Abstract:

The Uppermost Surface of the Moon

The Ap16 Clam Shell Sampling Devices (CSSDs) were designed to sample the uppermost surface of lunar soil. The two devices used beta cloth (69003) and velvet (69004) to collect soil from the top 100 and 500 μm of the soil, respectively. Due to the difficulty of the sampling method, little material was collected and as a result little research has been done on these samples. Initial studies (Noble et al., 2007) attempted to look at the material which had fallen off of the fabrics and was subsequently collected from inside the sample containers. However, this material was highly fractionated and did not provide an adequate picture of the uppermost surface. Recently, samples were obtained directly from the beta cloth using carbon tape. While still fractionated, these samples provide a unique glimpse into the undisturbed soil exposed at the lunar surface.

Understanding the properties of the uppermost surface is critical as it is the optical surface that is probed by remote-sensing data, like that which is and will be generated by instruments on orbiting missions (e.g. M^3, LRO). The uppermost material is also the surface with which future lunar astronauts and their equipment will be in direct contact, and thus understanding its properties will be important for dust mitigation and toxicology issues, as well as resource utilization (ISRU) purposes. An improved method of collecting samples of this uppermost surface should be developed and this type of sample should be routinely collected at all future human landing sites.

The Uppermost Surface of the Moon

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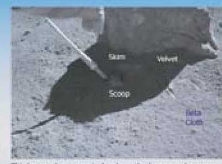
Introduction: The Ap16 Clam Shell Sampling Devices (CSSDs) were designed to sample the uppermost surface of lunar soil [1]. The two devices used beta cloth (69003) and velvet (69004) to collect soil from the top 100 and 500 µm of the soil, respectively. Due to the difficulty of the sampling method, little material was collected and as a result little research has been done on these samples. Initial studies [2] attempted to look at the material which had fallen off of the fabrics and was subsequently collected from inside the sample containers. However, this material was highly fractionated and did not provide an adequate picture of the uppermost surface. Recently, samples were obtained directly from the beta cloth using carbon tape. While still fractionated, these samples provide a unique glimpse into the undisturbed soil exposed at the lunar surface.

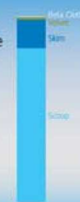
Training for the collection of samples with the CSSDs. The idea was to collect undisturbed soil from behind a boulder that would shielded from the lander exhaust and the dust kicked up by the astronauts as they walked.



This image shows precisely where the four samples were collected at Apollo 16 station 9, roughly 2.5 km from the lander.

Four samples were collected at this location which provide a cross-section of the upper surface.

- Beta cloth – top 100 µm
- Velvet cloth – top 0.5 mm
- Skim scoop – top 5 mm
- Regular scoop – top 3 cm



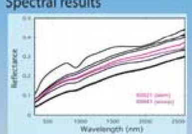
Images of the beta cloth (left) and velvet (right) samples after collection. Note how little sample was collected, particuarly on the beta cloth.

Rather than attempting to pull grains off of the fabric, we originally collected and studied material from inside the containers (i.e. the grains which had fallen off of the fabric during transport and handling). However, as one might expect, those samples showed evidence of substantial size fractionation and do not provide representative samples.

Samples were obtained directly off of the beta cloth swatch. Sampling was performed inside a glove box. Carbon double stick tape was placed on aluminum stubs and the tape stubs were gently pressed onto the fabric in the "dirtiest" areas as shown in the figures to the left. The "clean" circles left by the stubs which can be seen in the postprocessing image indicate that there was good recovery of the material at those spots. The samples were then coated with a thin layer of carbon to prevent charging and examined in the SEM at JSC. The weave of the fabric can be seen in the alignment of the grains in the backscatter image on the right.

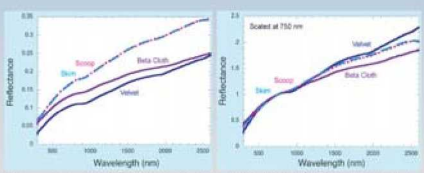
Results from original samples collected from inside container (the grains that fell off of the fabric)

Spectral results



For comparison, the <45 µm spectra of the skim and scoop samples are show along with several samples from the LSCC highland suite. They appear to by typical sub-mature to mature highland soils.

Following the methods of the Lunar Soil Characterization Consortium (LSCC) [3], spectra were obtained by RELAB at Brown University (C Pieters/T Hiroi), ferromagnetic resonance (FMR) was performed at JSC (R. Morris), and TEM analysis was also done at JSC (L. Keller).



Both the beta cloth and the velvet samples are darker than the skim and scoop, the velvet sample is also reddier, which may indicate more weathering, however, the 1 µm band is not attenuated as would be expected.

FMR results

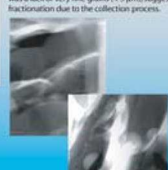
Sample	Fraction	I_s	FeO (wt%)*	I_s/FeO	I_s/FeO Morris 1978
69941 (scoop)	<250	520	5.7	91	85
69921 (skim)	<250	454	5.6	81	90
69004 (velvet)	<250	478	5.6	85	n/a
69003 (beta)	Bulk	331	5.6	59#	n/a

*Values for FeO taken from literature for bulk soil
#Sampling issues likely skewed results

FMR measures the amount of nanophase iron in a sample, and therefore, how "weathered" it is. These results suggest that the velvet sample is no more mature than the skim and scoop samples, and the beta cloth appears to be less weathered, though that is likely due to sampling issues.

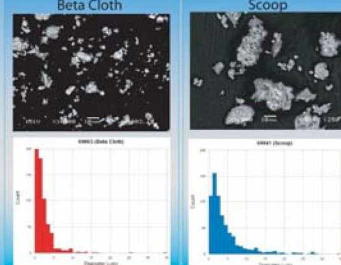
TEM results

Grains from 69004 (velvet) were examined in TEM, however few weathering products, such as those in the images below, were found and there was a lack of very fine grains (< 5 µm), suggesting fractionation due to the collection process.



Size Distribution - Is the uppermost surface finer grained than the bulk soil?

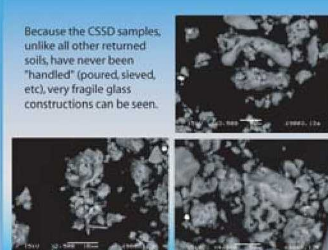
Beta Cloth | Scoop



Possible explanations for excess fine grains:
- Fine grains preferentially stuck to the fabric
- A typical representative size sample stuck to the fabric, but the larger grains fell off during handling leaving only fine grains on the fabric (we know that the material that fell off is depleted in fine grain materials and our analysis of soil stuck to space suit fabrics also show a concentration of fine-grained material)
- The soil adhering to the fabric represents the true size properties of the uppermost soil
- Or some combination of the above

If the uppermost ~100 µm does contain excess ultra-fines, there are several possible explanations :
- "Levitated dust" moves ultra-fine grains around at the surface
- Some other sorting mechanism (shaking, impact fragmentation, etc.) causes preferential concentration of the finest fraction in the uppermost layer of the lunar surface
- Or all lunar soil contains more ultra-fines than we currently recognize and some fraction of these fines are lost during handling and subsampling activities.

Because the CSSD samples, unlike all other returned soils, have never been "handled" (poured, sieved, etc), very fragile glass constructions can be seen.



References: [1] Horz et al. (1972) Ap 16 preliminary science report; [2] Noble et al. (2007) AGU abstract #P44A-06; [3] Taylor et al (1999) 30th LPSC Abstract #1859

Conclusions and Future Work: Understanding the properties of the uppermost surface is critical as it is the optical surface that is probed by remote-sensing data. The uppermost material is also the surface with which future lunar astronauts and their equipment will be in direct contact, and thus understanding its properties will be important for dust mitigation and toxicology issues, as well as resource utilization (ISRU) purposes.

It is clear from our study that the material pulled from the beta cloth contains excess amounts of ultra fine (sub-micron) grains, however, we can not determine whether that excess is due to fractionation during or after sampling, or if it represents the true size distribution of the uppermost lunar material. We plan to perform a similar study with the skim sample for comparison. A study of the velvet CSSD might yield further insights, however, we have not yet come up with a good method to extract the grains from the velvet. There is probably no way to difinitively solve this question with the current samples.

An improved method of collecting samples of this uppermost surface should be developed and this type of sample should be routinely collected at all future human landing sites.