Dl. FIELD GEOLOGY OF APOLLO 16 CENTRAL REGION

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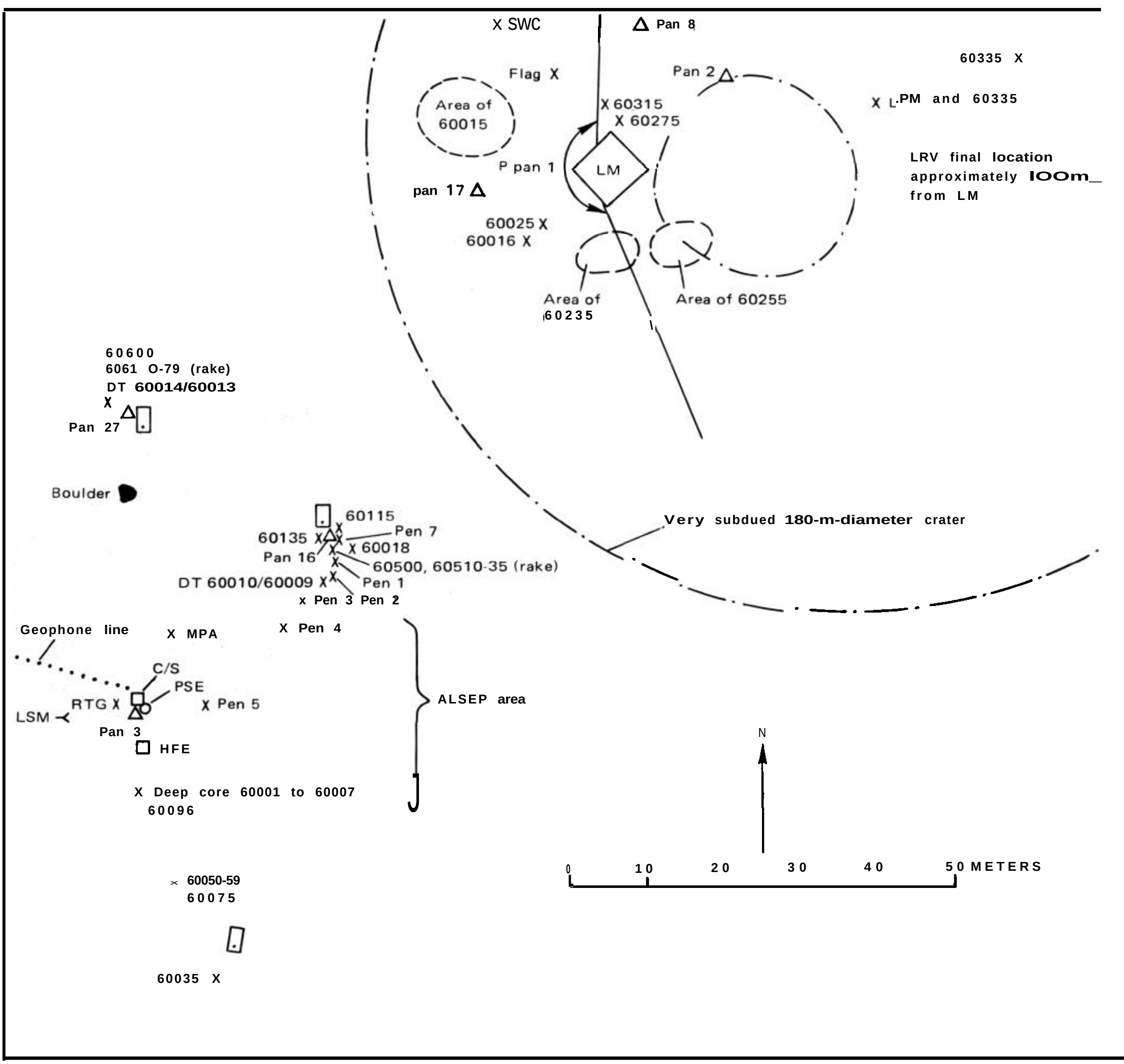
THE LM/ALSEP STATION

The central region of the Apollo 16 landing site includes three major areas-LM/ALSEP, station 1, and station 2-all underlain by materials of the Cayley plains. The LM/ALSEP station comprises five general areas-Lunar Module or LM, Apollo Lunar Surface Experiments Package or ALSEP, station 10, station 10, and the Lunar Roving Vehicle or LRV final parking site-ranging from approximately 70 m east to 140 m southwest of the LM (pls. 3 and 8; fig. 1). All five sites lie within but at the east edge of distinct ray material ejected from South Ray crater 5.7 km to the southwest (fig. 2).

The Cayley plains in the LM/ALSEP region are broadly undulating and slope to the southwest; the maximum relief within a radius of 400 m from the LM site is 25 m (fig. 3). The amount of surface covered by 2- to 20-cm fragments ranges from 1.3 to 6 percent and averages about 2 percent (fig1 4). Blocks as large as 0.5 m are relatively common (fig. 5). The largest boulder (33 m north of ALSEP) is several meters across. The rocks are uniformly distributed, not deeply buried, and are poorly filleted, some are perched, unburied, and lack fillets entirely. The rocks with little or no fillet are



EXPLANATION

	Crater rim	PSE	Passive seismic experiment
X 60335	Sample locality and number	LSM	Lunar surface magnetometer
DT	Drive tube	HFE	Heat-flow experiment
P pan	Partial panorama	RTG	Radioisotopic thermoelectric generator
Pan 2	Panorama location and number	MPA	Mortar package assembly
	LRV. dot on front	LPM	Lunar portable magnetometer
X Pen 5	Penetrometer reading, location and number	swc	Solar wind composition
c/s	Central station		

FIGURE 1.-Planimetric map of the **LM/ALSEP** area.

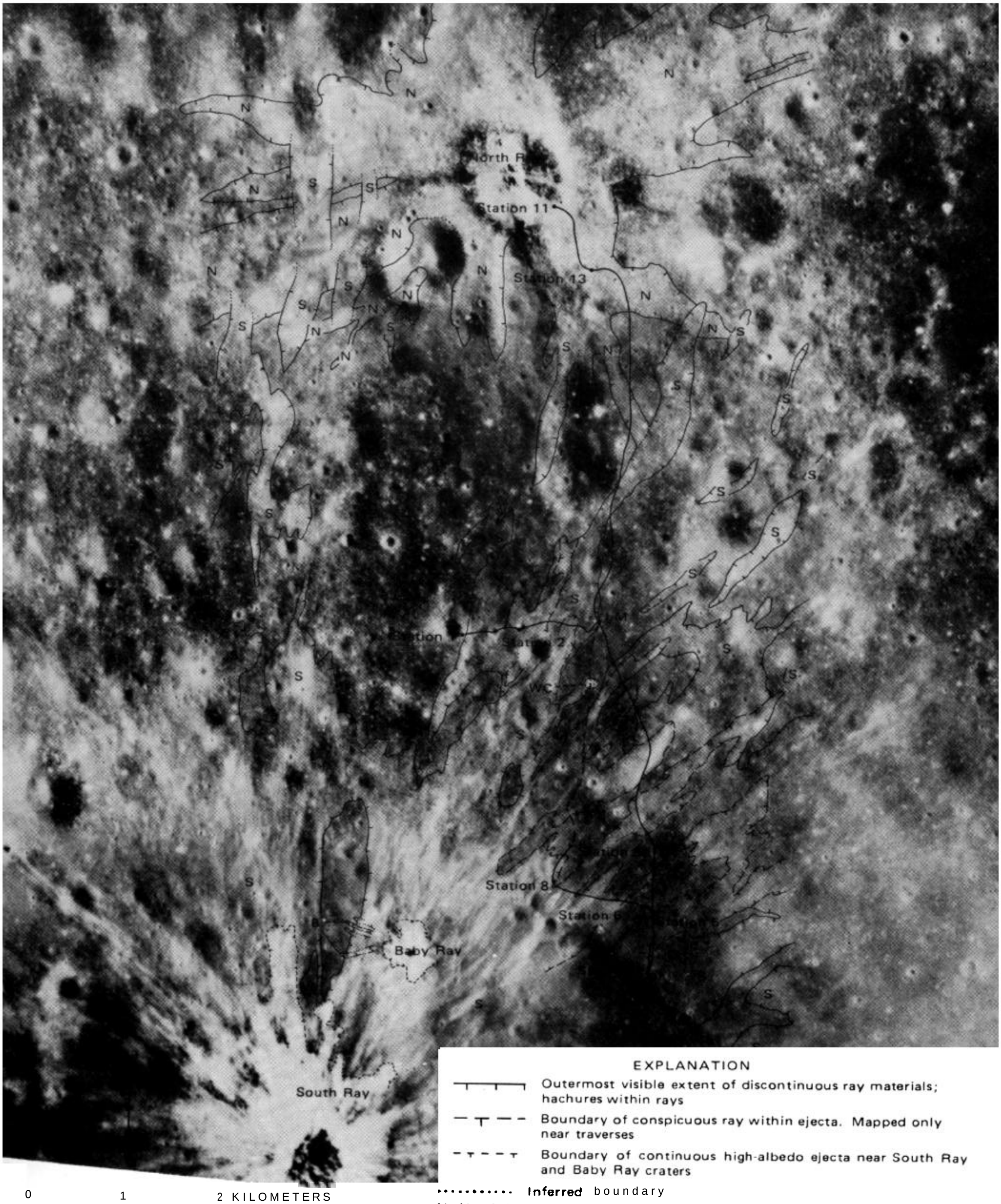
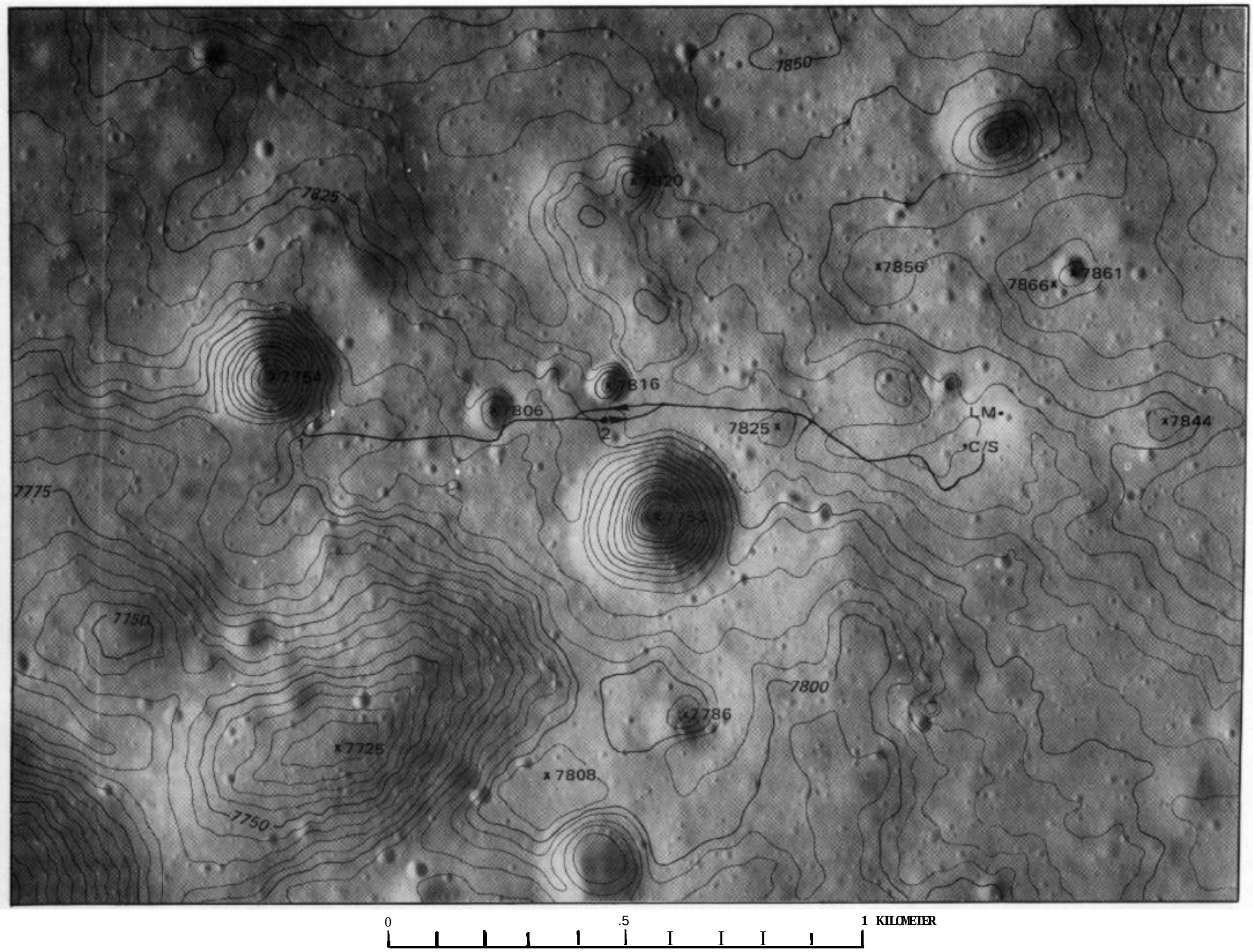
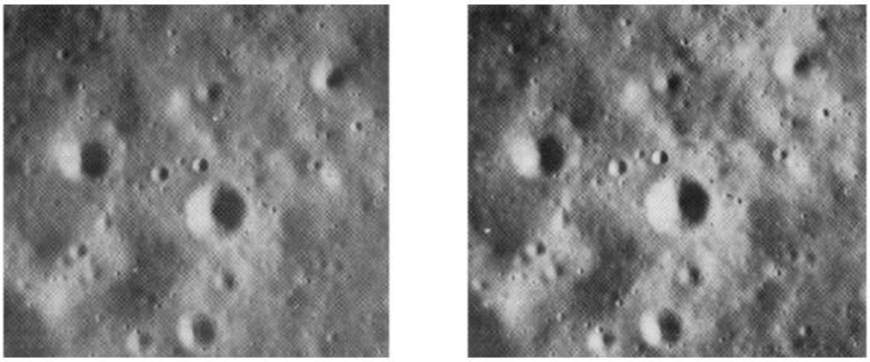


Figure 2.-Distribution of ejecta near the Apollo 16 landing site. Derived from second-generation film positives of Apollo 14 orbital photographs AS14-69-9520 and 9522 (500 mm), using stereoanalytic plotter (from Muehlberger and others, 1972).



A

FIGURE 3.-Map and stereopairs of the central part of the landing site. ***A,*** Contour map of Apollo 16 central landing site region superimposed on Apollo 16 panoramic photograph, frame 4618. LM sites and EVA-l traverse indicated. Contour interval, 5 m: arbitrary datum. Geographic names on figure 6. Topography compiled on AP/C plotter by G. M. Nakata from panoramic-camera photographs AS16-4618 and 4623. *B*, Stereopair showing the hummocky nature of the Apollo 16 landing site and central traverse region. Area of coverage identical to 3A. C, Stereopair showing the Lunar Module (arrow) on the lunar surface in the Descartes highlands. Note the relatively fresh 30-m-diameter crater 10 m east of the LM. Same photographs as in 3A and *B* greatly enlarged.



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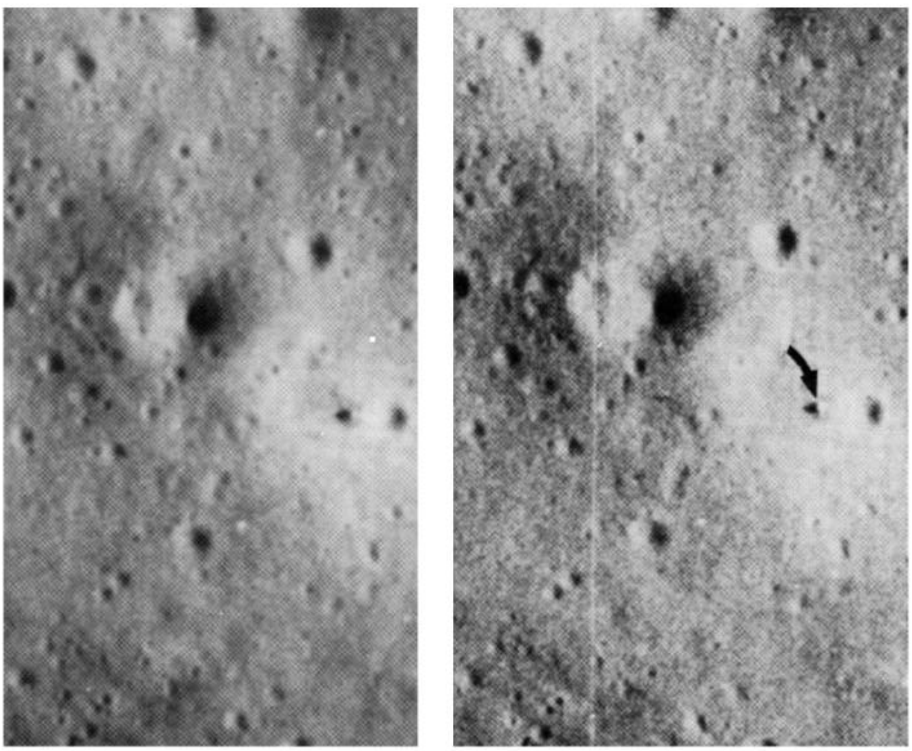

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FIGURE 3.-Continued.

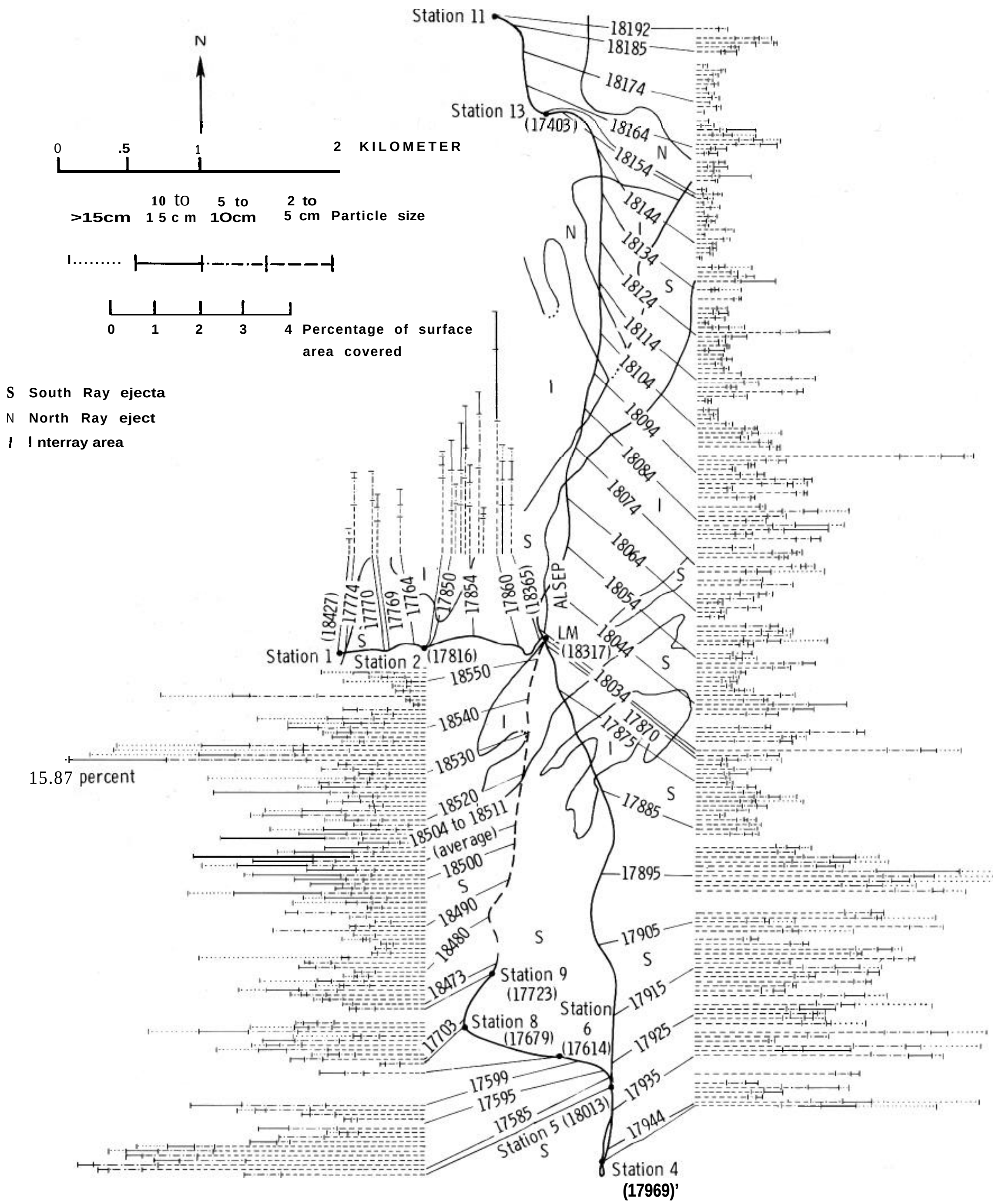


FIGURE 4.-Size distribution of fragments larger than 2 cm as determined from lunar surface photographs. Each line represents a size-distribution determination from a single photograph. Length is proportional to surface area covered by fragments as shown by bar scale. Five-digit numbers identify photographs; leaders tie them to their approximate positions along the traverse path (from Muehlberger and others, 1972).

thought to represent ejecta from South Ray crater. The largest boulder near ALSEP has a well-developed fillet and may have been ejected from the older North Ray crater.

The LM landed on the western wall of a very subdued crater, approximately 180 m in diameter, 10 m west of a moderaely subdued crater about 30 m in diameter. There are eight very subdued craters 125 m to 360 m in diameter within a radius of 400 m from the LM (fig. 6). Ejecta from these craters with excavation depths of 25 m to 70 m may be included in the material sampled at this station.

The ALSEP was deployed in an intercrater area about 3.5 m higher than the elevation of the LM. Stations 10 and 10' were on.the western rim crest of the crater in which the LM landed (fig. 6). Smaller, younger craters are common in the LM/ALSEP area, ranging from numerous 0.5 m to 2 m secondaries (probably produced by ejecta from South Ray crater) to less common primary craters as large as 40 m in diameter. Samples collected in the LM/ALSEP area include all eight categories of rocks described in the petrology section of this report (Wilshire and others, this volume; Wilshire and others, 1973): crystalline rocks (igneous, metaclastic), glass, and five types of breccias (table 1). The only other station where all rock types were collected was station 11. LM/ALSEP and 11 were the most thoroughly sampled of mission 16 stations.

The source areas and depths of the LM/ALSEP samples are not known with certainty, but some assumptions can be made. As the LM site is on the eastern edge of a distinct ray from South Ray crater (fig. 2), a large proportion of the samples collected may be from that source. The 30-m crater just east of the LM site (figs. 1, 3A), however, may have ejected material from as deep as 6 m in the floor debris of the LM crater. A possible secondary source of sampled material is the reworked ejecta from the eight very subdued craters mapped within a 400-m radius of the LM (fig. 6).

Many of the rocks collected in the LM/ALSEP area are at least partly glass coated and range from highly angular to subround (figs. 7-10). In general, the fine-

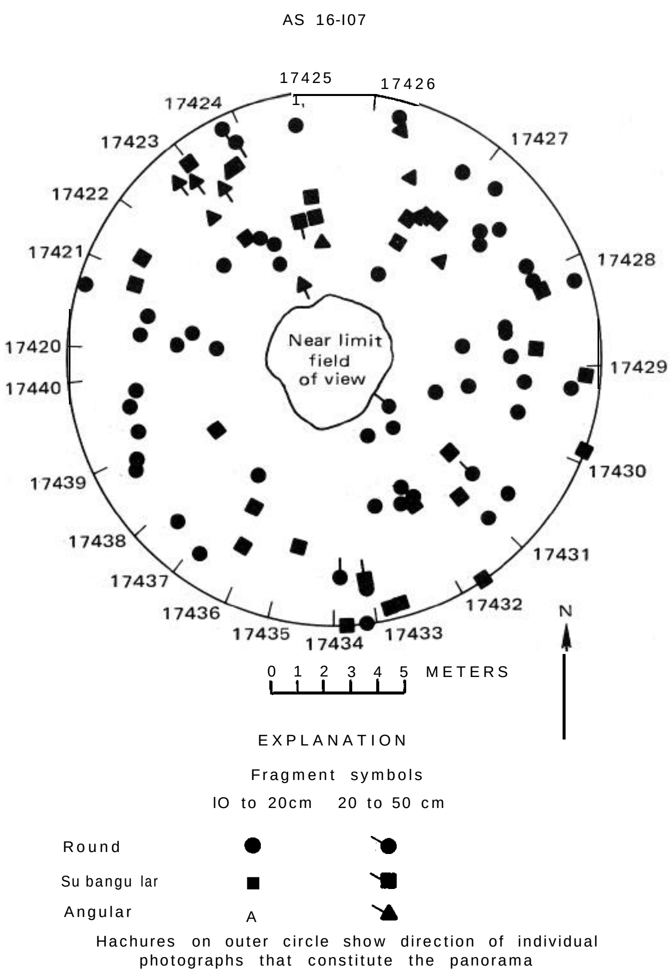


FIGURE 5.-Rock distribution within 10 m of the panorama site north of the LM (see pl. 3, pan 8).

TABLE *L-Number and percentages of rocks (>2 g) documented at the LM/ALSEP station*

category	Number of rocks collected	Percentage
Igneous:		
C_1 -------------------------------------	3	5.4
Metaclastic:		
C_2 --------------------------------	11	19.6
Breccia:		
B_1 (light matrix, light clast) ---------------	14	25.0
B_2 (light matrix, dark clast) -------------	4	7.1
B_3 (light and dark clast) ---------------------	6	10.7
B_4 (dark matrix, light clast	8	14.3
B_5 (dark matrix, dark clast)	1	1.8
Glass:		
G -----------------------------------		16.1
Total -----------------------		100.0

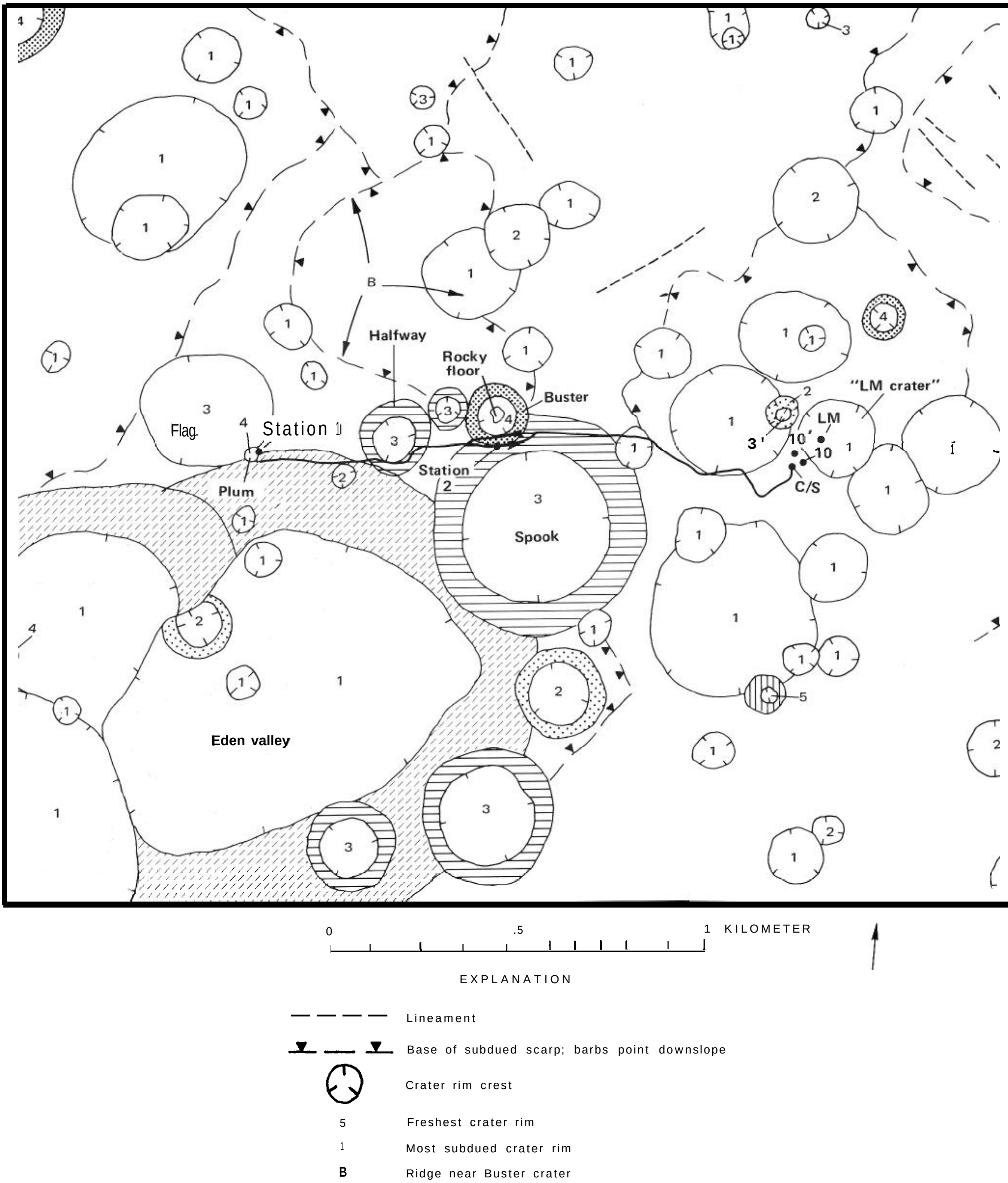


FIGURE 6.-Sketch map of landing site and central region showing distribution of fresh to greatly subdued craters of significant size and their relation to EVA- 1 traverse stations.

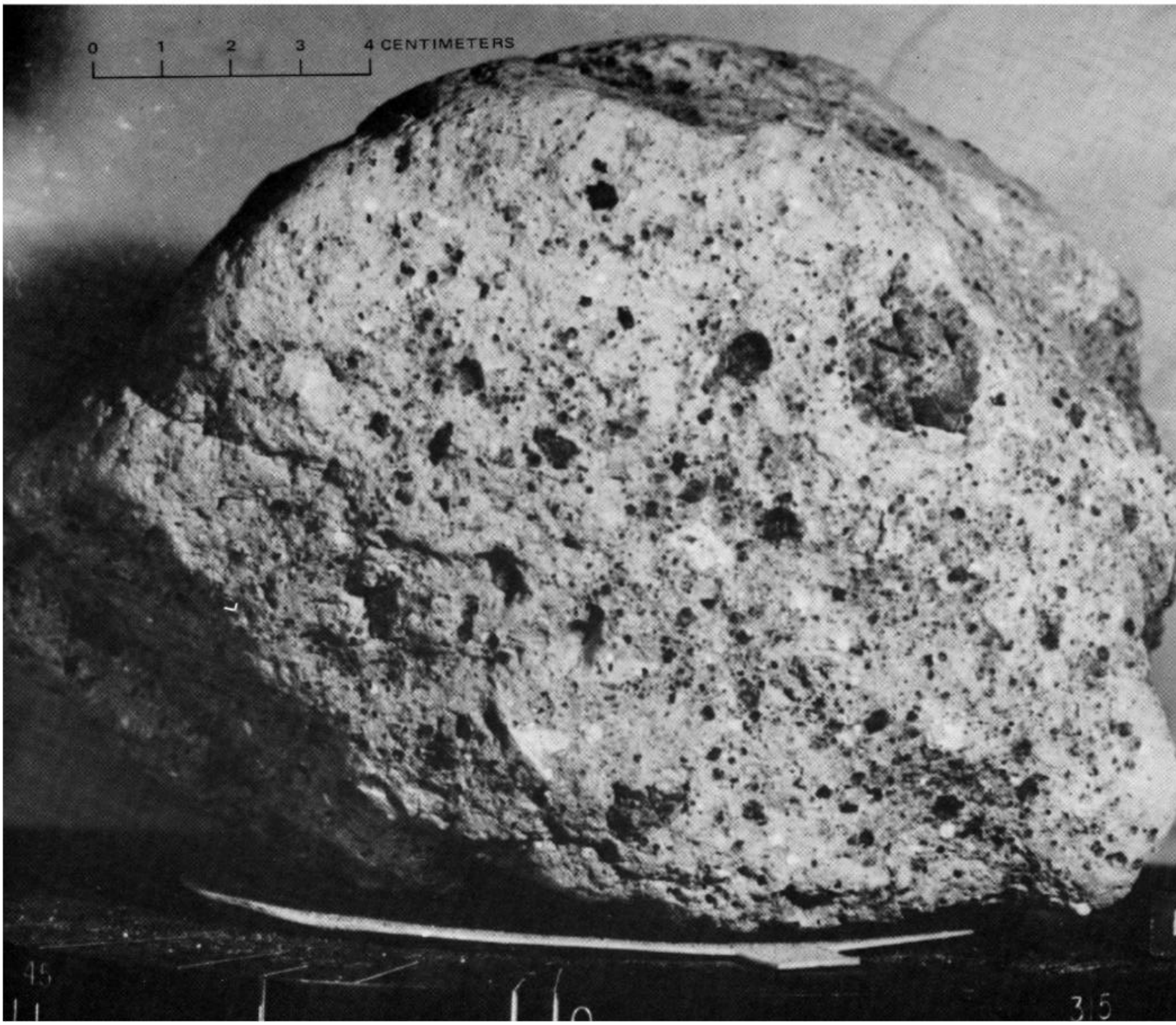
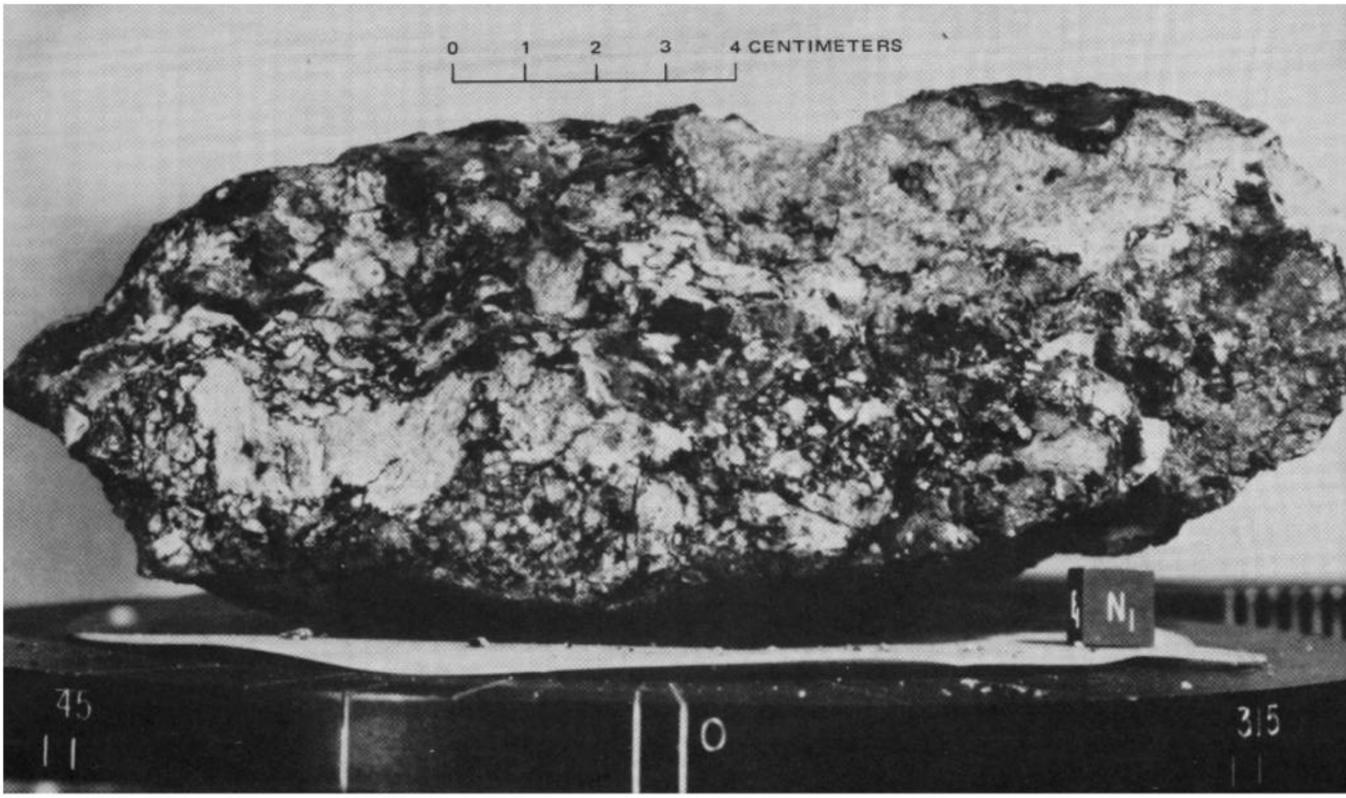


FIGURE 7.-Sample 60016. NASA photograph S-72-43829.



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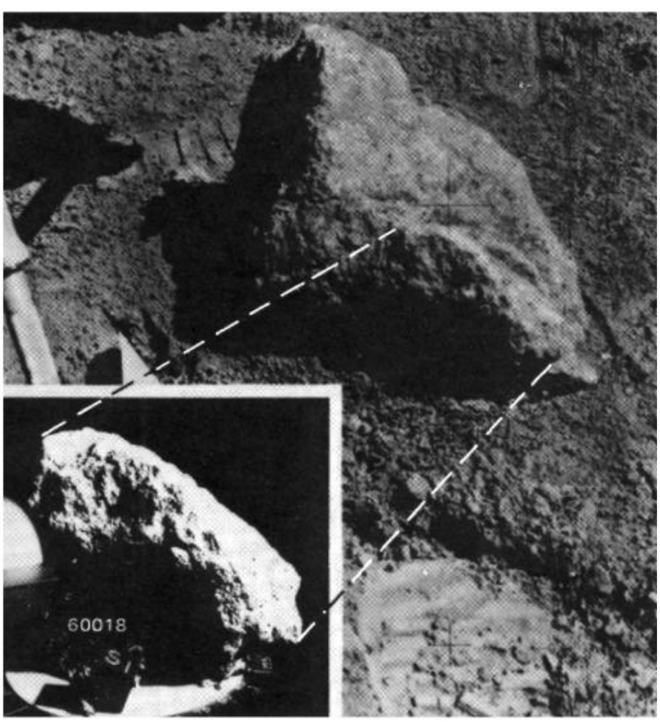
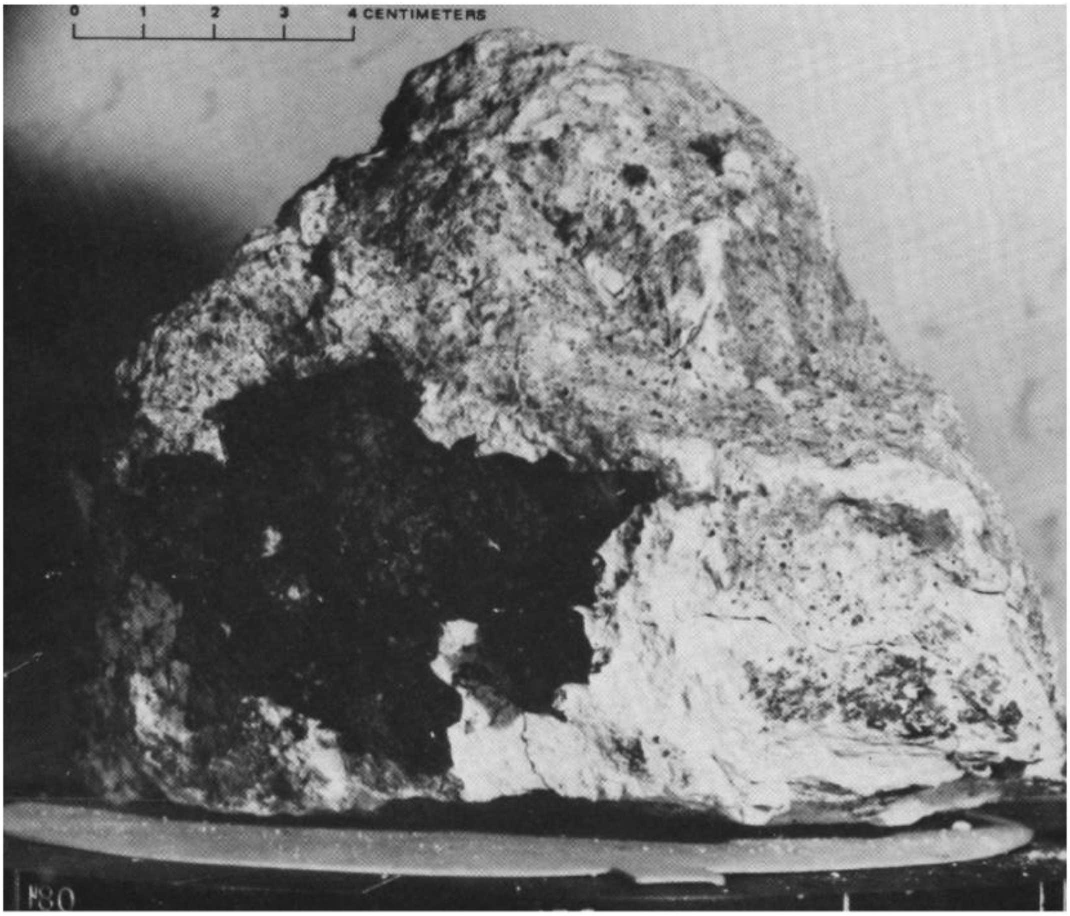


B

Figure 8.-Sample 60018. *A,* NASA photograph S-72-41499B. *B,* Approximate lunar orientation reconstructed in Lunar Receiving Laboratory compared with enlarged part of EVA photograph AS16-116-18689, taken cross-sun, looking north (inset photograph, S-72-41840). Reconstruction by R. L. Sutton.



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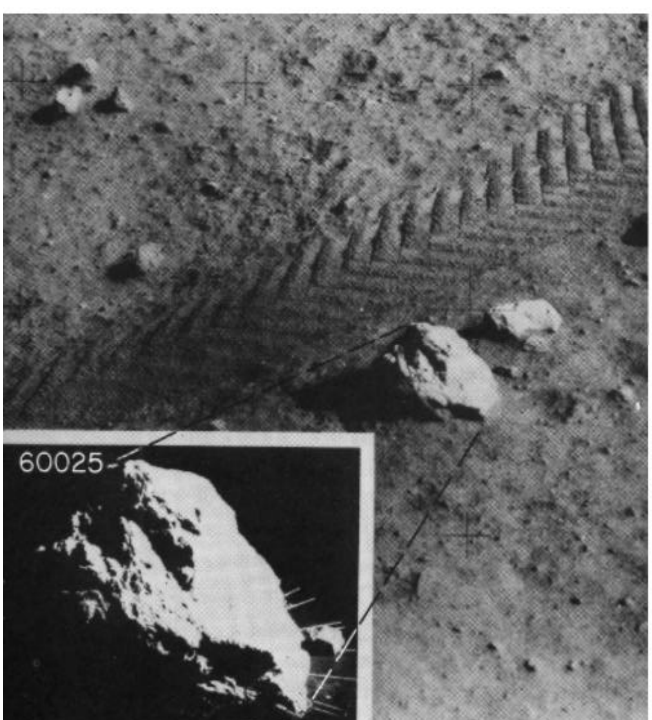

B

Figure 9.-Sample 60025. *A*, NASA photograph S-72-42593b. *B*, Approximate lunar orientation reconstructed in LRL, compared with enlarged part of EVA photograph AS16-110-17666, taken cross-sun, looking north (inset photograph, S-72-44019). Reconstruction by R. L. Sutton.

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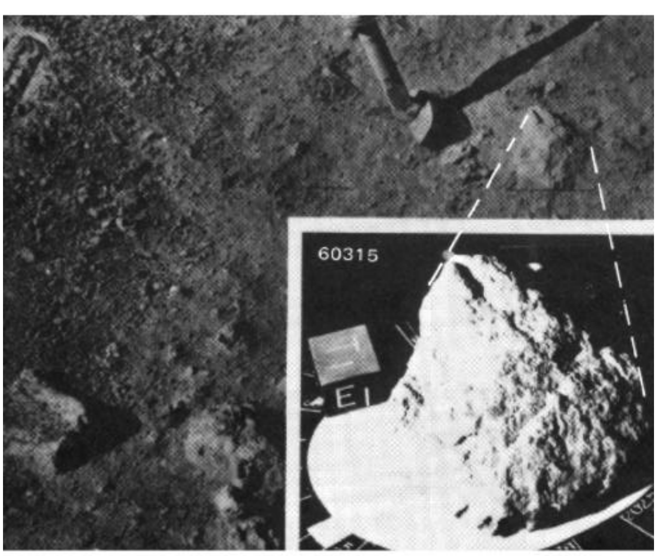


B

FIGURE 10.-Sample 60315. *A*, NASA photograph S-72-41572. *B*, Approximate lunar orientation reconstructed in the LRL compared with an enlarged part of EVA photograph AS16-117-18836, taken oblique to sun, looking southwest (inset photograph, S-72-41842). Reconstruction by R. L. Sutton.

grained chalky and crystalline rocks, approximately 5 percent of the rocks observed by the crew, are smaller (6- to 12-cm range) than most breccia fragments.

Documentation photographs of the samples collected at the LM/ALSEP station show that most of the rocks were either perched or only slightly buried, indicating that many samples from this station may be South Ray material.

The soil in the LM/ALSEP area is in general medium gray, but patches of high-albedo soil are present near the ALSEP. White soils are more abundant to the west (toward stations 1 and 2), where they underlie a thin, darker surface layer. The soil in the LM/ALSEP area generally is firm except in the intercrater area of the ALSEP, where it was found to be exceptionally loose and powdery. Soil of the intercrater regions associated with very subdued 200- to 300-m diameter craters typically is less compact than the walls and rim crests of such craters (Schaber and Swann, 1971).

Special samples collected at LM/ALSEP include a deep drill core at the ALSEP, double-core tubes at 10 and 10', rake samples at 10, and the Lunar Portable Magnetometer (LPM) sample at the LRV final park position (fig. 1). The deep-core, rake, and double core-tube samples may contain North Ray crater ejecta but should contain material representative of the Cayley plains beneath the LM/ALSEP station. The deep drill core (223 cm) may have penetrated the ejecta from the "LM" crater and the subdued crater, 270-m diameter, immediately west of the station (see fig. 6). Two Lunar Portable Magnetometer readings were taken in the LM/ALSEP vicinity, the first the ALSEP site, the second at the LRV final park position (approximately 80 m east of the LM). The ALSEP site remanent field strength was very high, 231 gammas, the LRV park reading considerably lower, 121 gammas. This difference represents a field magnitude gradient of 370 gamma/km, the maximum recorded during the mission. The minimum gradient measured was 1.2 gammas/km between station 5 and the LRV final park position (Dyal and others, 1972, p. 12-5).

Near the LRV final park location (fig. l), two LPM measurements were made to calculate the magnetic field of a surface rock sample (60335) in order to determine the total magnetization. The magnetic field was found to be below the resolution of the LPM (Dyal and others, 1972, p. 12-6).

The passive seismometer (PSE) deployed at the ALSEP station was the most sensitive of the four lunar seismograph stations in operation at that time. On the basis of the initial 45-day record of operation, seismic events occurred at a rate of 10,000 per year; the rate at the Apollo 14 site was 2,000 per year, and at the 12 and 15 sites, 700 per year (Latham and others, 1972, p. 9- 1). The higher sensitivity of the Apollo 16 seismometer has been attributed by Latham and others to the depth and elastic properties of the regolith, the inference being that the Apollo 16 regolith is deeper or weaker, or both.

The results of both the active and passive seismic experiments at Apollo 16 indicate that the regolith is not underlain by competent lava flows. Rather, the seismic velocities recorded suggest that a brecciated or .mpact-derived debris unit of undetermined depth underlies a 12.2-m-deep regolith. Petrographic analysis of the returned samples (almost entirely breccias) supports this hypothesis.

STATION 1

Station 1 was located near the rim of Plum crater approximately 1,400 m west of the LM and 45 m lower. Plum crater, 30 m across and 5 m deep, is on the rim of Flag crater, 290 m in diameter (pl. 5, pans 4 and 5; fig. 11) and 40 m deep. When formed, Flag crater probably penetrated 60 m into the underlying Cayley plains material, but it has been partly filled by talus. The crater is subdued, having only a slightly raised rim, and no rocky exposures are visible in its walls or floor. Small subdued craters as large as 10 m in diameter are common in the area.

The east part of station 1 appears to be crossed by a very faint ray from South Ray crater, but rock fragments >2 cm are less abundant (0.6 to 1.8 percent) than at station 2 or at the LM/ALSEP area (figs. 2, 4, 12).

Rocks larger than 10 cm cover only 0.2 percent of the surface at this station, whereas at station LM/ALSEP rocks of similar size cover 0.3 to 0.9 percent (fig. 4). The crew mentioned that South Ray crater ray material was visible about 50 m east of the station 1 area.

Samples (>2 g) collected at station 1, in table 2, are predominantly breccias of types B_2 B_3, and B_4. The complete absence of B1 breccias, at least in the samples collected, may be significant with respect to the low

TABLE 2.-*Number and percentages of rocks (>2 g) documented at station 1*

Category	Number of rocks collected	Percentage
Igneous:		
C_1	1	3.3
Uetaclastic:		
C_2	2	6.7
Breccia:		
B_1	0	0
B_2	3 (1 in rake)	10.0
B_3	10 (7 in rake)	33.3
B_4	4 (3 in rake)	13.3
Glass:		
G	10 (7 in rake)	33.3
Total	30	99.9

proportion of South Ray material in this station area relative to station LM/ALSEP, where 25 percent of the samples are breccias.

Four large samples, 61016 (B_4; 11,745 g), 61135 (B_3; 245 g), 61195 (G; 586 g), 61295 (B_3; 172 g), were collected from the rim crest of Plum crater (pl. 5, pan 5), and are probably ejecta from that crater (figs. 13-15). Large samples 61015 (B_2; 1,803 g) and 61175 (B_3; 543 g) were collected away from the Plum rim crest and in an arc concentric to and about 30 m from the rim crest of Flag crater (pl. 5, pans 5 and 6; figs. 16, 17). These samples may represent original ejecta from Flag crater, or possibly Flag rim materials reejected by Plum crater, which undoubtedly penetrated the upturned bedrock beneath Flag crater. A distinct, but smooth and somewhat subdued bench occurs in Plum approximately 3 m below the surface. No outcrop is visible, but the benched topography suggests a change in cohesion of the materials in the walls of the crater. This change may reflect the contact beween Flag ejecta and raised bedrock in the eroded rim of Flag crater and may be the source area of the large, filleted, partly buried boulder from which sample 61295 (B_3) was collected (fig. 15*B*; pl. 5, pan 5).

The largest of the Plum crater samples are B_3 and B_4 type breccias, whereas samples related to Flag crater are in the B_2 and B_3 categories. The B_2 breccias at this station may represent the deepest excavation level (60 m) of Flag crater, a stratigraphic horizon not tapped by the smaller Plum crater (5 m). Sampling of all rock types present at this station may not have been statistically sufficient because of time constraints.

At two places on the rim of Plum crater, the astronauts noted white regolith beneath a top layer of gray soil 1 to 2 cm thick. At one of these places, the light material lay beneath the gray on the fillet of a large boulder (fig. 18). This suggests that the fillet was formed by one of two mechanisms: (1) shedding of light material from the rock followed by postfillet deposition of a thin dark layer or (2) deposition of light material followed by darkening of the surface. White soil was observed at the trench site on the northeast rim west of Plum crater, where the top centimeter of gray soil was underlain by several tens of centimeters of white soil.

Other samples collected at station 1 included those from the trench (61240, 61245 to 61249, 61255 and 61220), a fillet soil (61280 at 61295-boulder), and two surface soil samples (61160 and 61180).

The crew observed that the large rocks were clearly more abundant on the rim crests of both Flag and Plum craters than in the intercrater areas, indicating that

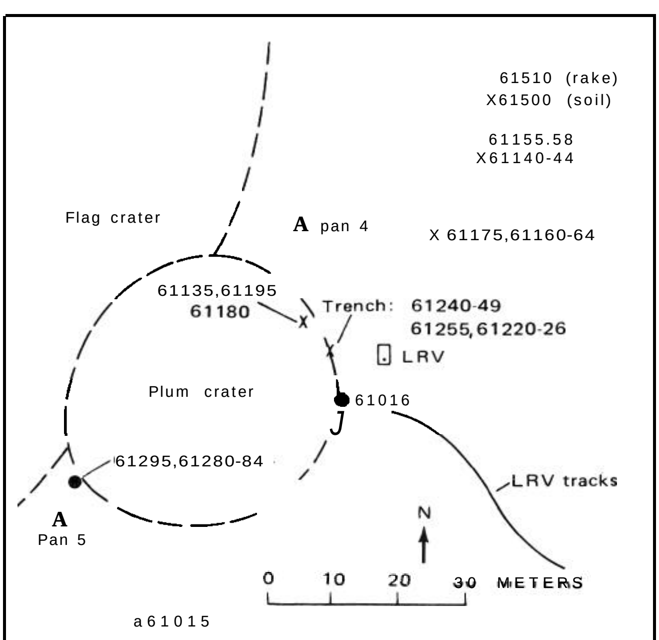


FIGURE 11.-Planimetric map of station 1.

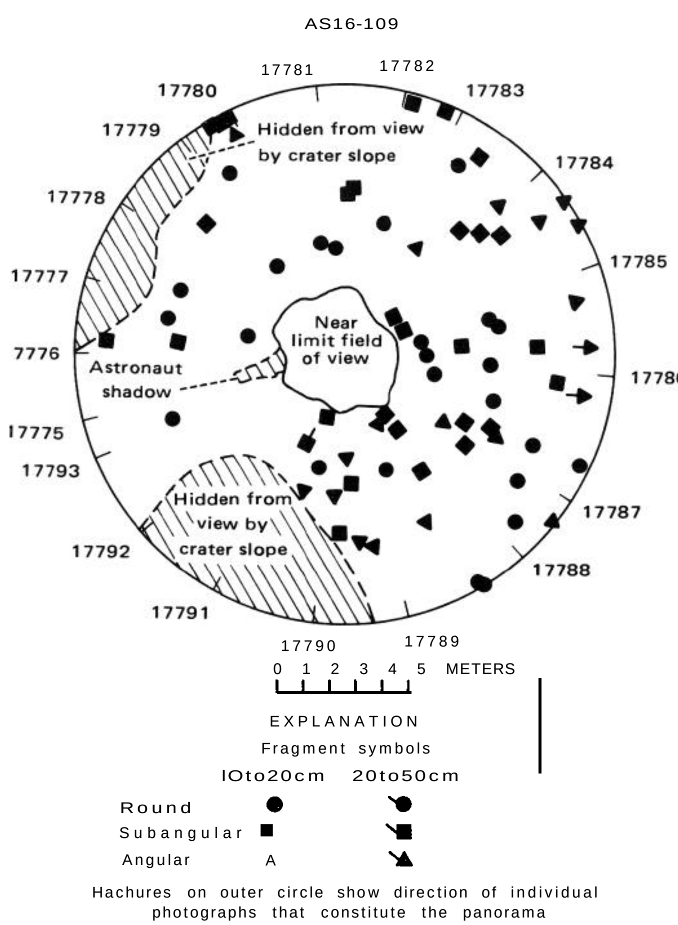


FIGURE 12.-Rock distribution within 10 m of site of panorama 4 station 1.

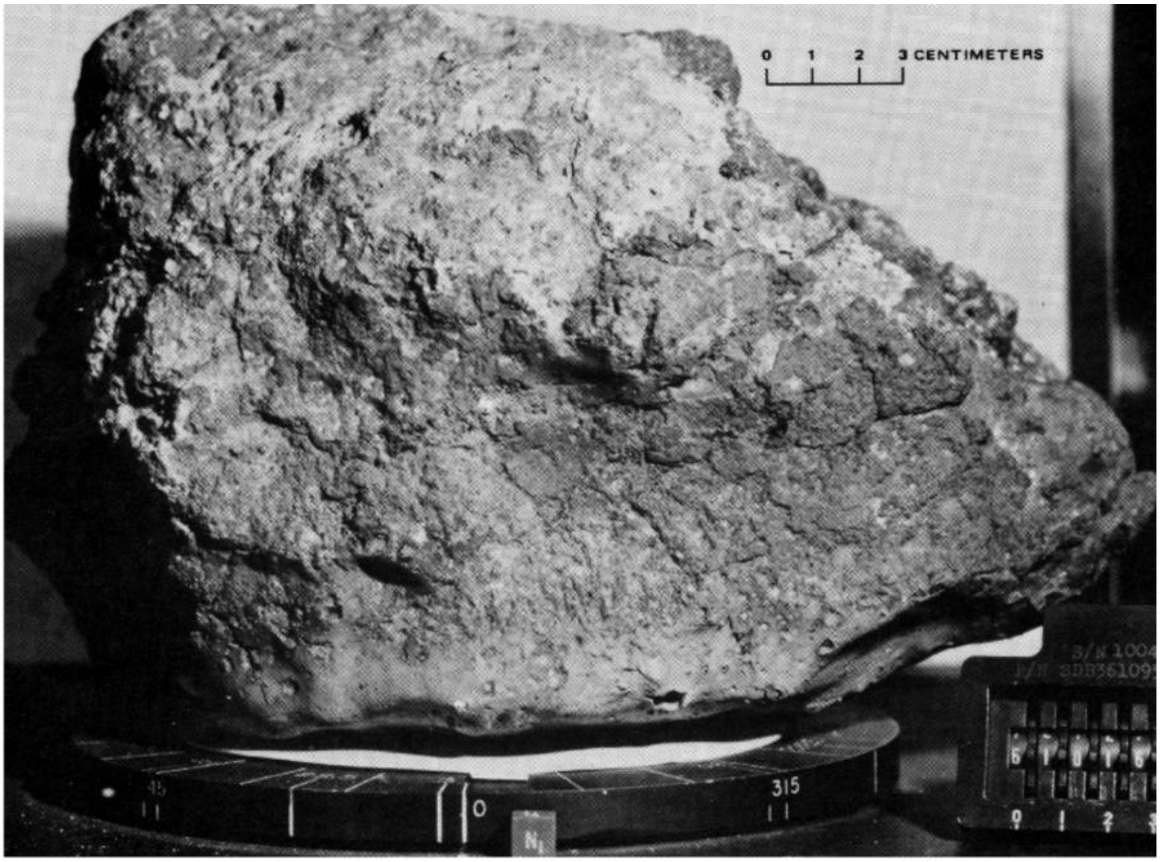


FIGURE 13.-Sample 61016. NASA photograph S-72-41545. (See Sutton, fig. 24*B*, this volume, for lunar orientation).

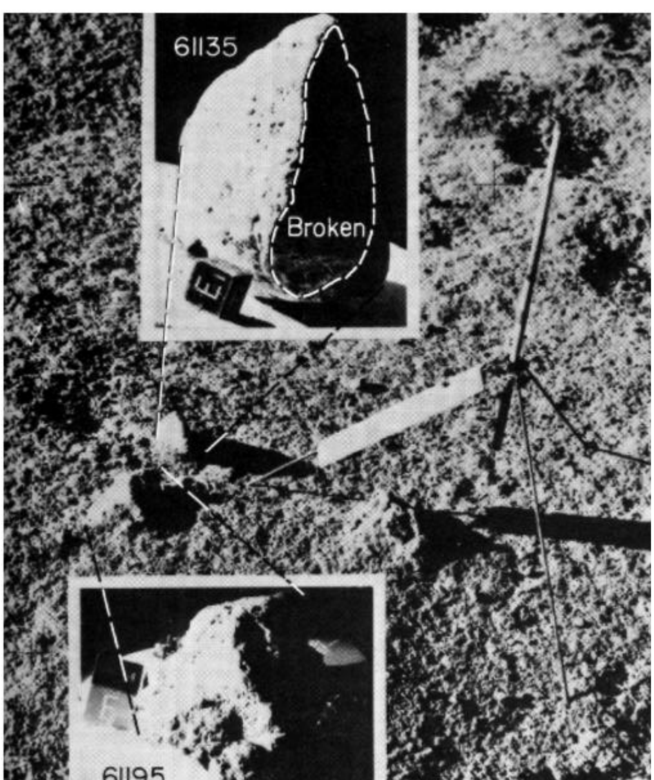
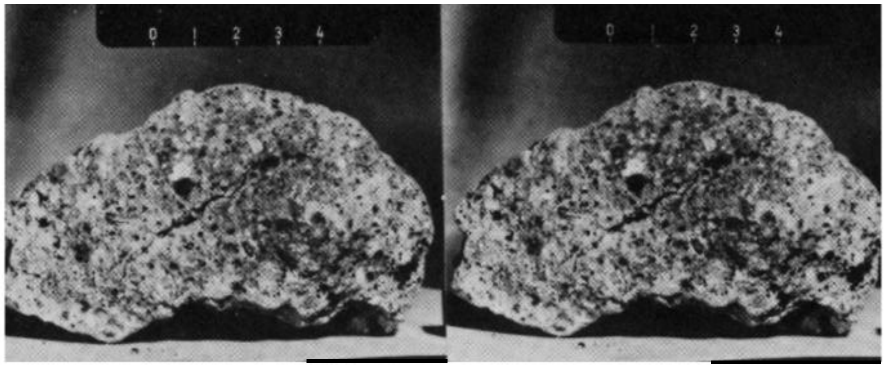


Figure 14.-Samples 61135 and 61195 showing approximate lunar orientations reconstructed in the LRL compared with an enlarged part of EVA photograph AS16-114-18405, taken cross-sun, looking south (inset photographs, S-72-41609 and 43315, respectively). Reconstruction by R. L. Sutton.



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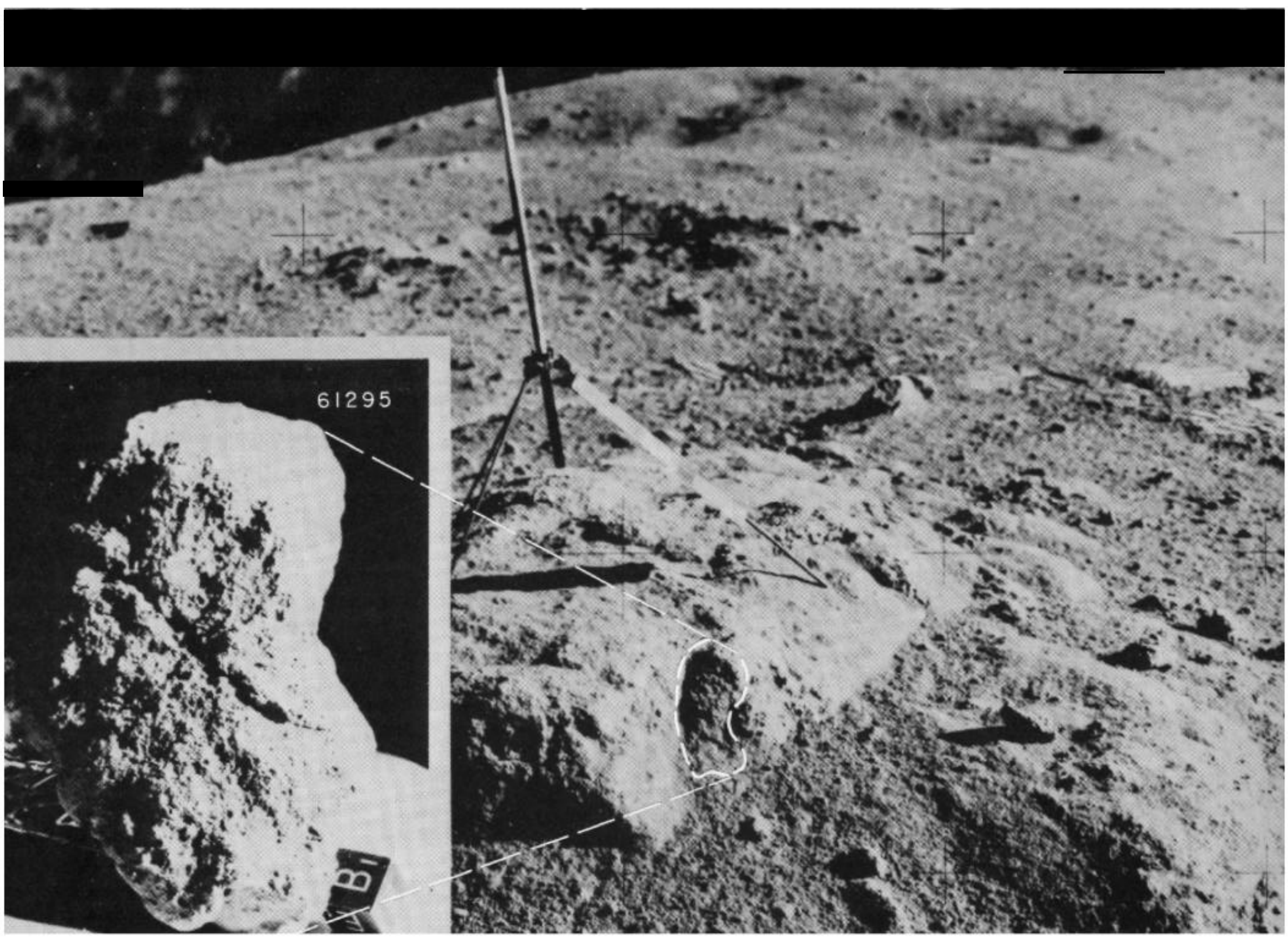


B

FIGURE 15.-Sample 61295. *A,* Stereopair composed of NASA photographs S-72-40946B and 40946. *B,* Approximate lunar orientation reconstructed in the LRL compared with an enlarged part of EVA photograph AS16-114-18412, taken cross-sun, looking north (inset photograph, S-72-40967). Reconstruction by R. L. Sutton.

these craters are the most recent source of the deposits. Two very large craters 180 m south of station 1 (450-m diameter and 630-m diameter, "Eden valley") may have contributed ejecta to the area from depths of 90 to 130 m before the impact at Flag crater (fig. 6). The significance of these materials in the collected samples has not been ascertained.

The surface rocks at station 1 are considerably less abundant, more eroded, less angular, and distinctly more buried than at station LM/ALSEP , demonstrating (pls. 3, 4, and 5) the scarcity of fresh South Ray ejecta at station 1.

STATION 2

Station 2, located approximately 850 m west of the LM, is just north of Spook crater (370 m diameter) and on the blocky south rim of Buster crater (90 m diameter) (pl. 5, pan 6; fig. 19). The area is crossed by a faint ray of high-albedo material thought to be derived from South Ray crater, 5.7 km to the southwest (fig. 2). Subdued, grooved lineaments radial to South Ray crater cross the area.

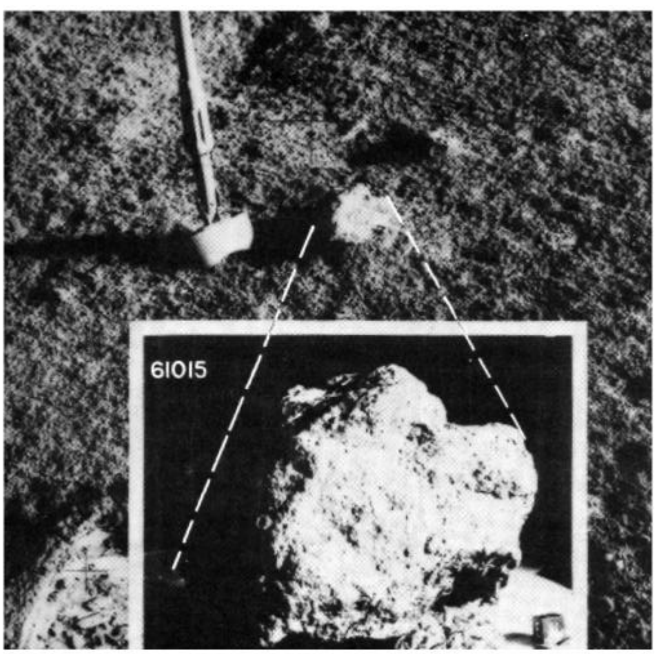


FIGURE 16.-Sample 61015 showing approximate lunar orientation reconstructed in the LRL compared with an enlarged part of EVA photograph AS16-109-17808, taken cross sun. looking north (inset photograph, S-72-4105). Reconstruction by R. L. Sutton.

Fragments as large as 0.5 m, but mostly 5 to 10 cm, are scattered over the station area; they cover 1.6 to 2.6 percent of the surface, averaging 2.0 percent (figs. 4, 20). Rocks larger than 5 cm cover 0.4 to 1.5 percent of the surface, averaging less than 0.8 percent. Most fragments are angular to subangular and are perched or only slightly buried. Fillets are rare.

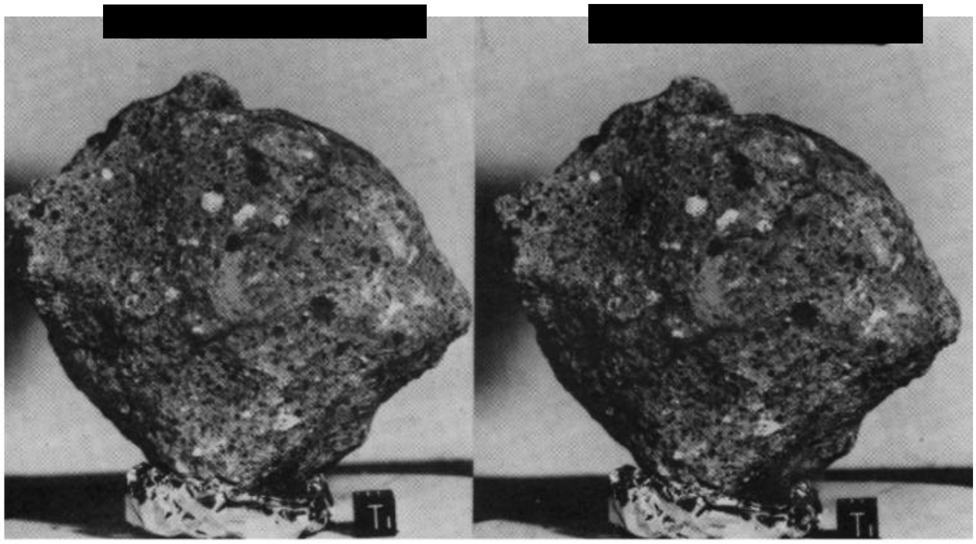
Station 2 lies within the continuous ejecta blanket of both Spook and Buster craters. Samples collected should include some material from both craters, although Buster is more clearly associated with surface rock fragments. Spook crater is symmetrical with a subdued but slightly raised rim; no rock exposures are discernible on the walls. Buster crater is about 100 m north of Spook crater and is superimposed on its outer rim. The rim of Buster is fairly sharp, the inner walls fairly steep. Ninety percent of the floor and a large part of the walls and rim of Buster crater are covered by blocky debris that trends northeast across the crater floor (pl. 5, pan 6). The rocks in the crater floor, as large as 5 m, are angular. The crew discerned northeast-trending planar structures dipping northward within the blocks and a parallel organization of the blocks.

Buster crater penetrates about 18 m into the south end of a subtle ridge, 15-18 m high (maximum) and 700 m long, that trends northwest from the station area ("B" in fig. 6). The conspicuous blocks on the floor of Buster crater may have been derived from this ridge. Halfway crater, 155 m west of Buster and off the ridge, is slightly more subdued and has very few associated blocks. The nature and distribution of the blocks in the floor and walls of Buster (pl. 5, pan 7) suggest that it penetrated a more coherent substrate than most craters of similar size and age in this region. A bench recognized in the blocky part of the wall of Buster crater may represent the change in coherence between the regolith and the inferred bedrock.

Spook crater penetrated 75 m into the Cayley plains; its location on the northeast edge of the "Eden valley" crater complex (penetration to 120 m) suggests that some of the material ejected may be from the earlier "Eden valley" impact (fig. 6).

A total of eight rocks larger than 2 g were collected from the station 2 vicinity; they represent both crystalline and breccia types, as shown in table 3.

The percentage of the B_1 breccias collected from stations LM/ALSEP (25 percent), station 1 (0 percent), and station 2 (37 percent) appears to show a relation to the presence of continuous-ejecta deposits from South



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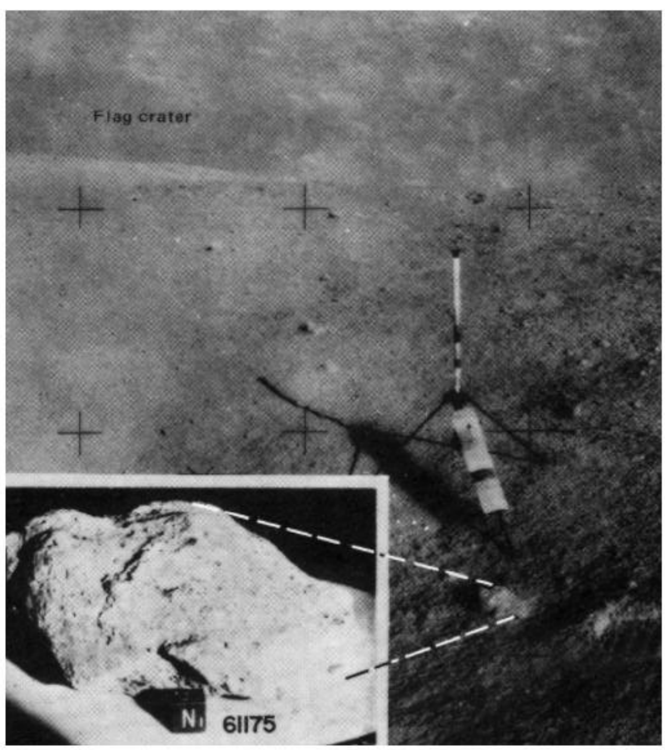


B

FIGURE 17.-Sample 61175. *A*. Stereopair, NASA photographs S-72-411 97 and 41197B. *B*, Approximate lunar orientation reconstructed in the LRL compared with EVA photograph AS16-109-17798, taken down sun, looking west (inset photograph, S-72-40966). Reconstruction by R. L. Sutton.

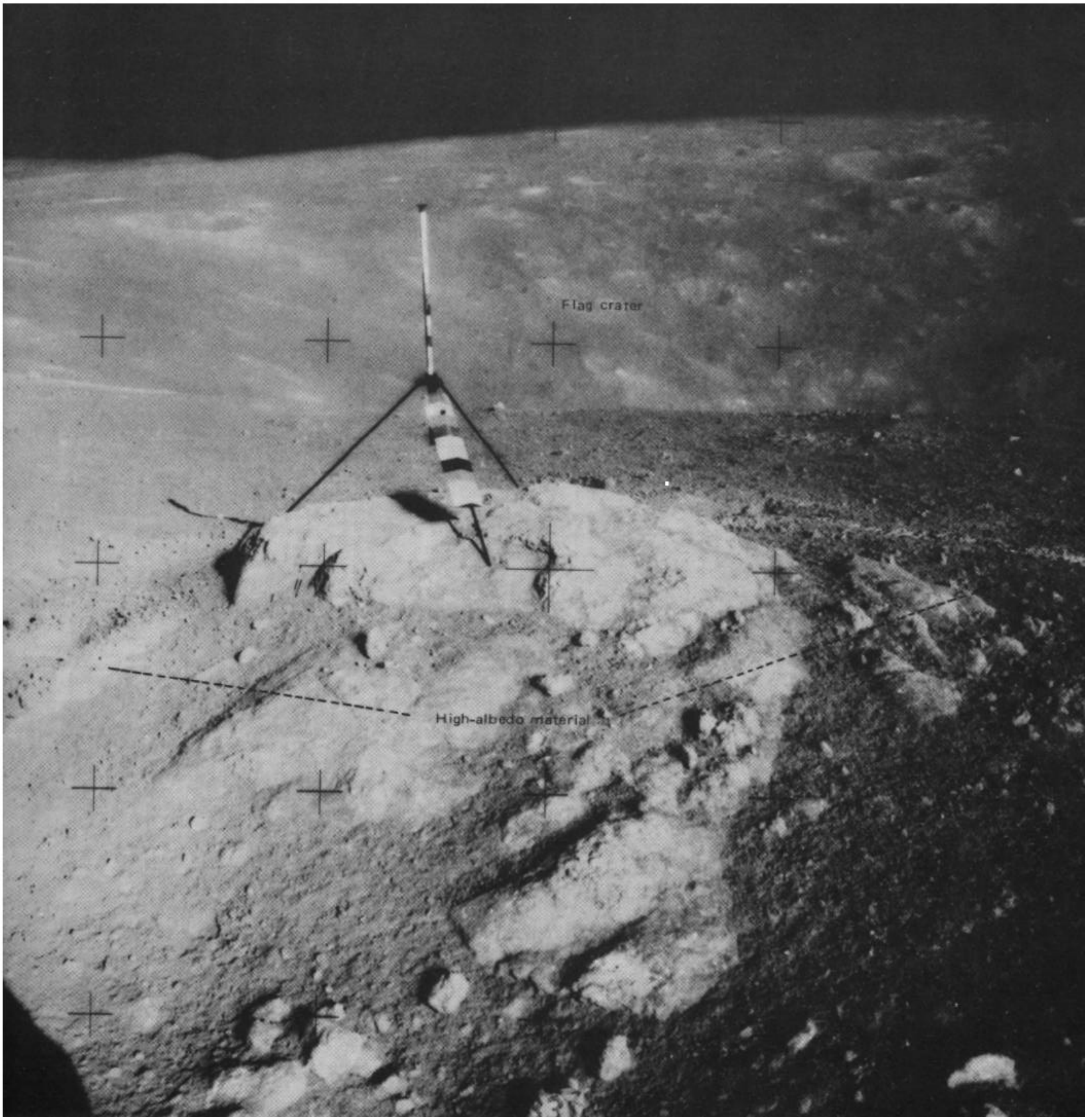


FIGURE 18-Large filleted boulder showing high-albedo material kicked by astronauts (AS16-109 17802).

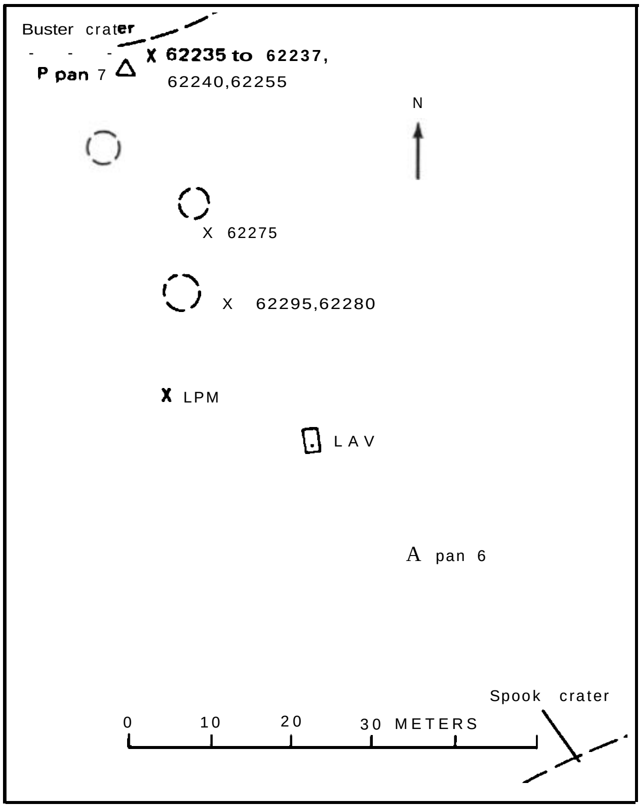


FIGURE 19.-Planimetric map of station 2. For explanation of Symbols see Figure 1.

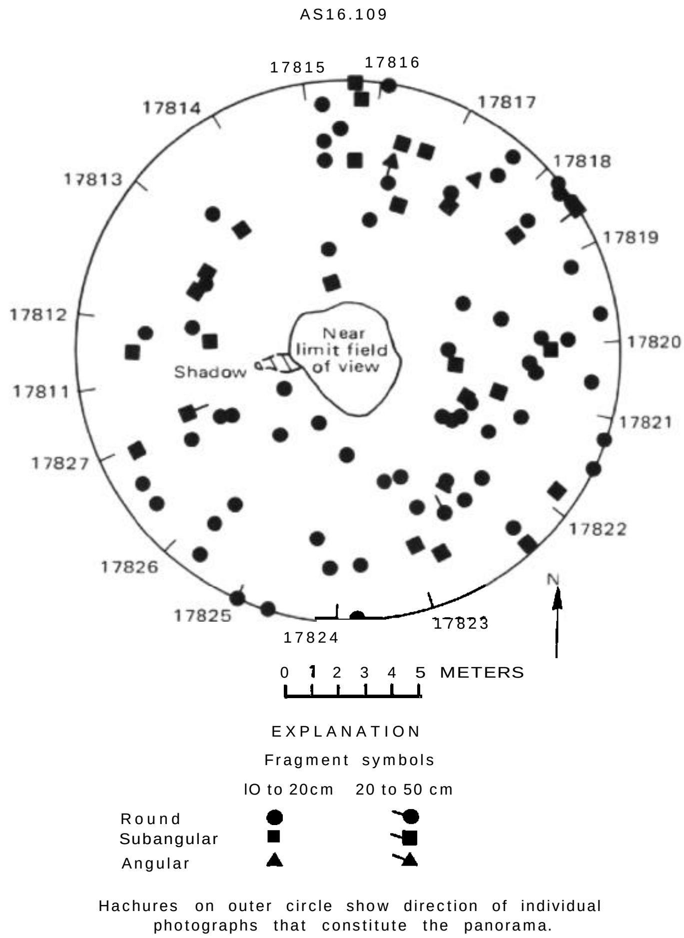
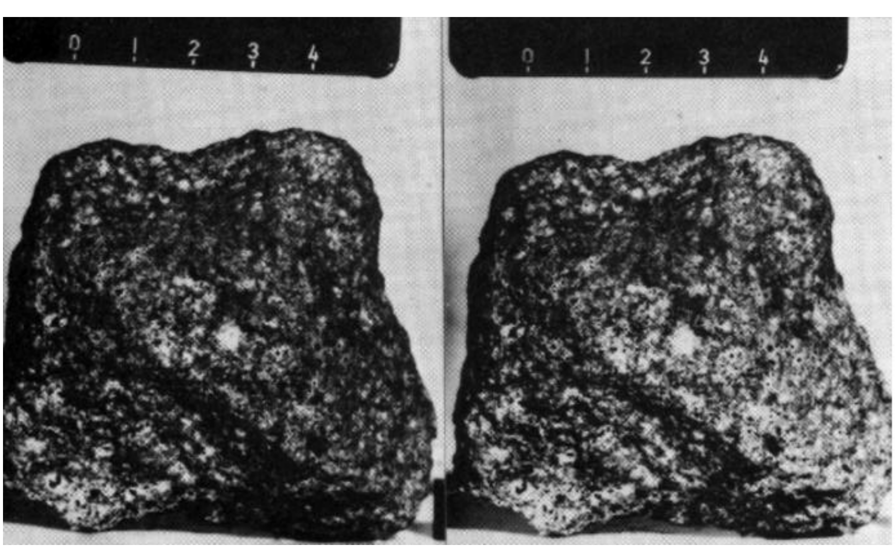
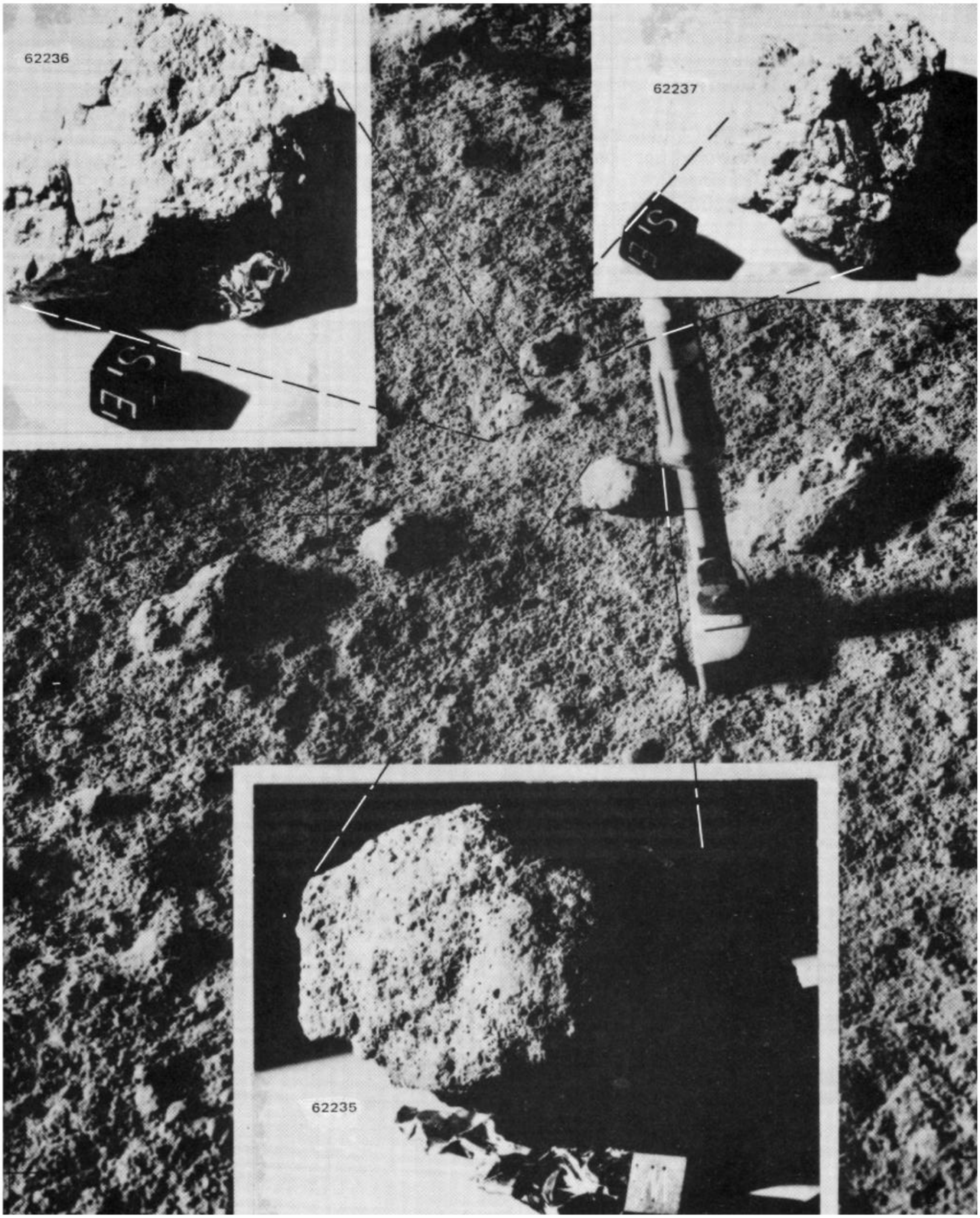


FIGURE 20.-Rock distribution within 10 m of site of station 2 panorama.



A

FIGURE 21.-Sample 62235. *A*, Stereopair (NASA photographs S-72-41280 and 41280B). *B*, Samples 62235, 62236, and 62237 showing approximate lunar orientation reconstructed in the LRL compared with an enlarged part of EVA photograph AS16-109-17838, taken cross-sun, looking south (inset photographs. S-72-41424, 41837, and 41838, respectively. Reconstruction by R. L. Sutton.



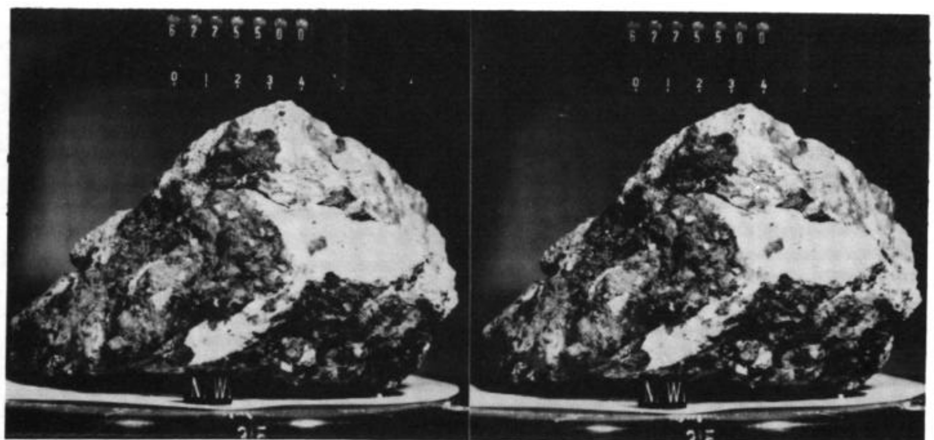
B

FIGURE 21.-Continued.

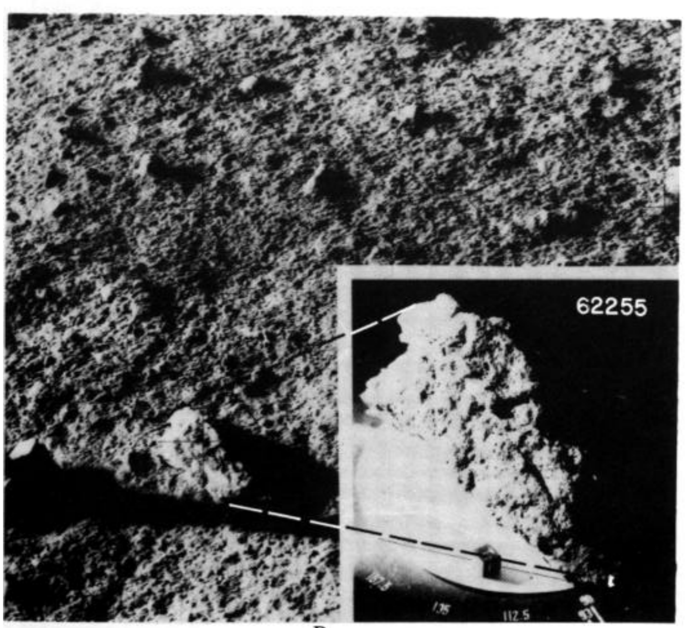
TABLE 3.-*Number and percentages of rocks (>2g) documented at station 2*

Category	Number of rocks collected	Percentage
Igneous:		
C_1	1	12.5
Metaclastic:		
C_2	1	12.5
Breccia:		
B_1	3	37.5
B_2	2	25.0
B_3	1	12.5
B_4	0	0
Total	8	100.0

Ray crater. South Ray ejecta crosses stations LM/ALSEP and 2 but is extremely sparse at station 1. This relation does not appear to hold, however, when the sample types collected at stations 6 and 8 are examined. Although these stations are much closer to South Ray crater, no B_1 breccias were collected from either site. If indeed the B_1 rocks at the stations LM/ALSEP, 1, and 2 sites are related to South Ray ejecta, they would have to represent a very shallow horizon within that crater, deposited primarily downrange. The association is tenuous at best. Breccia type B_4 was not sam-



A



B

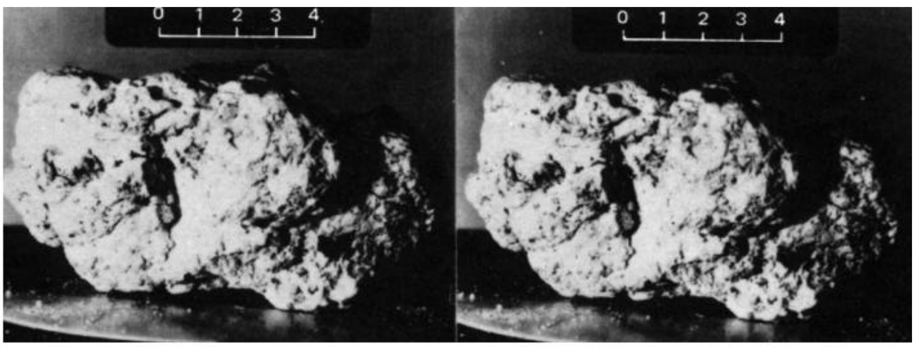
FIGURE 22.-Sample 62255. *A,* Stereopair (NASA photographs S-72-41823B and 41823). *B,* Approximate lunar orientation reconstructed in the LRL compared with an enlarged part of the EVA photograph AS16-109-17844, taken cross-sun, looking south (inset photograph, S-72-41834). Reconstruction by R. L. Sutton.

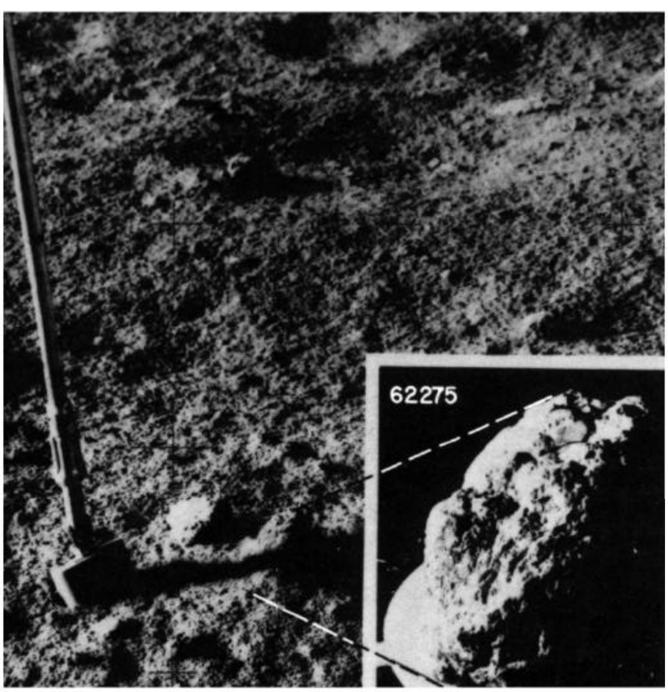
pled at station 2 but made up 14 percent of the rocks collected at LM/ALSEP and 13 percent of those re turned from station 1.

The planimetric map of station 2 (fig. 19) clearly shows that most sampling was done closer to Buster crater rim than to Spook crater. The samples collected nearest Spook were 6229 (C_1) and 62280 (soil) at a distance of about 70 m. Photographs and orientation diagrams for the station 2 large rocks are shown as figures 21 to 24.

Astronaut Duke commented regarding Buster crater, "The blocks are angular, but they are definitely coming out of Buster." The most recent source of collected samples therefore may have been Buster crater, which probably reexcavated much Spook crater material.

The surface soil at station 2 is medium gray with a higher albedo soil below the upper centimeter or so, similar to light soil at the ALSEP and at station 1. The compaction and granularity of the soils are typical of





B

FIGURE 23.-Sample 62275. ***A,*** Stereopair (NASA photographs S-72-40922B and 40922) ***B,*** Approximate lunar orientation reconstructed in the LRL compared with an enlarged part of EVA photograp h AS16-109- 17846, taken cross-sun, looking south. The sample is fragile and minor breakage has occurred; shadow details were impossibl e duplicate accurately in the laboratory (inset photograph, S-72-41426). Reconstruction by R. L. Sutton.

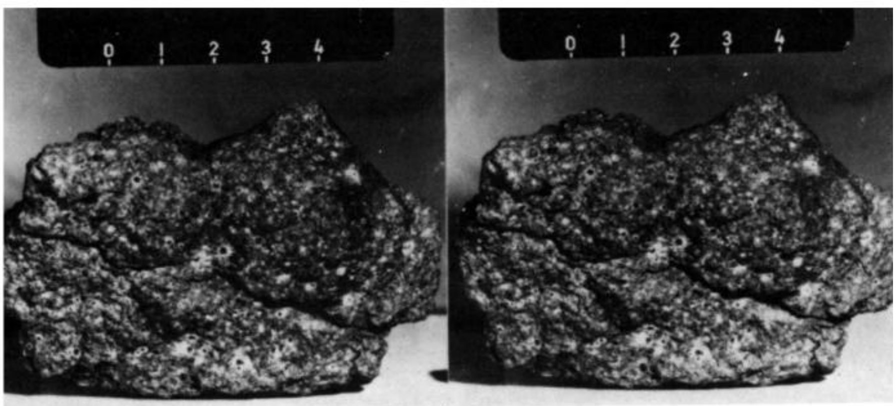
the area. Small craters as much as 2 m in diameter are distributed fairly uniformly; they are generally subdued but a few small fresh craters, possibly South Ray secondaries, have sharp rims on which cloddy ejecta is discernible.

SUMMARY

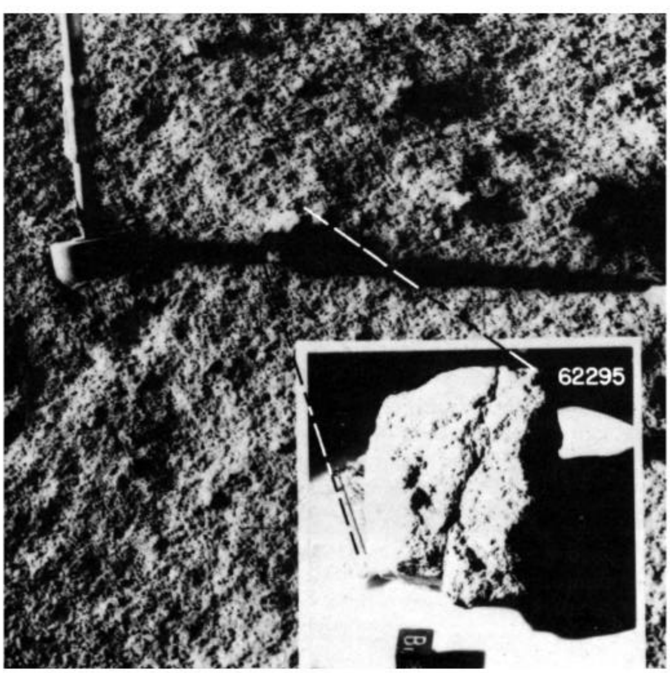
The samples collected from stations LM/ALSEP, 1, and 2 most probably represent materials of the Cayley plains to depths of 70 m or more and materials from the upper layers within South Ray crater. The proportions of rock types collected from each station were constrained by time available and may not be clearly indicative of the rocks present at depth.

The variety of rock types collected at stations LM/ALSEP, 1, and 2 indicates that the Cayley plains breccias are heterogeneous and suggests that they are composed of pockets of both light and dark breccias deposited by a turbulent process characteristic of large-basin ejecta emplacement.

The great amount of South Ray ejecta. within the central plains of the landing site, suggested by the distribution of high-albedo materials radial to that crater (fig. 2), appears to be a heterogeneous collection of light and dark breccias including all types collected throughout the region traversed during the mission.



A



B

FIGURE 24.-Sample 62295. A, Stereopair (NASA photographs S-72-44492 and 44492B). B, Approximate lunar orientation reconstructed in the LRL compared with an enlarged part of EVA photograph ASl6-109-17848, taken cross-sun, looking south (inset photograph, S-72-42563). Reconstruction by R. L. Sutton.