OLIVINE AND CARBONATE GLOBULES IN ALH84001: A TERRESTRIAL ANALOG, AND IMPLICATIONS FOR WATER ON MARS. A. H. Treiman. Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston, TX 77058, treiman@lpi.usra.edu.

Abstract: Carbonate globules in ALH84001 are associated with small olivine grains [1] – an unexpected finding because the olivines equilibrated at high T while the carbonate is chemically zoned and unequilibrated. A possible explanation comes from a terrestrial analog on Spitsbergen (Norway) [2], where some carbonate globules grew in cavities left by aqueous dissolution of olivine. For ALH84001, the same process may have acted, with larger olivines dissolved out and smaller ones shielded inside orthopyroxene. Carbonate would have been deposited in holes where the olivine had been. Later shocks crushed remaining void space, and mobilized feldspathic glass around the carbonates.

Introduction: The ALH84001 Martian meteorite is an orthopyroxenite, important for data it can provide about ancient Mars and its water. ALH84001 crystallized from basalt magma at ~4.55 Ga [3], was deformed, and had Mg-Fe-(Ca) carbonate deposited in it at ~4.0 Ga [3-5]. The carbonates formed at low temperature, 0-150°C [5]; possible environments include evaporite [6,7], hydrothermal [2], lacustrine [8], marine [9], and periglacial [10].

ALH84001 Carbonates and Olivine: ALH84001 contains chemically zoned masses of carbonate minerals in the forms of hemispherical globules (Fig. 1), pancakes, slabs, and lacework. Globules were first interpreted as replacing feldspar or feldspar glass [4,11-13]. However, their shapes are explained better as aqueous deposits in fluid-filled cavities [2,14; see 15]. Remaining open space would have been crushed closed during a shock event and filled by mobile feldspathic melts [4,5]. Pancakes and slabs were deposited in open fractures [16].

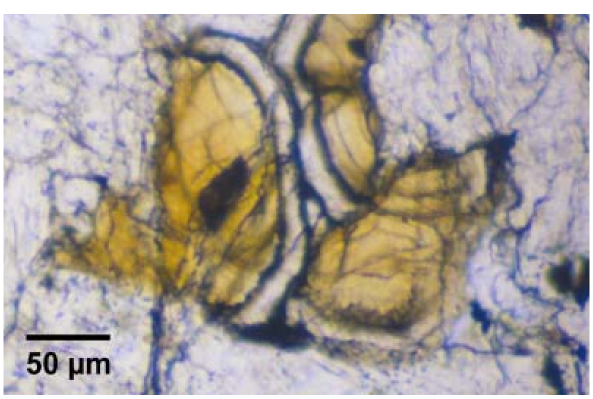

Fig. 1. ALH84001 carbonate globules. Crushed hemispheres in feldspathic glass and orthopyroxene (sect. ,142).

Small grains of olivine are scattered in the abundant orthopyroxene, but only within ~100 µm of carbonate globules [1]. This association of carbonate and olivine implies that they have related origins. But the carbonate globules are strongly zoned (Fig. 1) while the olivine grains are unzoned and equilibrated with surrounding orthopyroxene at T>800°C [1,11].

How can low-temperature carbonate globules be associated with high-temperature olivine? Shearer et al. [1] suggest that cation diffusion in carbonate is slow, and that olivine could have by reaction between orthopyroxene and magnesite from the globules, $MgCO_3 + MgSiO_3 = Mg_2SiO_4 + CO_2$, during metamorphism. However, cations in carbonate minerals diffuse rapidly enough that the ALH84001 globules could not have experienced significant times above ~450°C [17]. Studies of a terrestrial analog to ALH84001 provide a possible solution to this dilemma.

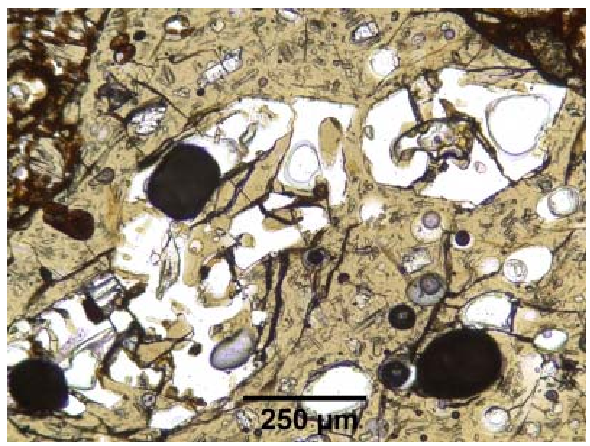

Fig 2a. Basalt sample 01SV08 from Sverrefjell, Norway; thin section, plane light. Tan is basaltic glass, vesicles to bottom and right. White area, upper right to lower left, is a cavity in the shape of olivine, with some relict olivine at lower left (Fig. 2b). Black areas are bubbles filled with crud.

A Terrestrial Analog: The best (and best documented) terrestrial analogs for the ALH84001 carbonate globules are in Quaternary basaltic volcanos of northern Spitsbergen Island, Norway [2]. There, chemically zoned masses of Fe-Mg-(Ca) carbonate mineral are found in pyroclastics, in pillow lavas, and in xenoliths of mantle and crustal rocks. The chemical compositions of the carbonates span a wide range, including that of ALH84001 [2]. As in ALH84001, their cores are generally enriched in Ca and Fe, and zone outwards toward pure Mg (magnesite). Commonly, globules lie on zeolites and are coated by smectite, suggesting that they formed at low temperatures.

Carbonate masses occur as hemispherical globules and slabs in what was open space. Most reported globules sit in vesicles, either in basalt or in melt pockets in xenoliths [2]. Globules also coat surfaces of pyroclasts and cement them together. In peridotite xenoliths, carbonate masses occur in cracks and holes through olivine. In a few thin sections, olivine is partially replaced by magnesite and silica, suggesting the reaction: $Mg_2SiO_4 + 2CO_2 = 2MgCO_3 + SiO_2$. To conserve volume, Mg and Si must be have been transported out of the xenoliths. Carbonate globules and slabs also occur in basalt, in holes that are shaped like olivine phenocrysts (Fig. 2a). These holes commonly contain small fragments of olivine (Fig. 2b), implying that they were olivine phenocrysts that were dissolved out, most likely by water. Carbonate 'slabs' coats the walls of these holes and the remnant olivine fragments (Fig. 2a). Pristine olivine phenocrysts are common near the phenocryst-shaped holes.

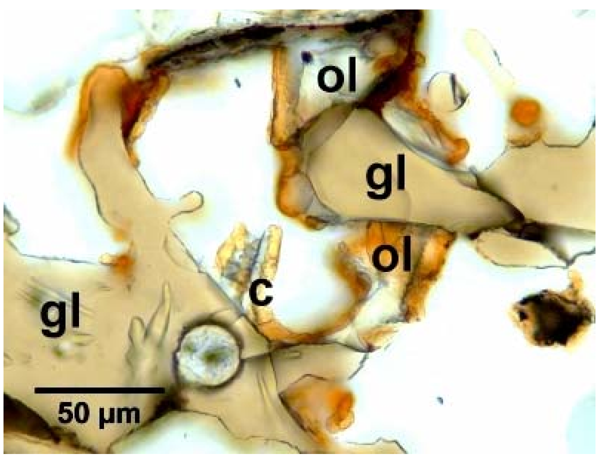

Fig. 2b. Detail of 2a, lower left. Basalt glass, gl; olivine, ol; carbonate masses, c (in orange) coat gl and ol, and partially fill open space where ol was dissolved out (Fig. 2a).

The Analog and ALH84001: Some igneous olivine in the terrestrial basalt (Figs. 2a,b) was dissolved away, and the resulting holes by carbonate globules and slabs. A similar event could have affected the ALH84001 Martian meteorite, and led to the association of olivine and carbonate globules. The following narrative incorporates the Spitsbergen globule story into the geological history of ALH84001 [4], with its named chemical and deformation events.

ALH84001 was originally an igneous orthopyroxenite cumulate with more olivine than is now preserved. This cumulate rock was strongly deformed and metamorphosed at ~4.5 Ga [3] in events D1 and Cγ of [4] (which probably represent an asteroid impact). Olivine grains in the original rock would have been fragmented and dispersed (as was chromite: Fig. 2a of [4]), leaving the rock with larger olivine masses and small grains scattered nearby in orthopyroxene. Later fractures (event D2b of [4]) were pathways for water entry and chemical reaction (Cδ of [4]); larger olivine grains were more likely to be breached than smaller. When water entered ALH84001 at ~4.0 Ga [3], breached olivine grains were dissolved out and nearby shielded grains survived. Carbonate globules were then deposited in cracks and holes (Cδ of [4]), including those once filled with olivine. Later shock deformation (D3 of [4]) collapsed these void spaces and injected feldspathic melts around the globules.

In this story, carbonate globules now occupy sites that once held larger olivine grains. Smaller olivine grains nearby were unaffected by the infiltrating waters that dissolved olivine and precipitated carbonate globules. Olivine dissolution can be ascribed to the same chemical event (Cδ of [4]) as carbonate deposition. This story is attractive but difficult to prove or disprove, because late shock events (D3-5 of [4]) would have erased most of the original textural evidence of ancient void spaces and dissolved olivine.

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