Developing a Carbonaceous Chondrite Based Simulant of Phobos

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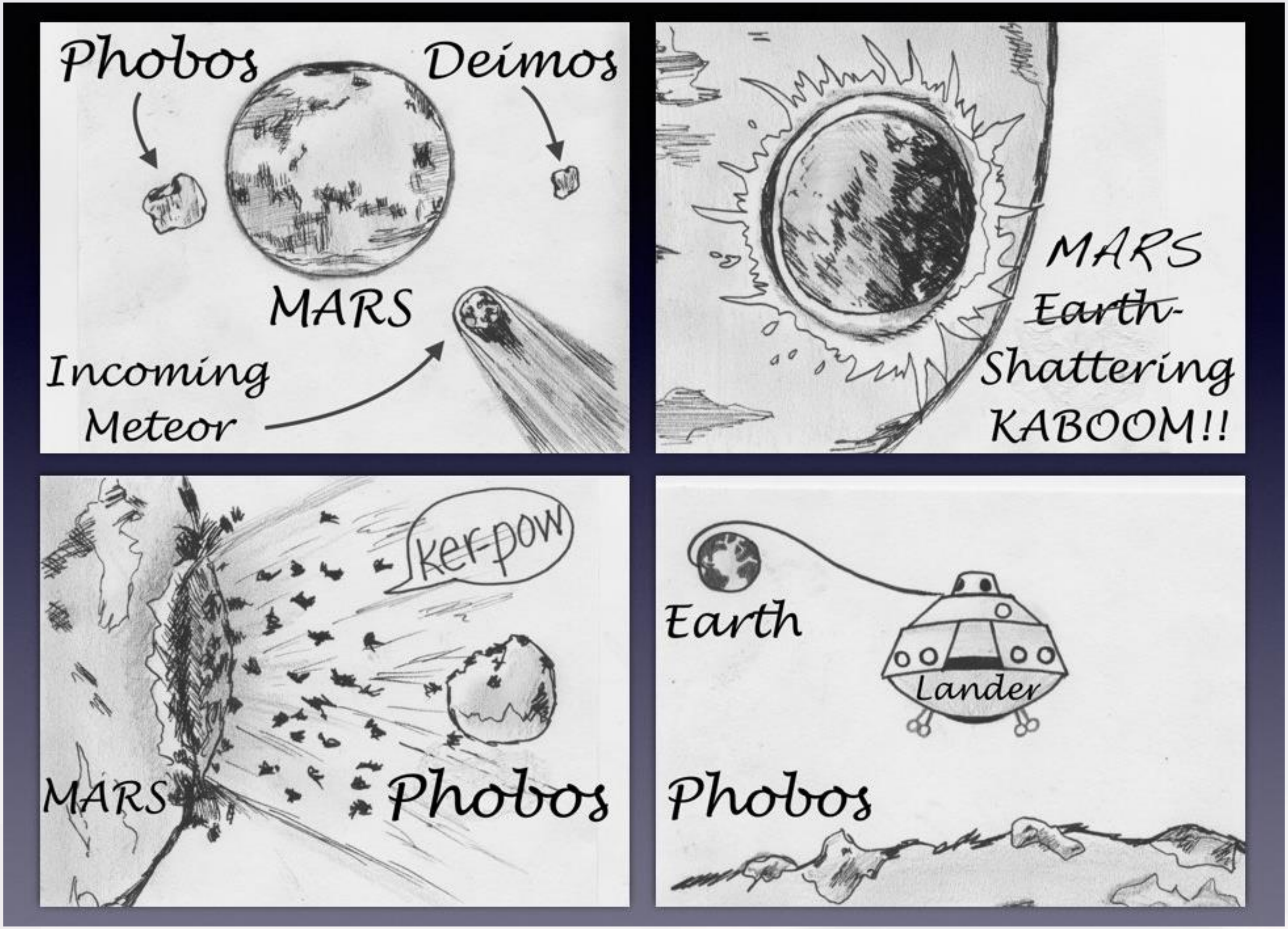
The Concept



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The Question

What is the likelihood that an organism originating on Mars could survive the impact on Phobos?

Answer – Either a SWAG or time to do experiments.

(Experiments pay better.)

Experimental Design I

Using a hypervelocity facility at the Open University, UK, impact biologically-seeded material (simulating material leaving Mars) into a simulant of Phobos. Then determine if the organisms remain viable.

Parameters for the experiment can be derived by considering the process being modeled as having two parts.

Part 1 - something has to leave the surface of Mars

Part 2 - that “something” has to hit the surface of Phobos

Experimental Design II

Part 1 – Something leaves the surface of Mars

Estimate/model the impactor interaction with the Martian surface.

Q: What would be a reasonable assumption for the composition of Martian crust to be kicked into space?

A: Basalt

From this effort we have “determined” limits on the velocity, mass and composition of Martian crustal material hitting Phobos.

Experimental Design III

Part 2 – The surface of Phobos is hit.

Q: How do you simulate the surface of Phobos?

A fundamental decision was made that the formation of Phobos regolith is likely to be akin to similar regolith forming processes on other small Solar System bodies.

In general four characteristics are needed to specify a simulant: composition, size distribution, shape distribution, and packing density (Rickman et al, 2013)

Phobos Simulant Characteristics

Packing density for the surface of Phobos can be guessed based on thermal properties. This is adjustable by the experimenter using handling protocols.

Shape distribution of the the particles at the surface of Phobos is unknown. And until recently, shape has been resistant to mathematically meaningful quantification.

Size distribution is constrained by the physical characteristics of the experimental equipment. Three size fractions were required – Fine, <425 µm, Medium, 1.2 to 3.3 mm, and Coarse, >5

Phobos Composition

The Phobos surface is spectrally heterogeneous (Murchie and Erard, 1996, Zellner and Wells, 1994, Rivkin et al, 2002).

There are two spatially distinct units, spectrally similar to P- and D-type asteroids.

These asteroid types both have low albedos with featureless, red spectra, possibly due to the presence of organic compounds.

Although no meteorites have been linked directly to P-type asteroids, **an example of a D-type asteroid is believed to be the Tagish Lake meteorite** (Brown et al., 2000).

Tagish Lake Meteorite I

The meteorite is highly heterogeneous, both mineralogically and texturally, Brown et al. (2000), Zolensky et al. (2002), and Blinova et al. (2009).

Though modal abundances have not been published, the most abundant minerals in the meteorite appear to be:

- Phyllosilicates (Mg-rich serpentine, saponite),
- Mg-rich olivine,
- Magnetite,
- Fe-Ca-Mg carbonates, and
- Fe-Ni sulfides.
- Organic carbon.

The organic carbon abundance of the meteorite is on the close order of a percent.

A review of the meteorite's organic chemistry is provided by Pizzarello et al. (2006). Chondritic organic species are predominantly insoluble macromolecules consisting of polycyclic aromatic cores linked by aliphatic and functionalised (N, O, S-bearing) species.

Tagish Lake Meteorite II

Assuming the Tagish Lake meteorite provides guidance is quite distinct from assuming it provides a detailed template to understand the surface of Phobos.

The surface of Phobos is likely to have been meteoritically gardened in the same way as the Moon, with consequent large-scale replacement by vesicular glasses of meteoritic or hypothetical asteroidal textures and minerals.

The level of certainty linking the composition of the surface of Phobos with the composition of the Tagish Lake meteorite is not overwhelming.

There were significant practical technical and cost constraints on what could be done in manufacturing a simulant, especially with respect to replicating textures (Rickman et al., 2013b).

Finally, the tests for ESA using the simulant were not expected to be sensitive to most textures.

Additional Constraints

All components in the design had to be reasonably available in sufficient mass, at an affordable cost, and in a timely manner.

It was also desired that they be both internally consistent and as well characterized as practical. These would greatly simplify subsequent work.

The components and their mixtures had to be safe to handle.

There are constraints imposed by the experimental equipment and the objective of the experiment. These include limits on

- particle size,
- sample mass,
- sample sterility.

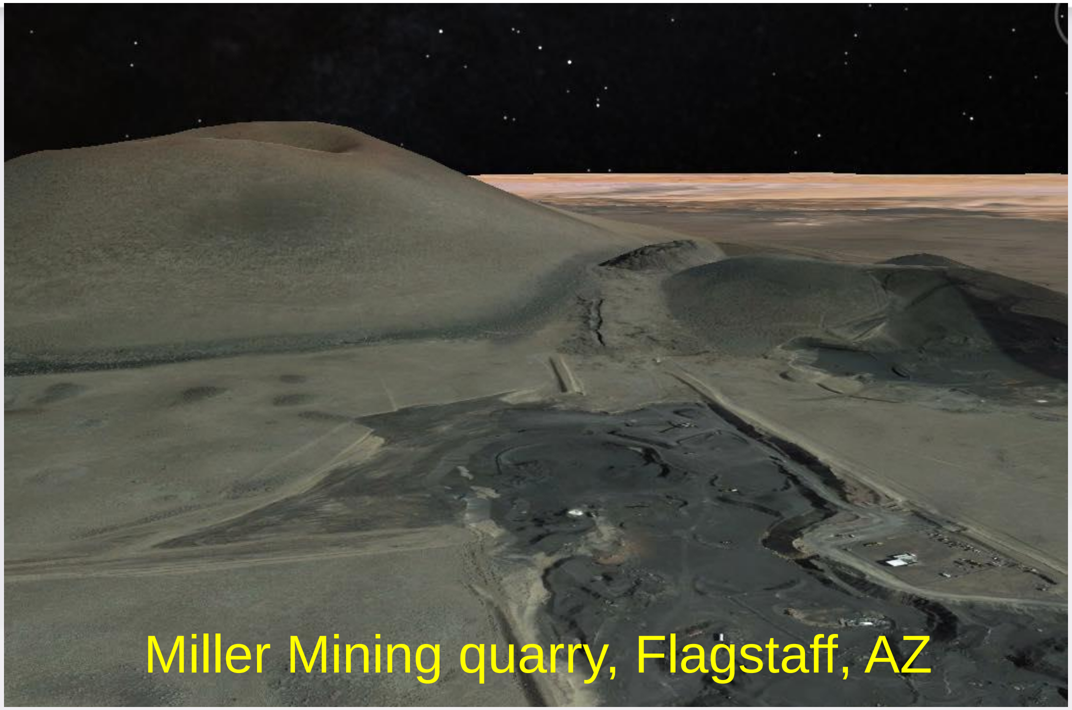
Components %

The compositional design of the Phobos simulant agreed on by the team reflects the stated considerations and is given here.

Component	Wt. %
JSC-1A source (ash & cinders)	46
Antigorite	35
Pseudo-agglutinate	15
Gilsonite	4

Simulant Composition I

Merriam Crater ash & cinders (46%) were used to provide a glassy and microcrystalline fraction of basaltic composition. It has the advantage of being extremely well known and well characterized within the community of users experimenting with lunar simulants, as it is the source for the JSC-1 series of simulants.

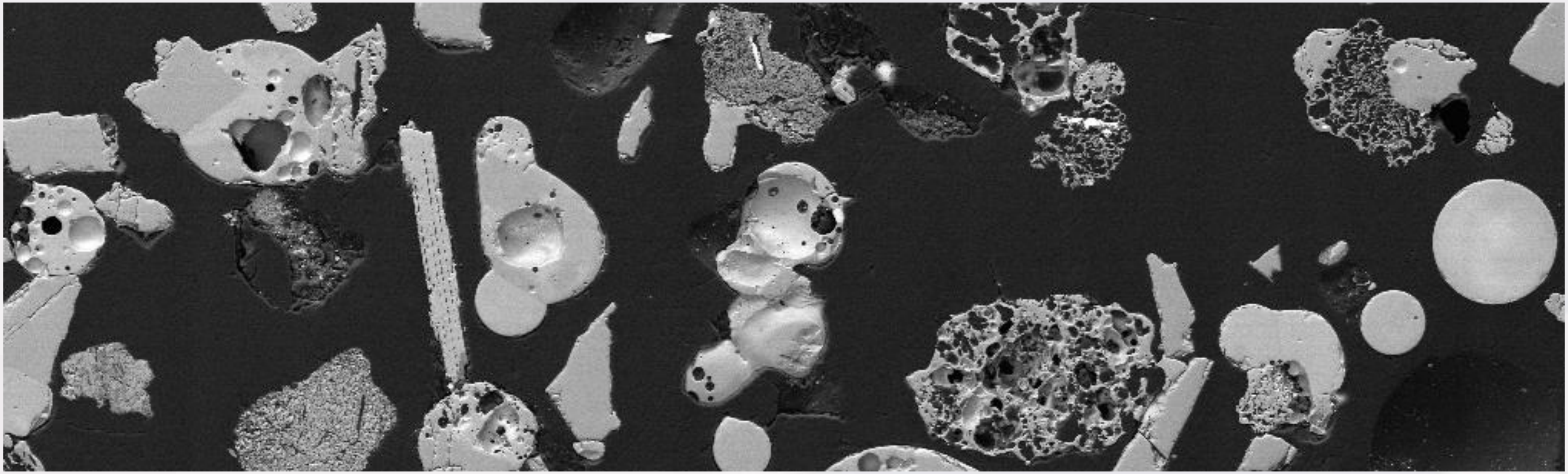


Commercially available antigorite (35%) from a Canadian producer was used to provide a hydroxyl-bearing phyllosilicate. A major consideration in selection of this material was the requirement that it be certified as free of asbestos. The material was checked at the United States Geological Survey and confirmed to be asbestos-free.

Simulant Composition II

The pseudo-agglutinates (15%) were produced by Zybek Advanced Products of Boulder, CO, under contract with the United States Geological Survey. (Weinstein et al., 2012; Rickman et al., 2013b). The starting material was a noritic mill-sand produced by the Stillwater Mine of Nye, Montana.

Pseudo-agglutinate provides a highly vesicular, glassy component with mineral grains of varying sizes, which replicates many of the textures found in lunar agglutinates. The nano-phase iron characteristic of the lunar material is absent, hence the term pseudo-agglutinate.



Simulant Composition III

Gilsonite (4%), sensu stricto, is an naturally occurring, commercially available asphaltite produced from vein deposits near the Colorado – Utah border, with large remaining reserves (Boden and Tripp, 2012).

Asphaltite is used as it chemically approximates the complex structure of the organic materials present in carbonaceous chondrites, such as the Tagish Lake meteorite.

Asphaltites are less heat sensitive than other alternatives.

Gilsonite is also brittle, which is important in the simulant manufacturing process.

Gilsonite has a long track record of use and is known to be safe with respect to human exposure.

Gilsonite is commercially available as pure, well characterized and uniform products.

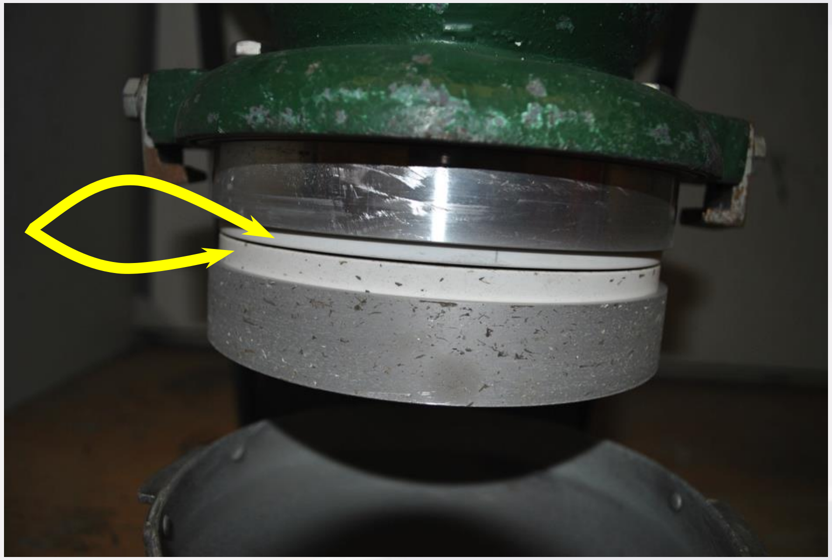
Processing

Because the four components have very different mechanical properties, the components were ground separately.

The individual components were milled using a plate grinder with the plates set 5 mm apart.

The materials were then sieved to yield the desired particle size range and blended together in an empty ball mill.

Grinding Plates



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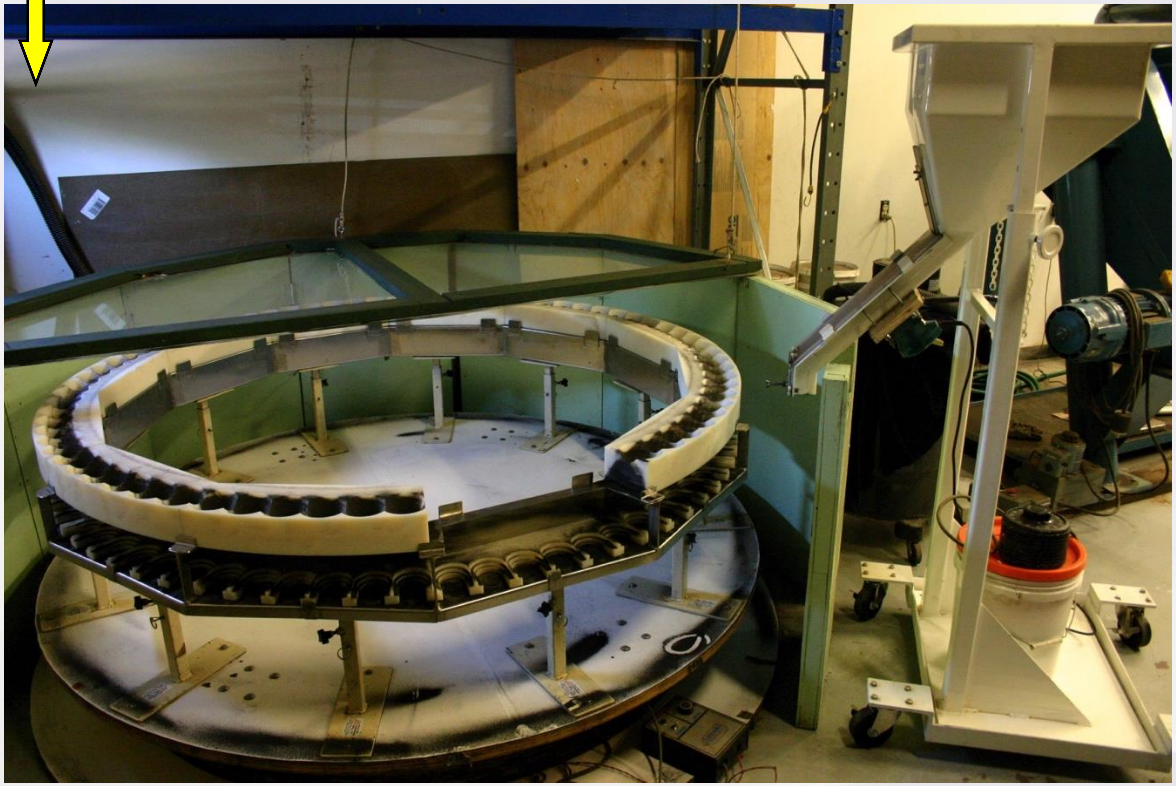
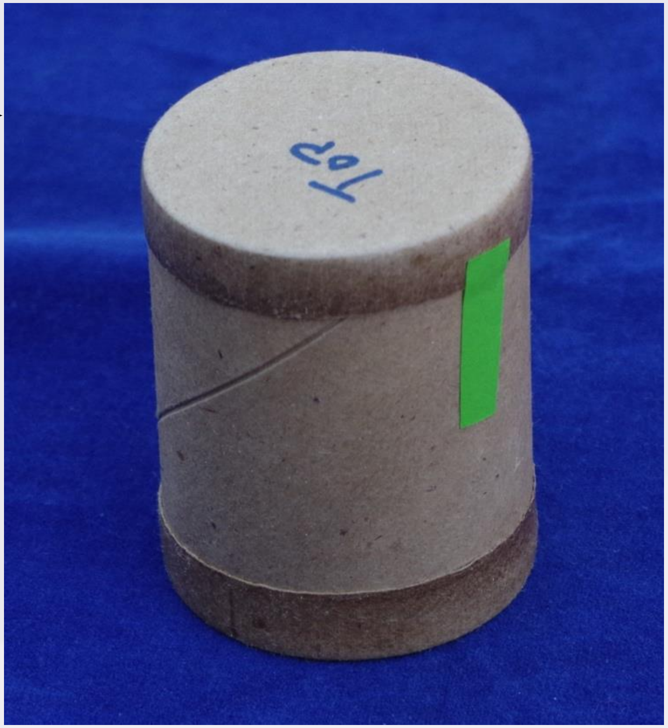
Packaging

To minimize handling and contact with the simulant after manufacturing, custom paper-board cylinders were procured.

After filling with simulant on a custom-made, rotating splitter, each cylinder was sealed in an individual plastic bag.





Paperboard cylinder dimensions were specified to fit into the Open University's sample holding chamber.

Sterilization I

Sterilization by heat could be done in the sample chamber, which is designed to be heated. Simulant could be introduced and then heated to an internal temperature of 170° C for 1 hour, or 150° C for 4 hours, or 140° C for 6 hours.

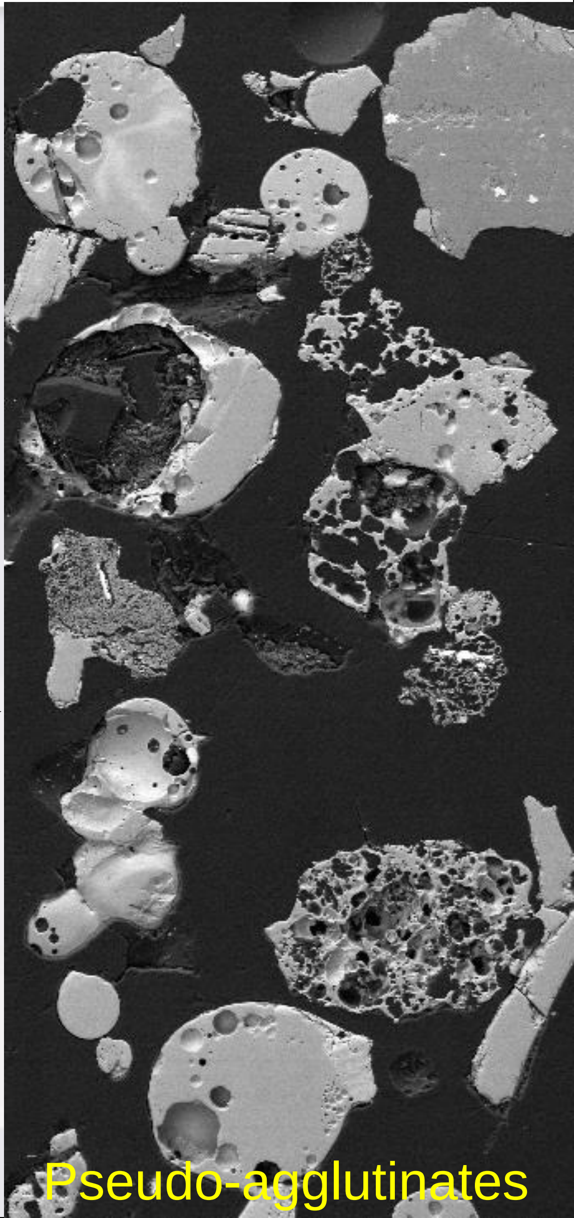
Monitoring internal temperature would need a probe, which could not remain in place during the subsequent experiment. Probe removal would disturb the particle packing. Heating without a probe would require substantially longer than the minimum time, which would add to the logistical problem.

Also, there was a concern that at high enough temperatures the asphaltite would soften and effectively glue the other material into a solid mass once cooled. This could be addressed by either using an asphaltite with a higher melting point, such as Impsonite or Grahamite.

Sterilization II

Sterilization by chemicals, gas or liquid, was deemed not practical for several reasons.

- The mean-free path in fine particulates is short compared to the sample dimensions. Therefore, introducing and removing gases or liquids in a dependable manner is problematic.
- Surface wettability for the components by potential sterilizing agents is unknown.
- The morphology of the particles includes nearly sealed vesicles (bubbles), and cracks.
- Possibility of chemical reaction with reagent and the simulant mineralogy.
- Can't be done with the simulant loaded into the sample holders, which means loading of holders would have to be done in a sterile environment.



Sterilization III

Sterilization using gamma irradiation was chosen.

This method has several very significant advantages:

- temperature of the material is not elevated,
- mineralogy is not effected to any appreciable extent,
- can be done with the simulant already loaded into sealed sample holders,
- the process is commercially available and inexpensive.

We used a company called Sterigenics.

Key Points

A simulant for the surface of Phobos has been developed for use in hypervelocity impact experiments at the Open University, UK.

The template for the simulant is the Tagish Lake meteorite. Therefore, the simulant can be used to emulate carbonaceous chondritic asteroids.

In developing the simulant several unusual problems had to be solved:

- A source for organic materials of appropriate composition and safe to use.
- How to sterilize the simulant.
- How to keep the material sterile until used.
- How to mill and mix materials of wildly different mechanical characteristics.

Availability

Information about the design, production, and performance of the simulant, “fit for purpose,” can be obtained from D. Rickman, doug.rickman@nasa.gov. He also retains small quantities for laboratory characterization, which can be made available in 1 – 20 gram quantities when appropriate.

Spent simulant **may** become available in the future from the Open University, contact Manish Patel, manish.patel@open.ac.uk, or Victoria Pearson, victoria.pearson@open.ac.uk.

At this time there is no surplus simulant and all bulk material has been shipped to the Open University. Production of additional material would require a substantial ($$$) commitment on the part of the purchaser.

Production of the simulant was done by Steve Wilson, swilson@usgs.gov.

Acknowledgements

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