MILLER RANGE 07273: AN UNUSUAL CHONDRITIC MELT BRECCIA. M. L. Hutson[1] and A. M. Ruzicka[1], [1]Cascadia Meteorite Laboratory, Portland State University, Department of Geology, 1721 SW Broadway, Portland, OR 97207, USA (mhutson@pdx.edu; ruzickaa@pdx.edu).

Introduction: Ordinary chondrite melt breccias (rocks composed of clasts set in an igneous matrix) are a rare, but potentially important rock type. We used optical, scanning electron microscope (SEM) and electron backscatter diffraction (EBSD) techniques to study Miller Range 07273 (MIL), a melt breccia that contains clasts of equilibrated H-chondrite set in a fine-grained (silicates <5 µm across), largely crystalline, igneous matrix.

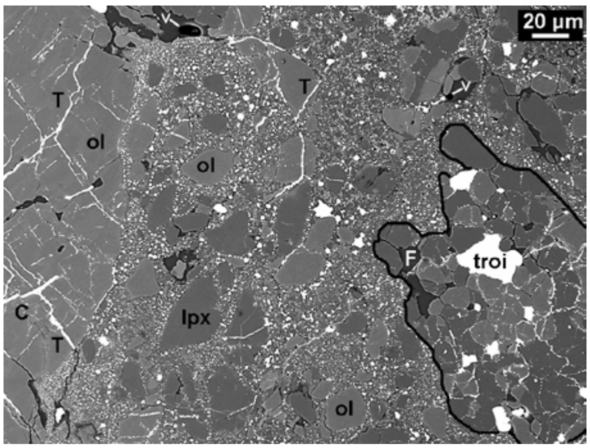

Fig. 1 Clasts of olivine (ol), low-Ca pyroxene (lpx), and feldspathic material (F) containing troilite (troil, T) blebs and veins, set in an igneously-textured melt matrix containing metal globules. Two vesicles (V) shown.

Chondrule Clasts and Coarse Metal: Chondrule silicate clasts in MIL are "blackened", caused by troilite-rich veins typically ≤3 µm wide that extend for tens to hundreds of microns and that are typically truncated at clast boundaries (Fig. 1). In places, veins are discontinuous and form inclusion trails.

Coarse metal grains appear "fluidized", with scalloped edges, appearing to fill interstices of adjacent silicates. Most of this metal is polycrystalline martensite, which shows grain core-rim zoning of Ni, with narrow Ni-rich rims, consistent with creation by fractional crystallization of metallic melt. Irregularly shaped kamacite and taenite grains occur with martensite, and lack core-rim zoning of Ni (Fig. 2). Taenite grains are surrounded by martensite with elevated Ni contents (Fig. 2 inset).

Plastic deformation of various minerals in MIL was quantified by Grain Orientation Spread (GOS), which gives the average angular misorientation within a grain [1]. In MIL, troilite is among the least deformed minerals, with GOS values for grains mainly <1°. Olivine and orthopyroxene grains in clasts tend to have the highest GOS values, often ~1-8° but up to 20° for olivine, and often ~1-5° but up to ~10° for orthopyroxene. Albitic feldspar (oligoclase-albite), diopside, clinoenstatite, and pigeonite in chondrule clasts have moderate GOS values, mainly ~0.5-3°, less than for coexisting olivine and orthopyroxene. Based on limited data, metal appears to have heterogeneous strain, with higher GOS values in what is interpreted as martensite (~1-7°) than in kamacite and taenite (<1°).

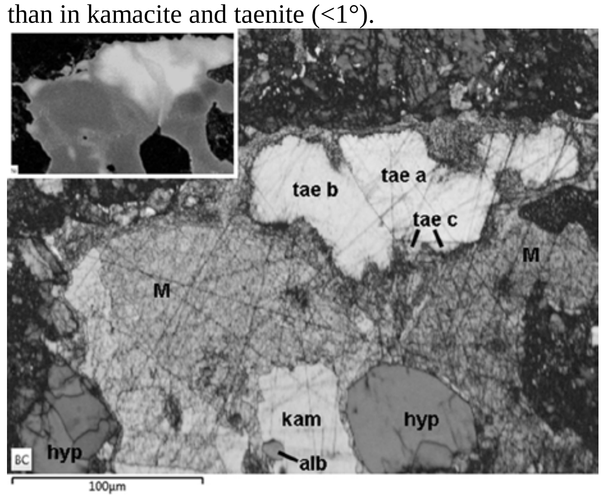

Fig. 2. EBSD band contrast image, with brightness related to crystallinity (brighter = stronger diffraction bands, darker = weaker). Martensite has weaker band contrast than kamacite and taenite. The inset shows a Ni X-ray map. Martensite surrounding taenite is enriched in Ni, forming a diffuse halo. Mineral abbreviations: tae = taenite (tae a, b, c identify different grains), kam = kamacite, ma = martensite, hyp = hypersthene, alb = albitic feldspar, troi = troilite.

Veining is most extensive in coarser olivine, common in low-Ca pyroxene (orthopyroxene) and larger chromite grains, relatively infrequent in melt matrix, and uncommon in feldspar, feldspathic glass, high-Ca pyroxene, or phosphate (almost exclusively merrillite in MIL, very rarely Cl-apatite). In the interior of one chondrule studied with EBSD, orthopyroxene that is slightly cracked and veined by troilite grades into patches of chemically similar, vein-free pyroxene that indexes as clinoenstatite and subordinate pigeonite. Cross-cutting relationships here imply secondary formation of clinoenstatite/pigeonite after orthopyroxene was veined. In an adjacent chondrule, clinoenstatite and pigeonite predominate over orthopyroxene in a chondrule that lacks veins.

Matrix Phases: The entire matrix of the rock has an igneous texture and represents a melt matrix. The melt matrix is fine-grained, rich in normative pyroxene, with coarser matrix areas distinctly rich in pyroxene, poor in feldspar, and somewhat poor in olivine compared to the host chondrite (Fig. 3). EBSD mapping indicates that the chief pyroxene phases in matrix are the clinoenstatite and pigeonite polytypes (space group $P2_{1/c}$). The matrix pigeonites are rich in Na and Al and approach ~30% of a jadeite ($NaAlSi_2O_6$) component, qualifying as omphacite. In two areas well-studied with EBSD, clinoenstatite and pigeonite comprise ~60-70% of the matrix. Both form equant or slightly elongate grains typically ≤1-4 µm across, or magnesian shell-like overgrowths on orthopyroxene (hypersthene) mineral clasts (Fig. 3). Matrix olivine is notably more ferrous than host olivine, and typically occurs as somewhat elongate, slightly irregular grains ≤2 µm long and <1 µm wide interstitial to pyroxene (Fig. 3), suggesting it crystallized somewhat after pyroxene during cooling.

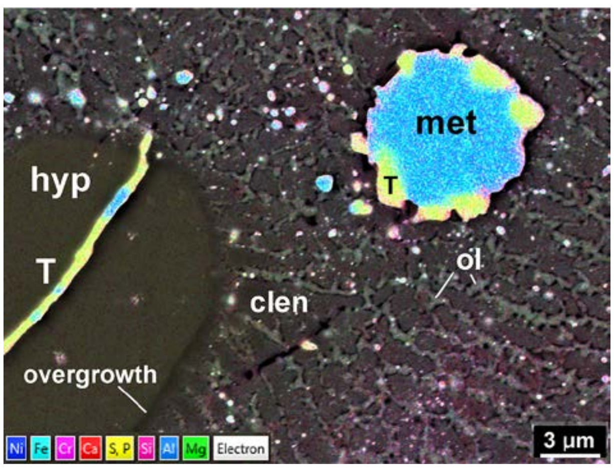

Fig. 3. Element map of representative matrix area. Orthopyroxene (hyp) with troilite (T) vein and overgrowth of clinoenstatite (clen). Met=metal; ol=olivine (light green).

In contrast to chondrule clasts, matrix olivine, pigeonite, and clinoenstatite grains have typical GOS values of <1°, with many grains having only ~0.3°, which is close to the inferred detection limit. Matrix grains are unambiguously less deformed than coexisting small clasts of chondrule-derived olivine and orthopyroxene. In places, olivine grains in these small clasts appear to have recrystallized, forming new, weakly deformed subgrains (Fig. 4).

Discussion: The features observed in MIL can be explained by a model involving a shock event that produced brief heating at high pressure, a sudden pressure drop, and a slower drop in temperature, which produced plastic deformation, brecciation, localized melting and crystallization. Incompletely liquefied metal flowed around silicate clasts and crystallized as martensite surrounding irregularly-shaped regions of taenite and kamacite that are interpreted as unmelted relict grains. Olivine and orthopyroxene in clasts were the least melted and the most deformed silicate phases, matrix was melted completely and crystallized to nearly strain-free minerals, and mesostasis phases of chondrule clasts (diopside, feldspar) evidently were melted and re-solidified before solidification of troilite was complete. Coarse olivine was deformed to shock stage S4.0 (weighted shock stage [2]), corresponding to ~4-5° of average grain misorientation. The characteristics of matrix silicates are attributed to the breakdown during melting of albitic feldspar and some olivine to form pyroxene at high pressure and temperature, possibly involving back-reaction of high-pressure polymorphs to pyroxene and olivine upon cooling. Troilite melted and was extensively mobilized into a vein network. Such veins are most concentrated in the least-melted phases (olivine, orthopyroxene, chromite). Up to ~50% of MIL was melted. Despite such intense heating, silicates outside of melt matrix have compositions that were not much changed. This implies that intense heating events might have little effect on mineral compositions if heating durations were sufficiently brief.

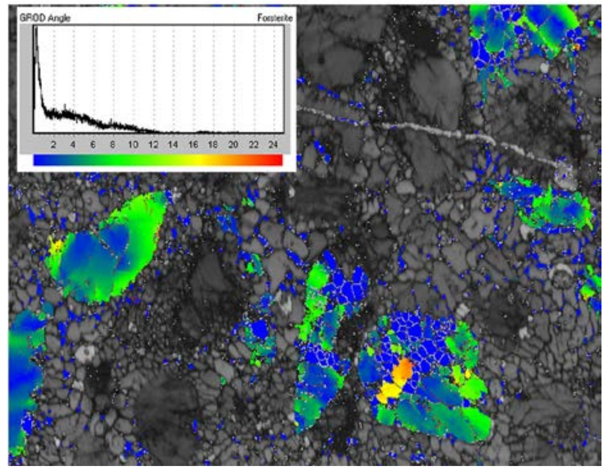

Fig. 4. GROD (grain orientation deviation) angle+band contrast image. Colors indicate the distortion of crystal lattice from a reference value for the grain. Matrix olivines and recrystallized portions of grains have low GROD angle values (<1 °, blue), whereas clasts are more distorted (1-8 °, green to orange), with distortion often at their edges.

References: [1] Brewer L. N., et al. (2009). In *Electron Backscatter Diffraction in Materials Science, 2nd Ed*. (eds. A.J. Schwartz, et al.), 251-262. [2] Ruzicka A. et al. (2015). *GCA 163*, 219-233.