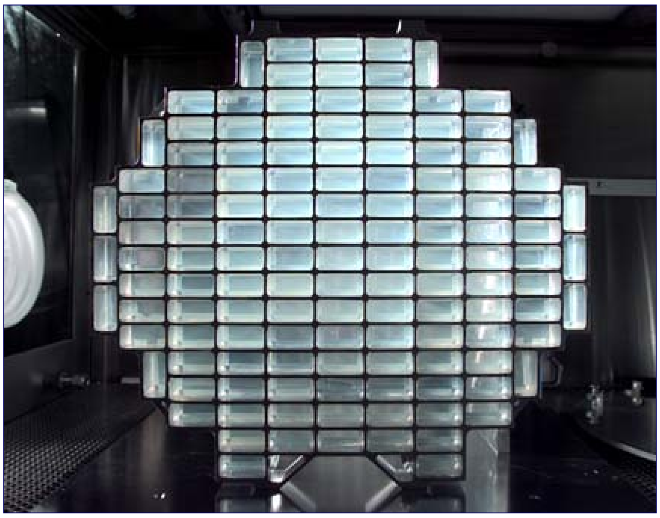
NASA illustration of Comet Tempel I with its many ice/gas geysers as Deep Impact prepares to launch its impactor into the comet on July 4, 2005. Graphic courtesy NASA.



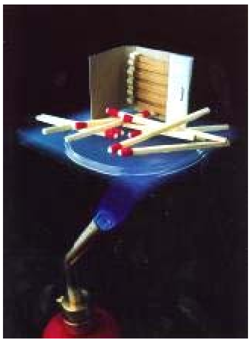
Moment of impact on potato-shaped Comet Tempel I at 10:52 p.m. PDT, July 3, 2005 / 1:52 a.m. EDT, July 4, 2005. Photograph by NASA, ESA, Johns Hopkins University Applied Physics Lab.

Seven months after Deep Impact exploded the crater in Tempel I, another comet investigator - the Stardust spacecraft - came back to Earth after flying repeatedly through the dust around Comet Wild 2 in the years 2000, 2002 and 2004. That comet dust was gathered in aerogel aboard Stardust. The "comet dust collector" was dropped back to Earth on January 15, 2006, and scientists have been studying particles from it since.

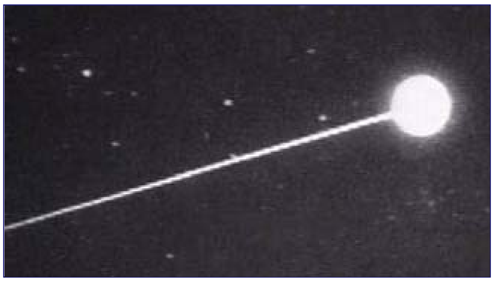
Stardust spacecraft flew through Comet Wild 2 dust in 2000, 2002 and 2004, collecting particles in aerogel. Image and graphic courtesy NASA.



Stardust aerogel collector. Aerogel is as light as air, but is strong and an excellent insulator. Images courtesy NASA.



Matches on top of aerogel disc above a gas torch flame illustrate the excellent insulating properties of aerogel. The aerogel used by Stardust is specially manufactured at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California.



Stardust sample return capsule came to Earth at 3:10 a.m. MST, January 15, 2006, landing in the U. S. Air Force's Utah Test and Training Range. The video image above was taken from a NASA DC-8 plane flying at the eastern edge of the Nevada state line.

What's interesting is that there are agreements, and differences, in the data between the two missions. Originally, scientists assumed that what would be found in one comet would be found in all comets. The hypothesis is that comets are primordial - residues of the cold, early solar system on or about the time that the sun began to flare into a hot star. The presumed ancient purity of comets has long tantalized planetary astrophysicists and astronomers who have asked: could comets be the source of Earth water and life?

As we enter 2007, both the Stardust and Deep Impact science teams are preparing papers for scientific journals about their respective discoveries so far. Recently, I talked to one of the chemists who gave me a glimpse into the data. Once it was thought that comet "snowballs" were born and grew up in the Kuiper Belt and Oort cloud that surround the solar system's planets. The picture that is emerging now about the solar system's birth is a churning mixing bowl. Icy dust from far beyond where Neptune and Pluto are today were swirled into the gases and dust around the new hot, sun and flung back out again to the frigid edges. Adding to the complexity is the fact that apparently not all comets are the same age.

Although the two science teams have ended up with different data concerning carbonates and clays, there is solid agreement that both Tempel I and Wild 2 comets have crystalline silicates, tiny crystalline rock such as peridot and jadite, which are pale to darker green on Earth. Those crystals imply both comet substances were exposed to high heating and rapid cooling.

The chemist who talked with me recently is Carey Lisse, Ph.D., Prof. of Physics and Senior Research Scientist, Johns Hopkins Applied Physics Lab (APL) in Laurel, Maryland. Prof. Lisse is also a member of the Deep Impact Science Team and Principal Investigator for the Chandra X-Ray and the Spitzer telescopes.

Interview:

Carey Lisse, Ph.D., Prof. of Physics and Senior Research Scientist, Johns Hopkins Applied Lab (APL) in Laurel, Maryland. Prof. Lisse is also a member of the Deep Impact Science Team and Principal Investigator for the Chandra X-Ray and the Spitzer telescopes: "One of the most important findings in both Stardust and Deep Impact – we are all very much in agreement on this – is there are silicates. There had to be a lot of mixing in the early solar system. In order to do the annealing, to change to glassy crystalline silicates, you had to be inside the orbit of present day Mercury. But the comets are formed out past Neptune. So, you had to have an efficient mechanism to bring stuff very close to the sun and then send it back out again.

One of the immediate consequences of all this is that the whole early solar system had to be churning and turning over and mixing radially. Stuff would come all the way into the sun and then go all the way out again. That is a very important result.

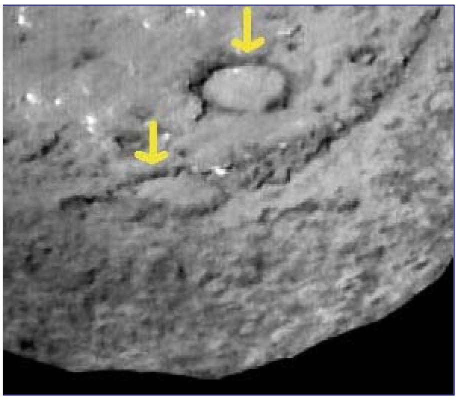
Different Deep Impact and Stardust Data

The carbonates and clays that we claim we detected with Deep Impact have *not* been found to date by the Stardust mission. We see a disagreement at least right now between Stardust and Deep Impact results. There is a number of reasons why those disagreements could be there. It could be as simple as the fact that Stardust collected its samples in a very hot way. In other words, the little pieces of dust had to be slowed down in aerogel and they were heated doing that.

It could also be that Stardust was only sampling surface material from their comet (Wild 2) and Deep Impact saw very definite differences between the surface material and the interior material from which the bulk of the ejecta came.

But also on the other hand, it could be that Deep Impact only sampled one place on Comet Tempel I. That's the place which just happened to be between two large impact craters. But Stardust sampled all throughout the coma of Wild 2. In other words, Stardust may well have sampled all along the surface of Wild 2 and gotten a much better *global* average.

Deep Impact may have in fact sampled a very unique place on Tempel I. Let's go back to those two impact craters. They were about 300 meters across (2,953 feet) that were on either side of our impact site. When you hit a comet – we know this because we saw this with Deep Impact – you eject a lot of dusty material. But you also create a lot of very hot water and carbon dioxide. We saw this with our Deep Impact fly-by spectrometers.



Yellow arrows point out the two craters about 900 meters (2,953 feet) in diameter between which the Deep Impact impactor crashed and exploded a crater of debris for scientists to study with spectrometers on July 4, 2005. Image courtesy NASA.

Those very hot gases can be reactive, can create chemistry. It's not hard to believe that you could have possibly made some of the carbonates and clays during the impact event. So, we have to think about this a lot and scratch our heads, but for right now, I would say time is going to tell whether with more work. Stardust has only looked at 10% of its samples – and has to worry about the implications of their system effects (where the dust is heated as it moves into the aerogel.) It's not clear. But maybe they are going to be able to work out what happens when stuff gets collected in aerogel.

What Deep Impact and Stardust won't be able to allow for is surface versus interior or one place on a comet versus many places on a comet in sampling. So, we're probably, unfortunately, in the end left with an open question mark and will have to wait until missions like Rosetta core into a comet - land on and sample a comet and look at it for a long time and really study the whole structure of the comet to answer questions about the carbonates and the clays.

> [Editor's Note: European Space Agency's Rosetta Orbiter Mission – The European Space Agency (ESA) office in Paris, France, says mission controllers the last week of November 2006 began preparing for the Rosetta spacecraft's swing-by Mars in February 2007.
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> Since its launch in March 2004, Rosetta has been on a trajectory that will eventually lead it to its final destination during the first half of 2014: to land and burrow into Comet 67P Churyumov-Gerasimenko. The spacecraft is heavy and needs to use three gravity assists from Earth and one from Mars in February 2007 to get to the comet seven years from now.
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> Comet 67P Churyumov-Gerasimenko was discovered in 1969 by K. Churyumov, University of Kiev, Ukraine, and S. Gerasimenko at the Institute of Astrophysics in Dushanbe, Tajikistan. The comet is 4 kilometers in diameter (2.4 miles) and orbits around the sun every 6.6 years at distances ranging between 186 million kilometers (115,599 miles) to 857 million kilometers (532,629 miles).
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> On arrival at Comet 67P, the Rosetta will enter orbit around the comet and stay with it as it journeys in towards the Sun.
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> Mission goals:
> To study the origin of comets, the relationship between cometary and interstellar material and its implications with regard to the origin of the Solar System.]

No Amino Acids, but Amorphous Carbons and PAHs

The amorphous carbons and the PAHs (polycyclic aromatic hydrocarbons) – I think everybody agrees on and is pretty exciting stuff. People have pretty much known the amorphous carbon before we ever went to a comet. That amorphous carbon of organic-like dust could contain the precursors to life – I think there is a connection there – a tenuous connection, but it's probably there. And we need to do a little bit more work. Again, we probably have to wait for Rosetta to dig some of this stuff up and put it in their sample bin.

> [Editor's Note:
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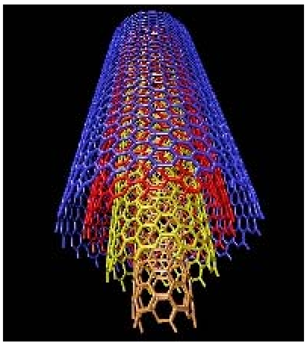
> Amorphous Carbons are not crystallized graphite, but glassy carbon.
>
> 'PAHs' are polycyclic aromatic hydrocarbons. Prof. Lisse: "Think Bucky Balls and carbon nanotubes and graphite which has been exposed to hydrogen and water. That could also be catalytic for life or it could be a component. But there is nothing that shrieks that there has to be bacteria or life. We don't have that."



Structure of a multi-walled nanotube © Alain Rochefort,
Center for Research on Computation and its Applications (CERCA).]

The PAHS are something we've seen between the stars, just like the silicates. We expect to see PAHs in comets if they are primitive material. I think we have very strong information about that from Deep Impact from watching the very hot PAHs when we first hit it (Tempel I). We see it in the Spitzer spectrometer. I think we're seeing indications of it with the Deep Impact fly-by infrared spectrometer. And we also see it later on with Spitzer in the cool material. The PAHs are there.

One thing that's important that I had not realized until I talked to my colleague who is a PAH expert, Dr. Lee, is that PAHs are very much a minority constituent. We see them easily because they are really very good emitters of thermal infrared radiation, but they are a very small fraction of the carbon in a comet.

They aren't the bulk majority of the carbon, which becomes important in chemistry later on to build the structures and chemicals and minerals we see on Earth. So, the PAHs are more a tracer of things. It's not clear if they are important at all in the astrobiology implications.

THE WHOLE POINT OF WONDERING ABOUT WHETHER COMETS MIGHT HAVE CONTRIBUTED TO DEPOSITING LIFE ON THIS PLANET OR OTHER PLANETS IS ONE OF THE MAJOR QUESTIONS THERE HAS ALWAYS BEEN: ARE COMETS PUTTING WATER AND POSSIBLY LIFE ON THIS PLANET, RIGHT?

Comets spend the vast majority of their lives very far out from the sun where it's very cold where chemical reactions move very slowly – it's much more likely, it seems to me, that comets brought the basic feedstocks of these materials to Earth. Comets bombarded Earth where we had liquid water and it was much warmer temperatures, so that's where the reactions occurred that led to life. We do see, for example – we haven't seen any evidence of amino acids or sugars or complex bio-molecules in comets. But we do see amino acids in the asteroids and meteorites that come from asteroids, which come from a much warmer, higher temperature process.

So, again, this is indirect evidence for the fact that if you brought - if you took a comet and melted it down and converted it, you could create amino acids, the same way if you took a comet and slammed it into the Earth and altered it and also warmed up the material on it, it could also create amino acids.

So, my answer to your question is that I do not think comets brought life itself. I think comets brought the materials that can *lead* to life.

I will point out one thing that is positive in your question is that the earliest life we know about on the Earth we think happened around 900 million years after the formation of the planets. And that is suspiciously around the same time where what we call the Late Heavy Bombardment – looks like the final, huge number of comets and asteroids coming in and pummeling the Earth and the moon, creating a huge number of craters that we still see on the moon today.

This would argue that if life formed about this time and comets were bombarding the Earth about that time, that comets did have something to do with it (evolution of life).It can certainly be interpreted as comets brought the feedstocks, if you will, the 'Purina life chow' to the Earth. Then there might have been a bit of bacteria or simple little piece of proto life that was forming and suddenly it had this very rich environment and took off from there once there was the very rich soup of material brought by comets.

COULD YOU DETAIL MORE THE DIFFERENCES BETWEEN DEEP IMPACT AND STARDUST DATA-GATHERING?

Stardust has the wonderful capability of having about 10 micrograms of cometary material in the lab. It can be tested and poked and prodded and probed with the most advanced compositional and physical techniques we have today to try to understand the structure and chemistry and what we call petrology, the actual formative minerals and what made up the dust that was around that comet, Wild 2? What was emitted from the comet?

There are some problems, or details, they have to worry about in that when they captured their Stardust dust, they captured it into what’s called aerogel, which is a very light, very fluffy, almost jello-like material made up of silica. Silicate is made of silica and oxygen, similar to the rock-forming elements we’ve been talking about.

Stardust captured the material at about 6 to 7 kilometers per second. It has to *decelerate* in a millimeter or two. And that is a very quick deceleration in a very shot distance. So, the dust gets heated up a bit, actually quite a lot. I’m not clear exactly how many hundreds of thousands of degrees.

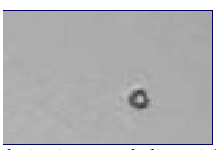
The details of exactly what happens to the dust when it is heated up after it is captured are still being understood. The understanding is actually on the job. They have many particles they can work with, which is good. But it’s going to take them time to figure out exactly the details.

What they have been looking at most of all are what are called ‘terminal particles.’ The particles are pretty small. For example, in Deep Impact, we basically saw particles between
point-1 and a few microns in size from our ejecta from deep inside the comet.

Stardust is finding that the vast majority of those size particles are severely altered when they are captured in the aerogel. They are small enough that they get heated a lot, changed a lot.

The really big particles, the ones that are 10 microns and larger. Just to give you an idea, your hair is probably like mine – thin Caucasian hair about 1 to 3 microns thick. The 10 microns or larger particles were so big that only their outer rims got affected at all. The rest of them survived very well.

Don Brownlee (Stardust Director) calls these “almost rocks or boulders.” What they are doing with their first preliminary analysis is they are looking at the composition of these “boulders.”



The small dark ring in aerogel slice might be the first
pieces of matter ever captured from outside our Solar System.
Image by Stardust@Home, Space Science Lab, UC-Berkeley and NASA.

[Editor's Note: You can help scientists look for interstellar dust on aerogel slices gathered in 2004 from Comet Wild 2 by joining an interactive microscope program **Stardust@Home.**]

They are seeing very simple olivines, pyroxenes and metal sulfides. They are able to do lots of studies on these rocks and boulders and they are inferring from that to their general overall data, their total findings. That’s a little worrisome.

With Deep Impact, we didn’t have any material in the lab (on Earth). We can’t do any of this direct analysis. We can’t use x-ray microprobes or any sort of time-of-flight mass spectrometry, or anything like that.

But what we have is not 10 micrograms. We have literally ten to the 15th times more material. We have 10 to the 9th grams of ejecta came out of our comet (Comet Tempel I). So, rather than the total equivalent of maybe one 30-micron interplanetary dust particle, we’ve got something the size of a small avalanche came out of the comet.

The problem is that we didn’t have it in front of us in the lab. It was three-quarter's of the distance between the Earth and the sun away from us when we looked at Comet Tempel I. All we could do is use what is called ‘remote sensing.’ So, what that means is that we have a spectra from Spitzer and this spectra has bumps and wiggles and we can try to infer from it. We’ve done a very good job, we think, of trying to fit this spectrum and try to understand what’s in it.

But, as the Stardust folks rightly point out, we have what is called a ‘uniqueness problem.’ We can tell you generally there is so much olivine and so much pyroxene and so much metal sulfide and so much carbonates. And we can tell you that it all fits the spectra very nicely. But without the material in our hand in the lab able to probe it and test it and figure out exactly what it is, we have the problem that it’s possible that someone could come up with a somewhat different recipe (for comet components) and identify and fit that spectra as well.

I don’t think this is very likely because I’ve put a lot of work into it. But I do have to be open-minded and the truth of the matter is there could be a different recipe in the two comets. And this is the issue. We were hoping to see an exact agreement between Stardust and Deep Impact and we don’t have that exact agreement right now.

Maybe Comets Are Not the Same In Composition and Age

WHY COULDN’T COMETS BE DIFFERENT?

The answer is that they could be. What you’re hearing from me is that’s a simple answer and you could be exactly right. And let me get to that in a second.

But both Deep Impact and the Stardust teams would like to have the comets be a Holy Grail, or be representative of the proto solar nebulae so that we can dig right into them. We were hoping to say here’s what’s in the comets: here are your dinosaur bones of solar system formation. Here’s your answers. We may be finding as you are suggesting that it’s more complicated than that.

We have one comet that was made, oh, let’s say, out by Uranus. And another comet that was made out by Pluto way past Neptune. And one was made a few million years after the sun turned on. And the other was waiting for 10 million years to get made. They are going to look very different. In fact, to answer your question, the more we look at Wild 2 and we look at Tempel I – to our eyes, the Deep Impact eyes – Wild 2 looks very young, very unprocessed. It looks like it was a comet from early on in the solar system and the Stardust results seems to be saying it has a very simple composition. It only has magnesium-rich silicates and the pyroxenes are calcium and iron and magnesium rich, but they also look simple.

In Deep Impact, our dust is looking more complicated – like there is a lot more iron-rich olivine. The clays and these carbonates look like water processing of the olivine and pyroxene.

Translation: Maybe Tempel I is actually made of material that had been baked and boiled and processed around the sun more and maybe spent more time in the proto solar nebula before it was incorporated into a comet. This is making sense for the compositional differences. It also makes sense when you look at the bodies. Tempel I really shows all kinds of different layers. It shows etching into the layers. It shows flows. It shows impact craters. It looks like it’s a very complicated surface that we are still trying to understand.

So, to answer your question: it’s very possible that there are big differences due to formation and evolution of these two bodies. We may still be learning that.

AND THAT AGE OF COMETS MIGHT BE ONE OF THE BIGGEST CHARACTERISTICS OR FACTS TO CONSIDER WHEN YOU ARE COMPARING DATA?

I am now 44-years-old. I have been doing comets only since the early 1990s. That's fifteen years I've been studying comets. We rally are in our infancy. If you think about it, with Deep Impact and Stardust, we've only managed to start looking at the surfaces and barely sampling two comets for material in the last few years.

It wasn't until 1950 – only fifty years ago – that we really began thinking about comets not as flying sandbags but as coherent bodies, icy snowballs – icy dirt balls, I should call them now to be correct, because it looks like they've got as much or more dirt and rocks on them as ices. It wasn't until then 50 years ago that we started thinking about them in the proper terms. And it's only in the last ten years that we've really started sampling them.

Fifty years from now, we might have another big paradigm shift and we're going to look back on this and answer your question just like you think the answer is, which is, 'Oh, yeah, once you start looking at ten, twenty, thirty comets up close and you get core samples from them and you look at them in the lab, you're going to see that they weren't all made at once. They didn't just all form immediately once the proto solar nebula collapsed. But some of them were formed early. Some of them were formed late. Some of them might have been heated when it came near a very young Jupiter, which could have been hot.

Others stayed forever out in the Kuiper Belt and were always cold and never had any changes at all. That's a very likely possibility. We just can't say anything about it now because we don't know that much.

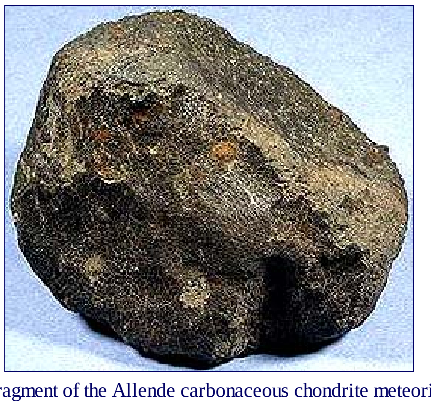
Water from Comets and Amino Acids from Meteorites

WHAT'S YOUR OWN GUT FEELING ABOUT WHETHER COMETS ARE GOING TO TURN OUT TO BE WHAT BROUGHT SOME DNA LIFE HERE?

My gut thinking is that I do not think comets in and of themselves brought DNA. I think comets brought the basic feedstocks and my training as a chemist is that liquid water is an incredibly fascinating and powerful medium for making reactions happen. You cannot underestimate the fact that with water life can happen so much easier.

It is fascinating I think and should not be understated that there *are amino acids* in meteorites. Amino acids have been found in the residues of meteorites such as the famous Allende meteorite.

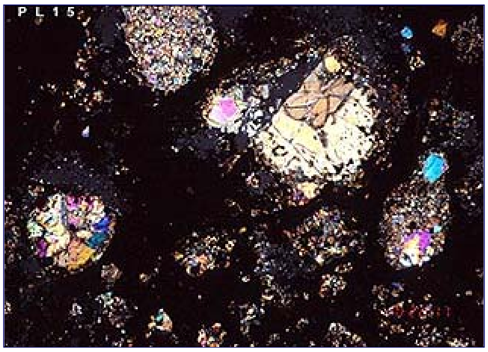
[Editor's Note: Allende Carbonaceous Chondrite Meteorite



A fragment of the Allende carbonaceous chondrite meteorite.
Source: *The Encyclopedia of Astrobiology, Astronomy and Spaceflight*.

A meteorite of the type known as a carbonaceous chondrite, which fell near the village of Pueblito de Allende, in the Mexican state of Chihuahua, on February 8, 1969. Several tons of material were scattered over an area measuring 48 kilometers (30 miles) by 7 kilometers (4.3 miles).

Specimens of the meteorite were found to contain a fine-grained carbon-rich matrix studded with many chondrules, both matrix and chondrules consisting predominantly of the mineral olivine.



A thin section of the Allende meteorite showing
a carbon-rich matrix around the chondrules. Source:
The Encyclopedia of Astrobiology, Astronomy and Spaceflight.

> *AAS Encyclopedia*: "Close examination of the chondrules, by a team from Case Western Reserve University, revealed tiny black markings, up to 10 trillion per square centimeter, which were absent from the matrix and interpreted as evidence of radiation damage. Similar structures have turned up in lunar basalt, but not in their terrestrial equivalent, which would have been screened from cosmic radiation by the Earth's atmosphere and geomagnetic field. Irradiation of the chondrules, it seems, happened after they had solidified but before the cold accretion of matter that took place during the early stages of formation of the solar system, when the parent meteorite came together.
>
> The Allende meteorite also contains fine-grained, microscopic diamonds with strange isotopic signatures that point to an extrasolar origin; these interstellar grains are older than the Solar System and probably the product of a nearby supernova."]

The fact that amino acids are in meteorites is very interesting. But now, remember that a meteorite, which we think comes from an asteroid, is a body that has undergone melting and been baked and boiled compared to a comet. A comet is a very primitive body, which is much more like a simple selection of the dust and gas that was originally between the stars and that fell together to form our very young proto solar nebula and fell into the sun and made the sun.

IS IT FAIR TO SAY THAT THE COMETS BROUGHT THE WATER AND THE METEORITES MIGHT HAVE BROUGHT THE DNA?

I don't think there is any evidence for DNA. I want to be very strong about that. But it's possible they might have brought the amino acids.

THAT WOULD END UP EVOLVING INTO DNA?

If you can make amino acids and precursors in asteroids, why can't you do it on the Earth's surface as well? In other words, in the process of melting a comet and slamming bodies into each other and reforming them in order to make the asteroids, why can't you do the same thing on the Earth itself. You should be able to once it's cool enough.

We are looking with our modern techniques and it seems like we are seeing a rate of planetary formation around stars in the order of 5% to 10%. So, there's maybe as many as 10 billion planets in our Milky Way galaxy. That's a lot of planets!

It could be that making life, finding an Earth and making a body that has oxygen and water on it really is an incredibly rare event. Then out of 10 billion planets, it only has to happen a few times. But we would not be having this conversation if it did not happen, right?

RIGHT.

That's the anthropomorphic principal. If life had not happened, we would not be discussing it. So, it's a chicken and egg problem. It had to happen for you and I to be having this conversation, to be alive here today. We're an existence proof that life can happen.

I'm often asked if there is life or something out there in the galaxy, my answer is that there are 10 billion planets in this galaxy. It happened here (on Earth). I think it has to have happened somewhere else. The problem is that it could have happened hundreds of light-years away, so the neighbors are very far away and hard to talk to. There is no such thing as a warp drive as far as we know in physics today. So, there may be life out there. I'm pretty sure there is. I think Jodie Foster said in *Contact*, 'It would be a terrible waste of space.' But it could be it's very hard for us to find it. Or if we do find evidence of it, it's going to be very hard to communicate with because communication has to move at the speed of light.

Where Did All of Earth's Water Come From?

IS THERE ANY EVIDENCE THAT ALL OF THE WATER OF EARTH CAME ONLY FROM COMETS?

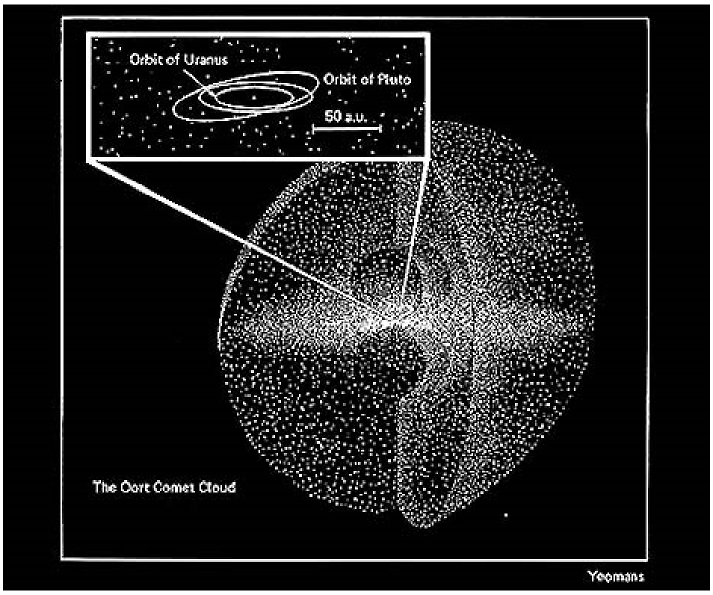
My current understanding is that there is no evidence. In fact, there is evidence to the contrary. It looks like there is an upper limit on the amount of water that could have come from comets. By studying the amount of deuterium, which is heavy water.

The amount of deuterium in comets – and deuterium is a hydrogen atom that has an extra neutron in it, so it’s called heavy hydrogen. When we compare what we saw in comets such as Hyakutake and Hale-Bopp with what we see in our oceans, a fellow named Rowen Meyer showed a few years back that comets have a lot more deuterium in their water than is in the Earth’s oceans.

Comet Hale-Bopp, April 1997. Image © by Alessandro Dimai at Col Druscie Observatory, Cortina d'Ampezzo, Italy.

So some Earth water could have come by comets, but if you had to match the deuterium to hydrogen ratio that we see in the Earth’s oceans, you have an upper limit in which only about 30 to 40 percent of our planet's ocean water could come from comets.

This is a fascinating result from looking at three of the bright comets in the last twenty years (Haley, Hyakutake and Hale-Bopp) . One problem with this analysis is that Rowen was looking at deep comets, or what we call Oort Cloud comets. They come from a giant sphere around our solar system and they are *not* the comets that we think did most of the bombardment during the Late Heavy Bombardment, which are the Jupiter family comets.



Solar system is where the two lines come together near the center of the Oort Cloud graphic, emphasizing how much greater the icy comet-making region is beyond planets. The Kuiper Belt, another comet-making region, is closer to the planets.

Those are comets that are found in a disc around our solar system and they are derived from the Kuiper Belt objects. They are bodies that performed at the edges of our solar system and are like Wild 2 or Tempel I. There might be a difference in the deuterium to hydrogen ratio.

No one has ever measured the D/H radio in a Jupiter family comet. The Rosetta mission will do this for the first time. So, that number of 30 to 40% is provisional for now. It might be a very good number. It's the best number we have today.

WHERE DID ALL THE REST OF THE WATER COME FROM?

OK, rocks have intrinsic water built into them. If you were to pick up a random rock outside and took it home and put it in your fireplace and heat the rock up, you would see vapor coming off of it. It's almost like seeing steam come up from a sauna. Rocks have what is called water hydration. They have chemical water bound into them, which can be removed from them upon heating.

So, when the Earth was a red lava ball, it was so hot to begin with that nothing could last on its surface and it boils off all the water and organic things and a lot of it does get destroyed and goes back into the atmosphere and back into the proto solar nebula.

But as it cools, eventually it cools enough that water is coming from the rocks in the interior. There is water in lava today. There's actually a lot of water. We see this. So we know there's water inside the rocks inside the Earth. That water could have come bubbling up from the inside of the Earth and remained stable on the Earth's surface."

Summary of Deep Impact Data So Far

(Stardust Data to Be Published in 2007)

No ammonia, methane or formic acid.

Confirmed and Maybe Substances:

1) **Amorphous Carbon -** Similar to glassy carbon, not crystallized graphite.
2) **Crystalline Silicates** - Such as olivines (like greenish peridots/fosterite)
3) **Hydrogen Cyanide** (HCN)
4) **Methyl Cyanide**
5) **Methanol**
6) **Carbon Monoxide, CO** - Maybe?
7) **Carbon Dioxide, CO2**
8) **Water** (Tempel I is about 40% to 50% water ice)
9) **Ethane** (Hydrocarbon consists of two carbons and six hydrogens; non-soluble in water. It is the simplest hydrocarbon containing more than one carbon atom.)
10) **Polycyclic aromatic hydrocarbons, PAHs.**
11) **Carbonates** (Iron and magnesium carbonates, not calcium/limestone.)
12) **Clays** - Rock mixed with acid or water (such as Smectite).

More Information:

For further information about Deep Impact, Stardust and other comet research, please see the **Earthfiles Archives:**

- **08/12/2005** -- Deep Impact Spectra: Carbonate, PAHs and Some Amino Precursors in Comet Tempel I
- **07/10/2005** -- First Data from Deep Impact Crash Into Comet Tempel I
- **06/29/2005** -- July 3-4, 2005: NASA "Deep Impact" Spacecraft to Blast Hole in Comet Temple I
- **01/13/2005** -- NASA "Deep Space" Craft Will Hit Comet On July 4, 2005
- **06/25/2004** -- Wild 2, An Amazing Comet - Stardust Mission

- 08/19/2006 -- Red Rain Cells of Kerala, India - Still No Definite DNA
- 09/16/2005 -- "Planet X" and the Kuiper Belt's Oddballs, "Santa" and "Easterbunny"
- 08/12/2005 -- Deep Impact Spectra: Carbonate, PAHs and Some Amino Precursors in Comet Tempel I
- 07/10/2005 -- First Data from Deep Impact Crash Into Comet Tempel I
- 06/29/2005 -- July 3-4, 2005: NASA "Deep Impact" Spacecraft to Blast Hole in Comet Temple I
- 05/06/2005 -- What Are The Straight Lines on Saturn's Titan Moon?
- 04/20/2005 -- Outer Space Impact At Serpent Mound, Ohio, 256 Million Years Ago
- 04/01/2005 -- What's Killing Off Marine Life Every 62 Million Years?
- 02/17/2005 -- Iapetus and Enceladus: Baffling Moons of Saturn
- 01/13/2005 -- NASA "Deep Space" Craft Will Hit Comet On July 4, 2005
- 12/17/2004 -- Is Our Solar System's Red, Mysterious Sedna An Alien Planetoid?
- 11/17/2004 -- European Space Agency's SMART-1 Satellite Begins Moon Orbit
- 09/20/2004 -- Part 1: Martian Water Vapor and Methane Overlap in Equatorial Regions
- 06/25/2004 -- Wild 2, An Amazing Comet
- 03/31/2004 -- Methane on Mars - Biology? Volcanic?
- 03/15/2004 -- Most Distant "Icy Planetoid" in Our Solar System Has A Most Baffling Orbit

- 10/11/2003 -- Is Our Universe Finite and Shaped Like A Dodecahedron?
- 09/02/2003 -- Astronomers Don't Think Asteroid Will Hit Earth in 2014
- 03/07/2003 -- Scientist's Record Sun's Plasma Interaction with Comet NEAT
- 10/07/2002 -- Large Kuiper Belt Planetoid Found Beyond Pluto
- 08/16/2002 -- Did CONTOUR Probe Break Apart Or Disappear Into Space?
- 07/25/2002 -- Mile and A Half Diameter Asteroid 2002 NT7 Might Impact Earth in 2019
- 07/11/2002 -- Hubble Telescope Photographs Seven Objects Traveling In Pairs Beyond Pluto
- 06/01/2002 -- Scientists Surprised by Abundance of Water On Mars
- 02/24/2002 -- Mysterious Slowing of Pioneer Spacecraft 7 Billion Miles from Earth
- 01/26/2002 -- Something Is Perturbing Comet Orbits in the Oort Cloud Surrounding Our Solar System
- 12/01/2001 -- 1200 B. C. - What Caused Earthquake Storms, Global Drought and End of Bronze Age?
- 11/01/2001 -- Astronomy News
- 01/14/2001 -- An Australian Zircon Crystal is 4.4 Billion Years Old
- 01/07/2001 -- Dinosaur-Killing Asteroid Punched 22 Miles Through Earth's Entire Crust
- 12/24/2000 -- Martian Bacteria?
- 12/03/2000 -- Bacteria from Outer Space?
- 10/01/2000 -- A Search for Earth's First Life
- 03/11/2000 -- Is 433 Eros Asteroid Younger Than Expected?
- 02/16/2000 -- 433 Eros, Orbiting An Asteroid Up Close
- 10/25/1999 -- A Mysterious "Perturber" at the Edges of Our Solar System
- 06/15/1999 -- Current Brightest Binocular Comet and Upcoming Solar Eclipse
- 02/01/1999 -- Astronomy Updates with Brian Marsden and John Huchra, Harvard

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Websites:

Stardust: http://stardust.jpl.nasa.gov/home/index.html

Deep Impact: http://deepimpact.jpl.nasa.gov/mission/index.html

Comets and Meteorites: http://comets.amsmeteors.org/

http://www.daviddarling.info/encyclopedia/A/Allende.html

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