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LUNAR-SURFACE CLOSEUP STEREOSCOPIC PHOTOGRAPHY ON THE SEA OF TRANQUILITY (APOLLO 11 LANDING SITE)

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SUMMARY

Analyses of returned lunar samples provide limited information about lunar geology. To obtain information about in-place lunar material, a closeup stereoscopic camera capable of photographing small-scale surface features was built and was used at the Apollo 11 landing site. Stereoscopic photographs were taken of surface areas relative to the lunar module, and the surfaces photographed were analyzed. The photographs are classified into five groups: soil disturbed by astronaut activities, generally undisturbed soil, loose aggregate surface material, crater bottoms with prominent glass deposits, and hard rock deposits. Glass deposits in the returned samples are described for comparison with the features observed in the photographs.

The stereoscopic photographs were of outstanding quality and show the nature of lunar-surface material in detail. Lunar topography was reconstructed from the photographs with an analytical plotter. The photography results indicate that the closeup stereoscopic camera provided information, otherwise unobtainable, about the physical composition and genesis of lunar soil at the Apollo 11 landing site.

INTRODUCTION

Preliminary information about the physical and chemical properties of the moon and Tranquility Base in particular has been provided by the lunar samples returned on the Apollo 11 mission. Because of the mechanical environment to which lunar samples are subjected during return from the moon, only limited information about lunar geology can be obtained from samples of the loose, fine-grained material that composes the upper surface of the lunar crust. To obtain information about in-place material on the lunar surface, a stereoscopic camera, the Apollo lunar surface closeup camera (ALSCC), was built under contract to NASA. The camera, capable of photographing

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small-scale (between microscopic and macroscopic) surface features, was used during the Apollo 11 mission. The camera was also used during the Apollo 12 mission (ref. 1).

The photographs taken with the closeup camera during the Apollo 11 mission are of outstanding quality and show the nature of the lunar-surface material in detail. Several photographs contain unusual features. In this report, the photography is described and an analysis (based upon the preliminary physical and chemical data obtained from the lunar samples) is presented of the surfaces photographed with the closeup camera. Also discussed is the reconstruction of lunar topography from the closeup photographs by use of an analytical plotter.

Thanks are due to the field geology team for the traverse map and to the crew of Apollo 11.

GEOLOGIC DESCRIPTION OF ALSCC STEREOSCOPIC PHOTOGRAPHS OF THE LUNAR SURFACE

The ALSCC, built under contract to the NASA Manned Spacecraft Center (MSC),[1] optimizes operational simplicity (fig. 1). The camera is an automatic, self-powered, twin-lens, stereoscopic camera capable of recording, in color, objects as small as 85 micrometers in diameter. Simplicity of operation was achieved by making the camera focus and the exposure controls fixed and by preloading the camera before launch with sufficient Ektachrome multispectral (SO-368) film for the complete mission. To take a photograph, an astronaut merely sets the camera over the material to be photographed and depresses the trigger located on the camera handle. The film is advanced automatically to the next frame, and the electronic flash is recharged when the exposure has been completed.

The requirement to simplify the ALSCC operation necessitated a reasonable depth of field that could be achieved only by reducing the image magnification produced by the system. The camera lenses are diffraction-limited, 46.12-millimeter, f/17, Kodak M-39 copy lenses focused for an object distance of 184.5 millimeters and providing an image magnification of 0.33. The lenses are mounted 29 millimeters apart with optical axes parallel. The area that is photographed is 72 by 82.8 millimeters and is centered between the optical axes. Thus, stereoscopic photographs with a base-to-height ratio of 0.16 are provided (fig. 2).

The specific locations at the Apollo 11 lunar landing site where individual stereoscopic photographs were taken cannot be determined with a high degree of confidence. Because of the limited size of the area photographed by the ALSCC, the subject material cannot be identified within the large-scale lunar-surface photographs. In the scientific debriefing of the Apollo 11 crew, the commander, Neil A. Armstrong, indicated the general areas relative to the lunar module (LM) where sequential sets of photographs were taken. Based upon the comments of Armstrong and the time history of

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[1] By T. Gold, Cornell University.

events while the astronauts were on the lunar surface, the general location of the photographs was established tentatively (fig. 3).

The photographs (figs. 4 to 21) can be classified into five groups that show common features: (1) soil disturbed by astronaut activities, (2) generally undisturbed soil, (3) hard rock surfaces, (4) loose aggregate surfaces, and (5) crater bottoms with prominent glass deposits.

Soil Disturbed by Astronaut Activities

Soil that was disturbed by astronaut activities is shown in figures 4 and 5(a). The disturbed soil has a granular texture and is composed generally of loose aggregates of surface material from 2.5 centimeters in size down to the lower resolution limit of the ALSCC (approximately 85 micrometers). The grain size of the material comprising the aggregates is generally less than the resolution of the ALSCC. Abundant small (1 millimeter and less), honey-brown reflections (probably from small glass shards) appear in stereoscopic transparency slides of figure 5(a). A small (approximately 2 millimeters) glass aggregate is seen in the upper left quarter of figure 4. The glass aggregate appears to have been exposed by the surface disturbance. The overall color of the surface material appears to be gray brown. The larger granular aggregates appear to have a planar structure. No impact pits are seen on the aggregate rocks in the photographs (figs. 4 and 5(a)).

Generally Undisturbed Soil

Soil that is believed to be generally undisturbed is shown in figures 6 to 11. The surface appears to be smooth, with linear flutings that appear to be caused by the erosion of a vertical planar structure in the soil. The structure may be the result of shock waves from nearby meteorite impacts. Erosion of the structure may be the result of the LM exhaust or may be an effect produced by the erosional process that rounded the lunar rocks. Rock fragments as large as 1 centimeter in diameter on or partly buried in the eroded surface are shown in figures 6 to 9. The rocks appear to be hard aggregates of surface material. Some loose, granular aggregates are scattered on top of the smooth surface (especially noticeable in fig. 10). This granular material may have been kicked up by the astronauts as a fine spray. The effect, caused by a nearby foot impression or by the camera on the sculptured surface, is shown in figure 11. The material has a rough, somewhat polygonal fracture pattern and a crusty appearance.

Glass spherules are shown in all figures (as large as 1.5 millimeters in fig. 10). Some of the spherules are shiny (as in fig. 11, upper right) and some are dull, dark gray (as in fig. 10; compare with the shiny spherule near the right edge of fig. 10). The disturbance in the area shown in figure 11 has spherules mixed in the soil. A few glass deposits are shown in figures 6 to 9 and in figure 11. These glass deposits include a general coating of small areas (as large as 1 centimeter in fig. 7), which appear to have been melt that flattened upon landing. The sculptured surfaces appear to be a lighter gray than the loose aggregates of the disturbed surface.

Loose Aggregate Surface Material

Loose aggregate surface material on the moon is shown in figures 12(a) and 13(a). These figures show large (greater than 4 centimeters) fragments of weakly coherent surface material that is similar to the broken crust shown in figure 11. The loose aggregate material has an irregular fracture and a faint planar structure. Glass spherules can be seen in figure 12.

The weakly coherent crust has been broken by the vesicular rock shown on the left in figure 13(a). Broken fragments of this crust are visible in the lower part of the photograph. This crust was broken by impact of the crystalline rock, forming a small secondary crater, or by the jarring loose of a partly buried rock.

Crater Bottoms with Prominent Glass Deposits

The bottom surfaces of small (1-meter diameter) craters that contain glass deposits that were visible to Armstrong are shown in figures 14 to 16(a). The craters with prominent glass deposits have raised rims. Six to eight glass-containing craters were observed. No sample material was collected from these craters. The glass deposits are of two types: (1) a coating of glass on rocks or on soil and (2) small clusters composed of one or more glass spherules. Both types of deposits are shown in figures 14 and 15. Armstrong stated that glass coatings from 1 to 10 centimeters in diameter occur on clusters of three to 10 deposits in the center of the craters in which glass deposits were observed. No glass coatings were observed on the crater rim or between craters. Many of the 1-meter-diameter craters did not have glass coatings. No glass deposits were observed in larger craters. Armstrong compared the glass deposits to balls of solder that had hit the surface in a fluid state and splattered flat on the bottom, with rounded corners and an irregular surface. He stated that these glass deposits had an opaque metallic luster, not the golden color that is shown in some of the photographs. No glass deposits were seen near the LM descent engine bell. The photographs show that the glass covers rock in a patchy fashion and occurs mostly on the prominences. The glass patches have a grapelike upper surface and appear to be composed of clusters of flattened droplets. A difference in the grain size and texture of the loosely aggregated fragments is shown in the upper half of figure 16(a) and the moderately well-indurated material appears to be in place and to have a planar structure. Glass is deposited on the indurated material. The coarser loose material appears to cover the indurated material with a sharp contact. The coarser loose material also appears partially to cover the glass.

Hard Rock Surfaces

Hard rock surfaces are shown in figures 17 to 21. The surface features of a 1- by 3-foot rock described by Armstrong as having the upper surface parallel to and slightly above the surrounding soil are shown in figures 17 and 18. The rock was described as being hard and having a weathered surface. The photographs were taken to show surface pitting of the rock and the breccia-fragment shapes. Rocks similar to many microbreccias that were found in the returned sample are shown in figures 17 to 20. The breccia includes lithic fragments of crystalline rocks of basaltic composition, crystal fragments, and glass spherules and shards. The pitting of a lithic fragment 3 centimeters in diameter and the fine matrix material are shown in figure 17. The surface pits are as large as 3 millimeters across, have slightly raised rims, and are glass lined. In addition, a light halo, probably a result of shock-induced microfracturing, surrounds the pits (especially in the crystalline fragments). Minor fluting of the soil occurs at the edge of the rock in figure 19. The rock shown in figure 20(a) is rounded. The rock surfaces shown in the other photographs also appear to be eroded. The lack of relief at the boundary of included crystalline fragments shows that the erosional process does not emphasize small differences in hardness. The large rock surfaces are generally without dust, which may have been caused by the LM exhaust.

Summary Description of the Glass Deposits in the Returned Samples

Because of the unique character of the glass deposits, it is interesting to compare the features observed in the photographs with the material examined in the Lunar Receiving Laboratory (LRL). Approximately 20 percent of the glass of the 1-millimeter to 1-centimeter size fraction of the returned samples in the LRL is composed of individual glass spherules. Most spherules appear to be partly hollow and to contain one or several vesicles. A broken glass spherule revealed a large central vesicle with smooth inner walls. Within the walls, which are 1.5 to 1 millimeter thick, 0.1- to 0.2-millimeter-diameter vesicles are abundant. The outer surface of the glass spherule is smooth. Many glass spherules are dulled by irregularities in the outer surface and by dust that adhered to the glass as the glass cooled. Approximately 5 percent of the large-fines fraction are blocky, angular fragments of brown to colorless glass. Twenty percent of the coarser fraction consist of angular and round pieces of glass, rock fragments, and mineral grains, bound together by a thin glass sheet in small irregular "pancakes."

Approximately 20 to 40 percent of the samples in the 37-micrometer to 1-millimeter size fraction are glass. This fraction includes spherules of colorless, brown-reddish, and green glasses, of which brown-reddish glass is the most abundant. The glass surfaces generally are smooth and shiny, causing the shiny reflections seen in closeup photographs of the lunar surface. Most of the spherules are solid glass; some glass spherules contain small vesicles in the center or slightly to one side. Some ovoid and dumbbell-shaped spherules are present. Some glass spherules are opaque, a result of surface texturing and devitrification. Angular, blocky glass fragments are also present, and these fragments exhibit the same variety of colors as the glass spherules.

The size fraction less than 37 micrometers is composed mostly of angular, blocky fragments of brown, red, and colorless glasses. The colorless glass generally has a refractive index of less than 1.54. The more deeply colored glasses have refractive indices as great as 1.70.

Present on many of the larger rocks are minute, irregular splashes, with some droplets radiating out from the center of the patch. Generally, the thickness of the splashes is approximately 0.5 millimeter. One of the larger splashes covers an area of approximately 6 by 3 centimeters on LRL specimen 10056,0. The glass is approximately 0.5 millimeter thick and has an irregular surface caused by irregularities in the underlying rock and by broken and unbroken bubbles in the glass coating.

Some of the smaller rocks are enveloped in a thin glass coating. The LRL specimen 10002,15 (which is an elongate, blocky, finely crystalline rock) is covered on four sides by a thin coating of glass. The 0.5-millimeter-thick glass coating closely adheres to the rock surface; the glass coating is a smooth version of the original surface. No obvious heating effects are evident in the mineralogy or texture of the coated rock. Abundant bubbles exist within the glassy film. On uncoated sides of the rock are thin streamers and droplet trains of glass.

Most of the returned rocks have small (3-millimeter diameter maximum) pits with raised rims. These pits are lined with dark glass. The glass in these pits apparently is caused by fusion of the rock during impact of micrometeorites or other high-velocity particles (fig. 21).

The spherules and splashes of glass appear to have been produced by the fusing of the rock and soil caused by the impacts of meteorites. Splashes that landed on loose soil (binding particles together in pancakes) are uniformly mixed through the lunar soil, as are glass spherules. Vesicular glass fragments and shards are also present. The contact is sharp between thin glass splashes and the rocks to which the splashes adhere. No heating effects are visible. If the glassy surfaces had been formed in place by the melting of the rock surface, a continuous gradation from glass to finely crystalline rock to coarsely crystalline rock (in the case of holocrystalline rocks) should exist. No such visible gradation is observed. The small rocks that almost or entirely are enclosed in glass probably were coated while in the explosion plume above an impact crater. The clusters of glass spherules probably resulted from the semi-coalescence of separate spherules in the explosion plume. Although the crewmembers observed glass deposits only in the bottoms of small craters, glass deposits too small to be seen by the crewmembers are shown in photographs that were taken near the LM and away from the small craters. There is an abundance of this material in the soil and on the rocks returned to the LRL.

SMALL-SCALE LUNAR-SURFACE TOPOGRAPHY

Topographic detail of the lunar surface was compiled on the AS-11A1 analytical plotter from photographs taken with the ALSCC. Five stereoscopic photograph pairs were selected for use in contouring. These pairs (shown as single frames in figs. 5(a), 12(a), 13(a), 16(a), and 20(a)) exhibit the most relief of the 17 stereoscopic pairs exposed. These stereoscopic pairs were assumed to be the ones in which scientists would be most interested in obtaining measurements in the third dimension. The topographic models (figs. 5(b), 12(b), 13(b), 16(b), and 20(b)) were compiled by the NASA MSC Mapping Sciences Laboratory.

Because of the great versatility of the analytical plotter, reconstruction of the given geometry of the ALSCC was possible. The parameters shown in figure 2 were used in orientating the models. A focal length of 61.5 millimeters was used for each photograph. A value of 184.5 millimeters was used for bz. (The distance from the front nodal point of each lens to the plane of best focus in the object field is represented by bz.)

Values of -14.5 and +14.5 millimeters were entered for bx for the left and right photographs, respectively, and for each of the other stereoscopic pairs. The contact-size film transparencies were centered by means of the four fiducial marks on each photograph. Because these fiducial marks do not indicate the location of the principal point nor of the optical axis in the format, an offset of +4.5 and -4.5 millimeters in x was applied to the left and right photographs, respectively. No correction for radial distortion was entered into the orientation of the models. A relative orientation of the right photograph to the left photograph was performed in every situation, using an average of eight orientation points for each model. The resulting residual y parallax was less than 10 micrometers in each model.

This orientation procedure resulted in the instrument-model scale being the same scale as the object-scene scale. The elevations in the model were equal to the elevation of each point on the lunar surface with respect to the plane of best focus. The elevations on the contour sheets were adjusted, however, to maintain positive values. Thus, the contour values indicate only the relative elevations of one point with respect to another point and have no relation to the plane of best focus. The contour interval for each sheet is 1 millimeter.

The models were plotted at a coordinatograph scale of 3:1 or 5:1 and subsequently reduced to model scale (actual size) for presentation. Because of the many vertical and undercut faces and shadow areas, contouring was difficult. No experimentation was performed with different methods of expressing the relief, such as different contour intervals coupled with form lines, methods of portraying cracks and shadow areas, or the use of profiles across selected directions.

The ideal presentation would seem to be an orthophotograph with a contour overlay, which would allow direct correlation of elevations with features on the photographs. The analytical plotter that was used does not have the capability of generating the required orthophotographs; thus, the correlation between the contour representation and the photographs may appear to mismatch. The individual photographs exhibit considerable horizontal displacement of features caused by the elevation differences with respect to the plane of best focus. The contour representation is an orthographic projection into the plane of best focus; hence, the contour representation shows the correct planimetric position of features.

CONCLUDING REMARKS

Photographs taken by the Apollo lunar surface closeup camera provide information about the physical composition and genesis of the lunar soil (or regolith) at Tranquility Base.

1. The regolith is composed of glass particles, rock fragments (basalt and a clastic rock composed of regolith material), and crystals from broken crystalline rocks.

2. The soil is weakly coherent and has a thin surface crust.

3. Rock surfaces are pitted. The glass-lined pits probably were caused by the impact of small meteorites.

4. Some rocks in the bottoms of small (1-meter diameter) craters are covered partly with glass coatings. The coatings could have formed as fallout of melt formed during the impact of small meteorites; the glass spherules and droplets could have been formed in the spray of melt ejected by the impact. Much of the regolith around the craters contains glass fragments and spherules formed in this manner.

Manned Spacecraft Center
National Aeronautics and Space Administration
Houston, Texas, December 1, 1971
914-50-CA-95-72

REFERENCE

1. Heiken, Grant H.; and Carrier, W. David, III: Lunar-Surface Closeup Stereoscopic Photography on the Ocean of Storms (Apollo 12 Landing Site). NASA TM X-58078, 1971.

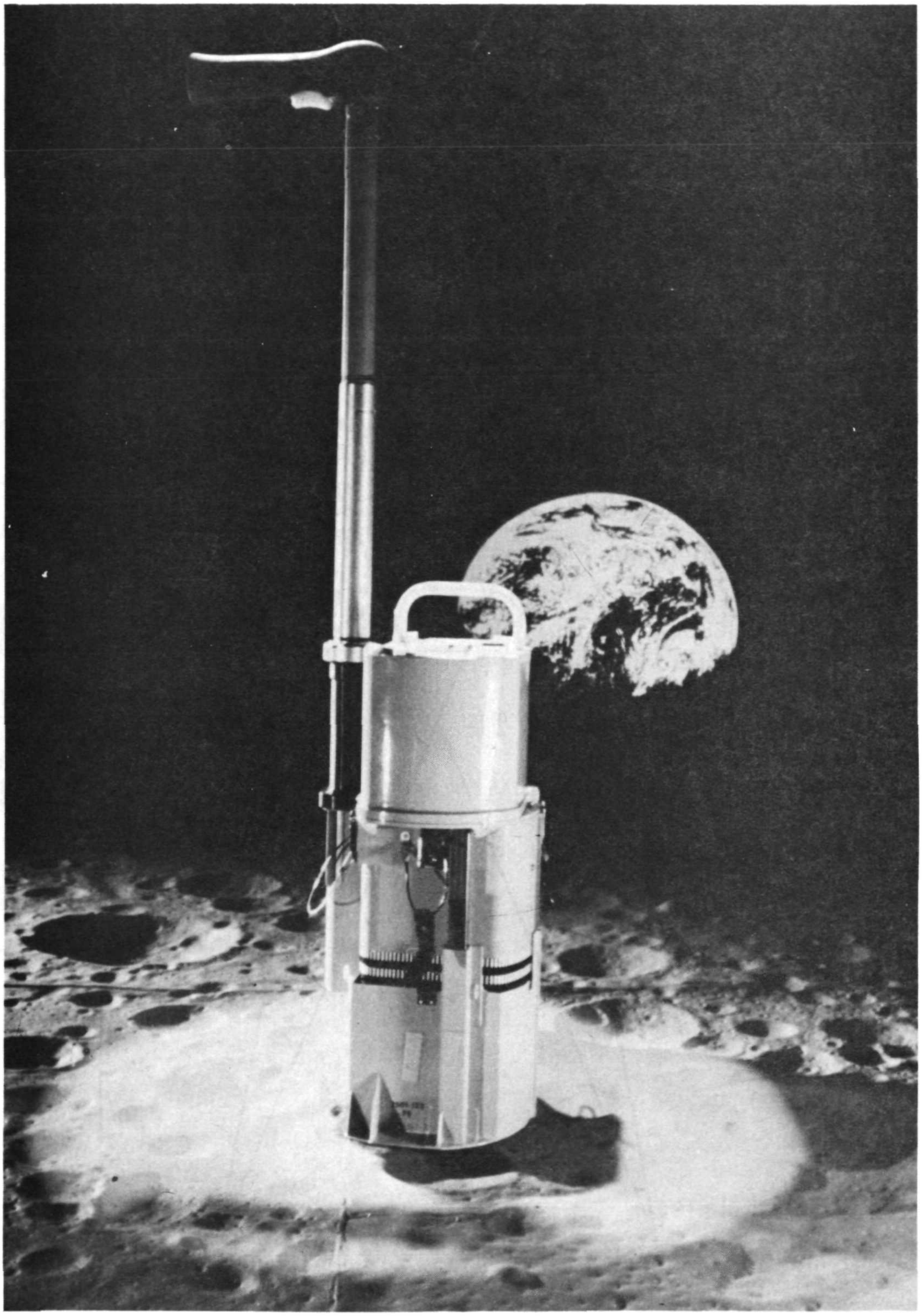


Figure 1. - Apollo lunar-surface closeup camera.

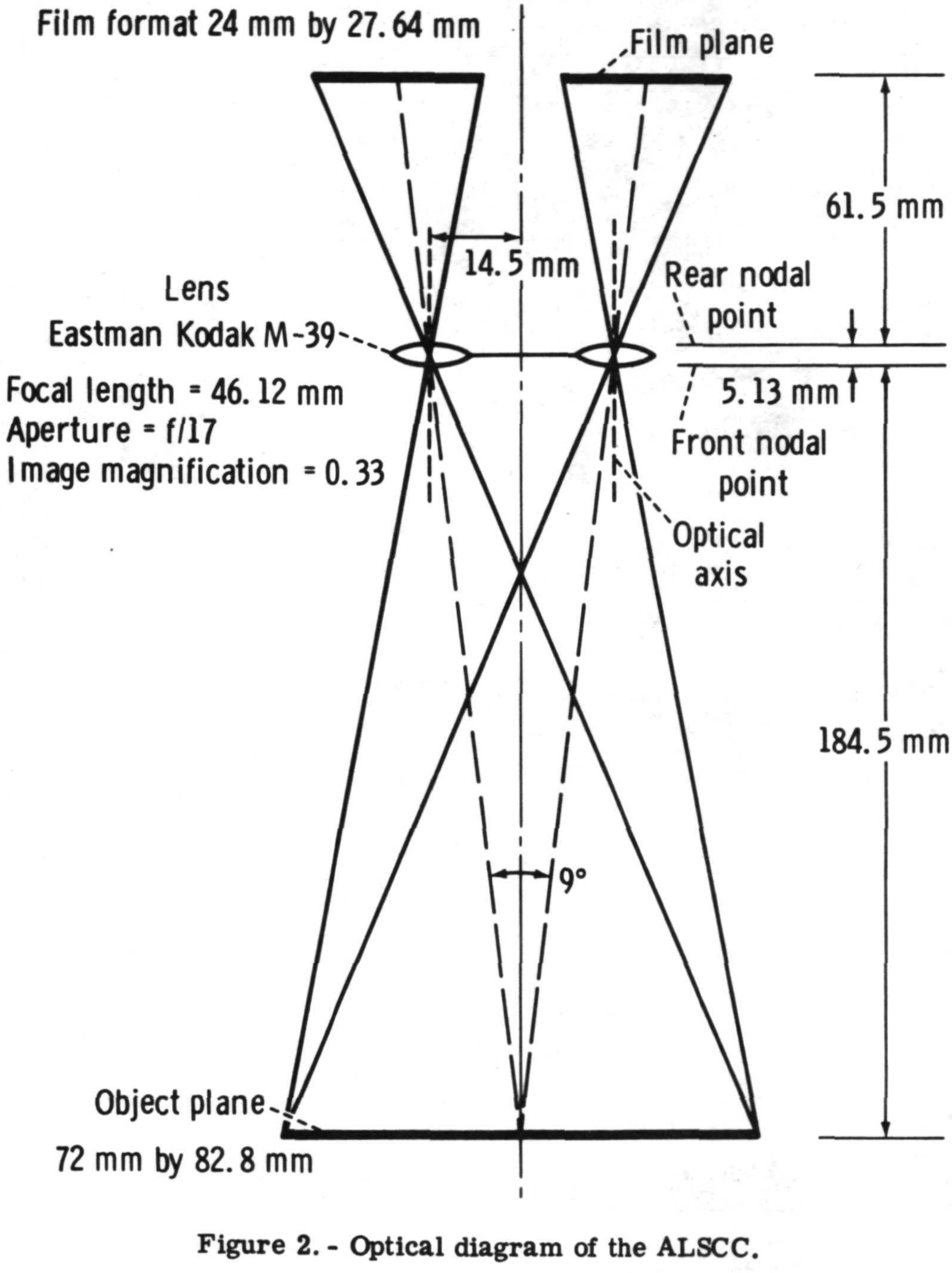


Figure 2. - Optical diagram of the ALSCC.

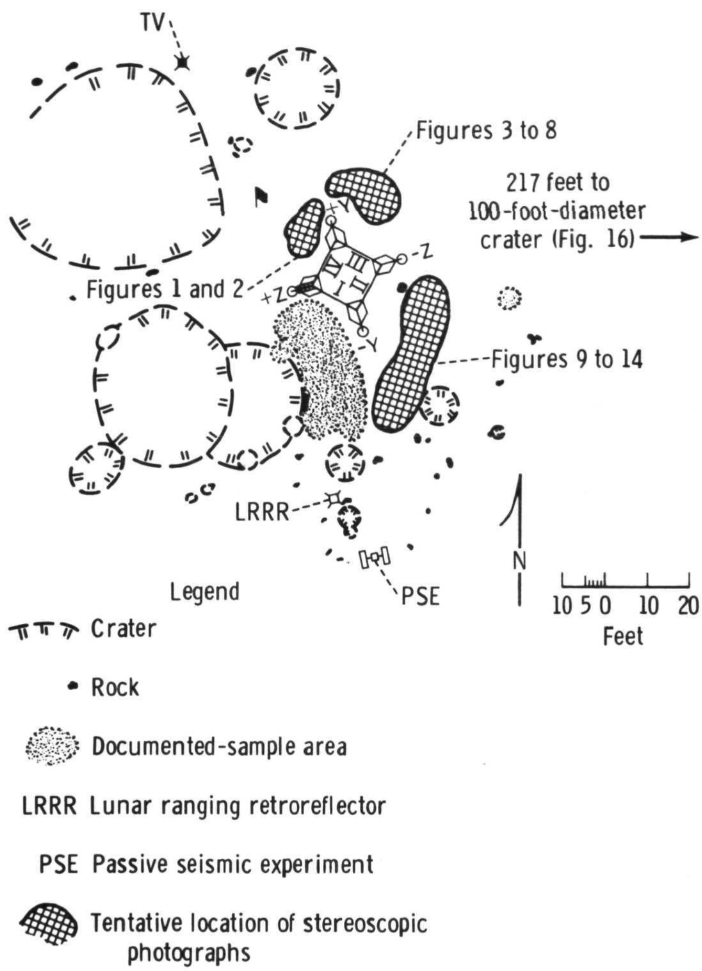
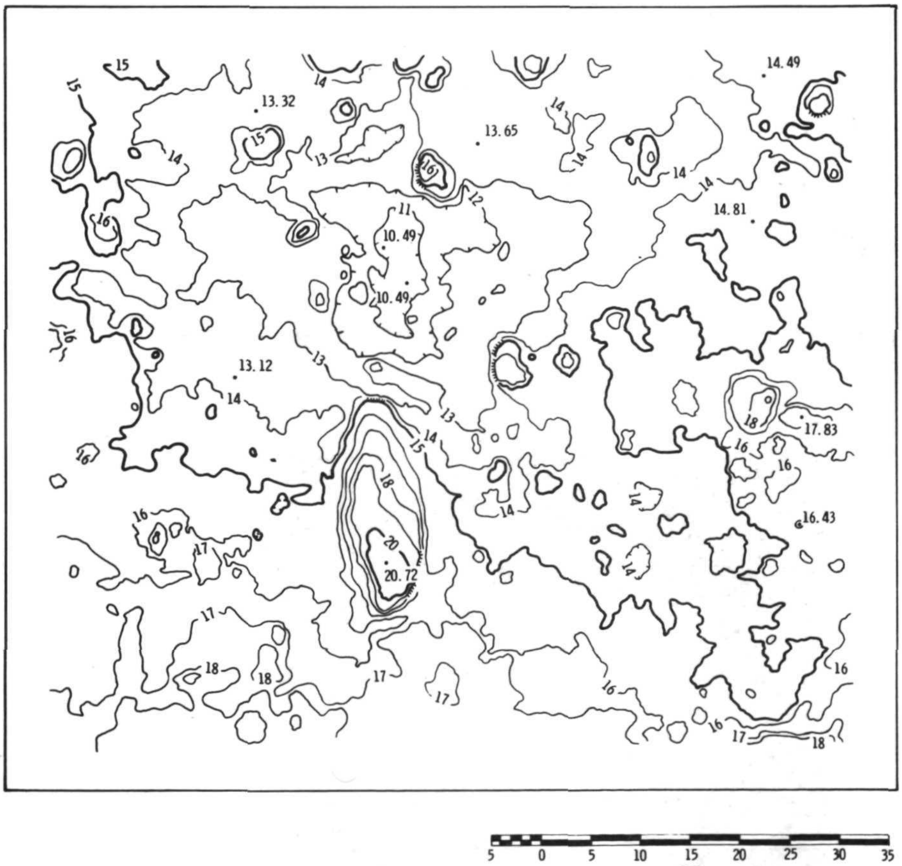


Figure 3. - Tentative location of ALSCC photographs.

Figure 4. - Lunar soil disturbed by astronaut activity (NASA AS11-45-6697).

(a) NASA photograph AS11-45-6698.



(b) Topographic representation.

Figure 5. - Lunar soil disturbed by astronaut activity.

Figure 6. - Lunar soil disturbed by LM engine exhaust (NASA AS11-45-6699).

Figure 7. - Lunar soil disturbed by LM engine exhaust (NASA AS11-45-6700).

Figure 8. - Lunar soil disturbed by LM engine exhaust (NASA AS11-45-6701).

Figure 9. - Lunar soil disturbed by LM engine exhaust (NASA AS11-45-6702).

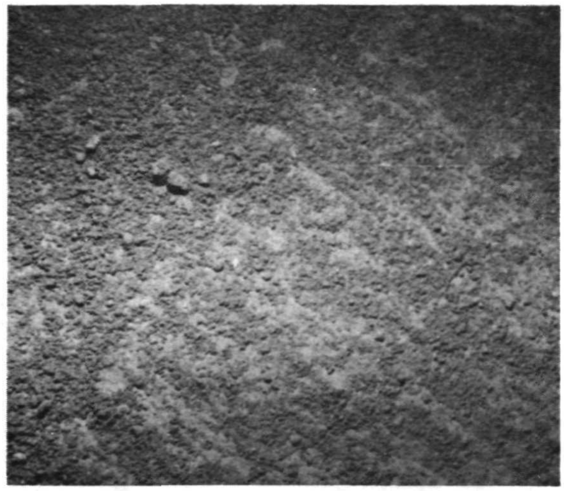
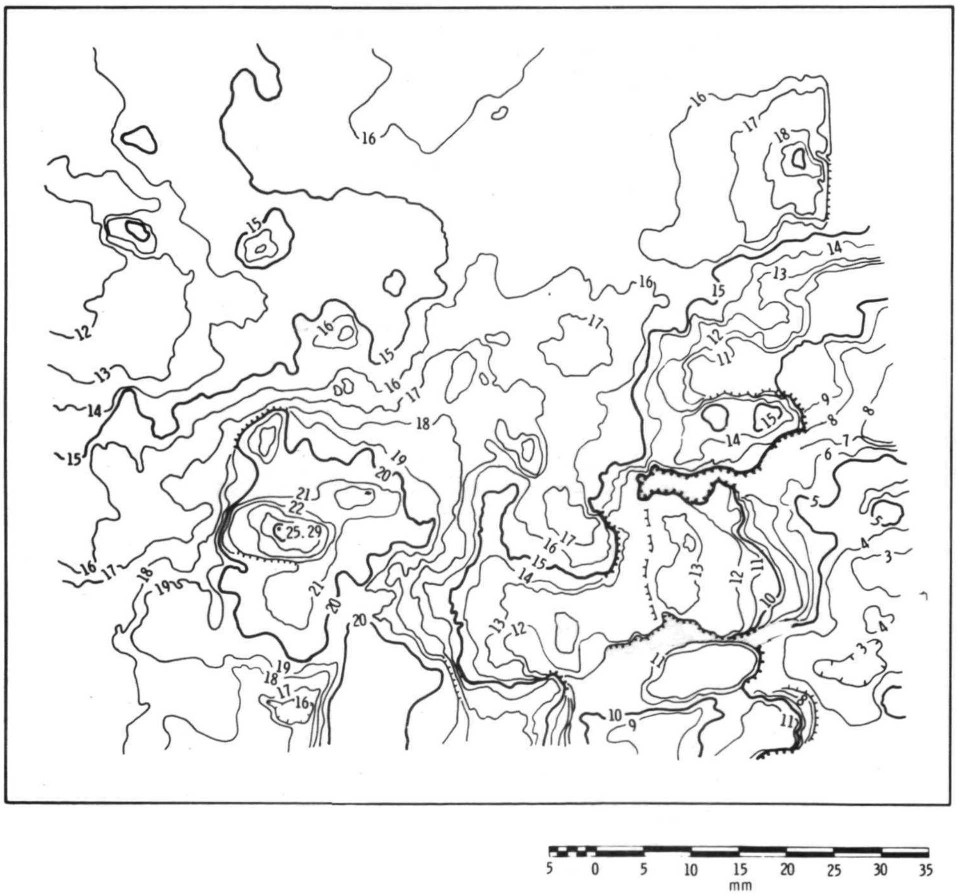


Figure 10. - Lunar soil disturbed by LM engine exhaust (NASA AS11-45-6703).

Figure 11. - Lunar soil disturbed by LM engine exhaust (NASA AS11-45-6702-1).

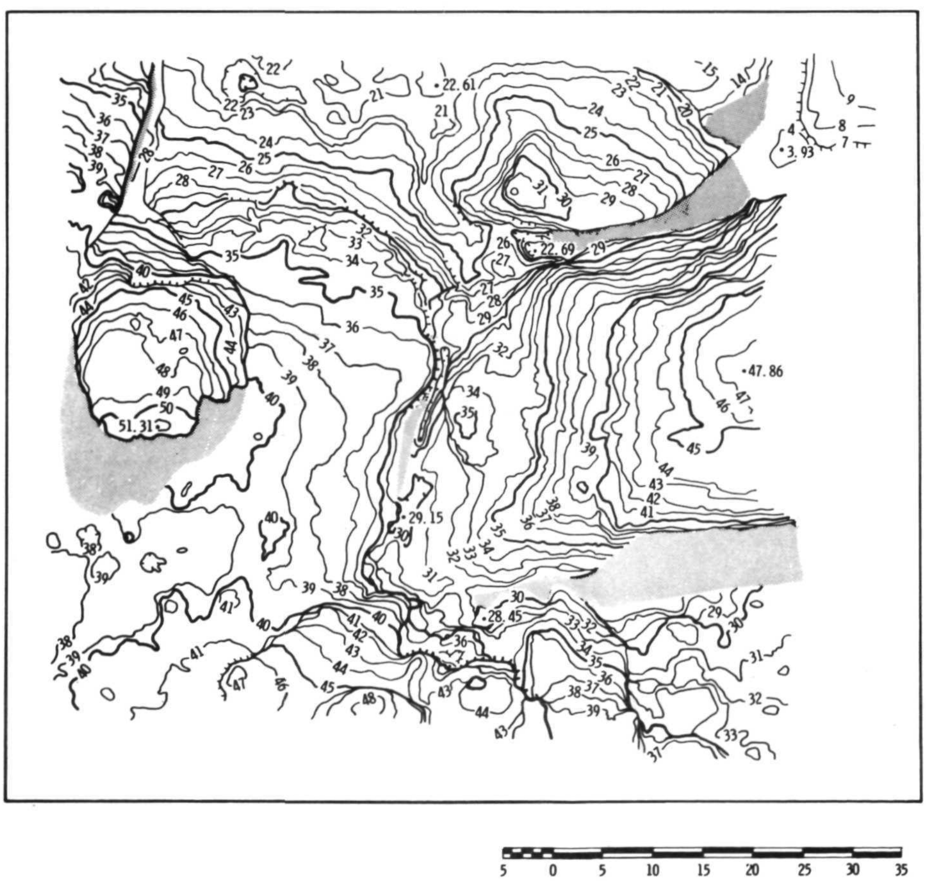
(a) NASA photograph AS11-45-6705.



(b) Topographic representation.

Figure 12. - Aggregate surface.

(a) NASA photograph AS11-45-6706.



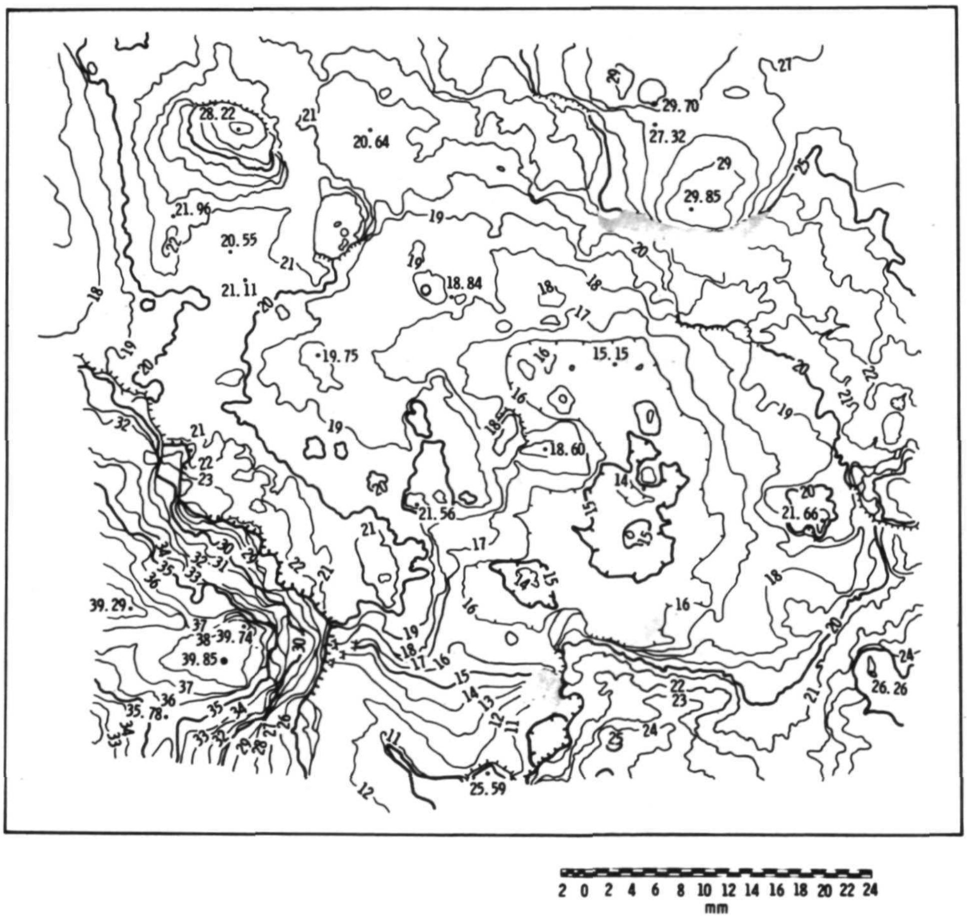
(b) Topographic representation.

Figure 13. - Aggregate surface.

Figure 14. - Crater bottom with prominent glass deposits (NASA AS11-45-6704).

Figure 15. - Crater bottom with prominent glass deposits (NASA AS11-45-6707).

(a) NASA photograph AS11-45-6708.



(b) Topographic representation.

Figure 16. - Crater bottom with prominent glass deposits.

Figure 17. - Pitted microbreccia surface (NASA AS11-45-6709).

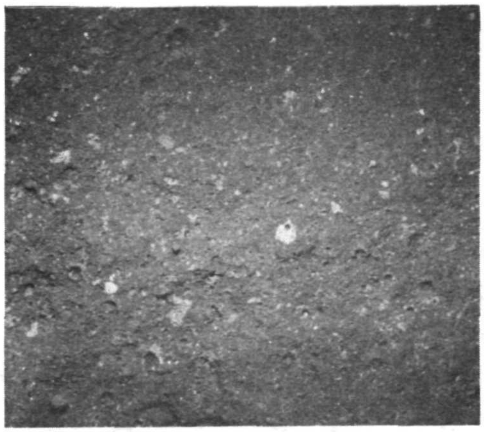


Figure 18. - Pitted microbreccia surface (NASA AS11-45-6710).

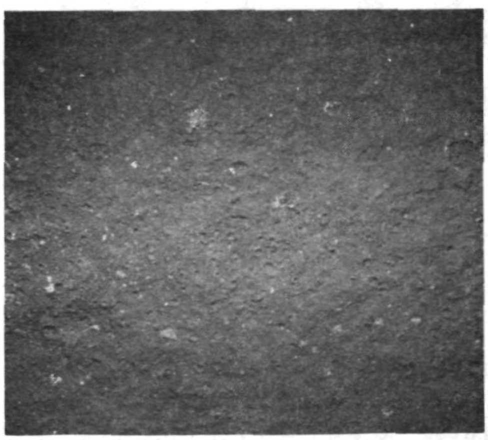
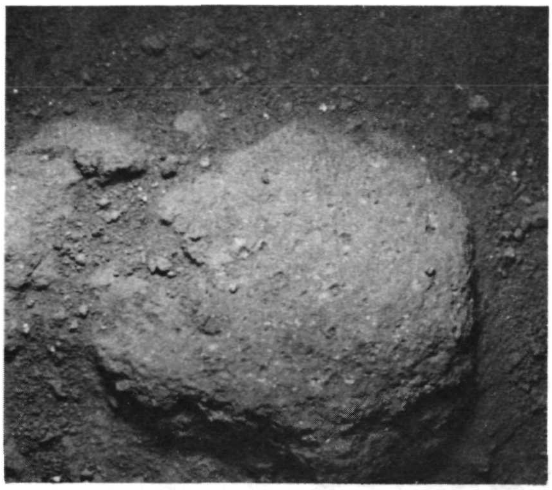
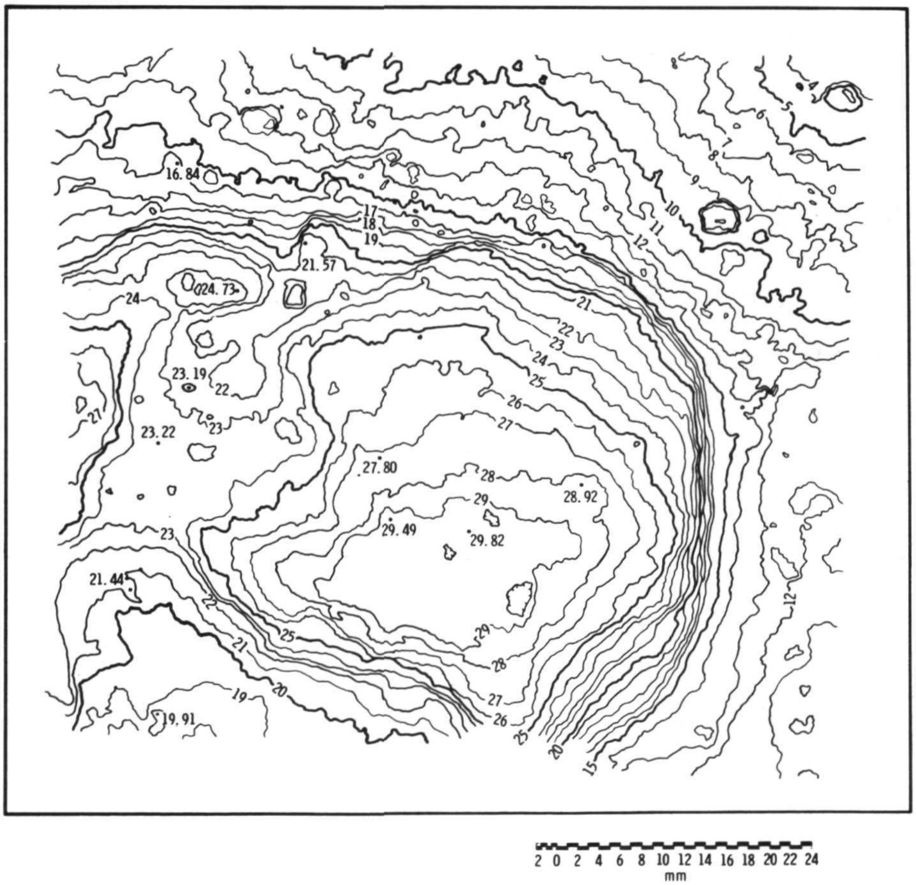


Figure 19. - Pitted microbreccia surface (NASA AS11-4516713).



(a) NASA photograph AS11-45-6712.



(b) Topographic representation.

Figure 20. - Pitted microbreccia cobble.

Figure 21. - Pitted microbreccia surface (NASA AS11-45-6714).

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