Icarus 254 (2015) 324–332

Contents lists available at ScienceDirect

Icarus

journal homepage: www.elsevier.com/locate/icarus

Variability, absorption features, and parent body searches in "spectrally featureless" meteorite reflectance spectra: Case study – Tagish Lake

M.R.M. Izawa [a,*], M.A. Craig [b], D.M. Applin [a], J.A. Sanchez [c,1], V. Reddy [c,1], L. Le Corre [c,1], P. Mann [a], E.A. Cloutis [a]

[a] Hyperspectral Optical Sensing for Extraterrestrial Reconnaissance Laboratory, Dept. Geography, University of Winnipeg, 515 Portage Ave., Winnipeg, Manitoba R3B 2E9, Canada
[b] Dept. Earth Sciences/Centre for Planetary Science and Exploration, Western University, 1151 Richmond St., London, ON N6A 5B7, Canada
[c] Planetary Science Institute, 1700 East Fort Lowell, Suite 106, Tucson, AZ 85719, USA

ARTICLE INFO

Article history:
Received 30 October 2014
Revised 8 April 2015
Accepted 10 April 2015
Available online 15 April 2015

Keywords:
Spectroscopy
Meteorites
Asteroids, surfaces
Near-Earth objects

ABSTRACT

Reflectance spectra of many asteroids and other Solar System bodies are commonly reported as "featureless". Here, we show that weak but consistently detectable absorption bands are observable in 200–2500 nm spectra of the Tagish Lake meteorite, a likely compositional and spectral analogue for low-albedo, "spectrally-featureless" asteroids. Tagish Lake presents a rare opportunity to study multiple lithologies within a single meteorite. Reflectance spectra of Tagish Lake display significant variation between different lithologies. The spectral variations are due in part to mineralogical variations between different Tagish Lake lithologies. Ultraviolet reflectance spectra (200–400 nm), few of which have been reported in the literature to date, reveal albedo and spectral ratio variations as a function of mineralogy. Similarly visible–near infrared reflectance spectra reveal variations in albedo, spectral slope, and the presence of weak absorption features that persist across different lithologies and can be attributed to various phases present in Tagish Lake. These observations demonstrate that significant spectral variability may exist between different lithologies of Tagish Lake, which may affect the interpretation of potential source body spectra. It is also important to consider the spectral variability within the meteorite before excluding compositional links between possible parent bodies in the main belt and Tagish Lake. Tagish Lake materials may also be spectral–compositional analogues for materials on the surfaces of other dark asteroids, including some that are targets of upcoming spacecraft missions. Tagish Lake has been proposed as a spectral match for 'ultra-primitive' D or P-type asteroids, and the variability reported here may be reflected in spatially or rotationally-resolved spectra of possible Tagish Lake parent bodies and source objects in the Near-Earth Asteroid population. A search for objects with spectra similar to Tagish Lake has been carried out among the Near-Earth Asteroids. We have identified three possible spectral matches, the best of which are Asteroids (326732) 2003 HB6, and (17274) 2000 LC16.

1. Introduction

Tagish Lake is a type-2 chondrite with affinities to CM, CI and possibly CR chondrites (Grady et al., 2002; Zolensky et al., 2002; Russell et al., 2010). The first spectral studies of Tagish Lake indicated spectral similarities to D- or P-type asteroids (Hiroi et al., 2001). Since the recovery and initial description of Tagish Lake (Brown et al., 2000; Zolensky et al., 2002), significant lithological variations have been discovered (Blinova et al., 2009; Izawa et al., 2010a, 2010b). The predominant component of the meteorite is a dark, fine-grained opaque matrix consisting of phyllosilicates (broadly similar to an intergrowth of saponite and serpentine), magnetite, siderite, and Fe–Ni sulfides (e.g., Zolensky et al., 2002; Bland et al., 2004; Howard et al., 2009). Set within the matrix are a variety of clasts including sparse chondrules, fine-grained aggregates and individual isolated grains of olivine with phyllosilicates and (rarely) pyroxene, rare CAI, and irregular nodules of Fe–Mn–Mg–Ca carbonates (Zolensky et al., 2002). Compared to the carbonate-poor lithology, the carbonate-rich lithology is characterized by a lower abundance of magnetite, a higher abundance of calcite, and almost no CAI (Zolensky et al., 2002). Izawa et al. (2010a) identified two other distinct lithologies, a carbonate-rich, siderite-dominated

* Corresponding author.
E-mail address: matthew.izawa@gmail.com (M.R.M. Izawa).

[1] Visiting Astronomer at the Infrared Telescope Facility, which is operated by the University of Hawaii under Cooperative Agreement no. NNX-08AE38A with the National Aeronautics and Space Administration, Science Mission Directorate, Planetary Astronomy Program.

http://dx.doi.org/10.1016/j.icarus.2015.04.013

lithology (studied further here, sample PB-02), and an inclusion-poor, magnetite- and- sulfide-rich lithology (which is not included in this study for lack of sample). Blinova et al. (2014a, 2014b) described an additional inclusion-poor, fine-grained lithology containing significant amounts of amorphous Fe–Mg-rich silicates, and appears to reflect variable low-temperature aqueous alteration of primary nebular anhydrous silicates. Tagish Lake presents an opportunity to study multiple lithologies within a single carbonaceous chondrite. Despite the lithological diversity of Tagish Lake, there has been little investigation of spectral variations in the near-ultraviolet, visible, and near-infrared regions since the initial studies of Hiroi et al. (2001). Hiroi et al. (2001) reported spectra (0.3–2.6 μm) for two Tagish Lake samples, PM-05 and ET-01, which probably originate from the carbonate-poor Tagish Lake lithology (Zolensky et al., 2002), though their bulk mineralogy has not been reported. Izawa et al. (2010a) found significant spectral variability in the mid-infrared (2.5–25 μm) that largely reflected mineralogical differences between Tagish Lake lithologies, but did not further investigate the spectra of Tagish Lake shortward of 2.5 μm.

This study combines reflectance spectroscopy in the ultraviolet, visible and near-infrared to investigate the spectral characteristics of five Tagish Lake samples for which the modal mineralogy has previously been determined by X-ray diffraction and Rietveld refinement (Izawa et al., 2010a). Similar to Cloutis et al. (2012), we find that absorption bands are present in the spectra of Tagish Lake samples, albeit at a much suppressed level due to the presence of abundant fine-grained opaque phases (e.g., magnetite, pyrrhotite) and organic compounds intimately associated with the matrix phyllosilicates. Analysis of these new Tagish Lake spectra reveals variations correlated to mineralogy that may enable future remote determination of lithological variations on carbonaceous asteroids similar to those known to exist in Tagish Lake.

Previous studies have searched for possible parent bodies for the Tagish Lake meteorite among main belt asteroids and Jupiter Trojans (Hiroi et al., 2001, 2003; Hiroi and Hasegawa, 2003; Dotto et al., 2004; Vernazza et al., 2013). Hiroi et al. (2001) compared the spectrum of a Tagish Lake meteorite sample with low-albedo-featureless asteroid spectra taken from the Eight-Color Asteroid Survey (ECAS) (Zellner et al., 1985) and the 52-Color Asteroid Survey (Bell et al., 1988). Hiroi et al. (2001) found that the reflectance spectra of asteroids belonging to the T-, P-, and D-type had spectral slopes similar to that of the Tagish Lake meteorite, and suggested 308 Polyxo, 36 Lacadiera (D-type) and 368-Haidea (P/D-type) as potential source bodies for Tagish Lake. Of the three proposed spectral classes, D-type asteroids showed the best overall match in terms of albedo and spectral shape throughout the entire wavelength range (∼0.3–2.4 μm). Hiroi and Hasegawa (2003) identified the T/D-type Asteroid 308 Polyxo as one of the best candidates for the source body of the Tagish Lake meteorite, based on the similarities in albedo, spectral shape (∼0.3–3.5 μm) and the presence of the 3-μm feature. However, mid-infrared spectroscopic observations (7–26 μm) of 308 Polyxo obtained by Dotto et al. (2004) with the Infrared Space Observatory (ISO) showed significant differences between spectra of Polyxo and the Tagish Lake meteorite in this wavelength range. Vernazza et al. (2013), compared reflectance spectra of the Tagish Lake meteorite with spectra of main belt asteroids and Jupiter Trojans obtained in the wavelength range of 0.4–25 μm. They determined that Tagish-like asteroids represent a very small fraction in the main belt (<4.5% of the total population), and even a smaller proportion among Jupiter Trojans (<0.02% of the total population). Of all asteroids in their study only one, 368 Haidea, was found to match the spectrum of the Tagish Lake meteorite. To date, no search for possible Tagish Lake source bodies among the Near-Earth Asteroid (NEA) population has been carried out. Due to their dynamical proximity to Earth, some NEAs could be the immediate precursor of meteorites, therefore searching for possible spectral matches among NEAs can lead to the identification of the source body from which the meteorite was derived. Alternatively, the identification of asteroids with similar characteristics could elucidate the source region(s) of Tagish Lake-like objects. For this reason, in the present study we have used publicly available data to search for possible source bodies or asteroid analogs among the NEA population.

2. Samples and analytical methods

2.1. Tagish Lake samples

The five Tagish Lake samples studied here were collected during the April–May 2000 collection (Hildebrand et al., 2006). Samples HG-42 and MM-38 were recovered as individual rock fragments, and samples MM-02, MG-02 and PB-02 were recovered as disaggregated powders, each from an individual collection site (Hildebrand et al., 2006). The Tagish Lake samples were prepared for X-ray diffraction and mid-infrared spectral analysis as described by Izawa et al. (2010a) and consist of very fine-grained powders with <45 μm nominal particle size. The modal mineralogy of the samples was determined using Rietveld refinement of X-ray diffraction data by Izawa et al. (2010a), and are summarized in Table 1, along with the modal mineralogy of a different Tagish Lake sample reported by Bland et al. (2004) for comparison. Sample PB-02 has a very high carbonate content, with 24 wt.% siderite and minor (1–3 wt.%) calcite, sample HG-42 is rather olivine-poor, and samples MG-02, MM-38 and MM-02 are probably mixtures of varying proportions of materials similar to the 'carbonate-rich' and 'carbonate-poor' lithologies (Brown et al., 2000; Zolensky et al., 2002; Izawa et al., 2010a). It should be noted, however; that there is no consensus on the mineralogy and composition of 'average' Tagish Lake meteorite, and as of this writing there is no average or reference Tagish Lake material analogous to, for example, the Allende reference material (Jarosewich et al., 1987). All the samples studied here are richer in pyrrhotite ($Fe_{1-x}S$) than the material studied by Bland et al. (2004), reflecting the heterogeneity of the Tagish Lake meteorite.

2.2. Ultraviolet spectral reflectance (200–400 nm)

Ultraviolet reflectance (200–400 nm) spectra were measured with an Ocean Optics (Dunedin, FL) Maya2000 PRO miniaturized spectrometer equipped with an HC-1 grating and 30 μm slit width, giving us an effective sampling interval of 0.48 nm at 200 nm and 0.46 nm at 400 nm. The detector is a 2D back-thinned linear CCD-array Hamamatsu S10420. Illumination was provided by an Analytical Instrument Systems Inc. Mini-DTA light source with a 30 W deuterium lamp whose output was through a bifurcated fiber optic bundle consisting of six illumination fibers surrounding a central pick-up fiber feeding into the detector array. This assembly consisted of 400-μm diameter solarization-resistant (XSR) fibers, with transmission efficiencies between 23% and 40% across the 200–400 nm range. The fiber optic bundle was used in normal incidence and we used an integration time of 4500 ms and averaged 200 individual spectra. Measurements for each sample were made by first acquiring a dark current spectrum (with the input to the spectrometer blocked), a reference spectrum followed by measurement of the sample. In order to increase the signal-to-noise ratio (SNR), reference spectra were acquired relative to a Labsphere (North Sutton, NH) Spectralon® 10% diffuse reflectance standard (SRS-10-0-10), which enabled an increase in integration time of one order of magnitude. All three measurements were made using