Interferometric Examination of Small Glassy Spherules and Related Objects in a 5-Gram Lunar Dust Sample

Abstract. *Over two hundred spherules and cylinders were extracted from the lunar dust sample. Sizes ranged from 0.75 to 0.03 millimeters, and most were shiny glassy objects, which were studied by interferometry. This study reveals very high specular reflection, frequent perfect sphericity, and clear evidence in some objects of microcracking and microchipping. Many spheres were once projectiles. Some have impacted in free flight with much smaller pieces of rocky material, which embedded in the surface. It is conjectured that the glassy spherules originated as a gas-blown shower from a pool of molten glass.*

This report is devoted to an examination of shapes and evidence for shock in glassy spherules in a presieved (1-mm sieve) lunar sample.

The sieved sample was sorted under the microscope. Over two hundred objects were found, some of which are shown in Fig. 1. They may be divided into the following groups: (i) specular, slightly transparent, red-brown glassy spherules (Fig. 1a), (ii) somewhat larger grayish spherules, which have a distinctly metallic luster but which are opaque, (iii) roughly spherical whitish nonglassy spherules, (iv) three faintly green and one deep blue, very clear, glassy sphere, (v) numerous specular, slightly transparent cylinders of red-brown glass (Fig. 1b).

The objects are so small that their total weight is little more than 0.01 percent of the whole sample, yet, if the sample is representative, this number, extracted from a mere 5 g, implies no less than 40,000 such objects per kilogram of moon dust!

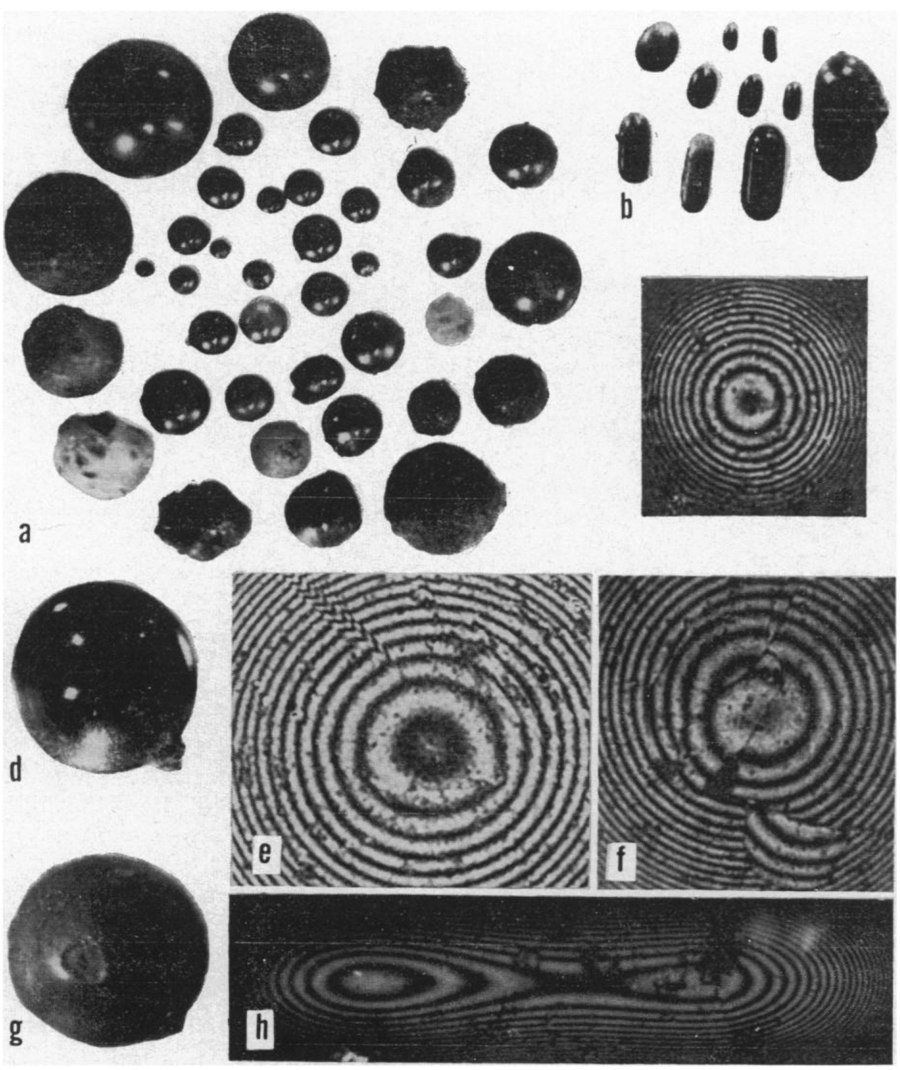

Fig. 1. Photomicrographs of objects found in a sieved sample of lunar dust. (a) Spherules; (b) cylinders; (c) typical fringe pattern in spherical shiny, glassy objects; (d) typical tail-like attachment on a spherule; (e) microcracks in a broken spherical object; (f) microchips in a broken spherical object; (g) a sphere with a small foreign object embedded in its surface; (h) fringe pattern in a typical cylinder.

The specular objects were studied by interferometry, using magnifications up to × 700 with a 4-mm microscope objective (λ 5460). All the numerous spherical shiny, glassy objects give good interference fringe patterns and, over most of their whole surfaces, show very regular "Newton's rings." The good fringe visibility and the circular perfection show that the surfaces are nearly spherical and are also highly specular, with refractive indices exceeding 1.6. A typical circular fringe pattern from a small spherule is shown in Fig. 1c. So nearly spherical are many of the objects that they must have been formed free from restraints, perhaps blown from a melt as fine droplets or perhaps as a spray of molten glass; thus they were able to solidify in free flight under influence of surface tension forces.

A number of the spherules, mainly of the gray metallic-luster type, have a tail-like attachment that is able to resist scraping action (Fig. 1d). The material in the tail is sintered gray dust particles. Its appearance strongly suggests that tails have been formed by impacting sintering action, as if the spherule had landed as a projectile. Except for the tail region, such particles are spherical. A few objects have several tails and give an impression of having rolled, while hot, in moon dust.

Many of the spheres have clearly been shocked. Some originally spherical objects have pieces broken off, and some show the existence of microcracks (Fig. 1e) or microchips (Fig. 1f). Several have on their surfaces collision impact craters. Tails are also evidence of violent impact.

A number of the larger spheres have been struck violently by much smaller rocky pieces of matter (Fig. 1g). In each case a small foreign object is embedded in the surface. Usually it has chipped away a circular fragment of the spherule. In several cases the incoming object has raised a circular crater. Most of the foreign embedded objects are reddish brown, but they look crystalline and give the impression of coming from the same parent material. The impact craters are found mainly on the grayish spherules with a metallic luster but are occasionally found on the red-brown glassy spherules.

The interferograms also show that

there are numerous, and even smaller, depressions. It is evident that crater formation and tail production are due to two quite separate impact mechanisms. The crater appears due to impact in flight with a particle, the tail to impact from landing on the dust-covered lunar surface.

A number of red-brown specular cylinders were found, some more transparent than others but all with hemispherical ends. From fringe patterns (Fig. 1h), it is safe to conjecture that the cylindrical object in its initial molten state was part of a breakup of a thin jet and was subdividing into two droplets but solidified before it divided. One long cylinder gives a fringe pattern that indicates onset of breakup into three droplets.

A number of the grayish metallic-like spherules exhibit vacuole regions within their otherwise solid interiors, and in each case this region has created a small opening in the surface. The interiors of the vacuoles are highly specular and spherical in shape. It is likely that small gaseous or liquid inclusions have in each case caused a blowout. One sample has a 0.5-cm radius of curvature.

The spherules bear no resemblance to tektites. However, this study was restricted to a fine mesh sample, and a comparison is not valid.

Two possible sources of origin for the lunar spherules may be considered. (i) If large lunar craters are due to meteoric impact, such impact could partly remelt the rock struck and could scatter droplets over a wide area. Such a mechanism should produce many small spheres and, also, many larger spheres, perhaps of the size of tektites (australites). (ii) Let us postulate that the inner floors of some large craters have at one time experienced volcanic reheating to create in effect a large pool of molten material. Further, let us suppose that this volcanic reheating is followed by violent (either explosive or prolonged) gas blowout from below. Remembering the low gravity, such a hot gas blowout could create an enormous fountain of fine molten droplets. It would also produce filaments of fine jets or threads, which would break up into cylinders. Furthermore, this same explosive mechanism could simultaneously create considerable neighboring microshatter and throw up a dense cloud of microparticles from the surrounding solid regions through which the glassy spherules could pass. These conditions would favor the production of microimpacts. Of course, a massive meteoric impact could also produce minute droplets, as well as a cloud of solid particles. If extralunar micrometeorites created the microcraters on the spherules, then a high concentration will need to be postulated for collision to occur in free flight. It might be argued that the glassy spherules were at some time in orbit around the moon for periods long enough to create the probability of collision of a tiny object by other micrometeorites. It is not known why the impacted particles resemble in color and appearance the kind of material from which so many spherules appear to have originated. At present, both meteoric impact or volcanic blowout appear to be equally plausible as causes of origin.

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Surface Properties of Lunar Samples

Abstract. *Fine-grained samples disrupted after exposure to oxygen and oxygen with 3.5 percent water above 2 torr. Chemical etching revealed plastic deformation in some samples, adhesion due to impact melting in others, dislocations in crystalline phases and evidence that some glasses were partially devitrified. Specimens of rock that were fractured in ultrahigh vacuum exhibited a time-dependent adhesion and a network of localized electrostatically charged areas.*

We studied processes of agglomeration and disruption of lunar material in order to determine those processes primarily responsible for the present state of the lunar environment. We investigated the effects of long exposure of surfaces of lunar material to the lunar environment. The approach used was (i) to study the chemical effects of exposure of nearly pristine lunar material to gases, (ii) to etch mounted and polished specimens chemically to study the defect structure and microchemical composition distribution at particle interfaces, and (iii) to measure adhesion forces in ultrahigh vacuum (UHV) between fractured and cleaved rocks (or both), studying electrostatic phenomena which could give long-range or short-range adhesional effects.

Exposure of lunar material to gases should start with material kept as close to lunar conditions as possible. Unfortunately, the best specimen type, the UHV sample, was not returned on Apollo 11. An attempt was thus made to use the high vacuum sample, but this could not be done because there was a leak in the contingency shipping container vacuum seal (that from

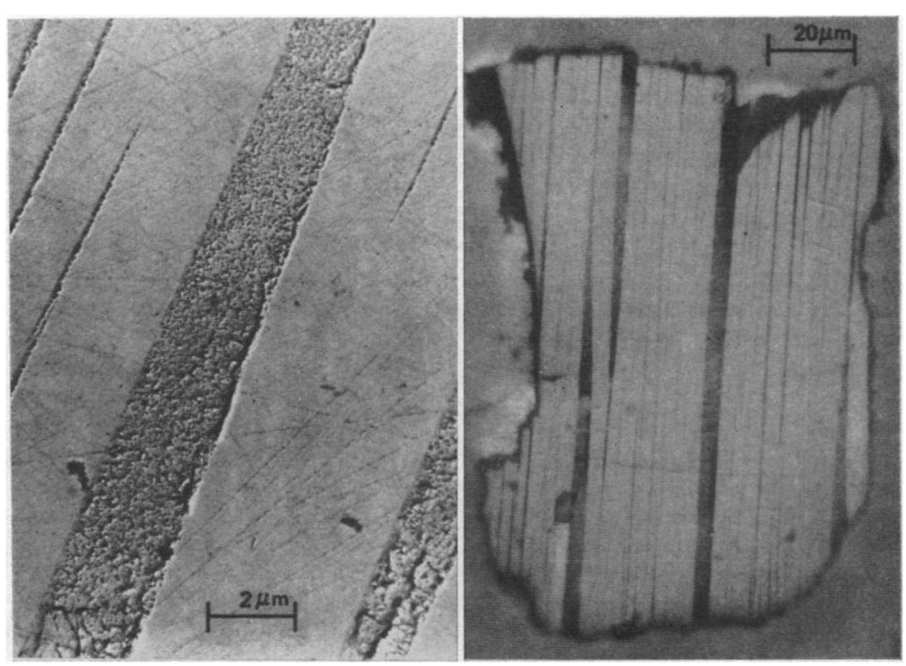

Fig. 1. A pyroxene grain from powder sample 10084,93. The particle composition is: SiO_2, 53.5 percent; MgO, 18.9 percent; FeO, 27.9 percent; CaO, 2.2 percent (hypersthene).