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Interpretation of Surveyor I Lunar Photos

Crater density is approximately one 4-meter crater in each 100 square meters.

(*Abstract on page 1361*)

INTRODUCTION

THE SURVEYOR I SPACECRAFT successfully landed, June 2, 1966, on the floor of Flamsteed P, a large, nearly buried crater about 100 km in diameter and centered at about lat 3° S. and long 44° W. (Figure 1). This spacecraft, which carried a television camera designed for operation on the lunar surface, was the first of at least seven spacecraft planned for soft-landing on the moon during 1967–68. The Surveyor I spacecraft consists of a main structure of tubular aluminum with two attached electronic compartments and a vertical mast topped by a movable solar panel and a high-grain antenna array (Figure 2). Each of three hinged landing legs includes a shock absorber and a footpad 1 foot in diameter.

Prior to landing, a solid fuel retro rocket, ignited by a radar altitude signal, slowed the spacecraft for the terminal descent. Following main retro burnout and jettison, three controllable liquid fuel vernier engines continued to slow and maintain altitude control of the spacecraft. The vernier engines were shut down about 3.4 m. (11 ft.) above the surface, and the spacecraft struck the lunar surface at about 3.6 m./sec. (11.6 ft./sec.) vertical velocity. Following impact, the spacecraft rebounded clear of the surface and touched down again about 0.1 second later.

The Surveyor television camera (Figure 3) consists of a vertically oriented vidicon tube and associated electronic components, shutter, zoom lens, iris, and filter wheel assemblies. Mounted above the filter wheel assembly is a mirror which can rotate in azimuth and tilt in elevation. The camera can scan down to about −67° and upwards to nearly +40° and rotate nearly 360° in azimuth. The camera is mounted about 1.6 m. above the plane of the footpads along an axis inclined 16° from the vertical axis of the spacecraft. The focal length of the camera lens is variable from 25 to 100 mm. but is normally operated at either 25 mm. (wide angle 25° field) or 100 mm. (narrow angle 6.4° field). The focal length, focus, filter, and mirror azimuth and elevation are controlled from Earth.

Over 11,000 television pictures were taken of the lunar scene through sun elevation angles ranging from less than 1° to about 88° during 2 lunar days. (One lunar day of

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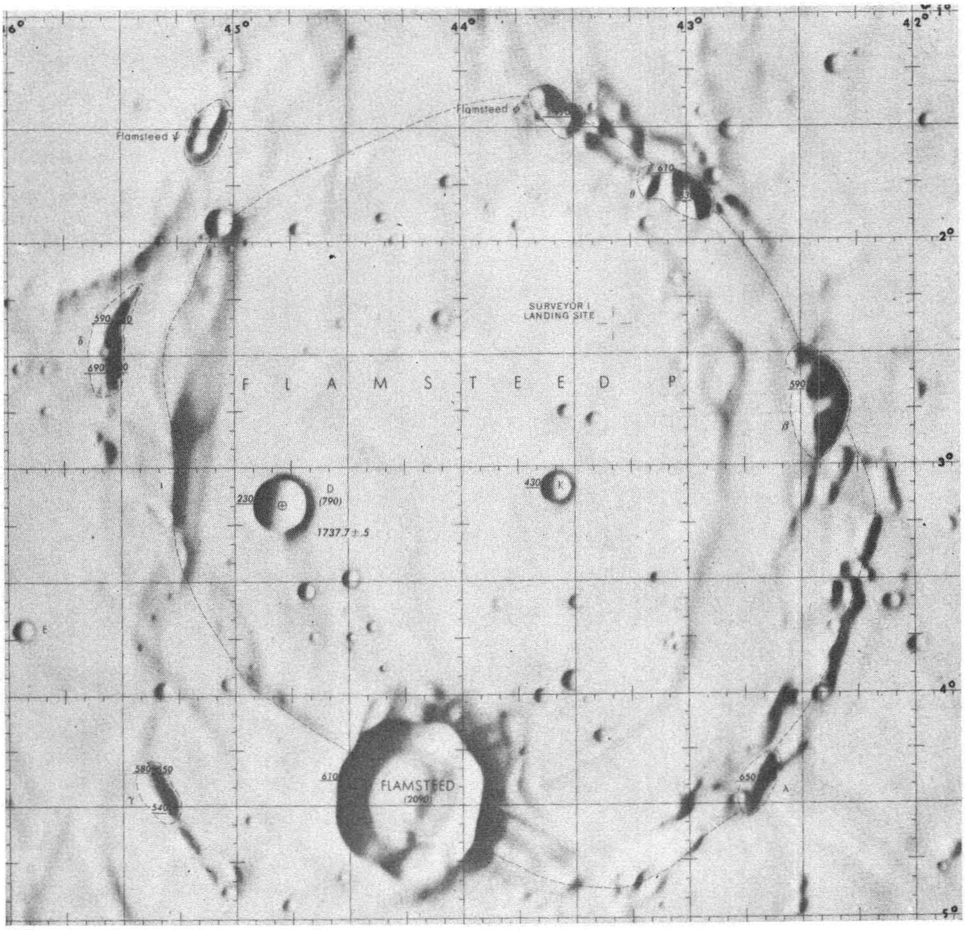

FIG. 1. Surveyor I spacecraft landed near lat 2.52° S. and long 43.34° W. on the nearly buried floor of the large Flamsteed P crater.

daylight is equivalent to 14 earth 24-hour days.) Surface details as small as 0.5 mm. were resolved near the spacecraft footpads—an improvement by three orders of magnitude over the highest resolution Ranger pictures. The lunar surface was observed repeatedly at different solar elevations because the fine surface textures and shallow relief features were best observed at low sun elevation whereas albedo and photometric data were determined when the sun was higher. Objects of special interest, such as nearby rocks, were examined frequently in order to obtain detailed information on their shape, texture, and color.

The U. S. Geological Survey is analyzing these pictures to interpret the nature of the lunar surface and the geologic processes acting on it. This analysis includes detailed studies of crater frequencies, fragmental debris, and photometry. Geologic and physiographic maps will be prepared of the landing site area. E. M. Shoemaker is Principal Investigator of the Surveyor television camera experiment for NASA and heads a U. S. Geological Survey team consisting of E. C. Morris, H. E. Holt, and R. M. Batson, co-investigators for the television experiment.

Morphology of Terrain Around Spacecraft

The terrain within 1 to 2 km. of the landing site of Surveyor I is a gently undulating surface pock-marked with craters. The true diameters of the craters cannot be measured but are estimated from angular width to range from a few centimeters to several hundred meters. One large crater, near the horizon southeast of the spacecraft, has a prominent raised rim about 4 m. high, and the exterior slopes of the rim materials are inclined as much as 11° to the horizon. The

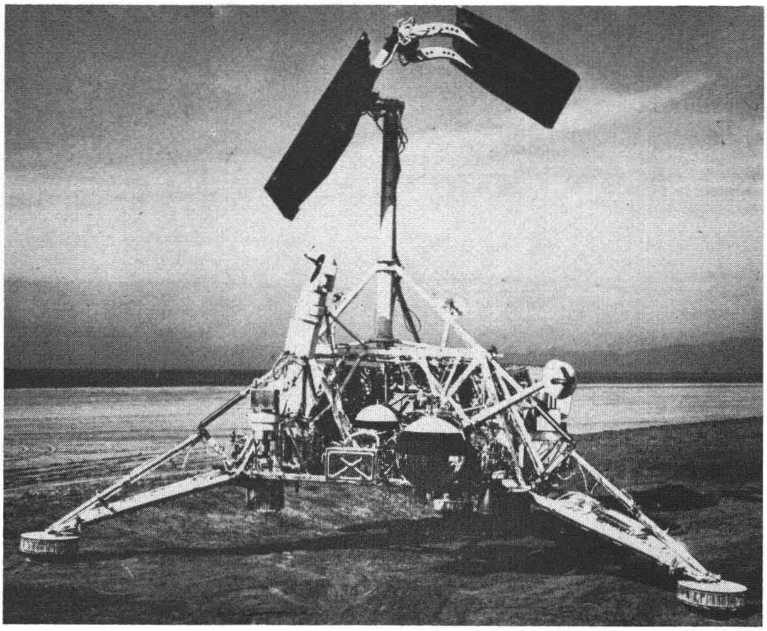

FIG. 2. Surveyor I spacecraft.

visible rim crest and exterior rim slopes are strewn with coarse blocky debris (Figure 4).

Most of the several dozen craters 3 to 20 m. in diameter photographed by Surveyor I have low, rounded, inconspicuous rims or are rimless. One prominent crater, about 3 m. across and 0.75 m. deep occurs about 11 m. southeast from the spacecraft. It has a distinct slightly raised rim and an inner wall that slopes about 28° (Figure 5).

The smaller craters, ranging in diameter from a few centimeters to 3 m., are more conspicuous at low illumination angles. They commonly have low rounded rims, but many are rimless. Close to the spacecraft the small craters may cover more than 50 percent of the surface.

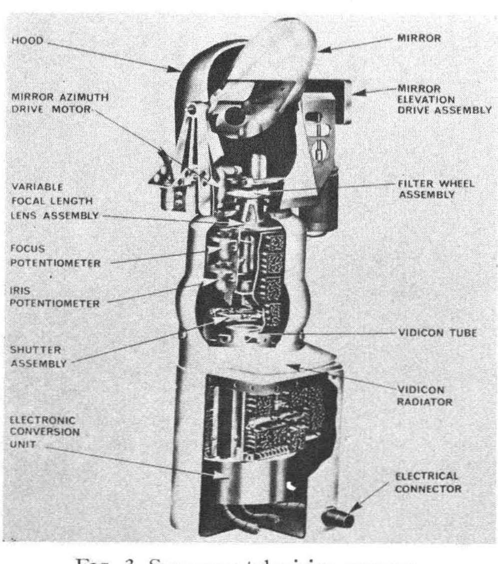

FIG. 3. Surveyor television camera.

Two sample areas (Figure 6), approximately 4 and 7 m. from the spacecraft were selected for a preliminary investigation of the size-frequency distribution of craters. Pictures taken at low sun elevations were used in order to identify the craters (Figures 7 and 8). Small craters easily discernible in the near field cannot be resolved in the more distant parts of the sample areas, so that the smaller craters appear to be too few in proportion to the larger craters. The integral frequency distribution of craters normalized to 100 m.[2] for each sample area is shown in Figure 9 with the estimated general size-frequency distribution of craters indicated by the heavy solid line. This line has the plot of

$$N=7.2\times 10^{4}d^{-1.8}$$

where N is the cumulative number of craters and d is the diameter of craters in centimeters.

One crater approximately 4 m. across would be expected in each 100 m.[2] surface area. The smaller crater frequencies have probably reached a steady-state for which frequencies should not change appreciably with time.

The size-frequency distribution of the craters is close to that predicted for the

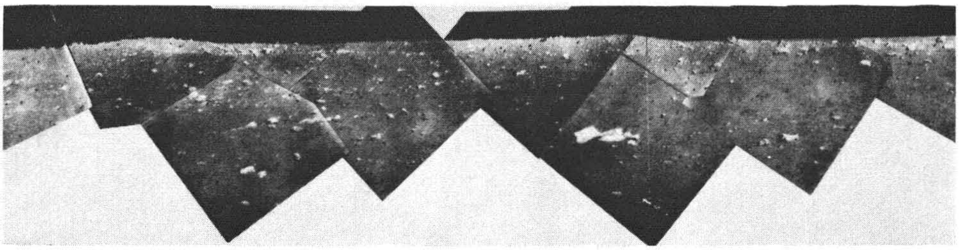

FIG. 4. Large crater southeast of the spacecraft, about 114° lunar azimuth. Crater is estimated to be about 30 m in diameter.

maria by extrapolation of the crater size-frequency distribution observed in the Ranger pictures (Figure 10). However, slightly more craters have been observed per unit area in the Surveyor pictures, which may be because craters in this size range are easier to identify on Surveyor pictures than on the lower resolution Ranger pictures.

DISTRIBUTION OF FRAGMENTAL MATERIAL

The lunar surface around the spacecraft is littered with large blocks and smaller fragments that appear to be nearly randomly distributed. However, blocks and finer rubble are significantly concentrated around certain craters out to a distance of about one crater diameter. Most of these blocks probably have come from within the craters.

The large blocks scattered about the surface are mostly angular to subangular, although some are rounded. Most angular blocks appear to rest on the surface with perhaps 80 to 90 percent of their bulk above the surface level, whereas many of the rounded blocks seem to be partly buried. The surfaces of the angular blocks are typically planar as though broken along joints or preexisting fractures. Some of the large blocks have demonstrable projections or overhangs; such blocks must have substantial cohesion and shear strength, especially if they have been ejected from craters (Figure 11). In

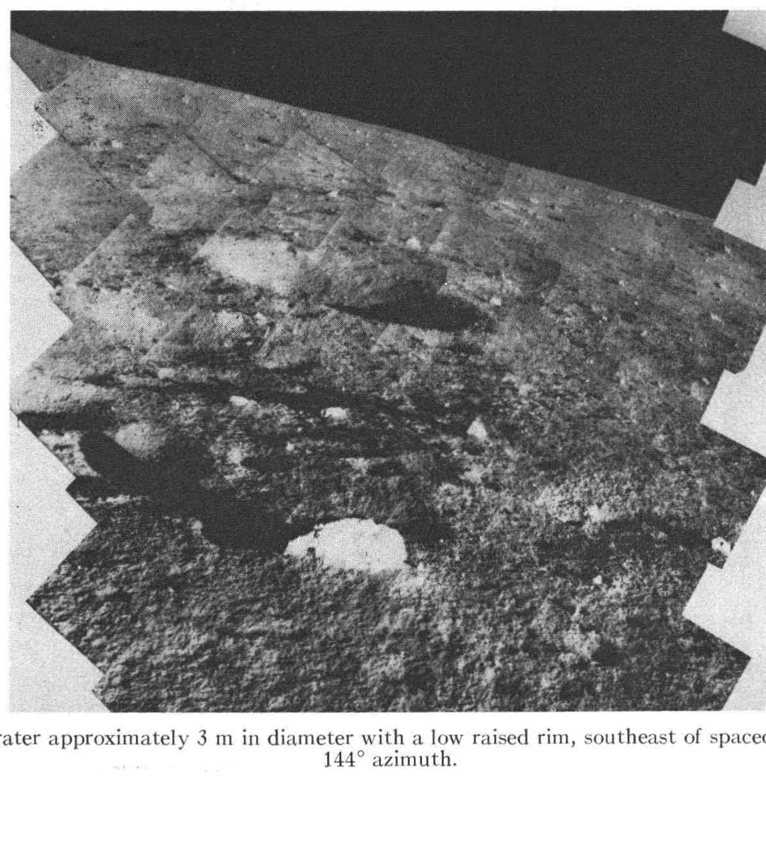

FIG. 5. Crater approximately 3 m in diameter with a low raised rim, southeast of spacecraft about 144° azimuth.

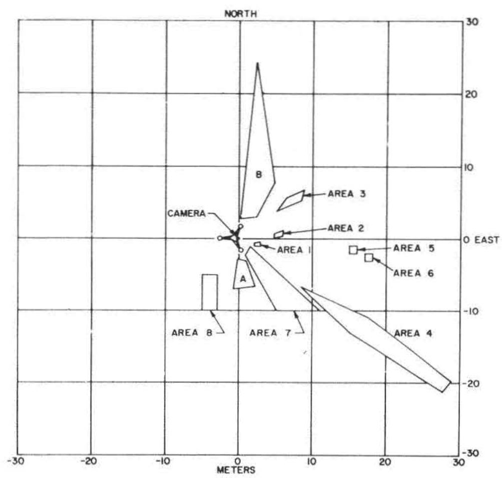

FIG. 6. Location of areas measured for crater size-frequency distribution (Areas *A* and *B*) and particle size-frequency distribution (areas 1–8).

addition, the larger blocks have greater reflectivity than the darker finer-grained surface material. This suggest that most of the blocks are distinct masses of rock.

One block, about 0.5 m. across, is some 5 m. southeast of the spacecraft and exhibits close-spaced dark spots a few millimeters across which are probably shadows within pores or cavities in the rock surface (Figure 12). The spots are distinctly elongated and their arrangement suggests flowage and distortion of vesicles in a volcanic rock. The block probably consists of rock congealed from a gaseous melt, produced either by strong shock or by volcanism; it could be an impactite, volcanic bomb, or fragment from the top of a vesicular lava flow.

Another block, slightly larger and about 5 m. southwest of the camera, is angular in shape with well-developed planar surfaces and slightly rounded corners and edges (Figure 13). This block does not have resolvable granularity, but it is distinctly mottled and the lighter parts tend to stand out as small knobs. A very pronounced set of intersecting fractures resemble cleavage planes which could have been produced during plastic flow of the rock under moderately high shock pressure. The block lies in a swarm of a least 50 similar smaller fragments. The impression gained is that the block has broken, perhaps on impact with the surface, and that it had low shear strength.

An attempt has been made to evaluate the

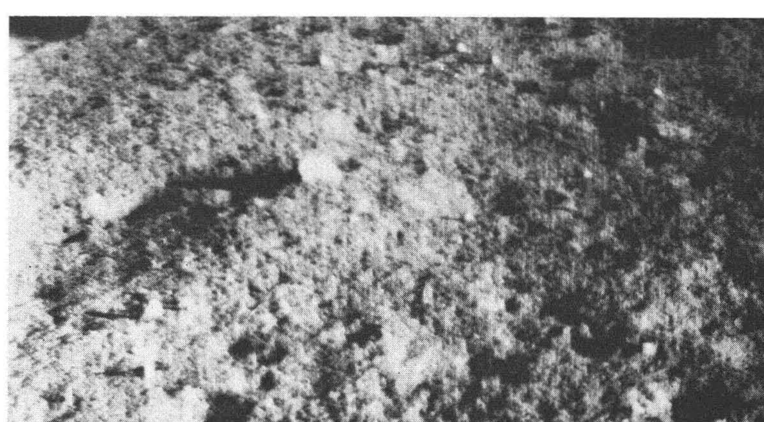

FIG. 7. Area *A* illuminated at sun elevation angle of approximately 20°.

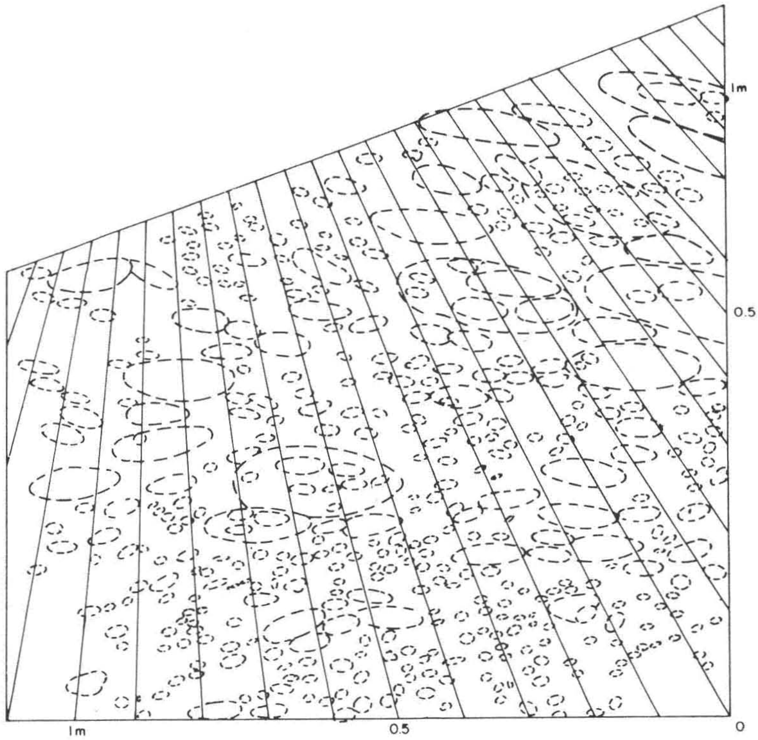

FIG. 8. Sketch map of craters counted and measured in Area *A*.

size-frequency distribution of fragments lying on the lunar surface in eight areas from 2.5 m. to about 20 m. from the spacecraft (Figure 6). All sharply formed fragments and grains that are easily recognizable in the pictures were measured and counted. The fragments, 2,045 in all, range in diameter from 1 mm. to more than 1 m.

The cumulative size-frequency distribution of the surface fragments for each sample area, normalized to an area of 100 m.², is shown in Figure 14. The size distribution functions of the fragments in the areas of overlapping resolution are considered as segments of one overall distribution function. Although some heterogeneity occurs from one area to another, the general size-frequency distribution of fragments on the lunar surface around the Surveyor I landing site is estimated by the heavy line in Figure 14, which represents the plot of

$$N=7\times10^{5}y^{-2.2}$$

where N is the cumulative number of fragments and y is the diameter of fragments in millimeters. This function extends to particle sizes below the limit of observational data (1 mm.) and indicates that one block about

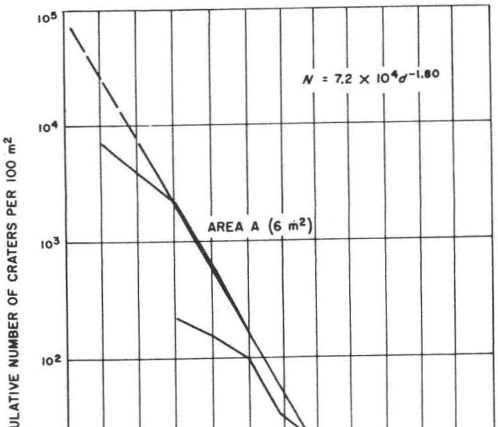

FIG. 9. Cumulative size-frequency distribution of craters on lunar surface determined from Surveyor I pictures.

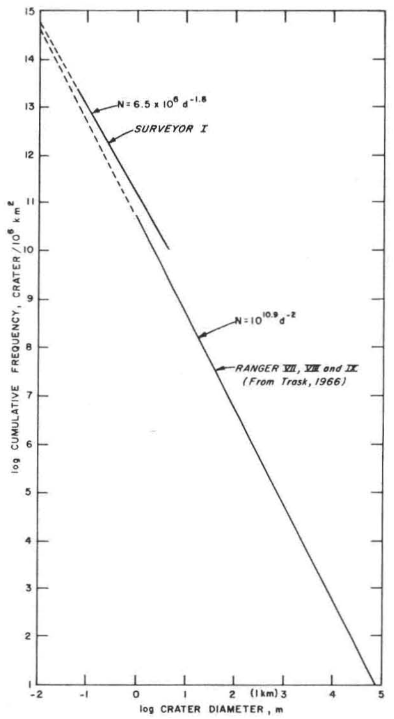

FIG. 10. Cumulative size-frequency distribution of craters on lunar surface determined from Surveyor I and Ranger VII–IX pictures.

0.5 m. across can be expected to occur on each 100 m.[2] of surface area. The observed angular fragments occupy 7.6 percent of the surface area and have a volumetric median diameter of 130 mm. The volumetric median grain diameter of all fragmental material on the surface is probably less than 1 mm. The form and constants of this size-distribution function are very similar to the size-frequency distribution of fragments produced by repetitive impact of rock surfaces.

Cohesion and Thickness of Surficial Fragmental Layer

Around the footpads of the spacecraft are raylike deposits of material ejected by the impact of the footpads. Some of the rays extend as far as 1 m., and a distinct ridge occurs near each footpad. This ejected material is dark and is composed of distinctly coarser lumps than the adjacent undisturbed surface material. The lumps in the freshly ejected material (Figure 15) are probably weakly consolidated aggregates of much finer grains and could probably be disaggregated into their constituent grains by moderate pressure or agitation. The mechanical behavior of the fine-grained lunar surface material appears to be similar to that of a dry fine-grained terrestrial soil.

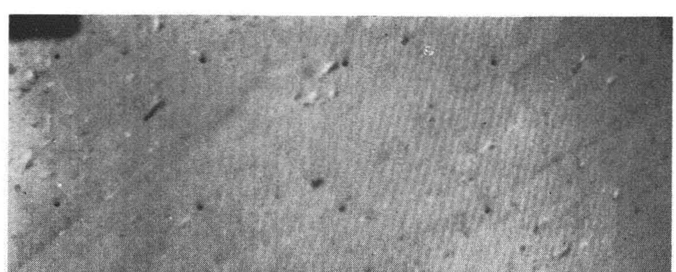

FIG. 11. Large block with overhangs indicating substantial cohesion and shear strength.

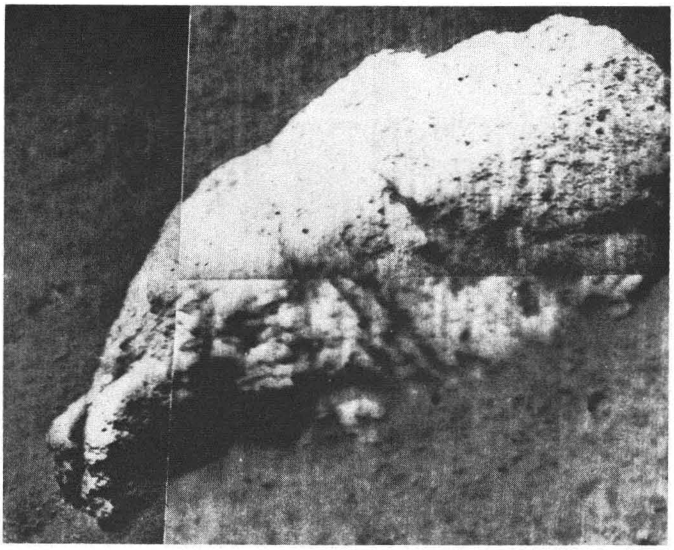

FIG. 12. Rounded block about 0.7 m long, showing dark spots which are considered to be pores or vesicles.

The disturbance of the surface material by the Surveyor I footpads and the shapes of small natural craters indicate that the material is very weakly cohesive. Similar small craters can be produced experimentally by impact only in a relatively fine-grained fragmental medium with very low cohesion (less than 10^4 or 10^5 dynes/cm.^{2}). The weakly cohesive layer composed of fragments similar to those observed directly at the surface probably extends to an average depth of 2 to 3 m. The raised rims of craters up to 4 to 5 m. across are relatively smooth (Figure 5), whereas raised rims of larger craters (Figure

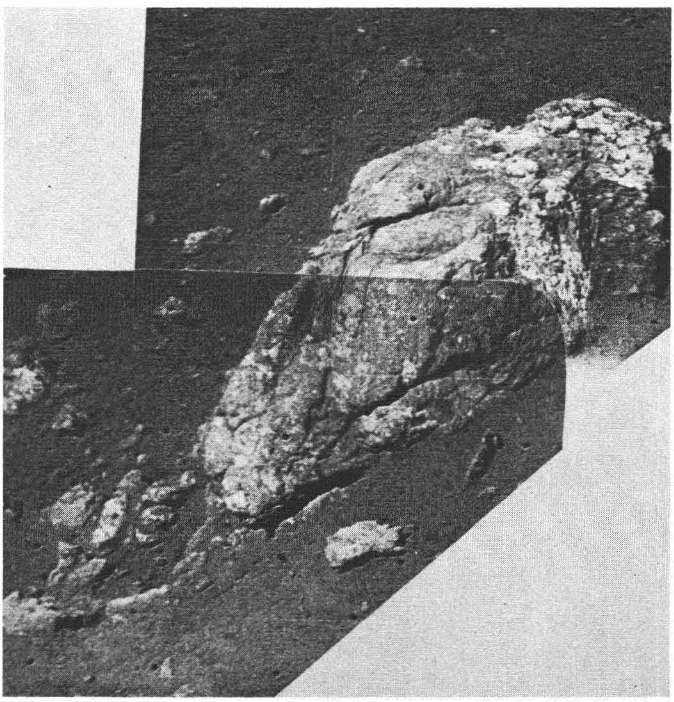

FIG. 13. Block about 0.6 m long, showing slightly rounded edges and a mottled appearance.

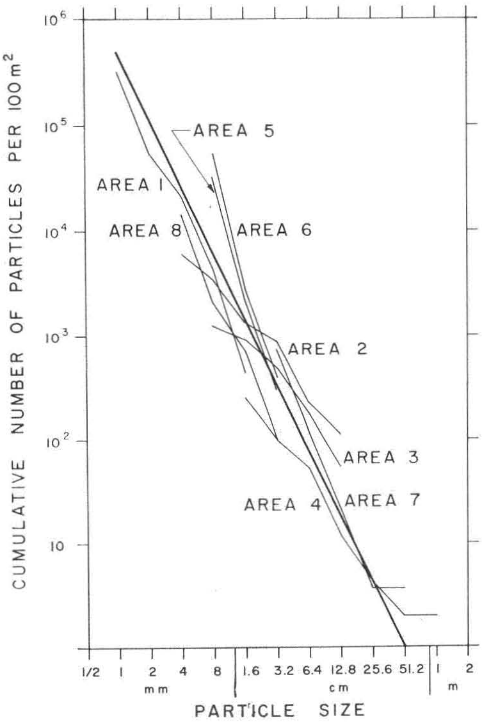

FIG. 14. Cumulative size-frequency distribution of particles on lunar surface as determined from Surveyor I pictures.

16) are covered with abundant angular blocks that have been derived from greater depths. This suggests that moderately well indurated rock is present below the 2- to 3-meter-thick layer of unconsolidated surficial material. The thickness of the surficial layer and the distribution of fragments and craters are in agreement with the expected thickness and surface characteristics of a fragmental debris layer formed primarily be repetitive bombardment from primary and secondary ejecta.

Photometric Properties

About 60 lunar surface areas were selected for photometric study in a pattern designed to provide a broad coverage in viewing geometry. The surface reflectance of each sample area was measured at intervals during the lunar day. The average normal albedo of the fine-grained lunar surface in the vicinity of the spacecraft was determined to be about 7 percent.

Luminance of the fine-grained surface materials was measured close to the shadow of the television camera during several earth days in the lunar afternoon, but phase angles lower than $1\frac{1}{2}°$ could not be obtained because of shadow interference. The normal albedo or zero phase-angle luminance was estimated to be about 950 lumens/ft.[2] by extrapolation

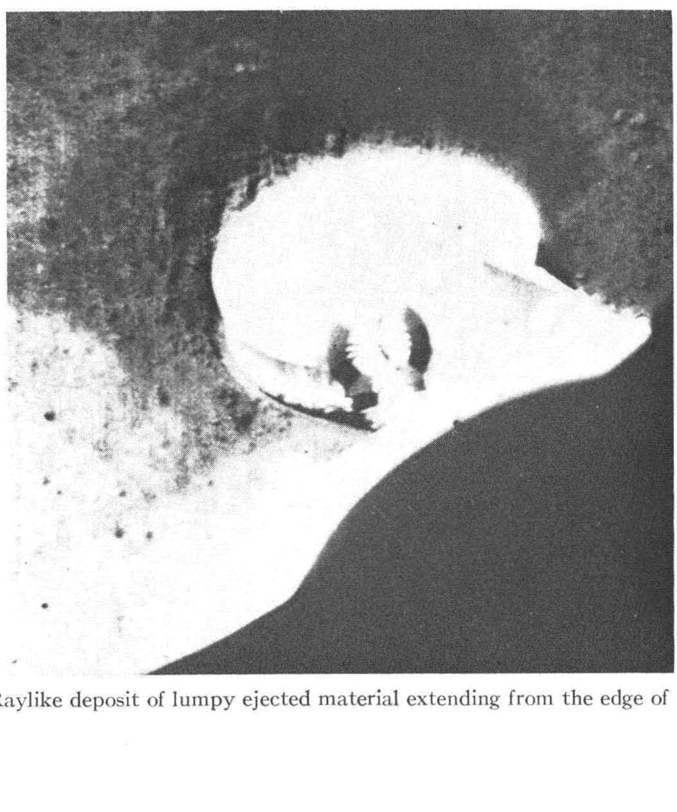

FIG. 15. Raylike deposit of lumpy ejected material extending from the edge of a footpad.

from surface luminances measured at low phase angles, which is 7.3 percent of the assumed 13,000 lumens/ft.[2] solar illuminance. Extrapolation of the luminances from several blocks measured at low phase angles suggest a rock albedo of 17–20 percent, whereas the dark material ejected by the footpads has an albedo of about 5 percent. Although the albedo of surface materials near the spacecraft ranged from about 5 to 20 percent, the integrated albedo is estimated to be about 7.7 percent. Several nearby areas were observed to show a patchiness in albedo during the lunar noon viewing period. This may be caused by thin deposits of fine-grained material derived from different areas by ejection during crater formation.

ABSTRACT: *The Surveyor I television camera transmitted more than 11,000 pictures. Lunar surface details as small as 0.5 mm were recorded. New data have been provided on the processes modifying the lunar surface and on the fine structure of the surface, such as size distribution, fabric, cohesion, and approximate thickness of the surficial layer of fragmental debris. The terrain within 1 to 2 km of the landing site is gently undulating, pock-marked with craters ranging in diameter from a few centimeters to several hundred meters, and littered with debris ranging in size from blocks over 1 meter across to smaller fragments set in a matrix of fine particles. The average thickness of the weakly cohesive surface fragmental material is probably near 2 or 3 meters.*

SUMMARY

The terrain within 1 to 2 km. of the landing site of Surveyor I is a gently undulating surface pock-marked with craters ranging in diameter from a few centimeters to several hundred meters. The smaller craters have subdued rims or are rimless, and are conspicuous only at low illumination angles.

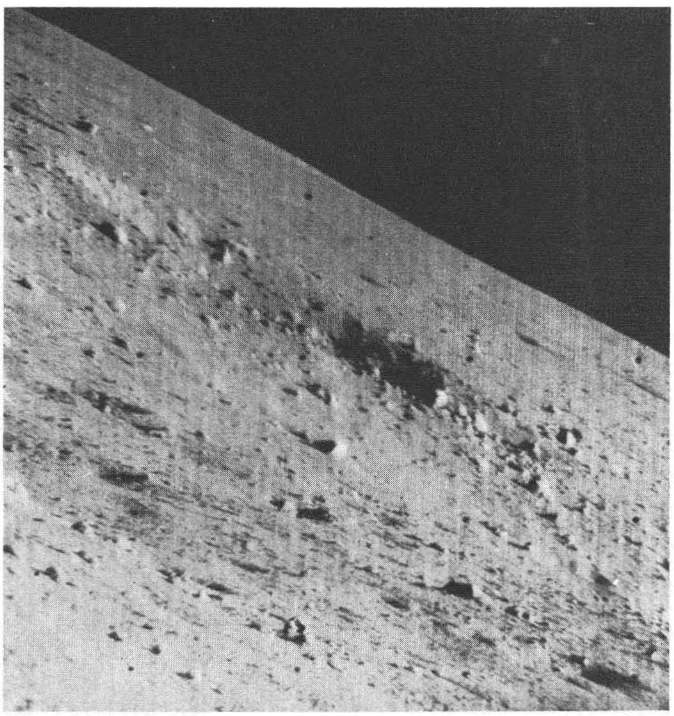

FIG. 16. Crater with a low blocky raised rim nearly 9 m across and about 3 m deep.

The crater size-frequency distribution indicates a density of one crater approximately 4 m. in diameter in each 100 $m.^2$ surface area; craters smaller than this have probably reached saturation or a near steady-state condition.

The lunar surface is littered with debris ranging in size from blocks more than 1 m. across to smaller fragments set in a matrix of fine particles. Coarse debris is concentrated around some craters out to a distance of about one crater diameter. Projecting surfaces on many blocks indicate substantial cohesion and shear strength for these blocks. The mechanical behavior of the fine-grained surface material during impact by the spacecraft footpads appears to be similar to that of dry fine-grained terrestrial soil, suggesting low cohesive strength on the order of 10^5 $dynes/cm.^2$ or less. Rim characteristics of craters formed within the surficial layer and craters which have penetrated the layer indicate that the average thickness of this weakly cohesive fragmental material is probably near 2 or 3 meters. Photometric data recovered from the pictures show the albedo of the fine-grained material to be about 7.3 percent, whereas the albedo of the blocks is 17–20 percent and that of the disturbed material by the footpads is only 5 percent.

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October in St. Louis

October in St. Louis is the story of a successful, stimulating and rewarding convention sponsored by the St. Louis Region of the American Society of Photogrammetry and the St. Louis Section of the American Congress on Surveying and Mapping. The event is history now, but little doubt of its tremendous success remains in minds of the nearly 1400 persons who registered at the Chase-Park Plaza Hotel during the week of October 2–5, 1967. The City of St. Louis had proclaimed the week as "Surveying, Mapping and Photogrammetry" week.

The wisdom of capable leadership, the cooperation and patience of the committees, and special contributions of the many friends was of untold value in shaping the convention program. Reference to the program reveals a well rounded presentation of technical papers submitted by most capable authorities in their respective fields. Exhibitors, 42 by actual count, were sincerely complimentary and delighted they had accepted the invitation to display their products and services. Most important, their unsolicited comment at the end of the week suggested a reasonable and profitable return on their investment.

The Official Opening of the technical sessions was accomplished Monday morning when Convention Director, Nick Michalas, welcomed all members and guests to the Convention, and introduced Mr. Donald Gunn, Acting Mayor of the City of St. Louis, who welcomed the assembly to the city. Opening remarks by ACSM National President, A. Phillip Bill, and St. Louis ACSM Chairman, Frank Roth, ASP National President, Heinz Gruner, and St. Louis ASP President, Gordon Stine, and ACIC Deputy Commander, Colonel H. D. Maxwell, Jr., concluded the ceremony. Upon conclusion of the opening remarks and comments pertaining to the aims and objectives of the Convention by Program Chairman, Joe Steakley, the group adjourned for the opening of simultaneous technical sessions.

The technical sessions, presenting many new innovations, were arranged by subject matter, first in speaker presentations and then by panel discussions germain to the

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