ADVANCES IN SMALL PARTICLE HANDLING OF ASTROMATERIALS IN PREPARATION FOR OSIRIS-REX AND HAYABUSA2: INITIAL DEVELOPMENTS.

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Introduction: The Astromaterials Acquisition and Curation office at NASA Johnson Space Center has established an Advanced Curation program that is tasked with developing procedures, technologies, and data sets necessary for the curation of future astromaterials collections as envisioned by NASA exploration goals [1]. One particular objective of the Advanced Curation program is the development of new methods for the collection, storage, handling and characterization of small (<100 µm) particles. Astromaterials Curation currently maintains four small particle collections [2]: Cosmic Dust that has been collected in Earth's stratosphere by ER2 and WB-57 aircraft, Comet 81P/Wild 2 dust returned by NASA's Stardust spacecraft, interstellar dust that was returned by Stardust, and asteroid Itokawa particles that were returned by the JAXA's Hayabusa spacecraft. NASA Curation is currently preparing for the anticipated return of two new astromaterials collections – asteroid Ryugu regolith to be collected by Hayabusa2 spacecraft in 2021 (samples will be provided by JAXA as part of an international agreement) [3], and asteroid Bennu regolith to be collected by the OSIRIS-REx spacecraft and returned in 2023 [4]. A substantial portion of these returned samples are expected to consist of small particle components, and mission requirements necessitate the development of new processing tools and methods in order to maximize the scientific yield from these valuable acquisitions. Here we describe initial progress towards the development of applicable sample handling methods for the successful curation of future small particle collections.

Contact Pad Particle Retention Experiments: OSIRIS-REx will capture at least 150g of asteroid Bennu regolith via its Touch-And-Go Sample Acquisition Mechanism (TAGSAM). The TAGSAM's sampler head will contact the asteroid surface and discharge a jet of N_2 gas, fluidizing regolith and trapping it in a sample compartment. In addition to this primary sampling mechanism, the TAGSAM has 24 surface contact pads that will collect material from the top layer of regolith by trapping particles in a VELCRO® stainless steel hook & loop system. This auxiliary sampling mechanism will collect particles from the uppermost surface of the asteroidal surface that will be important for space weathering science. The complex three-dimensional structure of the contact pad material will present unique sample processing challenges. We have performed contact pad particle retention experiments as a first step in developing viable extraction methods.

OSIRIS-REx contact pad replicas were produced by attaching stainless steel hook & loop fabric to 0.5" SEM stubs via carbon adhesive tabs and cutting the fabric to shape. The contact pads were pressed into two different asteroid dust/regolith simulants: polydisperse CV3 (Allende) powder produced by grinding via alumina mortar and pestle, and Tagish Lake simulant was used to test the primary collector efficiency.

For the Allende particle retention experiments, numerous clusters of fine-grained particles were found dispersed over the entire contact pad surface (figure 1). Several larger (>100mm) particles were found wedged between wire loops and embedded in the contact pad surface; some of these will present significant extraction challenges. The Tagish Lake simulant particle retention experiments appeared more effective at capturing larger (>100mm) particles. This observation may be due to a lack of fine particles in the simulant, or it may be due to a reduced organic component to the dust.

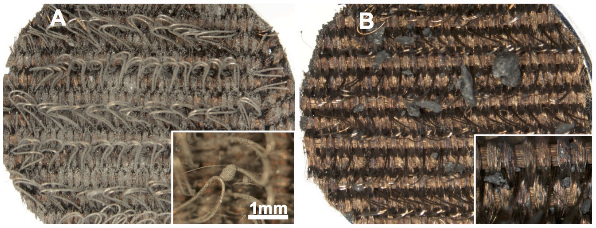

Figure 1: Contact pads after pressing into A) crushed Allende, and B) Tagish Lake simulant.

Contact pad sample removal experiments have thus far not been attempted, as particles retained by the contact pads present a contamination risk to our existing cleanroom facilities; however, we have recently repurposed a class 10,000 cleanroom specifically for OSIRIS-REx contact pad curation research, and expect to perform initial experiments by March 2018.

Mitigation of Tribolelectric Charging: At scales less than 100 µm, we observe that Van der Waals intermolecular forces and electrostatic forces dominate the behavior of particles. Van der Waals forces facilitate the manipulation of small particles, allowing curation activities such as transfer of particles between substrates to be conducted using pulled glass or tungsten microneedles. In most cases, electrostatic forces hinder the manipulation of particles. Triboelectric charging due to contact and frictional electrification [5] is the primary mechanism by which particles are lost during our transfer operations. Po-210 ionizers have been effective in reducing the effects of charging in normal cleanroom air environments; high ambient humidity also reduces triboelectric effects [6]. However, Hayabusa2 and OSIRIS-REx collections will be curated in sample processing cabinets purged with dry N_2 gas; in these low humidity environments, Po-210 ionizing sources may be insufficient in suppressing triboelectric charge accumulation of particles. As part of our Advanced Curation research, we have investigated additional methods of mitigating triboelectric charging.

Use of conductive substrates: Small particles have traditionally been stored and distributed to investigators in glass concavity slides. We have identified friction between these slides and particles as a major source of sample electrification. In cases where substrate transparency is not a curation requirement, the glass slide may be replaced with a silicon wafer. Particles retain a high level of visibility on such substrates (especially under coaxial illumination), and triboelectric charging is significantly reduced such that particles between 40-100 µm can be reliably manipulated and arranged in arrays without the use of a Po-210 source (figure 2).

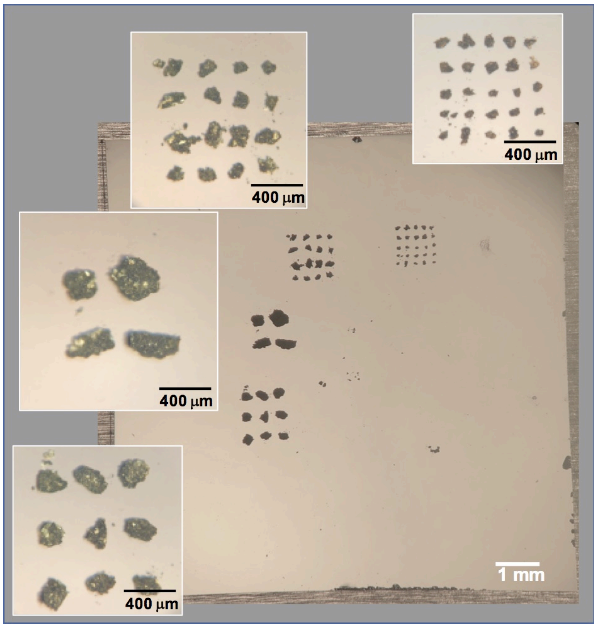

Figure 2: Size-sorted particles of CM2 meteorite arranged on a silicon wafer into arrays using tungsten carbide needle. Particles were transferred by hand and without use of Po-210 ionizer.

Tungsten Carbide Needles: Particles smaller than 20µm are typically transferred from a collection medium to an analytical substrate (e.g. beryllium disk or epoxy bullet) or to a storage container (e.g. concavity slide) using a microneedle made from glass or tungsten. The intermolecular forces between the needles and the particles in this size range are typically sufficient to overcome repulsion due to triboelectric charge accumulation. Larger particles have been more challenging to manipulate. When using the same glass and tungsten microneedles for particles larger than 20µm, charging effects significantly hinder the reliable manipulation of particles (even with the use of Po-210 ionizing sources). We have recently discovered that tungsten carbide needles are far superior to both pulled glass microneedles and tungsten metal microneedles for manipulating particles as large as 200µm. We speculate that the low taper ratio (~3:1) of these needles present greater contact surface area for intermolecular forces to capture particles, and that the needle shape may aid in the rapid redistribution of accumulated triboelectric charge; however, more tests are needed.

Next steps: We have repurposed a small N_2 sample cabinet with the intent of conducting initial particle manipulation experiments in a dry nitrogen environment, using the triboelectric charge mitigation methods described above, and we expect to have preliminary results by March 2018. Should these experiments prove successful, our next goal will be to design and construct custom N_2 gloveboxes that will accommodate a wide range of small particle processing requirements.

References: [1] McCubbin F. M. and Zeigler R. A. (2017) *Hayabusa 2017 Symposium of the Solar System Materials*. [2] Allen C C. et al. (2011) *Chemie der Erde-Geochemistry*, *71*(1), 1-20. [3] Minamino H. et al. (2012) *Asteroids, Comets, Meteors,* Abstract #6188. [4] Lauretta D. S. (2017) *Space Science Reviews 212,* 925-984. [5] Matsusaka S. et al. (2010) *Chemical Engineering Sci., 65*, 5871-5807. [6] Guardiola J. et al. (1996) *Journal of Electrostatics, 37*, 1-20.