Tracing Aqueous Alteration in Murchison Using NanoFTIR, SEM, TEM, and STXM

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Introduction: Previous work suggests that the formation of prebiotic compounds such as amino acids may be attributed to aqueous alteration in primitive meteorites[1]. Due to the sub-micron heterogeneity of precursor compounds and minerals within primitive planetary materials, prebiotic compounds found in primitive meteorites may be expected to be distributed heterogeneously as well. Here we show how nanoscale infrared spectroscopy (NanoFTIR), recently used to map the sub-micron heterogeneous distribution of minerals in cometary dust grains and Murchison, can be used to trace the aqueous alteration process in meteorites[2]. Our present study focuses on characterization of a ~50 micron-sized inclusion inside a chondrule and demonstrates the effectiveness of NanoFTIR at tracing aqueous alteration in Murchison.

Methods: *Sample Preparation:* A freshly cleaved section of Murchison was exposed, embedded in epoxy, and polished to optical smoothness to enable nanoFTIR imaging.

NanoFTIR: NanoFTIR imaging and spectroscopy was achieved using techniques described in our recently published work [2].

SEM-EDS: SEM/EDS showed a fine grained assembly containing phosphides, sulfides and silicate minerals.

FIB/STXM/TEM: A FIB slice was made in the same region as was imaged by NanoFTIR. STXM was used to obtain O and Fe XANES. TEM imaging and EDS mapping was used to connect nanophases with the NanoFTIR maps.

Results: Composite EDS maps of the inclusion revealed the presence of bright neworks of euhedral and subhedral semimetallic iron phosphide/sulfide crystals. These networks were likewise mirrored when imaged with NanoFTIR in a spectrally integrated (800-1100 cm^{-1}) mode. NanoFTIR also revealed the presence of several distinct silicates in the region. Infrared phonon modes corresponded to those expected for minerals based on SEM-EDS elemental compositions. Analysis of IR data across the olivine into the inclusion clearly showed a progression of pristine forsterite followed by chrysotile and Mg-rich serpentine, consistent with aqueous alteration in the region. STXM Fe^{+2}/Fe^{+3} maps from the FIB lamella of this region provide conclusive evidence for aqueous alteration in the region. Meanwhile, P=O molecular vibrations measured by NanoFTIR in this same region suggest a link between phosphonate production and aqueous alteration in primitive meteorites, as suggested by previous work [3]. Futher characterization is necessary to confirm the presence of bio-available phosphorus in this region of Murchison and its implications for the early solar system.

References: [11] Cobb A. K. and Pudritz R. E. 2014. *The Astrophysical Journal* 783:140. [2] Dominguez G.D. et al. 2014 *Nature Communications* 5:5445 [3] de Graaf R. M. et al. 1995. Nature 378:474.