Astromaterials Curation and Research in Canada: Why It Matters

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Summary

Astromaterials are solid samples of other planetary bodies in the Solar System, including meteorites from asteroids, the Moon and Mars, and samples returned by robotic and human missions. The diversity of astromaterials within the main meteorite collections in Canada (National at Natural Resources Canada (NRCan), Royal Ontario Museum, University of Alberta), within other institutional collections, and in private collections is unparalleled worldwide (Herd et al., 2008).

Meteorites collected within a few days of fall represent a unique opportunity both to study astromaterials that are relatively uncontaminated by exposure at the Earth's surface, and to examine and trace the source(s) of contamination. Two recent examples – the Buzzard Coulee and Tagish Lake meteorites – are highlighted here. Such studies assist in establishing standard operating procedures in the curation and handling of pristine planetary samples, including future meteorite falls and material from sample return missions. In essence, fresh meteorite falls act as analogues to sample return missions. The outcome of such studies will assist in achieving the goals established by the Astromaterials Working Group: to raise the international profile of astromaterials research in Canada, and to establish Canada as a reliable and uniquely-qualified world-class partner in sample return (Astromaterials White Paper, 2009).

Introduction

As soon as a meteorite falls to Earth, changes can begin as it is exposed to the terrestrial environment: oxidation in the reactive atmosphere; exposure to moisture; and contamination by mobile elements and compounds. Among the latter are organic compounds, which are ubiquitous in the terrestrial environment. Exposure to water can contaminate the meteorite with terrestrial compounds, as well as remove water-soluble compounds from the meteorite.

Since the primary purpose of astromaterials research is to determine the suite of processes recorded in the sample and thereby determine its history, any study of astromaterials, especially meteorites (falls or finds) requires elucidation of the degree to which the above-listed changes have affected their intrinsic characteristics. As such, "fresh" meteorite falls – those falls in which meteorites are recovered within a few hours to days after the fall – represent opportunities to study astromaterials that have been minimally contaminated, and to trace the source and determine the nature of terrestrial contaminants.

Examples

Two recent meteorite falls in Canada provide examples of "fresh" falls that can act as sample return analogues. The Tagish Lake (B.C.) meteorite (January 18, 2000) is an ungrouped C2 chondrite rich in primitive organic matter (Grady et al., 2002). The chance fall of the meteorite onto the frozen surface of Tagish Lake, the careful recovery of the first specimens within a week of the fall, and their subsequent curation makes these pristine samples the most significant as analogues for sample return. This case study will be outlined in detail below.

The Buzzard Coulee, Saskatchewan meteorite (November 20, 2008) is an H4 chondrite. In many ways this is a "typical" meteorite fall on the Canadian Prairies, having fallen onto land used for ranching and farming, and along roadsides and ponds. As an H4 chondrite, the meteorite is depleted in volatile elements and is not expected to contain significant concentrations of organic matter. Curation requirements are therefore limited to keeping samples away from moisture ("Store in a cool, dry place") and minimizing contamination by trace elements from storage media or handling tools. However, the first meteorites were recovered about a week after the fall, and represent an opportunity to study the suite of contaminants to which meteorites may be typically and rapidly exposed after fall in a rural developed environment. We rinsed the exteriors of two Buzzard Coulee meteorite specimens with dichloromethane (DCM), and analyzed the extracts with Gas Chromatograph Mass Spectrometry (GC-MS). Results demonstrate that the meteorites have been contaminated by various aliphatic and aromatic hydrocarbons, including amides and carboxylic acids, phenol, and benzene, likely derived from the terrestrial land surface onto which the meteorites fell, 9-octadecenamide and phthalate, derived from exposure to plastics, and squalene and cholesterol resulting from the direct handling of meteorites by higher organisms (i.e., humans). Ongoing trace element studies may also yield insights into the degree to which mobile elements may contaminate meteorites. Such work provides a baseline set of data that could be used in future to distinguish terrestrial contaminants from intrinsic compounds in meteorites, even in meteorites that have been exposed to the terrestrial environment for months or years.

Case Study: The Tagish Lake Meteorite

The Tagish Lake meteorite fell on January 18, 2000 onto the frozen surface of Tagish Lake in northern B.C. Samples of the meteorite were recovered within a week of the fall and kept frozen and untouched by hand. These samples are the world's most pristine meteorites, having been kept under near-optimum conditions of preservation of volatile elements and compounds. Currently, these pristine samples are in cold (< -25 °C), secure conditions at the University of Alberta and the Royal Ontario Museum.

Given the mobility of organic compounds and their ubiquitous presence at the Earth's surface, our research has focused on determining the suite of organic compounds in the pristine Tagish Lake meteorites, and elucidating the presence of terrestrial contaminants. Our focus has been primarily on the soluble organic compounds, with the hypothesis that these compounds are the most likely to have been affected by terrestrial contamination during collection and storage, and are also the most likely to be affected by curation and handling. As such, our research informs protocols and minimum standards for curation and handling of these unique samples.

Several samples of Tagish Lake have been analyzed for soluble organic compounds thus far, complemented by studies of insoluble organic matter, mineralogy and petrology (Blinova et al., 2009; Herd and Alexander, 2009; Herd et al., 2009). Soluble organic compounds were removed from each sample using DCM, toluene-methanol or ultrapure water, with the solvent added to a cold sample in order to capture all volatile compounds. Methods are described in Hilts and Herd (2008).

Terrestrial Contaminants

Analysis of the DCM extracts reveals variable complements of reduced organic compounds in the Tagish Lake samples. In one sample (11v) 67 compounds were identified, of which 10 were unequivocally terrestrial contaminants. The second-most prevalent compound in sample 11v is 9-octadecenamide, a plasticizer used in the manufacture of resealable plastic bags. The source of this contaminant was traced to the Ziploc bag in which the sample was stored after collection. Phthalates and other compounds that can be traced to exposure to plastics were also identified; however, these compounds are present in trace (ppm) levels. Limonene, a cyclic terpene produced in citrus fruits, was found in another sample (11i). Isotopic analysis of this compound by GC-IRMS at McMaster University yields $\delta^{13}C = -28 \pm 1‰$ and $\delta D = -170 \pm 30‰$, having a composition consistent with that of terrestrial limonene. The source of this potential contaminant is not known.

Indigenous Organic Compounds

Among the non-contaminant (indigenous) organic compounds in the Tagish Lake meteorite are several that are reactive or volatile. Naphthalene was found within both DCM and toluene-methanol extracts. A detailed study of monocarboxylic acids (Hilts et al., 2009) showed that formic acid is present in at unprecedented concentrations (up to 200 ppm in sample 11i). Both formic acid and naphthalene are volatile compounds, and would have been partially lost had the meteorite not been kept frozen since its recovery. Styrene, a reactive compound with a short lifetime in the Earth's atmosphere, was found in the toluene-methanol extract of sample 11v.

Recent work on amino acids in the Tagish Lake meteorite by ultrapure water extraction, derivitization and analysis by GC-MS show concentrations that vary from one sample to another. However, nearly all identified amino acids in all samples analyzed thus far show concentrations greater than those found in Tagish Lake samples collected during the spring thaw that were exposed to meltwater (Kminek et al., 2002). Details are provided in Simkus et al. (this meeting). These results demonstrate the rapidity with which meteoritic samples can be contaminated with biological molecules at the Earth's surface; such terrestrial contaminants obscure the study of compounds of prebiotic significance.

Conclusions

The two Canadian meteorite falls highlighted here provide contrasting examples in relation to the goal of tracing the source(s) of terrestrial contamination of planetary samples. Buzzard Coulee meteorites provide a blank for tracing contamination, e.g., in rural developed areas. The implication for the curation of Buzzard Coulee is that a few samples should be preserved as a record of the contaminants to which the meteorites may have been exposed; curation in a non-reactive atmosphere is not warranted.

Tagish Lake is unique in its complement of indigenous organics and its level of preservation – in spite of what we discovered, the first-collected Tagish Lake meteorites remain the world's most pristine. Furthermore, we can derive a list of recommended best practices for curation and handling of Tagish Lake meteorites:

- collection and storage using non-plasticized media, such as Teflon bags or jars
- rapid transfer after collection to cold conditions (< 0°C)
- long-term curation under cold conditions (< - 20 °C) to preserve volatile compounds and minimize reaction rates
- curation under non-reactive (Ar or N_2) atmosphere to prevent oxidation

All of the above should also be considered in the case of fresh falls of carbonaceous chondrites and samples returned from planetary bodies where organic compounds may be present.

Other handling and curation protocols for all Canadian astromaterials, fresh or not, are under consideration, to establish Canadian capacities and community in astromaterials research, and to show Canada's preparation for renewed space exploration efforts with international partners.

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