

## Hot Idea

— posted January 25, 2007

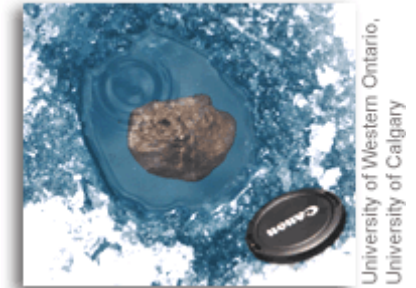
# Organic Globules from the Cold Far Reaches of the Proto-Solar Disk

--- Hollow organic globules in the Tagish Lake meteorite probably formed far from the proto-Sun, maybe even in interstellar space before our Solar System formed.

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## Tagish Lake meteorite



Keiko Nakamura-Messenger and colleagues at the NASA Johnson Space Center in Houston, Texas, studied minute globules of organic material in the Tagish Lake carbonaceous [chondrite](#). This meteorite was collected soon after it fell, so is fresh and likely to be uncontaminated with terrestrial organic compounds. Using microanalytical techniques the NASA team found that the globules had hydrogen and nitrogen [isotopic](#) compositions consistent with chemical reactions at strikingly frigid temperatures, only 10 to 20 [K](#) (-253 to -263 [C](#)). Temperatures that low occur in cold, interstellar [molecular clouds](#) like the one that collapsed to form the Solar System or in the outermost part of the disk surrounding the Sun when it was forming. These organic globules might represent the type of prebiotic carbon compounds that were delivered to young Earth.

Reference:

- Nakamura-Messenger, Keiko, Scott Messenger, Lindsay P. Keller, Simon J. Clemett, and Michael E. Zolensky (2006) Organic globules in the Tagish Lake Meteorite: Remnants of the proto-solar disk. *Science*, v. 314, p. 1439-1442.

## An Uncontaminated Sample

One of the greatest arguments in meteoritics erupted in the early 1960s with the announcement of the discovery of tiny fossils in carbonaceous chondrites. The research had been done by microbiologist George Claus (New York University Medical Center) and organic chemist Bartholomew Nagy (Fordham University). They thought they had found spores in the carbonaceous chondrites they studied. Botanists and biologists were mystified by the structures, which Claus and Nagy called "organized elements," but all agreed that they were probably biological in origin. Edward Anders and colleagues at the University of Chicago were instrumental in debunking the claim. They showed that the unusual structures were probably ragweed pollen that had been altered by a dye Nagy had used to make them easier to see. They were biological all right, but not extraterrestrial.

Contamination issues have also popped up in the debate about fossils in the ALH 84001 Martian meteorite (for examples, see **PSRD** articles: [Fossils Blowing in the Wind: More Contamination of Antarctic Meteorites](#), [Organic Compounds in Martian Meteorites May be Terrestrial Contaminants](#), [Martian Organic Matter in ALH 84001?](#).) ALH 84001 resided in Antarctica for 13,000 years before being found, ample time for contamination, even in the cold, seemingly lifeless Antarctic. Earth is so teeming with life that it is easy to contaminate a rock sitting in the ice or ground for even a few days or weeks.

No such problems with the Tagish Lake meteorite. It was found immediately after its fall (see **PSRD** article: [Tagish Lake--A Meteorite from the Far Reaches of the Asteroid Belt](#)), so is unlikely to be contaminated. It is also loaded with carbon compounds (2.6 % carbon by weight), giving us lots of sample to work with. Previous analyses showed that much of the carbon was in organic compounds, and in 2002 Nakamura-Messenger had found sub-micrometer hollow globules. However, she could not unambiguously show that the globules were extraterrestrial. New techniques for analyzing materials much smaller than a micrometer, in the nanometer range, are now available, and the Johnson Space Center is well-equipped with them.



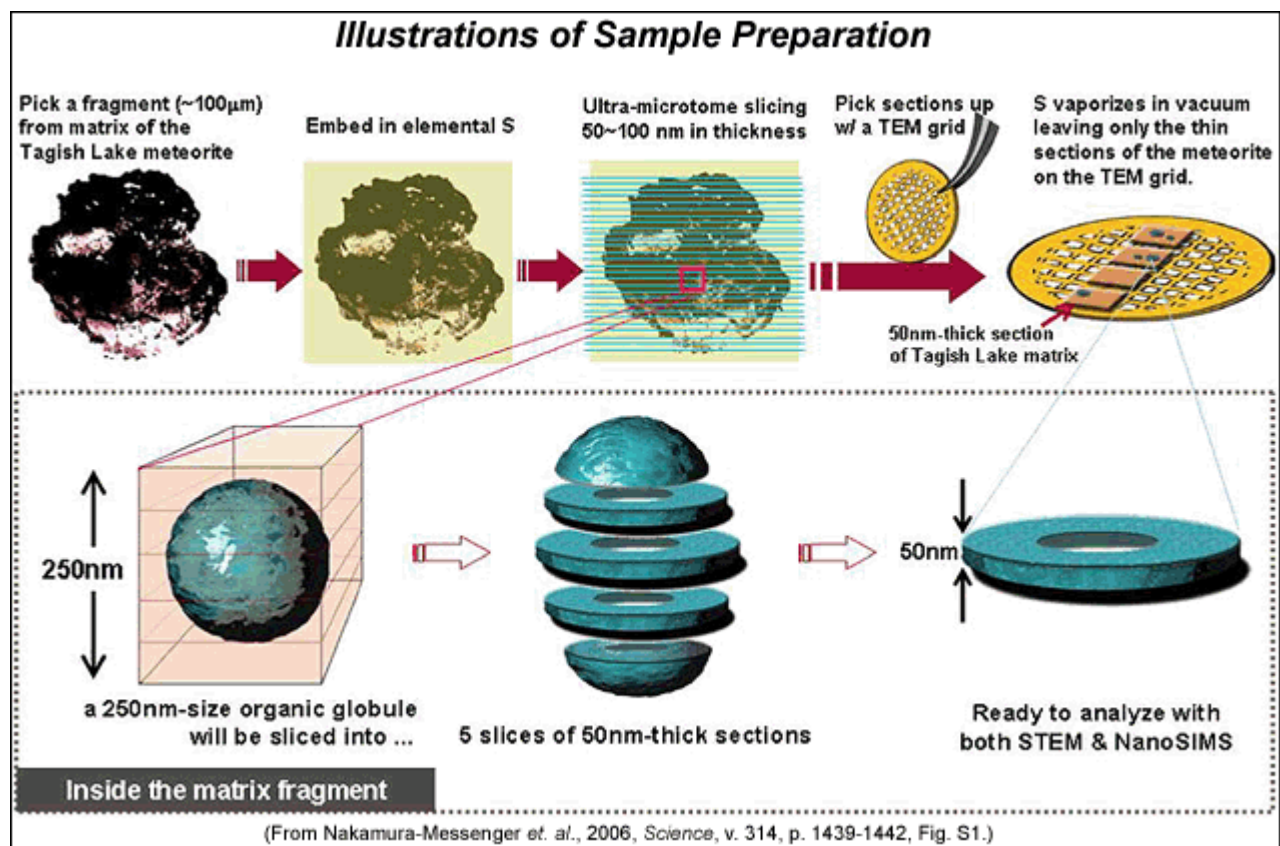
A 159-gram piece of Tagish Lake meteorite recovered in Canada. The right side of the broken stone shows the fusion crust formed by melting of the surface by friction with the atmosphere as it fell. The cube is 1 cm across. Image courtesy of Mike Zolensky, NASA JSC. (Click image for enlargement.)

(Image courtesy of Mike Zolensky, NASA JSC)

## Nano Nano

Cosmochemists can analyze incredibly tiny objects, as discussed in **PSRD** article: [Analyzing Next to Nothing](#). This is clearly essential when looking for objects that are smaller than a micrometer (1/1000 of a millimeter). Cosmochemists have developed some slick techniques to extract small samples and prepare them for study by electron microscopy and mass spectrometry. In the case of the Tagish Lake study, Nakamura-Messenger and her colleagues selected small samples about 100 micrometers in diameter from regions of the meteorite that did not contain carbonate veins (a non-organic distraction to their study). These samples were then mounted in molten elemental sulfur for further processing. Sulfur was used because the usual glue is epoxy, an organic compound--not good when studying organic compounds. Also, the sulfur vaporizes in vacuum, so is easy to get rid of.

The mounted sample was then cut with a specialized diamond knife (called a microtome) into ultra-thin slices only 50 to 70 nanometers across. These were placed on a conductive grid for study by transmission electron microscopy (TEM). When placed in a vacuum the sulfur vaporizes, leaving the nano-slices on the TEM grid.



Schematic of the sample-preparation procedure used by Keiko Nakamura-Messenger and her colleagues.

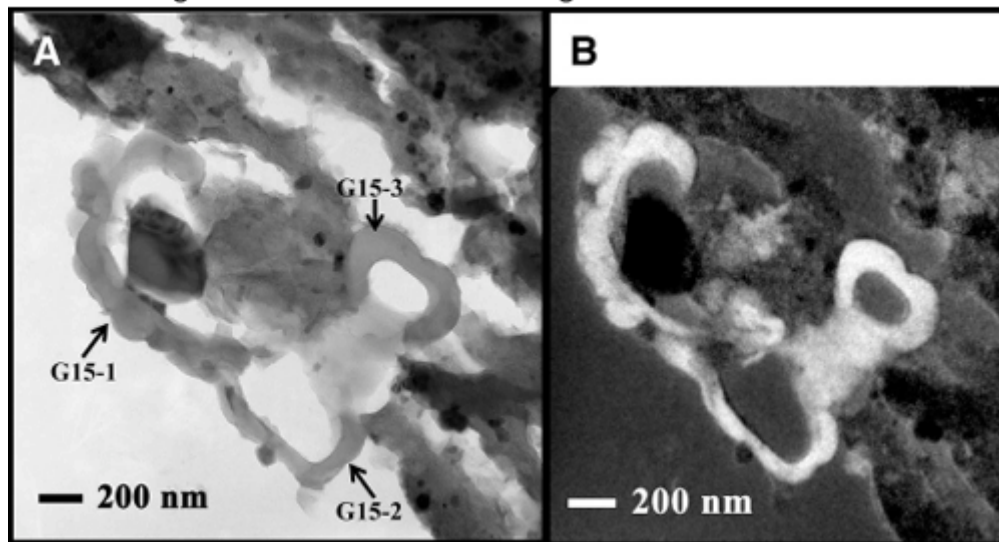
Examination in the TEM allowed the team to find the organic globules and then to study their internal structures. Once TEM work was done, the samples were transferred to a nano-SIMS, a specialized ion microprobe used to obtain isotopic compositions at the nanometer scale. [See PSRD article: [Ion Microprobe.](#)]

## Globules and Their Anomalous Isotopic Composition

Using a TEM the team observed numerous hollow organic globules. The average abundance was about one per 100 square micrometers, though the globules often occur in groups of 2 to 5. The globules average 140 to 1700 nanometers in diameter, but the walls of the globules are only 100 to 200 nanometers thick.

Nakamura-Messenger viewed the globules at high magnification in the TEM and used a technique called electron loss spectroscopy. These observations showed that the globule walls consist of non-crystalline carbon (hence not graphite), with nitrogen, oxygen, and hydrogen, consistent with them being organic compounds. The globule walls do not contain any rocky materials. They are gooey organic stuff.

### Organic Globules in the Tagish Lake Meteorite

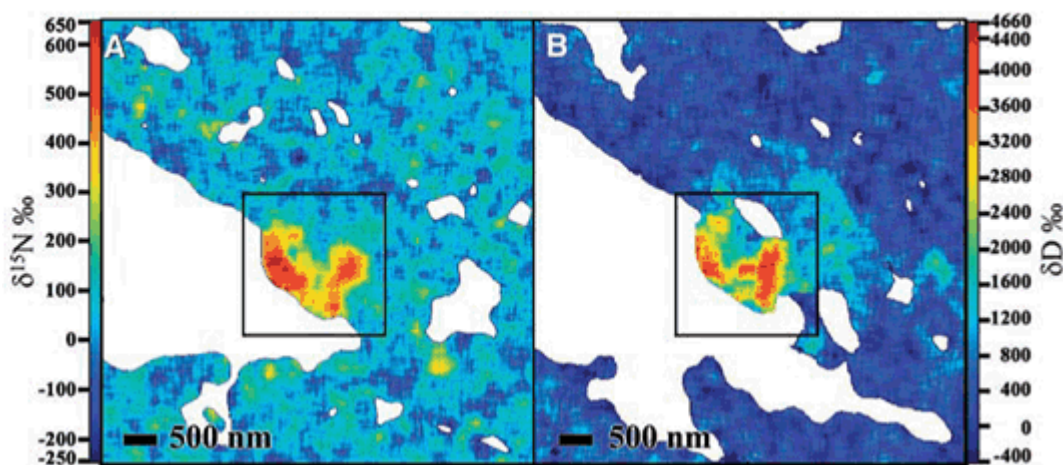


(From Nakamura-Messenger *et. al.*, 2006, *Science*, v. 314, p. 1439-1442, Fig. 1.)

TEM image (left) and carbon x-ray image (right) of a cluster of three organic globules in the Tagish Lake meteorite. The globule at the left in these photos labeled "G15-1" seems to be composed of smaller grains within its wall (the arc of material surrounding a void). Images of the isotopic composition (nitrogen and hydrogen) are shown below. The large grain in the middle of globule G15-1 is forsterite ( $Mg_2SiO_4$ , the magnesium end-member of the olivine solid solution series).

The nitrogen and hydrogen isotopic compositions of the globules are significantly different from organic materials on Earth, in other carbonaceous chondrites, and even in the bulk Tagish Lake meteorite. The isotopic compositions are expressed as deviations from terrestrial values of nitrogen-15/nitrogen-14 and deuterium/hydrogen. (Deuterium is heavy hydrogen—hydrogen with an extra neutron, so it has an atomic weight of 2, rather than 1 for hydrogen.) This is solid evidence that the organic globules in Tagish Lake were not altered by chemical reactions on the asteroid the meteorite came from. Equally important, it is evidence that the globules are extraterrestrial. No contamination here.

### Details of a Globule in Tagish Lake Meteorite



(From Nakamura-Messenger *et. al.*, 2006, *Science*, v. 314, p. 1439-1442, Fig. 3)

Maps of nitrogen and hydrogen isotopic compositions in globule G15-1 (see TEM image above). The scales indicate the deviation from terrestrial values in parts per thousands. The globule shows significant enrichments in nitrogen-15 relative to nitrogen-14 and in deuterium (heavy hydrogen) relative to hydrogen. This is proof of extraterrestrial origin of the globules and that they were not modified by chemical reactions on the asteroid in which the Tagish Lake meteorite was made.

The nitrogen isotopic compositions of the globules are much larger than most of the organic materials found in the Tagish Lake meteorite or in other carbonaceous chondrites. This indicates that the globules were not affected by processing on the Tagish Lake parent asteroid. In other words, they were not contaminated or altered while sitting in an asteroid. This important conclusion is strengthened by the observation that globules located only a few micrometers from each other vary in isotopic composition. Even mild aqueous processing of these globules should have smoothed out those variations. On the other hand, globules in direct contact have similar hydrogen and nitrogen isotopic compositions, perhaps indicating that they became attached before being incorporated into the Tagish Lake parent asteroid.

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## Cold Chemistry

Nakamura-Messenger and coauthors discuss a plethora of chemical processes in interstellar space (specifically in cold molecular clouds) and in the outer parts of the protosolar disk that could have led to the formation of organic molecules and anomalies in the proportions of nitrogen and hydrogen isotopes. They rule out nuclear reactions inside stars because there are only modest anomalies in carbon isotopes. This leaves chemical interactions at very low temperatures as the likely causes.

One of the interesting ideas is formation of small grains of water containing dissolved carbon dioxide ( $\text{CO}_2$ ), ammonia ( $\text{NH}_3$ ), methyl alcohol ( $\text{CH}_3\text{OH}$ ), and formaldehyde ( $\text{H}_2\text{CO}$ ). When subjected to ultraviolet radiation (which is everywhere in space), these compounds react and form complex organic compounds. It is intriguing that the penetration depth of ultraviolet light is 100 to 200 nanometers, about the thickness of the globule walls. Thus, exposure to ultraviolet light could form organic compounds, leaving a core of impure ice left over. The particles could have accreted into the Tagish Lake asteroid, and the ice would have been lost when the asteroid heated up, causing the formation of hydrated silicate minerals, carbonates, and other mineralogical features seen in the meteorite, and leaving a void in the center of the globules.



However the globules formed, they probably originated in the coldest part of the protosolar disk, where the Sun's rays were dimmed by dust and distance, or even in the cold cloud in which the Sun formed.

Nakamura-Messenger and her colleagues point out that similar organic globules should have been incorporated into comets. In fact, chemically similar particles containing carbon, hydrogen, oxygen, and nitrogen were detected in abundance by the European Space Agency's Giotto Mission and the international Vega project (managed by the Russian Space Research Institute) spacecraft that whizzed past comet Halley in 1986. The particles detected had sizes in the range 40 to 2000 nanometers, similar to the Tagish Lake globules.

Image of comet Halley taken by the European Space Agency's Giotto spacecraft in 1986.

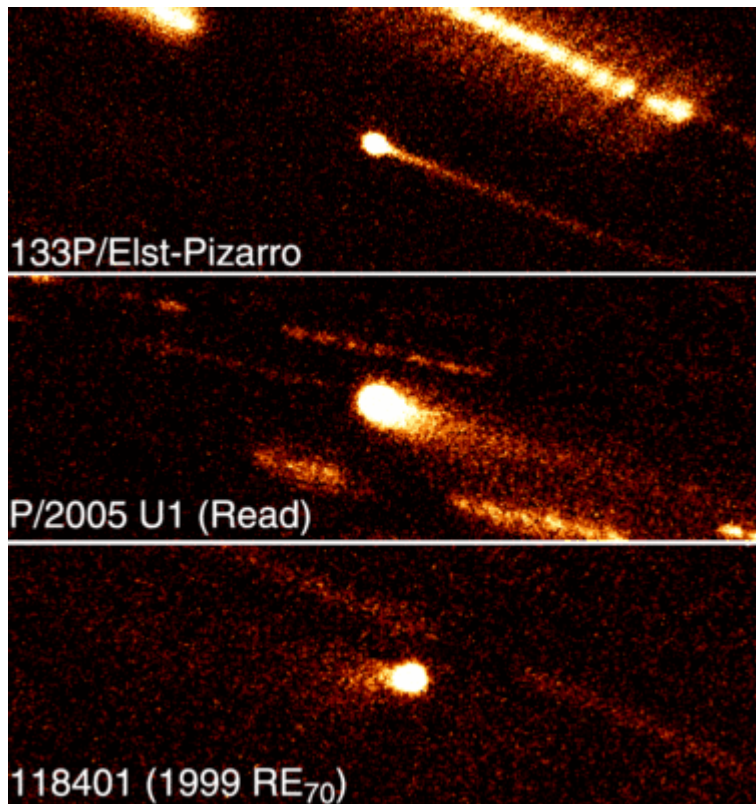
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## Seeding the Earth?

The presence of grains in comet Halley with the same composition and sizes as the organic globules in Tagish Lake lead Nakamura-Messenger and her colleagues to suggest that organic globules might have been common in prebiotic organic materials delivered to Earth very early in its history. Perhaps the membrane-like structures were important building blocks for life on Earth. Other research, such as that done by Jennifer Blank (University of California, Berkeley) and her colleagues show that organic materials will survive a high-velocity collision

such as those that take place when comets slam into planets. Not mentioned explicitly by Nakamura-Messenger and coworkers is the possibility that such organic structures were also incorporated into asteroids that never heated up much, such as the main belt comets discovered by Henry Hsieh and David Jewitt (University of Hawaii, Institute for Astronomy).

Maybe our ultimate ancestors were non-living globules in carbon-rich asteroids and comets!



(Images taken with the UH 2.2-meter telescope by H. Hsieh and D. Jewitt, University of Hawaii.)

Henry Hsieh and David Jewitt (University of Hawaii) discovered a new class of comets, which they have dubbed "main-belt comets." The first three they found are shown here, in the center of each image. The long streaks are stars smeared by the motion of the Earth as the telescope, located on Mauna Kea, Hawaii, tracked each comet. [Click on image for additional information.]

## Additional Resources

LINKS OPEN IN A NEW WINDOW.

- Blank, J. G., G. H. Miller, M. J. Ahrens, and R. E. Winans (2001) Experimental Shock Chemistry of Aqueous Amino Acid Solutions and the Cometary Delivery of Prebiotic Compounds. *Origins of Life and Evolution of the Biosphere*, v. 31, p. 15-51.
- Hsieh, H. H. and D. Jewitt (2006) A Population of Comets in the Main Asteroid Belt. *Science*, v. 312, p. 561-563. ([abstract](#))
- Mittlefehldt, D. W. (Dec. 2002) Tagish Lake -- A Meteorite from the Far Reaches of the Asteroid Belt. *Planetary Science Research Discoveries*. <http://www.psr.d.hawaii.edu/Dec02/TagishLake.html>
- Nakamura-Messenger, Keiko, Scott Messenger, Lindsay P. Keller, Simon J. Clemett, and Michael E. Zolensky (2006) Organic globules in the Tagish Lake Meteorite: Remnants of the proto-solar disk. *Science*, v. 314, p. 1439-1442.
- Taylor, G. J. (April, 2000) Analyzing Next to Nothing. *Planetary Science Research Discoveries*. <http://www.psr.d.hawaii.edu/April00/analyzingSmall.html>