SPARCLE: Electrostatically-Based Lunar Dust Control and Implications

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SPARCLE: Space Plasma Alleviation of Regolith Concentrations in the Lunar Environment

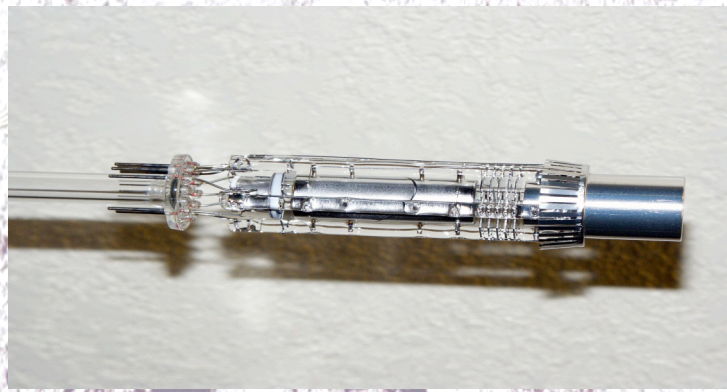
•A low power, lightweight NASA patent protected electrostatically-based tool (SPARCLE, Space Plasma Alleviation of Regolith Concentrations in the Lunar Environment) to remove dust in the airlock environment

•Concept to control charge transported to the dust covered surface, to induce dust flow (through repulsion) away from the surface and toward a surface with lower potential acting as a collector.

• Designed to be compact, low power device to be operational in <5 years

•Ion and/or electron beams, referred to as ionic sweepers, already been used to control the flow of potential across conducting and non-conducting surfaces of spacecraft (POLAR) in a highly charged environment (Comfort et al., 1998).

•In a simulated lunar environment, Immer et al (2004) already achieved success in moving dust, but not in controlling the direction of its flow, by systematic scanning of the surface with variable EMF.



Taking Advantage of Observed Electrostatic Behavior of Dust on the Moon

•Movement of dust through natural means (terminator approach) or locally mechanically induced stirring of the regolith causing dust to come into contact with and stick to conducting and non-conducting surfaces (Criswell, 1973; McCoy and Criswell, 1974; Berg et al, 1976, 1977).

•Fields, charged particles, dust particle interactions on Moon complex, dependent on highly variable environmental conditions and particle properties (size, composition, magnetic or electrical parameters.

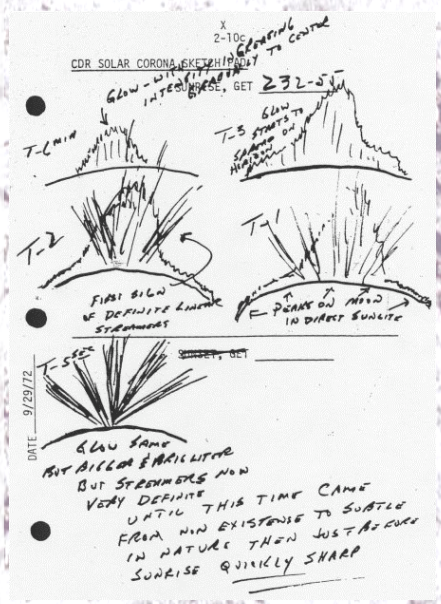
•Lunar fines have low electrical conductivity and dielectric loss, and tend to remain electrostatically charged (Carrier, Olhoeft, and Mendell, 1991).

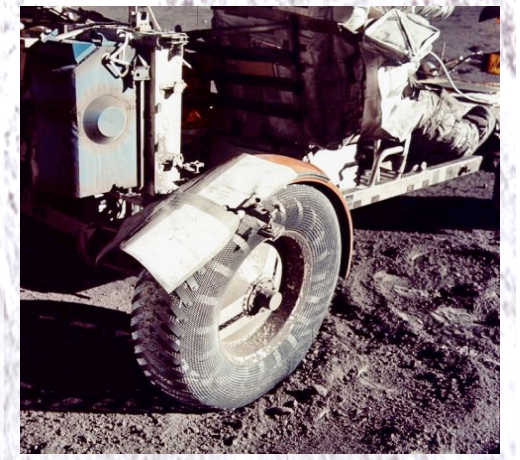
•Charged dust grains are repelled from like-charged surface or attracted to oppositely charged surface.

•Greater illumination, temperature increase surface potential.

•Electrostatic charging occurs via interaction of solar UV light with surface causing photoemission of electrons and interaction of the local plasma environment (Stubbs, Vondrak, and Farrell, 2005).

•Surface charging on the dayside driven by photoelectron currents, resulting in electron depletion and positive charging of surface; on nightside, plasma electron currents result in electron accumulation and negative charging of surface (Manka, 1973).





Two Forces causing 'sticking' of dust to surface, 1st approximations:

Van der Waal's between particle and surface: $F_{vdw} \sim A\ R/\ 6H^2$

where R is radius of particle

H is distance between surface and particle

A is Hamaker's coefficient measure of interaction between two substances ($\pi\ q_1\ q_2\ \lambda_{1,2}$)

$\lambda_{1,2}$ is London's coefficient dependent on atomic numbers of two substances where energy of interaction $E = \lambda_{1,2}\ H^6$

q_1 and q_2 are atoms/cm^3 for two substances

Electrostatics between particle and net opposite charge surface: $\sum(F_E/q) \sim E$

where E for surface of charge = $\sigma/2\varepsilon_0$

q is individual charge so F_E/q is force per unit charge

σ surface charge density

ε_0 electric permittivity

Dust Mitigation Strategy	Evidence/Results to Date
Mechanical Brushing	Apollo. Short-term Effectiveness. Particle abrasivity damaged surfaces, compromised seals. High surface area/volume meant high attraction (electrostatic and mechanical), minimal removal of finer particles leading to eventual mechanical joint failure. (Gaier, 2005)
Electrostatic Charging Mesh Grid Screen-Variable EMF	Dielectric, high surface area/volume means highly chargeable. Variable phased EMF moved dust but not in predictable direction. (Immer et al., 2006)
Electrostatic Charging e- Gun/Collector SPARCLE	Dielectric, high surface area/volume means highly chargeable. Ionic sweepers can control spacecraft surface potential. Control of potential should allow control flow direction. (Curtis et al, 2006)
Magnetic Susceptibility Magnetic Attraction	Collected fines have higher magnetic susceptibilities. Most of these mare soils. Are soils of all compositions equally susceptible? (Taylor et al., 2005)

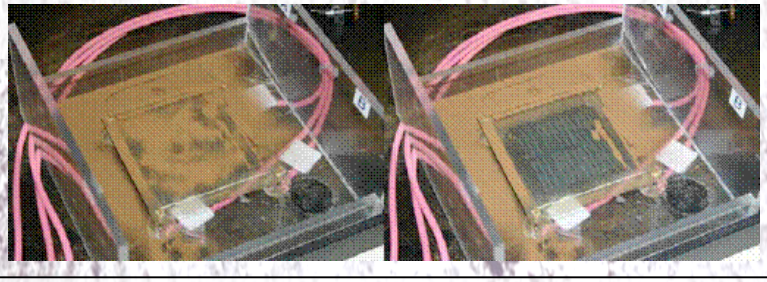
Electrostatic Variable EMF Mesh

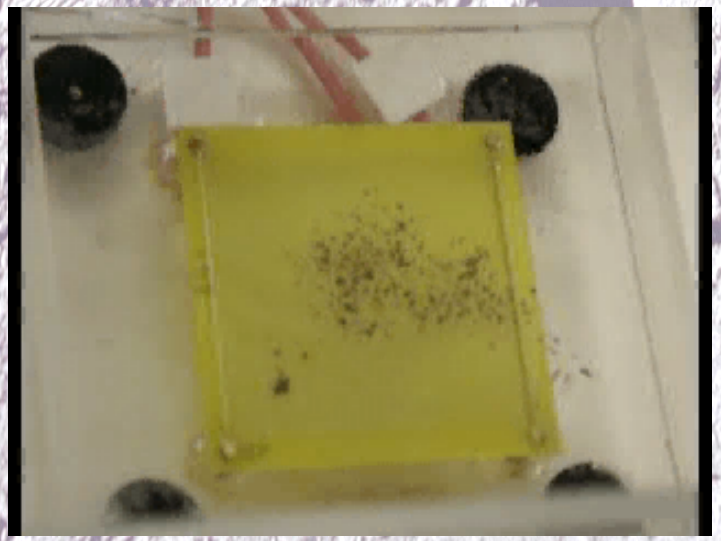
•Immer et al. (2006) performed a series of experiments which demonstrated that dust can be transported by electrostatic fields.

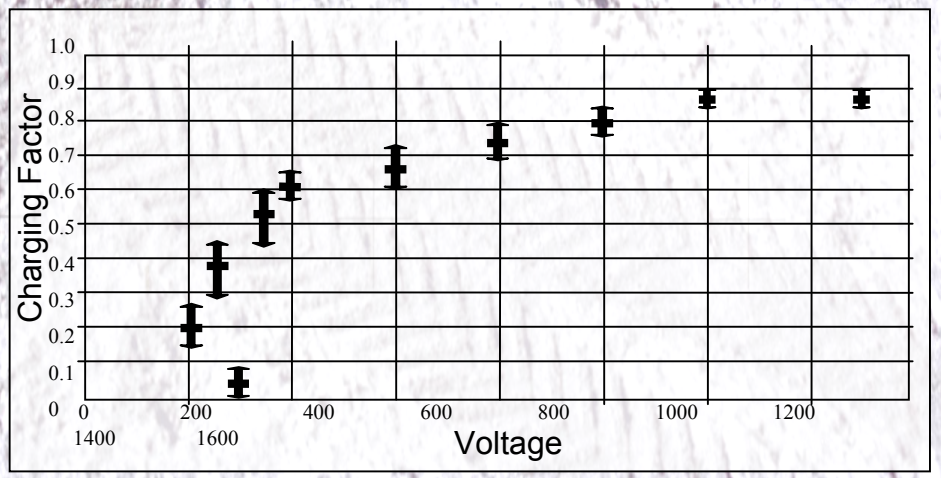
•Alternating waveforms of voltage applied to patterned grids of electrodes on 3-phase, copper-conductor screens fabricated using normal circuit board manufacturing techniques. Each phase was routed to a high voltage amplifier, allowing independent generation of phases.

•Optically transparent Indium Tin Oxide coated polyester screens, applied over solar panels, viewports, visors, or windows, demonstrated minimal degradation in performance.

•These images illustrate effectiveness of dust clearing, increasing with increasing voltage. The dip at 300 volts caused by resonance between switching phases causing dust to oscillate between mesh elements without being clear.







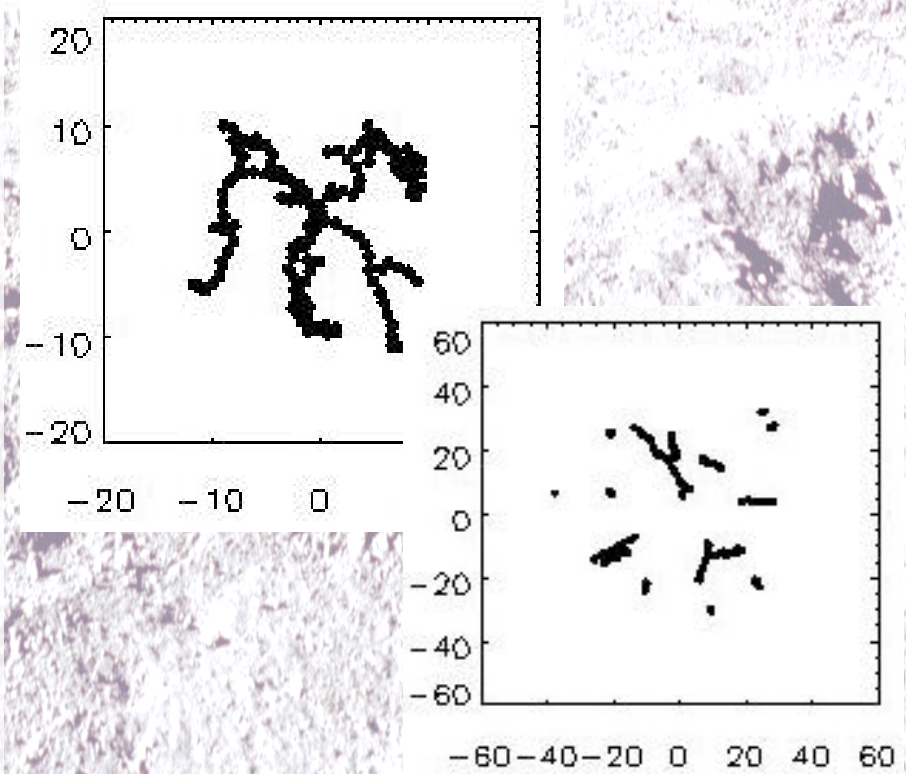
Dust Aggregation and Disaggregation

Marshall and coworkers demonstrations of particle behavior in simulated dust cloud environments indicating coulombic forces may play far greater role than gravity or van der Waals forces.

Regardless of composition, shape, or size, particles demonstrated to aggregate rapidly into linear chains in the presence of randomly distributed positive and negative charges and weak gravity to extent correlated with dust particle density.

Linear nature of the aggregation implies partial discharge during contact (tribocharging) creating an irregular charge distribution and a dipolar mechanism for particle attraction.

When only positive or only negative charges added to dusty environment, the environment distinctively dominated by positive or negative charges, and disintegration of aggregates occurred.



On left, computer-generated aggregate resulting from cloud collapse (neutral grains). On right, aggregates (formed by dipole interactions) in process of being dispersed by monopole forces (net charge on cloud).

Units = grain diameters.

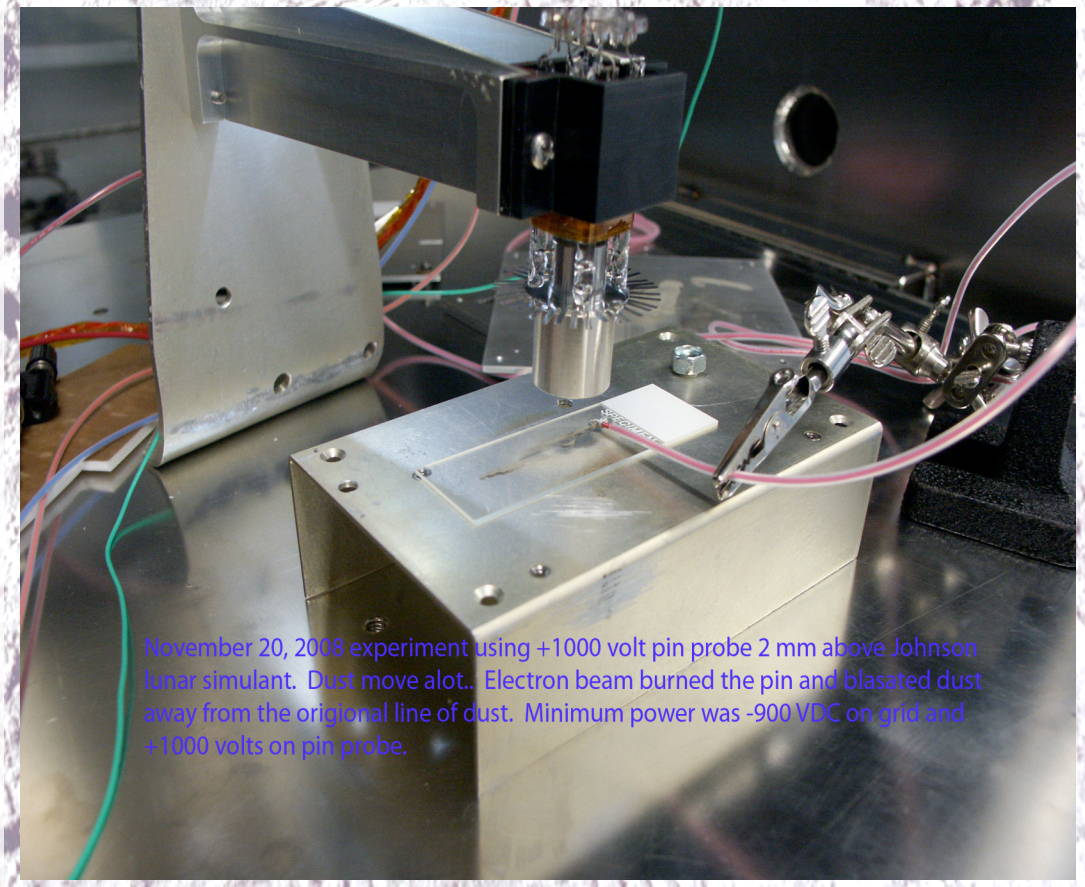
(Marshall and Sauke, 1999)

SPARCLE Experiment Setup

Experiment designed to test interaction between weak electron beam and dust particles (<20 micron JSC-1AF simulant) in presence of a weak electric field created with use of a small conducting object just above non-conducting dust-covered surface environmental chamber with intermediate vacuum (10^{-5} to 10^{-6} atmospheres) simulating the airlock.

Also analogous to conditions in typical solar nebula where dust grains are embedded in a gas that forms the basis for such a discharge.

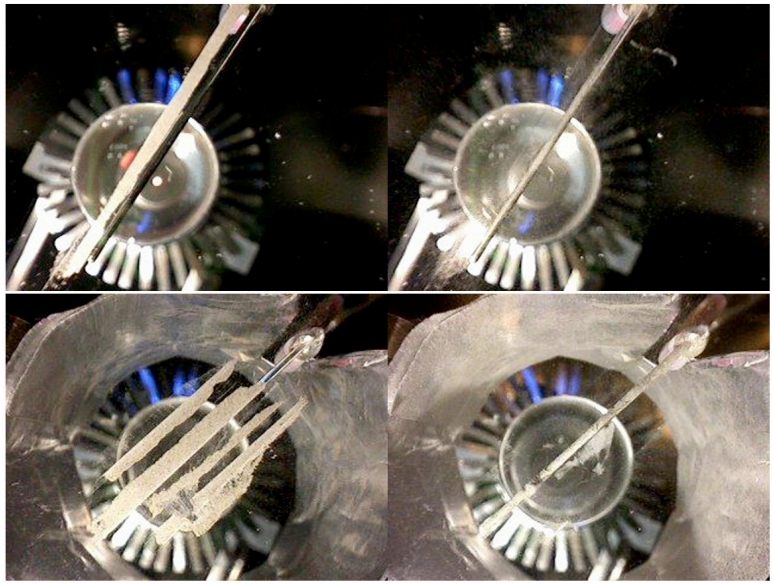
The less negatively charged surfaces surrounding the charged dusty surface, including chamber sides and gun nozzle act as collecting surfaces.



SPARCLE Experiment Results

Successfully focused weak electron beam using –900 V VDC grid and +1000 volt pin probe 2 mm above surface to control electrostatic potential of surface in presence of a moderate electric field of (500-1000 V) through the onset of a discharge.

Gun generated weak (milliamp range) electron beam. Introduction of a weak electric field of 500-1000 V initiated cascade of electrons in beam by ionizing surrounding low density gas, greatly increasing effective flux and luminosity of beam.

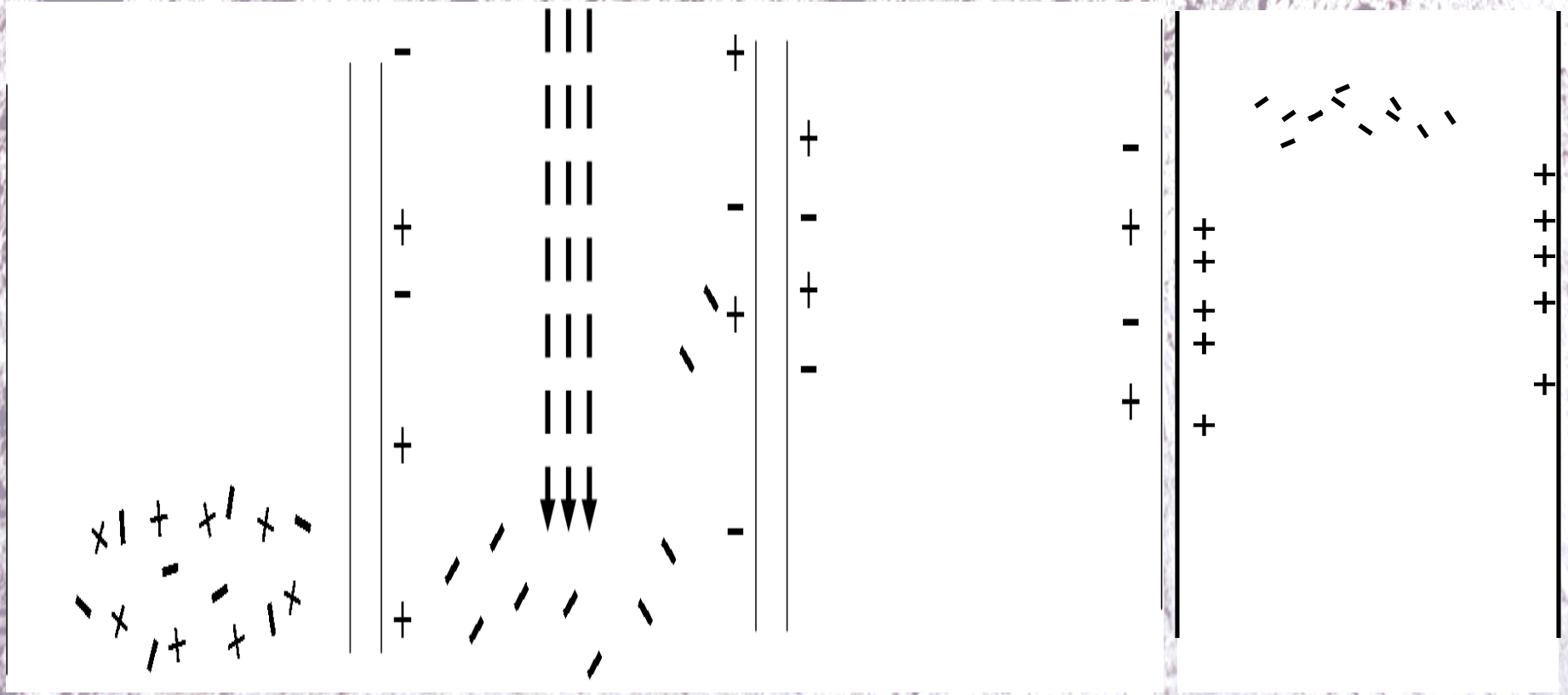


Negative charge/mass ratio of the initially neutral dust grains rapidly increased, causing sufficient electrostatic repulsion to accelerate grains rapidly away from the negatively charged surface and implant on surrounding relatively positively charged vacuum chamber walls.

Outside of electron beam, surfaces and particles should be neutral to weakly positive and collisions between strongly negatively-charged, accelerated dust and neutral to less strongly charged dust result in tribocharging, electrostatic attraction and sticking.

Model

An electrostatically based approach has overcome static charging as well as van der Waals forces. Dust removal from collection surface should be possible when its potential is considerably increased.



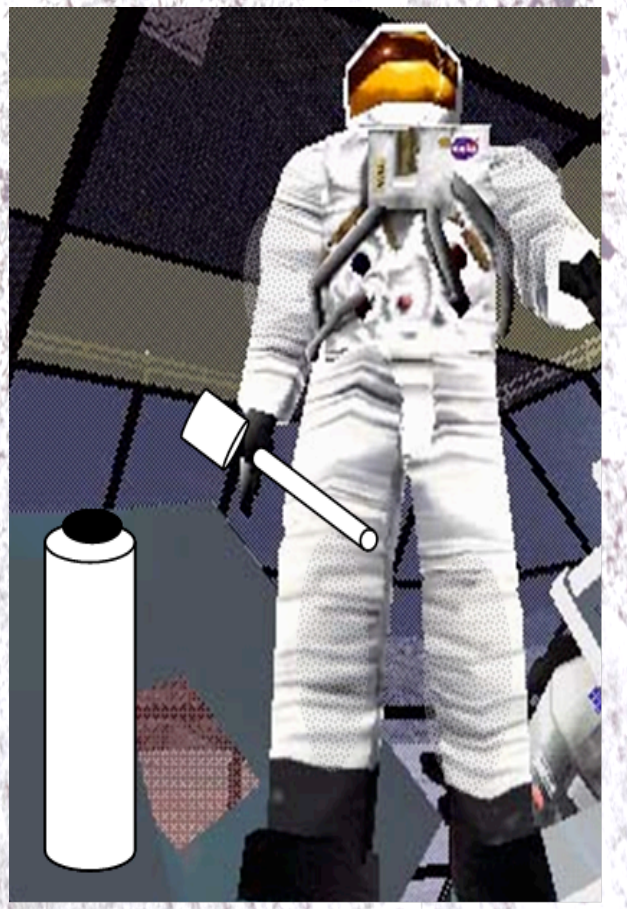
Conclusions and Future Work

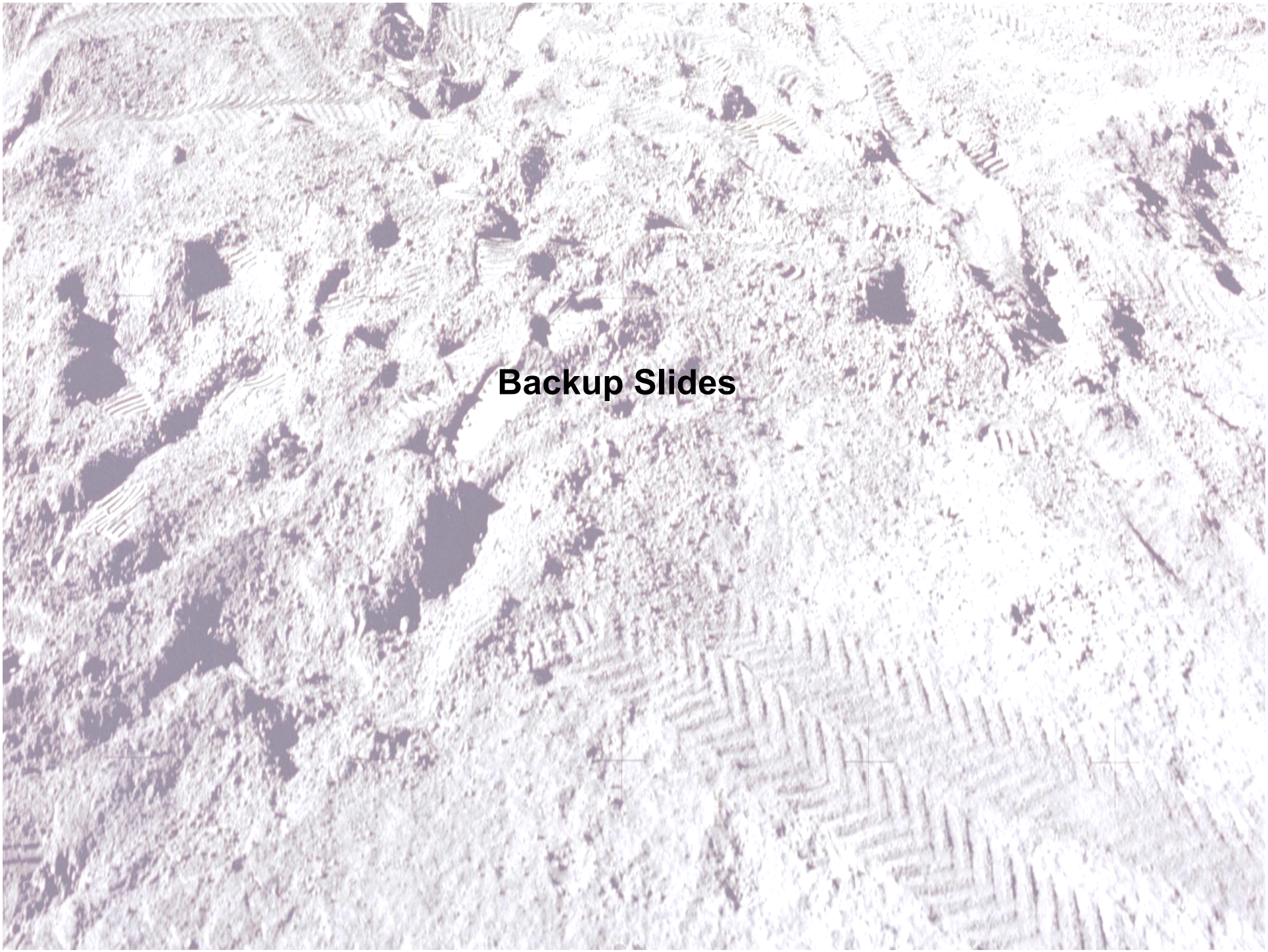
•Design of an effective dust mitigation system to support NASA's new initiative to return to the surface of the Moon must be a high priority, as observations reported here indicate.

•A number of strategies have been proposed. Successful ones must deal with both electrostatic and van der Waals 'sticking' effects. Some success has been achieved with electrostatically based strategies.

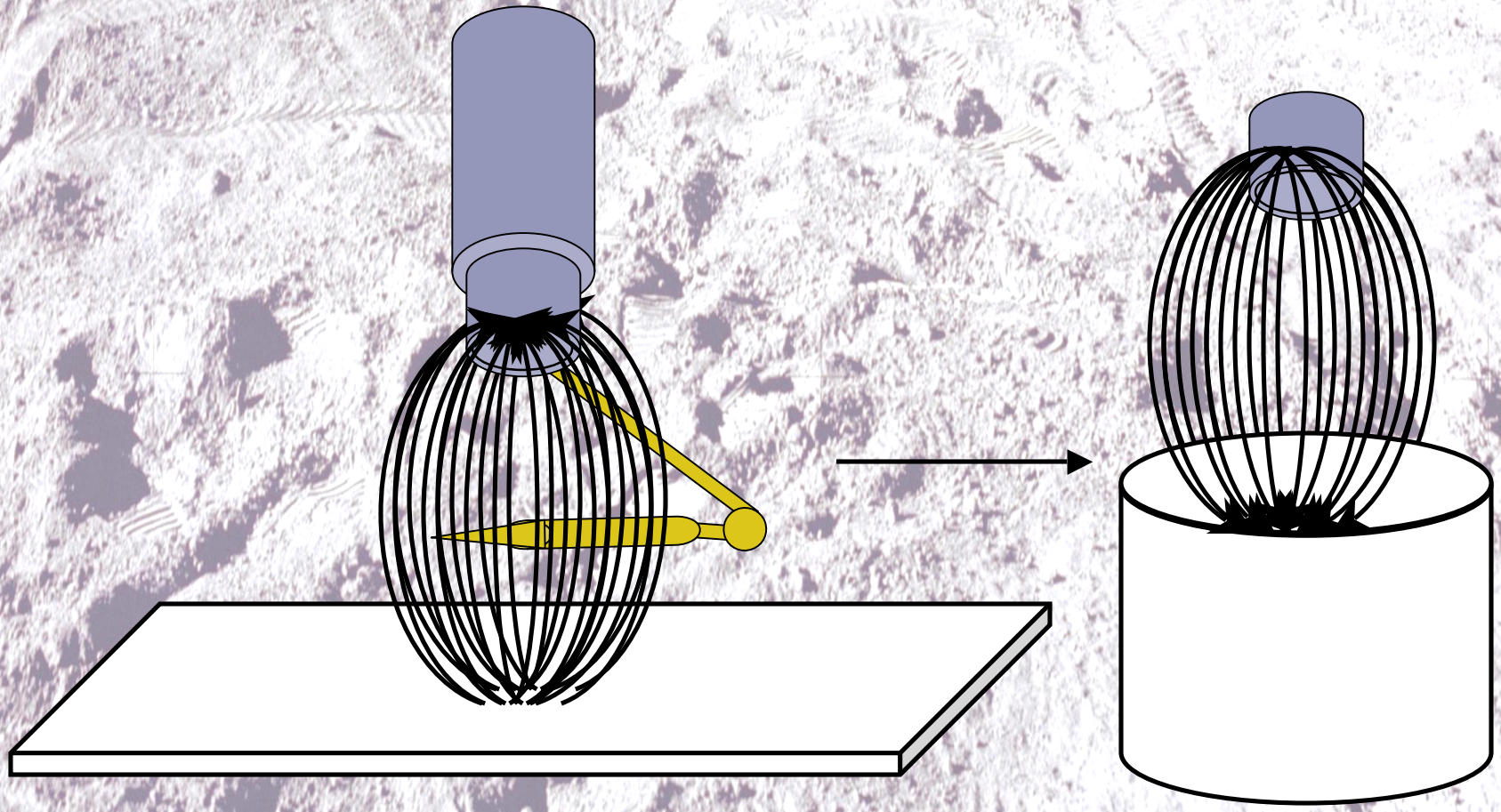
•SPARCLE concept was successfully demonstrated: an electron gun with a probe charged dust and the surfaces it is on in the presence of an electrical field, so that dust is repelled from same charged surface and attracted to relatively positively charged surface.

•Further experiments will be performed to determine optimal potential for collection surface, and the range of flux, field strength, and gas density over which this mechanism will operate, by varying electron gun voltage, electric field strength, wall potential, and vacuum settings over a range of dust grain sizes and compositions.





Backup Slides

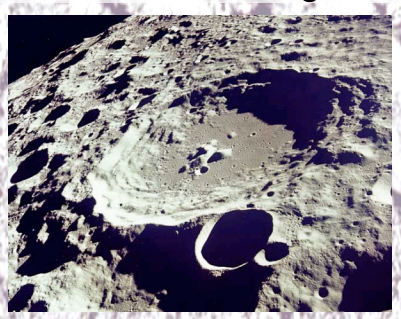
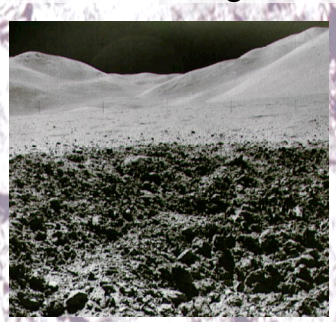
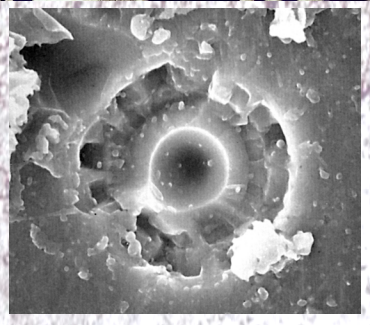
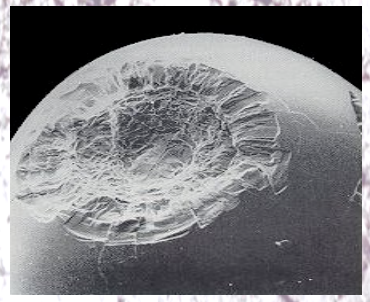
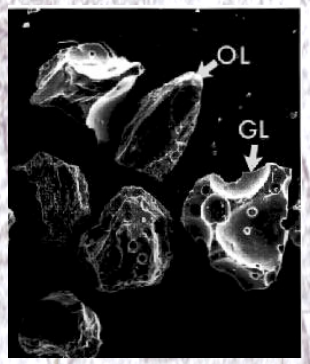


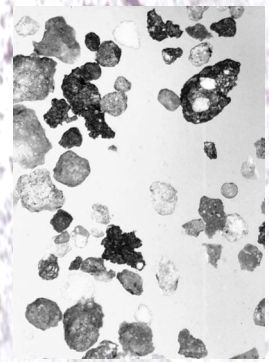
The SPARCLE development team is already partnered with the lunar habitat airlock design team at JSC who see tremendous potential for SPARCLE to provide lunar dust removal from any object in the airlock with minimal expenditure of resources. Our present concept involves using a cleaning wand with internal electron gun and probe in the presence of an electrical field to control dusty surface potential, repel and attract dust to an oppositely charged containment area. The process is reversed to repel dust from the containment area and attract it into a receptacle.

The Nature of Dust

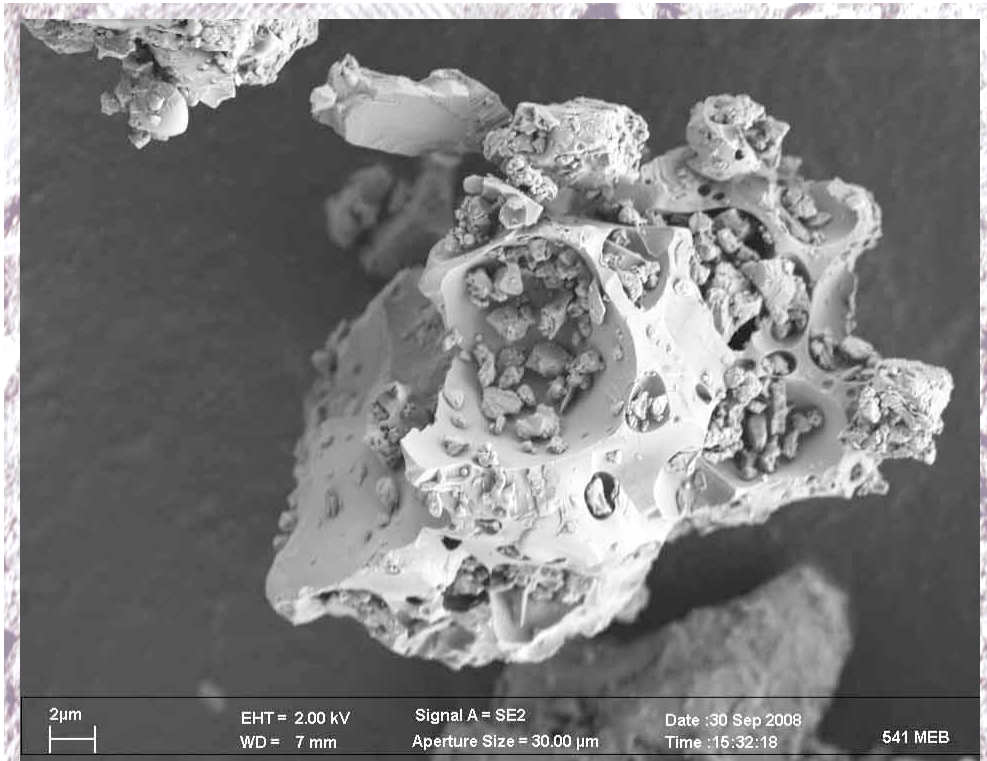
•The lunar regolith impact-generated soil-like layer above bedrock dominated by particles ranging in size from cm to submicron scales.
•Extensive remelting generates abrasive shard-like particles, highly irregular, angular, elongated (1:3 axis length ratio), high specific surface area (8X surface area as spheres with equivalent particle size distribution).
•Reentrant hook-like projections, anisotropic, porous, compressible, aligning along long axes.
•10-20% soil particles, called lunar fines, or dust, below 10 microns in size.
•Fines systematically less mafic, higher in silicic and felsic components (Walker and Papike, 1981; Devine et al, 1982; McKay et al, 1991).
•Metallic iron abundance and magnetic susceptibility increase with decreasing grain size in mare soils (Taylor et al, 2000).
•How much variation in magnetic susceptibility is present among lunar fines, including highland and mixed highland/mare soils.

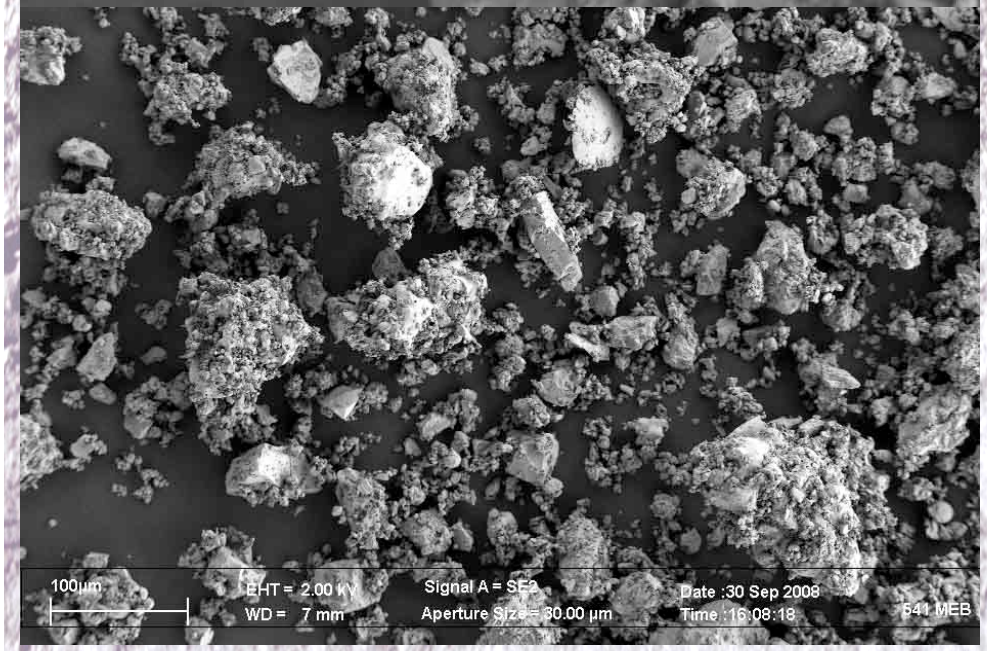
Impact bombardment of the Moon on scales ranging from megascale crater formation and rock debris field formation, to micrometeorite bombardment leading to modification of grains.

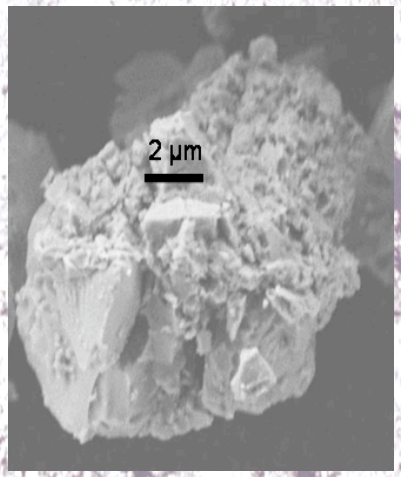








Bombardment generates lunar regolith properties illustrated by these photomicrographs, including high surface area/volume, irregular grains, and elongation along one axis.







SEM photo of grains comparing surface morphology of Lunar Dust and simulant (right) illustrating size distribution and clumping of smaller particles and the relatively complex surface morphology of lunar grains.