1695: PLANETARY REGOLITH ANALOGS APPROPRIATE FOR LABORATORY MEASUREMENTS

Robert M. Nelson[1,2] rnelson@psi.edu, **J. L. Piatek**[3], **Mark D. Boryta**[2], **K. Vandervoort**[4], **Bruce W. Hapke**[5], **Ken Manatt**[6], **Adaeze Nebedum**[2], **Yu. Shkuratov**[7], **V. Psarev**[7], **Desiree Olivia Kroner**[8], **William D. Smythe**[6]
1. Planetary Science Institute, Pasadena CA; 2. Mount San Antonio College, Walnut CA; 3. Central Connecticut State University, New Briton CT; 4. California State Polytechnic University, Pomona; 5. University of Pittsburgh, Pittsburgh PA;
6. NASA/Jet Propulsion Laboratory, Pasadena CA; 7. Karazin University, Kharkiv, Ukraine; 8. University of California at Los Angeles, Los Angeles, CA;

Introduction

Understanding remote sensing data from airborne or space-based platforms requires that the remotely sensed information be compared to comparable measurements on candidate regolith materials done in a laboratory controlled environment. The reflectance measured remotely varies with changing angles of incidence and emission and also the phase angle (sun-object-detector angle) at the time of observation.

Such measurements have been made since the time of Galileo [1]. Four centuries have elapsed since Galileo first observed Saturn's rings with the telescope. His acute observational skills allowed him to pioneer fundamental remote sensing photometric techniques simply by watching the Moon rising over a sun illuminated wall in his garden. He noted the fully illuminated Moon appeared darker than the sunlit wall. He correctly inferred that the intrinsic reflectivity of the Moon's surface was lower than the intrinsic reflectivity of his wall. Having made this observation he is to be credited with the first reported albedo measurement of the surface of an extra terrestrial object [2].

In the modern laboratory bi-directional angular reflectance measurements of candidate regolith material are made using instruments such as goniometric photopolarimeters (GPP). An instrument of this type is generally classified as a 'polarization-sensitive well-collimated radiometer;' particulate samples used to simulate planetary regoliths are classified as 'discrete random media'[3].

Typical bi-directional reflectance results of such materials are reported in our companion paper at this meeting # 1686)

Background

There are many reputable laboratories around the world that conduct bi-directional reflectance measurements . Slight differences in samples prepared at various facilities can lead to uncertainty when comparing measurements between laboratories and when applying these measurements to spacecraft results. High albedo surfaces have often been simulated in the laboratory using MgO, $BaSO_4$, or powdered, compressed Polytetrafluoroethylene (aka Teflon, PFTE, or HALON). These materials, while easily available, are not well sorted into particle sizes that are larger than, comparable to, or less than the size of the incident light used in most GPP devices. Therefore, in 2000, we introduced powdered aluminum oxide Al_2O_3 as a material that might appropriate for simulating high albedo regoliths in the laboratory [4].

Powdered Al_2O_3 is widely used as an optical abrasive. It is available in particle sizes that are as small at 0.1 µm to several hundred microns from various commercial suppliers. We acquired these materials in a wide range of particle sizes from Micro Abrasives Corp of Westfield Mass, USA and the Stutz Company of Chicago IL, USA. The product identifications and approximate particle sizes are shown in Table 1. Both the GB and WCA designations were previously offered by Microabrasives Corp. These materials have since been measured at reputable GPP laboratories around the world [4- 7].

The Al_2O_3 particulates are supplied in two different particle shapes. The sizes larger than 2 µm (WCA) are described by the supplier as 'platelet shaped'; those smaller than 1.5 µm (GB) are described as 'equant'. These morphology differences should be apparent with analysis of particle packing density and in photomicrographs.

Table 1. Manufacturer's Product Identification and approximate particle diameter

Product ID	Diam (µm)	Product ID	Diam (µm)
WCA 40	30.09	GB 1200	1.5
WCA 30	22.75	GB1500	1.2
WCA 20	12.14	GB2000	1
WCA 12	7.1	GB 2500	0.5
WCA 9	5.75	GB 3000	0.1
WCA 5	4		
WCA 3	3.2		
WCA 1	2.1		

Atomic Force Microscopy

In order to further address possible ambiguities regarding the morphology of these Al_2O_3 particulates one of us (KV) acquired Atomic Force Photomicrographic (AFM) images of the Al_2O_3 samples. The AFM images were obtained in air in intermittent contact mode using a Quesant Instruments Universal Scanning Probe Microscope housed in the Physics and Astronomy department at the California State Polytechnic University at Pomona, CA. Commercial silicon cantilevers from MikroMasch™ were employed. Images consisted of 500 lines of 500 points per line for a total of 250,000 pixels of data. The Al_2O_3 samples were deposited on glass slides, previously cleaned and coated with poly-l-lysine to assure surface adhesion of the particles to the glass. Typical results are shown in Figures 2 and 3.

Figure 1 is an AFM image of three typical particles that are identified by the supplier as D=~ 1.0 µm (GB 2000). The three particles also show a range of size about the mean particle size. It is clear that they are equant in character as described by the manufacturer. Figure 2 shows a particle of 22.75 µm diameter. It is obviously platlet shaped.

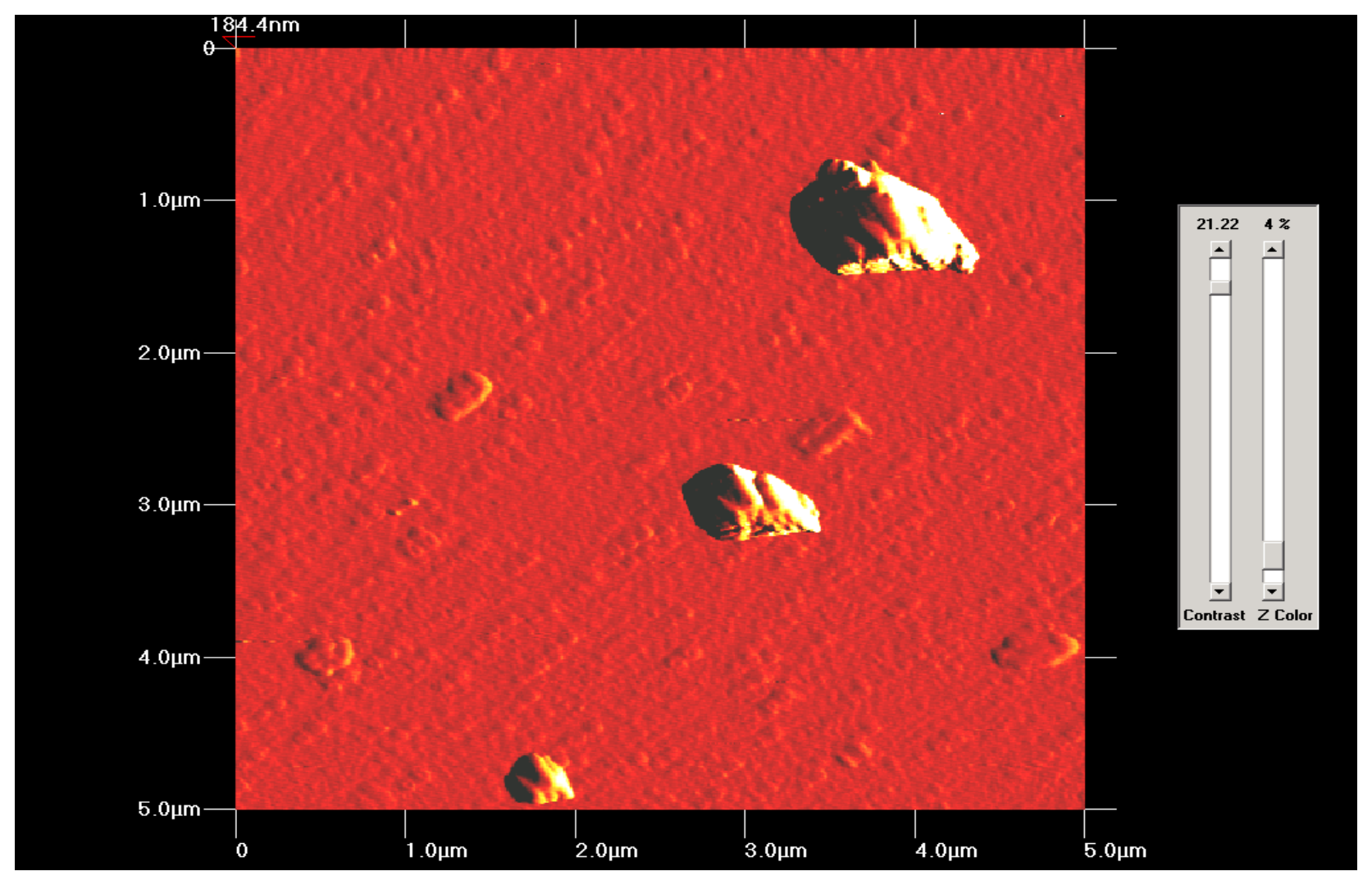

Fig. 1. Atomic Force Photomicrograph of typical Al_2O_3 particles of D=~ 1.0 µm (GB 2000). The particles are representative of the variation about the mean particle size

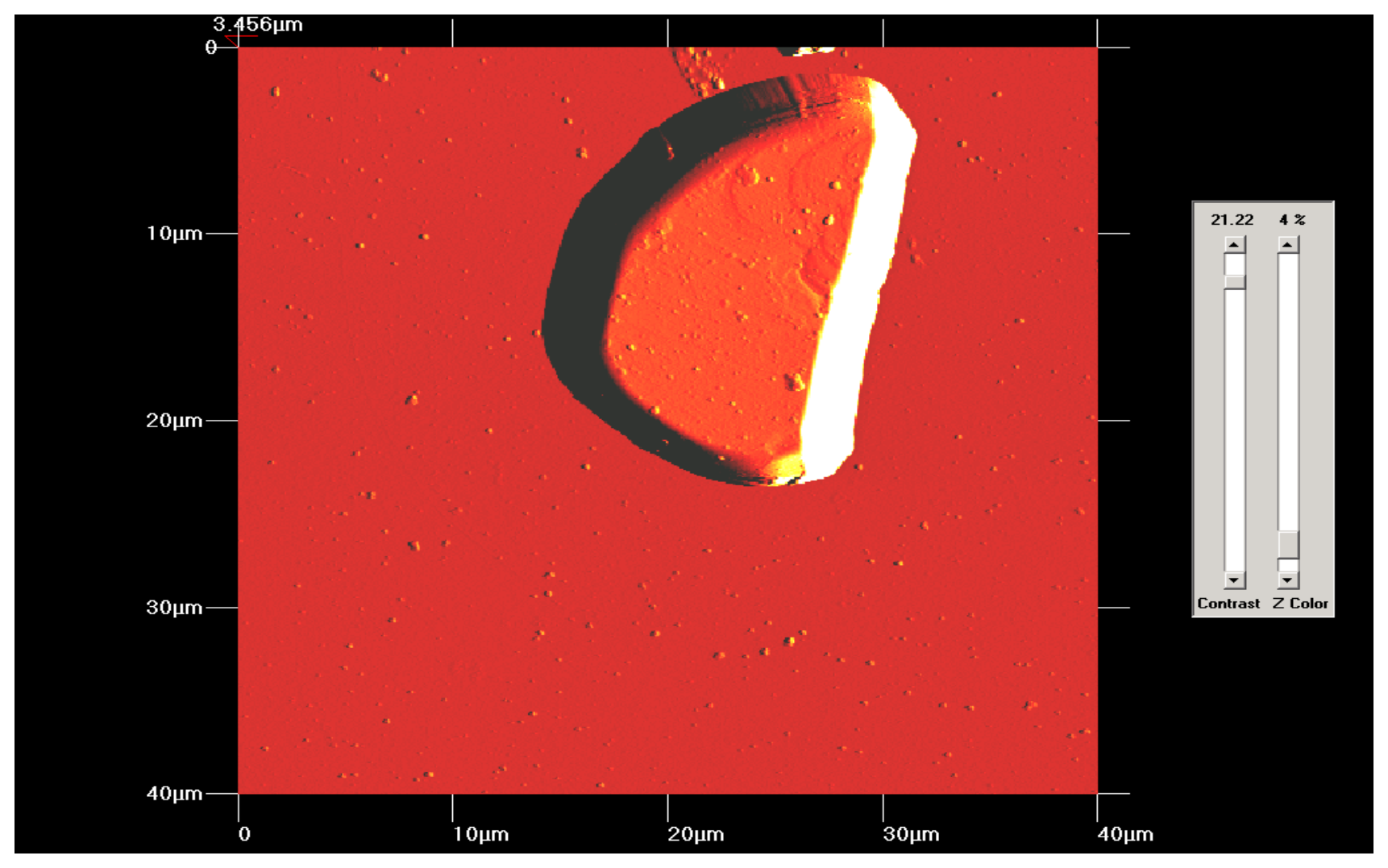

Fig. 2. Atomic Force Photomicrograph of a typical Al_2O_3 particle of D=~ 22.75 µm. The platlet shape is clearly evident.

Particle Packing Density

We studied 13 separate particle sizes 0.1 <d <30 1.5 µm. Five of these were 1.5 µm or smaller. The samples were poured into sample cups of known height and gently shaken to flatten the surface. This permits settling so as the surface might best replicate a powdered surface of a planetary regolith as viewed by a remote observer. The mass of the material was measured. The void space was calculated based on the density of Al_2O_3.

The results, shown in Fig. 3, are consistent with the manufacturer's description. The particle sizes <~1.5 µm (shown as 'Equant' in Figure 1 and designated GB) pack together with much larger void space than the particles of size >~2.1 µm (Shown as 'Platelet' in Figure 2 and designated WCA). This is consistent with the statements of the manufacturer as reported in [4].

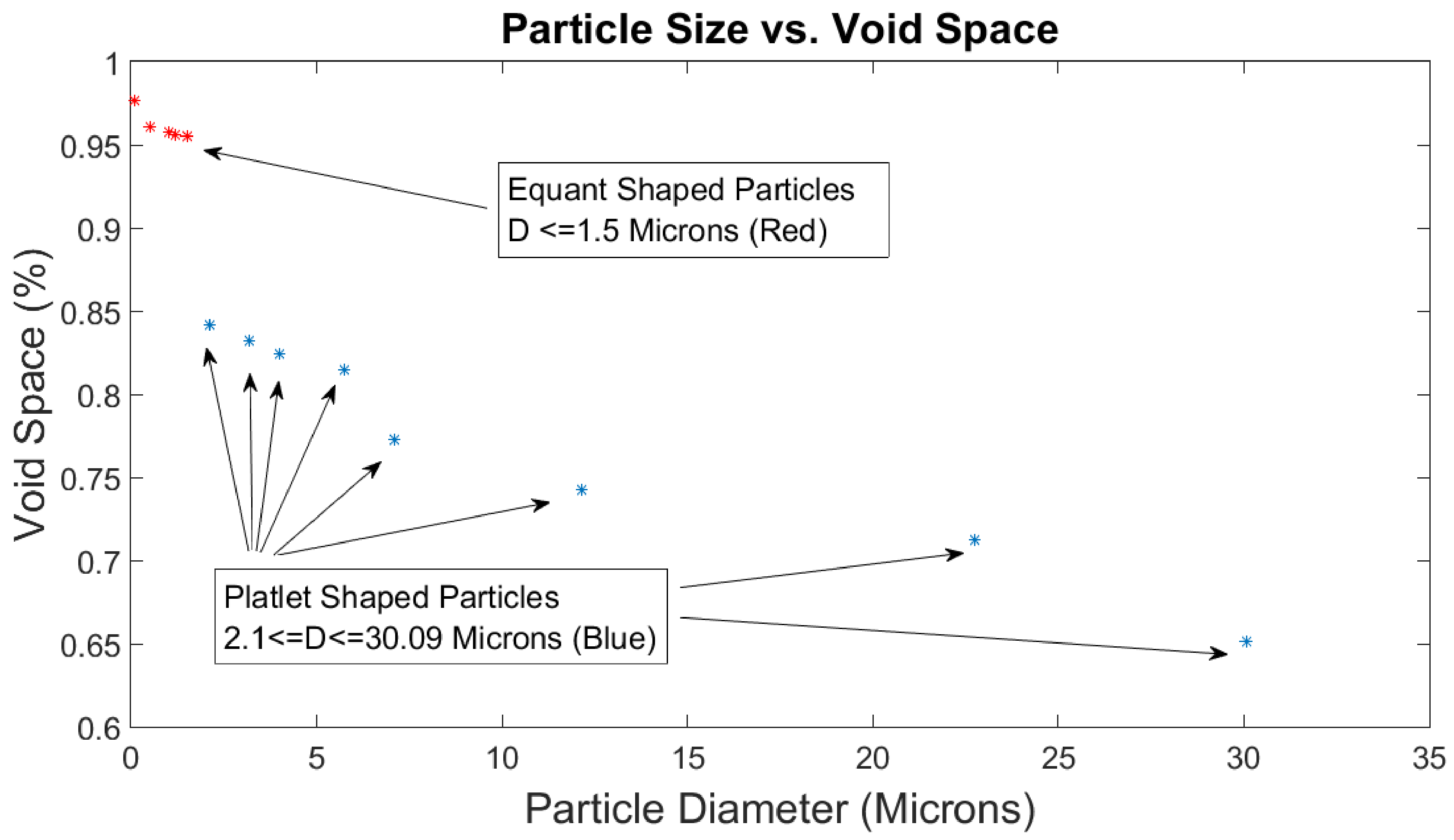

Fig. 3. Particle Size vs. void space for 13 Al_2O_3 powder samples. The platelet-shaped particles exhibit greater packing efficiency. The equant particles produce greater void space. These void space results are consistent with those in previous studies [4,5,7].

Conclusion

This work clarifies any ambiguity that may have arisen regarding the morphology of these Al_2O_3 materials that have been used widely since we first introduced them as high albedo particulate planetary surface analogues [4]. We encourage other laboratory investigators to acquire these materials and measure them for the purpose of inter-comparison of data sets acquired by various instruments around the world. In a companion paper (Nelson et al this meeting) we use these materials to infer important properties of the regolith of Jupiter's satellite Europa.

References

[1] Galilei, G., 1632. Page 92, Figure 7 and onward. Dialogue Concerning the Two Chief World Systems. Stillman Drake translation, 1981. Modern Library Paperback Edition, 2001. Random House, New York. [2] Hapke, B. W. Theory of Reflectance and Emitence Spectroscopy, p 1. Cambridge University Press ISBN 978-0-521-88349-8 2012, [3] Mishchenko, M. page 13, in Polarimetry of Stars and Planetary Systems, Kolokolova, Hough and Levasseur-Regour eds. Cambridge Univ. Press, 2015 ISBN 978-1-107-04390-9. [4] Nelson, R. M. et al, Icarus **147**, 545, 2000. [5] Shkuratov, Yu et al. Icarus, 159, 396, 2002, [6] Kaasalainen, S. Astron and Astrophys., 409, 765, 2003. [7] Piatek et al., Icarus, 171, 531, 2004.

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