

**Oxygen Isotopic Composition of Tagish Lake Lithologies: Insights into Parent Body Alteration.** C. D. K. Herd<sup>1</sup>, Z. D. Sharp<sup>2</sup>, C. M. O'D. Alexander<sup>3</sup>, and A. Blinova<sup>1</sup>, <sup>1</sup>Department of Earth and Atmospheric Sciences, 1-26 Earth Sciences Building, University of Alberta, Edmonton, AB, T6G 2E3, Canada, [herd@ualberta.ca](mailto:herd@ualberta.ca). <sup>2</sup> Department of Earth and Planetary Sciences, 200 Yale Blvd., University of New Mexico, Albuquerque, NM, 87131. <sup>3</sup>Department of Terrestrial Magnetism, Carnegie Institution of Washington, 5241 Broad Branch Road NW, Washington, DC, 20015.

**Introduction:** The Tagish Lake meteorite, an ungrouped C2 chondrite with CI and CM affinities [1], shows a much higher degree of variation than initially observed among several characteristics. Although mineralogical variations among the specimens are small, petrological observations, including preservation of chondrule glass and relative proportions of porous matrix and framboidal magnetite, suggests a broad range in the degree of aqueous alteration [2-3]. Variations in insoluble and soluble organic matter among the specimens is consistent with differing degrees of aqueous alteration on the Tagish Lake parent body, providing insights into the parent body modification and preservation of primitive organic matter [4].

The characteristics of insoluble organic matter (IOM) in the Tagish Lake meteorite suggest hydrothermal conditions of alteration, at temperatures ~300 °C, by analogy with experiments [5-7]. Such conditions are at odds with the mineralogy and preservation of volatile organic compounds [4]. Herd et al. [4] suggested that the more extensively altered specimens were subjected to longer periods of alteration or higher water/rock ratios, instead of higher temperatures. The kinetics of IOM modification are largely unknown, so it is unclear whether the Tagish Lake IOM trend can be explained by alteration for longer periods than the experiments at <300°C. Here we use whole-rock oxygen isotopic compositions to test these possible mechanisms.

**Samples and methods:** The four Tagish Lake specimens examined here are the same as those studied previously [4], namely 5b, (mass 4.3 g); 11h (6.2 g); 11i (4.7 g); and 11v (5.6 g). All four specimens are 'pristine,' collected from the surface of the frozen lake within days of the fall [4]. On the basis of petrology and organic geochemistry, the specimens increase in degree of aqueous alteration in the order 5b < 11h < 11i. Specimen 11v, which is disaggregated material (as collected), is heterogeneous, consisting of clasts with petrologic characteristics in common with the other specimens. A homogenized 200 – 600 mg sample of each specimen was subsampled to provide 10-20 mg samples for this study.

Each sample was washed with nitric acid and then treated with 1 M HCl and H<sub>2</sub>O<sub>2</sub> to remove carbonates and organic matter. Oxygen was extracted using laser

fluorination using O<sub>2</sub> as the analyte in the mass spectrometer. All data are reported relative to SMOW, with a precision of 0.1‰ for δ<sup>18</sup>O and δ<sup>17</sup>O values and <0.05‰ for Δ<sup>17</sup>O values. All analyses were made at the University of New Mexico.

**Results:** Results are shown in Figures 1 and 2. Our data and those of two previously determined whole-rock compositions [8] (these are the same data as reported in [9]) lie on a single mass fractionation line that is slightly below the terrestrial fractionation line (TFL). The isotopic compositions of specimens 11h and 11v are similar to the previous Tagish Lake analyses. The compositions of specimens 5b and 11i, the least and most altered samples, differ significantly from those of 11h and 11v. The composition of 5b lies quite close to the CCAM line, whereas the composition of 11i has the highest δ<sup>18</sup>O whole-rock value of any chondrite [cf. 10]. Selected carbonaceous chondrite compositions from [10] are shown for comparison in Figures 1 and 2.

**Discussion:** The range of whole-rock oxygen isotope compositions of aqueously altered carbonaceous chondrites (e.g. CIs, CMs, and CRs) is generally thought to result from variable alteration of primary, high <sup>16</sup>O/<sup>18</sup>O anhydrous silicates with relatively low Δ<sup>17</sup>O, and low <sup>16</sup>O/<sup>18</sup>O water with relatively high Δ<sup>17</sup>O [10]. There is less consensus about whether the alteration occurred in a closed system in which water/rock interaction is static [10] or an open system involving fluid flow [11]. Closed system behavior would require that meteorites from a single chondrite group accreted with a range of ice/rock ratios in order to explain differences in their whole-rock isotope compositions. While this cannot be ruled out, most evidence suggests that chondrites from a single parent body are quite homogeneous in terms of the primary features (trace element contents, petrology, etc.) that they inherited at the time of accretion. If the chondrite parent bodies were ≥80 km, there should have been fluid flow in them [12], but to date evidence for extensive fluid flow in chondrites (e.g., correlated variations in soluble elements with the extent of alteration) is equivocal.

The isotopic compositions of isolated refractory olivine grains, chondrules, and chondrule olivine cores and rims in Tagish Lake lie on the CCAM line, with

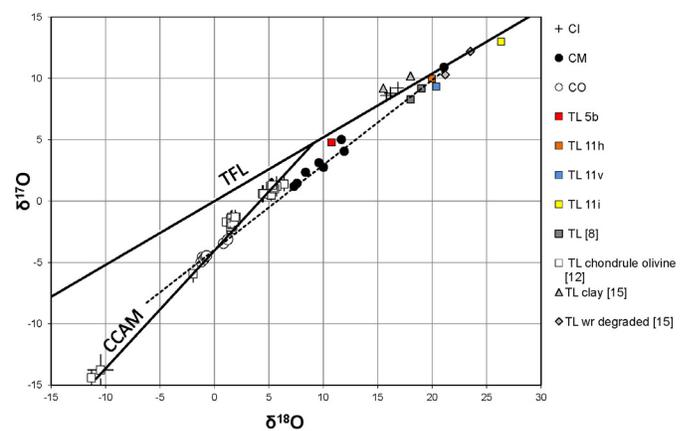
maximum  $\delta^{18}\text{O}$  values of +6 ‰ [13-14], consistent with data from other carbonaceous chondrites [10]. Of the Tagish Lake specimens, the least-altered 5b lies closest to the CCAM line. This is what would be expected by the models [10-11], except that the majority of the measured anhydrous material in Tagish Lake and all other carbonaceous chondrites have more negative  $\Delta^{17}\text{O}$  values than 5b. Although the previous Tagish Lake analyses of [8], as well as our results for specimen 11h and 11v fall on the CM-CO alteration trend of [8], the trend defined by our analyses instead parallels the TFL with a slope of 0.525 (Figure 2). This trend cannot be modeled by single-stage mixing in an open [10] or closed [11] system.

The alteration of the Tagish Lake meteorite must have occurred in two stages. As in the models, the anhydrous material had high  $^{16}\text{O}/^{18}\text{O}$  and low average  $\Delta^{17}\text{O}$  and the water had low  $^{16}\text{O}/^{18}\text{O}$  and a high  $\Delta^{17}\text{O}$  value. These components were mixed and brought into isotopic equilibrium. Further alteration then occurred resulting in the spread of values along a slope 0.525 line. This second stage occurred either through equilibrium water/rock interaction in a closed system, with a greater proportion of isotopically heavier phyllosilicates in the more altered specimens (e.g., 11i), or in an open system in which water was redistributed among the specimens. Although unconstrained by our data, the temperature of alteration in Tagish Lake is less than 150 °C [8, 15]. At such temperatures, the composition of the final water, now lost from the system, would have been isotopically light.

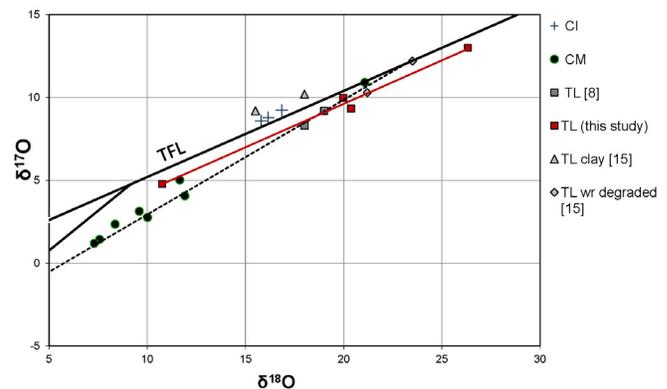
The isotopic composition of Tagish Lake specimen 11v is consistent with it being a mixture of the multiple lithologies. That its whole-rock isotopic composition coincides with that of the intermediately-altered specimen 11h as well as the previous analyses of [8], suggest that Tagish Lake is composed of a binary mixture of two endmembers, represented by specimens 5b and 11i. Such an observation is consistent with the brecciated nature of the meteorite [1].

**Conclusions:** The Tagish Lake meteorite shows a greater range in oxygen isotope composition than any other carbonaceous chondrite. Whole-rock compositions of four well-characterized specimens define a mass fractionation trend. Variation in isotopic composition among the specimens is consistent with variations in the degree of aqueous alteration, with more altered specimens having endured higher water/rock ratios or longer duration alteration. That Tagish Lake preserves a different and unique mode of aqueous alteration relative to CM and CI chondrites is consistent with observations of large variations in soluble and insoluble organic matter [4].

**References:** [1] Zolensky M.E. et al. (2002) *M&PS*, 37, 737-761. [2] Blinova A. et al. (2010) *M&PS*, 45 (Suppl.), A17. [3] Blinova A. et al. (2009) *LPSC XL*, #2039. [4] Herd C.D.K. et al. (2011) *Science*, 332, 1304-1307. [5] Huang Y. et al. (2007) *EPSL*, 259, 517-525. [6] Oba Y. and H. Naraoka (2006) *M&PS*, 41, 1175-1181. [7] Yabuta H. et al. (2007) *M&PS*, 42, 37-48. [8] Clayton R.N. and T.K. Mayeda (2001) *LPSC XXXII*, #1885. [9] Brown P.G. et al. (2000) *Science*, 290, 320-325. [10] Clayton R.N. and T.K. Mayeda (1999) *GCA*, 63, 2089-2104. [11] Young E.D. (2001) *Phil. Trans. Royal Soc. London A*, 359, 2095-2109. [12] Young E.D. et al. (2003) *EPSL*, 213, 249-259. [13] Russell S.D.J. et al. (2010) *GCA*, 74, 2484-2499. [14] Blinova A. et al. (2011) *M&PS*, 46 (Suppl.), A22. [15] Russell S.D.J. et al. (2008) *LPSC XXXIX*, #1709.



**Figure 1.** Oxygen isotopic composition of Tagish Lake (TL) and selected representative data from CI, CM and CO chondrites [10]. Also shown is the CO-CM alteration trend of [10] (dashed line).



**Figure 2.** Detailed view of a portion of Figure 1, also showing line-of-best-fit to the Tagish Lake whole-rock results of this study (red line), and the CO-CM alteration trend of [10] (dashed line).