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Examination of returned Surveyor III surface sampler

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Abstract—The scoop and portions of the arms of the Surveyor III soil mechanics surface sampler were returned to earth by Apollo 12 Astronauts Conrad and Bean. A careful surface examination of the scoop has been made both visually and microscopically under a variety of lighting conditions. The blue of the original paint has been changed to a light tan color, but the change is not uniform on all surfaces. In places, the surface exhibits a blotchy appearance, probably due to differential thicknesses of a soil coating, which protected the surface from solar radiation. Although the surface is scratched and abraded, it is not known if this is due to preflight sandpapering or lunar surface operations. No micrometeorite pits were observed. Lunar soil adhered preferentially to (1) painted, (2) Teflon, and (3) metallic surfaces. The strength of the soil adhesion to the paint was in the order of 10^4 dynes/cm^2. Glassy spheres adhered more strongly to the paint than did other lunar granular material.

INTRODUCTION

THE SURVEYOR III spacecraft became operational at its landing site in Oceanus Procellarum on the moon 20 April 1967. It carried a Soil Mechanics Surface Sampler (SMSS) device for the purpose of performing mechanical tests of the lunar surface. The sampler was turned on the day after landing, and, after an initial calibration sequence, it was used to conduct the first controlled tests of the physical and mechanical properties of the lunar surface (SCOTT and ROBERSON, 1968). When the spacecraft was shut down for the lunar night on 3 May 1967, the surface sampler had been operated for 18½ hours and had responded to a total of 1900 commands. During the surface operations, it was pushed into the lunar surface in 25 bearing and impact tests, and was dragged through the lunar granular material approximately 6 meters in the course of performing trenching tests. The spacecraft did not respond to commands sent on the second lunar day.

On 19 November 1969 Astronauts Conrad and Bean of the Apollo 12 mission landed close to Surveyor III and retrieved the scoop and part of three arms of the surface sampler along with other Surveyor III components. The returned portions of the SMSS were examined in detail at the Hughes Aircraft Company (HAC) facility in Culver City, California. This brief report presents some of the results of that examination.

CONDITION OF SCOOP BEFORE EXAMINATION

At the close of Surveyor III lunar surface operations a few grams of lunar soil remained inside the closed bucket of the sampler scoop; some soil also adhered to the scoop door mechanism and scoop exterior. After the scoop was retrieved by Conrad and Bean it was stored in the Apollo 12 lunar module and later in the command module under the atmospheric conditions prevailing inside these spacecraft. During quarantine in the NASA Lunar Receiving Laboratory (LRL) at Houston, Texas, the scoop was removed from its container bag at least once and exposed to the earth's atmosphere. It is not to be expected, therefore, that the lunar soil accompanying the scoop will exhibit the same properties as it possessed in the vacuum at the lunar surface. When the plastic bag containing the scoop was opened, it was found that the soil inside the bucket had spread over the exterior and interior surfaces of the scoop and the inside of the bag. The soil was observed adhering to various scoop surfaces to differing degrees, and some attempts were made to test the strength of this adhesion, although the mechanism of adhesion may be different from that existing on the moon.

EXAMINATION OF SCOOP SURFACE

The scoop and the attached arms were examined visually and microscopically up to about 100× magnification. In addition, the returned scoop and an essentially identical flight model, which had remained on earth, were photographed under white, ultraviolet, and infrared light conditions. The color photographs obtained in some of these studies are not reproduced here, but may be found in a more detailed report (SCOTT and ZUCKERMAN, 1971).

Figure. 1, an Apollo 12 photograph, shows the left side of the scoop (right and left as viewed by the Surveyor III camera) on the moon. In another picture, not shown, there appears to be a coating of soil on the bottom of the right side, near the scoop

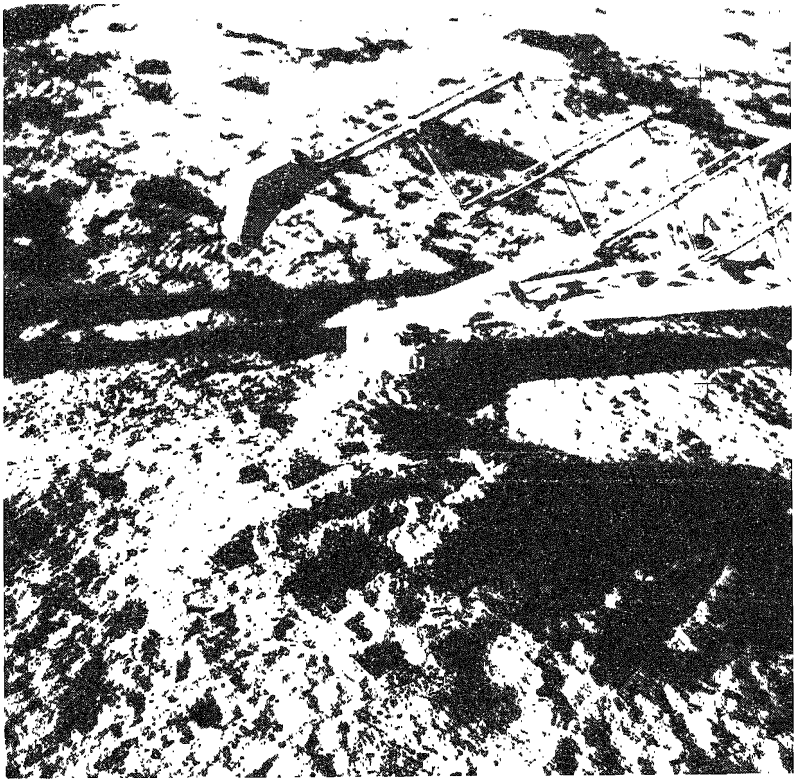

Fig. 1. Apollo 12 view of left side of scoop on moon. NASA AS 12–48–7128.

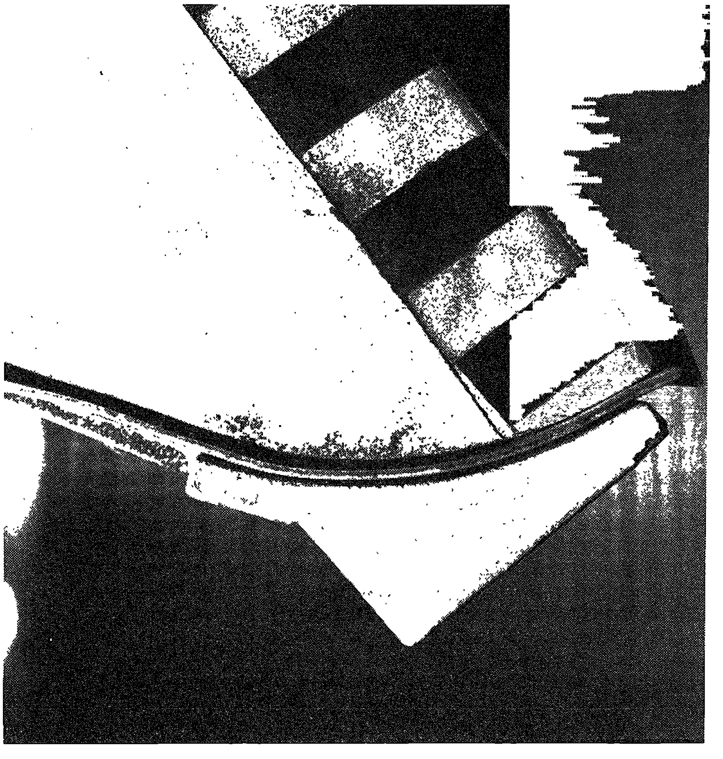

Fig. 2. Laboratory photograph of right side of returned scoop. Width of field = 4.9 cm.

door. The left side (Fig. 1) shows a shading pattern in which the bottom of the scoop side is lighter. In the preliminary examination of the scoop at the LRL, the right side was heavily coated with soil in the approximate pattern shown in the photograph. This would appear to have been the original lunar soil picked up during surface sampler bearing tests. The shading pattern on the left side is also visible, particularly in the color photographs. The condition of the scoop as it appeared for the examination at HAC (Fig. 2) indicated that most of the soil adhering to the bottom of the right side had been rubbed off, but it can be seen that there is a lighter shading over the area to which it had adhered.

In appearance, a number of changes were manifest in the returned surface sampler. First of all, the blue paint which covers most of the surface appeared to have faded in color from the original light blue color to a whitish blue in the relatively protected or concealed areas of the arms and scoop. The original color of the paint is 5.0 PB 7/6 on the Munsell scale and the paint on the returned Surface Sampler was 10.0 B 8/2 on the cleaner (not soil-covered) areas and 10.0 B 7/2 on less clean parts. However, on the upper surfaces of the arms and on the upper and side surfaces of the scoop itself the color of the paint has been changed to a light tan. This tan is most pronounced on the upper surfaces and shades into a whitish blue on the underside of, for example, the arms. A microscopic examination of the paint surface at a magnification of 100× appears to indicate that the tan is a change in the painted surface rather than a light coating of particles covering the surface.

During transit from the moon and subsequent handling in the Lunar Receiving

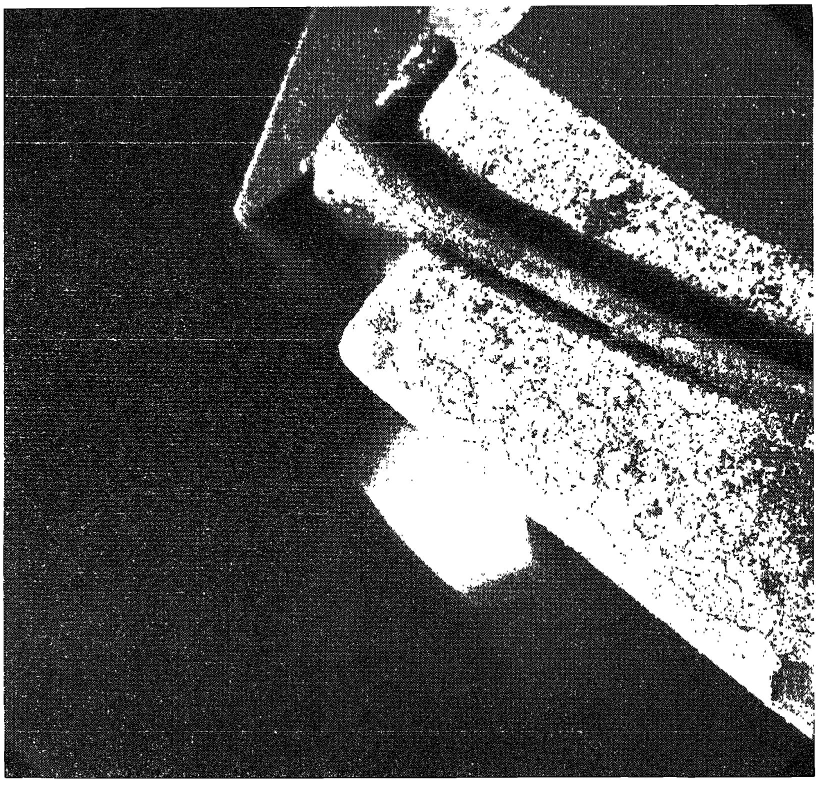

Fig. 3. Left side of returned scoop tip. Width of field = 1.7 cm.

Laboratory and elsewhere, some of the paint around the edge of the scoop door may have been abraded and removed (Fig. 3) since some paint chips appeared in the associated soil. Some of the paint probably was also removed during operations on the lunar surface. It can be seen that the paint is covered with lunar soil particles, including a substantial proportion of small glassy spheres. The irregular bumpy texture of the painted surface is characteristic of the original painted coating. It is not clear if the change in color of the painted surface is due to a surface alteration of the paint or to a thin layer of fine particles on the surface. The color change is not everywhere uniform, and it seems to depend on the degree to which the surface was exposed to solar radiation. On the sides and top of the scoop, light tan blotchy patterns can be seen. In places, these patterns can be correlated with a protective covering of lunar soil apparent both in some of the original Surveyor III pictures and in the astronaut photographs (Fig. 1). The most pronounced color difference between the terrestrial and returned scoops is apparent in the ultraviolet pictures (Scott and Zuckerman, 1971). These observations are more consistent with a color change caused by solar radiation rather than a change resulting from a thin soil coating. It is not known why general gradational differences in the degree of the color change exist on apparently uniformly exposed sides of the scoop. It is possible that these are due to changes from place to place in the scoop paint thickness or composition, or may be due to the presence on the moon of differing thicknesses of dust coatings resulting from lunar surface operations. A further possibility is that the abrasion of the paint which took place before launch or during the lunar surface testing resulted in different sensitivities of the paint to the possible irradiation in different areas. It has also been shown (SCOTT *et al.*, 1971) that, at some time between the end of Surveyor III operations in May 1967 and the visit of the Apollo 12 astronauts in November 1969, two of the Surveyor spacecraft's shock absorbers had collapsed, probably moving the spacecraft slightly. Some soil could have been shaken from the left side of the scoop at this time. Alternatively, since the left side of the scoop was more exposed to the effects of the Apollo 12 descent engine, soil may have been removed from this side during final stages of the Apollo 12 landing.

A second item of interest concerning the painted surface is the crazing or cracking of the paint on the sides and base of the scoop door. Polygonal fracture patterns are apparent in Fig. 3. This portion of the scoop was made of a glass fiber-impregnated resin coated with the standard paint. The fracture pattern does not appear on the painted metallic surfaces of the rest of the scoop, and may therefore be related to the different thermal expansion characteristics of the paint, the resin, and the metal. It is also possible that radiation damage to the paint could have resulted in volume changes of the paint. In this case, the appearance of fracture patterns on the scoop door would be related to either the different thickness of the paint or different nature of bonding of the paint to that surface as compared with the other metallic surfaces. The chipping of the paint from the scoop door tips indicates that the bonding between the paint and the resin was weaker there than elsewhere. A careful study of the Surveyor III television pictures was inconclusive in regard to the presence of chipping or flaking at these points during the lunar surface operations in 1967. Observations during handling of the returned surface sampler indicate that the paint at the corners chips quite easily. Chips of paint were observed in the lunar soil which was collected from the inside and outside of the scoop.

The terrestrial flight model scoop has been employed in a variety of soil testing operations in a number of different soils on earth, and it was observed that the general effect of this soil contact has been to smooth down the irregularities in the painted surface without the development of scratches. Considerably less soil contact took place with the Surveyor III scoop, but it is evident, as shown in Fig. 4, that the surface has been scratched and abraded. A general smoothing of the surface of the paint is also evident in Fig. 4. It was initially thought that the scratches on the Surveyor III scoop apparent in Fig. 4 were due to the lunar surface operations, but it has since been learned that the painted surface of the scoop (and other portions of the spacecraft) may have been lightly sandpapered (and in some instances repainted) prior to launch to remove defects in the paint. The direction and orientation of the scratches on the gear box (Fig. 4) and the right side of the scoop (Fig. 5) are consistent, however, with their production by lunar surface operations. This uncertainty may be resolved by a detailed comparison of scratch orientation on all scoop surfaces. The inside of the scoop, which was subjected to a great deal of lunar surface contact, was free from any signs of scratching or abrasion. Adhesion of the lunar soil to all surfaces of the returned scoop is readily apparent in a photograph of the Surveyor III scoop door mechanism (Fig. 6). Even the Teflon seal of the scoop door is relatively heavily coated with lunar soil particles (Fig. 7). The lunar soil scattered about the surface sampler appears to adhere preferentially to the different surfaces of the sampler.

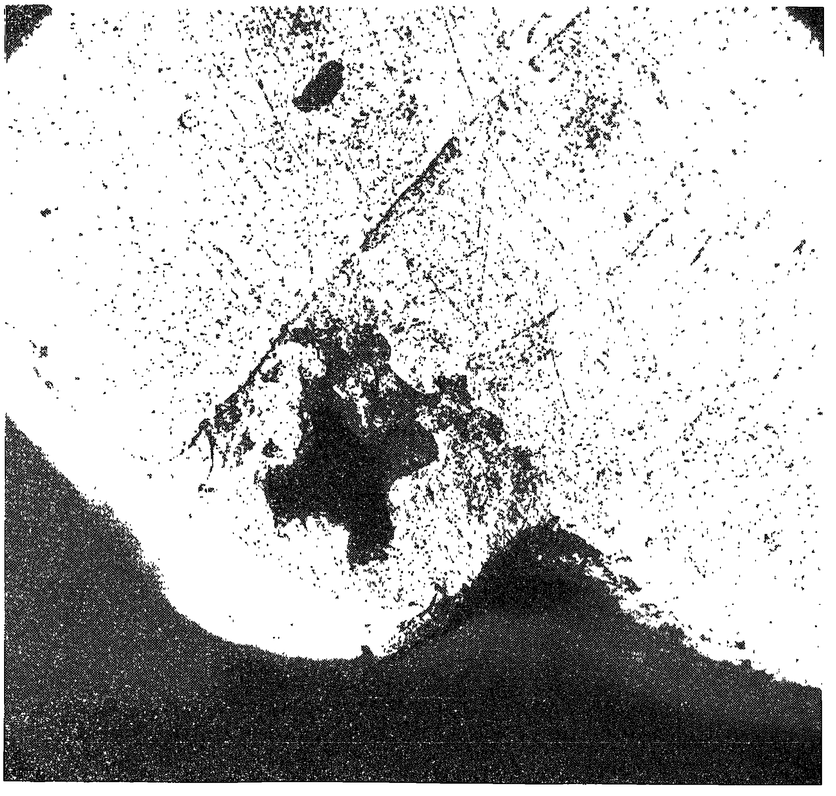

Fig. 4. Screw head in gear box of returned scoop. Width of field = 1.7 cm.

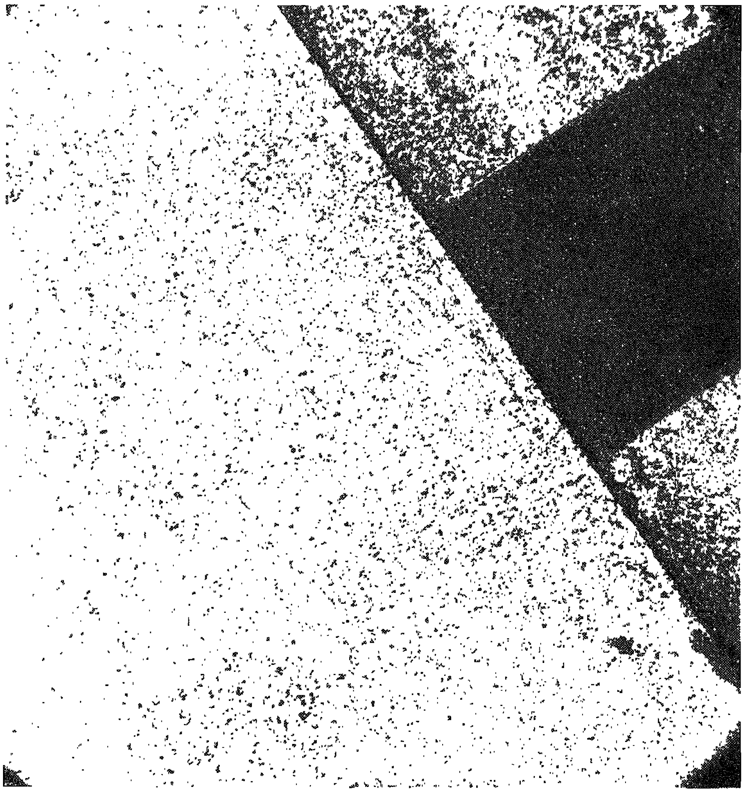

Fig. 5. Scratches on right side of returned scoop. Width of field = 1.7 cm.

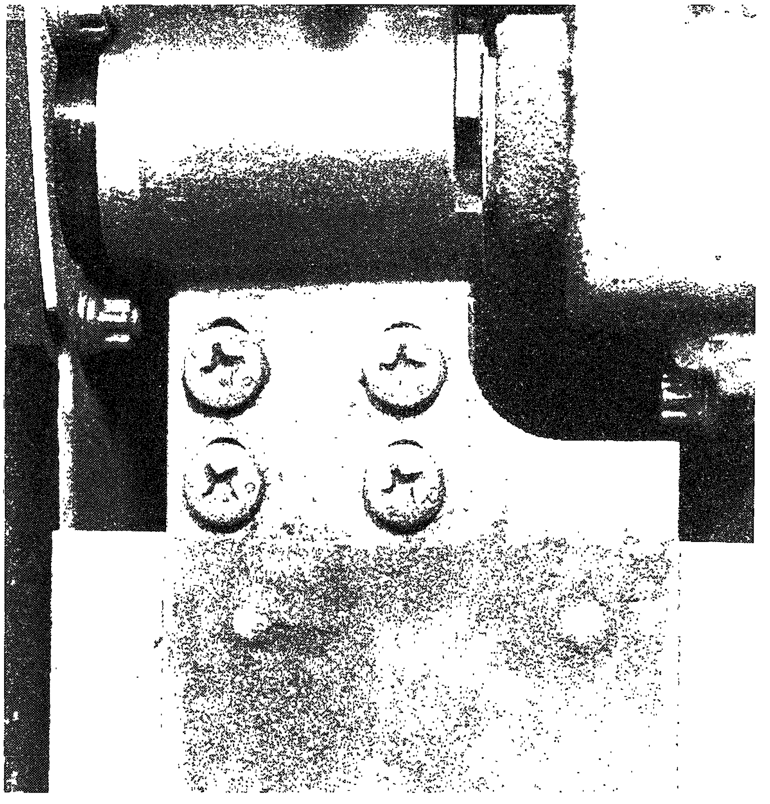

Fig. 6. Door of returned scoop. Width of field = 1.7 cm.

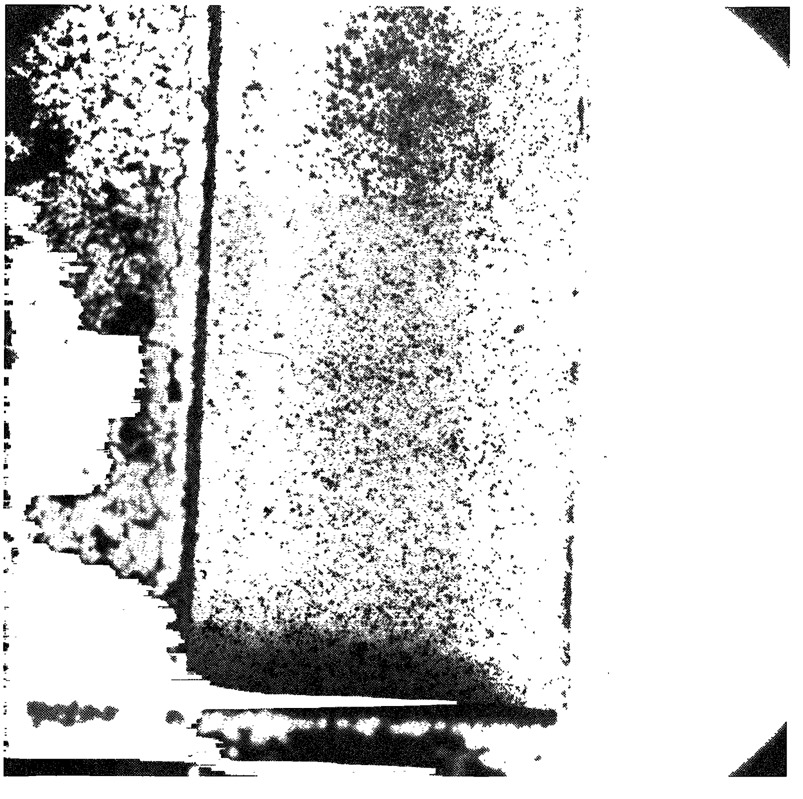

Fig. 7. Teflon on door of returned scoop. Width of field = 0.56 cm.

The most obvious observation is that the lunar material adheres more readily, in order, to (1) painted, (2) Teflon, and (3) metallic surfaces. It should be noticed, of course, that the metallic surfaces are not absolutely clear of lunar soil. It was not possible to tell in a superficial examination if there was selective adhesion of various components of the lunar soil.

Adhesion of the soil to the Teflon, and a slight color change of the Teflon itself was observed (Fig. 7). The Teflon appears slightly brown on its outer edges, shading to the original milky white appearance next to the metal part of the scoop door. It is apparent that this change took place rather quickly on the lunar surface since it is also visible in the Surveyor III pictures.

Measurement of Adhesion of Lunar Soil to Surface of Returned Scoop

An attempt was made to measure the magnitude of the existing adhesion (whatever its nature) between the lunar soil and the various surfaces of the scoop by the following technique: A small vacuum-cleaning apparatus was built in order to remove the soil from the surface sampler surface. It consisted of a small pump, plastic hose, and two lucite chambers containing different sizes of filter papers. At the input end, a pen holder was used to retain a nozzle through which the soil was sucked. A number of different nozzle sizes was tested. In practice, the experiment and cleaning operation consisted of starting the vacuum pump and bringing the nozzle closer to the surface of interest while holding it at right angles to the surface. It was generally observed that at some particular distance from the surface a circular area underneath the nozzle tip would quite suddenly become clean leaving, in most cases, a very abrupt discontinuity between the clean surface and the adjacent soil-covered area. This result was interpreted to mean that the adhesion of the lunar soil to itself was somewhat greater than its adhesion to the scoop surface. Thus, when a critical surface shearing stress was reached due to the air flow over the surface, the soil detached itself from the surface and passed into the nozzle and thus into the collection chambers. By carefully measuring the distance of the nozzle from the surface of the scoop and the radius of the area which was made clean at the critical distance of approach, an estimate of the surface shearing stress required to remove the soil could be made. To make this estimation, the nozzle was calibrated by measuring the mass rate of flux of air into the nozzle at different distances of approach from various flat plates. From these tests it was estimated that the adhesive strength of the lunar soil to the painted surface was in the order of 10^4 dynes/cm^2. The adhesion of soil to the metallic surfaces of the sampler was somewhat less and was in the range of 2 to 3×10^3 dynes/cm^2.

It was observed that in an area of painted surface which had been cleaned off by this technique, the remaining particles consisted almost entirely of glassy spheres. It would appear that the adhesion of the spheres to the paint, at least, was considerably greater than that of other granular fragments, since one might expect that angular fragments would exhibit a greater degree of mechanical interlocking with a rough surface than spherical particles.

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