

COMPLEX HETEROGENEOUS AQUEOUS ALTERATION IN THE MATRICES OF UNEQUILIBRATED ORDINARY CHONDRITES BY LOW TEMPERATURE HYDROTHERMAL SOLUTIONS. E. Dobrică and A. J. Brearley, Department of Earth and Planetary Sciences, MSC03-2040, 1University of New Mexico, Albuquerque, NM 87131-0001, USA. (edobrica@unm.edu and brearley@unm.edu).

Introduction: Previous studies of the fine-grained matrices of unequilibrated ordinary chondrites (UOCs) have provided important information on the textural and mineralogical characteristics of these complex materials. These TEM studies showed that the matrices of low petrologic type UOCs have experienced partial hydrous alteration [1] and consist of both primary solar nebular materials as well as secondary alteration products. Based on these observations, [2] proposed that interchondrule matrices were probably formed from the products of fragmentation of chondrules.

New higher resolution analytical techniques (FEGSEM/FIB/TEM) allow us to probe the fine-scale mineralogy of these complex fine-grained matrix materials in more detail. These studies are essential in helping to constrain the complex record of solar nebular and parent body processes that have contributed to the characteristics of matrix. In an effort to understand the earliest stages of secondary parent body processes on UOC matrices, we are continuing our microanalytical studies of matrix in MET 00526 (L3.05) chondrite [3-5]. In this study, we have focused on the relationship between hydrous phases and the development of secondary FeO-rich olivine.

Methods: One polished thin section of MET 00526 was initially studied on a FEGSEM operating at 30 kV using backscattered electron (BSE) imaging. After detailed SEM characterization, one TEM section was prepared from an object with a distinct FeO-rich rim embedded within the matrix. TEM sample preparation was carried out using the focused ion beam (FIB) technique with a FEI Quanta 3D FEGSEM/FIB instrument. Bright- and dark-field TEM images, quantitative EDS X-ray analyses and selected area electron diffraction (SAED) were performed using a JEOL 2010F FEGTEM/Scanning TEM (STEM) at 200 kV.

Results: SEM studies show that the matrix of MET 00526 presents considerable textural heterogeneity. In particular, two distinct textural types of matrix are apparent, one with a compact texture and a second, less common, type with a higher porosity (Fig. 1, dark submicron pits in the upper, right area of the image). These porous regions of matrix are generally more MgO-rich than the compact regions (Fig. 1). Our previous TEM studies of the compact matrix [6] show that they consist of regions of amorphous material and/or phyllosilicates that are crosscut by submicron veins of ferroan olivine [6]. However, in BSE images, the overall texture of the compact regions is generally similar to the more porous regions. In particular, micron-sized grains within the porous matrix also show evidence of

the development of ferroan olivine rims. In order to understand the development of these rims in more detail, we identified several textural and compositionally distinct objects in one porous region of matrix, for further TEM study. These objects include one refractory inclusion (~14 μm in size) and two objects with FeO-rich rims (~8 and 3.5 μm in size, Fig. 1) all occurring in close proximity to one another.

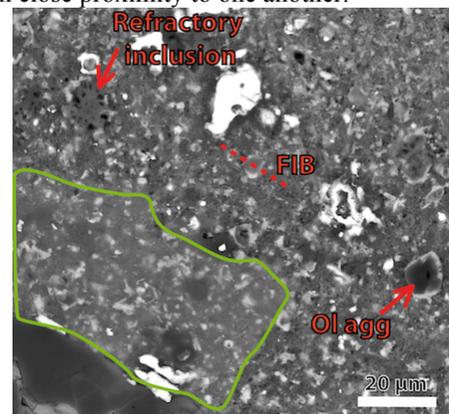


Figure 1. BSE image of the matrix of MET 00526 in which three different objects (refractory inclusion, two objects with FeO-rich rims: one olivine aggregate = ol agg and one phyllosilicate-rich objects – FIB) were identified. The upper right part of the image shows a more porous and generally more MgO-rich matrix than the compact regions (green line, lower left on the image).

Two phyllosilicate-rich objects (Fig. 2) with well-defined boundaries were observed in the FIB section. The phyllosilicates in these objects are polycrystalline and coarser-grained than any of the surrounding matrix materials. Their chemical compositions and basal spacing (~1 nm) are consistent with smectite.

One of the phyllosilicate-rich objects (2.2 μm in diameter) has a rounded morphology and is surrounded by a continuous FeO-rich rim that varies in thickness between 300 and 600 nm (Fig. 2). Two Fe,Ni metal grains ($\text{Fe}_{45}\text{Ni}_{55}$, 200 nm and 0.5 x 1 μm in size) and a chromite (~300 x 700 nm) were identified in contact with this phyllosilicate-rich object. The second object is more irregular in shape (4 x 5 μm in size) and contains veins which are more FeO-rich than the associated phyllosilicate phases.

The mineral phase constituting the rim of object 1 and veins in object 2 was identified by quantitative EDS analysis and electron diffraction analysis as ferroan olivine (Fa_{66-72} , $N = 12$). The ferroan olivine is polycrystalline with a grain size of up to 30 x 150 nm. The crystals are rather elongated in the rims of the object 1 and veins of object 2. However, in a region at

the lower edge of the object 2, ferroan olivine has a larger, more rounded grain size, typically <300 nm. In all occurrences, the ferroan olivine has the same chemical composition.

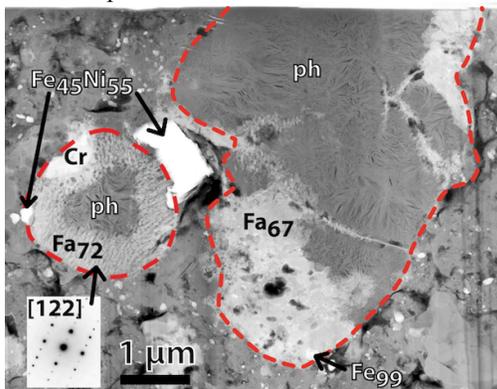


Figure 2. DF-STEM image of the two phyllosilicate-rich objects identified in the matrix of MET 00526 (Ph = phyllosilicate, Cr = chromite). FeO-rich ferroan olivine rims and vein fillings are present. An electron diffraction pattern indexed as the [122] zone axis of ferroan olivine from the rim of the round phyllosilicate-rich object is shown.

Discussion: Our TEM observations provide new insights into the complex processes that have affected MET 00526 matrix. Although phyllosilicates have been recognized as an important component of the matrices of many UOCs, the coarser-grained phyllosilicate-rich objects found in this study have not been recognized or described before. The distinct morphology and sharp boundaries of these objects with the surrounding fine-grained matrix materials suggest that they have been formed by aqueous alteration of preexisting micron-sized objects, i.e. by pseudomorphic replacement. Whether this alteration took place in situ or some other location is not clear. In the latter case, emplacement of the objects into their present location could have occurred as a result of parent body brecciation, that mixed different components together. However, the region of matrix studied shows no clear evidence of brecciation, as indicated for example by the absence of chondrule or other mineral fragments embedded within the matrix.

If alteration occurred in situ, one possible precursor could be the fragile glassy microchondrule-like spherules identified in different regions of MET 00526 matrix of UOCs (see Dobrica E. & Brearley A. J., 2012, LPSC abstract). The size, shape and chemical compositions of phyllosilicates and glassy vesiculated microchondrule-like spherules are similar, except the concentration of Na₂O (1.4 wt% vs. 4.1-6.5 wt%) and MgO (15.3 wt% vs. 7.3-9.8 wt%). The discrepancy in Na₂O contents could be explained by leaching of alkali elements during the alteration process. The identification of several glassy spherules with fibrous rims indicates that the glass can readily be hydrated and transform into phyllosilicates.

The phyllosilicate-rich objects have both undergone further replacement by ferroan olivine which occurs both as overgrowths and in vein-fillings within the objects. The spatial relationships between the phyllosilicates and ferroan olivine clearly indicate that the ferroan olivine formed after phyllosilicate formation. The presence of ferroan olivine rims on many other objects within the same region of matrix clearly suggests that this process occurred in situ.

The occurrence of veins of ferroan olivine with a similar texture were previously described in adjacent regions of compact matrix in MET 00526 [6]. The texture of ferroan olivine indicates that a FeO-rich aqueous fluid may be involved in their formation. As suggested previously, based on studies of CV3 chondrites, the ferroan olivines may have formed by precipitation from hydrothermal solutions during low temperature alteration [6-9]. However, our new data show, for the first time that formation of ferroan olivine can occur by direct replacement of phyllosilicates. The very low petrologic type of MET 00526 and the thermodynamic calculations constrains the temperature (<200 °C [11]; <350 °C [10]) and the water rock ratios [10] at which the ferroan olivine rims have formed.

Conclusion: Distinct, relatively coarse-grained phyllosilicate-rich objects occur in the matrix of the type L3.05 chondrite MET 00526. These objects may have formed by the advanced aqueous alteration of glassy vesiculated microchondrule-like spherules which we have found recently in MET 00526. The preservation of completely unaltered glassy spherules in other regions of MET 00526 matrix demonstrates that aqueous alteration was highly heterogeneous in this meteorite. Replacement of the phyllosilicate-rich objects by ferroan olivine clearly postdated aqueous alteration and clearly occurred in situ on the MET 00526 parent body. We suggest that the ferroan olivine was formed by a hydrothermal growth mechanism at low temperatures, consistent with previous observations for the CV chondrites and thermodynamic calculations [7, 10].

References: [1] Alexander C.M.O.'D., *et al.* (1989) *Geochim. Cosmochim. Acta* **53**, 3045-3057. [2] Alexander C.M.O.'D., *et al.* (1989) *Earth Planet. Sci. Lett.* **95**, 187-207. [3] Grossman J.N. and Brearley A.J. (2005) *Meteorit. Planet. Sci.* **40**, 87. [4] Berlin J. (2009) Ph.D. thesis, University of New Mexico, Albuquerque, New Mexico. [5] Righter K. (2007) *Antarctic Meteorite Newsletter* **30**, 1-4. [6] Dobrica E. and Brearley A. J. (2011) *Lunar Planet. Sci.* #2092. [7] Krot A.N., *et al.* (2004) *Antarctic Met. Res.* **17**, 153. [8] Brearley A.J., (2009) *Lunar Planet. Sci.* #1791. [9] Krot A.N., *et al.* (2000) *Meteorit. Planet. Sci.* **35**, 1365-1386. [10] Zolotov M.Y., *et al.* (2006) *Meteorit. Planet. Sci.* **41**, 1775-1796. [11] Cody G.D., *et al.* (2008) *Earth Planet. Sci. Lett.* **272**, 446-455.

Acknowledgements: This work was funded by NASA Cosmochemistry grant NNX11AK51G to A. J. Brearley (PI).