A SURVEY OF COMPOSITIONS OF CLEAR GLASS PARTICLES IN APOLLO 16 SOILS, AND THE SOURCE OF CLEAR GLASSES IN THE LUNAR REGOLITH. Hartley R. Rogers, Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, and Department of Geological Sciences, Harvard University, 24 Oxford Street, Cambridge MA 02138.

Following the example of the Apollo Soil Survey and similar early investigations (1,2,3,4), I have analyzed ~100 clear glass particles in each of three <1 mm soil samples from the Apollo 16 mission. Abundances of the oxides of Na, Mg, Al, Si, P, K, Ca, Ti, Cr, Mn, and Fe were determined by electron microprobe analysis. 69941,127 is from a scoop sample taken at station 9 on the Cayley Plains mapping unit. 68841,127 is from a reference soil sample taken at station 8, which is less than 500 m from station 9, and is photogeologically interpreted as being on the ejecta blanket of South Ray Crater. 63501,133 is the fines fraction from a rake sample taken at station 13, close to North Ray Crater and probably on its ejecta blanket (5,6). Glasses from two more samples, taken at station 4 in the Descartes Mountains mapping unit, will be analyzed by the time of the 12th LPSC. 64421,116 is from a trench sample and 64801,107 is from a rake sample. Similar studies by Ridley et al. (3) of glasses from station 1 and 10/ALSEP soils are available for comparison.

In considering the results, comparisons were made with ~1000 glass analyses in the literature, the data of Ridley et al. (3), and data from studies of rock compositions (7,8,9). Seven clusters can be defined in the results (Figs. 1,2,3), all of which correlate well with literature glass clusters for the site (Fig. 4) and previously defined clusters of rock compositions. Six first-order observations can be made.

1) There are no remarkable differences in compositional clustering of glasses among the three samples studied, except possibly for a scarcity of Fra Mauro basalt compositions in 63501,133.

2) The compositional clustering in the glasses studied is very similar to that found by Ridley et al. (3, not shown) in ~300 glasses from two other Apollo 16 stations.

3) Compositions of agglutinate particles studied (not shown) cluster tightly around soil compositions for the site, while compositions of the clear glasses are much more diverse (Figs. 1-4 vs. Fig. 5). This is consistent with a local origin for agglutinates, but a more widespread source region for the clear glass particles.

4) Clear glasses are also much more diverse compositionally than Apollo 16 rocks (not shown). Again this is consistent with a significant amount of non-local glass formation.

5) The whole body of Apollo 16 glass analyses (Fig. 4) includes a few with mare basalt compositions (10). These glasses are certainly not of local origin.

6) Mare glass compositions are more similar to soil than rock compositions (11), and the soil and glass compositions tend to lie on mixing lines between mare and highland rock compositions (Fig. 5). On the other hand, it is interesting to note that highland glass and soil compositions, which also correlate well with each other, are not similarly displaced towards mare rock

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compositions. A possible explanation for this non-reciprocity is that mixing of mare and highland compositions in mare soils is not due, as one would assume, solely to ballistic transport of debris from cratering events in the highlands to the maria, especially at sites remote from highland terrain (e.g. Apollo 12). Instead, fairly local impacts may punch through the shallow (12) basalt flows and excavate basement debris of highland composition. This is an effect that would not operate in the opposite way in the highlands.

The type of cratering activity that produced the clear glass particles studied by the Apollo Soil Survey, and others, has never been defined. It appears that clear glass particles must be created by a form or phase of cratering activity that is not large or energetic enough to engage major amounts of primary rock from beneath the regolith. Nonetheless, this impact form or phase must be energetic enough to (a) cause soil melting and homogenization more thorough than that seen in agglutinates and (b) project the droplets great distances [much farther than the scale of A16 EVA's (a few km), and in some cases farther than the distance to the nearest mare (hundreds of km)].

Three possible phases of cratering activity and scales of target involvement can be considered for the impact production of glass particles: melt-jetting at the moment of projectile/target contact; melt-vapor ejection during the early phases (penetration and cavitation) of the cratering process; and melt ejection during the excavation stage of the cratering process.

Jetting, as described by Kieffer (13), is a phenomenon whereby melt is sprayed away from the plane of initial contact of projectile and target. Jetting can occur during impacts at $\geq$4 km/sec, a value well below most lunar impact velocities. A possible objection to this mechanism is that it seems it would generate liquids containing roughly equal proportions of projectile and target material. If so, all jet-produced glasses should contain $\geq$0.5% NiO derived from the meteoritic projectiles. This is not the case. Clear glasses contain only $\sim$0.05-0.1% NiO (14) [comparable to the $\sim$0.01-0.05% NiO levels (15,16) in soil samples]. It is thought, however, that jet melting of a porous, compressible regolith target may be more efficient than that of a solid meteorite projectile (17). This could suppress the meteoritic component. However, if regolith compression plays a role, then it seems such low-angle jetting as occurs would be intercepted by local regolith that the jetting interface got pushed down into.

Melt-vapor ejection during the early stages of cratering (18,19,20) is a better documented process than melt-jetting. The penetration and cavitation stages [as defined by the modelling studies of O'Keefe and Ahrens (18)], during which melt and vapor are ejected at high angles, appear to be good candidates for producing clear glass particles. Again there is some uncertainty as to the degree of mixing of meteoritic and target components. Melted and vaporized material is ejected during the impact in amounts varying from 1.5 to over 315 times the volume of the meteoroid (18), so a significant proportion of meteoritic Ni in the ejecta is probably not to be expected. When considering regolith impacts, energy is not consumed by plastic deformation so more of it can go into vaporizing, melting, and ejecting regolith material (18). This could further reduce the meteoritic component.

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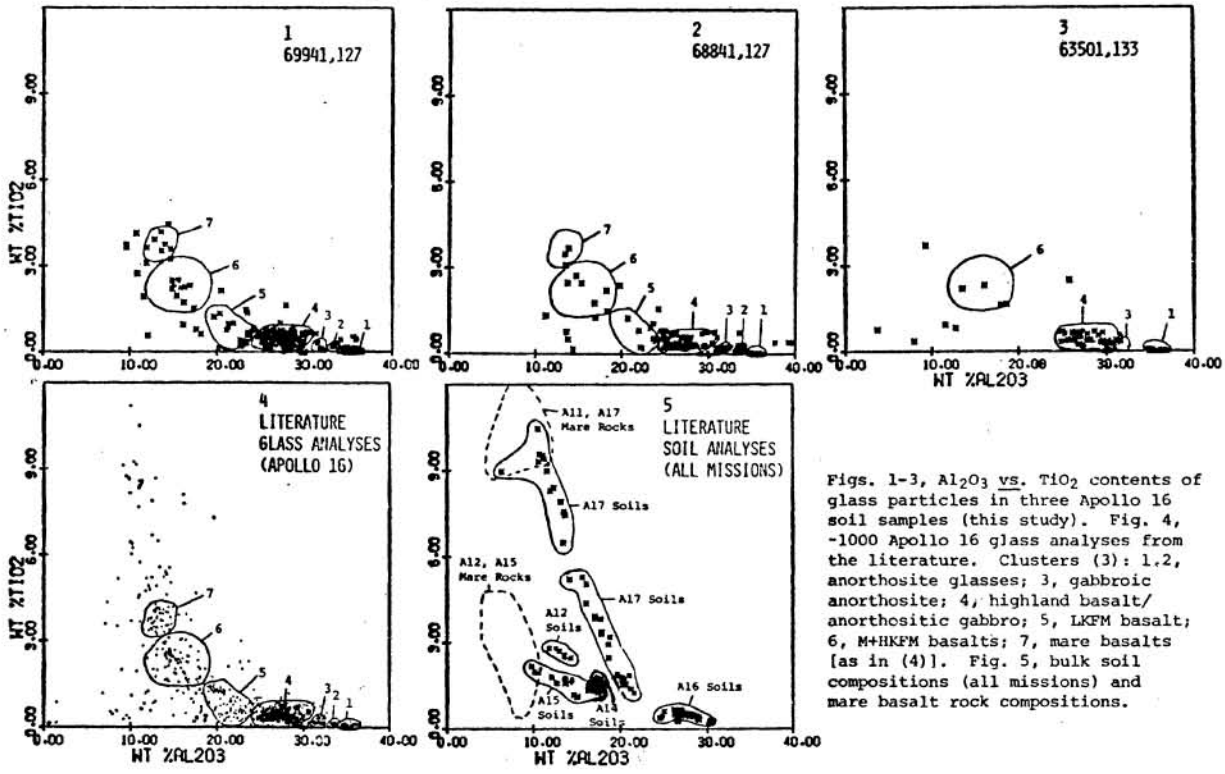
Finally, major amounts of melt are ejected during the excavation phase of large cratering events. The highland melt rock lithologies were formed in this way. Such an event must also be accompanied by a finer spray of droplets, which could chill to glass. The problem with this as a source of clear glass particles is that excavation occurs at a later, deeper stage than penetration/cavitation, and is therefore more likely to engage basement rock in the case of large impacts. The melt spray of such an event should reflect rock, not soil, compositions. In this connection, however, we should remember that not all glass compositions have been shown to be derived from soils rather than rocks, and one glass type, at least, is very unlikely to have been derived from a soil: the almost-pure anorthositic glasses that appear as cluster 1 in Figures 1-4. A mechanism such as ejection during the excavation of large amounts of melt rock may be needed to account for these.

In general, however, since glasses appear to be formed largely from soil and not rocks, phases and scales of cratering that engage mostly soil are likely to be the chief mechanism for glass particle production. The best candidates are (a) the penetration/cavitation stages of cratering in the range of impact sizes where basement rocks are not engaged by these processes, and (b) the excavation stage in a more limited range of impact sizes, again where basement rocks are not engaged. Since it is likely that anorthosite glasses formed from primary rock, larger impacts which operate below the regolith may be a source mechanism for these.



Figs. 1-3, Al_2O_3 vs. TiO_2 contents of glass particles in three Apollo 16 soil samples (this study). Fig. 4, ~1000 Apollo 16 glass analyses from the literature. Clusters (3): 1,2, anorthosite glasses; 3, gabbroic anorthosite; 4, highland basalt/anorthositic gabbro; 5, LKFM basalt; 6, M+HKFM basalts; 7, mare basalts [as in (4)]. Fig. 5, bulk soil compositions (all missions) and mare basalt rock compositions.

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