INVESTIGATION OF THE TAGISH LAKE CARBONACEOUS CHONDRITE BY X-RAY MICRODIFFRACTION

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Introduction: Tagish Lake is an ungrouped C2 chondrite, which has been the subject of intense study since it was recovered in 2000 [1]. We present the preliminary results of an investigation of Tagish Lake using X-ray micro diffraction (µXRD) and conventional powder X-ray diffraction (XRD).

Micro X-ray Diffraction (µXRD): µXRD is a versatile technique in geoscience. In meteoritics, it is particularly attractive for non-destructive mineralogical analysis at 500 to 50 µm scales. It is also ideal for *in situ* studies of whole-rock specimens, cut surfaces and thin sections. µXRD data were collected with the Bruker D8 Discover diffractometer at the University of Western Ontario (UWO), operating with Cu Kα radiation (λ = 1.5418 Å) at 40 kV and 40 mA. A 2-dimensional general area diffraction detector system (GADDS) allows detection of textural features such as crystallite size, alignment, and strain. A 2.9 g intact fragment sample and an uncoated thin section were surveyed. This reconnaissance serves two main purposes: To study individual clasts and grains with their natural context preserved, and to inform the later work with powdered bulk samples. We also seek to determine how much mineralogical information can be gleaned from completely unmanipulated meteorite samples via µXRD.

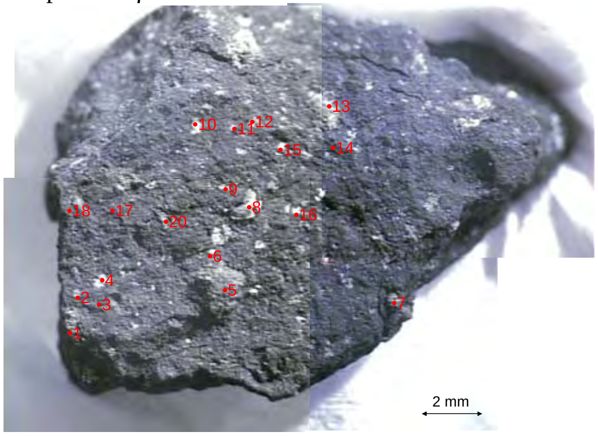

Figure 1: Intact Tagish Lake fragment showing the 20 points investigated by µXRD.

Matrix points studied in both the thin section and intact fragment are dominated by fine-grained saponite ($(Ca,Na,K)(Al,Mg,Fe,Mn)_2(Si,Al)_4O_{10}(OH)_2 \cdot nH_2O$), serpentine ($Mg_3Si_2O_5(OH)_4$) and magnetite ($Fe_3O_4$). Sulfides are present in minor amounts as pyrrhotite ($Fe_{1-x}S$) and rarer pentlandite ($(Fe,Ni)_9S_8$). Siderite ($FeCO_3$) is the predominant carbonate in matrix. Forsteritic olivine (Mg_2SiO_4) appears in most matrix sites as very fine (~few microns) fragments.

Within the chondrite matrix are a variety of clasts. Forsteritic olivine appears in both pristine chondrules and finer grained irregular aggregates. Saponite and serpentine occur in both chondrules and aggregates, particularly along rims. Magnetite and sulfides are present, but are not as abundant as in matrix. Pyroxenes are very rare, but traces of diopside ($CaMg(Si_2O_6)$) and/or hedenbergite ($CaFe(Si_2O_6)$) have been found in both chondrules and aggregates. Carbonates usually occur as small irregular nodules. One spectacular carbonate nodule in thin section contains spinel (*sensu stricto* $MgAl_2O_4$). It is primarily dolomite ($CaMg(CO_3)_2$) with calcite, siderite, magnetite and saponite. This nodule provides excellent examples of textural features detectable via µXRD.

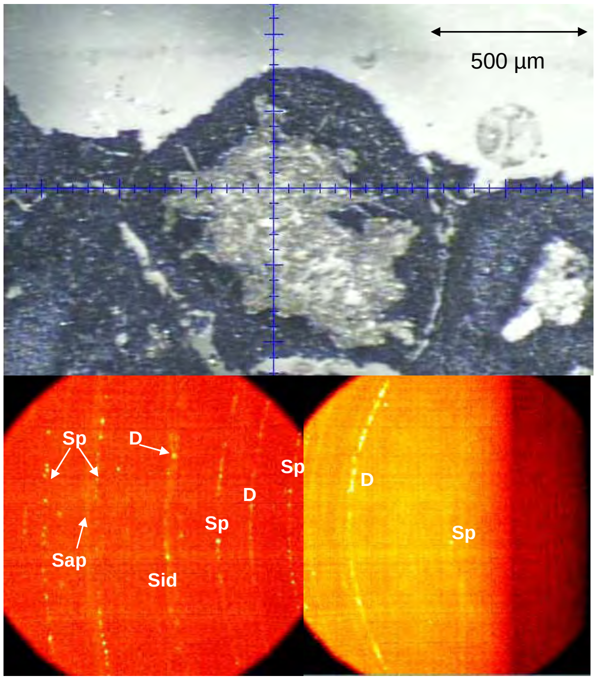

Figure 2: Tagish Lake carbonate nodule in thin section, with GADDS images. Sp = spinel, Sid = siderite, D = dolomite, Sap = saponite. Note the discrete spots created by coarser grained dolomite and spinel and the continuous rings created by fine grained siderite and saponite.

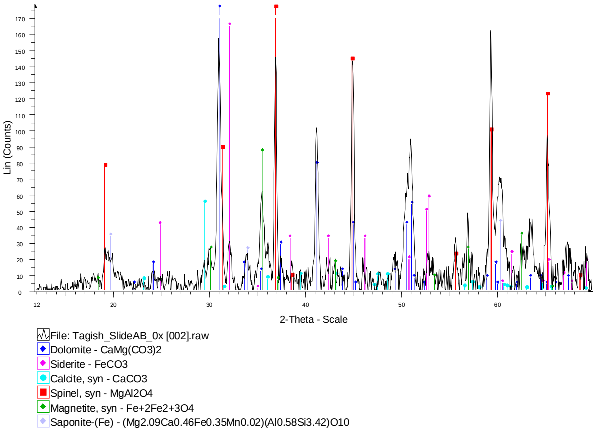

Figure 3: Phase analysis for Tagish Lake carbonate nodule

Conventional powder X-ray Diffraction (XRD): A disaggregate bulk Tagish Lake sample was ground to a fine powder. XRD data was collected with the Panalytical X'pert diffractometer at Queens Univeristy with Co Kα radiation (λ = 1.79801 Å) at 40 kV and 40 mA.

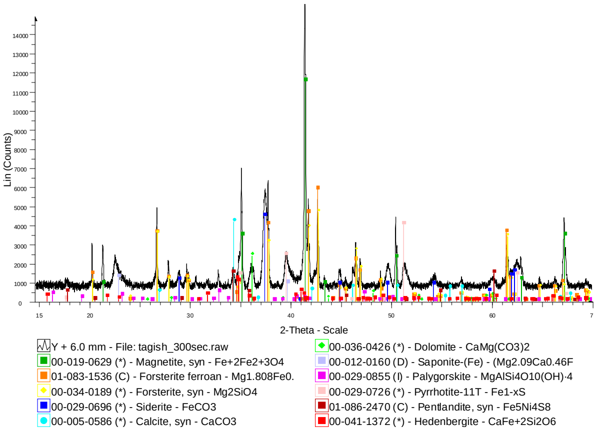

Figure 4: Powder XRD pattern for bulk Tagish Lake material.

Phase identification made use of the International Centre for Diffraction Data (ICDD) database [2], using the Bruker AXS EVA software, informed by the μXRD reconnaissance and previously published data [3,4]. At this resolution, two distinct olivine patterns are observed, one corresponding to nearly pure (>99% Mg) forsterite, the other best matching a ~10% Fe composition. This is consistent with the two distinct forsterite populations previously reported [5]. Siderite is the predominant carbonate, with minor dolomite ($CaMg(CO_3)_2$) and calcite ($CaCO_3$). Very broad peaks correspond to saponite, serpentine and probably other phyllosilicates. Magnetite, pyrrhotite and pentlandite are again observed. Pyroxene may occur at a trace level, but it is difficult to resolve in the bulk sample due to peak overlap and low signal.

Modal Mineralogy via Rietveld Refinement: It would be ideal to obtain accurate modal mineralogy for each of the samples studied. One way to obtain modal abundances is by Rietveld refinement, a well-established technique which uses least-squares optimization to fit a calculated diffraction pattern based on a structural model to a measured diffraction pattern [6]. This technique can find modal abundances accurate to the 1% level even in complex systems of many phases [7]. Rietveld refinement has not been widely applied to meteoritic material, but shows promise. The laboratory equipment and specialist software required are widely available, and only a very small (~50 mg) sample is required. Sample preparation involves only powdering, and the powder can be reused for other analyses. No matched standard materials are required. A preliminary test, with a simplified mineral chemistry and many refinable parameters held fixed gives reasonable results. These results are summarized in table 1, along with the modal abundances reported by Bland *et al* [4]. It is emphasized that the refinement carried out here is a preliminary test of the method. Rietveld refinement was carried out using Bruker AXS TOPAS3 software. The large errors in the refined abundances will be greatly reduced by improvements to the model.

Table 1: Preliminary results of Rietveld refinement on Tagish Lake.

Mineral	%wt	Error
Saponite	25.0	3.1
Serpentine	13.9	5.7
Forsterite	23.2	7.5
Siderite	22.5	7.2
Magnetite	7.6	3.1
Pyrrhotite	5.5	2.3
Pentlandite	2.4	1.0

References: [1] Hildebrand, A.R. et al. (2006) *Meteoritics & Planet. Sci., 41*, 407-431. [2] NIST Int. Ctr. F. Diffraction Data: Newtown Square Corporate Campus 12 Campus Blvd Newtown Square, PA 19073-3273, [3] Zolensky, M. E., et al. (2002). *Meteoritics & Planet. Sci 37*, 737-761. [4] Bland P. A. et al (2004) *Meteoritics & Planet. Sci.,39*, 3-16. [5] Russell, S.D, et al. (2004) AGU Fall mtg. Abs. V43C-1431, [6] Rietveld, H. M. (1969). *J. Appl. Crystallography 2*: 65-71. [7] Shankland, K. (2004). *J Rsch. of NIST 109(1):* 143-154.