Table 1. Chemical composition of lunar surface at Surveyor V site.

Element	Atomic percent*
Carbon	< 3 ±
Oxygen	58 ± 5
Sodium	< 2
Magnesium	3 ± 3
Aluminum	6.5 ± 2
Silicon	18.5 ± 3
$28 < A < 65$†	13 ± 3
(Fe, Co, Ni)	> 3
$A < 65$	< 0.5

*Excluding hydrogen, helium, and lithium. These numbers have been normalized to approximately 100 percent. †This group includes, for example, S, K, Ca, Fe, Co, Ni.

(above background) beyond channel 73 indicates a relatively low abundance of elements of mass number heavier than 65. Similarly, the high-energy proton spectrum (above channel 60) is characteristic of protons from aluminum.

The observed alpha and proton spectra have been analyzed thus far by a computer into the spectra of only eight elements: C, O, Na, Mg, Al, Si, "Ca," and "Fe." The "Ca" stands for elements with $28 < A < \sim 45$, and "Fe" represents elements with $\sim 45 < A < 65$, where A stands for the mass number of the element. Figure 2, A and B, shows the agreement between the observed data (after subtraction of the background and heavy-element contribution) and the computer-calculated results. Analysis into only eight elements represents the data with very few systematic deviations. One of the regions of poor fit is between α-channels 63 and 74.

The results obtained in this way on the chemical composition of the lunar surface are presented in Table 1. The errors quoted are the present estimates of the reliability of the results; the statistical errors are much smaller. The most abundant element on the lunar surface, as on the earth, is oxygen. More than half of all the atoms are of this element. Second in importance, as on the earth's crust, is silicon. Next in abundance is aluminum (*4*), and the quantity of magnesium is somewhat lower. At this stage, only upper limits can be placed on the amounts of carbon and sodium present. The data indicate surprisingly large amounts of elements heavier than silicon. Although a breakdown of these elements cannot be made at present, it is possible to place a lower limit of 3 percent on the combined abundance of Fe, Co, and Ni, and an upper limit of 0.5 percent on that of still heavier elements. The chemical analysis, therefore, indicates that the sample analyzed is a silicate rock similar to materials available on the earth.

Although an elemental analysis (even one more precise than the present one) can be only a rough indicator of detailed rock type, it is of interest to compare the present results with the chemical composition of some materials that have been considered as constituents of the lunar surface). In Fig. 3, where a comparison of the present results is made with the analyses of average dunites, basalts, granites, tektites, chondritic meteorites, and basaltic achondrites (*5*), the comparison shows that the lunar surface at the Surveyor V landing site cannot consist entirely of material similar to chrondritic meteorites or to ultrabasic rocks such as dunite. Tektitic or granitic materials are more consistent with the present estimates of errors, although these materials are apparently ruled out by the γ-ray measurements of Vinogradov *et al.* (*6*). Of the comparisons in Fig. 3, the closest agreement appears to be with the chemical composition of basaltic achondrites and with that of terrestrial basalts.

Figure 3 represents only a few of all possible comparisons. Such comparisons will be even more meaningful when the data obtained by Surveyor V have been completely processed. However, even now, the results provide experimental information on the chemical environment on the surface of the moon, the possible raw materials there, and clues to the history of this long-time partner of the earth.

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3. *Surveyor V Mission Report, Parts I to III, JPL Technical Report* (Jet Propulsion Laboratory, Pasadena, California, 1967); see also L. D. Jaffe and R. H. Steinbacher, *Science*, this issue.
4. Consideration has been given to the possibility that the high value of aluminum observed in this experiment was due to contamination from the main retro rocket which had aluminum powder in its fuel. Estimates from the known burnout height of this motor and trajectory of the spacecraft after burnout indicate that this source of aluminum contributes less than 0.5 atomic percent to the observed aluminum abundance.
5. A. Palm and R. G. Strom, *Space Sciences Laboratory Research Report* (University of California, Berkeley, 1962), series 3, issue 5.
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Surveyor V: Lunar Surface Mechanical Properties

Abstract. *The mechanical properties of the lunar soil at the Surveyor V landing site seem to be generally consistent with values determined for soils at the landing sites of Surveyor I and III. These three maria sites are hundreds of kilometers apart. However, the static bearing capability may be somewhat lower than that at the previous landing sites (2×10^5 to 6×10^5 dynes per square centimeter or 3 to 8 pounds per square inch). The results of the erosion experiment, the spacecraft landing effects, and other observations indicate that the soil has significant amounts of fine-grained material and a measurable cohesion.*

The Surveyor V terminal landing maneuver resulted in nominal landing velocities of 4.2 m/sec vertically and 0.5 m/sec horizontally. After the initial touchdown, the spacecraft slid about 0.8 m before reaching its final position on a 20-degree slope. The trench dug by one of the footpads during landing is shown in Fig. 1. As indicated by the appearance of the disturbed soil, the penetration into the soil by the footpads during landing, and landing loads in the leg shock absorbers, the mechanical properties of the lunar soil at the Surveyor V landing site seem to be generally consistent with values determined for the soils at the Surveyor I (*1*) and III (*2*) landing sites. However, the values for static bearing capability of the lunar soil at the landing site may be somewhat lower than the previous range of values, which is 2×10^5 to 6×10^5

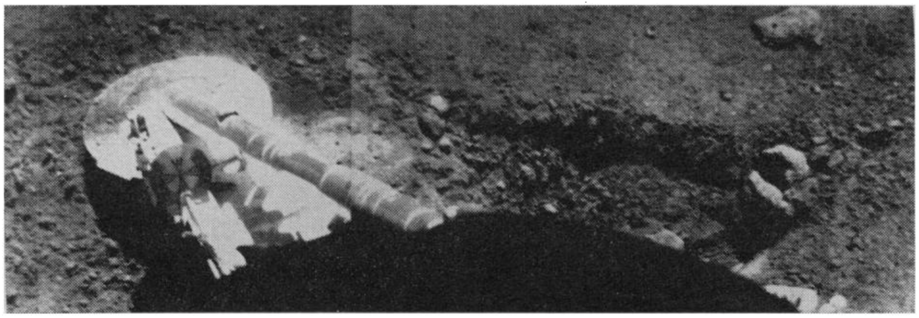


Fig. 1. During the landing, the spacecraft slid down the slope. The 0.8-m trench made by footpad 2 is shown in this picture. Most of the clumps of soil near the circular footpad were ejected during the landing. Soil clumps fell into the trench after the footpad had moved past (catalog No. 5-MP-19. GMT day 257; approximately 05).

Fig. 2. Mosaic of narrow-angle television pictures of the lunar surface under vernier engine 3, as seen through the auxiliary mirror, before the engine firing. Sun elevation was 44 degrees, relative to the lunar surface beneath the spacecraft, and came from the left. The shadows of the spacecraft cover part of the surface. The wavy shadow is caused by the flexible cable to the sensor head and not by surface contours (catalog No. 5-MP-17. GMT day 256; approximately 01).

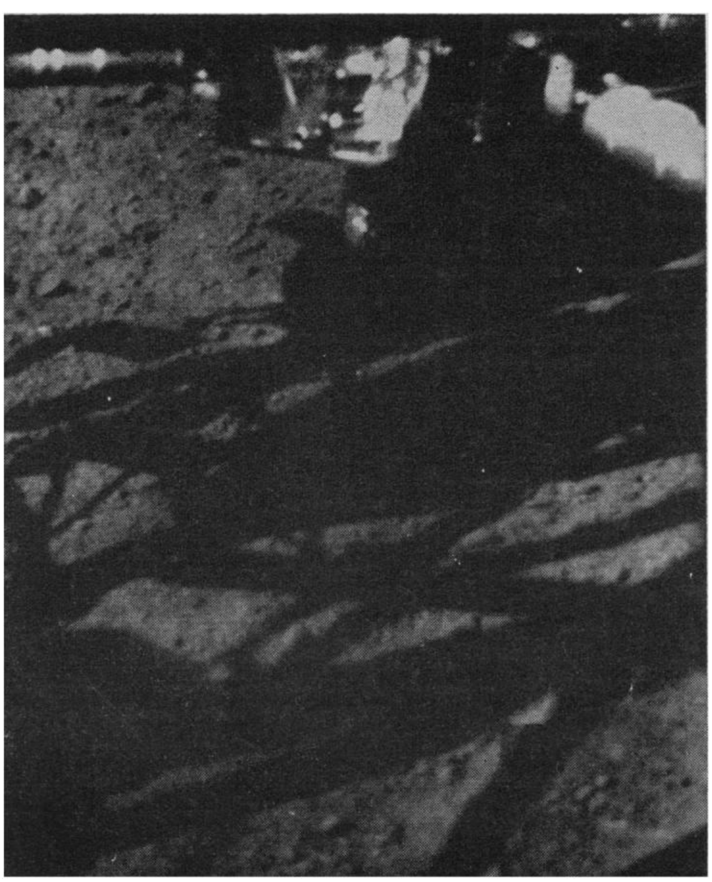
Fig. 3. Mosaic of narrow-angle television pictures of the lunar surface under vernier engine number 3, as seen through the auxiliary mirror, after the engine firing. The depression created by erosion (visible in Fig. 7) was not visible because of the high Sun angle and spacecraft shadows. Sun elevation was 47 degrees, relative to the lunar surface beneath the spacecraft. Compare with Fig. 2 and note the smoother appearance of the lunar surface and the removal of fragments or clumps (catalog No. 5-MP-18. GMT day 256; approximately 07).

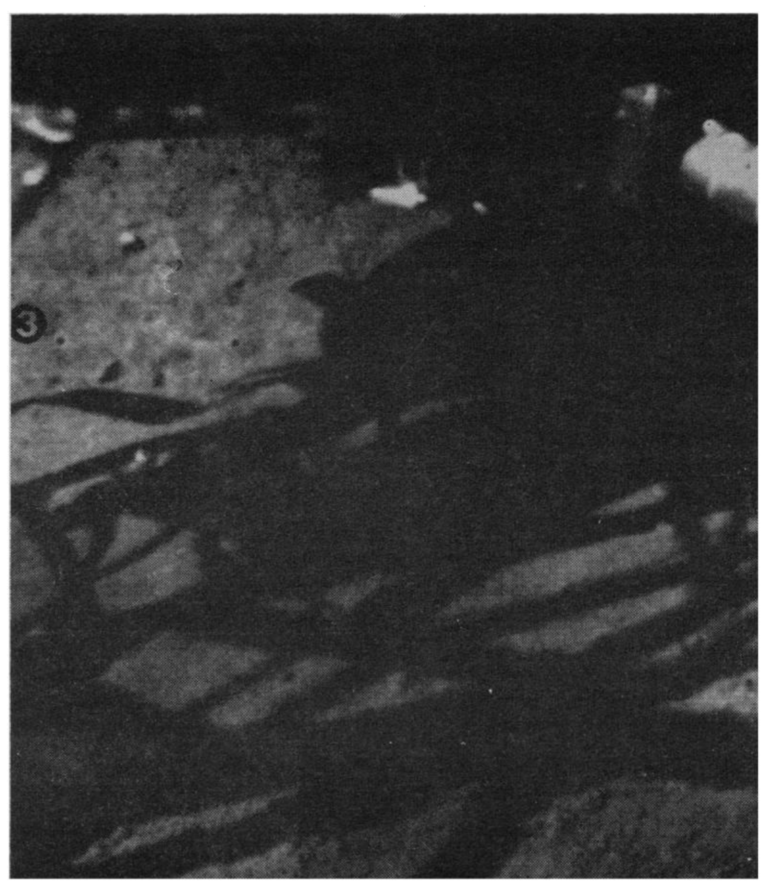
Fig. 4. Mosaic of narrow-angle television pictures showing the sensor head and the lunar surface area near it. The wide distribution of rock and soil fragments existed before the vernier engines were fired. The wavy cable in the foreground created the shadow seen in Fig. 2. Sun elevation was 35 degrees, relative to the lunar surface beneath the spacecraft (catalog No. 5-MP-16. GMT day 255; 04:53 to 05:26).

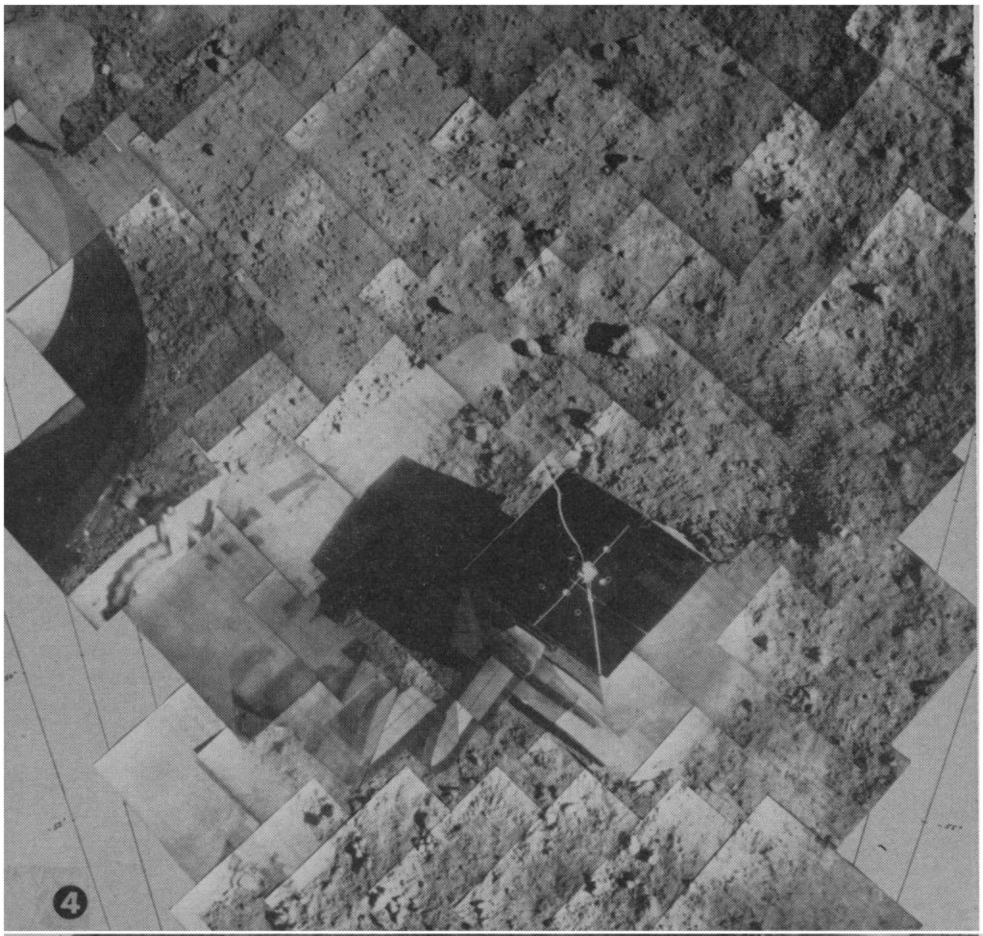
Fig. 5. Mosaic of narrow-angle television pictures showing the area around the sensor head after the spacecraft vernier engines were fired. The sensor head moved approximately 11 cm down a 20-degree slope. Compared to Fig. 4, there is evidence of fine soil and large fragment movements toward the upper right-hand corner. Sun elevation was 57 degrees, relative to the lunar surface beneath the spacecraft (catalog No. 5-MP-20. GMT, day 257; 06:58 to 07:01).

Fig. 6. Mosaic of narrow-angle television pictures showing the lunar surface under vernier engine 3, as seen through the auxiliary mirror, 9 Earth days after the firing of the vernier engines. The horseshoe-shaped depression is 20 cm across and less than 2 cm in depth and was formed by the firing of the vernier engines. The open end of the depression faces toward the sensor head. Afternoon elevation of the sun was 15 degrees, relative to the lunar surface beneath the spacecraft (catalog No. 5-MP-22. GMT day 265; approximately 14:00).

Fig. 7. Mosaic of narrow-angle television pictures showing a direct view of part of the crater formed under vernier engine 3 during the firing of the vernier engines. We estimate that the exit plane of the engine nozzle was between 40 and 45 cm above the lunar surface. The engine thrust level was approximately 115 newtons (26 lb). Sun elevation was 15 degrees, relative to the lunar surface beneath the spacecraft (catalog No. 5-MP-21, GMT day 265; 13:37).



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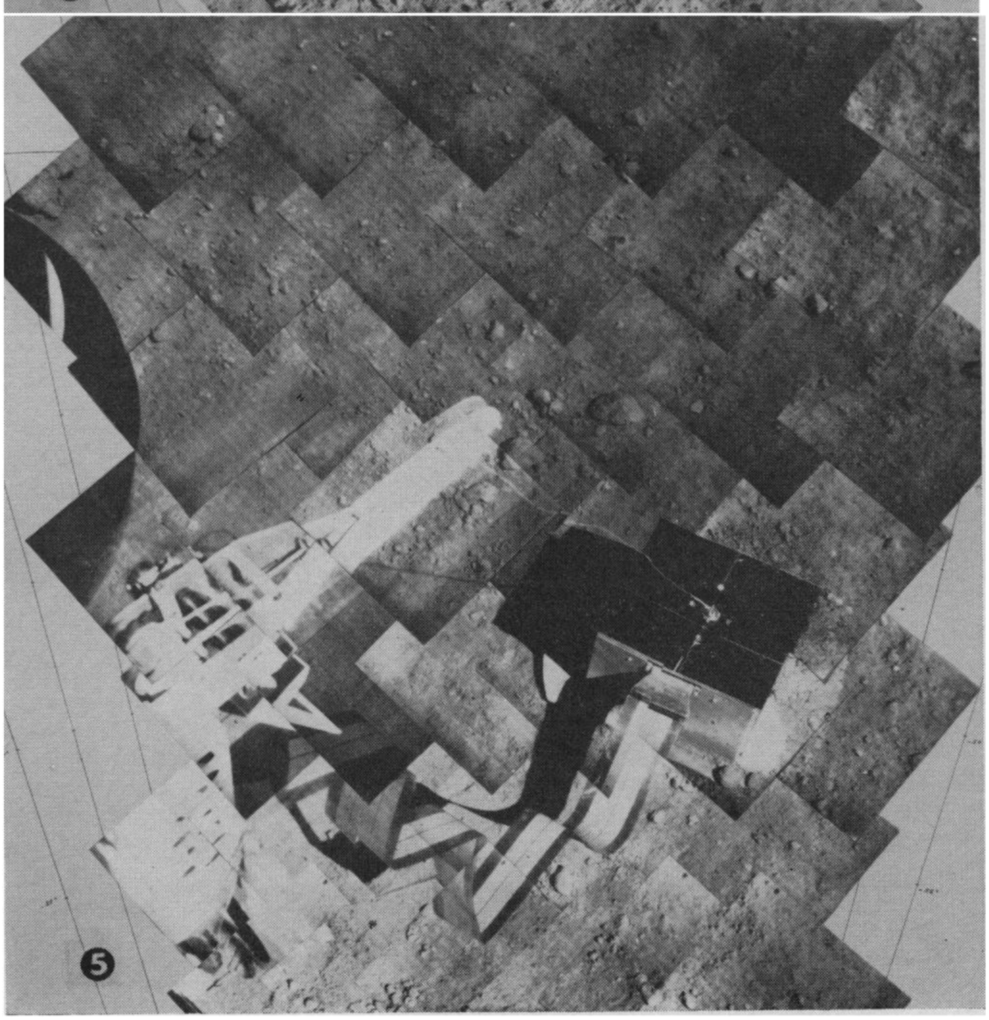
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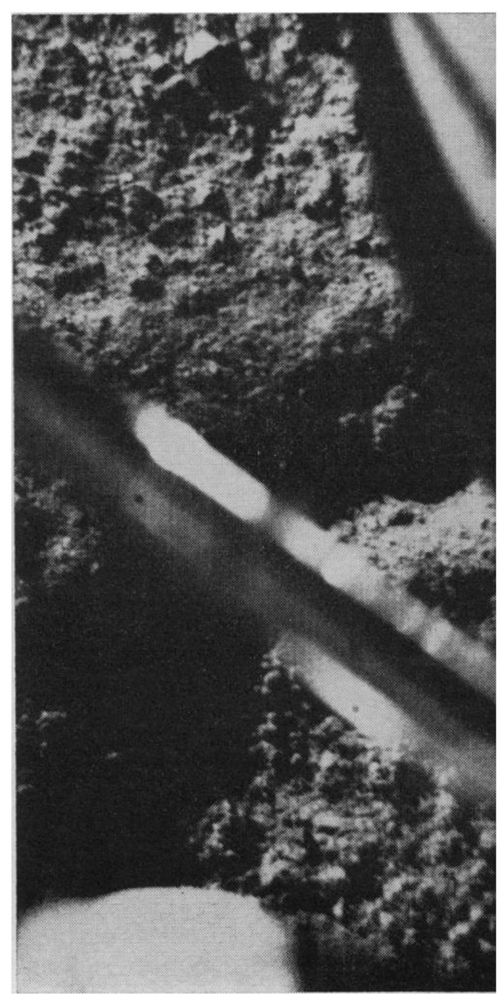

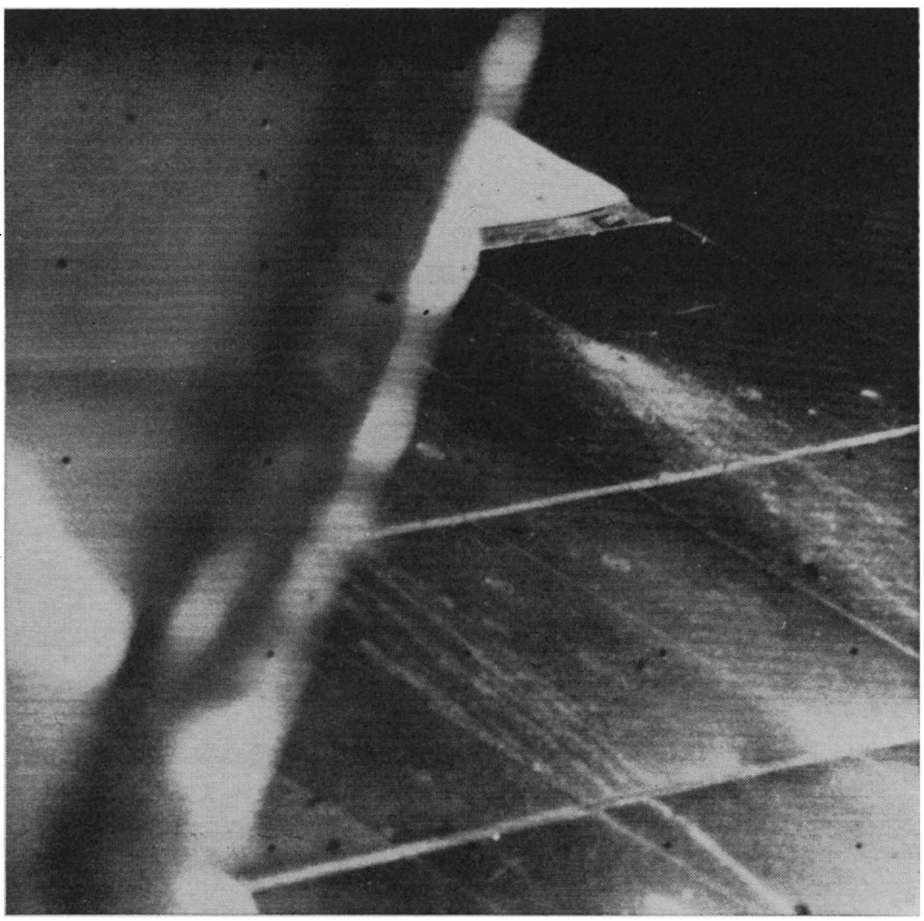

Fig. 8. Narrow-angle television picture showing a part of the top of electronics compartment B. Sprays of fine material that resulted when the vernier engines were fired (GMT day 265; 05:48:58).

dynes/cm^2 for the observed footpad penetrations.

Fifty-three hours after the spacecraft landed, a lunar soil erosion experiment was performed by firing the liquid-propellant vernier engines for 0.55 second. The purpose of the experiment was to investigate the effects produced by exhaust gases impinging on the lunar surface and to determine more accurately soil characteristics such as particle size, cohesion, and permeability. Two types of erosion were expected: a "viscous erosion" during the firing of the engines and a "diffused gas blowout" immediately after engine shutdown. Viscous erosion causes movement of particles radially away from the exhaust stagnation position and close to the local contours of the lunar surface. The quick removal of surface pressure during the engine shutdown releases the exhaust gases in the soil and results in an explosive uplift of gas and entrained soil.

There is evidence that both types of erosion occurred. Effects attributed to viscous erosion (from vernier engine 3) are shown by comparing Fig. 2 (before firing) to Fig. 3 (after firing), and Fig. 4 (before firing) to Fig. 5 (after firing). Some displacement of fine soil, and of rock or soil fragments (or both) has occurred. During the erosion experiment, the alpha-scattering instrument sensor head (mass, 2.2 kg) was moved approximately 11 cm away from vernier engine 3. The material impinging on the sensor head changed the appearance of the vertical side (Fig. 5, smudge on the lower part) facing the engine, but produced no significant change to the top of the sensor head.

The diffused gas blowout probably was the predominant cause of the horseshoe-shaped depression, 20 cm wide and less than 2 cm deep, which is visible in Figs. 6 and 7. The movement of soil resulting from blowout is generally upward, in contrast to the horizontal movement during viscous erosion. The broken clump and spray of soil on top of compartment B (Fig. 8) apparently are results of this blowout. The compartment top was 1.1 m above the lunar surface.

No functional effects on the spacecraft were observed as a result of firing the vernier engines. There were no noticeable changes in spacecraft temperatures, although the thermal characteristics of the two electronic compartment tops and the top of the sensor head would have been significantly modified by a thin layer of soil. During the vernier firing, the spacecraft remained stationary except for the motion of the sensor head.

The results of the erosion experiment appear to be compatible with soil parameters as determined from Surveyors I and III; that is, the soil has significant amounts of fine-grained material and has a measurable cohesion.

Analyses of the sliding of the spacecraft during landing and of the movements of the sensor head, various clumps, and rock fragments during the firing will be used to further define various properties of the lunar surface material.

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