STEM-EDS Analysis of Chemical Variation During Asteroidal Aqueous Alteration in the Primitive Meteorite LAP 02342

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Chondritic meteorites act as time-capsules from the early solar system. Containing up to 10 wt% H_2O and complex organic materials, carbonaceous chondrites may be one of the key building blocks of Earth, giving it the compounds required to form a biosphere. In general, chondrites are sedimentary rocks, composed of igneous blebs (chondrules) held together with a fine-grained matrix. These fascinating rocks offer the opportunity to study some of the first solid materials to have formed in our solar system and to investigate the role of water in the alteration of both mineral and organic components.

The primitive meteorite LAP02342 is particularly enigmatic, as shown by several preliminary studies [1-5]. It is classified as a Renazzo-type carbonaceous chondrite (CR) by the teams at the Smithsonian and Johnson Space Center, with an alteration type of 2 (CR2) and weathering stage A/B. This designates that it has experienced low-temperature aqueous alteration before landing on Earth and a low level of terrestrial alteration. It is a moderately-sized dark stone with large chondrules and abundant fine-grained matrix. The chondrules are commonly surrounded by fine-grained accretionary rims, indicating that it probably has not seen significant brecciation. This combined with little to no terrestrial alteration make LAP02342 ideal for observing the effects of asteroidal hydrous alteration.

In order to investigate the variation in the effects of the aqueous alteration on the mineralogy of LAP 023242, we used scanning transmission electron microscopy(STEM) imaging and energy dispersive x-ray spectroscopy (EDS) to analyze two extracted cross-sections. The cross-sections were prepared with focused ion beam methods (FIB); one using a Helios G3 Ga^+ FIB-SEM at NRL, and the other using a Helios G4 Xe plasma FIB at the Thermo Scientific demo lab. The Xe-FIB preparation enabled extraction of an exceptionally long (~50 µm) section of a S-rich rim of a Mg-rich porphyritic chondrule (type IA). The Ga+-FIB-prepared section was extracted from a region matrix a few mm away from the S-rich rim. Both cross-sections were characterized with the Nion UltraSTEM 200-X, equipped with a windowless, 0.7 sr Bruker SDD EDS system at NRL.

The S-rich rim is compact and well-formed, consistent with it being a primary accretionary rim. EDS mapping demonstrates that this section has sustained a moderate level of aqueous alteration, indicated by ubiquitous FeNi sulphides (likely pentlandite) associated with botryoidal Fe-oxides (i.e. magnetite) and the lack of FeNi metal grains. Most high Z phases are rich in Fe, Ni, S and O, consistent with the Fe-oxysulphide, tochilinite (see Fig. 1), similar to chemical redistribution seen in other CR chondrites EET92105 and EET87770 [6-7]. Abundant patches of incipient crystallites are spatially associated with the tochilinite and lattice spacings of ~0.7nm, consistent with the formation of the hydrous phyllosilicate chrysotile [8]. Assemblages of tochilinite, pentlandite, magnetite and chrysotile, such as observed here, are common features of asteroidal aqueous alteration observed in carbonaceous chondrites.

The section of matrix shows less alteration, consistent with that reported by [4-5]. Many more areas remain amorphous silicate, compared to that seen in the section of rim described above. FeNi metal grains are again absent, replaced by abundant FeNi sulphide grains, most likely pendlandite. Several larger high Z grains have only been partially converted into O-rich material, with remnant sulphide cores (see Fig. 2). This texture could be the result of two distinct alteration events, the first S-rich and the second O-rich. Alternatively, these high Z grains could have resulted from a single alteration event during which the composition of the fluid grew more O-rich with time.

References:
[1] JT Wasson and AE Rubin GCA **73** (2009), p. 1436-1460.
[2] S Pizzarello *et al.* GCA **74** (2010), p. 6206-6217.
[3] JT Wasson and AE Rubin M&PS **49** (2014), p. 245-260.
[4] CE Moyano-Cambero *et al*. LPSC **47** (2016), p. 2537.
[5] RM Stroud *et al.* MetSoc **9** (2016), id#6360.
[6] PV Burger and AJ Brearley LPSC **36** (2005), abs#2288.
[7] AJ Brearley and PV Burger MetSoc **72** (2009), p. 5148.
[8] LJ Chizmadia and AJ Brearley GCA **72** (2008), p. 602-625.
[9] The authors acknowledge NASA grant #NNH16AC42I and thank FEI for preparing the S-rich rim section as part of a demonstration of a Helios G4 Xe PFiB at their factory. JMTR thanks Spanish Ministry of Science and Innovation under research project AYA2015-67175-P

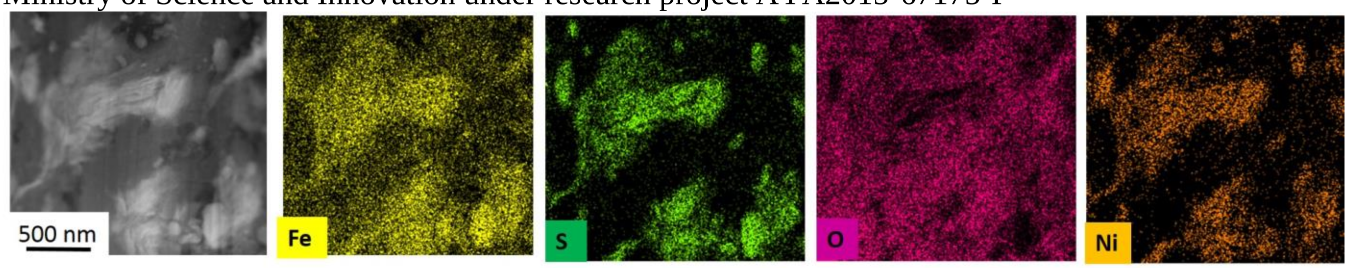

Figure 1. HAADF and EDS images of regions rich in Fe, Ni, S and O, consistent with tochilinite. The Fe-poor regions are rich in Mg, Si and O, consistent with chrysotile.

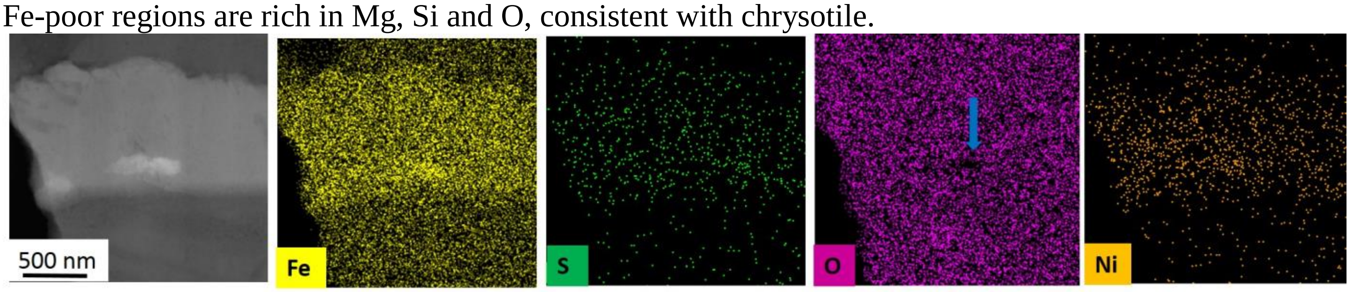

Figure 2. HAADF and EDS images of a FeNi oxide grain with an O-poor relict core (blue arrow).

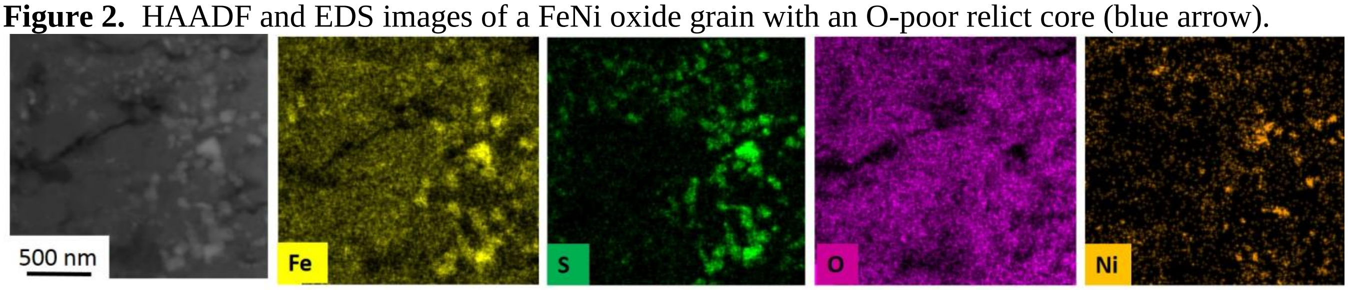

Figure 3. HAADF and EDS images of a S-poor conduit present within the matrix (lower right of images). The O-map (pink) shows that the Fe-sulphides are O-poor and Ni-rich.