GRAIN SIZE DISTRIBUTION AS AN INDICATOR OF THE MATURITY OF LUNAR SOILS. David S. McKay, Ruth M. Fruland and Grant H. Heiken, NASA Johnson Space Center, Houston, TX 77058.

Size Parameters. Size parameters of 42 Apollo 17 soils are presented in Fig. 1, which includes combined coarse fine and submillimeter data. As previously shown (1,2) this plot serves to separate the samples along a somewhat linear trend in which the coarsest samples are the most poorly sorted and the finest samples are the best sorted.

Soil Maturity. It has been shown that well reworked or mature soils have high agglutinate contents, high track ages, high rare gas contents, and are finer grained and usually better sorted compared to immature soils (1,3). Consequently, we have divided the samples in Fig. 1 into fields representing the state of maturity of the samples; soils coarser than about 120 μm are classified as immature, soils from 80-120 μm are submature, and soils finer than 80 μm are mature. The average agglutinate content of each of the three major groups as determined by petrographic analysis of the 90-150 μm fraction is also shown in Fig. 1. As expected, the immature soils contain the fewest agglutinates and the mature soils contain the most. Sample 79221,1 was not included in the averages because it is anomalous in that it contains relatively high agglutinates but possesses immature size characteristics; it is discussed below. In most cases, the maturity state of the samples can be understood in terms of the specific sample locality. For example, immature soils 71041 and 71061 were collected from the blocky rim of a fresh appearing 10 M crater. 75081 was collected from near the rim of Camelot and its submaturity may reflect an intermediate age for Camelot. The most mature samples were collected from undisturbed areas away from blocky craters. The orange and black glass form a separate class and cannot be considered normal soils. They are very immature having low track ages and low agglutinate contents, but are the best sorted and among the finest grained of any lunar material. It has previously been proposed that these samples may represent pyroclastic ejecta (4,5,6).

Size Histograms. Fig. 2 shows size histograms derived from the cumulative curves for a typical sample in each field of Fig. 1. Fig. 2A is an immature soil (71061) having a pronounced bimodal distribution with a coarse mode (peak of the histogram) at 8 mm or larger and a fine mode between 31 and 62 μm. The other bimodal samples having a similar coarse mode include 71041, 75061, and 79221. The remainder of the immature samples display a broad relatively flat histogram with a single major mode, mostly between 31 and 62 μm. Compared to immature samples, submature samples (Fig. 2B) have much less material in the coarse size ranges above 250 μm. The major mode of most of these samples is between 31 and 62 μm but in some it is between 16 and 31 μm. The histogram (Fig. 2C) of a typical mature sample (72141) is characterized by a steeply rising peak, and a well defined mode between 16 and 31 μm. All submature and mature soils are negatively skewed and contain a deficiency of material in the fine tail compared to the coarse tail of the histogram. Fig. 2D is the orange glass 74220; size characteristics of the black glass 74001 are nearly identical.

Histogram Shapes and Soil Evolution Paths. The grain size distribution of lunar soils results from a series of complex interactions in the regolith

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but it may be possible to understand size distribution in terms of simplified models or soil evolution paths. In path 1, reworking dominates mixing. An initial grain size distribution is created by a single impact into hard rock. This grain size distribution has been determined experimentally for small impacts in basalt (7) and in granite (8) and is illustrated in Fig. 2E. The size distribution of some of the suevite ejecta from the Ries (9) somewhat resembles this distribution (Fig. 2F) as does the soil from the rim of Cone Crater (Fig. 2G). If such fresh ejecta is now subjected to reworking and comminution by small meteorites, the coarse material will be broken up, additional fine material will be produced, and, after passing through intermediate stages (immature, submature), an eventual size distribution looking something like Fig. 2H might be produced. This distribution resembles that calculated by the Shoemaker "bucket model" for the Apollo 11 site and based on prolonged comminution of bedrock and regolith by meteorites. If nearly all of the material less than 16 μm in Fig. 2H were converted to agglutinates which were then distributed among the size fractions where they are normally most abundant (500-16 μm), the calculated distribution could be made to resemble rather closely the actual size distribution of a mature soil (Fig. 2C) and the agglutinate contents of these size fractions would be on the order of 50% which is about the agglutinate content actually present in these size ranges in a mature soil. At any stage along this evolution path, all of the size fractions have had a common history and a common degree of maturity. This first soil evolution path, dominated by reworking, can be contrasted to a second soil evolution path in which physical mixing of different soils dominates reworking. In evolution path 2, a mature soil can be physically mixed by impact with an immature soil or with fresh ejecta. If for example a soil were formed by mixing half 14141 (Fig. 2B) and half 72141 (Fig. 2C), the resultant size distribution would be very similar to an immature soil (Fig. 2A), but the soil would differ from an immature path 1 soil in that different size fractions have had different histories and represent different degrees of maturity. In the example, the finest size fractions are completely dominated by 72141 and are mature whereas the coarser size fractions are dominated by 14141 and are immature. It then becomes necessary to consider the bulk maturity and the maturity of each size fraction separately and the sample can be considered to have a fractional maturity. In principal it should be possible to tell soils which have followed evolution path 1 from those which followed path 2 by detailed analyses of each size fraction. Possible examples of path 1 may be the North Ray Crater soils at the Apollo 16 site. A possible example of a path 2 soil may be 79221, the anomalous soil noted above. In this soil, the coarser size fractions may be dominated by Van Serg ejecta whereas the finer fractions may be dominated by a more mature pre-existing soil having a high agglutinate content. Apollo 16 South Ray soils may also represent path 2 evolution in which a pre-existing mature soil has had some slight contribution, primarily in the coarsest size fractions, by South Ray ejecta (10). It is of course possible for a soil to jump back and forth from one evolutionary path to the other. In summary, soil may follow different evolutionary paths, may show fractional maturity, and may require detailed analyses of size fractions to completely characterize maturity.

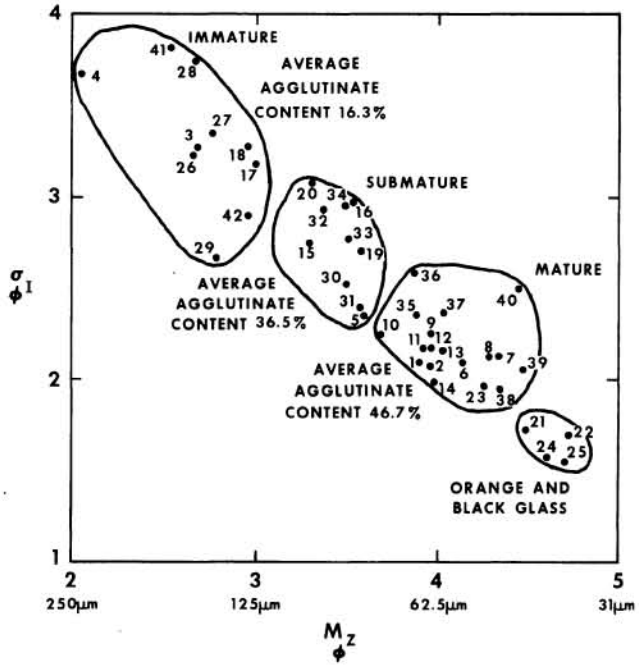

Figure 1. Graphic mean grain size (Mz) vrs. graphic standard deviation (σ_I).

The numbers on the graph correspond to the following samples:

1. 70161,1	12. 72501,29	23. 74121,12	34. 76281,6
2. 70181,1	13. 72701,29	24. 74220,6	35. 76321,10c
3. 71041,1	14. 73121,10	25. 74220,82	36. 76501,1
4. 71061,1	15. 73141,4	26. 74240,6	37. 77531,1
5. 71501,1	16. 74121,12	27. 74241,61	38. 78221,8B
6. 72141,1	17. 73221,1	28. 74260,5	39. 78421,1
7. 72141,15	18. 73241,9	29. 75061,2	40. 78501,1
8. 72321,7	19. 73261,1	30. 75081,1	41. 79221,1
9. 72441,7	20. 73281,1	31. 75081,36	42. 79261,1
10. 72461,5	21. 74001,2	32. 76241,24	
11. 72501,1	22. 74001,10	33. 76261,26	

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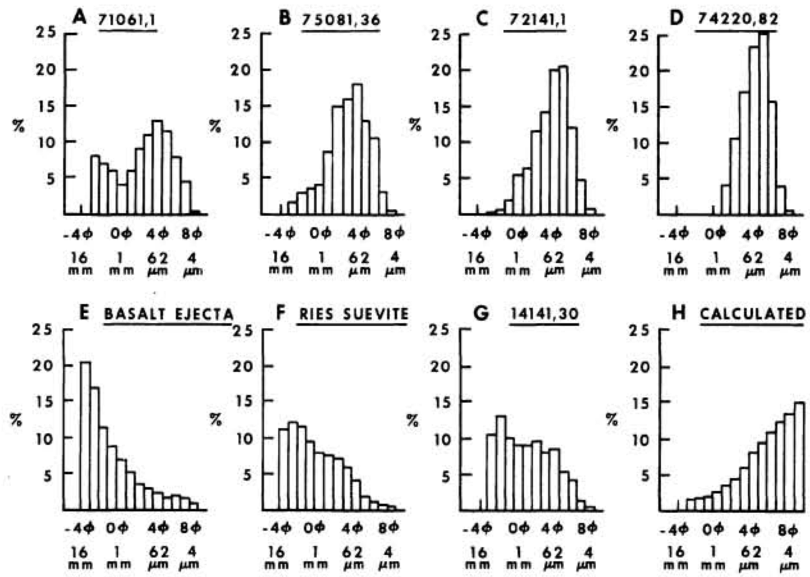

Figure 2. Grain size histograms: A. Typical immature soil; B. Typical submature soil; C. Typical mature soil; D. Orange glass; E. Single impact into basalt from ref. 7; F. Wornitzostheim suevite from Fig. 6 in ref. 9, part of coarse tail not included; G. Sample 14141; H. Possible distribution from prolonged comminution of E, redrawn from Fig. 11, ref. 10.