TRANSMISSION ELECTRON MICROSCOPY ON HIGHLY ^{15}N-ENRICHED CHONDRITIC CLASTS IN THE ISHEYEVO METEORITE. H. A. Ishii[1]* , J. P. Bradley[1], L. Bonal[2], A. N. Krot[2], G. R. Huss[2], K. Nagashima[2], I. D. Hutcheon[1] and N. Teslich[1], [1]Institute of Geophysics & Planetary Physics, LLNL, 7000 East Avenue, Livermore, CA 94550 USA, [2]Hawai‘i Institute of Geophysics and Planetology, University of Hawai‘i at Manoa, 1680 East-West Road, Honolulu, HI, 96822 USA *hope.ishii@llnl.gov

Introduction: Previous whole-rock analyses of the metal-rich CH/CB-like meteorite Isheyevo show δ^{15}N enrichments up to ~+1500‰ [1]. Bonal et al. [2,3] reported the discovery of unique chondrite lithic clasts in Isheyevo having large "bulk" ^{15}N enrichments (δ^{15}N ranges from +1000 to 1300‰). These clasts may represent the primordial carrier of a ^{15}N anomaly in Isheyevo which avoided high-temperature thermal processing during nebular (CAI- and chondrule-formation) and asteroidal (impact melting) processing. In addition to bulk enrichment, these clasts contain µm-sized "hotspots" with δ^{15}N values reaching up to +4000‰ as measured by the University of Hawai‘i Cameca ims1280 ion microprobe [2]. Due to the fine-grained nature of the matrix material in the ^{15}N-rich clasts, we initiated FIB/TEM studies to explore the possible origin of these clasts and to identify the carrier(s) of their "bulk" and "hotspot" ^{15}N enrichments. Here we report the initial TEM results.

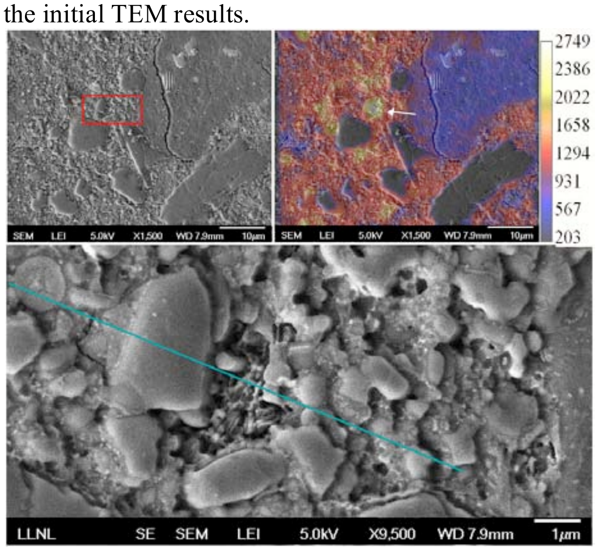

Figure 1. (top left) SEM image of the isotope-mapped region of a Group II chondritic clast. (top right) SEM image overlaid by the δ^{15}N isotope map. Silicate grains act as landmarks for aligning the images. The "hotspot" (arrow) reaches a δ^{15}N value of +2700‰, and neighboring "bulk" material averages δ^{15}N of ~+1200‰. (bottom) Higher-magnification SEM image of the region indicated by the red box above. The location of the section extracted by FIB is indicated by the line, and the "hotspot" material lies in the middle of the line and to the right of the silicate grain.

Methods: Using a high resolution JEOL JSM-7401F FE-SEM at LLNL, the surface topography in isotope-mapped regions of the clasts was carefully correlated with δ^{15}N maps (Fig. 1). Electron-transparent thin sections extracted using an FEI Nova600 NanoLab dual-beam FIB (focused ion beam instrument) contain "hotspot" material as well as neighboring bulk material also significantly enriched in ^{15}N (Fig. 2). Subsequent transmission electron microscopy analysis was carried out on a 200kV FEI Tecnai TF20 G2 analytical (scanning) TEM.

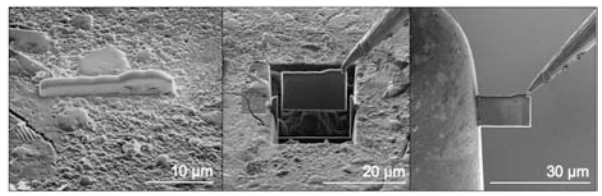

Figure 2. (left) FIB-SEM image after deposition of a Pt strap to protect the region of interest. Sample is rotated ~180° and tilted 52° relative to Fig. 1. (middle) FIB-secondary ion image after extraction of a ~µm-thick section of clast matrix material including a "hotspot". (right) FIB-secondary ion image after attachment of the section to a TEM grid.

Results: Initial TEM analysis of this FIB section shows that the entire section is extensively aqueously altered. The "hotspot" material extends in a vein ~1–2 µm wide through the FIB section. It contains a network of carbonaceous material with ~10–50 nm thick strands and occasional larger globules (Fig. 3) embedded in fined-grained, highly aqueously altered material. The hydrated material consists of regions containing a) phyllosilicates consistent with smectites (~12Å basal spacings, although most regions are disordered),

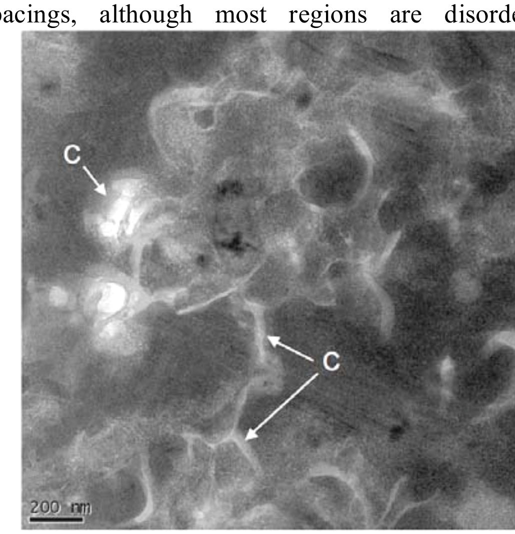

Figure 3. Brightfield TEM image of "hotspot" material showing the interconnected network of carbonaceous material (lighter strands) in heavily hydrated matrix.

b) domains of cronstedtite (~7Å basal spacing) intergrown with a poorly-ordered material, possibly tochilinite (with domains of 5Å spacings plus minor Ni and S), and c) another beam sensitive Fe-rich phase compositionally consistent with ferrihydrite. (Rigorous identification is hampered by the low degree of crystallinity.) Also embedded in the vein are ~50–500 nm grains of silicates, olivines and low- and high-Ca pyroxenes, displaying partial hydrous alteration on their peripheries (Fig. 4). One high-Ca pyroxene approximately on the boundary between "hotspot" and "bulk" material displays features typically resulting from high shock processing (Fig. 5) as well as partial alteration by hydration.

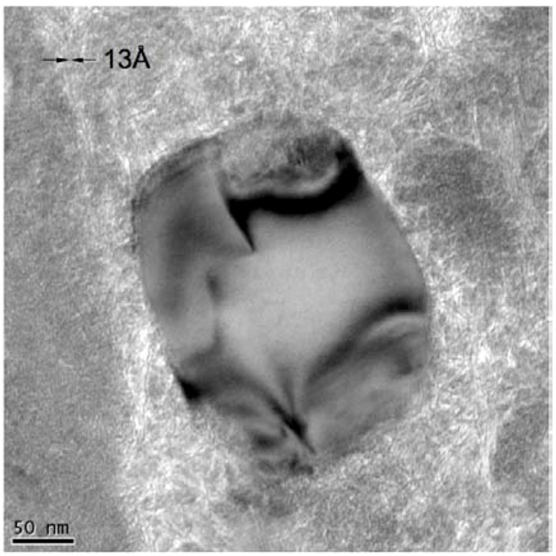

Figure 4. Brightfield TEM image of an olivine grain ($Fo_{\sim 85}$) partially altered into surrounding smectite. Strain induced by alteration is evident in the bands of contrast in the crystal.

The "bulk" matrix is comprised of the same highly aqueously altered phases as the "hotspot" vein. Embedded within are larger olivines and pyroxenes ranging in size from tens of nanometers to several microns. Pseudomorphic replacement of minerals, particularly silicates, is evident in several places, and the least altered remnant crystals are primarily low-Fe olivines. Secondary framboidal magnetite is also present.

A significant difference between "bulk" and "hotspot" materials is that no discrete carbonaceous material has yet been identified in the bulk matrix. Carbon analyses are, however, complicated by the sensivity of the material to electron irradiation requiring weak beam imaging and spectroscopy conditions.

Summary and Future Work: We initiated FIB/TEM studies of chondritic clasts in the Isheyevo meteorite to explore the possible origin of these clasts and to identify the carrier(s) of their "bulk" and "hotspot" ^{15}N enrichments. Initial TEM analyses of the fine-grained matrix shows it resembles chondritic matrix that experienced aqueous alteration on a parent body prior to incorporation in the Isheyevo meteorite. The "hotspot" region is most notably distinguishable from surrounding regions by the presence of a network of carbonaceous material. Results of more detailed study of the hotspot and surrounding ^{15}N-enriched fine-grained material in this and additional FIB-prepared TEM sections will be presented for comparison to the matrix components of other chondrites and to other clasts in CH and CB meteorites [c.f. 4–6]. Energy-filtered imaging and electron energy loss spectroscopy (EELS) will be explored at the C, N and O edges for additional chemical correlations.

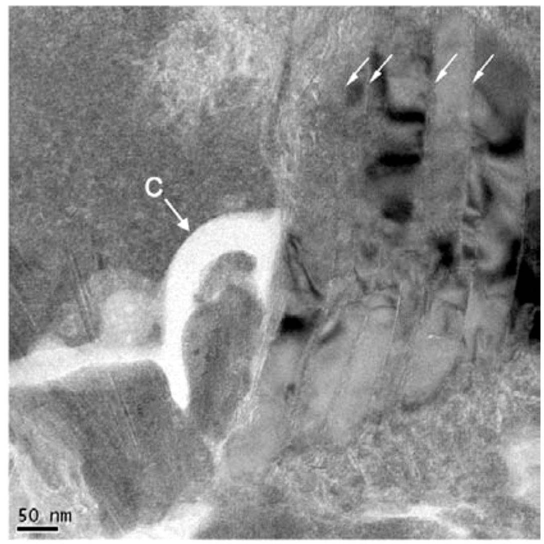

Figure 5. Brightfield TEM image of a high-Ca pyroxene displaying banded features typical of high shock processing. The dense defect bands (arrows) have been replaced by the phyllosilicate products of aqueous alteration. A portion of the carbonaceous material is present next to the pyroxene.

Following TEM analyses, NanoSIMS isotope mapping will provide higher resolution correlation of the ^{15}N-enriched areas with specific petrographic features. The powerful combination of microscopy, spectroscopy and spectrometry via SEM, TEM, EELS and SIMS techniques will enable identification of the carrier phase(s) of the very large bulk and hotspot ^{15}N anomalies in these unique chondritic clasts.

References: [1] Ivanova et al. *MAPS, 43*, 915. [2] Bonal et al. (2009) *LPS XL,* Abstract #2046. [3] Bonal et al. (2008) *GCA*, *submitted*. [4] Greshake et al. (2002) *MAPS, 37,* 281. [5] Greshake et al. (1997) *GCA, 61,* 437. [6] Tomeoka and Buseck, *GCA, 52,* 1627.

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