Collecting time-sequenced records of micrometeorites from polar ice caps

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Introduction

Micrometeorites are terrestrially collected extraterrestrial dust particles smaller than about a millimeter. Our goal is to design, build and calibrate a collector that can obtain time-sequenced records of micrometeorites and terrestrial dust during hot-water drilling operations into polar ice caps. Our collector is designed to attach on the end of a hot-water hose and will suction and extract particles melted out of the ice onto an internal scrolling filter that advances as the drill descends. The 10-cm-diameter prototype collector will serve as a 1/3-scale model of one proposed for use during drilling of the IceCube neutrino observatory at South Pole. It is also operational in its own right for use with smaller hot-water drills.

Scientific Significance

About 30,000 tons of sub-millimeter ET material enters Earth's atmosphere each year of which ~ 10% survives entry as micrometeorites [1,2]. The accretion rate, size distribution and composition of micrometeorites bears on numerous studies: deducing the compositions of parent bodies; calibrating sedimentation rates; interpreting the isotopic record of seawater; linking influx to global climate change; assessing the role of ET materials in life processes.

Micrometeorite collections are difficult to obtain. Desirable attributes are large numbers of particles, low terrestrial contamination and weathering, precise age constraint and known collection area. We have large collections from polar ice [3,4], two large flux calibrated collections [2], collections from different aged blue ices [5] and samples from a deep ice core, that has excellent age and area constraint but very low particle counts [6]. No collections exist that can assess changes in micrometeorites over 1,000-yr time scales.

Our collector will provide technology capable of retrieving a time-sequenced particle collection from deep polar drill holes. If multiple holes are drilled at the same location, such as those planned for IceCube, correlation between samples on the filters will yield a statistically significant number of micrometeorites for given time intervals.

Collection System

The collector has a shaped body to flatten the hole bottom (to improve time resolution). Hot water will flow through the 2-m-long collector body and discharge horizontally at 4 m/s. The body will confine flow and entrained particles to a 1-cm annulus adjacent to the ice wall for high heat-transfer rates. A seal at the top of the collector body (0.3-m-dia.) will direct flow inside (minimum flow velocity 1.4 m/s or ~ 3 times the fall velocity of a 2,000-µm iron spherule). The flow will manifold into a single pipe that spirals downward. A 30-m-long x 150-mm-dia. tube filter will be bunched up over this pipe. As the collector descends, spiked wheels engage against the ice walls and rotate a spool that pulls the filter, at a rate of 25 mm per 2 m of drill descent, through a sleeve and over the discharge end of the pipe. A second sleeve limits the open length of the filter to 25 mm and flattens the filter as it winds onto the spool. Entrained particles deposit on the inside of the tube filter, with each 25-mm of filter length preserving a 2-m depositional interval. The flow will then exit the collector above the seal and continue its ascent. After the drill completes a hole, we will open the collector body and retrieve the spooled filter.

We focus on two critical issues: (1) performance of the shaped drill head and (2) collection efficiency and time resolution of the scrolling filter. Other requirements include high collection efficiency (>90%), fine time resolution, minimum contamination, and efficient post-collection particle handling.

A flat-bottomed hole, ideal for particle time resolution, cannot occur for finite heat input. Heat-transfer rates [7] decrease approximately linearly with flow velocity and water temperature, and both of these decrease nearly as the square of the hole diameter without a shaped drill head. We combined these expressions with an energy balance for the water and ice to predict the flattening benefit of using a shaped drill head. Figure 1 shows that a drill head that maintains a 1-cm annular gap with the ice wall can achieve a 0.3-m-dia. hole within 2 m of the drill tip. This 2-m interval represents uncertainty in particle depositional ages. For example at South Pole 2-m of ice represent 20 yr near the surface and 100 yr near the bottom of the hole [8].

We considered many particle-extraction and sequencing concepts and selected filtering through a scrolling tube-membrane filter as the best compromise between simplicity and performance. In the absence of contamination, particle concentrations are low, and clean-filter pressure losses dominate the design. We measured pressure losses per unit area for 1–53-µm membrane filters. Our design develops losses of only 20 kPa through the 17-µm filter, plus 13 kPa losses along the external annulus and internal spiral pipe.

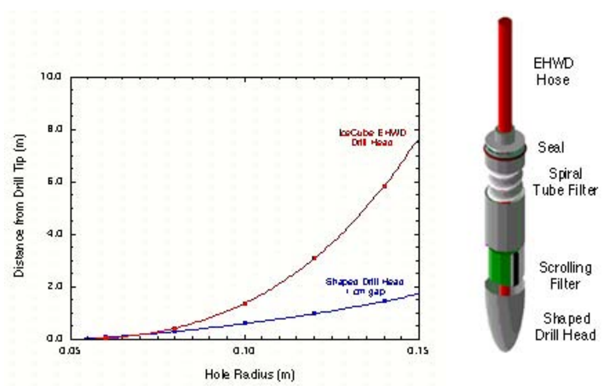

Fig. 1. Flattening of hole bottom using a shaped drill head, and the resulting collector packaging.

We tested the ability of a scrolling filter to sequence the captured particles, by building a test apparatus where we inject tracer particles into the flow and capture them on a 7.5-cm-dia. scrolling filter (Figure 2). The result of one test is shown in Figure 3. Here blue, red and green silicate particles were injected sequentially into the flow and appear in the proper sequence in the filter. Current work involves improving the seals, packaging the scrolling filter into the drill head, and conducting detailed calibration tests for time resolution and collection efficiency.

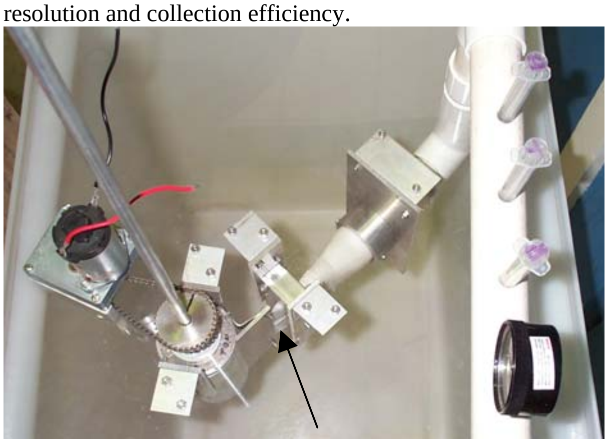

Figure 2. Apparatus used to test scrolling filter. Arrow shows open area of tube filter between discharge seal and scroll canister.

Figure 3 Injected particles deposited along the filter in sequence.

Conclusions

Presently we have large collections of micrometeorites [3,4], two collections that are well dated [2], collections from blue ice deposits that are tens of thousands of years old [5] and a few micrometeorites from a deep ice core [6]. If we could collect micrometeorites during the routine hot-water drilling of holes in polar ice, particularly multiple holes such as those proposed for IceCube nutrino experiment at South Pole, we could address the following questions:

Can we identify unique particles from periodic comets or from terrestrial impact events?

Are micrometeorite lifetimes, as measured by cosmic-ray exposure ages, related to the particle size, type and terrestrial depositional age?

Can the ^{3}He and Os record from micrometeorites be used to evaluate temporal variability in ET influx?

Why are the ^{3}He variations in seafloor sediments 180 degrees out-of-phase with the predicted IDP influx?

Does the flux of ET carbon, nitrogen, water, and organic molecules (e.g., amino acids) in the micrometeorite samples change as a function time?

How does the record of biogenic materials and terrestrial grains change with time?

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