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LUNAR-SURFACE CLOSEUP STEREOSCOPIC PHOTOGRAPHY ON THE OCEAN OF STORMS (APOLLO 12 LANDING SITE)

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS 77058

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SUMMARY

To obtain information about in-place lunar rocks and soil, a closeup stereoscopic camera capable of photographing small-scale surface features was used at the Apollo 12 landing site on the Ocean of Storms. The camera was the same type as the one used during the Apollo 11 mission. Fifteen stereoscopic photograph pairs were obtained. Because the photographic activity was limited by the lack of time, the areas photographed were mostly around the lunar module. The types of lunar surfaces photographed were soil and rock surfaces not greatly disturbed by the lunar module descent engine exhaust, soil surfaces disturbed by the lunar module descent engine exhaust, and soil surfaces disturbed by astronaut boots.

The stereoscopic pairs were of excellent quality and showed the in-place lunar material in detail. The photographs were analyzed and the results compared with the results of the Apollo 12 core sample analysis and other investigations. Significant information about the physical composition and genesis of the lunar soil at the Apollo 12 landing site was obtained. The cohesive soil on the Ocean of Storms probably results from repetitive bombardment of basalt flows by meteorites over long periods of time.

INTRODUCTION

Information about soil and rocks in place on the lunar surface was obtained during the Apollo 12 mission by the Apollo lunar surface closeup camera (ALSCC). This stereoscopic camera has an attached light source and is capable of photographing an area 72 by 82.8 millimeters and objects as small as 85 micrometers in diameter. The ALSCC, which was built under contract to the NASA Manned Spacecraft Center,[1] was also used during the Apollo 11 mission; details concerning the camera as well as descriptions of the Apollo 11 photographs may be found in references 1 and 2.

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[1] Built by Eastman Kodak, Inc.; cognizant scientist, T. Gold, Cornell University.

During the Apollo 12 mission, photographs were obtained of soil and rock surfaces not greatly modified by the lunar module (LM) descent engine exhaust, soil surfaces swept by the LM descent engine exhaust, and soil surfaces disturbed by astronaut boots. Nearly all of the photographs were taken by the lunar module pilot (LMP), Astronaut Alan L. Bean, close to the LM at the end of the second traverse. The following description of the ALSCC photographic activity by the astronauts was taken from reference 3.

"The ALSCC photographic activity suffered somewhat from the lack of time remaining to do it at the end of the extravehicular activity period. The areas photographed were mostly around the LM. We were able to get a few shots of some areas we had not been in, but most of the photographs were of the bottoms of small craters, dust patterns on the lunar surface, rocks, and footprints in the lunar soil. Two photographs were taken in the vicinity of the LM descent engine. The entire sequence of ALSCC photographs was completed in about 5 min; this did not allow enough time to properly report the camera orientation and to document photographs by describing what was being taken."

In the Apollo 12 Preliminary Science Report, Gold et al. (ref. 4) presented single frames from each stereopair, reproduced in black and white and accompanied by a brief description. The estimated locations of some of the photographs were also indicated in the report. In this report, both photographs of each stereopair are reproduced, and a more detailed description of each photograph is given. The photographs are printed in actual size so that any measurements can be made directly, without a scale change. The photographs, however, have a 2:1 depth exaggeration. Where appropriate, comments made by the LMP and the commander (CDR) while the photographs were being taken have been included in the description of each stereopair. The times shown are in days:hours:minutes:seconds after launch.

Also discussed is information on lunar-soil formation. The information was derived by analyzing the stereoscopic photographs and comparing the results with the results of the Apollo 12 core sample analysis and other investigations.

As an aid to the reader, where necessary the original units of measure have been converted to the equivalent value in the Système International d'Unités (SI). The SI units are written first, and the original units are written parenthetically thereafter.

GEOLOGIC DESCRIPTION OF ALSCC STEREOSCOPIC PHOTOGRAPHS OF THE LUNAR SURFACE

Fifteen stereoscopic photographs of soil and rock surfaces were taken with the ALSCC (fig. 1) during the Apollo 12 mission. The estimated location of some of the photographs is shown in figure 2 (ref. 4). The types of lunar surfaces photographed were (1) soil and rock surfaces not greatly disturbed by the LM descent engine exhaust, (2) soil surfaces disturbed by the LM descent engine exhaust, and (3) soil surfaces disturbed by astronaut boots (table I).

Soil and Rock Surfaces Not Greatly Disturbed by the LM Descent Engine Exhaust

Because most of the ALSCC photographs were taken near the LM, very few photographs show undisturbed soil surfaces. The soil surfaces consist primarily of fine-grained fragments, with sizes below the resolution of the camera (figs. 3 and 4). In the photographs, the fragments with bright reflections are probably glass. In the samples returned from the Apollo 12 landing site, colorless to dark-brown glass spheres, ovoids, and angular fragments make up approximately 20 percent of the soil (ref. 5). Agglutinates, spinose masses of soil fragments, and glass held together by glass spatter are also present.

Fine soil fragments cover most of the rock fragments in the photographs, and positive identification is therefore impossible. Differentiation among dust-covered breccias (rock made up of fragmental debris), clods (moderately coherent soil broken into blocks), and crystalline rocks is difficult.

Some visible rock surfaces (fig. 5) were coated with glass spatter (i.e., melt probably formed and thrown out of a crater by meteorite impact) (ref. 6). The rock surface photographed in figure 6 is nearly free of small soil particles. Whether the photograph was taken in an area affected by the LM descent engine exhaust is not known.

Soil Surfaces Disturbed by the LM Descent Engine Exhaust

The soil surfaces disturbed by the LM descent engine exhaust (figs. 7 to 14) exhibit fluting (parallel, elongate ridges a few millimeters high), and the loose soil fragments are alined into elongate patches, parallel to the fluting. The linear features appear to have been formed when the surface was swept by exhaust gases from the LM descent engine. In some cases, fragments as large as 1 centimeter in diameter were plucked from the surface, which left steep-walled pits.

Soil Surfaces Disturbed by Astronaut Boots

Soil surfaces disturbed by astronaut boots are shown in figures 15, 16, and 17. The first two photographs (figs. 15 and 16) were taken of impressions left by the tread of astronaut boots in the lunar surface. The soil grains shown in figure 15 are considerably coarser than the soil grains shown in figure 16. One possible explanation for the difference in grain size is to assume that the figure 15 photograph was taken closer to the LM, where more LM descent engine exhaust erosion had taken place, which resulted in a coarser grained soil.

The cross section of the boot treads is slightly trapezoidal; the depth of the tread is 4.5 millimeters. The clean-cut appearance of the boot-tread impressions, as well as the stability of the nearly vertical walls of the impressions, is indicative of the cohesive nature of the lunar soil. On the basis of the soil mechanics surface sampler experiment on the Surveyor III spacecraft (ref. 7), the value of the cohesion has been estimated to be 343 to 686 N/m^2 (0.05 to 0.10 psi). For this range of lunar-soil cohesion, calculations show that a vertical wall of lunar soil 1 to 2 meters (3 to 6 feet) high will remain intact.

Lunar-soil cohesion is not destroyed by large deformations; this implies that the cohesion is not due to particle cementation. If the soil particles were cemented together, deformation of the soil (as when a bootprint is produced) would rearrange the particles and thus break the particle connections and irreversibly destroy the cohesion. This is not the case with lunar soil; the soil can be completely remolded, and yet it will retain some of its cohesion. The figure 15 and 16 photographs also show that the adhesion between the lunar soil and the boot sole is very small, because the clean, smoothly deformed surfaces would not be possible if lunar soil clung to the boot treads. (At one time, some scientists feared that the lunar soil would build up on the astronauts' boots like wet clay and thereby hamper their activities.)

SOIL FORMATION

The lunar soil (or regolith), which consists of angular rock fragments, individual crystals, and glass, probably results from repetitive bombardment of basalt flows by meteorites over long periods of time. The debris layer of the Apollo 12 landing site in the Ocean of Storms is 1 to 4 meters thick (ref. 8). Volcanic ash was possibly added to the lunar regolith at the Apollo 12 landing site, but the contribution seems minor when compared to the fragmentation and melting of surface debris by meteorite impact. J. Lindsay has suggested in personal communication with the authors that the mean grain size of the lunar soil should decrease near the surface. Larger particles on the lunar surface probably originated from deep impact craters that reached either bedrock or coarser lunar-surface debris.

In several of the photographs (figs. 3, 10, 11, and 13), a thin crust of slightly more coherent soil appears to exist on the lunar regolith. The thin crust is 1 to 2 millimeters thick, is a lighter gray than the less coherent soil beneath it, and appears to be finer grained (fig. 3). In the 40-centimeter-long core sample collected near Halo Crater at the Apollo 12 landing site, several layers of dark-gray soil were found that contained lighter friable fragments interpreted as fragments of a surface crust broken and mixed into the underlying soil by impacts of small meteorites (ref. 5). The lighter colored blocks in the soil sampled by the core tube are slightly more coherent than the matrix material. The coherence and strength of the crust appear to be due to a concentration of particles with a small mean grain size and better sorting than the underlying soil.

The concentration of fine-grained fragmental material in the upper few millimeters of the lunar soil could be due to bombardment of the lunar surface by very small high-velocity particles that break up surface fragments. These impacts do occur, as evidenced by a myriad of glass-lined, high-velocity impact pits on exposed rock surfaces (fig. 6).

An alternative hypothesis is that the uppermost soil layer is sorted by a form of thermal solifluction. Temperature changes on the lunar surface have a significant effect on only the upper few millimeters of lunar soil (ref. 8). It is possible that the sorting is due to the movement of particles by expansion and contraction.

CONCLUDING REMARKS

The closeup stereoscopic photographs taken by the Apollo 12 crewmembers provide information about the physical composition and genesis of the lunar soil (or regolith) on the Ocean of Storms landing site.

1. The lunar regolith consists of angular rock fragments, individual crystals, and glass. The soil composition probably results from repetitive bombardment of basalt flows by meteorites over long periods of time. Volcanic ash contribution appears to be minor.

2. Exposed rocks have many glass-lined impact pits as a result of bombardment by very small high-velocity particles.

3. Some rocks are coated with glass splatter (melt probably formed and thrown out of a crater by meteorite impact).

4. The lunar soil is cohesive and the cohesion is not caused by particle cementation.

5. The regolith has a thin, fine-grained, cohesive crust. The crust cohesion and strength appear to be due to the concentration of particles with a smaller mean grain size and better sorting than the underlying soil. The concentration could be due to the bombardment of the lunar surface by small high-velocity particles that break up surface fragments. Another hypothesis is that the uppermost soil layer is sorted by thermal solifluction.

6. Larger particles on the surface probably originated from deep impact craters or from coarser lunar-surface debris.

Manned Spacecraft Center
National Aeronautics and Space Administration
Houston, Texas, December 2, 1971
914-50-CA-95-72

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6. Greenwood, W. R.; and Heiken, Grant H.: Origin of Glass Deposits in Lunar Craters. Science, vol. 168, no. 3931, May 1, 1970, pp. 610-611.

7. Scott, R. F.; and Roberson, F. I.: Soil Mechanics Surface Sampler. Surveyor Project Final Report. Part II — Science Results. JPL Tech. Rep. 32-1265, 1968, pp. 195-207.

8. Shoemaker, E. M.; Morris, E. C.; Batson, R. M.; Holt, H. E.; Larson, K. B.; Montgomery, D. R.; Rennilson, J. J.; and Whitaker, E. A.: Television Observations from Surveyor. Surveyor Project Final Report. Part II — Science Results. JPL Tech. Rep. 32-1265, 1968, pp. 21-136.

TABLE I. - LUNAR-SURFACE CLOSEUP STEREOSCOPIC PHOTOGRAPHS

Description of the lunar surface	NASA photograph number[a]	Figure
Soil and rock surfaces not greatly disturbed by the LM descent engine exhaust	AS12-57-8454	3
	AS12-57-8455	4
	AS12-57-8452	5
	AS12-57-8446	6
Soil surfaces disturbed by the LM descent engine exhaust	AS12-57-8441	7
	AS12-57-8442	8
	AS12-57-8443	9
	AS12-57-8444	10
	AS12-57-8445	11
	AS12-57-8449	12
	AS12-57-8450	13
	AS12-57-8453	14
Soil surfaces disturbed by astronaut boots	AS12-57-8447	15
	AS12-57-8448	16
	AS12-57-8451	17

[a]The NASA photograph numbers were assigned in the chronological order in which the photographs were taken on the lunar surface.

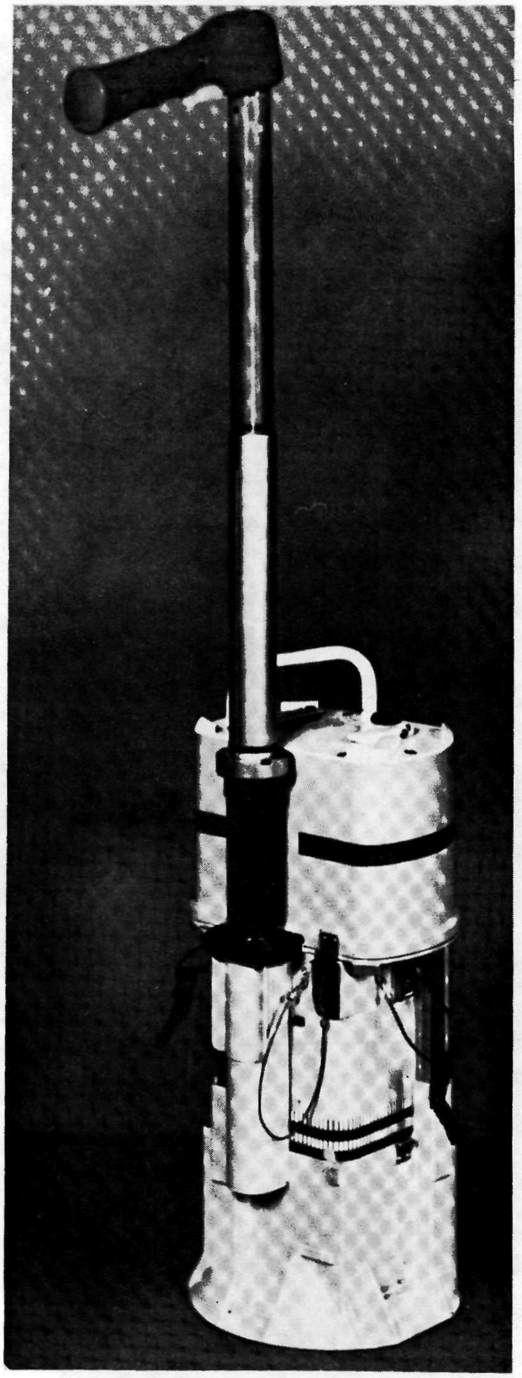


Figure 1. - Apollo lunar surface closeup camera.

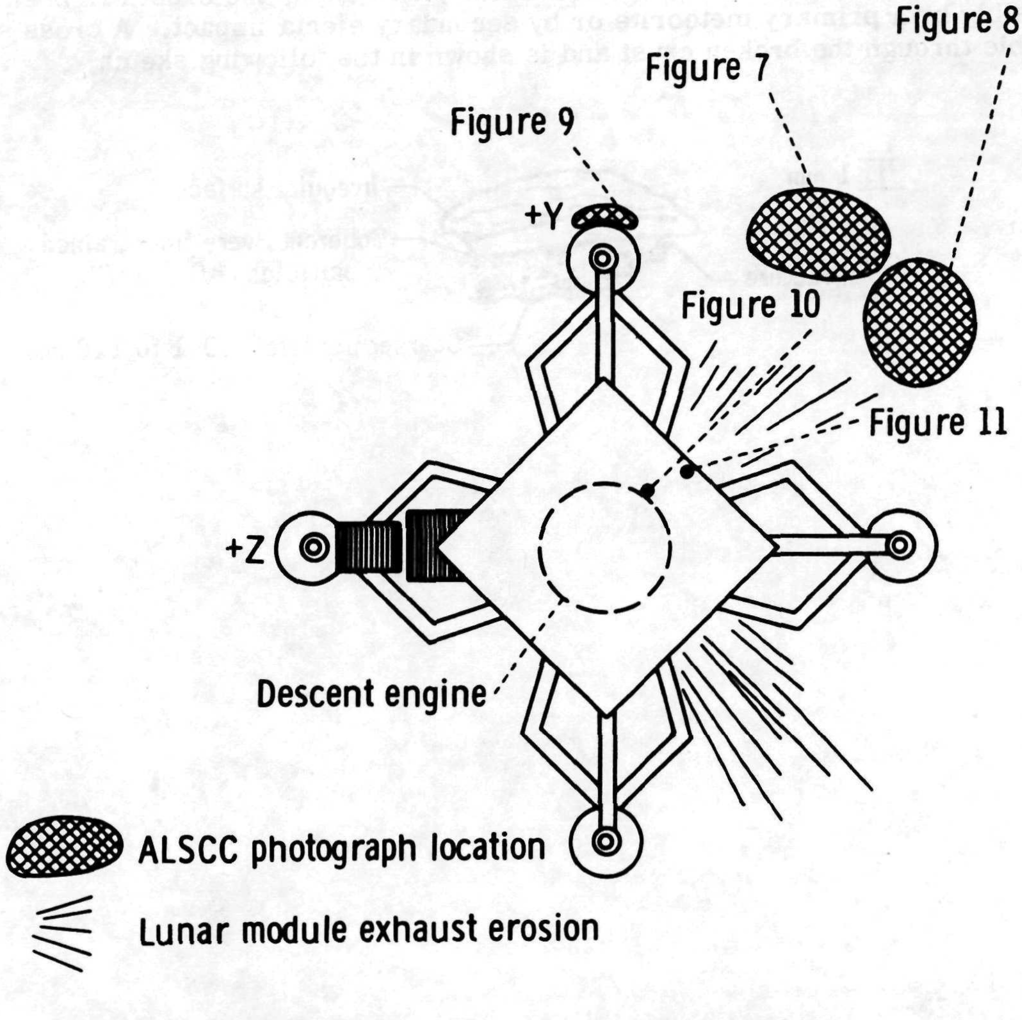


Figure 2. - Location of the Apollo 12 lunar surface closeup camera photographs (modified fig. 11-1(a), ref. 4).

Figure 3. - NASA photograph AS12-57-8454. The soil surface appears to be undisturbed by the LM descent engine exhaust. Clumps of soil and perhaps some soil-covered rock fragments are covered by a thin, irregular, moderately coherent crust, which was possibly cracked (cracks visible at the top of the photograph) by the downward pressure of the camera body on the soil. Nearly all loose surface fragments have either been incorporated into the crust or blown off. Rock fragments are difficult to identify in the photograph.

As shown in the lower center portion of the photograph, the crust has been disturbed, possibly by a primary meteorite or by secondary ejecta impact. A cross section is visible through the broken crust and is shown in the following sketch.

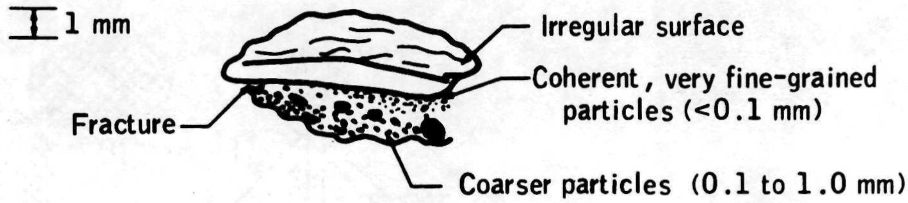


Figure 4. - NASA photograph AS12-57-8455. The soil consists of angular crust fragments(?) (1 to 25 millimeters long) and agglutinates (rock fragments, breccia fragments, and glass droplets bonded by glass spatter) in a fine-grained matrix. The agglutinates have spinose, irregular, vitreous surfaces, dulled slightly by loose surface dust. The matrix material probably has a particle-size distribution similar to that of the lunar soil studied by the Lunar Sample Preliminary Examination Team (ref. 5), with a median grain size of approximately 62 micrometers.

The soil surface shown in the photograph is irregular, with a crust of unknown thickness. The crust shown in the lower right portion of the photograph is cracked. None of the fragments can be positively identified as crystalline rock fragments. The large fragment shown in the upper right portion of the photograph is partly coated with glass spatter. The parallel lines in the photograph are due to film defects.

05:15:06:27 LMP: Okay, Pete, I'll take this as my last one.

Figure 5. - NASA photograph AS12-57-8452. The rough, irregular soil surface has abundant 1- to 10-millimeter-long angular rock fragments embedded in the soil and lying loose on the surface. The composition of the fine-grained soil (grain size less than 1 millimeter) cannot be determined from the photograph. The particles with bright reflections in the photograph have the same general appearance as the brown glass droplets and angular fragments in the lunar-soil samples. Glass is probably a significant component of the soil shown in the photograph.

Most rock fragments are covered with fine-grained soil or glass spatter and cannot be identified. However, shown in the upper right corner of the photograph is a dark-gray rock with abundant white angular phenocrysts, which may be a crystalline basalt. Near the upper left corner of the photograph, a medium-gray breccia with abundant feldspar clasts is visible. In the upper left near the top edge of the photograph, an angular feldspar-rich rock fragment is visible.

Most of the rocks greater than 2 millimeters in diameter are coated with glass spatter. The largest fragment, shown in the lower left portion of the photograph, is a good example. The top of the rock has been coated completely with dark-brown botryoidal glass, which is streaked out along the sides. (One side is visible.) Depressions in the smooth glass surface reflect the underlying rock surface and the vesicles that collapsed before quenching. Near the center of the rock, glass spatter has been broken away by later high-velocity impacts, which exposed the rock surface. The impacted points are roughly circular light-colored areas on the rock surface. In the center of each are pits lined with glass fused in place during the impact.

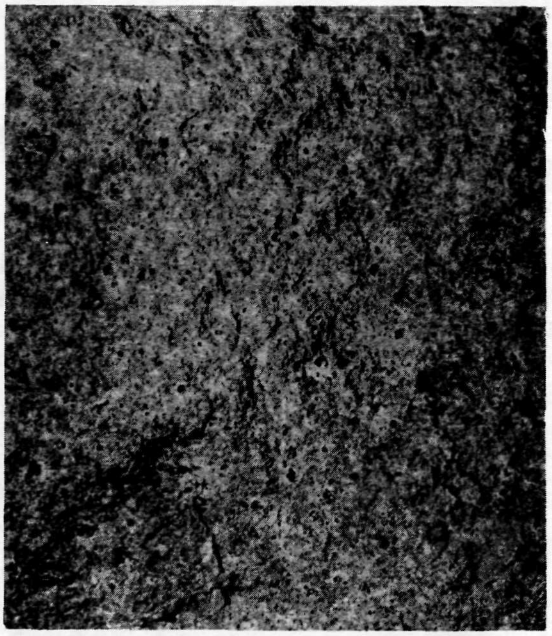
This locality of the lunar surface has been swept by either the LM descent engine exhaust or by some other type of current. Loose rock fragments are concentrated in depressions (upper right portion of the photograph) and on the surface of the largest rock, but the higher areas shown in the photograph are nearly free of loose debris. A lineation from the lower right to the top center portion of the photograph is visible on the higher area that crosses the center of the photograph.

Figure 6. - NASA photograph AS12-57-8446. The photograph shows the surface of a medium-crystalline basalt fragment. The surface has many glass-lined impact pits, each surrounded by a small white halo of fractured rock. The overall white appearance of the rock is due to the fracturing by the impacts. Pit diameters range from the limits of resolution in this photograph (0.01 millimeter) to 2 millimeters.

The surface is completely free of soil particles. If any soil particles were present, they were probably swept off by the LM descent engine exhaust. It is also improbable that soil particles would remain on the surface of an outcrop or exposed fragment, because of the bombardment by small meteorites.

An alternate explanation is proposed by Gold et al. (ref. 4), who have suggested "that there is a dust-transportation process over the lunar surface that has a strong tendency for downhill flow and in which the particles are generally not lifted as high (i.e., more than 5 or 10 cm) as the surfaces of the rocks that exhibit the clean areas."

05:15:02:59 LMP: Here's one of a rock.



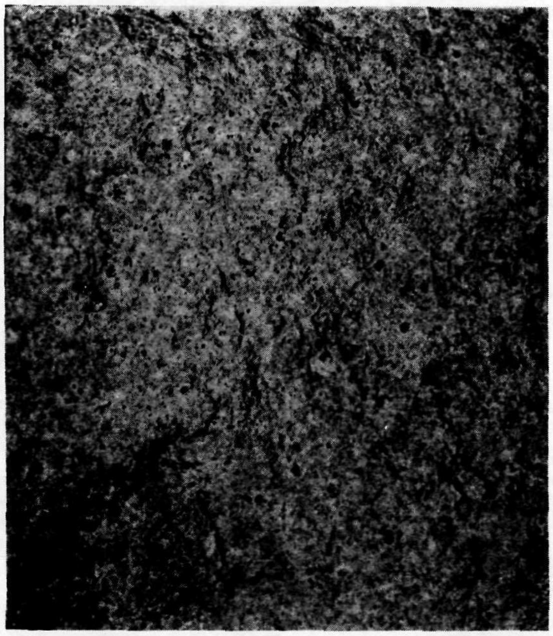
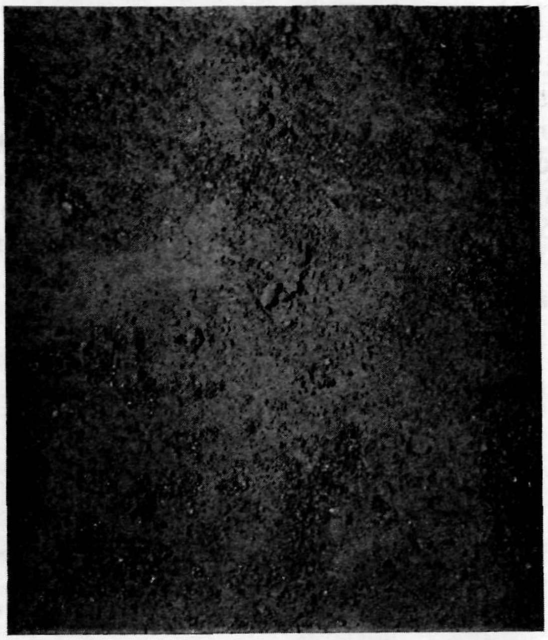


Figure 7. - NASA photograph AS12-57-8441. The lineations eroded into the surface crust by the LM descent engine exhaust are parallel to lines of loose fragments on the surface. Loose particles on the surface include clods of fine soil, feldspar crystals, and glass fragments, nearly all of which are less than 2 millimeters in diameter.

05:15:01:21 LMP: ... On this stereocamera, I'm taking a picture now, about 10 feet from the LM between the plus Y and minus Z strut, and I am hoping to show the effects of the engine exhaust on the lunar surface ....



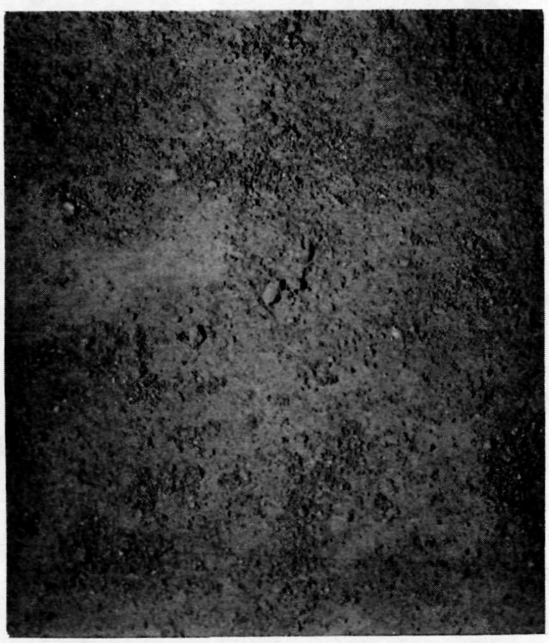
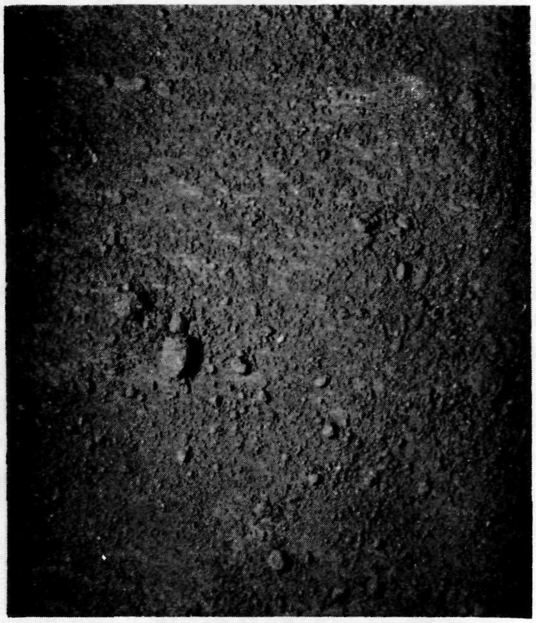


Figure 8. - NASA photograph AS12-57-8442. The photograph shows a soil surface that was swept by the LM descent engine exhaust. Most of the coarser fragments appear to have been transported from outside the small area that was photographed; no lee-side collection of finer particles next to the coarser fragments is evident. The coarser fragments appear to be subangular, equant fragments of breccia and glass agglutinates (glass and soil particles stuck together in an irregular, grapelike mass).

05:15:01:21 LMP: ... I'm going to take another one ....



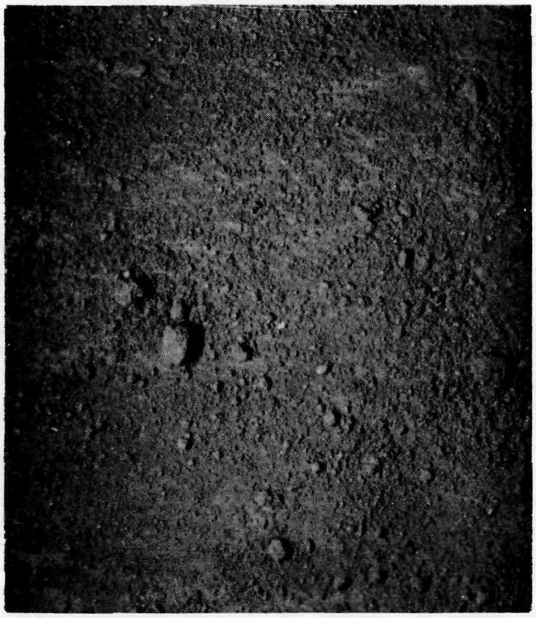
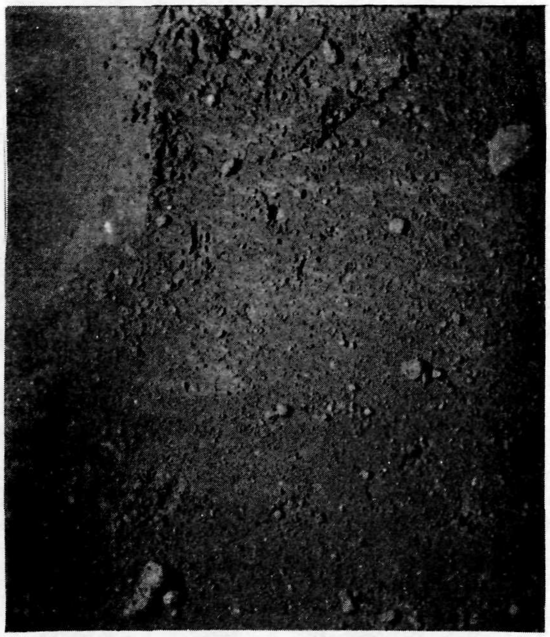


Figure 9. - NASA photograph AS12-57-8443. The soil surface has been swept by the LM descent engine exhaust, which left lineations. Depressions are left where 2- to 3-millimeter-diameter particles were possibly plucked out of the surface and swept along by the exhaust gases. The 1- to 10-millimeter-diameter particles lying loose on the surface appear to be mostly subrounded breccias, some with glass coatings.

The soil in the upper quarter of the area photographed was cohesive enough to form a vertical wall at the edge of the exhaust-gas disturbance and for a clump of it to slide over the surface without fragmenting (right center portion of the photograph). The photograph was possibly taken of an area in which the soil had been compressed by the LM footpad (ref. 4). However, the location of the area photographed is tentative, at best.



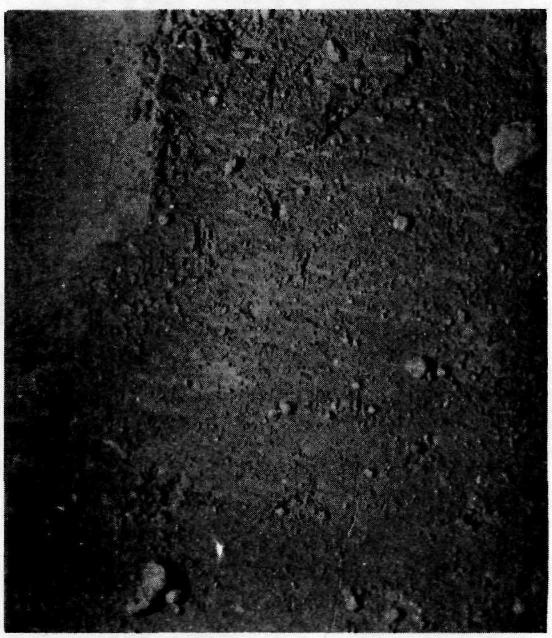


Figure 10. - NASA photograph AS12-57-8444. The crustlike, coherent soil surface has been swept by the LM descent engine exhaust. What appears to be a crust is highly irregular in shape and has been partly eroded by the LM descent engine exhaust. Parallel ridges and troughs, with relief of a few millimeters, are parallel to lines of loose soil that remain on the surface. Cracks in the crust are visible on the far lower right and extreme upper left portions of the photograph. One- to 2-millimeter-diameter basalt, breccia, and feldspar(?) fragments are lying on the coherent surface. The round hole approximately 1.5 millimeters deep (lower right portion of the photograph) is caused by either a fragment plucked out of the surface by the LM descent engine exhaust or by the impact of a small meteorite.

05:15:01:21 LMP: ... And I am taking the fourth picture right up next to the engine, here ....

Figure 11. - NASA photograph AS12-57-8445. The soil crust has been swept by the LM descent engine exhaust. Smaller particles have possibly been winnowed out, leaving 0.5- to 2-millimeter-diameter fragments bound into the surface crust. Fine-grained soil forms tapering ridges behind some of the larger protruding fragments, which indicates that the soil was sculptured by a current moving from the top to the bottom of the photographed area.

The cracks in the crust and the coherent fragment thrust up (right side of the photograph) appear to have been caused by disturbance by the camera or the astronaut's boot (or both). The crust is approximately 2 to 10 millimeters thick.

05:15:01:21 LMP: ... Okay, another one close to the engine, about 2 feet from the engine ....

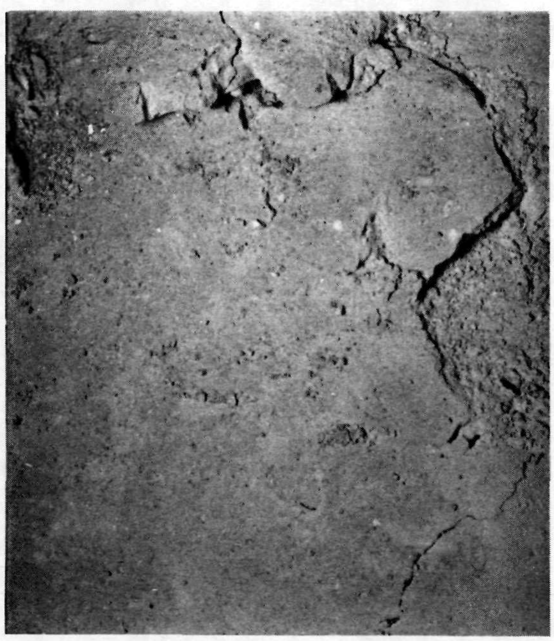


Figure 12. - NASA photograph AS12-57-8449. Erosion of a coherent surface crust by LM descent engine exhaust gases formed irregular, subparallel troughs. Larger particles (up to 6 millimeters long) that were bonded into the crust remain on pedestals of the soil (crust). The rock projecting out of the soil on the far left is covered with glass spatter. Loose particles on the crust surface consist of clods of fine soil, glass fragments, and several basalt(?) fragments. The crust is broken in the lower center part of the area, possibly by an exhaust-blown saltating fragment, by a fragment plucked out of the crust, or by the impact of a small meteorite.

05:15:04:44 LMP: I'll take some of these pictures until you give me a call, Pete.

05:15:04:48 CDR: Why don't you just start working your way over here, Al? And we've got an awful lot of gear, and we will start getting her up.

Figure 13. - NASA photograph AS12-57-8450. The soil surface, with 0.5- to 30-millimeter fragments protruding from the surface, has been swept by the LM descent engine exhaust or by an undetermined current. Much of the fine-grained fragmental material has been winnowed out, which left coarse-grained particles on the surface of a moderately coherent crust. The crust surface has been sculptured by the current, which left lineations and elongate oriented fragments.

A clastic rock, partly coated with glass, is visible in the lower right corner of the photograph. The rock is firmly embedded in the surrounding soil and is tilted in place. The soil crust adhering to the rock was also tilted.

Figure 14. - NASA photograph AS12-57-8453. The irregular surface crust on the soil was probably swept by the LM descent engine exhaust gases, which removed most of the loose particles from the crust surface. One- to 4-millimeter-long particles were held fast in the moderately coherent crust, and these particles project above the surface, sometimes on pedestals.

Shallow depressions 5 to 10 millimeters deep, shown in the lower right and left center portions of the photograph, may have been caused by small meteorite impacts or by secondary impacts of ejecta from larger craters. Several 1-millimeter-long glass droplets are visible near the lower left corner of the photograph. Broken bits of crust and loose soil, where the surface was disturbed by the camera or by the astronaut's boot, are visible near the upper edge of the photograph.

Figure 15. - NASA photograph AS12-57-8447. The following items of interest are visible.

1. A small cross-shaped particle at point A seems to have fallen out of the rim of the tread wall at point B.

2. A small round particle at point C may have been plucked out of the soil at point D when the astronaut withdrew his boot.

3. A large flat particle at point E, evidently composed of much finer coherent particles, has slipped off the tread wall. Perhaps the soil was disturbed by the camera edge.

4. The distribution of coarse particles in the finer particle matrix is not uniform.

05:15:02:59 LMP: Now, I am taking a picture of Pete's footprint in the soil. You can take a look at the interaction of that. Take another one.


A
B
C
D
E

Figure 16. - NASA photograph AS12-57-8448. The following items of interest are visible.

1. The grain size is uniformly fine.

2. The tread wall at point A, which has broken off, was probably disturbed when the astronaut withdrew his boot. Note that many of the aggregates consisting of smaller cohesive particles have remained intact.

3. The tread at point B has cracked completely through, because of the slight difference in elevation.

4. At point C, a hairline crack is running through the soil.

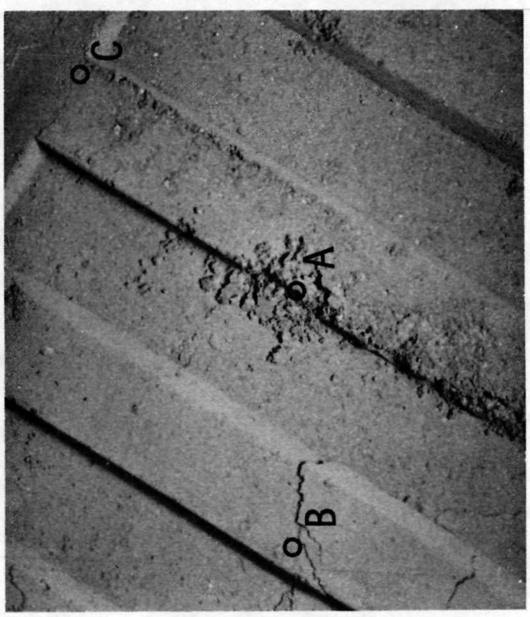

C
A
B

Figure 17. - NASA photograph AS12-57-8451. The surface was possibly covered by soil kicked over it by an astronaut. The photograph appears to be of a resistant flat surface, covered by loose soil fragments. Most of the 1- to 5-millimeter-diameter particles appear to be moderately coherent soil aggregates (clods). No definable rock fragments are visible in the photograph.