

WHOLE-ROCK, CLAY MINERAL, AND OLIVINE OXYGEN AND HYDROGEN ISOTOPE COMPOSITIONS OF THE TAGISH LAKE CARBONACEOUS CHONDRITE. S. D. J. Russell¹, F. J. Longstaffe¹, P. L. King^{1,2} and T. E. Larson³, Department of Earth Sciences, The University of Western Ontario, 1151 Richmond Street, London, ON N6A 5B7, Canada; ²Institute of Meteoritics, University of New Mexico, Albuquerque, NM 87131, USA; ³Los Alamos National Laboratory, Earth and Environmental Sciences Division, Hydrology, Geochemistry and Geology Group, MS-D469, Los Alamos, NM 87545, USA (sdrussel@uwo.ca; flongsta@uwo.ca)

Introduction: The Tagish Lake meteorite has been proposed to be a C12 carbonaceous chondrite or, at the very least, a new variety of type 2 carbonaceous chondrite [1,2,3]. It is composed of chondrules, isolated olivine grains and rare Calcium Aluminum Inclusions (CAIs), contained in a matrix dominated by phyllosilicates, carbonates and magnetite [3]. We present chemistry and oxygen isotope data for chondrules and isolated olivine grains as a tracer of primary crystallization processes. Whole-rock and clay-separate oxygen and hydrogen isotope data are used to discuss the alteration history of the Tagish Lake meteorite.

Samples and Methods: Chondrules and isolated olivine grains were hand-picked from disaggregated Tagish Lake meteorite material collected from melt pockets in the frozen (Tagish) lake surface. Chondrules were selected for study when their mass (>1 mg) was sufficient for characterization chemically using electron probe microanalysis (EPMA) and isotopically using laser fluorination. Colourless (Fo_{99.0-99.8}; henceforth Type-I olivine) and olive green (Fo₃₉₋₈₇; henceforth Type-II olivine) isolated olivine grains were differentiated and characterized using micro-Fourier transform infrared spectroscopy, EPMA and cold cathodoluminescence.

Whole-rock samples were subdivided into pristine (collected immediately after the meteorite fall) and degraded material (collected approximately 4 months later from the frozen Tagish Lake surface). The clay-size mineral fraction (<2 µm) was isolated by disaggregation (using a probed-tip ultrasonicator), magnetite removal and centrifugation. Clay mineralogy was determined using X-ray diffraction.

Pyrolysis was performed *in vacuo* to obtain OH⁻ from clay minerals and CO₂ from carbonates. The measured δD value of a kaolinite standard (KGa-1) was reproducible to ±3 ‰. Additionally, a bulk sample was reacted with orthophosphoric acid to obtain the carbonate oxygen isotope composition using traditional analytical methods.

Whole-rock oxygen isotope analyses were performed offline using methods similar to [4]. Analytical accuracy and precision were tested using NBS-28, which had a δ¹⁸O value of 9.6 ‰ and a 1σ standard deviation of 0.1 ‰. Laser fluorination oxygen isotope analyses were performed using a Merchantek Mir 10-25 CO₂ laser-BrF₅ line following the methods of [5]. Ana-

lytical accuracy and precision were tested using San Carlos olivine, which yielded values of 2.72 ‰ and 5.17 ‰ (n = 39), and a 1σ standard deviation of 0.05 ‰ and 0.06 ‰ for δ¹⁷O and δ¹⁸O, respectively. All oxygen and hydrogen isotope results are reported relative to VSMOW in permil (‰) [6].

Results: Chondrule and isolated olivine grain oxygen isotope values range in δ¹⁸O from -7.2 to 5.9 ‰ and in δ¹⁷O from -9.6 to 2.2 ‰ and describe a line (δ¹⁷O = 0.95 * δ¹⁸O - 3.24; Fig. 1) similar to the carbonaceous chondrite anhydrous mineral line (CCAM) [7]. The clay-separates have oxygen isotope compositions (δ¹⁸O = 15.5 to 18.0 ‰; δ¹⁷O = 9.2 to 10.2 ‰; Δ¹⁷O = 0.5 to 0.8 ‰) within the range known for CI-type meteorites. The pristine whole-rock samples (δ¹⁸O = 16.9 to 17.5 ‰; δ¹⁷O = 8.5 to 9.0 ‰) plot close to, but below the Terrestrial Fractionation Line (TFL) [8]. Degraded whole-rock samples also plot just below the TFL, but are more enriched in ¹⁸O and ¹⁷O (δ¹⁸O = 21.2 to 23.5 ‰; δ¹⁷O = 10.3 to 12.2 ‰) than pristine samples. Clay mineral and whole-rock oxygen isotope values are shown in Figure 2. The hydrogen isotope compositions (δD = 271 to 454 ‰) of the clay-separate and whole-rock samples are enriched in D relative to CI meteorites [9]. CO₂ released during pyrolysis has δ¹⁸O values ranging from 24.8 to 32.0 ‰ while carbonate analyzed by acid digestion has a δ¹⁸O value of 38.7 ‰, within the range reported earlier by [10].

Discussion: The compositions of Type-I isolated olivine and chondrules trend towards less negative Δ¹⁷O values with decreasing Fo content. The trend for δ¹⁷O versus δ¹⁸O values for Type-II isolated olivine generally has a higher slope (m = 1.03) than the carbonaceous chondrite anhydrous mineral line (CCAM; m = 0.95). The normal chemical zonation and oxygen isotope compositions of Type-II isolated olivine suggests that it crystallized from an evolving melt that exchanged with a ¹⁶O-poor reservoir different from those that interacted with Type-I isolated olivine and chondrules.

All bulk samples follow a trend that is close to the CM meteorite mixing line, as do results for two bulk samples reported earlier by [1]. The variation in oxygen isotope compositions of the bulk samples is consistent with variable abundance of carbonate and clay-rich matrix.

Clay minerals in the Tagish Lake meteorite provide

a record of the aqueous alteration of its parent body. The temperature of formation of Tagish Lake clay minerals and carbonates has been calculated using the oxygen isotope compositions of these phases, appropriate mineral oxygen-isotope geothermometers and two possible models [11,12] of the evolution of the water isotopic composition (resulting in cooling from 325 to 125 °C versus 100 to 10 °C). The temperatures obtained using mineral-pair oxygen isotope compositions for clay and carbonate phases lie outside of the calibrated range for the geothermometers but appear to indicate a very low temperature for the aqueous alteration.

Pyrolysis CO_2 $\delta^{18}\text{O}$ values were not the same as those determined for the carbonates by acid digestion (after the respective fractionations associated with each of these procedures were taken into account). The results from pyrolysis may reflect exchange with hydroxyl oxygen during evolution of the CO_2 .

The Tagish Lake meteorite contains remnants of primitive phases (chondrules, isolated olivine grains and CAIs), unlike CI meteorites. We also note that the Tagish Lake meteorite has the highest δD values presently known for CI meteorites. There may be a trend of decreasing D-enrichment in CI meteorites, with the Tagish Lake example being among the most primitive of this class, or perhaps even a CI precursor.

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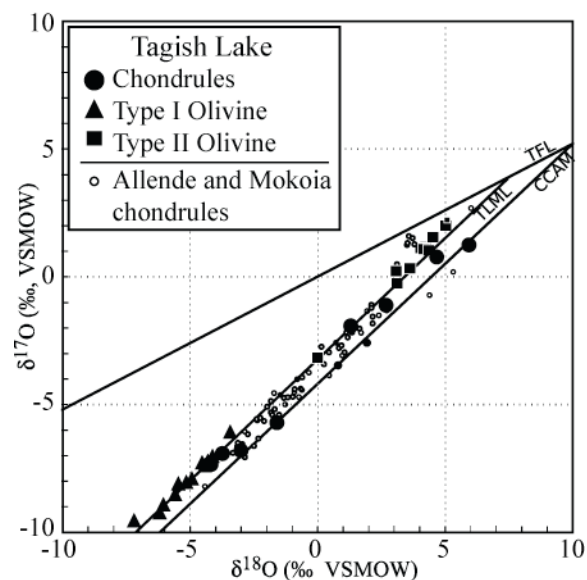


Figure 1 Oxygen isotope compositions of Tagish Lake meteorite chondrules and isolated olivine grains. Results for Allende and Mokoia chondrules from [13,14]. TLML is a linear regression of Tagish Lake meteorite isolated olivine and chondrule isotope values. The carbonaceous chondrite anhydrous mineral line (CCAM) is from [7].

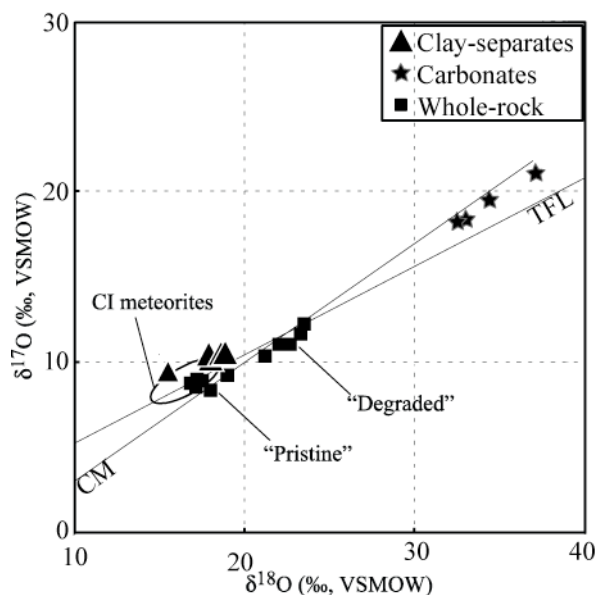


Figure 2 Oxygen isotope compositions of Tagish Lake clay-separates and whole-rock samples. The CM line and CI field are from [12]; carbonate results are from [10]; two "pristine" whole-rock results are from [1].