FLUID INCLUSIONS IN ALH 84001 AND OTHER MARTIAN METEORITES: EVIDENCE FOR VOLATILES ON MARS R. J. Bodnar, Fluids Research Laboratory, Department of Geological Sciences, Virginia Tech, Blacksburg VA 24061-0420. e-mail: bubbles@vt.edu

Introduction: The important role that volatiles play in planetary evolution is well known. On earth, volatiles have and continue to play key roles in the development and properties of the crust, hydrosphere and atmosphere. More recently, the recognition that the mantle contains small but ubiquitous quantities of volatile components has led to an improved understanding of mantle rheology and chemistry and the recycling of volatiles in the earth system. And, of course, volatiles, especially water, are considered to be a prerequisite for the origin and evolution of life as we know it.

The recent announcement that evidence for life had been discovered in the ALH 84001 martian meteorite (1), combined with the highly successful Mars Pathfinder Mission has led to renewed interest in the geochemical evolution of Mars. Much of the scientific effort in this area has been devoted to characterizing the volatiles present in the SNC meteorites and, by inference, the volatiles present on Mars when the rocks formed. Here, the occurrence of "free" volatiles (i.e., volatiles occurring in the fluid state, and not as minor components of minerals and/or glasses) in the ALH 84001 and Nakhla meteorites is reported, along with possible implications.

Background: Fluid inclusions are micro-samples of fluid (liquid or gas) trapped in rocks and minerals either at the time of their original formation, or at some later time as fluids flow through rocks along fractures (2). The presence of fluid inclusions in terrestrial rocks is the rule rather than the exception. Indeed, the rock sample that contains no inclusions that are visible at high magnification (>1000x) is rare, and many minerals such as milky quartz may contain up to 10^9 fluid inclusions per cubic centimeter.

The precursor of the martian meteorites is thought to be ultramafic igneous extrusive and/or intrusive rocks that were blasted from the surface of Mars during an impact event. Similar igneous rocks on earth commonly contain fluid inclusions along with the more abundant silicate, sulfide and carbonate melt inclusions. As such, it is reasonable to expect that the SNC meteorites should contain fluid inclusions that represent fluid trapped in the rocks while they were on the surface of Mars. A review of the recent literature failed to find any references to fluid inclusions in these well-studied samples, and a systematic search of available SNC meteorite samples was undertaken.

Observations: Fluid inclusions have been found in two thin sections of SNC meteorites - one in Nakhla (NSNM 5891-3) and one in ALH 84001, 146.

Nakhla (NSNM 5891-3). The inclusion in the Nakhla sample is tubular in shape and is about 8 microns long. The inclusion is one of several dozen inclusions forming a healed fracture that cuts through an orthopyroxene crystal. Most of the inclusions along the fracture are dark with noticeable microfractures extending from the inclusion into the surrounding mineral, indicating that the inclusions have decrepitated (exploded) owing to pressure buildup within the inclusion. This behavior is common for high-density liquid fluid inclusions in terrestrial samples. A few other inclusions along the fracture were clear (transparent) but did not contain a visible bubble. This is because either the inclusions were empty, or contained only liquid with no vapor bubble, or contained a bubble that was motionless and hidden in a corner of the inclusion. The bubble in the one unambiguous fluid inclusion in this fracture plane was in constant. slow motion, proving that the inclusion did indeed contain a liquid phase.

Although it was not possible to conduct the types of tests normally used to determine fluid inclusion compositions because of the manner in which the sample had been prepared, the difference in index of refraction between the liquid and the vapor bubble is consistent with the inclusions containing liquid and vapor carbon dioxide, although it is possible that the inclusion contained liquid water and water vapor.

ALH 84001, 146. The second sample that contained liquid inclusions with moving bubbles was ALH84001, 146. The inclusions in this sample were spherical to negative-crystal shaped, about 1-2 microns in diameter, and not along an obvious fracture (Figure). The fact that the inclusions are not along a fracture is important because it suggests that the inclusions are primary, i.e., trapped during growth of the enclosing pyroxene. The fluid in the inclusions thus represents the magmatic fluid that exsolved from the crystallizing melt as the igneous rock formed on Mars. As such, the inclusions can provide valuable information about degassing early in Mars history. As with the inclusion in Nakhla, no direct chemical tests could be conducted on these inclusions, but the optical behavior of the inclusions suggests that they contain liquid and vapor carbon dioxide.

Figure Caption: Series of photomicrographs captured from a video tape showing a fluid inclusion with a moving vapor bubble in the martian meteorite ALH 84001, 146. The inclusion is about 1.8 microns in diameter. Note that the dark, rounded vapor bubble, indicated by the arrow in the third image from the top, is located in a different position in each of the five images. When examined under the microscope at room temperature, the bubble is in continuous rapid Brownian motion from the small thermal gradients caused by the microscope light source.

Implications: The occurrence of (presumably) carbon dioxide fluid inclusions in both the Nakhla and ALH 84001 meteorites suggests that carbon dioxide was migrating through these igneous rocks at some time duration or after their formation on Mars. If the carbon dioxide was present at or near magmatic temperatures, pyroxene (enstatite) would not be stable in the presence of carbon dioxide, and would react to form a carbonate and a silica-rich phase (3). This is consistent with a high temperature origin for the carbonates in the SNC meteorites, as originally proposed by Harvey and McSween (4). This interpretation also suggests that the carbonates were present in the rocks before they were ejected from the martian surface. However, by analogy with terrestrial samples, the carbonates did not necessarily have to form as a result of the impact event but, rather, may have formed as a result of natural high temperature igneous metasomatic processes before the impact.

References:

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