POSSIBLE EVIDENCE FOR SULFIDIZATION REACTIONS IN THE MILLER RANGE BRACHINITES(?) S. A. Singerling, T. J. McCoy, and K. G. Gardner-Vandy, Division of Meteorites, Department of Mineral Sciences, Smithsonian Institution, Washington, DC 20560-0119. Email: singerlings@si.edu.

Introduction: Six ungrouped achondrites were recovered in Miller Range, Antarctica during the 2009 ANSMET field season. They are MIL 090206, 090340, 090356, 090405, 090805, and 090963. Preliminary classification of these meteorites concluded that they were ureilites or, more generally, ungrouped achondrites [1-4]. Subsequent work by [5] and [6] argued that these MIL samples are brachinites based on their petrology.

A prominent feature of these meteorites is a grain boundary symplectite (Fig. 1) that is ubiquitous throughout this pairing group. Although previous studies have focused extensively on the relationship of the MIL pairing group to other achondrites, here we focus specifically on the petrology, mineralogy and origin of these symplectites.

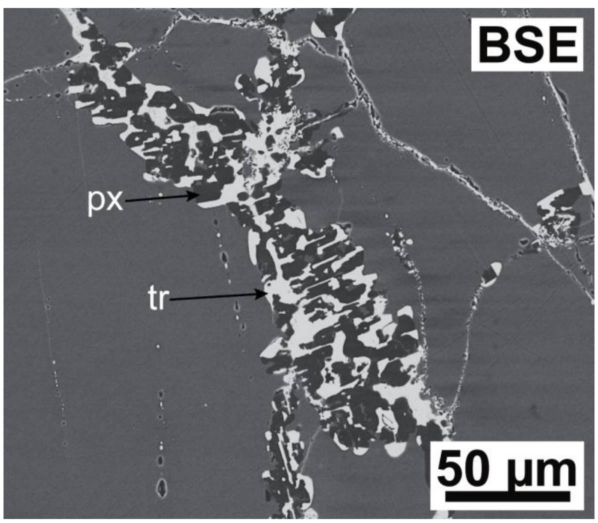

Fig. 1. Backscattered electron image of the symplectic intergrowth texture that occurs along olivine (light gray) grain boundaries in the MIL ungrouped achondrites.

Methods: Thin sections of the six MIL samples were analyzed for textures and basic petrography with a polarizing light microscope. Backscattered electron (BSE) images and X-ray maps were obtained using the FEI Nova NanoSEM 600 at the Smithsonian Institution NMNH Mineral Sciences Department. The BSE images and X-ray maps were obtained under the following operating conditions: 15 kV accelerating potential, 4.5 µm beam width, and 6 mm working distance.

Results: Symplectites are composed of a subequal mixture of orthopyroxene and troilite and occur at olivine grain boundaries. Large olivine ($Fo_{71.5-73.4}$) and orthopyroxene ($En_{72.4}Wo_{2.3}$) grains are in equilibrium [5,6]. In contrast, symplectite orthopyroxene is more magnesian ($En_{75.9}Wo_{1.3}$ [5] to $En_{78.2}Wo_1$ [6]). Other phases observed in the intergrowths in lesser amounts are chromite and a hydrated iron oxide of terrestrial origin (Fig. 2).

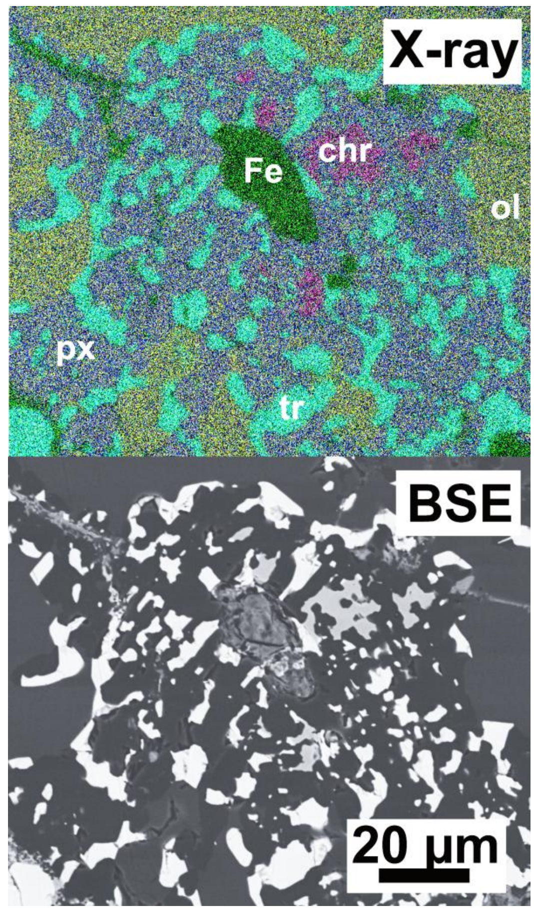

Fig. 2. X-ray map and corresponding BSE image depicting the different phases present in the symplectites. (chr – chromite, tr – troilite, px – pyroxene, ol – olivine, Fe – hydrated iron oxide)

Symplectites do not occur evenly distributed through the MIL meteorites. Instead, intergrowths are less common in orthopyroxene grains than in adjacent olivine grains, even when the two are in contact. Symplectites are not observed at orthopyroxene-troilite interfaces (Fig. 3). It is apparent that intergrowth formation is preferred in olivine.

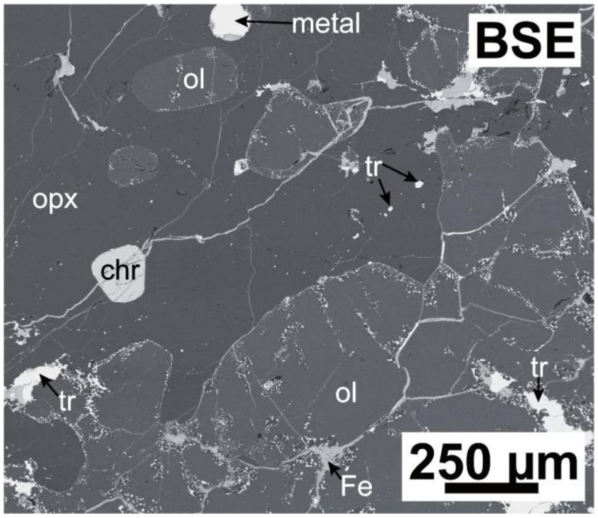

Fig. 3. BSE image of MIL 090206 illustrating the relationship between the intergrowths, orthopyroxene, and olivine. (chr – chromite, tr – troilite, opx – orthopyroxene, ol – olivine, Fe – hydrated iron oxide, metal – Fe,Ni metal)

Discussion: Symplectite textures have been reported in brachinites (Reid 013, Hughes 026, NWA 5191, and NWA 595) and the ungrouped achondrite (brachinite?) NWA 1500 [7]. In these heavily weathered meteorites, the opaque phase has been terrestrially altered, and its original composition is unknown. Previous authors discussed mechanisms for the formation of symplectites consisting of metal and/or sulfide, but they largely favored reduction as the mechanism that formed ureilite grain boundary metallic blebs. In the MIL achondrites, preservation of these symplectites requires a mechanism for forming opx-sulfide intergrowths. We argue that these symplectites formed relatively late in the petrogenesis of the MIL achondrites, owing to the disequilibrium between large opx and symplectite opx.

We considered three possible origins for the intergrowths:

Partial melting occurred; the melt migrated and was trapped at grain boundaries. Although low degrees of Fe,Ni-FeS eutectic and basaltic partial melts are rich in troilite and pyroxene, they would also be expected to contain Fe,Ni metal (~15% of the eutectic) and plagioclase (~50% of the basaltic melt). As neither of these other phases are present in any of the symplectites we examined, this explanation seems implausible.

Small amounts of melt were produced along grain boundaries as a result of impact. Two-phase symplectites in howardites [8] and acapulcoites [9] have been attributed to shock melting. These opx-sulfide symplectites have similar intergrowth textures and mineralogies as those observed in the MIL ungrouped achondrites. However, the symplectites in howardites are found at grain boundaries between primary troilite and orthopyroxene, suggesting they formed as shock melts in diogenitic clasts in the howarditic regolith [8]. In contrast, symplectites are not observed at primary opx-sulfide grain boundaries in the MIL achondrites, suggesting an alternative mechanism of formation.

Sulfidization reactions between an S-rich fluid or gas and primary olivine produced the opx-sulfide symplectites. The occurrence of the symplectites primarily in olivine and occurring with only orthopyroxene and troilite suggests a reaction between olivine and $S_{(g)}$ to form the intergrowths of orthopyroxene and troilite (FeS). An idealized version of such a reaction could follow the formula:

$$2(Fe,Mg)_2SiO_4 + S_2(g) \rightarrow 2MgSiO_3 + 2FeS + O_2(g)$$

In detail, the composition of the symplectite orthopyroxene is only slightly more magnesian than that of the host olivine or orthopyroxene, so formation of subequal proportions of orthopyroxene and troilite is problematic. A possible solution includes the presence of metallic iron prior to sulfidization. A reaction of this type could occur at grain boundary surfaces, consistent with its occurrence in the olivines of the MIL achondrites.

Conclusions: The two-phase symplectic intergrowth texture observed in the MIL ungrouped achondrites is likely the result of a sulfidization reaction that occurred post-crystallization from an infiltrating S-rich gas. If the MIL ungrouped achondrites are linked to the brachinites, the presence of symplectite textures in other brachinites suggests this was a widespread process on the brachinite parent body. Late-stage sulfidization reactions do not appear to have been common on other primitive achondrite parent bodies.

References: [1] *Ant. Met. Newsl.* 34(1), 2011. [2] *Ant. Met. Newsl.* 34(2), 2011. [3] *Ant. Met. Newsl.* 35(1), 2012. [4] *Ant. Met. Newsl.* 35(2), 2012. [5] Warren P. H. and Rubin A. E. (2012) *LPS XLIIII,* Abstract #2528. [6] Goodrich et al. (2012) *Ann. Met. Soc. LXXV,* Abstract #5272. [7] Goodrich et al. (2011) *Met. Planet. Sci., 45,* 1906-28. [8] El Goresy A. et al. (2005) *Geochim. Cosmochim. Acta, 69,* 1883-1898. [9] Patzer A. and McSween H. Y. (2012) *Met. Planet. Sci., 47,* 1475-90.