A COMPARISON BETWEEN SULFIDE ASSEMBLAGES IN MARTIAN METEORITES ALH 84001 AND GOVERNADOR VALADARES. C. K. Shearer and C. Adcock, Institute of Meteoritics, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque NM 87131, USA.

Introduction: Understanding the development, timing, and setting of sulfide and sulfate deposition is critical to interpreting S isotopic systematics in martian meteorites and future mission samples. For example, to properly interpret S isotopes as a marker for biogenic activity in low-temperature hydrothermal mineral assemblages, it is important to understand the relative sequence of sulfide and/or sulfate precipitation, the temperature of precipitation [1], the openness of the system [2] and the post-depositional thermal history of the sulfide-sulfate assemblages [3]. To interpret S isotopes in magmatic assemblages, it is critical to decipher the effect of subsolidus processes.

Approach: In this study, the sulfide assemblages in ALH 84001 (orthopyroxenite) and Governador Valadares (Nakhlite) were documented using optical microscopy, EMP, and SEM. The orthopyroxenite assemblage of ALH 84001 represents crystallization and crystal accumulation in a larger intrusive body, whereas the clinopyroxenite assemblage of Governador Valadares reflects the crystallization and crystal accumulation in either a ultramafic basalt flow or a shallow intrusion. Identification of individual sulfide grains were made using reflectance characteristics and EMP analyses. Individual sulfide grains were analyzed for $\delta^{34}S$ using the Cameca ims 4f at the University of New Mexico following the approach of Shearer et al [1].

Results: ALH 84001 and Governador Valadares contain both pyrite and pyrrhotite. Pyrite is the dominant sulfide in ALH 84001, whereas pyrrhotite is dominant in Governador Valadares. Other S-bearing phases that were identified include chalcopyrite in Governador Valadares and a sulfate associated with pyrite in ALH 84001. The sulfides in ALH 84001 occur in several different textural setting that imply different origins and thermal histories. *(Sulfide type 1)*: Small pyrite and pyrrhotite inclusions (1 to 10 μm) are associated with large, relatively unbrecciated chromite grains (FIGURE 1). Small pyrite grains also occur near the grain boundary between the chromite and orthopyroxene. *(Sulfide type 2):* Large pyrite aggregates (10 to 80 μm) occur within brecciated zones (FIGURE 2). Ubiquitous chromite and rare pyrrhotite are phases that may be spatially associated with the pyrite aggregates. The interface between the pyrite and silicate phases are sharp. There is a transition between textural type 1 and 2 that is associated with highly deformed chromate. *(Sulfide type 3):* Small irregular grains of pyrite are associated spatially with the base of the carbonate globules. *(Sulfide type 4)* Very irregular shaped sulfides occur in the shock glass. The sulfide is probably pyrite. EDS compositional maps indicate that the sulfide is not homogeneous and may contain abundant sulfate (Fig. 3). *(Sulfide type 5):* Submicron-sized sulfides have been identified in the carbonate. These sulfides have not been well characterized. In EDS maps of the carbonates, the sulfide abundance as reflected by S concentration appears to be highest in the two Fe-rich zones in the carbonate globules and lowest in the Mg-rich zones (Fig. 4). The sulfide mineralogy in Governador Valadares is less complex. Pyrrhotite and minor pyrite predominantly occur as minute grains (2 to 25μm) that are immersed in the mesostasis that is interstitial to the cumulate augite (Fig. 5). Pyrrhotite also occurs infrequently as inclusions in the subhedral augite.

Discussion: The wide variability in the $\delta^{34}S$ of sulfides in ALH 84001 compared to that in other martian samples [1,4,5] reflects the multi-generational nature of sulfide formation and the effect of post-magmatic heating-impact events. The sequence of events that effected the $\delta^{34}S$ in the sulfides are as follows: (1) Magmatic crystallization and accumulation of sulfides. (2) Precipitation of pyrite following the formation of the impact-induced cataclastic texture. The S source was both internal and external to the orthopyroxenite. (3) Fine-grained, sub-micron sulfides co-precipitated with the carbonate. The Fe-rich carbonates contained a high proportion of sulfides. (4) A post-carbonate heating event undoubtedly effected the sulfides and may have perturbed the $\delta^{34}S$. Small sulfides were entrained in and reacted with the shock glass during this heating event (Fig. 3). In addition, it is possible that the sub-micron sulfides in the carbonates were formed during a high-temperature heating event that resulted in preferential volatilization of the Fe-, S- enriched carbonate zones.

Conclusions: Although ALH 84001 and Governador Valadares have similar sulfide assemblages (pyrrhotite and pyrite), they differ with regards to their complexity. The sulfide assemblage in Governador Valadares is dominated by pyrrhotite and appears to be magmatic in origin with some subsolidus reequilibration. On the other hand, the sulfide assemblages in ALH 84001 reflect magmatic and multiple low- and high-temperature subsolidus processes. The more complex genetic history of the sulfides in ALH

84001 is reflected in the relatively large variability of $\delta^{34}S$ (1 to 9 per mil) compared to other martian meteorites. This range reflects both high-temperature and low-temperature reservoirs and in-situ mixing of these components.

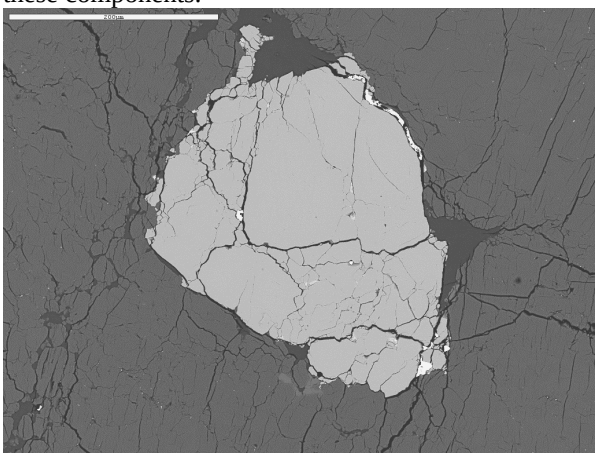


Fig. 1. Chromite with minute sulfide inclusions. Scale bar = 200 μm.

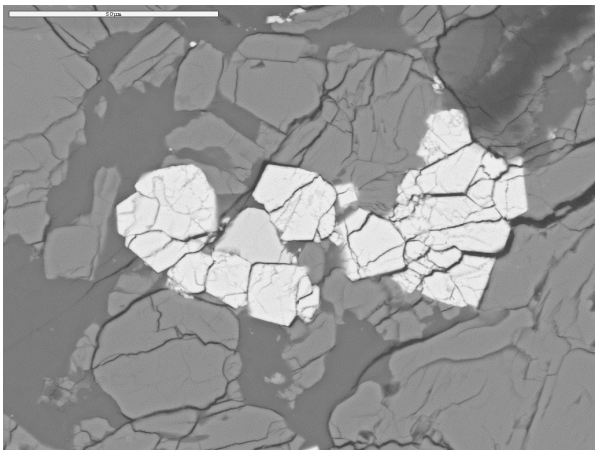


Fig. 2. Large pyrite aggregate within brecciated zone. Chromite grains are commonly associated with aggregates. Scale bar = 50 μm.

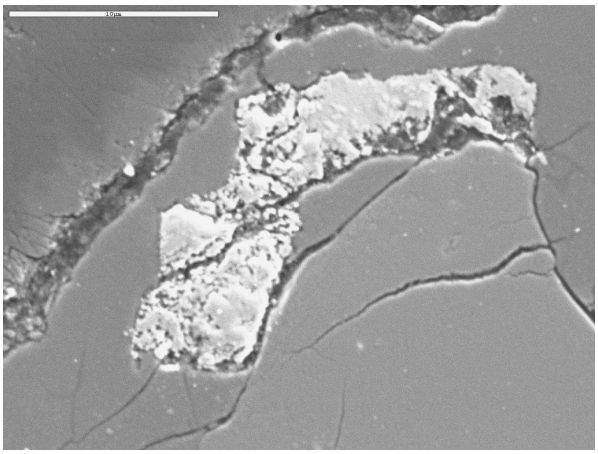
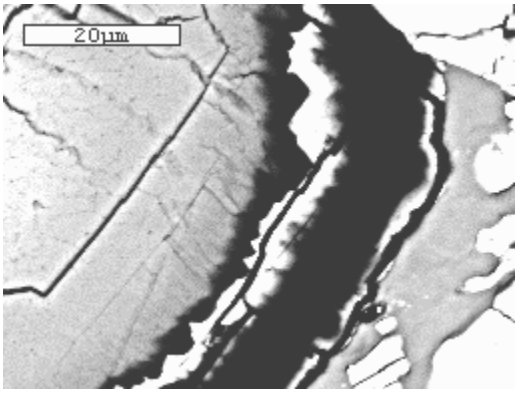


Fig. 3. Sulfide grain entrained within shock glass. Irregular surfaces on grain appear to be sulfates. Scale bar = 10 μm.

A.



B.

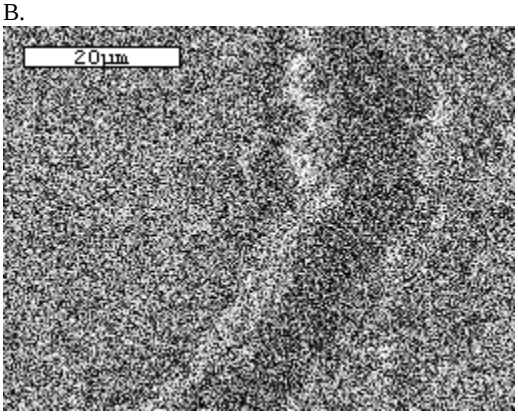


Fig. 4. A. BSE image of outer zones in carbonate globule. The two high-Fe zones are bright. The two high-Mg are black. B. S x-ray map of the carbonate globule. High S concentrations are associated with high-Fe zones.

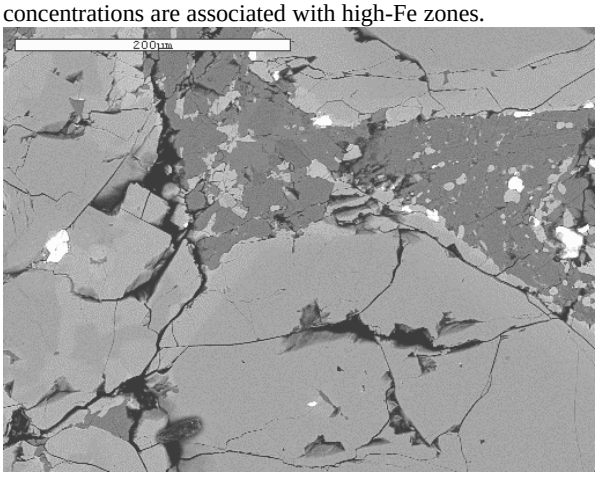


Fig. 5. Sulfides in Governador Valadares. Pyrrhotite inclusion occurs in the augite. Pyrrhotite and minor amounts of pyrite are immersed in the mesostasis and closely associated with the Fe-Ti oxides. Scale bar = 200 μm.

References: [1] Shearer et al. (1996) *GCA,, 60,* 2921. [2] Shearer (1997) *LPSC XXVIII,* 1289. [3] Shearer and Adcock (1997) *LPSC XXIX*. [4] Greenwood et al. (1997) *GCA, 61,* 4449 [5] Greenwood et al (1998) *LPSC XXIX*.