ABUNDANT WATER IN ORDINARY CHONDRITES: EVIDENCE FROM A CLAST WITH UNIQUE ALTERATION ASSEMBLAGE IN THE NORTHWEST AFRICA (NWA) 12380 (L3) CHONDRITE.

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Introduction: Many carbonaceous chondrites, as well as some other chondrites and clasts derived from asteroidal bodies, experienced pre-terrestrial aqueous alteration resulting in a variety of alteration assemblages [1, 2, 3, 4]. Here we report the discovery of a clast with a unique assemblage of minerals produced by aqueous alteration in the Northwest Africa (NWA) 12380 L chondrite.

Petrology: Fig. 1 shows a BSE mosaic of the ~1cm x 1cm clast, which is densely packed with chondrules. In hand specimen and transmitted light, the clast appears dark compared to the host meteorite. The majority (~75%) of clast chondrules are type II chondrules. Clast chondrule sizes (mean diameter 0.83 mm, N=48), abundance, and iron content of unaltered olivine and pyroxene ($Fa_{16.5\pm9.4}$, N=56; $Fs_{10.0\pm7.8}$, N=31) suggests an L or LL chondrite affinity with a 3.3 subtype.

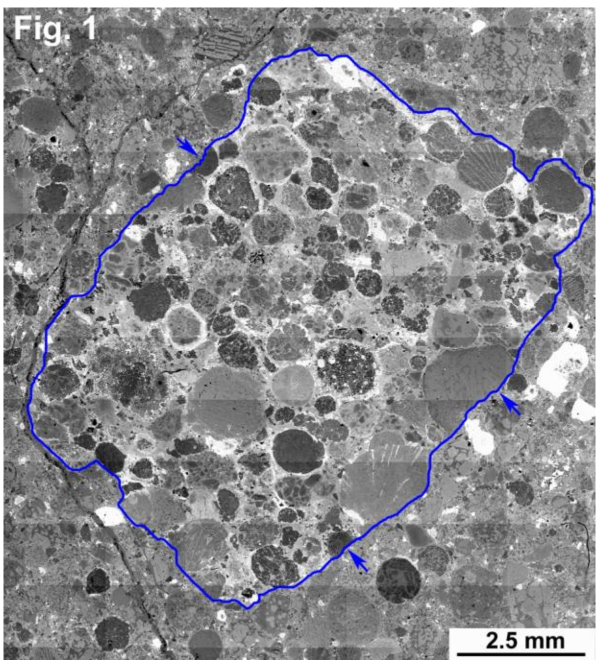

Fig. 1. BSE mosaic of dark clast in NWA 12380. Clast boundary cuts across chondrules (arrows). Most chondrules are surrounded by rims rich in Fe-rich phases, including cronstedtite, that grade into surrounding clast matrix.

The host meteorite is fairly weathered, with roughly 80-90% of the opaque minerals replaced by Fe-hydroxides. Additionally, a large vein of calcite cross-cuts the meteorite host (left side of Fig. 1) but does not appear to penetrate the dark clast. The contact between clast and host is a sharply defined breccia contact (Fig. 1, 2). The clast has a distinctive suite of minerals (Table 1) that are absent in the host.

Mineralogy and Chemistry of Clast: Fig. 2 shows a false color element map of the contact between the host (left) and clast (right). Unlike the host matrix, which is rich in olivine and pyroxene, the clast matrix is largely comprised of material with a smectite composition and stoichiometry, which appears to be a saponite-montmorillonite mixture (Fig. 3). The smectite in NWA 12380 is richer in Ca and depleted in Na compared to those observed in other chondrites, including O chondrites [3]. The clast matrix also contains abundant rounded clumps of an iron-rich phase (whitish in Fig. 2), which has a chemistry and stoichiometry consistent with Fe-Mg serpentine (Fig. 3).

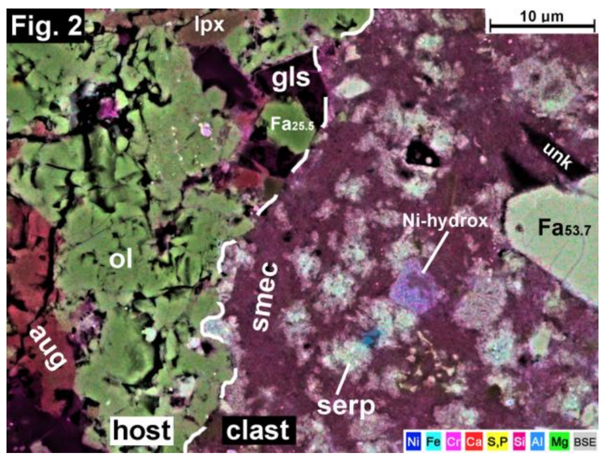

Fig. 2. Element map of clast contact. Contact between host and clast is sharp, but irregular. Host meteorite to left contains olivine (ol), low-Ca pyroxene (lpx), augite (aug) and albitic glass (gls). Clast phases include smectite (smec), serpentine (serp), Ni-rich Fe hydroxide (Ni-hydrox), unknown phase (unk), and a fayalitic ($Fa_{53.7}$) olivine grain.

Chondrules in the clast contain olivine and pyroxene grains that show evidence for alteration. Larger olivine grains have cores which appear to be unaltered, which are surrounded by progressively fayalitic olivine (up to $Fa_{88.8}$), which in turn are surrounded by cronstedtite and Fe-hydroxides. Unaltered pyroxene grains appear to be replaced by a Ca-Al-rich pyroxene. Chondrule mesostasis in olivine-rich chondrules has pyroxene-like stoichiometry, but low totals (Table 1), whereas in pyroxene-rich chondrules, mesostasis more often appears similar to clast matrix. Feldspathic material is rare in the clast.

Table 1: Average compositions (wt%) of some hydrous phases in clast, obtained via quantitative EDS (SEM). * Mesostasis analyses from olivine-rich chondrules.

	Matrix Smectite N=15	Chondrule Mesostasis* N=10	Fe-Mg Serpentine N=34	Cronstedtite N=23
SiO_2	44.1	46.9	31.6	21.8
TiO_2	0.19	0.40	0.03	0.05
Al_2O_3	6.29	1.33	1.75	1.73
Cr_2O_3	0.33	1.36	0.19	0.36
FeO	14.7	12.8	38.6	55.3
MnO	0.16	0.45	0.24	0.31
NiO	2.10	0.33	0.70	0.73
MgO	10.6	14.3	19.5	4.96
CaO	7.69	14.5	0.62	0.64
Na_2O	0.09	0.79	0.05	0.08
K_2O	0.32	0.11	0.07	0.05
P_2O_5	0.09	0.72	0.24	0.50
S	0.12	0.01	0.13	0.26
Total	87.2	93.4	93.7	86.8

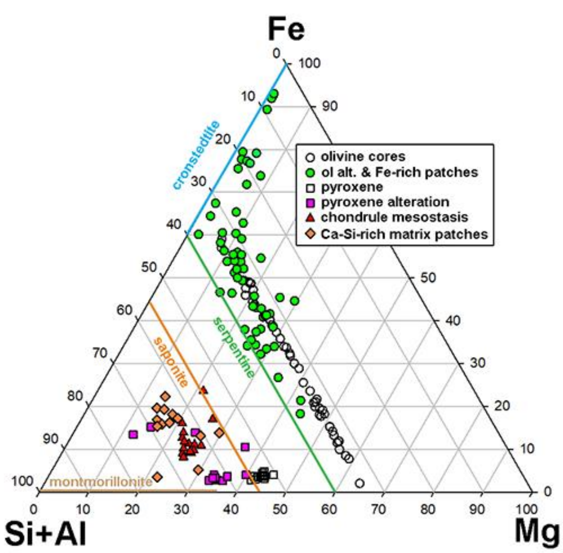

Fig. 3. Ternary diagram showing silicate phases observed in NWA 12380 compared to serpentine, cronstedtite, and smectite (saponite and montmorillonite) reference lines.

In addition to silicates, the clast in NWA 12380 contains small equant calcite patches that sometimes form chains around the edges of a clast, similar to those described by [5]. There are sulfur-rich regions that appear to be due to alteration of troilite. These often contain central voids surrounded by gypsum, which is in turn surrounded by a complex mixture of phases that include jarosite and barite, often with a rim of iron hydroxides (Fig. 4).

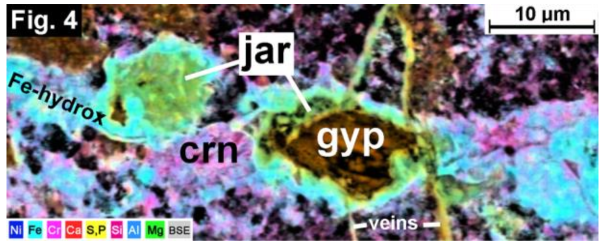

Fig. 4. Element map of the edge of a sulfur-rich region. Gypsum (gyp) tends to form the cores of grains, surrounded by jarosite (jar), which can also form as separate grains. Both are surrounded by iron hydroxide (Fe-hydrox). The gypsum grain is connected by small sulfate-rich veins to a larger sulfur-rich region above image. Crondstedtite (crn) is part of the matrix.

Unique Alteration Assemblage: The alteration assemblage in NWA 12380 differs from those previously described (e.g., [1]). Not found in the clast are pentlandite, magnetite, halite, or sylvite. The clast is notably depleted in Na and Cl, but not in Ca. This is reflected by low Na and high Ca contents in smectite and other hydrous phases (Table 1). Pyrrhotite is mostly absent; only one remnant grain of FeS (possibly pyrrhotite) was found along the edge of the clast. No P-bearing sulfides (e.g., [6]) were observed. Instead, P is concentrated in the Ca-Si-rich mesostasis grains in olivine-rich chondrules, and to a lesser extent in cronstedtite and Fe-Mg serpentines. Sulfates are abundant, and include phases such as jarosite and barite, which have not been reported as alteration phases in carbonaceous and ordinary chondrites [e.g., [1]).

Conclusion: The characteristics of the clast suggest it was derived from an especially wet lithology of ordinary chondrite, prior to becoming incorporated in a more typical portion of the L chondrite parent body. The alteration assemblage produced was not the same as that in other ordinary or carbonaceous chondrites evidently reflecting different formation conditions.

References: [1] Brearley A. J. (2006), in MESS II, Lauretta D. S. and McSween Jr., H. Y. (eds.), U of Az press. [2] Patzek M. et al. (2018) *Meteoritics & Planet. Sci., 53,* 2519-2540. [3] Alexander, C. M. O'D. et al. (1989) *GCA 53,* 3045-3057. [4] Rubin A. E. and Bottke W. F. (2009) *Meteoritics & Planet. Sci., 44*, 701-724. [5] Hutchison R. et al. (1987) *GCA, 51*, 1875-1882. [6] Palmer E. E. and Lauretta D. S. (2011) *Meteoritics & Planet. Sci., 46*, 1587-1607.