CARBONATE GLOBULES, ANALOGOUS TO THOSE IN ALH84001, FROM SPITZBERGEN, NORWAY: FORMATION IN A HYDROTHERMAL ENVIRONMENT. David F. Blake[1], Allan H. Treiman[2], Hans E.F. Amundsen[3], Stephen J. Mojzsis[4], and Ted Bunch[1]. [1]Exobiology Branch, NASA Ames Research Center, Moffett Field, CA 94305. [2]Lunar & Planetary Institute, 3600 Bay Area Boulevard, Houston TX 77058 <treiman@lpi.jsc.nasa.gov>. [3]Saga Petroleum AS, N1301 Sandvika, Norway. [4]Dept. Earth and Space Sciences, University of California Los Angeles, Los Angeles, CA 90095.

Carbonate mineral globules in ALH84001 may preserve evidence of ancient martian life [1], but their mode of formation remains unclear [1-4]. and have thus become embroiled in controversy. Did the carbonate globules form at temperatures low enough to allow life-as-we-know-it? There has been no definitive answer to this question, in part because we lack a geologic context for ALH84001 and in part because we lack analogous carbonate globules on Earth to study.

Last year, we reported [5] that ALH84001 carbonate globules are similar to globules of ankerite-magnesite carbonates (AMCs) in some basalts and peridotite xenoliths contained therein from NW Spitzbergen, Norway [6-9]. Here, we confirm the similarity and give evidence the Spitsbergen AMCs formed under hydrothermal conditions.

Carbonate Globules from Spitsbergen: Zoned globules of ankeritic - magnesitic carbonates (AMC) occur in vesicles and fractures of basalts and their xenoliths from four Pleistocene volcanoes in northern Spitsbergen, Norway [5-9]. The globules, 25 – 100 µm (diam.) occur on fracture surfaces (Fig. 1, 2), in vesicles in melted portions of xenoliths (Fig. 1 of [5]) and in their host basalt (Fig. 2 of [5]) The globules are frequently contained within carbonate of magnesian-calcite to dolomite composition. Xenoliths of mantle peridotite and of granulitic gneiss contain similar AMC. AMC are hemispherical when in vesicles, and are pancake-shaped discs when in fractures. In AMC, individual carbonate crystals radiate outward from the globule cores. Chemical compositions in the AMC are concentrically zoned, from ankerite/siderite cores to magnesite rims [5], commonly with many alternating layers of richer and poorer in Fe (Fig. 3). Chemical zoning is not identical in all xenoliths and vesicles, though AMC in each xenolith have similar or identical sequences. Clay minerals are intimately intermixed with the carbonates, and form discrete layers in some AMC. In many samples, cryptocrystalline silica coats AMC and separates it from it mineral substrates. Isotopic compositions of C and O are consistent with crustal contributions in a hydrothermal regime [10].

Comparison with ALH84001: In mineralogy, compositions, and petrologic settings, the Spitsbergen AMC are quite similar to the carbonate globules in ALH84001. In both samples the carbonates formed as open-space fillings [1,11]; carbonate crystals radiate from the cores [12]; chemical zoning goes from ferroan calcian cores to magnesian rims [2,12]; fine-scale chemical zoning is preserved [13]; and the carbonates are associated with clays and silica [2, 14]. There are differences, of course: the AMC contain no magnetite or Fe-sulfides [1], and the AMC do not show wide variations in δ18O like the ALH84001 carbonates [10, 15]. Even so, the AMC must be considered the best documented terrestrial analogs for the carbonate globules in ALH84001.

Formation Temperature: The origin of the AMC and related carbonates has been in considerable doubt, with many theories offered: pristine mantle material, melts immiscibile in the mantle, melts mobile on eruption, hydrothermal, and diagenetic. A hydrothermal origin is consistent with all available data. First, it seems unlikely that the AMC are pristine mantle materials, or immiscible mantle melts because; (1) AMC are found in granulite xenoliths as well as in mantle peridotite xenoliths and (2) AMC are present in vesicles and fractures in the host basalts, as well as the xenoliths. Second, a diagenetic (i.e., groundwater) origin seems inconsistent with the oxygen isotopic composition of the carbonates [10]. Third, the presence of clays, serpentine, and cryptocrystalline silica with the AMC suggest formation from a water-bearing fluids. Fourth, small AMC occur in liquid-bearing fluid inclusions that outline healed fractures in the xenoliths (Fig. 4). It is worth noting that fluid inclusions have been found in ALH84001 [16]. On the other hand, glasses in the basalt and adjacent to the AMC show only slight or no alteration to clays.

Future Work: The Spitsbergen AMC are the best known terrestrial analog for the carbonate globules in ALH84001; further studies of the AMC and their origin are important for understanding the carbonates in ALH84001. The most pressing need is for field studies of the AMCs' source volcanoes on Spitsbergen Island. The available samples of the AMC were selectively chosen as interesting xenoliths, with little attention paid to field relationships and the presence of obvious carbonate. With additional data on field relations, further stable isotope studies, and $^{87}Sr/^{86}Sr$ measurements to constrain the origin of the carbonate (contributions from crustal, marine, and mantle sources), we can determine how the AMCs formed, at what temperature, and whether biota were involved.

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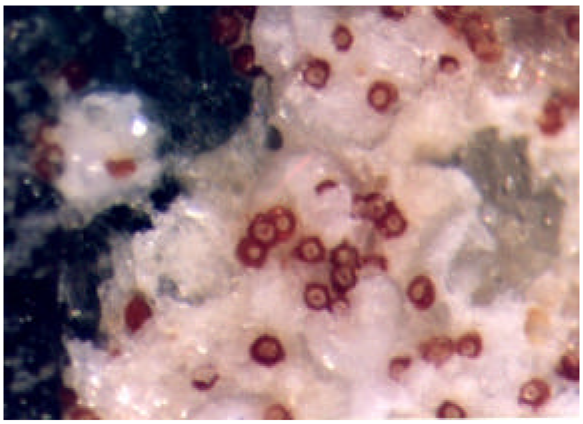

Figure 1. AMC globules on fracture surface, xenolith HA-1. Globules are ~ 75 µm in diameter. True color image. FOV ~ 1.75 mm.

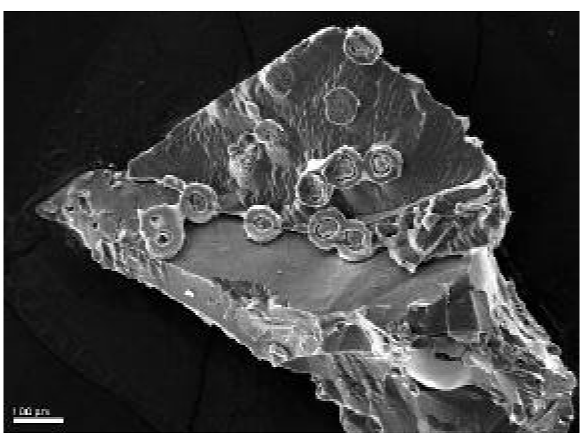

Figure 2. AMC 'pancakes' on fracture surface, broken fragment of xenolith HA-1. SEM image, scale bar 100µm. Flat upper surfaces of 'pancakes' were in contact with rock surfaces, now removed, that defined an open fracture. Hummocks on upper rock surface, may suggest that it was etched during or after deposition of the 'pancakes'.

Figure 3. Detail of AMC 'pancakes' of Fig. 2, fractures surface of xenolith HA-1. SEM image, scale bar 10 µm. Note fine-scale concentric layering, which reflects differences in density (i.e. Ca and Fe content), vis. Fig. 1 of [2]. Note the hollow layers, which appear to represent layers that were dissolved after deposition of the 'pancakes.'

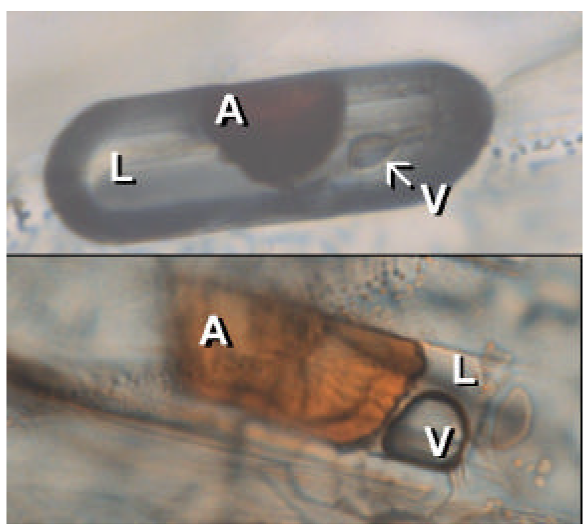

Figure 4. AMC carbonate globules (arrows) in fluid inclusions in olivine, xenolith SV-43. Plane polarized light; image widths ~125 µm. A = AMC; L = liquid; V = Vapor.