

**EXAMINING METASOMATISM IN LOW  $fO_2$  ENVIRONMENTS: EXPLORING SULFIDATION REACTIONS IN VARIOUS PLANETARY BODIES.** P. Srinivasan<sup>1,2</sup>, C. K. Shearer<sup>1</sup>, F. M. McCubbin<sup>2</sup>, A. S. Bell<sup>1</sup>, and C. B. Agee<sup>1</sup>. <sup>1</sup>Institute of Meteoritics and Dept. of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, USA. <sup>2</sup>NASA Johnson Space Center, Mail Code XI2, 2101 NASA Parkway, Houston TX 77058. Email: psrinivasan@unm.edu.

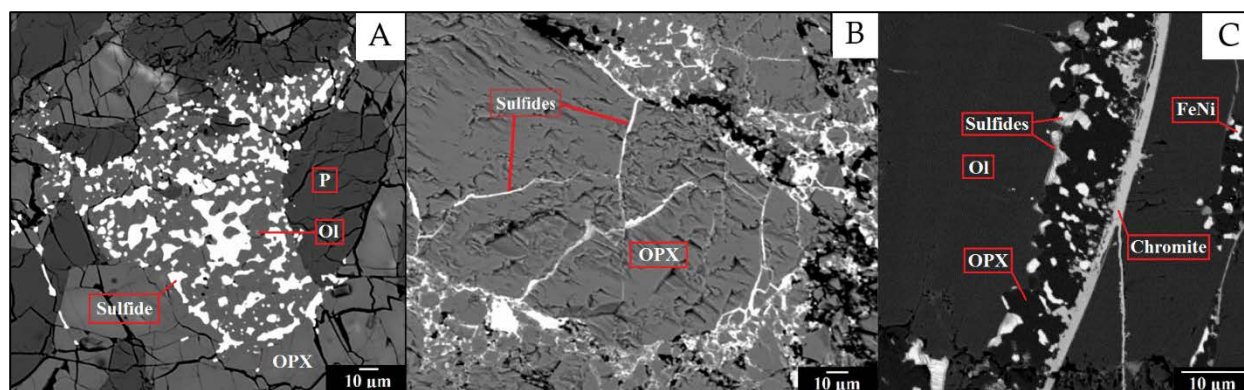
**Introduction:** Hydrothermal systems are common on Earth in a variety of tectonic environments and at different temperature and pressure conditions. These systems are commonly dominated by H<sub>2</sub>O, and they are responsible for element transport and the production of ore deposits [1-2]. Unlike the Earth ( $fO_2$ ~FMQ) [3], many other planetary bodies (e.g., Moon and asteroids) have  $fO_2$  environments that are more reduced (IW±2) [4], and H<sub>2</sub>O is not the important solvent responsible for element transport [5]. One example of a texture that could result from element transport and metasomatism, which appears to occur on numerous planetary bodies, is sulfide-silicate intergrowths. These subsolidus assemblages are interpreted to form as a result of sulfidation reactions from a S-rich fluid phase [e.g. 6-10]. The composition of fluids may vary within and among parent bodies and could be sourced from magmatic (e.g. Moon) or impact processes (e.g. HED meteorites and Moon). For example, it has been previously demonstrated on the Moon that the interaction of olivine with a hydrogen- and sulfur-bearing vapor phase altered primary mineral assemblages, producing sulfides (e.g. troilite) and orthopyroxene [7-8,11]. Formation of these types of “sulfidation” assemblages can be illustrated with the following reaction:  

$$Fe_2SiO_4^{ol} + \frac{1}{2}S_{2\text{system}} = FeS^{troi} + FeSiO_3^{opx} + \frac{1}{2}O_{2\text{system}}$$
[12]. The products of this reaction, as seen in lunar rocks, is a vermicular or “worm-like” texture of intergrown orthopyroxene and troilite [7]. Regardless of the provenance of the S-bearing fluid, the minerals in these various planetary environments reacted in the same manner to produce orthopyroxene and troilite.

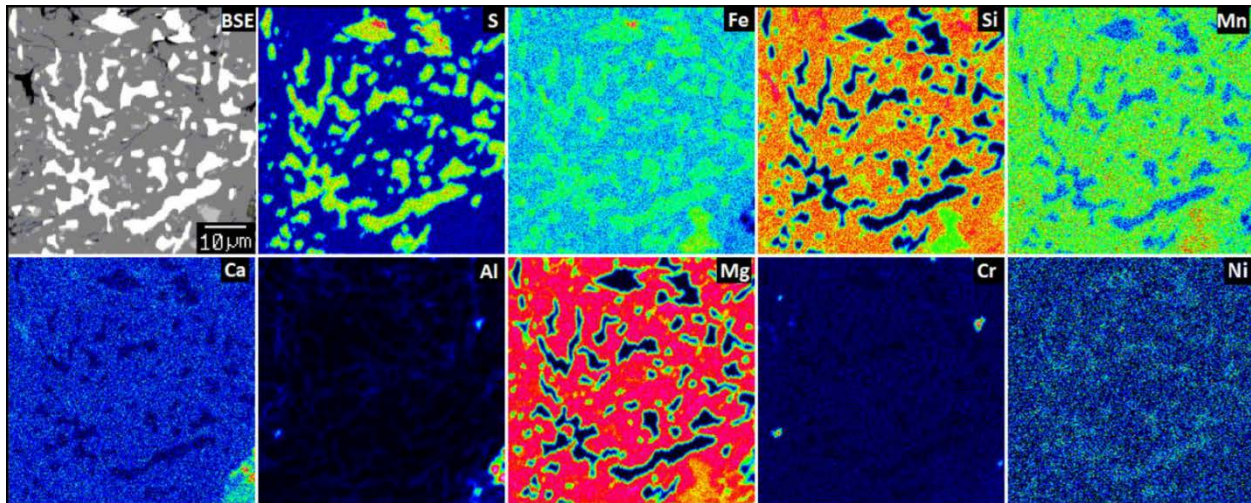
Although similar textures have been identified in a variety of parent bodies [6-15], a comparative study on the compositions and the origins of these sulfide-silicate assemblages has yet to be undertaken. The intent of this study is to examine and compare sulfide-silicate intergrowths from various planetary bodies to explore their petrogenesis and examine the nature of low  $fO_2$  (IW±2) element migration and sulfidation reactions.

**Methodology:** Eight thin sections representing several planetary bodies were examined for this study: brachinite NWA 8674 (UNM AJ-2), lunar 67016,294, mesosiderite Mount Padbury (UNM Pad 7), howardites Melrose B (UNM 1110) and Kapoeta (UNM 1010), eucrites Pasamonte (UNM 223) and LEW 88010,7, and diogenite Roda (UNM A43.1). All thin sections were carbon coated for quantitative electron-beam analysis. A FEI Quanta 3D FEG SEM was used to produce BSE images, and EPMA analyses and X-ray maps were obtained using a JEOL 8200 superprobe at the University of New Mexico.

**Results:** BSE images from the eight achondrites indicate the most common sulfidation texture is a vermicular texture composed of intergrowths of low-Ca pyroxene and troilite and, depending on the meteorite, minor amounts of olivine, oxides, and Fe metal (Fig. 1a). These textures were only observed within a clast or within a larger grouping of grains, rather than dispersed throughout the entire section. Other textures we observed are sulfide veins cutting across pyroxene grains (Fig. 1b) and nano- to micrometer-sized blebs of sulfides within a mixture of silicates, typically olivine and low-Ca pyroxene (Fig. 1c). Figure 2 shows X-ray maps from howardite Melrose B. The X-ray maps allow



**Figure 1.** BSE images of sulfidation textures in various meteorites. A) Vermicular texture in lunar sample 67102. B) Veining in diogenite Roda. C) Symplectite texture in brachinite NWA 6874. Ol=olivine, P=plagioclase, OPX=orthopyroxene.



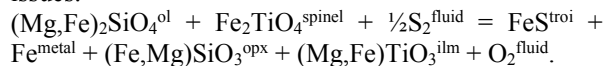
**Figure 2.** BSE image and corresponding X-ray maps illustrating elemental distribution in howardite Melrose B. Observed sulfidation assemblage includes olivine, OPX, troilite, and a Cr-rich oxide.

us to observe phases and features not easily seen with BSE images.

EPMA results show that troilite is the dominant sulfide in all analyzed achondrites, whereas, a wide range of olivine and pyroxene compositions are observed among these meteorite groups. Pyroxene ranges from  $FS_{20-60}$ , and olivine ranges from  $FA_{40-90}$ . In every case, orthopyroxene (opx) is Mg-enriched compared to olivine. Some meteorites have a large range in opx composition (e.g. NWA 6874,  $FS_{20-40}$ ), and some meteorites have a more limited range in opx composition (e.g. Melrose B,  $FS_{42-44}$ ). This difference may be attributable to either the variations in composition of the fluid or the starting composition of the unaltered rock.

**Discussion:** Three textures were observed in this study: vermicular/symplectite, veins, and micrometer-sized inclusions. The differences are likely due to how the S-bearing liquid moved through the rock and also how elements were transported at subsolidus conditions.

The compositional variation of orthopyroxene as well as the addition of minor phases gives us more insight into the sulfidation reaction of each meteorite. Although the sulfidation reaction defined by [12] results in the breakdown of olivine, it is an oversimplification and does not account for minor phases nor does it explain how an Mg-enriched orthopyroxene can grow at the expense of olivine. A more refined sulfidation reaction was defined by [11] to account for these two issues:



In contrast to Earth ( $fO_2 \sim FMQ$ ), the low oxygen fugacity of these achondritic planetary systems ( $IW \pm 2$ ) will have a profound effect on fluid composition. Additionally, small variations in  $fO_2$  among these achondritic bodies will change the fluid. Although

planetary bodies originate and experience different histories (i.e. differentiation, thermal alteration, impacts), many bodies display evidence of sulfidation on their crusts [6-15]. Sulfide-silicate intergrowths observed on the lunar crust were shown to be a result of sulfidation reactions caused by degassing of intrusive magmas [7]. Other studies have shown that sulfidation reactions may have occurred from interactions with an  $S_2$ -rich gas during impact events [9,14].

Future analytical work and thermodynamic analysis of sulfidation assemblages will potentially reveal additional details about the compositions of the fluid phases, the capability of these fluids to transport elements, temperature/pressure constraints on the mineral phases, textures of replacement phases, as well as how sulfidation reactions occur.

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