FINE-GRAINED RIMS AND MATRIX IN UNEQUILIBRATED ORDINARY CHONDRITES: A COMPARATIVE STUDY OF NORTHWEST AFRICA 5717 (UNG. 3.05) AND SEMARKONA (LL3.00).
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Introduction: Unequilibrated ordinary chondrites (UOCs) contain some of the most primitive Solar System materials available for study, including a fine-grained component (matrix) that may preserve original Solar System condensates, as well as pre-solar grains [e.g., 1]. Additionally, many chondrules have fine-grained (micron-sized) silicate rims (FGRs) that also contain primitive materials. Our previous work on Northwest Africa (NWA) 5717, a highly primitive (3.05) ungrouped OC (with H-like O isotopes and L-LL bulk composition [2]), shows that ~60% of chondrules contain FGRs composed of mineral and lithic fragments and microchondrules [3-6]. Some rim inclusions are overprinted with FeO-rich material, suggesting secondary alteration that postdates rim formation [3, 4]. Thus, FGRs preserve a range of materials from primitive to processed, and record processes ranging from presolar, to solar, to asteroidal.

Here we present a comparative microanalytical (SEM and TEM) study of the fine-grained components (matrix and FGRs) in two of the most primitive UOCs (NWA 5717 and Semarkona – LL3.00). Our goals are to document and compare the nature of the fine-grained materials in UOCs and decipher the nebular, accretionary, and alteration histories they record.

Analytical Techniques: FGRs and adjoining matrix were studied in thin sections of NWA 5717 (AMNH-1) and Semarkona (AMNH 4128-5) using the JEOL JSM-6390 LV/LGS scanning electron microscope (SEM) at Kingsborough-CUNY and the Hitachi S4700 Field Emission SEM at AMNH. Bulk compositions of FGRs and matrix material were obtained using a Cameca SX100 electron probe microanalyzer (EPMA) at AMNH. Microprobe operating conditions were an accelerating voltage of 15 kV, a beam current of 20 nÅ, and a dwell time of 20 s for all elements with the exception of Na and K, which had 10 s dwell times.

Using a focused ion beam (FIB), ultra-thin cross-sections of rim and matrix material surrounding three chondrules from NWA 5717 and two chondrules from Semarkona were prepared with a Quanta 3D dual-beam field-emission gun at JSC. Petrologic and geochemical analyses were carried out on a JEOL 200FX ATEM and a JEOL 2500SE 200kV Field Emission Gun STEM equipped with a Noran thin-window EDX spectrometer at JSC.

Results: NWA 5717 FGRs (NWA-FGRs) and Semarkona FGRs (Sem-FGRs) have sharp boundaries with surrounding matrix (Fig. 1). The boundary between FGRs and matrix of NWA 5717 is marked by a higher abundance of fayalitic olivine in the rims (Fig. 1a, c). The matrix in NWA 5717 contains abundant amorphous material, which is interspersed with phyllosilicates. Some of the amorphous material in the matrix occurs as globules containing Fe-sulfides and Fe-Ni-metal that are similar in appearance to the glass with embedded metal and Fe-sulfide (GEMS) found in interplanetary dust particles (IDPs) [7]. Such globules are not observed in the FGRs. However, NWA-FGRs have some amorphous material that occurs both as part of the groundmass and as individual amorphous inclusions embedded among the silicates. Phyllosilicates (dominantly saponite) in NWA-FGRs generally occur as growths along the surface of, and possibly replacing, fayalitic olivine, and are less commonly associated with the amorphous material. The groundmass of NWA-FGRs contains 70-95% (area%) fayalitic olivine, while phyllosilicates and amorphous material form ~5% of the rim groundmass. Fayalitic olivine in the NWA-FGR groundmass ranges from 10 – 100 nm, is typically tabular, and forms a crystalline matrix that hosts inclusions of larger silicates up to 1 µm in size.

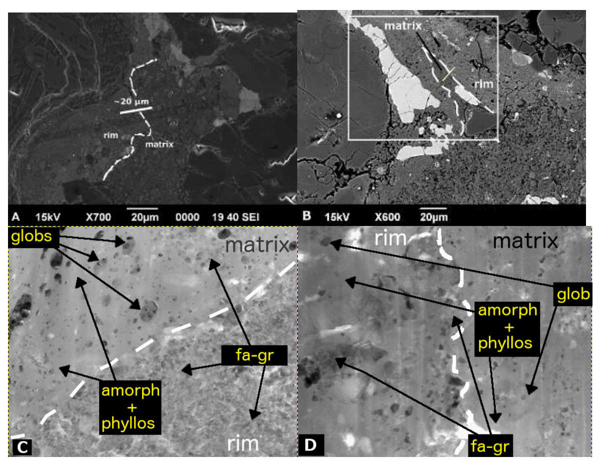

Fig. 1 BSE images showing FGR and matrix boundaries (dashed white lines) were FIB sections were extracted from C44 in NWA 5717 (a) and C10 in Semarkona (b). Solid white lines show the ~20 µm transects from where the FIBs were extracted. TEM bright field images (field of view 6 µm wide) showing the boundaries between FGRs and matrix in NWA-C44 (c) and Sem-C10 (d). Abbreviations are as follows: amorph – amorphous material, phyllos – phyllosilicates, fa-gr – fayalitic olivine grains, glob – GEM-like globules.

The Sem-FGRs we studied contain less fayalitic olivine than NWA-FGRs, the former having more phyllosilicate and amorphous material (Fig. 1d). Fe-sulfide globules are present in both Sem-FGRs and matrix. Similar Fe-sulfide globules are present in NWA 5717 matrix but was not found in the rims.

In constrast to NWA-FGRs, the phyllosilicates in Sem-FGRs are more abundant, generally coarser-grained (~50 nm), are associated with, possibly replacing, amorphous material, and are serpentine-saponite mixtures. Phyllosilcates in NWA-FGRs appear to be dominantly saponite with only minor serpentine and are generally associated with fayalitic olivine.

Mineralogy and composition: Table 1 shows average (EDS) compositions of phyllosilicates from the NWA- and Sem-FGRs. Silicates in NWA-FGRs are olivine (Fo_{17-94}), enstatite (En_{98-99}), low-Ca pyroxene (En_{54-84} Wo_{3-7}), and rare Ca-rich pyroxene (En_{39-45} Wo_{27-31}). Fe-sulfide (troilite, pentlandite) and Fe-Ni-metal are also present. Phyllosilicates in NWA-FGRs are Fe-rich saponite (FeO wt% 20.7-23.9) with lattice spacings 8.2-9.5 Å. Amorphous material contains (in wt%) Na_2O – 16.1, CaO – 18.9 and is FeO-rich (24.1) with minor MgO (6.3). Sem-FGRs also contain fayalitic groundmass, but this component is less abundant (~50%). In contrast to NWA-FGRs, Sem-FGRs are generally more abundant in phyllosilicates (50-75%), which are composed of serpentine (lattice spacings ≤ 7.5 Å) as well as saponite. Inclusions of silicates include endmember forsterite (Fo_{99}), enstatite, and low-Ca pyroxene.

Table 1. Average compositions for phyllosilicates (wt%) in FGRs. Parenthetical numbers represent sampling size. Compositions for Cr_2O_3 and MnO, not included in the table, are 0.1-0.3. The last three rows are previously reported compositions of smectite in Semarkona and Bishunpur (LL3.15) [8].

Description	Na_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	FeO
NWA-C39(2)	1.6	12.9	4.3	37.4	0.4	3.6	37.6
NWA-C44(3)	1.1	8.6	9.6	49.6	0.5	1.3	22.6
NWA-C47(3)	1.7	9.3	5.1	57.5	0.2	7.3	17.4
Sem-C10(2)	1.5	11.9	5.3	36.5	0.3	0.4	16.1
Sem-[6]	6.1	8.9	5.4	44.0	0.9	0.1	34.1
Bish-[6]-1	5.6	8.8	7.7	65.0	1.5	1.7	8.5
Bish-[6]-2	5.3	11.9	9.0	51.8	0.6	6.5	14.0

Discussion & Implications: Based on our SEM and TEM study of the FGRs and matrix surrounding 3 chondrules from NWA 5717 and 2 from Semarkona, FGRs and matrix contain primary nebular-formed materials as well as phases formed during secondary alteration. The primary phases include magnesian olivine and pyroxene and amorphous material. The wide-ranging composition of olivine and pyroxene and the ubiquitous occurrence of amorphous materials in rims and matrix of Semarkona and NWA 5717 attests to the primitive nature of these highly unequilibrated OCs. Amorphous material appears to be a component of the most primitive members of all chondrite groups [e.g., 9]. Its presence in FGRs is consistent with the origin of chondrule rims as materials that accreted onto chondrule surfaces prior to accretion and, most likely, shortly after chondrule formation [3, 4]. It should be noted that pre-solar grains have also been identified in FGRs [1].

Secondary alteration in the FGRs from NWA differs from that in Semarkona. NWA-FGRs have a higher abundance of fayalitic olivine whereas, Sem-FGRs have greater abundances of phyllosilicates. Thus, the degree of hydrous alteration appears to be greater in the Semarkona rims, whereas chondrule rims in NWA 5717 were subjected to greater degrees of enrichment in FeO (i.e., metasomatism) resulting in formation of fayalitic olivine. Thus, the alteration history was sharply different for these two OCs. This may point to separate parent bodies for these two OCs, different regions of the same parent body, or variations in local regions of the pre-accretionary disk.

Although differential parent body alteration may have occurred in OC parent bodies, the possibility of processing of fine-grained mateial in the solar nebula cannot be ruled out at this time. Sharp compositional and mineralogical boundaries between the FGRs and matrix in NWA 5717 and Semarkona suggest pre-accretionary alteration for chondrule rims. In addition, the degree of alteration appears to differ from one rim to another, adding further support to an alteration event that pre-dates chondrite accretion.

References: [1] Leitner J. et al., (2014) *LPSC XLV*, #1099. [2] Bigolski J. N. et al., *77th MetSoc*, #5187. [3] Bigolski J. N. et al. (2013) *LPSC XLIV*, #2239. [4] Bigolski J. N. et al. (2012) *LPSC XLIII*, #2426. [5] Dobrică et al. (2013) *LPSC XLIV*, #2107. [6] Bigolski, J. N. et al. (2015) Microchondrules in UOCs, *MAPS* (in revision). [7] Bradley J. P. (1994) *Science 265,* 925-929. [8] Alexander C. M. O. et al. (1989) *GCA* 53, 3045-3057. [9] Greshake A. (1997) *GCA* 61, 437-452.