

## FTIR AND CARBON-XANES EXAMINATION OF ORGANIC CARBON IN TAGISH LAKE: EVIDENCE FOR A MODERATELY VOLATILE ORGANIC COMPONENT.

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**Introduction:** On Jan 18<sup>th</sup>, 2000, after observation of a fireball over the Yukon Territory and British Columbia, dozens of fragments of a meteorite were recovered from Tagish Lake. We obtained an ~30 mg sample, from a piece of the Tagish Lake meteorite that was recovered from the land adjacent to the lake several months after the fall, from The Meteorite Market.

**Chemical Analysis:** We separated a chip, measuring ~1 mm x 1 mm x 0.5 mm in size, from the ~30 mg sample of the Tagish Lake meteorite and performed x-ray fluorescence composition measurements using the synchrotron X-Ray Microprobe on beamline X26A of the National Synchrotron Light Source (NSLS). The analysis beam was ~15 x 15 micrometers in size, penetrating the sample at a 45° angle. The escape depth of the fluorescence x-rays limited our analysis volume to ~10<sup>-8</sup> cm<sup>3</sup> (a mass of ~3x10<sup>-8</sup> grams). Because of the small analysis volume, we performed 14 individual analyses of different spots on the chip. We obtained element/Fe ratios for Ca, Cr, Mn, Ni, Cu, Zn, Ga, Ge, As, Se, and Br, that were converted to element abundances using the 19.3% Fe content of Tagish Lake determined by Brown et al. [1].

The averages of the 14 spot analyses of the chip are given in Table 1. The average abundances of the moderately volatile elements (Cu, Zn, Ga, Ge, As, and Se) in the chip agree to within ~10% with the values reported by Brown et al. [1]. These abundances are between the mean CM2 and the mean CI1 compositions, consistent with Brown et al.'s [1] classification of Tagish Lake as a CI2 meteorite. However, Cr, Mn, and Ni are all higher by 25 to 30% in this Tagish Lake sample than in the one analyzed by Brown et al. [1].

Element abundance patterns can be used to monitor the degree of terrestrial alteration or contamination of meteorites. This is particularly important in the case of the Tagish Lake meteorite because CI and CM carbonaceous chondrites are rather porous, and some fragments were recovered months after the fall and after exposure to water from the melting snow. Many chondritic meteorites and micrometeorites show evidence of terrestrial contamination by elevated levels of Pb, loss of sulfur-rich phases (which we monitor using Se), or alteration of the halogen content (such as Br). The ~30 mg sample of Tagish Lake has a Se content comparable to the larger sample analyzed by Brown et al. [1] and shows no evidence for elevated levels of Pb (which has an L-line near the As K-line) or the loss of Br (see Table 1), suggesting it has experienced no more alteration than the Brown et al. [1] sample.

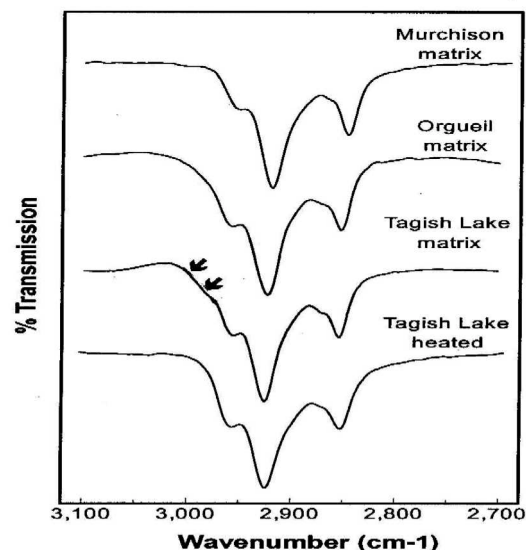


Figure 1. Infrared absorption spectra of Murchison, Orgueil, Tagish Lake (with the unusual features at 2988 and 2995 cm<sup>-1</sup> marked with arrows) and Tagish Lake heated for ½ hour at 100° C.

Our measurements provide an opportunity to assess the heterogeneity of the Tagish Lake meteorite. The 14 spot analyses show variations from the mean of no more than a factor of 3, quite a bit smaller than the range we measured for ~10<sup>-8</sup> cm<sup>3</sup> fragments from the CM2 meteorite Murchison, but comparable to the range we measured for ~10<sup>-8</sup> cm<sup>3</sup> fragments of the CI1 meteorite Alais. This low degree of heterogeneity indicates that, within this sample, the mean grain size is much smaller than the ~10<sup>-8</sup> cm<sup>3</sup> analysis volume.

**FTIR Examination:** We employed Fourier Transform InfraRed (FTIR) spectroscopy, using a Continuum FTIR microscope on Beamline U10B of the NSLS, to characterize the organic carbon in ~10 to 30 μm chips taken from an ~30 mg fragment of the Tagish Lake meteorite. We took spectra of the CM2 meteorite Murchison and the CI1 meteorite Orgueil, for comparison with Tagish Lake. We obtained high-quality infrared absorption spectra over the 4000 to 650 cm<sup>-1</sup> spectral range. The Tagish Lake meteorite is dominated by hydrated silicates, carbonates, sulfides oxides and trace phases [2]. These minerals, which have strong absorptions over most of the spectral range we analyzed, interfere with detection of organic features over much of the infrared spectrum. However in the region from 2700 to 3100 cm<sup>-1</sup>, where the C-H stretching vibrations occur, the major minerals exhibit only a broad water feature, and the sharper C-H stretching fea-

tures can be easily identified.

The Tagish Lake samples all exhibit three sharp absorptions features, at  $\sim 2950$ ,  $2926$  and  $2854$   $\text{cm}^{-1}$ , and a much weaker feature near  $2870$   $\text{cm}^{-1}$  (see Figure 1). The pair of features at  $2926$  and  $2854$   $\text{cm}^{-1}$  correspond to the asymmetrical and symmetrical stretching vibrations of  $\text{CH}_2$  in an aliphatic hydrocarbon, while the pair at  $2960$  and  $2870$   $\text{cm}^{-1}$  correspond to the asymmetrical and symmetrical stretching vibrations of  $\text{CH}_3$  in an aliphatic hydrocarbon. Despite the overlaps, we also detected the  $\text{CH}_2$  and  $\text{CH}_3$  bending vibrations (at  $\sim 1465$   $\text{cm}^{-1}$  and  $1375$   $\text{cm}^{-1}$ ) as shoulders on the carbonate (see Fig. 3 of reference 2). We detected no features in the  $3000$  to  $3050$   $\text{cm}^{-1}$  region, where the  $\text{CH}$  stretching vibrations of aromatic hydrocarbons occur.

The Tagish Lake samples also show two weak absorption, at  $\sim 2988$  and  $\sim 2995$   $\text{cm}^{-1}$ , not seen in Orgueil or Murchison. We heated fragments of Tagish Lake to  $100^\circ$  C for  $\frac{1}{2}$  hour and both features disappeared, indicating that this sample of Tagish Lake contains a volatile phase that is lost or altered on heating. We have not yet identified the functional group(s) responsible for these features, but they are likely to result from C-H stretches, indicating this material is organic.

**STXM Characterization:** Another small chip from the  $\sim 30$  mg fragment was embedded in elemental sulfur. Ultramicrotome thin sections were cut and deposited on an  $\text{SiO}$  substrate for analysis using the Scanning Transmission X-Ray Microscope (STXM) on Beamline X1A of the NSLS. Because of the heating during embedding in S, the phase responsible for the  $2988$  and  $2995$   $\text{cm}^{-1}$  absorptions detected by FTIR was lost from the STXM sample. We imaged the section at energies above and below the C K-edge, and generated a map of the carbon distribution in the section. We then obtained X-ray Absorption Near Edge Structure (XANES) spectra over the energy range from  $280$  to  $305$  eV at carbon-rich spots on the section (see Fig. 2).

Carbon was abundant in this section. Highly absorbing submicron carbon-rich grains and larger but less strongly absorbing regions of carbon-rich material were identified. We obtained four distinctly different C-XANES spectra. Spectra like Spot C and Spot D were obtained on the strongly absorbing (probably denser) grains, while the less strongly absorbing regions gave spectra like Spot A and Spot B. Spot A shows three pre-edge absorptions near  $285$ ,  $286.5$ , and  $288$  eV. The Spot A spectrum is very similar to the C-XANES spectrum of organic matter extracted from the CM2 carbonaceous meteorite Murchison.

The spectrum taken at Spot B is similar to that at Spot A except that the  $288$  eV absorption, resulting from carbon-oxygen bonding, is larger than in the Spot A spectrum, indicating at least two types of organic carbon are present. The Spot C spectrum shows an additional absorption just above  $290$  eV, consistent with carbonate (also identified by TEM and FTIR). Carbonate grains in this section were all small ( $\leq 1/2$   $\mu\text{m}$ ) and were spatially associated with organic material. The Spot D spectrum, dominated by the  $285$  eV absorption, is consistent with reference spectra of amorphous carbon.

**Conclusions:** The STXM examination indicated that carbon was quite abundant in this Tagish Lake sample. Carbon-XANES spectroscopy showed that the small area of the Tagish Lake meteorite that we examined contains at least four distinct types of carbonaceous material: carbonate, amorphous carbon, and two spectrally distinct organic components. The FTIR spectroscopy showed C-H stretching features very similar to those in Murchison and Orgueil, as well as two features at  $\sim 2988$  and  $\sim 2995$   $\text{cm}^{-1}$ , that are lost on heating to  $100^\circ$  C, indicating the presence of a moderately volatile organic phase.

**References:** 1) P. G. Brown et al, *Science*, 290, 320-325, 2000. 2) L.P. Keller and G.J. Flynn (2001) Matrix Mineralogy of the Tagish Lake Carbonaceous Chondrite, *Lunar & Planet. Sci. XXII*, this volume.

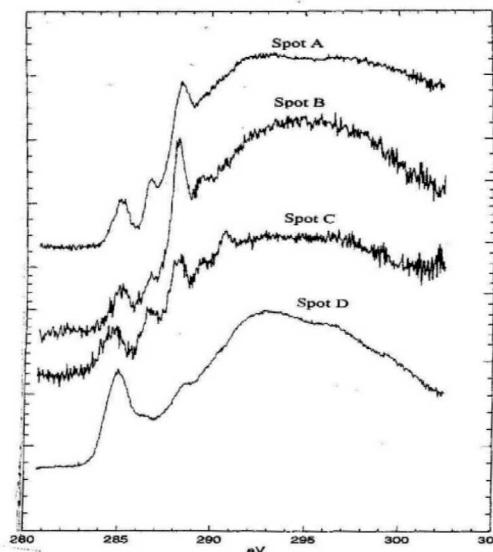


Figure 2: C-XANES spectra of Tagish Lake.

Table 1: Chemical Composition of the Tagish Lake Meteorite

Sample	Ca	Cr	Mn	Fe	Ni	Cu	Zn	Ga	Ge	As	Se	Br
	(%)	(ppm)	(ppm)	(%)	(%)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
Bulk*	0.99	2840	1450	19.3	1.16	116	253	8.4	30	1.74	14.3	2.8
SXRF Avg. 14	0.7	3550	2000	19.3**	1.45	126	240	7	27	<3***	16	~2

\*from Brown et al. [1] \*\* Fe fixed at 19.3% in SXRF data reduction \*\*\*As includes a contribution from Pb