

Hot Idea

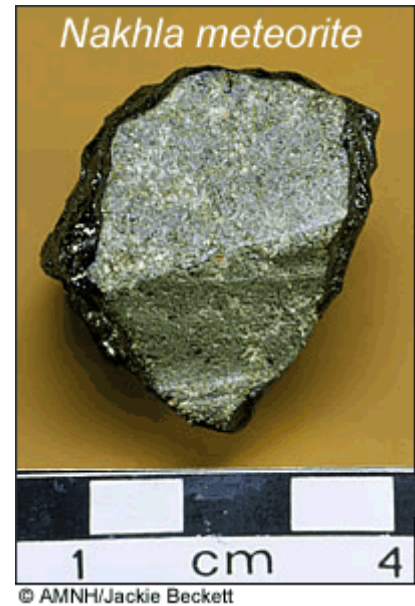
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Martian Meteorites Record Surface Temperatures on Mars

--- Gases trapped in Martian meteorites indicate that Mars has been a cold desert for a long, long time.

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Using published data for argon (Ar) released when Martian meteorites are heated, David Shuster (California Institute of Technology, now at Berkeley Geochronology Center, Berkeley, CA) and Benjamin Weiss (Massachusetts Institute of Technology) show that the nakhlite group of [Martian meteorites](#) and unique Martian meteorite ALH 84001 were probably not heated above about 0 °C for most of their histories. This indicates that the surface of Mars has been cold for almost four billion years. If a warm, wet environment existed on Mars (inferred from previous studies of surface features and geochemical parameters), it occurred before four billion years ago.

Reference:


- Shuster, David L. and Benjamin P. Weiss (2005) Martian surface paleotemperatures from thermochronology of Meteorites. *Science*, vol. 309, p. 594-597.

Soaking Wet, Bone Dry Mars

Climate change on Earth is often in the news. Climate specialists worry about swings in global temperatures of several degrees Celsius. This does not sound like much, but it is enough to cause ice ages sometimes and widespread shallow seas at other times. But those changes are nothing compared to what the planet Mars seems to have experienced. Mars is decorated with huge channels eroded when vast quantities of water flowed through them. Oceans may have existed in the northern plains. Valley networks decorate the planet's surface. Yet now it is a dry, cold place. The daily average temperature at the equator is an ultra-nippy 60 °C below zero. Its monotonous dry climate has been enlivened occasionally by water seeping from the sides of impact craters, and changes in the planet's tilt may have moved glaciers from the current poles to more equatorial regions, but basically it has been colder and drier than anyplace on Earth. Yet at some time in the past, probably billions of years ago, Mars was a much warmer and wetter place.


Mars flaunts strong evidence for vigorous water activity in the past (see images below from left to right), such as immense, water-carved outflow channels, valley networks, possibly an extensive northern ocean, and presence of layered deposits whose origin involved evaporation of salty water.

Water Features on Mars



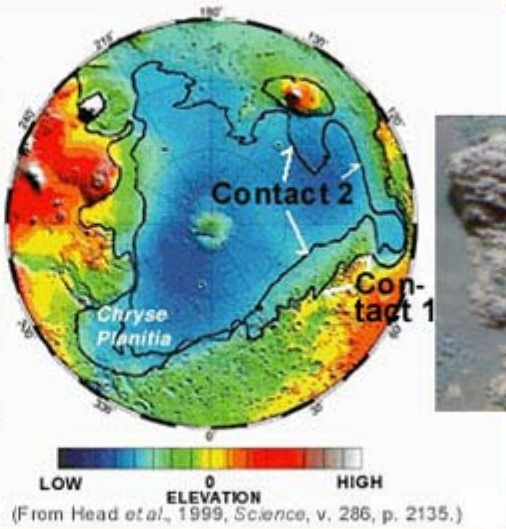
<Flood Channels near Lucus Planum
THEMIS image

NASA/JPL/ASU



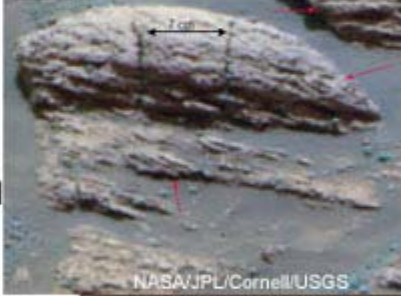
^ Fine Channel Networks
Viking Orbiter image

NASA/JPL PIA00413



^ Elevation Map of Northern Hemisphere
Showing Possible Ocean Margins

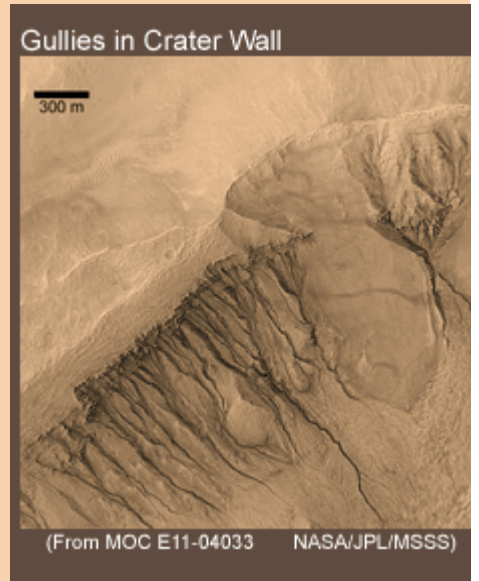
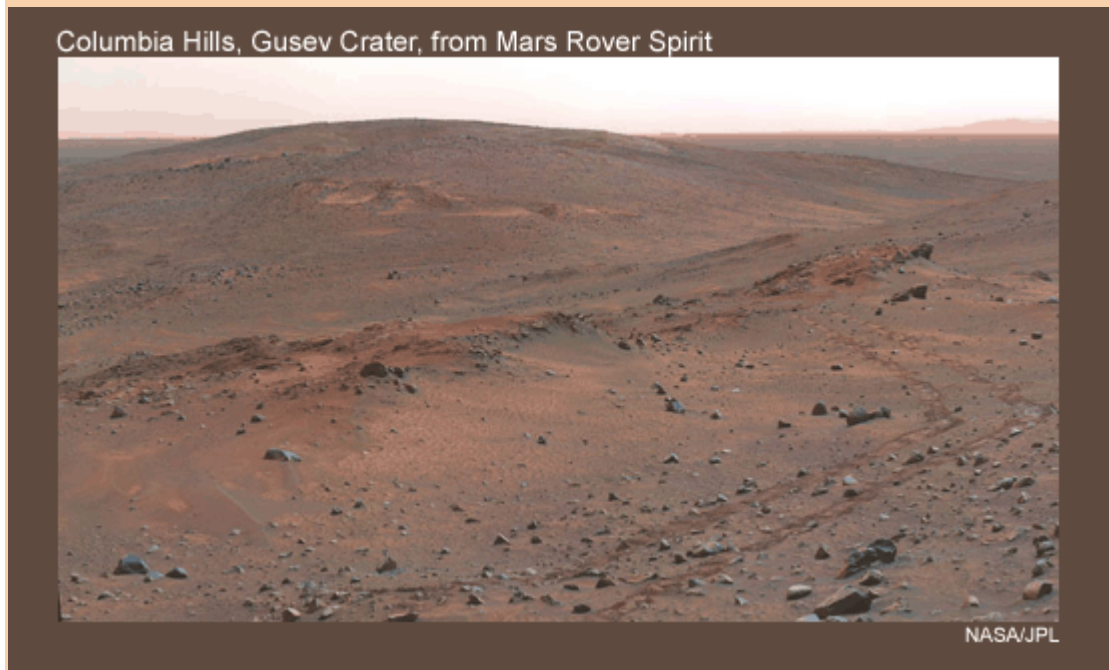
(From Head *et al.*, 1999, *Science*, v. 286, p. 2135.)



^ Opportunity Camera
Finds Crossbedding in
"Last Chance" Rock --
Evidence for Underwater
Origin

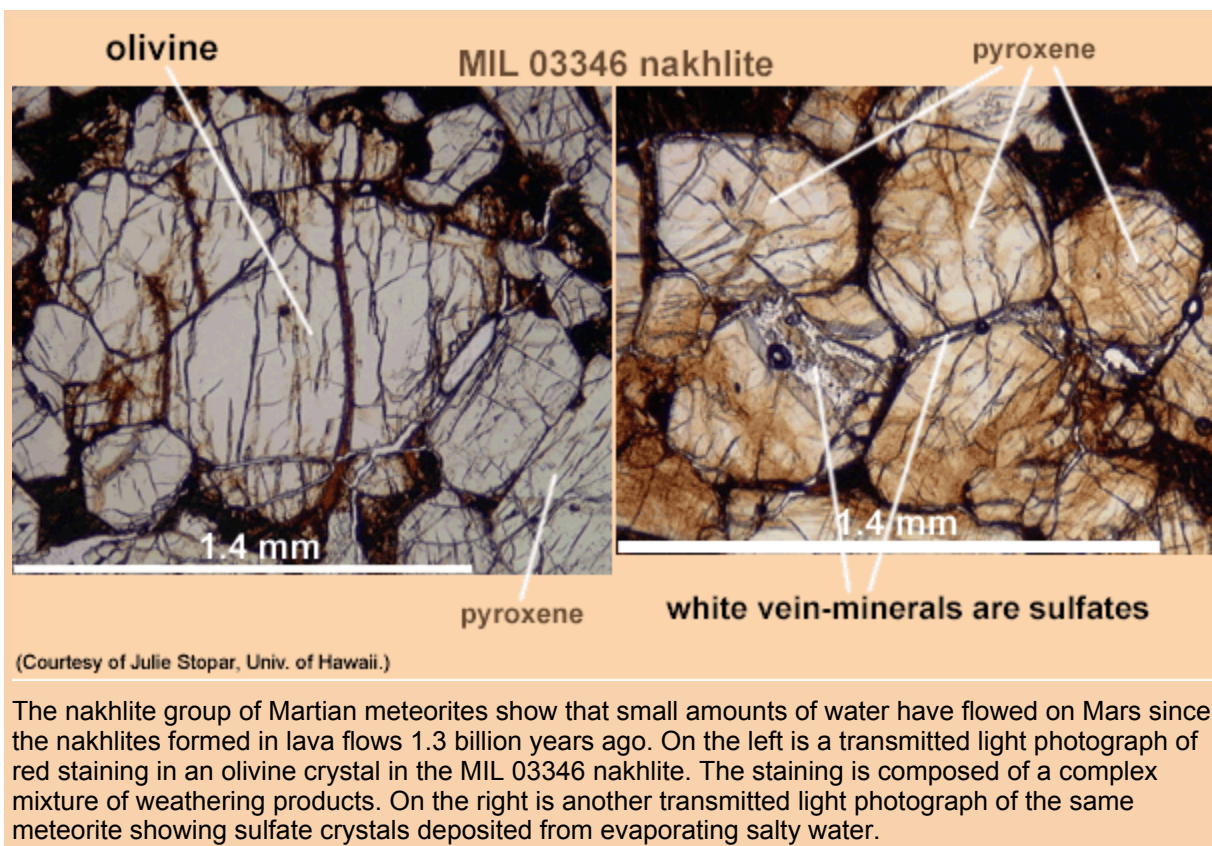
NASA/JPL/Cornell/USGS

On the other hand (see images below), it appears today to be extremely dry, a vast desert shaped mostly by wind, except in a limited number of locales where water has recently formed gullies on the walls of impact craters.



David Shuster and Benjamin Weiss wanted to determine past temperatures during this impressively long Martian cold, dry spell. Experts in determining the ages of rocks using potassium-argon dating and its advanced cousin, $^{40}\text{Ar}/^{39}\text{Ar}$ dating, they reckoned that Martian meteorites contained a record of surface temperatures. This is possible because Ar leaks out of rocks unless they are kept cool enough. They chose to study the nakhlite group of Martian meteorites because they do not have the same level of shock damage by meteoroid impact as do other types of Martian meteorites, thereby minimizing one form of heating besides surface temperature. They also studied data from Allan Hills (ALH) 84001 because it is by far the oldest in our collection of Martian meteorites. (For evidence that Martian meteorites actually do come from Mars, go to the [curatorial office](#) at the Johnson Space Center.)

Nakhlites have already proven to be useful in assessing the timing of relatively recent aqueous events on Mars (see [PSRD article: Liquid Water on Mars: The Story from Meteorites](#)). The nakhlites contain mineral grains formed by the reaction of water with original minerals and deposition of others as the solutions dried up (see images below). Tim Swindle and his colleagues at the University of Arizona determined from potassium-argon dating that these water-based alteration events were of short duration and took place intermittently during the past 600 million years or so. Shuster and Weiss hoped to look at a broader time scale and to set limits on the temperature during the past 4 billion years.

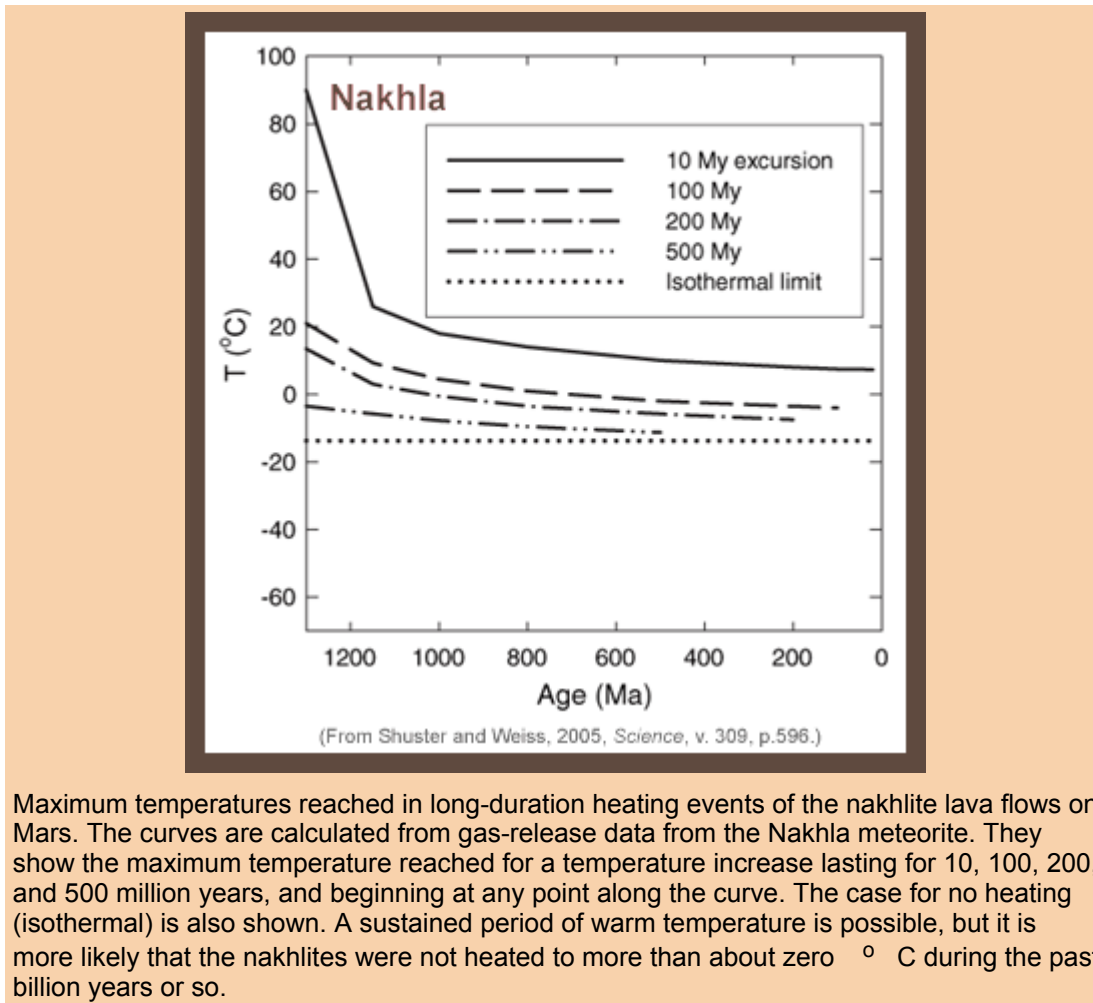


Using Ages to Deduce Temperatures

The startling thing about nakhlites is that all age dating techniques give the same age for their origin as igneous rocks, 1.3 billion years. You'd think that the concordance of ages by potassium-argon, rubidium-strontium, uranium-lead, and samarium-neodymium would not be surprising. If these techniques really work to date a rock and the rock formed at a given time, shouldn't they all yield the same result? They would, if nothing happened to a rock after it was formed, but it can be heated, metamorphosed, shocked (by impact), and altered by water. Because each age-dating technique is affected by these events differently, they tend to yield different apparent ages. The fact that the nakhlites give the same age for all systems indicates that they have had a relatively simple history. Even uranium-thorium-helium dating, which is easy to alter because helium leaks out of minerals like sand through a sieve (even at low temperatures), gives about the same age (0.8 to 1.2 billion years).

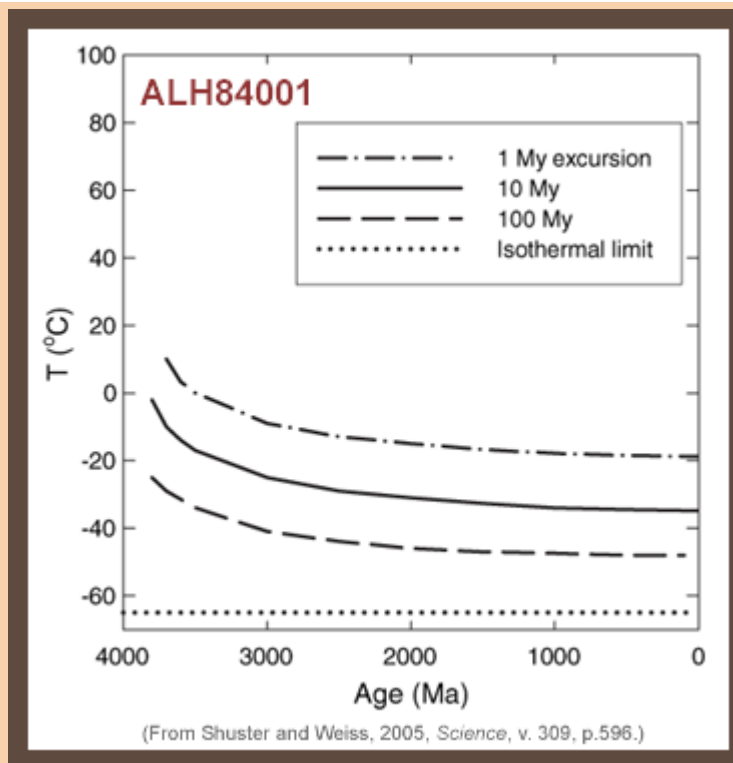
$^{40}\text{Ar}/^{39}\text{Ar}$ age dating involves irradiating a sample with fast neutrons in a nuclear reactor and then measuring the ratio as the sample is heated progressively from low temperature (about 250 °C) to higher temperature (up to 1200 °C). Because ^{39}Ar is produced from nuclear reactions with ^{39}K , the experiment measures both potassium and ^{40}Ar at the same time. This progressive heating causes release of the gases from different minerals sequentially, providing information about the temperature-time history of the rock. This can be quantified by knowing the rates at which argon diffuses out of mineral grains and the sizes of the mineral grains. The result is that the nakhlites appear to have lost only 1% of the ^{40}Ar produced by the decay of ^{40}K since they formed 1.3 billion years ago.

The problem is that Shuster and Weiss did not know how hot the nakhlites got or for how long. Nevertheless, they could test different intensities of heating events to produce a set of solutions that result in loss of only 1% of the ^{40}Ar from the nakhlites. The calculations are shown in the diagram below. If the nakhlites were never heated after they formed, they would preserve their age if held at a temperature of about minus 15 °C. If heated for a period of 10 million years, they could have reached as high as about 90 °C if the heating happened soon after they formed, but much less if more recent. A 10-million-year heating event that occurred during the past one billion years would not have heated the nakhlites to more than about 20 °C. Longer duration heating events must have been much cooler than 20 °C, and most likely not much higher than zero °C (see graph below).



Maximum temperatures reached in long-duration heating events of the nakhlite lava flows on Mars. The curves are calculated from gas-release data from the Nakhla meteorite. They show the maximum temperature reached for a temperature increase lasting for 10, 100, 200, and 500 million years, and beginning at any point along the curve. The case for no heating (isothermal) is also shown. A sustained period of warm temperature is possible, but it is more likely that the nakhlites were not heated to more than about zero °C during the past billion years or so.

A similar analysis can be done for the ancient ALH 84001 meteorite. The calculations in that case indicate that in all likelihood that meteorite, which was shock-heated 3.9 billion years ago, was not since heated above 0 °C for longer than a million years. In fact, it is likely that it was never hotter than about 7 °C for more than a million years during the past 3.9 billion years (see graph below). This suggests that Mars has been mostly a dry desert for all that time.

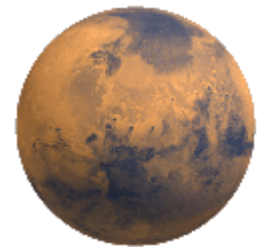


The ancient meteorite ALH 84001 formed about 4.5 billion years ago, but was shocked (probably when excavated from great depth) 3.9 billion years ago. Since then, it could not have been heated to much more than zero °C for more than a million years.

One worry is that the nakhlites and ALH 84001 could have been heated when a big impact launched them from Mars. Shuster and Weiss address this problem. Using the same techniques to calculate gas loss, and knowing from the cosmic ray exposure ages of nakhlites that they were launched 11 million years ago, Shuster and Weiss calculate that the meteorites could not have been heated to more than 350 °C for more than a few hours.

The Long Drought

If Shuster and Weiss' analysis is correct, the areas on Mars that were home to the nakhlites and ALH 84001 got neither warm nor wet for very long. Short increases in temperature and brief wet spells are certainly allowable, and even required by the presence of weathering products in the nakhlites. Mars appears to have been a desert for billions of years. This implies that if life arose on the Red Planet, it is likely to be hidden underground. Places with groundwater beneath a permanently frozen underground cryosphere may be teeming with life. Or not. We can search for this life by drilling deep into the crust, or by choosing the right spots to sample, such as the terminations of young gullies and other apparently youthful features shaped by flowing water.



Shuster and Weiss also point out that the lack of heating of the nakhlites and ALH 84001 when they were blasted off Mars indicates how easily undamaged materials can be lifted off Mars and sent to Earth. The inner planets might not be biologically isolated from each other. Life on Mars (if there is life on Mars) might be related to life on Earth. We may all be one big, solar system family.

Additional Resources

LINKS OPEN IN A NEW WINDOW.

- [Mars meteorites](#) comprehensive page from Ron Baalke, Jet Propulsion Lab.
- [Martian meteorites](#) from the American Museum of Natural History.
- MIL 03346: New Martian meteorite found in Antarctica, [News release](#) from Case Western Reserve University (2004).
- Shuster, David L. and Benjamin P. Weiss (2005) Martian surface paleotemperatures from thermochronology of Meteorites. *Science*, vol. 309, p. 594-597.
- Taylor, G. J. (2000) Liquid Water on Mars: The Story from Meteorites. *Planetary Science Research Discoveries*. <http://www.psrд.hawaii.edu/May00/wetMars.html>



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