HIGH POROSITY CHAINED AGGREGATES FROM THE TOPSOIL OF THE LUNAR REGOLITH DUST

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Introduction

The surface of the moon is covered with a fine dust formed by numerous meteoroid impacts over the eons which have elapsed since the formation of the Moon. This type of soil, known as lunar regolith, is unknown on the Earth. The first accurate estimation of lunar grain size was published by Wesselink (1948), who based his calculations on cooling curves obtained from telescope observations of the Moon during a lunar eclipse. Wesselink calculated that the grains in lunar powder must be smaller than 0.3 mm. The return of samples from the Luna and Apollo missions has enabled actual measurements of regolith grain size to be made and have confirmed Wesselink's upper limit. Only 10 wt% of grains were found to be larger than 0.25 mm and most grains were smaller than 10 μm. In this paper the results are presented of a morphological examination on lunar soil samples collected by Luna 16. Luna 16, launched in September 1972, was the first robotic probe sent to the Moon and collected samples from a depth of 15-18 cm.

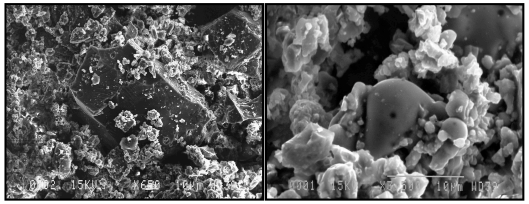
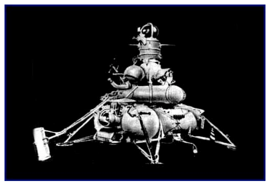


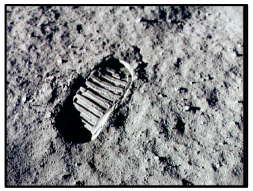
Figure 1. SEM micrographs of studied lunar soil morphology show (A)- larger grain 100 μm in diameter decorated by fine dust below 1 μm, (B)- fine dust particles show spherical and broken glassy splash and condensation features. (scale bars are 10 μm)

Technique

A transmission X-ray microscope (TXM) (with a resolution of 90 nm, maximum magnification of 2640 and beam energy 8 – 11 keV), and a scanning electron microscope (SEM) were used to produce images and 3D surface reconstructions of the substructure of lunar regolith



Luna 16 – first robotic sample return probe sent to the Moon.



Footprint of an Apollo 11 astronaut on the Moon – note the sharpness of the imprint due to the very small grain size of lunar dust.

Results

The SEM (figure 1) and TXM (figures 2 and 3) images show that lunar regolith has a highly porous substructure. Particles in the sample were between 120 nm and 1.8 μm in size with a median diameter of 480 nm. The particles appear to be aggregated into slabs about 500 nm thick separated from each other by 100 – 250 nm. The slabs are combined into larger particles separated from each other by about 4 μm. Figure 4 shows a simple model of lunar regolith based on the SEM and TXM measurements.

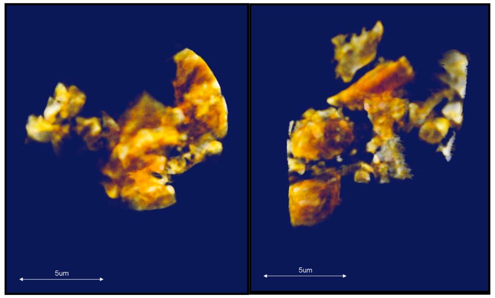


Figure 3. Space, 3D reconstruction of the lunar dust particle space arrangement. (A)-Cylinder facial cut. (B)- Cylinder vertical cut. Cylinder is 12.1 μm long and 10.2 μm in diameter, scale bar is 5 μm).

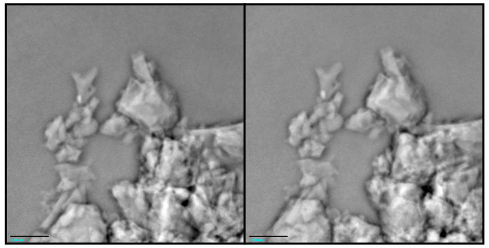


Figure 2. Stereo-pare images taken from 181 2D TXM micrograph (angular separation 15 degrees) showing long chained fine dust particles with a large void separating aggregates (scale bar 2.5 μm)

Reference: Wesselink, A. J. (1948) Heat conductivity and nature of lunar surface material. *Bulletin of the Astronomical Institutes of the Netherlands*, ***X*, *390*:** *351-363.*

Heat conduction model

The physical model of lunar regolith presented in figure 4 enables a basic model of heat conduction to be formulated. Heat can be removed from an object by three processes – convection, conduction and radiation. In the case of the lunar regolith there can be no convection as there is no fluid to convect. The 3D mages show that lunar regolith contains voids that are large compared to structural components, with only a small area of contact between particles. This suggests that radiation losses will dominate over conduction losses. An estimate of an effective thermal conduction (*k*), can be made by combining the Stefan-Boltzmann law and the heat conduction equation (the per unit area version) and solving the differential equation for *k*.

$$\frac{dQ}{dt} = \sigma T^4 = k\frac{dT}{ds} \Rightarrow k = \sigma \int \frac{T^4}{dT} ds = 4\sigma s T^3$$

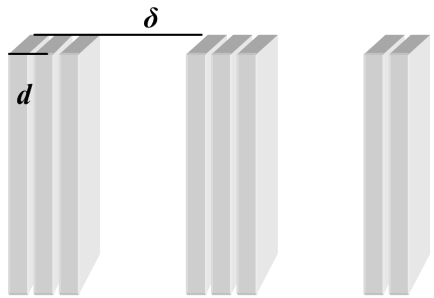


Figure 4. Simplified model of the lunar aggregated topsoil layers.; *d* is the thickness of one slab plus one space and δ is the basic module of lunar topsoil 6.25 μm in size.

Where *Q* is heat (J), *t* is time (s), σ is the Stefan-Boltzmann constant (5.75×10^{-8} W m^{-2} K^{-4}), *s* is the grain-space element from this model, 7.5×10^{-7} m (750 nm), *T* is the initial temperature at the start of cooling is 370.79 K (i.e. the temperature of the surface of the Moon just prior to the eclipse). These figures produce a conduction value of 8.67×10^{-6} W m^{-1} K^{-1}, which is a factor 373 less than that calculated by Wessel, who used a value of *s* of 2.8×10^{-4} m. Another key difference between the models is that Wessel assumed a porosity of 33% compared to 76% in this model.

Conclusion

The results presented in this study suggest that the effective thermal conductivity of lunar regolith is much lower than previously thought due to voids within the substructure. This characteristic of lunar soil increases its attractiveness as thermal insulation material for any future lunar bases.