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Hot Idea

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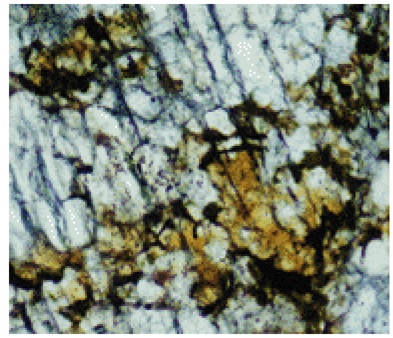
Shocked Carbonates May Spell N-O L-I-F-E in Martian Meteorite ALH84001



Photomicrograph of carbonates (gold color) in fractured pyroxene crystal. Width 300 micrometers. (by A. Yamaguchi)

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In an electrifying paper published in August, 1996 in the journal *Science*, David McKay (NASA Johnson Space Center) and his colleagues suggested there were fossils of martian organisms associated with carbonate minerals in martian meteorite ALH84001. How these carbonate minerals formed (biologic origin or not) and the temperature at which they formed (low or high) are hotly debated questions. We have proposed an entirely different origin: the carbonates in ALH84001 formed in seconds at high temperatures (>1000^{o}C) from melts produced during a large impact on Mars 4.0 billion years ago (Scott and others, 1997). We infer that it is unlikely that the carbonates or any minerals in them contain mineralogical evidence for ancient martian life.

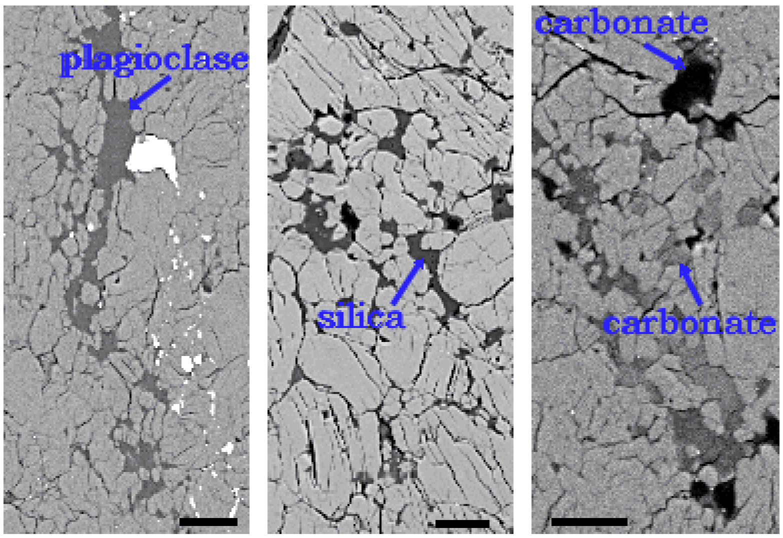
Reference: Scott, E.R.D., A. Yamaguchi, and A.N. Krot, 1997, "Petrological Evidence for Shock Melting of Carbonates in the Martian Meteorite ALH84001", *Nature,* v. 387, p.377-379.

Story of a Shocked Rock

When an asteroid or comet hits a planet its kinetic energy is transformed into high-pressure shock waves that travel into the ground, compressing, vaporizing, melting, fracturing, and moving the target rock. An important feature of ALH84001 is that it was part of the target material on Mars when a powerful impact event took place about 4.0 billion years ago, as depicted in this artist's rendition. This event no doubt moved ALH84001 from its original location in the martian crust, and heated the rock enough to record the time of the event. The shock wave also converted the silicate mineral, plagioclase, into glass. We studied meteorite ALH84001 because we wanted to know how the carbonates and other minerals had been affected by shock events. We infer that the shock wave melted and drastically redistributed the carbonate minerals, already present in the rock, obscuring how they were originally formed. (Graphics by Brooks Bays, PSR Discoveries graphic artist.)

Close Look at the Cracks

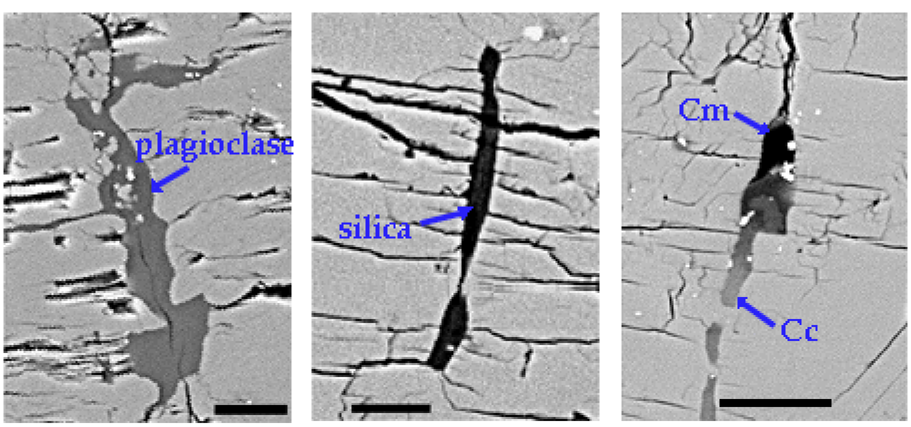
An optical microscope and a scanning electron microscope gave us a close look at the settings where carbonate and other minerals occur in martian meteorite ALH84001. We were surprised to find other grains besides carbonates filling the cracks in the meteorite. These grains are tiny (0.005-0.05 millimeter) and are made of glass with chemical compositions very close to the minerals plagioclase and silica. Grains or veins of carbonate commonly occur in the same or parallel cracks. The cracks are found in pyroxene crystals (the mineral that makes up over 95% of the rock). Some carbonate grains enclose broken pieces of pyroxene.



Scale bars are 20 µm. (from Scott et al., 1997)

Scanning electron microscope images of ALH84001 (above) show plagioclase feldspar (left), silica (center), and carbonate (right). All surround broken pieces of pyroxene. We suggest that these texures formed by high-pressure shock waves that not only fractured the pyroxene but also injected molten plagioclase, silica, or carbonate into the cracks.

Plagioclase, silica, and carbonate also occur as thin veins within pyroxene crystals as seen in the three images below.



Scale bars are 20 µm. (from Scott, et. al., 1997)

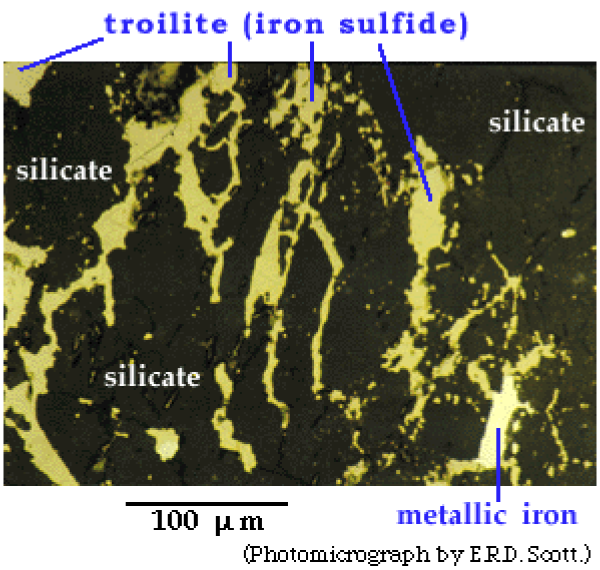
Carbonate veins vary in composition from calcium rich (Cc) to more magnesium rich (Cm). We think the cracks in the pyroxene crystals were sealed quickly under pressure squeezing and trapping the melts inside.

The shapes, compositions, and locations of glasses and carbonates in ALH84001 suggest that they ***all*** formed from melts produced by a shock wave. The melts then squirted into fractures in the pyroxene where the melts cooled quickly and the fractures resealed under pressure. As the pyroxene crystals were not heated by more than a few hundred degrees centigrade, the tiny volumes of melted minerals must have solidified in seconds before they could mix together or react with the pyroxene.

Other Shocked Meteorites Add to the Story

Comparisons with strongly shocked meteorites called L chondrites are useful in understanding the abundances, shapes, sizes, and location of carbonates and glasses in martian meteorite ALH84001. L chondrites are composed of silicate minerals (mostly olivine and pyroxene, but feldspar as well), metallic nickel-iron and iron sulfide (called troilite). Most of them are severely shock-damaged, probably by a large impact on the asteroid in which they formed.

Plagioclase feldspar and silica are readily melted by shock waves to form glasses. Yet, pure melts of these minerals are not generally present in veins in shocked rocks. Instead, the shock melts normally seen in veins are made from several minerals. However, when we examined some strongly shocked L chondrites, we found tiny veins and grains of glass with compositions close to that of plagioclase feldspar. These veins and grains are found in healed fractures in silicates, just like those in ALH84001. They hadn't been described before probably because they are so tiny and difficult to analyze.



Silicate crystal in an L chondrite contains shock melts of troilite (iron sulfide) and metallic iron-nickel.

Other researchers have concluded that the troilite and metallic iron-nickel melts were injected into cracks in the silicate crystals as the shock pressures decreased. Carbonate and troilite melts both have very low viscosities, unlike plagioclase and silica melts. The difference in viscosity is comparable to the difference between water (low viscosity) and something like shampoo (relatively higher viscosity). Although carbonate is readily heated by shock it is liable to decompose to form carbon dioxide unless pressures are high enough during cooling. We do not know of other meteorites and rocks with shock-melted carbonates that are quite like those in ALH84001.

Reconciling Conflicting Interpretations

A different impact mechanism for the formation of the martian carbonates was proposed in July, 1996 by

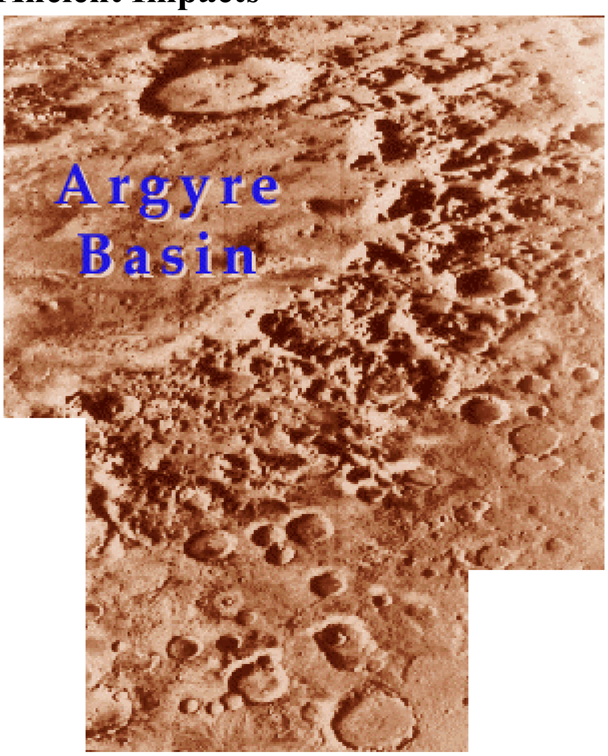
Ralph Harvey (Case Western Reserve University) and Harry Y. McSween (University of Tennessee). Harvey and McSween inferred that the carbonates formed by reaction between silicates and an impact-produced fluid rich in carbon dioxide that infiltrated fractured rock at depth. Their model differs from ours in several important respects. We find no textural or mineralogical evidence to suggest that the existing carbonates formed by reaction between silicates and a fluid. We argue instead that carbonates were already present in the rock before the impact. Because the melts were only hot for seconds, there was not enough time for the melts to react significantly with the silicates or for the chemical variations in the carbonate crystals to be erased.

Supporters and some critics of the paper by McKay and coworkers argue that the carbonates in ALH84001 formed at low temperatures by precipitation from a fluid. [For example, see **PSR Discoveries** article "Low-temperature Origin of Carbonates consistent with Life in ALH84001."] This interpretation is based largely on the heterogeneous (nonuniform) composition of the carbonates, a common feature of carbonates produced at low temperature on Earth. In addition, the carbonates in ALH84001 could not have been at high temperatures for long periods (days or weeks) or they would have uniform compositions.

The possibility of high-temperature formation in a few seconds was not previously considered as the rock itself is too large to cool in seconds. However, impacts can do amazing things: tiny volumes of various mineral melts can be produced by shock, squirted into fractures, and cooled quickly under pressure. Carbonate melts form crystals rather than glasses when cooled rapidly because atoms diffuse quickly in carbonate melts. The unusual surface texture of fractured carbonates reported by McKay and colleagues may reflect rapid growth in a rapidly cooling melt.

We suggest that the key evidence necessary for understanding the origin of the carbonates in ALH84001 is the similar distribution and shape of the carbonates and glass veins and grains in the fractured pyroxene crystals. Our observations lead us to infer that the carbonates in ALH84001 crystallized from impact melts, and therefore could not have formed at the low temeratures needed for life. Experiments are now needed to test if carbonates can solidify from melts to form heterogeneous crystals like those in ALH84001. We conclude that the search for fossil evidence of life on Mars should not be focused on the carbonates in ALH84001.

Ancient Impacts



Argyre basin, about 900 kilometers in diameter, is an impact structure in the southern hemisphere of Mars (50^{o}S, 40^{o}W). It probably formed very early in the history of Mars, about 4 billion years ago. Other smaller impact craters decorate the area. (NASA Viking Orbiter mosaic P17002.)

No matter how our study affects the case for life on Mars, it demonstrates the importance of impacts on ancient planetary surfaces. The surfaces of Mars, the Moon, and Mercury, as well as many of the satellites of the outer planets, were bombarded severely early in their histories. This bombardment greatly affected the crust of the Moon, as we know from samples returned by the Apollo missions, but ALH84001 is the first sample from Mars to give us a first-hand look at the effects of impact early in the history of the red planet. Whether or not there is fossil life in ALH84001, this rock contains a wealth of information about the ancient martian crust.

Editor's note: The temperature at which the carbonates in ALH84001 formed is one of the most hotly debated issues about the evidence for fossils in the meteorite. For an opposing view, see **PSR Discoveries** article Low-temperature Origin of Carbonates Consistent with Life in ALH84001 posted on May 22, 1997.

Additional Resources

Harvey R.P and H. Y. McSween Jr., 1996, A possible high-temperature origin for the carbonates in the martian meteorite ALH84001, *Nature,* v. 382, p. 49-51.

Kerr R., 1997, Martian "microbes" cover their tracks, *Science,* v. 276, p. 30-31.

McKay D.S. et al., 1996, Search for past life on Mars: possible relic biogenic activity in martian meteorite ALH84001, *Science,* v. 273, p. 924-930.

Scott E. R. D., A. Yamaguchi, and A. N. Krot, 1997, Petrological evidence for shock melting of carbonates in the martian meteorite ALH84001, *Nature,* v. 387, p. 377-379.

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