MINERALOGY AND PETROGRAPHY OF MIL 090001, A HIGHLY ALTERED CV CHONDRITE FROM THE REDUCED SUB-GROUP. Lindsay P. Keller, Robert M. Walker Laboratory for Space Science, Mail Code KR, ARES, NASA Johnson Space Center, Houston, TX 77058 (Lindsay.P.Keller@nasa.gov).

Introduction. MIL 090001 is a large (>6 kg) CV chondrite from the reduced subgroup (CV_{red}) that was recovered during the 2009-2010 ANSMET field season [1]. The CV_{red} subgroup meteorites retain primitive characteristics and have escaped the Na and Fe metasomatism that affected the oxidized (CV_{ox}) subgroups. MIL 090001 is, however, reported to be altered [1], and thus a major objective of this study is to characterize its mineralogy and petrography and the extent of the alteration.

Methods and Samples. Two double polished thin sections (MIL 090001,10 and ,11) from two different chips (,7 and ,8) were examined using optical and electron microscopy. Backscattered electron imaging and elemental mapping were performed using a JEOL 7600F field-emission scanning electron microscope (SEM) equipped with a Noran Si drift detector. Quantitative analyses were obtained using a Cameca SX-100 electron microprobe operated at 15kV with a beam current of 12 nA and a 10 μm defocussed incident probe. Small fragments of matrix and mesostasis were extracted from one thin section and prepared for analysis in the transmission electron microscope (TEM) using ultramicrotomy. We obtained imaging, diffraction and chemical data from the microtome thin sections using the JSC JEOL 2500 field-emission STEM equipped with a Noran thin window energy-dispersive X-ray (EDX) spectrometer. Quantitative element maps were acquired by rastering a 4 nm incident probe whose dwell time was minimized to avoid beam damage and element diffusion during mapping. Successive image layers were acquired and combined in order to achieve ~1% counting statistics for major elements.

Results. The meteorite is a breccia, containing a fragment of at least one dark clast (~3 mm) with a different chondrule:matrix ratio than the host in section (,10). No apparent shock features (veins, chondrule flattening or undulatory extinction) are observed. Optical microscopy shows extensive Fe-staining throughout the sections from terrestrial weathering. Chondrules (<2 mm) are abundant and dominated by porphyritic types (including a few type II FeO-rich chondrules), with lesser barred and radial varieties. Chondrule mesostasis is largely replaced with fibrous green to reddish-brown phyllosilicates (Figure 1) and carbonate grains. Several mm-sized, rounded metal objects are also present in the meteorite. Chondrule olivines range in composition from Fa1-Fa40 (Figure 2). Metal is abundant in chondrules and matrix and is dominantly kamacite although altered and corroded to Fe oxide/hydroxides – no taenite has been observed. The coarse sulfides in chondrules are troilite and pyrrhotite. Ca- and Al-rich inclusions (CAIs) are common and highly altered, with residual spinel and perovskite surrounded by Al-rich phyllosilicates and $CaCO_3$. Amoeboid olivine aggregates (AOAs) are also common and are forsterite-rich, although not as altered as the CAIs.

Matrix is fluffy and highly altered. Defocussed electron microprobe analyses show low totals (~88%) and plot along the serpentine solid solution line in a Mg-Fe-(Si+Al) ternary (Figure 2). The matrix phyllosilicates are not as aluminous as those replacing chondrule mesostasis. Fine-grained magnetite is abundant in matrix and occurs in framboidal, plaquette and spherulitic forms and as euhedral grains up to 10 μm (Figure 3). Fine-grained olivine has not been observed to date in matrix, although >10 μm-sized grains of $CaCO_3$, enstatite and partly altered kamacite are present. Sulfides in matrix are sub-μm grains of pyrrhotite and pentlandite surrounded by fine-grained phyllosilicates (Figure 4). Preliminary TEM observations show that the matrix phyllosilicates are a mixture of coarse (μm-sized) plates of serpentine (7 Å basal spacing) and chlorite (14 Å basal spacing) with Fe/Fe+Mg (at.) ranging from 0.42-0.65 based on EDX analyses. Additional TEM analyses are in progress to determine the mineralogy of the phyllosilicates that occur in altered chondrules and CAIs. The Na- (nepheline, sodalite) and Fe-rich phases (fayalite, andradite, hedenbergite) common in the matrices of the altered CV_{ox} subgroup [2] have not been observed in MIL 090001.

Discussion. The alteration assemblage of serpentine+chlorite+calcite+magnetite is very similar to that observed in CR chondrites [3, 4] and we infer similar alteration temperatures for MIL 090001 (~250-300˚C). Oxygen isotopic analyses of co-existing magnetite and $CaCO_3$ in matrix are planned and should provide stronger constraints on the temperature of alteration and the fluid composition. Chlorite is uncommon in altered CV chondrites and has been reported previously only in matrix and chondrule mesostases in the Grosnaja CV_{ox} chondrite [5] and in some dark inclusions in the Efremovka CV_{red} chondrite [6]. The framboidal magnetites in MIL 090001 are similar in size and morphology to those in other heavily-altered (type 1 and 2) carbonaceous chondrites (e.g. [7]).

Conclusions. The extent of parent body fluid alteration in matrix and chondrules indicate that MIL 090001 should be classified as a CV2 chondrite. It is the most heavily altered CV chondrite reported to date.

References. [1] Ant. Met. News Lett. (2010) 33(2). [2] Krot, A. N. *et al*. (2002) *MAPS* 33, 1065. [3] Weisberg, M. K. *et al*. (1993) *GCA* 57, 1567. [4] Weisberg, M. K. and Huber, H. (2007) *MAPS* 42, 1495. [5] Keller, L. P. and McKay, D. S. (1993) *MAPS* 28, 378. [6] Krot, A. N. *et al*. (1999) *MAPS* 34, 67. [7] Hua, X. and Buseck, P. R. (1995) *MAPS* 33, A215.

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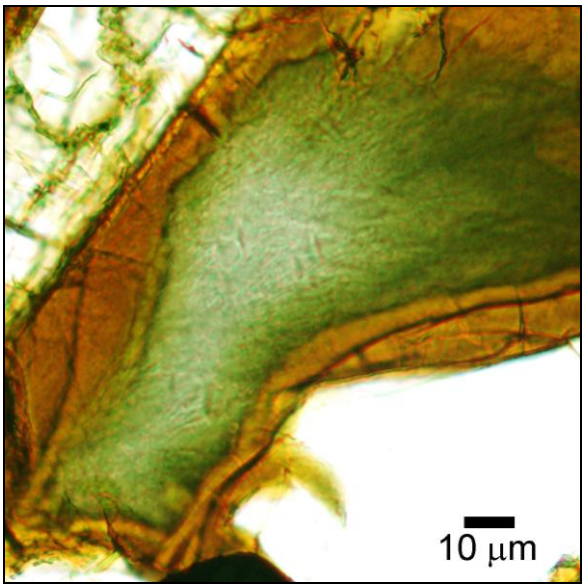

Figure 1. Plane light image from part of a porphyritic olivine chondrule with mesostasis replaced by green to reddish-brown phyllosilicates. The clear grains are forsteritic olivine.

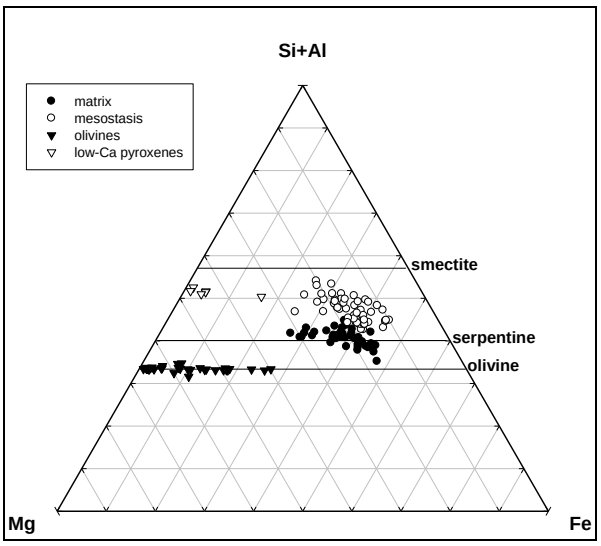

Figure 2. Electron microprobe analyses of olivines, pyroxenes, matrix and mesostasis in MIL 090001 plotted on a Mg-Fe-(Si+Al) (at.%) ternary diagram.

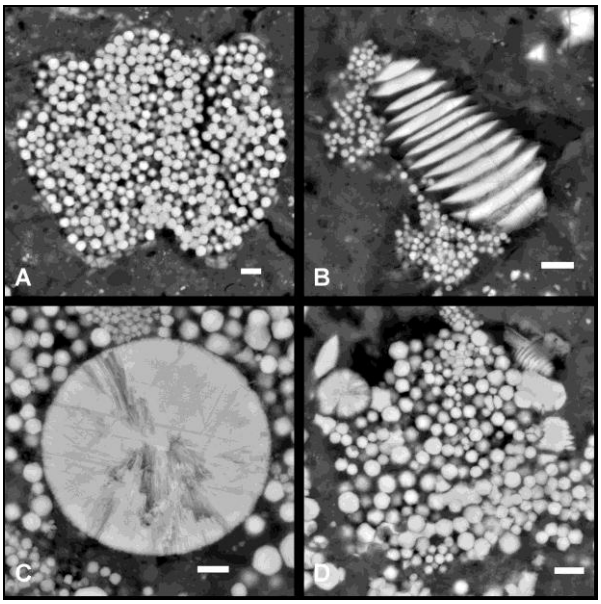

Figure 3. Backscattered electron image of magnetite morphologies in MIL 090001 matrix: a) framboidal, b) plaquette, c) spherulitic and d) all three forms together. The scale bar in each image is 1 μm.

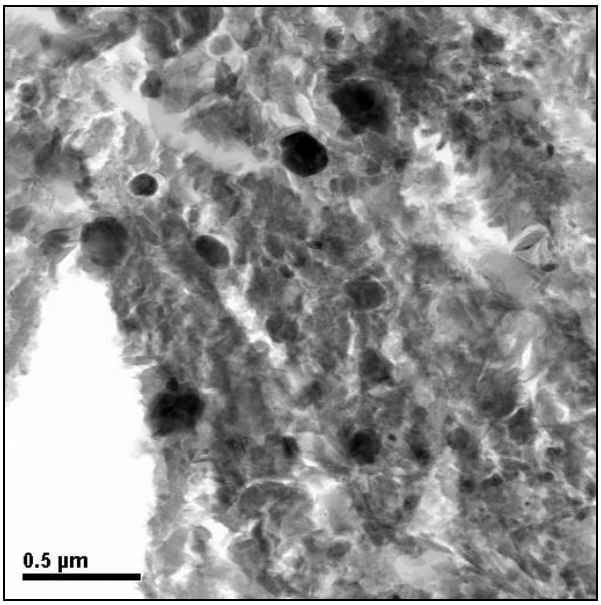

Figure 4. Brightfield STEM image of fibrous matrix phyllosilicates with ~100 nm pyrrhotite and pentlandite inclusions.