

Hot Idea

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30th Lunar and Planetary Science Conference: Some Highlights

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The thirtieth annual Lunar and Planetary Science Conference took place March 15-19, 1999, at the Johnson Space Center in Houston. The LPSC is the largest conference devoted exclusively to planetary science, and certainly the most diverse in its coverage. One highlight of the week was a group photograph of the thousand participants. Similar photographs were taken during the tenth and twentieth conferences. Almost 900 oral and poster presentations were made during the conference. They discussed a vast array of topics: studies of the oldest materials in the Solar System, the nature and origin of surface features on Venus and Mars, volcanism throughout the Solar System, and the geology and compositions of the icy moons of the outer planets. This article reports some highlights about martian life, the Moon, and an unusual new meteorite, reflecting the sessions I attended, not the lack of fascinating results in other sessions!

Reference:

Lunar and Planetary Science Conference XXX, 1999, LPI Contribution No. 964, Lunar and Planetary Institute, Houston (CD-ROM). Available from the Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston, TX 77058, and also online at <http://www.lpi.usra.edu>.

Martian Meteorites: Maybe More Fossils, but Possibly Devastating Contamination Problems

The Contamination Problem

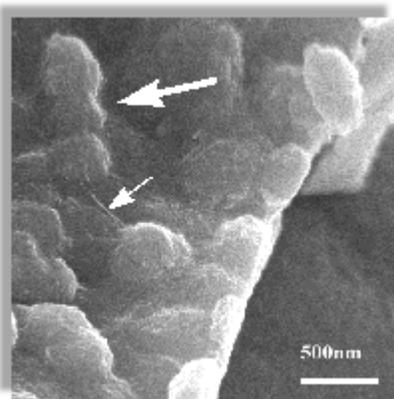
The second half of a session devoted entirely to [astrobiology](#) (the first such session in the history of the Lunar and Planetary Science Conference) contained new results from the search for life in meteorites from Mars. Andrew Steele (presently at the Johnson Space Center), a microbiologist, gave a thought-provoking talk about biological contamination in meteorites. He showed that many meteorites contain terrestrial bacteria and fungi. An especially dramatic example was a chip of the Murchison chondrite, which had been stored at the Johnson Space Center for 12 years. Examination 12 years ago using a scanning electron microscope (SEM) did not reveal any microorganisms on the surface. In startling contrast, examination recently showed that it was covered with an extensive mat of fungus. The sample had been stowed in a sample-storage cabinet, a place that would seem to be relatively clean. The problem is that the Earth so teems with life that it is very difficult to avoid infestation with microorganisms. By the end of Steele's talk, this correspondent wanted to take a long shower using vast quantities of antibacterial soap!

Steele argued that appreciation of the contamination by terrestrial microorganisms of meteorites is only now

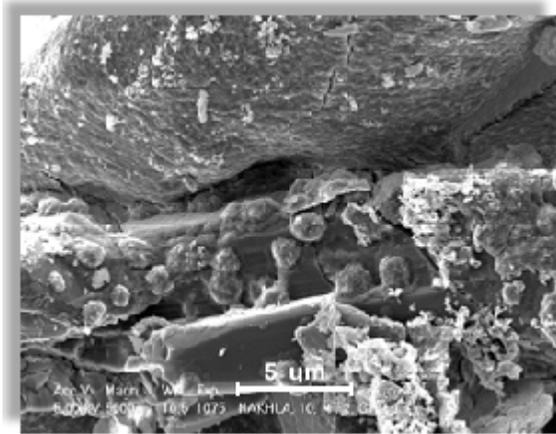
becoming clear to astrobiologists. He suggested several reasons for the delay in acceptance of the idea. *Little impetus* for examining biological contamination of meteorites found in Antarctica until Dave McKay and his colleagues claimed to have found evidence for past life in the ALH 84001 meteorite. *Ignorance of the diversity of terrestrial biota in Antarctica.* Studies of microorganisms in Antarctica have been made in earnest only during the past 15 years, and have shown that almost every major, common microbial species lives somewhere in Antarctica. *No systematic studies of the mechanisms of how meteorites become contaminated.* Steele said that any meteorite thought to be contaminated was declared ineligible for study of its organic constituents, thereby eliminating any chance of discovering how it became contaminated. *Use of thin sections in meteorite studies.* Most of us studying meteorites microscopically use very thin (30 micrometers) slices of rock mounted on glass slides. This makes detection of organisms in cracks next to impossible. Examination of rock chips with an SEM is necessary. *Instrumental methods* are also important. If an SEM is not set up for the study of microorganisms, it may not be possible to see them. Most meteoriticists study the minerals in meteorites, so tune the SEM for that purpose. Biota are distributed heterogeneously. Steele said that colonies of microorganisms seem to have random distributions on any substrate. Some samples will be free of them; others will have a few colonies; still others will have abundant colonies. We need to develop, Steele argued, a rapid screening technique to identify samples that are or are not contaminated.

Fossils in Other Martian Meteorites?

David McKay and colleagues at the Johnson Space Center, undaunted by two and a half years of unrelenting, passionate criticism of their claim to have found fossil life in ALH 84001, showed evidence for possible mineralized bacterial bodies in two other martian meteorites, Nakhla and Shergotty. Both meteorites were observed falls, Nakhla in Egypt in 1911 and Shergotty in India in 1865. (One of the forty or more individual stones of Nakhla that fell is reputed to have killed a dog!) In contrast to the suspected fossilized organisms in ALH 84001, the microorganisms McKay described are in the size range of conventional terrestrial bacteria (larger than a few hundred nanometers in diameter). Some examples even resemble dividing bacteria. McKay compared the objects in Nakhla and Shergotty to microorganisms in Columbia River basalts and terrestrial hot spring deposits.



Scanning electron microscope (SEM) image of an area in the Nakhla meteorite. Large arrow points to joined spheres which resemble dividing bacteria. Small arrow points to a fine filament which looks like bacterial fibrils. (From McKay and others, 1999.)



(from David McKay, Johnson Space Center.)

The spheres in this SEM image are, according to McKay and co-workers, possible martian fossilized microbial cells attached to a mineral in Nakhla. They range from about 1 to 2 micrometers in size. Each one is firmly attached to the crystal by clay minerals which are known to commonly form on cells as part of the mineralization or fossilization process. The scale bar is 5 micrometers long or about 1/10 the thickness of a human hair. (From D. McKay, Johnson Space Center.)

The possibility of fossils in Nakhla and Shergotty has great ramifications for life on Mars, including the possibility of life existing today. These meteorites are much younger than ALH 84001. The carbonate minerals in that meteorite formed about 4 billion years ago, when the climate on Mars was wet and warm, hence relatively conducive to life. Nakhla (1.3 billion years old) and Shergotty (only 180 million years old) formed when Mars was much as it is now, a cold, wind-blown desert. Thus, the young ages of these meteorites pegged the skepticism meters on many scientists. Some believe you cannot identify fossilized microorganisms from shapes alone. Others argued that the samples were contaminated since arriving on our life-infested planet.

Unfortunately, their views were not aired during the session, because the session chair, Ian Gilmour, did not allow questions. Each talk at the conference is allocated fifteen minutes, eight for the talk and seven for questions. Most speakers finish by ten minutes, leaving a reasonable amount of time for questions, but McKay had used up the entire fifteen-minute time slot. When Gilmour announced this, the packed room erupted into yells and boos. "It wouldn't be fair to the other speakers," he tried to explain. More hoots and hollers. This unfortunate situation happened because McKay ran overtime and Gilmour did not cut him off at the ten-minute mark. Since it is not often that you hear a session chair booed, the whole episode was a conference highlight for me.

Dave McKay noted at the end of his talk that he and his colleagues are working with contamination expert Andy Steele to determine if the objects in Nakhla and Shergotty are terrestrial contaminants or not. They will study the same samples and examine the issue critically, with Steele making a special effort to prove contamination and McKay and coworkers trying to prove that the objects are Martian. Of course, also to be resolved is the question of whether the objects are biological at all. None of these issues will be resolved soon!

Tiny magnetites in ALH 84001

One of the chief lines of evidence McKay and colleagues used in their famous paper about fossil life in ALH 84001 [See [PSRD](#) article: [Life on Mars?](#)] is the presence of magnetite, which they said was produced by bacteria. Joe Kirschvink (California Institute of Technology) reviewed the properties of such [magnetofossils](#) on Earth. He argued that natural selection drives bacteria to produce magnetite crystals with specific characteristics that increase the amount of magnetism per iron atom. These are: (1) High chemical purity. (2) Sizes in the right range (about 0.1 micrometers long) to make them single magnetic domains. (3) Crystals free of internal defects. (4) Magnetic crystals arranged in linear chains, thus maximizing the amount of magnetism of each bacterial cell. (5) Magnetite crystals within the chains aligned with their long dimensions parallel to the chain direction, again maximizing the amount of resulting magnetism. (6) Crystal morphologies unique to biologically-produced magnetite. During the question and answer period, Alan Treiman asked if Kirschvink could show that magnetites produced inorganically could not look like those produced biologically. Kirschvink said that identification in a terrestrial rock of magnetofossils is done on the basis of the entire set of

characteristics, not just one of them. It is not just shape. He had also noted at the beginning of his talk that the science of paleontology is based on the idea that morphology can be distinctive.

Kathie Thomas-Keprta, one of the original authors of the paper asserting to have discovered fossil life in ALH 84001, presented a comparison of magnetites in that meteorite with those in terrestrial samples known to have been produced by biological processes. Using the same criteria as described by Kirschvink, she said that 25% of the magnetites in ALH 84001 are chemically pure, and have the sizes and shapes characteristic of terrestrial magnetofossils. She suggested that the remainder of the magnetite grains in the rock formed by inorganic processes. In particular, she noted that whiskers of magnetite can form by inorganic processes, but at low temperatures (less than 150° C).

There was quite a line of questioners after Thomas-Keprta's talk. Hap McSween (Univ. of Tennessee) emphasized that the long, prism-shaped magnetite crystals can be made at high-temperature by growth from a vapor. Thomas-Keprta replied that almost all data pointed to a low-temperature origin for the carbonates, so the vapor-growth analogy is simply not appropriate. (There is a growing consensus that the carbonates formed below about 250° C, but there are still some holdouts to that view.) John Kerridge (UCLA) noted that some of the magnetite could have formed by decomposition of iron-rich carbonates. Thomas-Keprta reiterated that the magnetite grains formed in more than one way. Her co-author Susan Wentworth noted that the magnetites are chemically pure, but formation from carbonates would produce magnetites containing other elements besides iron and oxygen, especially manganese. Peter Buseck (Arizona State Univ.) again questioned the whole idea of uniqueness of morphology in distinguishing magnetite crystals produced by biologic processes from those produced inorganically. Thomas-Keprta again referred to use of the set of criteria to distinguish the two cases.

The carbonates in ALH 84001

The search for life in ALH 84001 centers on complicated deposits of carbonate minerals scattered throughout the rock. Lars Borg and colleagues (Johnson Space Center) have done a remarkable job dating the formation of the carbonates. This required painstaking, sequential chemical separations. Using the rubidium-strontium method, they had previously reported an age of 3.90 (+/-0.04) billion years. This year they obtained a lead-lead age (which is actually an age using the decay of uranium and thorium) of 4.02 (+/-0.02) billion years, in reasonable agreement with the rubidium-strontium age. Thus, the carbonates formed about 4.0 billion years ago. Potassium-argon ages for the meteorite, which date a severe heating event caused by an impact event, are also 3.9-4.0 billion years, possibly suggesting a relation between the impact and the formation of the carbonate. However, the uncertainties in the age determinations are too large to determine whether the carbonate formed before, during, or after the impact event. Nevertheless, the age data show that the carbonates formed during the early, wet period in martian history.

Origin and temperature of formation of the carbonates remains mysterious. Some scientists argue that the carbonates formed at low temperatures, less than 150° C, and possibly less than 100° C. The latter temperature is cool enough for life to have formed and survived. Others argue that the carbonates either formed as the result of an impact event or were severely modified by it. In this case they suggest formation above about 700° C. Now there's a serious discrepancy! However, several papers at the conference produced new data favoring formation at a relatively low temperature, less than about 250° C. This conclusion was made on the basis of experimental formation of carbonates and measurements of the rate at which calcium, magnesium, and iron move through carbonate crystals. This would seem to rule out formation from an impact melt, as has been proposed, but C. H. van der Bogert and colleagues (Brown University) have done some experiments on carbonate minerals to test whether the minerals could be melted by friction heating during an impact event. They brought cylinders of rapidly spinning marble (made of a carbonate mineral called dolomite) and quartzite (made essentially entirely of quartz) into contact for a few seconds and examined the products. The samples contained small areas where carbonate melted and was injected into the surrounding rock, as observed in ALH 84001. Thus, it is possible that the carbonates formed at low temperature, but were remobilized by frictional

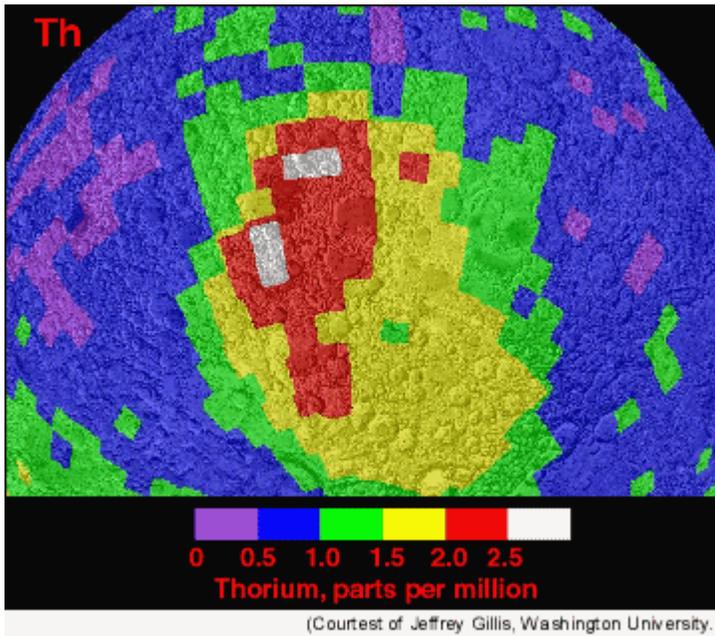
heating associated with extremely rapid deformation of the rock during an impact event. This might make everyone in the argument partly correct, a turn of events that would probably please none of them!

Renaissance in Lunar Science

Lunar scientists are awash in new data. The [Lunar Prospector](#) mission, currently whizzing around the Moon, is sending back data on the Moon's magnetic field, gravity, and surface composition. The mission came on the heels of the spectacularly successful [Clementine](#) mission (run by the Department of Defense, with science support from NASA). Clementine produced the first global topographic map and returned images in several wavelengths. These images allowed scientists to determine the concentrations of FeO and TiO₂ on the lunar surface [See [PSRD](#) article: [Moonbeams and Elements](#)]. The vast amounts of new data are now beginning to be used to understand the Moon's geologic history.

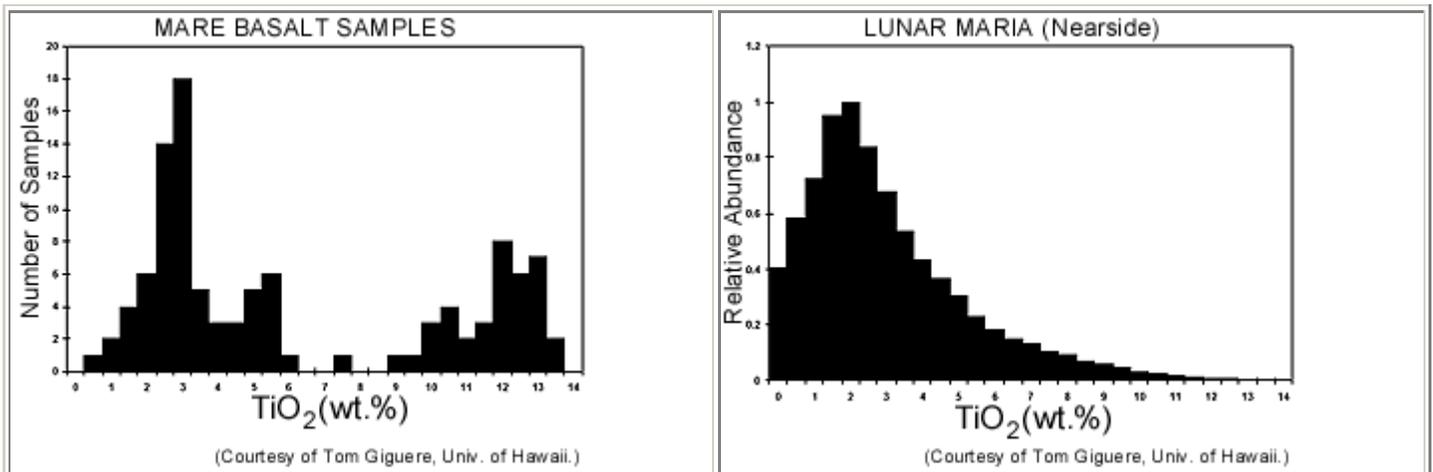
A significant development has been the creation of strong collaborations between scientists expert in lunar sample analysis and those expert in remote sensing techniques. This brings all lunar science expertise to bear on problems in lunar science and is leading to new ideas that the data will allow us to test. This effort is being helped along by the Lunar Initiative, an interdisciplinary project inspired by the Curation and Analysis Planning Team for Extraterrestrial Materials (CAPTEM for short), which is chaired by Jim Papike (University of New Mexico). The initiative is designed to enhance interdisciplinary studies of the Moon. (For those interested in the history of acronyms, CAPTEM used to be called LAPST, the Lunar And Planetary Sample Team. LAPST was the renamed version of LSAPT, the Lunar Sample Allocation Planning Team, which had been created during the [Apollo](#) program to allocate lunar samples to qualified investigators. The name changes reflect the evolving nature of lunar science and extraterrestrial research during the past three decades.)

A lot of work is being done to understand the South Pole-Aitken (SPA) basin on the lunar farside. This is a gigantic impact crater 2500 km across. David Blewett (University of Hawai'i) and colleagues identified several distinct compositional regions within the basin and showed that compositional trends are not consistent with any known lunar rock type. Moreover, although models of the impact process indicate that most of the floor should be composed of rocks from the lunar mantle, no mantle rocks are recognized in the floor of the basin. SPA has a region of elevated thorium in the northwestern part of the basin, which Larry Haskin (Washington University in St. Louis) and his colleagues argue is due to a concentration of ejecta from the Imbrium impact. The Imbrium basin, which makes up the Man-in-the-Moon's right eye, is exactly half way around the Moon from SPA. In fact, the effect of the Imbrium impact on the geology of the lunar nearside is being re-examined. Some scientists, such as Haskin's colleague Randy Korotev, suggest that virtually all impact melts with a composition nicknamed "LKFM" were made by the Imbrium impact, including those from Apollo 15, 16, and 17. This concept is being debated enthusiastically.



Map of the thorium concentration on the farside of the Moon. The map is centered on the South Pole-Aitken basin. The highest thorium concentrations are in the northwest part of the basin (white and red areas), which may represent material from the Imbrium basin.

The value of having chemical compositional data for the entire lunar surface can be shown by the example of the TiO_2 contents of the basalts making up the lunar maria. Tom Giguere (University of Hawai'i) and colleagues compared the relative abundance of mare basalt samples returned by the Apollo and [Luna](#) missions to the Moon with global data obtained by the Clementine mission. The differences are startling, as shown in the histograms (bar graphs) below.



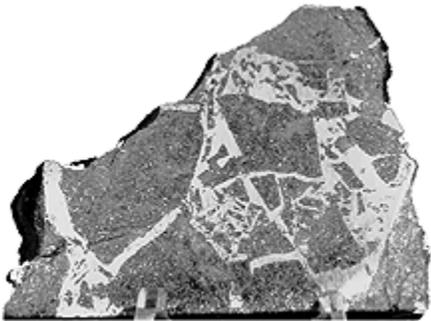
Relative abundances of the titanium oxide concentrations of samples of lunar mare basalts (left) suggest a high abundance of both low- and high-Ti basalts, but few in between. Recent data from the Clementine mission (right), however, shows that basalts with intermediate titanium concentrations are more abundant than those with high concentrations.

If you assumed, as many of us who work on lunar samples had, that the returned samples were representative of the entire Moon, then you would conclude that the basalts come in two major varieties, low-Ti and high-Ti, with little in between. On the other hand, when you look at the global data from Clementine, you see that there are more basalts with intermediate TiO_2 contents than there are high-Ti basalts. The samples returned to Earth are a biased set. This has enormous implications for the nature of the lunar interior.

A Unique, but Important, Meteorite

Ordinary [chondrite](#) meteorites come from several different [asteroids](#). Meteorite specialists have been studying them for many decades, leading up to a relatively simple history of the asteroids. The raw ingredients accreted from the cloud of gas and dust in which the solar system formed, forming objects a few tens to perhaps 200 kilometers in diameter. The decay of [radioactive](#) elements heated the asteroids, causing widespread [metamorphism](#), but no melting. Impacts during this time and after the asteroids had cooled may have disrupted the bodies, which would reassembled into complicated rubble piles.

This somewhat complicated story may be incomplete. A new chapter in the ordinary chondrite story may be written by scientists working on a new meteorite. At about 7:30 a.m. on June 13, 1998, a meteoroid broke up in the atmosphere. The fragments were strewn over an area 7 kilometers long and about 2 kilometers wide near the town of Portales in eastern New Mexico. Forty-nine fragments have been collected, ranging in size from a few tens of grams to 17 kilograms. The meteorite is classified as a "type H ordinary chondrite," but there is something extraordinary about it. It is cut by striking veins of metallic iron-nickel that is decorated with a pattern called the Widmanstätten structure, never seen in a chondrite before. It is unusual enough, in fact, that specimens are selling for several thousand dollars per kilogram! Following standard procedure, the meteorite was named after a local topographic feature, Portales Valley.



(from D. A. Kring, University of Arizona)

Photograph of a polished slice of the Portales Valley meteorite; the slice is 47 millimeters across the base. The rock is crosscut by numerous veins of metallic nickel-iron, unusual for a chondrite.

Parts of Portales Valley appear to be normal chondritic rock, containing 8 volume percent (vol%) metallic iron-nickel, about 4 vol% iron sulfide, and 88 vol% silicate minerals. These percentages are typical of a class of chondrites called H chondrites. However, the rocky portions near the metallic veins contain only half as much metallic iron (4 vol%) and three times as much iron sulfide (12 vol%) as H chondrites normally have. In addition, the regions near the metal veins contain smaller silicate crystals than do typical H chondrites. Then there's the striking metallic veins: these are unprecedented in H chondrites, especially because they contain the Widmanstätten pattern. This pattern is an intergrowth of two metallic minerals, one low in nickel and the other high in nickel. Compositions and sizes of the minerals indicate a cooling rate of about 5 degrees C per million years, in the range experienced by most H chondrites. There are no signs that the meteorite has been shocked by an impact event. (Shock is recorded in mineral grains and different levels of shock produce diagnostic features in minerals.) Finally, potassium-argon dating of the rock indicates that the rock is 4.5 billion years old.

All speakers at the conference agreed on these observations. There were differences of opinion about how the metallic veins were formed, however. Dave Kring (Univ. of Arizona), Alex Ruzicka (Univ. of Tennessee), and Al Rubin (UCLA) argued that the large metallic veins and other unusual features in the rock were produced by an impact event on the H-chondrite asteroid. This event would have happened very early in the history of the asteroid and the portion that gave rise to Portales Valley must have been buried deeply after the impact. The slow cooling after the impact would have erased any shock effects from the event. Dave Kring even tried to reconstruct the crater, estimating that it was at least 20 km in diameter. However, such estimates require better knowledge of the thermal conductivity of the crater deposits than we currently have.

An alternative viewpoint was expressed by Lewis Pinault (Univ. of Hawai'i). He and his colleagues argued that the veins could have formed by partial melting of the H-chondrite asteroid, which caused the metal and sulfides to migrate and collect into veins. This is a startling departure of our previous view of the H-chondrite parent asteroid, which depicted an upper limit of only about 900° C, below the melting temperature of H-chondrites. If this is correct, then the lack of shock effects is understandable: there never were any in this rock. Ed Scott, Pinault's co-author, presented a separate talk in which he argued that several H-chondrites experienced melting, as did other meteorite groups previously thought not to have been heated enough to melt.

Neither side explained the distribution of iron sulfide or why the ratio of metallic iron to iron sulfide varies in different parts of the rock. Clearly, much more research is needed. The work is important as it may completely change our view of the geologic histories of the asteroids in which several types of meteorites formed. Impacts may have been more severe or the bodies may have melted more extensively, or both, than thought previously.

Additional Resources

All abstract references listed below are from:

Lunar and Planetary Science Conference XXX, 1999, LPI Contribution No. 964, Lunar and Planetary Institute, Houston (CD-ROM). <http://www.lpi.usra.edu>.

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Borg, L. and others, 1999, Pb-Pb Age of the Carbonates in the Martian Meteorite ALH84001 [abstract #1430].

Giguere, T. and others, 1999, distribution of the Titanium contents of Lunar Mare Basalts: Not Bimodal [abstract #1465].

Haskin, L. and others, 1999, On the Distribution of Th in Lunar Surface Materials [abstract #1858].

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McKay, D. S. and others, 1999, Possible Bacteria in Nakhla [abstract # 1816].

Pinault, L. and others, 1999, Extraordinary Properties of the Metal-Veined, H6 Portales Valley Chondrite: Evidence for Internal Heating Versus Shock-Melting Origins [abstract #2048].

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van der Bogert, C. H. and others, 1999, Experimental Frictional Heating of Dolomitic Marble: New Insights for Martian Meteorite Allan Hills 84001 [abstract #1970].

[Astrobiology](#): the study of the living universe.

[Lunar Prospector](#) homepage.