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

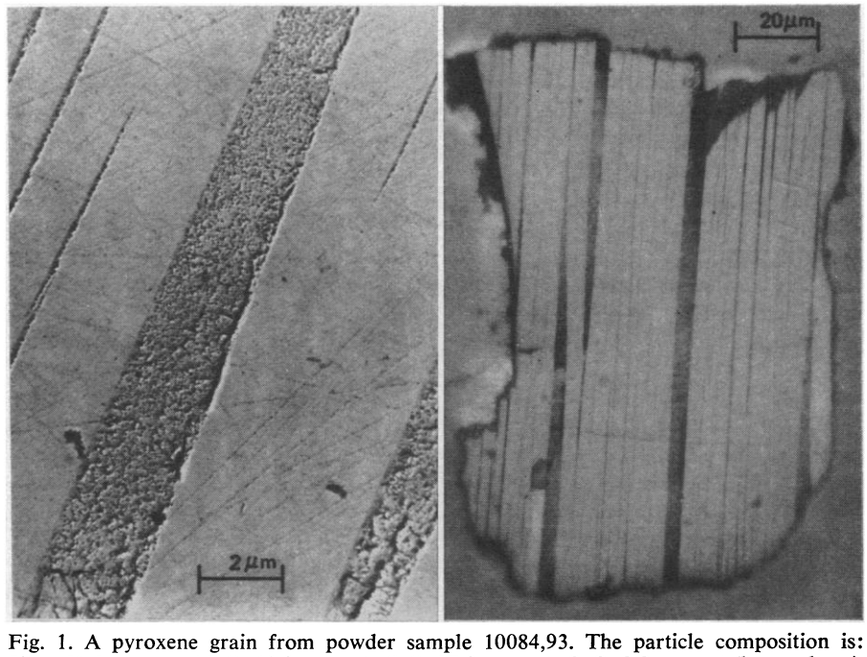

Fig. 1. A pyroxene grain from powder sample 10084,93. The particle composition is: SiO_2, 53.5 percent; MgO, 18.9 percent; FeO, 27.9 percent; CaO, 2.2 percent (hypersthene).

chamber F-201). Accordingly, a sample of 10084,93 fine powder maintained in N_2 was finally used. It was transferred to a UHV micromanipulator chamber and then treated as if it were a UHV sample. Small samples were transferred to optically flat walled reaction tubes, sealed, and finally attached to a specially designed vacuum manifold for preparation and metering of gases at controlled pressures from 10^{-10} torr to greater than 1000 torr, and at controlled temperatures from 20° to 400°C. To date, particles and bonded particle pairs have been exposed to O_2 and O_2(3.5 percent H_2O) at 2, 500, and 760 torr, and at 27°C and 200°C.

Disruption was definitely observed in three cases. On two occasions, translucent crystals attached to large opaque particles broke off, the first when exposed to O_2, and the second to O_2(3.5 percent H_2O). In the third case, a small section of a large particle broke off when exposed to the same O_2-H_2O mixture but exposed for about 7 hours. Furthermore, after an exposure of 6 days to O_2 and 9 days to the O_2-H_2O mixture, further disaggregation of the large particles was observed, appearing as a rounding of the corners. The disruption appears to have occurred at microbreccia interfaces. Microphysical and microchemical analyses of these fractured interfaces have not yet been made.

The coherence of the fine, lunar material is well known (*1*). In our etching experiments, where about 100 mg of powder sample 10084,93 was etched with a slow fluorosilic acid etch (H_2SiF_6 : HCl : citric acid; 1 : 1 : 1), most of the particles were dispersed after reaction. Only a few aggregates of black and white crystallites remained intact. Oriented etch figures, random etch figures, mottled surfaces, and unaffected areas were found. Larger particles which could be picked up with tweezers were found to be microbreccia. Another sample of the powder was etched using HBF_4 in place of H_2SiF_6. Except for a slower etching rate of glass-like material, the results were similar.

A portion of 10084,93 was mounted in plastic, lapped, polished and etched. Figure 1 shows a plastically deformed pyroxene in which the dislocation density varies between 10^{10} dislocations per square centimeter in the bands and a density equivalent to 6×10^{10} dislocations per cm^2 along slip planes. Also,

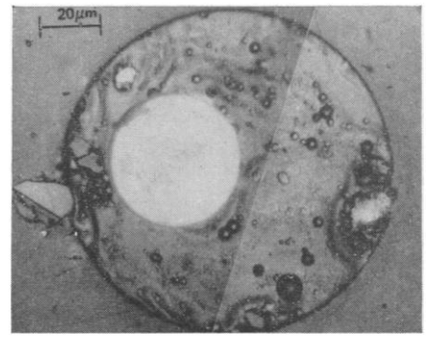

Fig. 2. Lapped and etched section of a glass sphere from powder sample 10084, 93. Impact adhesion of small grain on left side is seen with etched interface. The light circle is a spherical cavity.

microcracks are found along the band borders where the fracture stress was exceeded due to dislocation pileup (*2*). Figure 2 is a photomicrograph of a glass sphere section, to which a small fragment is attached (left side). Deformation of the sphere brought out by etching in the vicinity of the fragment indicates contact while still slightly fluid or more possibly local heating due to the impact. The white circle is a spherical void in the particle, and the dark to light dots are satellite voids and etch figures.

Some particles had shear deformed platelet inclusions and appeared to be fused to a glass-like microbreccia. One glass sphere, which also had been impact deformed exhibited a regular etch pattern suggesting partial recrystallization. Similar etch patterns were found on nonspherical particles.

A rock specimen of 10058,40 was mounted, lapped, polished, and etched with HF, HCl, and citric acid. Figure 3 shows bands in a crystal that was sheared in a direction normal to the surface. It is attached to a very heavily

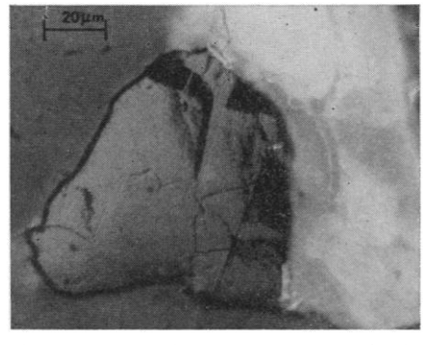

Fig. 3. Photomicrograph of chemically etched pyroxene deformation bands. The heavily etched crystal is a plagioclase.

etched crystal that is tentatively identified as a plagioclase by its optical and etching characteristics. Other crystals from this rock specimen (probably pyroxenes) etched with the H_2SiF_6 etch exhibit band-like lines which form sharp angles enclosing three- and four-sided polygons. As yet, their origin is not known. However, a deformation feature, namely cross slip, has been observed in electron micrograph replicas of these etched surfaces.

The experimental apparatus for performing ultrahigh vacuum cleavage-fracture of silicates (*3*) has been used to fracture one lunar rock fragment (from 10065,33) to date. The fragment is a very friable, highly vesicular, igneous rock. Its dimensions prior to fracture were about 0.6 by 0.4 by 0.4 cm, and it was fractured roughly perpendicular to its long axis. Fracture was made at a system pressure of 7×10^{-10} torr. The halves were then brought together with contact made over only a very small area. The resultant adhesion force was about 8×10^2 dynes. This decreased to 2×10^2 dynes in 4 minutes and dropped below measurement capabilities (1×10^2 dynes) about 15 minutes later.

Microscopic examination of the fracture surface, after the system was brought to atmospheric pressure, revealed a large number of particles standing on end. These remained so even when moved laterally by a needle probe. Other particles, lying horizontally, would in some cases jump to the vertical position when moved. Movement of particles also, on occasion, caused others to jump to new positions and orientations. Attraction of particles to the needle was common. These observations indicate electrostatic charging of surfaces. The fractured specimens were then suspended in a covered container with the fractured faces downward. Water vapor was then introduced, and maintained, to determine whether the charge on the adhering particles and fracture faces could be neutralized. After 4 days, several particles had fallen from the bottom fracture face. All these observations are in accord with findings (*3, 4*) that cleavage of terrestrial silicates produces electrostatic charging that persists, though very much reduced when the system is brought to atmospheric pressure. The adhesional forces observed for the lunar sample are of the same order of magnitude as those found for terrestrial silicates (*3*).

The x-ray analyses of traverses across particle interfaces of lapped and polished crystalline specimens are typical of material formed from high-temperature phases. Low-temperature sintering (*5*) has not been found in the fine grained vesicular material from the powder 10084,93, in the coarse fines 10085,36, or in the rock specimen 10065,33. However, the Apollo 11 samples that were exposed to N_2 may have already disrupted at sintered interfaces.

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Solar Radiation Effects in Lunar Samples

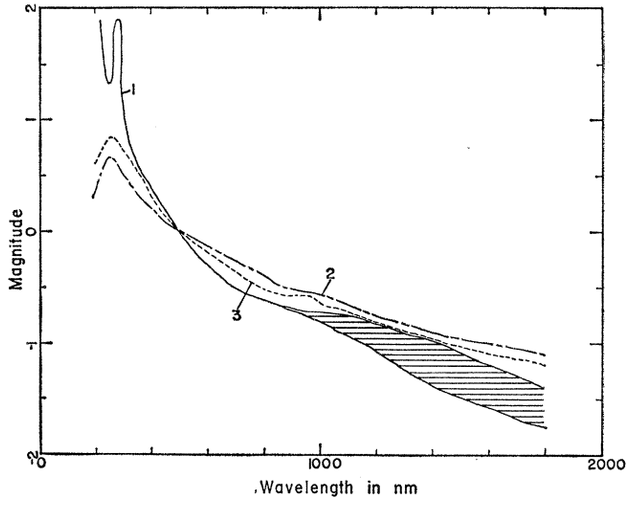
Abstract. *Optical properties of the pulverized crystalline rocks from the Apollo 11 samples are different from the optical properties of lunar soil. Changes in these properties were induced in the samples by ultraviolet and x-irradiation, standing, and heating. The albedo and spectrum of the soil differed significantly from expected values.*

The purpose of our work is to ascertain the possible role that various types of radiation may have played in determining the optical properties of the lunar surface. We investigated the effects of low-energy protons, ultraviolet and x-ray irradiation, heating, particle size, composition, and packing on the albedos and spectra of the samples.

The particle size distribution in fines sample 10084,81 was measured by sieving and sedimentation. The median particle size, weighted by mass, was about 40 μm, with over 35 percent of the mass contained in particles smaller than 20 μm. These results are in agreement with a previous size determination (*1*) and with estimates of "mean particle size of a few tens of microns or less" (*2*), based on telescopic optical data.

According to Wildey (*3*) the 0° phase angle albedo of the moon in the vicinity of the Apollo 11 site is approximately 0.099. Correcting this value for photometric function to a 6° phase angle gives 0.079. However, the subsurface soil appears to be darker than the surface material by 5 to 30 percent, depending on location (*4*). Since most of the sample presumably came from below the surface, a 6° albedo in the range of 0.060 to 0.076 is thus to be expected. The actual measured value relative to MgO is 0.090. The degree of compaction of the material cannot reduce this value sufficiently. We conclude that the returned sample of fines may not be representative of the general region of the moon around Tranquillity Base, at least as far as the factors that determine albedo are concerned.

The reflection spectrum of the fines, as measured by a Cary 14 spectrophotometer, is shown in Fig. 1 along with the general spectrum of the moon (*5*). The general lunar spectrum is considerably redder than the spectrum of the fines. We are not certain of the reason for this discrepancy; it may reflect errors in our measuring techniques, or it may indicate that this material is not typical of the surface of the moon as a whole, possibly because of alteration processes acting on the lunar surface or changes which occurred during or after collection. There is no sign in the fines of the 290-nm band reported in the lunar spectrum. We caution that the apparent peak at 250 nm in our data may be spurious. However, an absorption band at 900 to 1000 nm due to Fe^{2+} is clearly present in the spectrum of the fines.



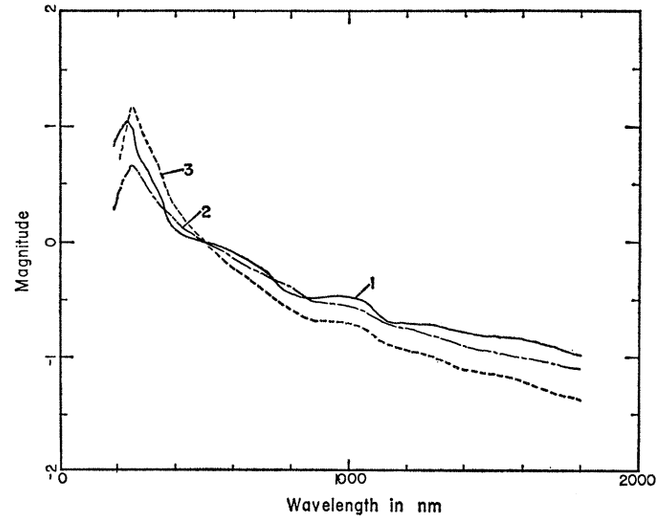


Fig. 1 (left). Relative reflection spectra, in magnitudes, of lunar materials, normalized at 500 nm; curve 1, average moon; curve 2, fines; curve 3, fines after ultraviolet irradiation. Fig. 2 (right). Relative reflection spectra, in magnitudes, of lunar materials, normalized at 500 nm; curve 1, pulverized crystalline rock 10022; curve 2, fines; curve 3, powdered rock after H-ion irradiation.