In the Cold: The Future of Astromaterials Curation?

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Introduction: Astromaterials, including meteorites, lunar samples, solar wind, cometary dust, asteroidal regolith and interplanetary dust, provide a unique record of the conditions that prevailed during the formation of our solar system, and the subsequent processes involved in the evolution of a variety of planetary bodies. However, the majority of astromaterials formed in environments not found at the Earth's surface [1]. Therefore, curation is a critical component in the planning of sample return missions [1] (and can be captured in the question: Why spend billions to bring samples back if they become contaminated during sample handling and curation?).

Modern curation facilities have as their primary goal the isolation of astromaterials from the terrestrial environment [1]. Airborne particulate contaminants are mitigated using HEPA filtration systems, as well as recognized clean room practices (e.g., use of gloves, gowns, boots, etc.). Due to the relative abundance of organic compounds at the Earth's surface, organic contamination is particularly problematic, and may be mitigated by specialized handling practices to limit the transfer of terrestrial organics to the samples, and cleaning procedures and methods for identifying and monitoring contaminants [e.g., 2]. However, astromaterials can be compromised in ways other than simple sorption of non-indigenous compounds on exposed surfaces, or via mixture with airborne dust. Oxidation and hydrolysis are a type of invasive contamination as both processes permanently chemically alter the intrinsic compounds and minerals in the sample; for this reason, inert atmospheres are utilized in curation to limit reaction of the indigenous organics and minerals with atmospheric water and molecular oxygen gas. However, the recognition of volatile and/or reactive organic species in carbonaceous chondrites [e.g., 3] necessitates considerations of curation at low temperature, in order to prevent the loss of intrinsic volatile species.

Insights from Tagish Lake: The Tagish Lake meteorite fell January 18 2000 onto a frozen lake surface in northern British Columbia, Canada. Samples of the meteorite were recovered within a week of the fall and kept frozen and untouched by hand (the so-called "pristine specimens"). Studies of the Tagish Lake meteorite demonstrate that it is an ungrouped Type 2 carbonaceous chondrite with affinities to CI and CM chondrites [4]. Tagish Lake is among the most enriched in carbon of all chondrites, containing up to ~6 wt% total C, of which approximately half is organic [5]. The soluble organic component, while relatively small (~2 % of organic C), contains several classes of compounds of prebiotic interest, including some which are particularly volatile (e.g., formic acid) [6-8]. Systematic study of different lithologies within Tagish Lake demonstrate variation in organic matter characteristics that correlate with mineralogy and petrology [9]; these variations are thought to represent a record of the effect of parent body alteration on the structure and composition of the organic matter [10]. Further details on intrinsic and contaminant organic species found in the Tagish Lake meteorite are summarized by [11].

Cold curation in practice: The pristine specimens of Tagish Lake necessitated the development of a facility that would enable the documentation, processing and storage of astromaterials under cold, inert conditions. The Subzero Curation Facility for Astromaterials at the University of Alberta is designed with these considerations in mind, within the limitations of funding available. At the heart of the facility is an Ar gas glove box (MBraun, Inc.), housed within a controlled environment chamber capable of maintaining temperatures between -30 and -10 °C (Fig. 1). The glove box consists of a single user station made of brushed 304 stainless steel with radius corners, with a polycarbonate window with chemical and scratch resistant coating (Fig. 1c). Integrated into the window is a binocular microscope (Leica, Inc.), fitted with a camera adapter (Fig. 1c). An adjustable stage sits beneath the microscope, within the glove box. On the right side of the main box is a secondary, storage box made of the same materials as the main box (Figure 1c); separated from the main box by a sealable door, this box allows for temporary storage of samples while experiments (e.g., involving solvents) are being carried out in the main box. The atmosphere within the glove box is maintained using an MB 20 G gas purifier (MBraun, Inc.); once charged with high-purity oxygen-free (99.998%) argon, the system continuously recirculates the argon through a purification system, which removes airborne contaminants and maintains O_2 and H_2O to < 1 ppm. HEPA filters on gas inlets also reduce any particulate matter that may be otherwise be circulated into the glove box. An activated carbon filter unit on the gas outlet for the main glove box removes any volatile organic compounds that might contaminate the materials used within the purifier; this feature also allows for organic solvents (e.g., chlorinated solvents such as dichloromethane) to be used within the glove box, either for cleaning purposes or to carry out organic extractions on samples within a purified inert atmosphere at low temperature. A Class 1000 clean room (Lasco Services, Inc.) serves as a room temperature anteroom to the freezer chamber (Fig. 1a). This anteroom was established to provide a source of clean air for the freezer chamber, since HEPA filtering of the freezer chamber air was not practicable. The anteroom also provides improved storage for the University of Alberta Meteorite Collection. Further details are provided in [11], including methods and results pertaining to commissioning of the facility.

Figure 1. The Subzero Curation Facility at the University of Alberta, consisting of a Class 1000 room temperature anteroom (A), and a walk-in freezer (B) in which an Ar glove box is housed (C).

Insights into cold curation for future sample return: Processing of Tagish Lake specimens now occurs on a routine basis within the Subzero Curation Facility for Astromaterials. To date, no significant levels of organic contaminants have been observed in any meteorite samples, although the use of witness plates is planned but not yet implemented. In practicality, the facility accomplishes the purpose for which it was built, i.e., to enable the processing of Tagish Lake specimens under clean, cold conditions in an inert atmosphere (although Tagish Lake specimens remain in storage in air, [11]). The two main limitations encountered thus far in the use of the facility include mitigation of a glove box leak and user comfort – the low temperature of the freezer chamber compounds the challenges associated with glove box work. As with any cold environment work, standard operation involves donning insulated clothing (under the clean room smocks), working with a partner, and limiting exposure to the cold – typically 15-20 minutes at a time. The main advantage of the facility is the reduced risk to specimens once they are transferred into the glove box, allowing for frequent user breaks (to warm up). However, in the case of a sudden leak or atmospheric contamination event, rapid mitigation of the problem can be hampered by the cold, especially if the user has already been working in that environment before the problem is noticed.

Conclusions: In spite of the challenges, cold curation provides significant advantages over room-temperature curation, including: the retention of intrinsic volatiles; the suspension or inhibition of microbial activity; the minimization of outgassing of glovebox components; and the reduction in reaction rates of oxidation and hydrolysis of intrinsic organic compounds and minerals. Therefore cold curation is recommended for future sample return from *any parent body in which volatile components are anticipated* (e.g., organic-rich asteroids, cometary nuclei, Mars). The optimal design of a cold curation facility will need to balance the parent-body-specific conditions required to preserve the sample with those which maintain user comfort. In practice, this will most likely require the ultra-cold (~ -80°C) storage of specimens and the handling and processing of specimens under cold (~ -15°C) conditions. Notably, micromanipulation of small samples under cold conditions has yet to be tested, and is an important consideration for future sample return mission planning.

References

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