ISOTOPICALLY HETEROGENEOUS ORGANIC MATTER IN THE TAGISH LAKE METEORITE.
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Introduction: The Tagish Lake meteorite is an ungrouped carbonaceous chondrite that represents some of the most primitive material available for study. It contains a high amount of organic carbon (~2.6 wt%), most of which is insoluble in polar solvents [1]. Like organic matter in other primitive meteorites, as well as in IDPs, Tagish Lake preserves hydrogen and nitrogen isotopic anomalies consistent with an interstellar or outer solar system origin [2, 3]. Hollow carbonaceous nanoglobules in Tagish Lake are argued to be the carriers of D and ^{15}N enriched "hotspots" in the bulk insoluble organic matter (IOM) of Tagish Lake [3].

Lithological variations, beyond what has been previously described [4] are evident from casual inspection of the exterior of individual samples of the pristine Tagish Lake meteorite shower [5]. The origin of these variations are not known. By systematically investigating the mineralogical, petrological, geochemical and organic chemical similarities and differences among lithologies within the Tagish Lake meteorite, we hope to gain insights into presolar, nebular and parent-body processes preserved within it. Results of the *in situ* isotopic analysis of organic matter (dominated by IOM) are presented here; soluble organic analysis results are presented in [6] and preliminary results of SEM and TEM analysis are presented in [7].

Experimental: Fragments up to 40 µm across were selected from samples of the Tagish Lake meteorite that had previously been disaggregated during soluble organic extraction [6]. The samples are representative of the macroscopic lithological variations observed in the meteorite [5]: Sample 5b is a compact, coherent fragment composed of chondrules set in a fine-grained matrix of phyllosilicates, sulfides, abundant magnetite, and rare carbonate. It appears to be most similar to the carbonate-poor lithology of [4]. Sample 11i is an example of a "dark, dusty" lithology consisting almost entirely of fine-grained (<5 µm) material typical of matrix (incl. phyllosilicates, magnetite, and sulfides) and lacking chondrules or CAIs.

Several fragments of each sample were selected, pressed into gold foil, and coated with gold. For both samples, fine-grained, dark fragments, presumably representing the matrix, were preferentially selected. The samples were analyzed by raster ion imaging in the Carnegie NanoSIMS 50L. Negative secondary ions of ^{12}C, ^{13}C, $^{12}C^{14}N$, $^{12}C^{15}N$, ^{16}O and ^{28}Si were measured for a total area of 1800 µm^2. Most of the same areas were re-measured for ^2H and ^1H. Terrestrial Si_3N_4 and organic standards, as well as well-characterized IOM from the QUE 99177 CR chondrite [8], were used to align mass peaks and determine instrumental mass fractionation. The L'Image software package was used to plot ratio images and calculate quantitative data for selected regions of interest (ROIs). Scanning electron microscopy (SEM) imaging and EDS analysis were used to characterize samples before and after NanoSIMS analysis.

Results: The fragments investigated contain ample carbonaceous material; up to tens of % by area based on ^{12}C maps. There appears to be no systematic difference in relative abundance of carbonaceous material between the two lithologies. The average H, N and C isotopic compositions of the carbonaceous material in each lithology (obtained by summing ROI values) are comparable to values obtained for bulk IOM [8].

As seen previously [2, 3] organic matter is isotopically highly heterogeneous on the nanoscale. An example of a fragment from sample 11i is shown in Figure 1; isotopic hotspots (regions which deviate significantly from the average composition) are clearly visible. Two prominent hotspots are near the upper-left margin of the fragment (arrows); these have typical $\delta^{13}C$ values (~−50 ‰), but high $\delta^{15}N$ and δD values (~+700 ‰ and +4,000 ‰, respectively; ellipse in Fig. 3). Notably, these hotspots correspond to 1-2 µm features that closely resemble isotopically anomalous organic globules observed previously in Tagish Lake and other primitive chondrites (Figure 2). The D hotspot at the lower left of the fragment (Figure 1 arrow) has normal to depleted $\delta^{15}N$ (ROI TL11i-3-8; Fig. 3).

Figure 3 shows H and N isotopic data for 660 ROIs measured for both elements. ROIs are typically 200-800 nm in diameter. Although there is a broad general trend of increasing ^{15}N with increasing D, there is no simple correlation. Many ^{15}N hotspots do not have corresponding D enrichments and vice-versa; e.g., the ROI with the largest D/H ratio (δD = 14,000 ‰) has $\delta^{15}N$ within error of the bulk Tagish Lake IOM. ROIs with $\delta^{15}N$ in the range of 700-900 ‰ show a factor of ten variation in D/H ratio. Furthermore, we observe that ^{15}N and D hotspots are not always associated with organic globules.

Most ROIs have $\delta^{13}C$ values within errors of the bulk Tagish Lake IOM value of $\delta^{13}C = -14$ ‰. However, two ROIs show moderate ^{13}C depletions ($\delta^{13}C$ ~ −100 to −200 ‰) and one organic ROI with large ^{15}N and D enrichments (TL11i-4-171; Fig. 3) also has an unusual moderate ^{13}C excess ($\delta^{13}C$ ~80 ± 20 ‰).

Comparison of lithologies: Figure 3 compares the range of compositions of ROIs from the two Tagish Lake samples. Sample 11i (dark, dusty lithology) contains a greater number of ROIs with ^{15}N enrichments than sample 5b (chondrule-bearing). Although the statistics are limited, sample 11i appears to contain a greater range of isotopic compositions than sample 5b.

Discussion and implications: Overall, the average isotopic composition of the IOM in each of the two Tagish Lake lithologies investigated is the same, and they are similar to the bulk IOM reported previously [8]. However, our results suggest that the range of isotopic compositions is greater in the matrix-rich, dark, dusty lithology. Bulk and NanoSIMS isotopic analysis for concentrated IOM residues from each sample are planned; results will indicate the degree to which the enriched portions of the IOM in each lithology leverage the bulk composition. Our observations of 1) diverse isotopic compositions of organic matter on the nanoscale, 2) poorly correlated ^{15}N and D enrichments and 3) lack of association between ^{15}N and D enrichments and globular structures provides insights into the source and processing of primitive organic matter. Comparison of Tagish Lake IOM with that from other meteorites [8, 9] indicates that the former has undergone significant processing (lower bulk D/H and $^{15}N/^{14}N$, higher aromaticity, etc). However, the high degree of variation in isotopic composition, particularly in sample 11i, indicates that this processing must have been quite heterogeneous. The decoupling of H and N isotopes probably indicates a diversity of molecular precursors and a corresponding diversity in the response to processing on the parent body.

References: [1] Grady M.M. et al. (2002) *M&PS, 37,* 713-735. [2] Busemann H. et al. (2006) *Science, 312,* 727-730. [3] Nakamura-Messenger K. et al. (2006) *Science, 314,* 1439-1442. [4] Zolensky M.E. et al. (2002) *M&PS, 37*, 737-761. [5] Herd R.K. and C.D.K. Herd (2007) *LPSC, XXXVIII*, Abstract #2347. [6] Hilts et al. (2009) *This meeting*. [7] Blinova et al. (2009) *This meeting*. [8] Alexander C.M.O'D. et al. (2007) *GCA, 71,* 4380-4403. [9] Cody G.D. and Alexander C.M.O'D. (2005) *GCA, 69,* 1085-1097.

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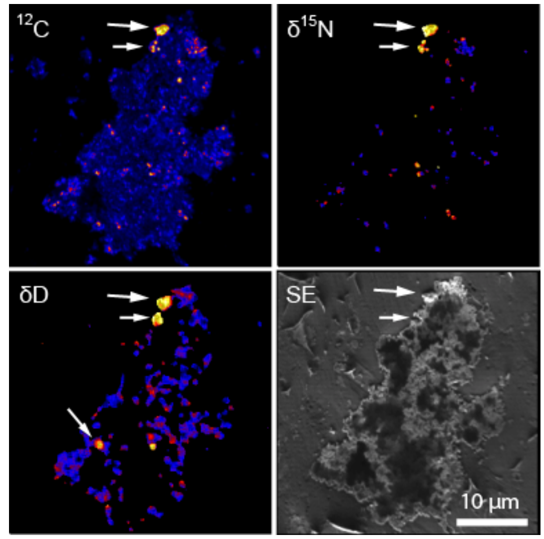

Figure 1. Isotopic, isotopic ratio and secondary electron (SE) images of a fragment of Tagish Lake sample 11i.

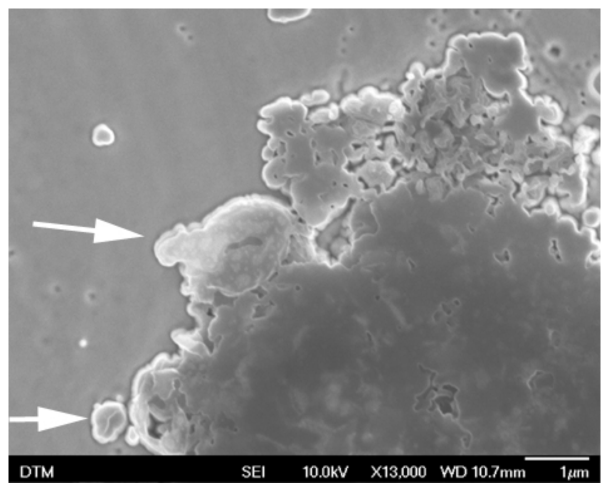

Figure 2. SE image of two hotspots shown in upper part of Figure 1.

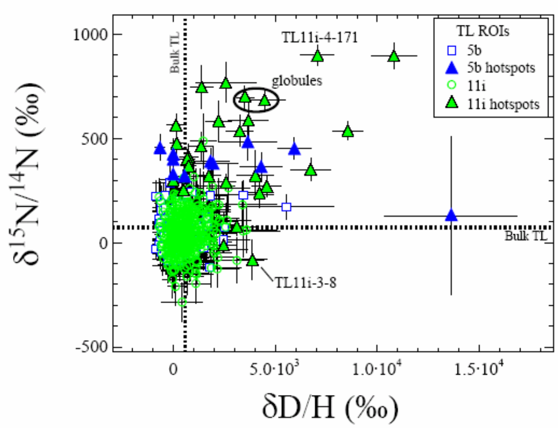

Figure 3. Plot of N and D isotopic compositions of ROIs in Tagish Lake.