

# The Tagish Lake Meteorite: Microstructural Porosity Variations and Implications for Parent Body Identification

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## Summary

Analysis of meteorites provides insight into the various material that could comprise the parent body; be it asteroidal, planetary or cometary in origin. Here we present new data relating to the physical characteristics of the Tagish Lake meteorite and in doing so infer its possible origin. In our study, porosity was determined via scanning electron microscope imagery coupled with image analysis techniques. Our results, measured on images taken at 100 and 300 × magnification, show a range in porosity values of between 4.5 and 15.4 percent, and that porosity tends to increase towards the edge of the sample. In comparison with the available published data for bulk samples of the Tagish Lake meteorite we find our porosity values to be much lower. However, when compared to other carbonaceous chondrite falls we find our data is in good agreement. A high porosity deduced for the bulk samples of the Tagish Lake meteorite reflect the highly fragmental nature of the parent object and that this parent is likely to be brecciated and loosely consolidated.

## Introduction

On the morning of the 18<sup>th</sup> January, 2000, a 56 tonne meteoroid entered Earth's atmosphere, resulting in some 1300 kg of material falling on the frozen surface of Tagish Lake in northern British Columbia, Canada (Figure 1). At least 500 meteorite fragments were collected from the extensive fall strewn field. Much of the material was encased in ice at the time of recovery but some surface material was also collected, with the latter providing us with material from a unique carbonaceous chondrite group that has not suffered significant terrestrial alteration. This investigation looks at the porosity of the meteorite and uses this data to infer origins concerning the parent body.

## Methods and results

We have conducted a scanning electron microscope (SEM) investigation of Tagish Lake samples E, F, and G (see Figure 2), on loan to us from the University of Western Ontario, and determine a mean value for the measured microporosity of 7.5 percent. In detail, porosity measured at 100 × magnification varies between 4.5 to 10.8 %. This value increases at higher magnification (up to 15.4 % 300 × magnification). Details of our SEM procedure can be found in Coulson *et al.* (2007).

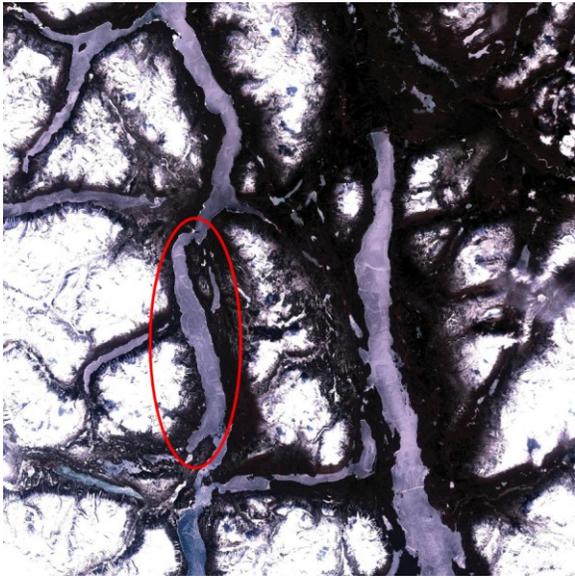


Figure 1: Landsat image of the frozen Tagish Lake, British Columbia, Canada. (Image appears courtesy of NASA).

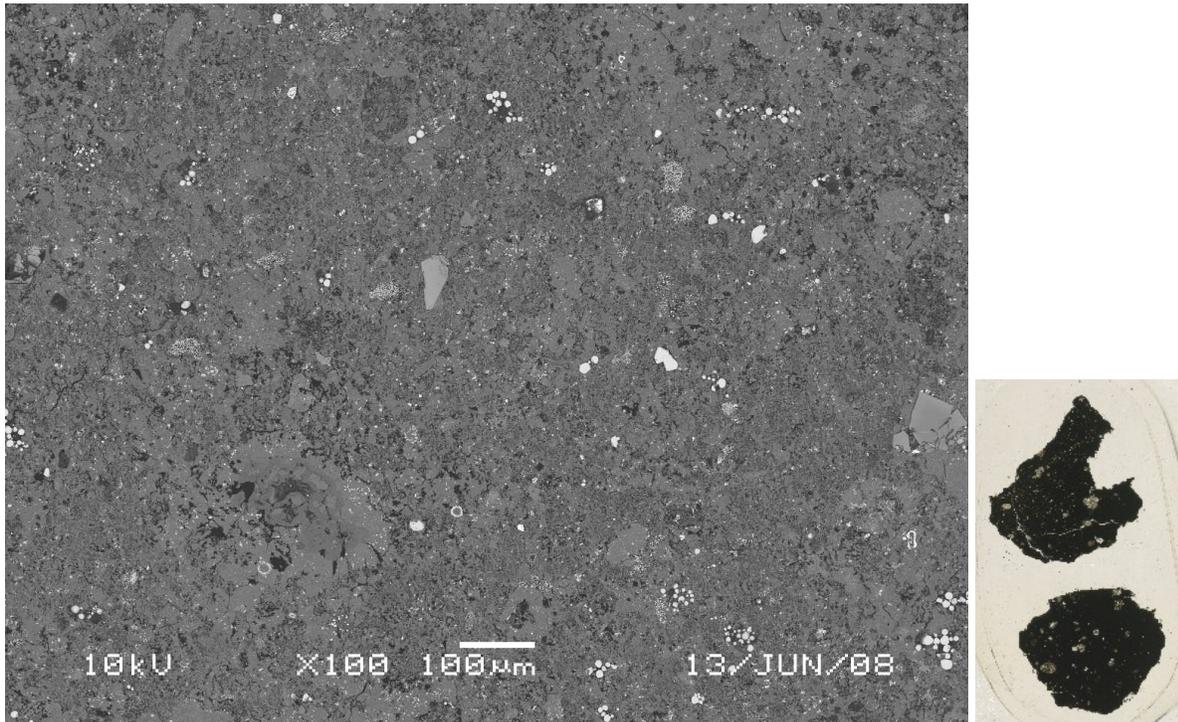


Figure 2: Back-scattered electron image of Tagish Lake meteorite sample E at 100 × magnification. Note that chondrules are rare but one appears at the lower left of the image. Inset image is the polished thin section containing two fragments (samples E and F) of the meteorite. Thin section field of view is 36 mm × 20 mm.

We find from the literature that porosity measurements have been determined on bulk samples of this meteorite. For example, Hildebrand *et al.* (2006) present data for the porosity values for 7 Tagish Lake fragments. In their study the mass of the fragments varies from 14 to 7 gm (sizes of order 2 - 3 cm) and the range of measured porosity values is from 35 to 43 percent. The average bulk density for these same samples was found to be a low  $1.64 \pm 0.02 \text{ gm/cm}^3$ . Estimates for the mass and porosity of the parent meteoroid are given in Brown *et al.* (2002), using an entry model for the Tagish Lake fireball constrained by seismic, satellite and infrasound data. Here they determine that the initial mass was of order 56 tonnes (which is a diameter of order 4 metres) and the fireball light curve requires the porosity to be in the range 37 to 58 %.

From the collected data we can say that when compared to porosity data for average carbonaceous chondrites our data is in good agreement (Hildebrand *et al.*, 2006). With respect to the studied bulk samples of the Tagish Lake meteorite, however, we find our porosity values to be much lower. These high porosity determinations for the bulk samples of the Tagish Lake meteorite most likely reflect the fragmental nature of the parent object and that this parent is likely brecciated and loosely consolidated. This brings us to a discussion of the possible parent to the Tagish Lake fall.

## Discussion and conclusions

While many meteorite groups have been associated with one or another of the asteroid types, the ordinary chondrites with S-type asteroids, and the HED achondrites with (4) Vesta, the parent bodies of the carbonaceous chondrites remains unclear. The high carbon content, clear evidence for aqueous alteration and high porosity that characterises Tagish Lake, as well as the CI and CM meteorites, make them especially intriguing, and indeed it has been suggested that a cometary, rather than an asteroid, parent body is likely (Lodders and Osborne, 1999). This being said, Hiroi *et al.* (2001) have suggested, on the basis of reflectance spectroscopy studies, that Tagish Lake is possibly derived from a D-type asteroid. These asteroids are predominantly found in the outer asteroid belt and “the Nice Model”, which describes the dynamical evolution of the outer Solar System and the late heavy bombardment, suggests that they formed in and are derived from the Kuiper Belt region. With an aphelion distance of 3.3 AU (Brown *et al.*, 2000), the Tagish Lake pre-cursor body would sit within the 2:1 mean motion resonance region with Jupiter, and it is likely, therefore, that the parent body was situated near this instability region.

During the past several years it has become increasingly clear that the main belt asteroid region hosts a hitherto unexpected reservoir of cometary nuclei (Jewitt, 2009) - this is an additional reservoir beyond those of the Kuiper Belt and the Oort cloud. Currently 4 such main belt comets (MBC) have been identified and interestingly, we note, three of them [P/2005 U1 (Read), 133P/Elst-Pizarro and 1999 RE70) have slightly eccentric orbits and semi-major axes that place them permanently close to the 2:1 mean motion resonance (Hsieh and Jewett, 2006), making them potential parent bodies for the Tagish Lake meteorite.

Jewitt (2009) suggests that the main belt comets formed *in situ* and have survived against sublimation loss by the build-up of extensive refractory mantles. The trigger mechanism for the occasional MBC outbursts is most likely that of impact “gardening” (Beech and Gauer, 2002; Jewitt, 2009). Extensive surface reworking of an MBC nucleus might well be expected to produce considerable brecciation of the surface mantle and the formation of aggregates with high porosity and low bulk density - indeed, all of the distinctive physical characteristics of the Tagish Lake meteorite. We suggest, therefore, that the Tagish Lake parent body may well have been a surface, mantle fragment derived from a main belt comet nucleus. Further, if this

association is correct and that the parent comet formed *in situ* within the main belt asteroid region, then the bulk composition of Tagish Lake should be reflective of the solar nebular close to the ice-line boundary, rather than the region out of which the Kuiper Belt objects (the suggested precursors of D-type asteroids) formed.

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