APOLLO 16 SPECIAL SAMPLES

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INTRODUCTION:*

The interaction of the space environment with the lunar surface is the subject of a variety of investigations. These studies primarily yield valuable information about processes within the sun or the solar system in general, but it has already been demonstrated that the space environment also represents an important agent which constantly modifies the physical and chemical make up of planetary surfaces in general and specifically that of the Moon. Such investigations are concerned with the particle track record of solar and galactic radiation, the chemical make up of solar wind, radioactive isotopes produced by solar flares and cosmic radiation, noble-gases, micrometeoroids and selective volatilization and ionization of specific elements. A quantitative understanding of these processes will contribute to our knowledge of the solar system. It also is required to delineate the character and dynamics of lunar surface processes such as erosion of rocks, regolith-transport mechanism, turn over rate of regolith, the obliteration of impact craters, the migration of volatiles and semivolatiles and the influx of meteoritic materials. Collectively, these studies will also have important implications for remote sensing not only of the lunar surface but other planetary bodies as well.

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*This document supplements the reports by the Preliminary Examination Team, the Field Geology Investigation Team and the Apollo 16 Lunar Sample Information Catalog prepared by the curatorial staff. The interested reader will find a variety of additional details in the above documents. No attempt was made to acknowledge pertinent literature related to the many topics discussed in this report, because it is assumed that the reader interested in these special materials will be familiar with the appropriate literature.

While the investigation of Apollo 11, 12, 14 and 15 materials were able to yield valuable information about some general trends, it became increasingly mandatory for a more quantitative understanding of these processes that either specific samples were obtained and/or some samples were collected in a very specific fashion. A successful attempt was made during the Apollo 16 mission to return a variety of such materials.

The purpose of this report is to give the individual investigator documentary background information about these samples. Though most of the samples were collected for the purpose of investigating rather specific problems, most of the materials returned may serve multiple purposes. It is not intended to outline all these possibilities; this is left to the individual investigator who may use the samples as he sees fit to suit his specific needs. Nevertheless, where appropriate, the main rationale for collecting a specific sample is outlined and in general these materials will be particularly suitable for the purposes indicated.

A) MATERIALS OF THE VERY LUNAR REGOLITH SURFACE

Most of the above investigations are specifically concerned with the properties of the uppermost lunar surface, i.e. materials from less than 1 mm depth. Thus an effort was made to collect regolith materials from various, extremely shallow depths and to return actual rocks, the surfaces of which are carefully protected to ensure their pristine character.

1) Regolith Materials:

Sample: 69003 (beta-cloth)

69004 (velvet cloth)

69920 (skim)

69940 (scoop)

69960 (shielded soil)

Two special "surface samplers" were used to collect the uppermost regolith layer of Station 9, i.e. roughly 2.5 km distance from the Landing Point (Figure 1). This is considered a safe distance to rule out possible effects of the LM descent engine blast. Furthermore, the actual sampling area was behind a boulder facing away from the LM. Thus because of distance and ballistic shielding of the boulder, LM descent engine effects can probably be excluded. Great care was taken by the crew not to contaminate the samples with local regolith by keeping the kicking up of dust at a minimum and by using the boulder again as a "ballistic shield".

Next to the two surface sampler devices two other regolith samples were taken which incorporated successively deeper soil materials. The "skim" sample was retrieved by carefully skimming with the regular scoop across the very regolith surface and it is estimated that the maximum penetration was 5 mm. The fourth sample was a regular scoop sample with an estimated penetration of 3 cm (Figure 2). A drive tube taken in the vicinity (see CSVC) provides material from even greater depth (estimated penetration: 27 cm).

After collection of these materials, the boulder was turned over and a soil sample from underneath the boulder was taken (Figure 3). This soil was shielded from the space environment since the time the boulder was deposited; therefore, it may be valuable material to compare "exposed" versus "shielded" soils.

The surface sampler devices arrived at the LRL in apparently nominal condition. No obvious failures could be detected, though their outside was heavily dust-coated (Figure 4). Since these samplers require special processing, they were not opened as to date and no information can be given to the amount and type of material collected.

2) Pristine Rock Surfaces:

Sample: 67215 (padded bag #1)

67235 (padded bag #2)

In order to avoid abrasion and other factors resulting in a possible degradation of rock surfaces, two "padded bags" (Figures 5, 6, 7) were used at Station 11.

Due to the scarcity of crystalline rocks (which would have made more ideal samples) at the rim of N-Ray Crater, the crew had to select breccias. In addition, the velcro-strap tightening mechanism failed. Upon arrival in the LRL it was, however, obvious that the two bags were well protected by normal soil-sample bags placed around the padded bags within the bigger Sample Collection Bag. It appears that sample 67235 is a hard, recrystallized breccia; sample 67215 seems to be a moderately tough breccia (Figure 8).

B) EROSION MECHANISM AND RATE

Although the combination of a variety of special investigations (particle tracks, γ-ray spectroscopy of short lived isotopes, noble-gases, micrometeorite craters) may eventually lead to a quantitative understanding of lunar erosion processes, an independent approach is offered by sampling fillets banked up against a boulder and comparing the fillet soil with actual materials off the "parent-boulder". "Fillet samples" may be used to characterize the erosion mechanism and -rate of lunar rocks. Furthermore, the fillet samples may yield some information about the transportation mechanism and -rate of regolith materials. Fillet samples collected are from:

1) Station 1

Samples: 61295 (boulder chip)

61280 (fillet soil)

A boulder sitting on the South-rim of Plum Crater possessed a well developed fillet (Figure 9). The boulder itself is a moderately friable breccia. It is not established at present whether the boulder is related to the Plum, Flag or South-Ray cratering event.

2) Station 8

Samples: 68115 (boulder chip)

68120 (fillet soil)

Station 8 was located in a boulder strewn-field related to the South-Ray cratering event. One boulder (8a) consisted of a highly recrystallized, probably glass-rich breccia (Figures 11, 12). Hardly any fillet had developed around the boulder, thus allowing the study of the erosion of hard rocks.

3) Station 11

Samples: 67455 (boulder chip 1)

67475 (boulder chip 11)

67460 (fillet soil)

A group of white boulders attracted the attention of the crew. Though a "fillet sample" was not necessarily planned, the variety of materials collected (67455, 67475 (see Figures 26 and 27), 67460) satisfies the requirements for such a sample set. The white boulders have a feldspar-rich, very friable breccia matrix and are probably very easily eroded.

4) Station 9

The most ideal "fillet sample", however, is a combination of various soils and boulder chip materials obtained on a breccia boulder at Station 9 (Figures 1-4, 19-22).

b) Flux of Micrometeoroids

Samples: rocks 69935, 67115, 60135, 60095, 64455, 61016, 68415 and others

By combining the absolute microcrater density and absolute surface residence time on the very same rock surface, the flux of micrometeoroids over the last few million years can be obtained and thereby an important agens for lunar erosion and regolith transportation processes may be characterized. Especially suitable surfaces for these studies are glass-coated rocks. Rock 60135 is only illustrated in this report as a classical example for lunar erosion processes (Figure 13).

C) DATING OF IMPACT CRATERS

By combining a variety of surface exposure age studies (e.g. particle tracks, γ-ray spectroscopy, noble gases) it is possible to date the age of a cratering event, provided the materials collected can be unambiguously related to the event in question. Two basic approaches are possible. Either a large number of small rocks (with possibly complex surface histories) are investigated, leading to a statistical best estimate of the impact event or a few chips taken off big boulders are investigated. The latter case is to be preferred because it is assumed that large boulders have a less complex tumbling history and therefore the interpretation of the exposure age measurements is less ambiguous. Consequently, an attempt was made to collect representative chips of meter-sized boulders on the ejecta blankets of the South and North-Ray impact craters.

1) Dating of South Ray Crater

A variety of chips were taken on Stations 8, 9 and 10 from boulders which - according to field evidence - are part of the South-Ray ejecta blanket. If necessary, these chips can be supplemented with a large number of normal hand specimen collected on the surface and which are also interpreted to be associated with the South-Ray Crater event. (See FGE Report.) However, here we will describe the boulder chips only.

Station 8, Boulder a:

Sample: 68115

One chip off a large, dense, recrystallized breccia boulder (see Figure 11).

Station 8, Boulder b:

Samples: 68415

68416

Two chips of igneous appearance were taken off breccia boulder b (Figure 14). Though the parent boulder appears to be a breccia with many genuine clasts, the two chips dislodged from this boulder are rather homogeneous to the naked eye (Figures 15, 16). Surface documentary photographs indicate that the materials collected may be typical of the boulder matrix.

Station 8, Boulder c:

Sample: 68815

The parent boulder is again a dense breccia (Figure 17), though it appears that it predominantly consists of recrystallized glass;

the rock (Figure 18) has no igneous texture and in thin section a multitude of flow structures of the original glass are observed.

Station 9:

Samples: 69935 (top chip)
69955 (bottom chip)

Two chips were taken off one breccia boulder (see Figure 2). One chip originated from the very top of a boulder about 60 cm in diameter; the other one was dislodged from the bottom side of the same boulder, after it was turned over by the crew. (Figures 19, 20). Thus not only a comparison of "shielded" versus "exposed" materials is possible, but the set of chips may also serve to investigate large scale gradients of e.g. the production of radioactive isotopes or tracks caused by very energetic galactic radiation. Therefore these two chips are particularly valuable to reconstruct the formation age of South-Ray Crater. Unfortunately a straightforward comparison of the two chips may be complicated because the individual chips differ drastically in their lithology. The top-chip is a dense breccia and the bottom-chip a pure anorthositic clast (Figures 21, 22, 23).

Station 10:

Sample 60018

A dense, tough, highly breccia with a variety of clasts originated from an about 40 cm diameter breccia boulder in the vicinity of the LM (Figures 24, 25). According to the crew's interpretation, this boulder originated also from the South-Ray cratering event, though admittedly with less certainty than the boulders sampled at Stations 8 and 9.

2) Dating of North-Ray Crater

As is the case for South-Ray Crater, a large number of rocks were collected at the rim of North-Ray Crater. However, because of its more advanced state of degradation, North-Ray Crater is judged to be considerably older than South-Ray and as a consequence, most of the hand specimens collected have probably such a complicated surface history that some of the exposure age techniques mentioned above are not applicable because of saturation and exposure geometry difficulties. Again the most suitable materials originate from very large boulders.

Station 11, "White Boulders"

Samples: 67455 (boulder-matrix)
67475 (individual clast)

Two samples were dislodged from a white breccia boulder roughly 5 m long and 2 m high (Figure 26). One of the samples represent the highly friable, feldspar-rich matrix (67455). Due to its friable nature it broke into several large pieces during transit; a surface orientation cannot be reconstructed (Figure 27). The other sample (67475) is a dense, very fine-grained, isolated clast dislodged from the white boulder.

Station 11, "House Rock"

Samples: 67915 (normal boulder surface)
67935 (within spall area)
67955 (within spall area)

A boulder roughly 5 x 2 x 2.5 m was sitting next to the even bigger "House Rock" (Figure 29). Though three different samples were taken, only one is highly suitable for attempting to date the North-Ray event. This chip was part of a very dense, feldspar rich clast (67915, Figure 30). The other two areas sampled (67935, 67955) were within a freshly broken "spall zone" of an impact crater, the center of which resembles a percussion-cone. The depth of the spall zone, i.e. the thickness of the material removed, is in the order of 2-3 cm. For the latter two samples the only techniques which may still obtain useful information for the time of emplacement of the parent boulder may be a variety of noble-gas studies. However, according to field evidence, there is the discrete possibility that the entire 5 m boulder may have been dislodged from the bigger "House Rock" at an unknown time after the North-Ray cratering event. Thus the total exposure history and especially geometry cannot be established with great confidence.

Station 13, "Shadow Boulder"

Samples: 60017

63335

63355

A boulder roughly 6 x 5 x 3 m was encountered at about 1 crater diameter away from the rim of N-Ray (Figure 31). A total of three different areas were chipped (Figures 32, 33, 34). The samples obtained are all of the dense, dark matrix breccia type. All samples should be suitable for the above studies, though sample 60017 is probably the most suitable one because of its large size. Because of time line considerations, photographic documentation was kept at a minimum.

3) Dating of Buster Crater:

Samples: 62235

62295

A total of six rock samples larger than 25 grams were collected on the rim of Buster Crater, notably samples 62235 (Figure 36) and 62295 (Figure 37). These samples can be associated with high confidence to the Buster ejecta blanket. Considering its diameter and state of preservation, Buster is probably a rather recent event. However, no information is available to establish its relative age compared to South-Ray Crater. If their ages should differ significantly, valuable information about erosion and obliteration of 100 to 1000 m size craters could be obtained and applied to other lunar surfaces. Furthermore, the possibility that Buster is a secondary crater from South-Ray cannot be categorically dismissed, though it is unlikely. Information about its age of formation may dismiss or support such an interpretation.

4) Other Craters

A variety of samples were collected around other craters visited by the Apollo 16 crew (see FGE Report). However, their relation to the ejecta blankets of their respective source craters is somewhat ambiguous. Thus they are deleted from this report.

D) GEOCHEMICAL INVESTIGATIONS

1) Permanently Shadowed Soil

Samples: 63320 (shadowed soil)

63340 (reference soil)

Migration and redistribution of volatile and semivolatile elements on the lunar surface was discovered in a variety of investigations on regolith materials from previous missions. Neither the activation mechanism nor the mode of migration is well established. By sampling soil materials from permanently shadowed areas, it is hoped to find a concentration of these elements because it is envisioned that the shadowed areas will act as cold-traps. Therefore, the soil from the very surface of a permanently shadowed area should be especially enriched in volatiles and semivolatiles and a soil sample from greater depth at the same location may serve as reference sample.

A hole more than 1 m deep and roughly 50 cm wide was observed at the South-end of "Shadow Rock" at Station 13 (see Figure 31). Soil materials were taken in the manner described above. Because of the shadowed condition, no precise surface photography is available. However, the comments of the crew about the geometry of the "gopher-hole"

are such that a permanent shielding geometry from the sun can be established with high confidence. After sample receipt in the LRL, samples 63320 and 63340 were placed in specially sealed containers, in order to prevent possible alterations of the samples. The closest soil sample (63500) from normal, i.e. exposed regolith was taken roughly 15 m to the SE of "Shadow Boulder" in connection with a rake sample.

2) E-W Split

Samples: 67940 (E-W split)

67960 (reference soil)

A variety of rare gases and other volatiles make up what can be called a "lunar atmosphere". Most interest has focused on Argon. It is envisioned that a large proportion of these gases is present in an ionized state and therefore may be accelerated and redistributed by the solar wind electric field along, roughly speaking, N-S trending trajectories. At the completion of their trajectory the gases are implanted into the regolith materials. The angle of incidence seems to be rather small. If one collects soil materials between two boulders, the sides of which strike in an E-W direction, the interboulder area should be devoid of such reimplanted gas species. Comparison with an unshielded soil sample collected in the vicinity should result in a more quantitative understanding of the implantation of rare gases.

Such a set of soil samples was taken at Station 11 between "House Rock" and a 5 m boulder at the South end of House Rock (Figures 29, 37). The gap between these boulders is striking almost perfectly E-W; its overall length is about 2 m, the height of the House Rock side about 3 m (if not 10 m, when one considers the entire House Rock) while the boulder to the South is approximately 2.5 m high; thus perfect shielding geometry is achieved. The soil sample (67940) was taken at the geometrical center of the E-W gap. The corresponding, unshielded "control" sample (67960) was taken about 5 m to the E along the direction of the gap. Due to time line considerations and especially limited mobility, no detailed photography of the individual sampling areas exists.

3) Core Sample Vacuum Container (CSVC)

Though the precision of chemical analysis has significantly improved in the last decade, it is envisioned that analytical techniques may be improved still further. For a variety of investigations, notably organic components the "contamination" by the spacecraft and the astronauts' Life Support systems presently poses already serious problems. In order to collect a chemically ultraclean sample, a single drive tube - taken at Station 9 - was inserted into vacuum sealed container (CSVC, Figures 38, 39) immediately after extraction from the lunar surface. Upon arrival at the LM, the CSVC was placed into ALSRC No. 2, which itself arrived vacuum-sealed in the LRL. After opening of the ALSRC in the LRL sterile nitrogen atmosphere, the CSVC was immediately placed into another vacuum container. The sample will be stored for an undetermined time under an N_2-vacuum of about 10^{-4} torr. Following the entire history of this particular sample, spacecraft contamination can be excluded because it was collected 2.5 km away from the LM and protected by two vacuum seals. Contamination by the Life Support Systems was minimized by taking samples from depth and placing them immediately into a vacuum container.

E) CORES

A total of four double drive tubes and one 2.25 m drill core were taken on stations 4, 8, and in the LM-ALSEP area (Table 1). A total length of about 480 cm (excluding CSVC) of core materials were returned. These cores were x-rayed shortly after unpacking; the following preliminary descriptions were derived from the resulting x-radiographs.

In addition to providing documentation, x-radiographs have been successfully used on previous missions as a preliminary guide to stratigraphy and dissection. Changes in texture and structure, including grain size and shape, degree of packing, density, bedding types, and contacts are clearly seen in the films. Particles with a metallic composition are readily detected because of their high x-ray absorption coefficient. By use of stereopairs, components can be located in three dimensions, and selective emphasis of coarse and x-ray opaque particles simplifies some aspects of interpretation. On the other hand, there are several limitations which should be kept in mind when reading the detailed core logs. Particles with a low x-ray absorption, such as feldspars, tend to be invisible; data on grain size distribution, sorting and density are not unambiguous and the exact location of components may be uncertain because of parallax distortion.

1) Station 4:

Samples: 64001 (bottom stem)

64002 (top stem)

Detailed Core Log (see Figure 40):

Unit 1 Depth: 58 to 70 cm Thickness: 12 cm

Characterized by angular to subangular opaques, coarser than above.

2% opaque, up to 5 mm diameter, mostly 0.5 to 1.0 mm, but with only moderately good sorting, most fragments equant but notably angular to subangular, some with irregular outline.

5% semi-opaque rock fragments with distinct outline, 0.3 to 0.8 cm diameter, mostly about 0.5 cm., with irregular, equant, subangular outline.

25% semi-opaque rock fragments with indistinct, mottled outline, up to 1.0 cm diameter, but most appear to be in the range of 0.5 cm. Fragments appear to be equant to slightly elongate, and irregular in outline.

Unit 2 Depth: 51 to 58 cm Thickness: 7 cm

Finest-grained section in the core.

1% opaque, as in Zone 5.

10% semi-opaque rock fragments with moderately indistinct outline, as in Zone 5, except that most are 0.3 to 0.8 mm diameter.

10% semi-opaque rock fragments with indistinct, irregular outline, up to 1.1 mm diameter, mostly 0.5 to 1.0 mm diameter, equant, scattered in indistinct layers at about 53 and 56 cm.

At 54 cm is a partially void space surrounding a large, elongate rock fragment. The void is herein interpreted as being created by disturbance of the rock fragment during sampling.

Unit 3 Depth: 49 to 51 cm Thickness: 2 cm

Characterized by abundant, large rock fragments.

1% opaque, up to 0.8 mm diameter, mostly 0.3 to 0.5 mm diameter, with fairly even size distribution, good sphericity and rounding.

60% semi-opaque rock fragments with moderately indistinct outline. In contrast to upper layers, rock fragments in this zone do not show distinct outlines throughout, but some are distinct and others vague. Rock fragments range from 0.3 to 1.6 cm most between 0.5 and 1.1 cm, and most are elongate and irregular.

10% semi-opaque with vague outline, "clods", as above.

Unit 4 Depth: 42 to 49 cm Thickness: 7 cm

Similar to above, but with fewer rock fragments, more matrix.

2% opaque, up to 1.5 mm diameter, sorting and rounding as above.

15% semi-opaque with distinct outline, similar to above, except for absence of elongate rock fragments.

10% semi-opaque with vague outline, as in Zone 1.

Unit 5 Depth 14.5 to 42 cm Thickness: 27.5 cm

Characterized by very abundant, large, varied rock fragments.

2% opaque, up to 2.0 mm diameter, mostly about 0.2 to 0.5 mm, relatively poorly sorted, most pieces equant, well rounded.

20% semi-opaque with distinct outline, mostly 0.5 to 1.0 cm diameter, but ranging up to 1.4 cm. Most fragments are equant, but about 5% (of total rock) distinctly elongate. Margins straight, subangular.

60% semi-transparent, with vague outline, similar to Zone 1.

<u>Unit 6</u> Depth: 11 to 14.5 cm Thickness: 3.5 cm

Finer-grained than above, with fewer rock fragments.

1% opaque, up to 0.8 diameter, mostly 0.3 to 0.8 mm, well sorted and rounded.

30% semi-opaque, with vague outline, largest rock fragments 0.8 cm in diameter, in contrast to above. Most fragments are under 0.5 cm, and appear to have a more even size distribution than above.

<u>Unit 7</u> Depth: Surface to 11 cm Thickness: 11 cm

Characterized by abundant, coarse rock fragments.

2% opaque, all under 1.2 mm diameter. Most between 0.5 and 1.0 mm, appear to be of even size distribution (well-sorted), mostly spherical and well rounded.

10% semi-opaque with sharp outline, 0.5 to 1.3 cm long, mostly about 1.0 cm, subangular, with noticeably straight edges.

50% semi-opaque with vague outline, 0.1 to 1.2 cm, mostly between 0.3 and 0.5 cm. Clod-like appearance, but probably not clods, which tend to be transparent to x-rays.

General:

The purpose of this double drive tube taken at the highest elevation reached on Stone Mountain was to recover typical Descartes material (Figure 41). Due to the omni-presence of South-Ray ejecta material, however, the original objective may have not been reached. Nevertheless the x-radiographs indicate a distinct change in grain size, abundance of rock fragments and rock type at a depth of 51 cm. As a working hypothesis this change is interpreted as a contact of South-Ray ejecta (upper 51 cm) and underlying Descartes (?) material.

The stratigraphy described above can be closely correlated with the penetrometer resistance taken from a penetrometer section adjacent to the drive tube site. As indicated in Figure 42, the upper 11 cm of the core contains abundant rock fragments, and penetration resistance, as indicated by stress, increases markedly. The next 3.5 cm is distinctly finer-grained, and there is a correspondingly small increase in resistance. From 14.5 to 49 cm is a reverse-graded bed with an abundance of rock fragments at the top. Highest resistance in the penetrometer section was encountered in the upper part of the bed, where it appears that repeated pushes were necessary to overcome the resistance of the rocks in the interval. Stress then decreased downward to 49 cm, in correspondence to a decrease in grain size. From 49 to 51 cm in the drive tube is a thin rock layer; a thin zone of high resistance reflects the layer in the penetrometer. Stress again decreases with grain size to 58 cm, where the increase in soil "density" on the x-radiograph corresponds to an increase in penetrometer resistance.

2) Station 8:

Samples: 68001 (bottom stem)

68002 (top stem)

Detailed Core Log (see Figure 40):

Unit 1 Depth: 42.5 - 64 cm Thickness: 22 cm +

Coarse-grained unit with diverse rock types

Matrix: 40%, x-radiographically very "dense" and distinctly granular. Opaques, about 4% of total, range from limit of vision to 3.5 mm diameter, and appear to be very poorly sorted, with equal numbers of each size class. About 80% of the fragments are equant, the remainder are elongate, commonly comma-shaped. Half of the fragments are well rounded, the rest tend to be blocky and angular.

Framework: 25% semi-opaque, rock fragments with distinct outlines: 0.3 to 2.6 cm length, with very poor sorting but with many large fragments, over 1 cm diameter. These rock fragments tend to be equant to polygonal to wedge-shaped, with straight to slightly curved edges and angular to subangular corners. 35% semi-opaque density concentrations with indistinct outline, probably rock fragments (some particles may be soil clods, but clods tend to be more transparent to x-rays), 0.1 to 2.0 cm, mostly equant, with lumpy outline tending to rounded edges. Less than 5% of these fragments are elongate; the elongate particles, however, tend to be ragged in outline, with long axes horizontal; and they may be glass fragments.

Unit 2 Depth: 38 - 42.5 cm Thickness: 4.5 cm

Thin bed with well sorted small rock fragments, spherical opaques

Matrix: 70%, as unit 1, notably denser than overlying unit (#3), and with much higher percentage of rounded, spherical opaque fragments than overlying bed, which contains mostly blocky, angular fragments.

Framework: 30%, semi-opaque density concentrations with indistinct outline. Size 0.1 to 0.5 cm, mostly 0.3 cm, well sorted, equant to 1:1.5 elongate with long axes, where present, horizontal; notably lumpy, rounded edges.

NOTE: Lithologic Units 1 and 2 form a continuous graded bed, with a sharp upper contact marked by a gently undulating surface.

Unit 3 Depth: 34.2 to 38 cm Thickness: 3.5 cm

Fine-grained bed with scattered rock fragments, blocky, angular opaques

Matrix: 80%, distinctly less "dense" than below, although finely granular. This bed contains about 2% opaques, up to 1.5 mm diameter, poorly sorted with median size about 0.7 mm; fragments are all equant, blocky, with subangular to angular corners, rounded and elongate particles are noticeably absent.

Framework:

5% semi-opaque with distinct outline, equant, blocky rock fragments 0.2 to 0.6 cm diameter, mostly about 0.2 cm, with relatively straight sides, subangular corners.

15% semi-opaque, vague outline, 0.1 to 0.8 cm diameter, most fragments about 0.3 cm diameter, very indistinctly equant, lumpy to rounded.

Unit 4 Depth: 34.5 to 34.0 cm Thickness: 0.5 cm

Fractured Zone

Interval as below (unit 3) in composition, but penetrated by numerous en-echelon crescentic fractures, up to 8 mm long, 1 mm across.

Unit 5 Depth: 34.0 to 29.5 Thickness: 4.5 cm

Fine-grained bed with scattered rock fragments, blocky, angular opaques

Matrix: 80% finely granular, with about 3% opaques, limit of resolution to 2.5 mm diameter, poorly sorted with median size about 0.8 mm. Fragments are equant-blocky with about only 10% spherical, 5% elongate to comma-shaped and irregular, the rest blocky with subangular to angular corners.

Framework: 10% semi-opaque rock fragments with distinct outline, 0.2-0.5 cm diameter, equant to elongate, rectangular to wedge-shaped, with relatively straight edges and subangular to subrounded corners.

10% semi-opaque with indistinct outlines: 0.1 to 0.4 cm diameter, mostly around 0.3 cm, equant, and lumpy in outline.

Unit 6 Depth: 28 to 29.5 cm Thickness 1.5 cm

Fractured zone at top of core

Matrix: 40%, distinctly less dense than underlying layers, principally because of void space, but also noticeably less finely granular, with about 4% opaque, 0.1 to 2.1 mm diameter, mostly 0.6 to 0.8 mm, principally equant, to tear-drop shaped, with blocky outlines, angular to subangular corners.

Framework: 60%, semi-opaque density concentrations with irregular outlines, fragments range from 0.2 to 1.3 cm diameter, poorly sorted, with equant, lumpy outlines. Internal fractures in some of these fragments could be a result of disturbance during sampling and handling.

Unit 7 Depth: 23.5 to 28 cm Thickness: 4.5 cm

Coarse-grained bed, abundant rock fragments

Matrix: 30%, distinctly and irregularly granular to finely lumpy, with 3-4% opaques, limit of resolution to 1.5 mm diameter, mostly about 1.0 mm, tending to be equant and blocky, with only a few elongate, comma-shaped particles. About 10% of opaques show rounding, rest are angular.

Framework:

40% semi-opaque rock fragments with distinct outline, 0.2 to 2.3 cm length, poorly sorted, equant to rod-shaped, with irregularly lumpy edges, subrounded corners. These lumpy rock fragments contrast strongly with rock fragments of some other intervals, with noticeably straight sides. The large elongate fragment at 25 cm depth has a long axis parallel to the tube, and is associated with some cracking and void space, and appears to have been rotated to this configuration during sampling.

30% semi-opaque with indistinct outlines, probably rock fragments, 0.1 to 1.3 cm diameter, mostly about 1.5 cm, although moderately poorly sorted. Most fragments equant, irregularly lumpy.

<u>Unit 8</u> Depth: 20.5 to 23.5 cm Thickness: 3 cm

Fine-grained bed with sparse mottles

Matrix: 75%, distinctly finely to very finely granular, with about 1% opaques, up to 0.9 mm diameter, moderately well sorted with most particles about 0.5 mm equigranular, subangular to subrounded.

Framework: 25% semi-transparent density concentrations with indistinct outlines, possibly rock fragments, 0.1 to 0.9 cm diameter, poorly sorted with all sizes present in equal abundances; mostly equant to subequant with lumpy, nodular outlines, more mottled appearing than rock-fragmental appearing.

Note: Contact between Units 7 and 8 is Abrupt, but Indistinct

Unit 9 Depth: 13.5 to 20.5 cm Thickness: 7 cm

Fine-grained unit with sparse rock fragments

Matrix: 85% definitely finely granular, with 3% opaques up to 1.5 mm diameter, most between 0.5 to 1.0 mm and only moderately assorted. 80% of the opaques are equant, mostly rounded and spherical, although about 10% are blocky. The remaining 20% of the opaques are void, rod, or comma-shaped with well rounded corners.

Framework:

10% semi-opaque rock fragments with distinct outline; 0.3 to 0.5 cm diameter, ovoid to equant-polyhedral with straight margins and rounded to subrounded corners. There is a thin layer of these rock fragments at 16 cm depth.

5% semi-opaque, probably rock fragments, with indistinct outline, 0.2 to 0.8 cm diameter, poorly sorted with equal size distribution throughout, equigranular lumpy to nodular appearance, with rounded to subrounded corners, where visible.

Note: Fractured Zone Marks Contact between Unit 8 and Unit 9

Unit 10 Depth: 3.5 to 13.5 cm Thickness: 10 cm

Coarse-grained bed with diverse rock types

Matrix: 50%, distinctly finely granular, with 3% opaque, limit of resolution to 1.6 mm diameter, mostly 0.5 to 1.0 mm, only moderately well sorted. As below (Unit 9) nearly all fragments are equant and spherical, with a small but distinct component of blocky, ovoid, rod or comma-shaped particles.

Framework:

5% opaque; one large fragment, 1.2 cm diameter, equant, with jagged, angular protuberances on all sides.

20% semi-opaque rock fragments with distinct outline, 0.1 to 1.3 cm diameter, poorly sorted with all sizes equally represented. Rock fragments are mostly elongate-polygonal, with some equant particles; a few elongate fragments have smooth edges and angular corners; the rest have irregular to lumpy margins and are angular to subangular.

25% semi-opaque with indistinct outline, 0.1 to 1.2 cm diameter, moderately poorly sorted as the fragments with distinct outlines, but these particles have very irregular, subrounded (where visible) lumpy outlines.

Unit 11 Depth: 0 to 3.5 cm Thickness: 3.5 cm

Fractured interval with abundant rock fragments

Matrix: 40%, not very dense, probably because of void space, finely granular, with about 4% opaque, ranging from limit of resolution to 1.5 mm diameter, most fragments 0.5 to 0.7 mm, moderately poorly sorted, with about 50% spherical and the rest lumpy and subangular.

Framework:

30%, occupied by one large fragment, 2.7 cm diameter, an equidimensional block, subrhomboidal in outline, with moderately irregular margins, angular corners.

30% semi-opaques with vague outlines, 0.2 to 0.5 cm diameter, well sorted, mostly equigranular and lumpy, reminiscent of lumps of cotton.

The entire interval appears to be somewhat fractured, with much void space. This is probably a sampling artifact, but the core was collected from the center of a small crater, and fracturing could be a result of the crater.

General:

This drive tube was taken within a strewn field of meter-sized boulders originating from South-Ray crater (Figure 43). As indicated in Figure 43b, the tubes were driven 1 to 2 m from the edge of a 10 to 15 m crater that appears to be about 2 m deep. Small craters, less than 0.5 m are common in the area. Stereopair examination of these photographs also reveals concentric ridges of coarser material, scalloped and lineated radially to the 10-15 m crater. This field configuration of the coarse and fine material suggests the presence of ejecta from the 10 to 15 m crater, some of which should be represented in the drive tube section.

Within the core, the upper 13.5 cm is notably coarse-grained, with diverse rock types. The upper 3 cm is highly fractured, possibly the effect of impact and generation of the small crater from which the sample was taken or it is possibly an artifact.

Unit 8 is distinctive in having no rock fragments and a very low content of x-ray opaque material in the matrix. Beneath the finer-grained units (8 and 9) is a bed with very coarse, abundant rock fragments that are notably lumpy, in contrast to the smooth-outlined rock fragments of other coarse-grained units. The coarse-grained unit 7 is underlain by finer-grained layers (units 4, 5, and 6) with scattered rock fragments, soil fractures, and nodules. Opaques of the matrix in these beds are notably blocky and angular, in strong contrast to opaques of the other units, in which there is a strong component of spherical opaques. The lowest 26 cm of the core, unit 1, (possibly even more below the core) is very coarse-grained, and consists of a singl graded bed with a great diversity of rock fragment shapes and densities. The top surface of this interval is gently undulating, and may represent a buried topographic surface.

Unit 1, the lowest graded bed, is the most distinct unit in the core. By bringing together a diversity of larger rock fragments, this event is comparable to action which may have deposited coarse-grained, lithologically diverse beds in other Apollo 16 cores.

3) Station 10':

Samples: 60013 (bottom stem)

60014 (top stem)

Detailed Core Log (see Figure 40):

Unit 1 Depth 60.0 - 68.0 Thickness: 8 cm

Fine-grained unit, sparse in opaques

Matrix: 80%, indistinctly granular, less than 1% opaques, limit of resolution to 1.5 mm, poorly sorted, equigranular, and generally subrounded.

Framework: 5% semi-opaque rock fragments with distinct outline: 0.2 to 0.6 cm diameter, blocky, equant, and subangular to angular. 15% semi-opaque density concentrations, indistinct outline: 0.1 to 0.4 cm diameter, moderately well sorted, equidimensional to slightly elongate, with lumpy outline.

Unit 2 Depth 45.5 - 60.0 cm Thickness: 14.5 cm

Pebbly mudstone with angular opaques

Matrix: 60% (unusually high for interval with this degree of coarseness) finely granular, with about 2% opaques, limit of resolution to 2.5 mm, moderately weel sorted, coarse, with average grain size about 0.9 mm, with about 90% of fragments equant, and spherical to lumpy subrounded; and with only about 10% elongate, although many elongate fragments are sharply angular.

Framework: 30% semi-opaque rock fragments with distinct outline, 0.1 to 3.3 cm diameter, most rocks relatively coarse, from 0.5 and 1.5 cm diameter, but with a poor degree of sorting. Most rock fragments are slightly to moderately elongate (1:1.5 to 1:2.5) and polygonal to blocky with straight to slightly curved edges, angular corners. Distribution of these particles indicates matrix, rather than framework support, relatively uncommon in Apollo 16 cores.

10% semi-opaque with indistinct outline: 0.5 to 0.8 cm diameter, averaging about 0.3 cm and fairly well sorted, equant, with lumpy outlines. Sorting of these particles is comparable to that of the opaques, and seems to be very different from that of the distinct rock fragments.

Unit 3 Depth: 43.0 - 45.5 cm Thickness: 2.5 cm

Fine-grained interval with sparse rock fragments

Matrix: 75%, very finely granular, with 1% opaques, limit of resolution to 1.2 mm, relatively coarse grained, averaging about 0.8 mm diameter, equant, spherical to subrounded blocky. The angular opaque component is notably absent in this thin bed.

Framework: 25% semi-opaque with indistinct outline: 0.1 to 0.8 cm diameter, mostly about 0.3 to 0.4 cm, moderately well sorted. 80% of fragments have a lumpy outline, but the rest are notably dendritic to fragmental in appearance, with ragged outline.

Unit 4 Depth: 36.5 - 43.0 cm Thickness: 6.5 cm

Pebbly bed with small rock fragments, dendritic opaques

Matrix: 60%, very finely granular and noticeably more dense than the overlying unit, with about 3% opaques, limit of resolution to 3.5 mm diameter, average size 0.8 to 1.2 mm, and moderately poorly sorted. About half of the opaque fragments are spherical to slightly elongate; the remainder are lumpy to elongate, many showing a dendritic outline.

Framework: 15% semi-opaque rock fragments with distinct outline: 0.1 to 1.1 cm, averaging about 0.6 cm and being moderately well sorted, especially in the two layers at the top of the interval. Fragments nearly all elongate, wedge-shaped to polygonal with straight to slightly curved margins, angular to subangular corners. 25% semi-opaque with vague outline: 0.1 to 1.3 cm diameter, mostly equidimensional to slightly elongate, distinctly lumpy.

Unit 5 Depth: 21.5 - 36.5 cm Thickness 15 cm (3 cm in '09, 12 cm in '10)

Coarse-grained, loosely compacted zone with fine grained opaques

Matrix: 35%, notably less dense than underlying or overlying beds, opaques, 3%, range from limit of resolution to 1.2 mm diameter, but are noticeably much finer-grained than the underlying beds, average size about 0.5 mm. About 30% of the opaques tend to be spherical, about half are blocky to lumpy and subangular, and the remainder are elongate, comma-shaped to dendritic.

Framework: 65% is similar compositionally to bed 2, but is distinctly more tighly packed, and appears to have a framework-supported texture in notable contrast to the matrix-supported texture of bed 2.

40% semi-opaque rock fragments with distinct outline: 0.1 to 2.4 cm diameter, with average size about 0.7 cm, but with poor sorting.

Most of the rock fragments are slightly to moderately elongate (1:1.5 to 1:2.5) and blocky-polygonal to wedge-shaped, with straight to slightly curved edges and angular corners.

25% semi-opaque density concentrations with indistinct outline: 0.1 to 0.6 cm diameter, mostly about 0.3 cm and moderately well sorted. Density concentrations appear as nodular fragments with no ragged fragments.

Unit 6 Depth: 14.5 - 21.5 cm Thickness: 7 cm

Coarse-grained, "dense" zone

This interval is gradationally transitional with the immediately underlying unit 5, and is separated here arbitrarily at the highest occurrence of >1 cm rock fragments.

Matrix: 35%, finely granular, "dense" in x-radiograph, transitional to the underlying unit, with about 3% opaques, ranging in size from the limit of resolution to 1.2 mm diameter, average size about 0.5 mm. Shape distribution is about equal between spherical particles, lumpy to blocky subangular particles, and elongate to dendritic material.

Framework: 25% semi-opaque with distinct outline: 0.1 to 0.8 cm diameter, average diameter about 0.4 cm, moderately well sorted, fragments equant to slightly elongate, with straight to slightly curved outlines, about 1/3 with irregular scalloped outlines, but all fragments angular to subangular.

40% semi-opaque with indistinct outline: 0.1 to 0.7 cm, most fragments about 0.2 cm diameter, moderately well sorted, equant, or in clumps of equant particles, with irregular outline.

Unit 7 Depth: 5.0 - 14.5 cm Thickness: 9.5 cm

Loosely compacted zone with moderate number of rock fragments, abundant opaques

Matrix: 50%, loosely compacted, less dense than underlying bed, very finely granular, with 4% opaques, limit of resolution to 3.5 cm diameter, poorly sorted with median diameter about 0.5 mm. 25% of opaque fragments are spherical, about 50% are equant to slightly elongate and notably lumpy-subangular; the rest are elongate to comma-shaped, but not dendritic.

Framework: 15% semi-opaque rock fragments with distinct outline: 0.1 to 0.8 cm diameter, mostly about 0.4 to 0.5 cm, and moderately well sorted. Most rock fragments are equant to only flightly elongate, with a tendency to irregularly jagged, subrounded to subangular outlines with angular, sharp corners.

35% semi-opaque with indistinct outline: 0.1 to 0.5 cm, mostly in the 0.2 cm range and moderately well sorted. As below, these particles appear as equant individuals or lumpy concentrations of particles, fading to nothingness as subrounded particles.

Unit 8 Depth: 0 to 5.0 cm Thickness: 5 cm

Fine-grained interval with scattered rocks

Matrix: 70%; very finely granular, and "thin" appearing, about 4% opaques, ranging from limit of resolution to 2.5 mm, moderately well sorted with most particles about 0.5 mm diameter, about 1/3 are spherical, 1/2 equant and lumpy subangular, the remainder elongate and comma-shaped to notably dendritic.

Framework: 25% rock fragments with distinct outline: 0.2 to 1.7 cm diameter, poorly sorted, equant to slightly elongate with straight to slightly curved margins, angular corners, noticeably different from lumpy rocks below. 5% density concentrations with vague outlines: 0.1 to 0.3 cm diameter, but mostly all about 0.2 cm, and well sorted.

General:

Drive tubes 60013 and 60014 were taken in the vicinity of the LM (Figure 44). In comparison to the other Apollo 16 cores the soils are relatively fine grained. The surface material is relatively coarse grained with 50 to 20 cm diameter blocks moderately abundant (Figure 43). Furthermore, the area is unusual in that there are few small craters, even though there are some large (10-20 m) craters.

The basal 8 cm of the core section appears to be fine-grained in the x-radiograph (although it may contain an abundance of whitish aggregates as noted by the LMP on the moon - if so, the whitish aggregates would not show up on the x-radiograph because of their low x-ray absorption) with sparse opaques, and a few percent of rock fragments. The rock fragments present, appear as indistinct, mottled clusters. Bed 2 shows a concentration of similar fragments, but with a matrix similar to unit 1, and probably is genetically akin to unit 1.

The next 22.5 cm is relatively coarse-grained, relatively thinly laminated, and terminates at the top in a very noticeable surface. The intermediate bedded zones are more or less transitional, distinguished on the basis of grain size and type.

Units 3 and 5 are similar in containing a dense matrix with a fair scattering of equant, sharp-edged rock fragments. Unit 4, in between, seems to contain a mixture of properties of the lower beds, with the matrix of the basal units and the rock fragments characteristic of unit 3; furthermore, opaques in the matrix of unit 4 are bimodal with coarse particles as in unit 3, and fines resembling those of unit 1. Unit 6 seems to be similar to 5, but better sorted, and unit 7 exhibits the matrix properties of units 5 and 6, but is distinctly coarser grained.

The uppermost 36 cm is much more massively layered, with a less grainy and less compact matrix. There is a noticeable component of oval, 2 to 4 mm matrix opaques, and ragged-edge-appearing semi-opaque density concentrations that probably represent a rock type not found in lower intervals.

Units 1 and 2 may represent fine-grained Cayley formation. Units 3 through 7 are physically similar, and are believed to represent variations on one major event, presumably ejecta from a major, near-by crater (North-Ray?). The upper massive zone, differs physically from the lower zones, indicating a different source; and its massiveness suggests less reworking by small-scale cratering events, as a result of newness. On the basis of this evidence, it is inferred that this zone resulted from South Ray activity.

4) ALSEP-Area:

Samples: 60009 (bottom stem)

60010 (top stem)

Detailed Core Log (see Figure 40):

Unit 1 Depth: 59 - 67 cm Thickness: 8 cm

Fine-grained interval with sparse opaques and indistinct mottles

Matrix: 95% x-radiographically dense, medium to finely granular; opaques approximately 1%, 0.3 to 1.0 mm; ave. diameter approximately 0.6 mm, with good sorting, consistently equant, somewhat irregular and subrounded to subangular, with only a trace of spherical particles.

Coarse Fraction: 5%, semi-transparent with indistinct outline: 0.2 to 1.6 cm, mostly about 0.6 cm, equant, fading out over broad areas, or in well rounded curves, distinctly different from the lumpy particles, which commonly occur in Apollo 16 cores.

Unit 2 Depth: 58 - 59 cm Thickness: 1.0 cm

Layer of small rock fragments

Matrix: 50%, as in Unit 1.

Framework: 50% semi-opaque rock fragments, distinct outline: 0.2 to 0.6 cm with median diameter about 0.4 to 0.5 cm, indicating good sorting. Rock fragments are equidimensional-polyhedral to slightly elongate with relatively straight margins, subangular to subrounded corners.

This lamina may be a micrometeoritically-winnowed concentration of coarse particles at the top of Unit 1, as matrix and rock types are similar and opaques and semi-opaques at the top of the interval are aligned horizontally.

Unit 3 Depth: 58 - 53 cm Thickness: 5 cm

Fine-grained with dense matrix, sparse rock fragments, varied opaques

Matrix: 85% finely irregularly (vs. uniformly) granular, moderately dense; with 3% opaques, limit of resolution to 7 mm, average about 1 mm, over half of which are equant and angularly lumpy to dendritic, only 10% are spherical and 1/3 are elongate to rod-shaped with smooth edges, rounded corners, not angular.

Coarse Fraction: 5% semi-opaque rock fragments with distinct outlines: 0.2 to 0.8 cm diameter moderately to poorly sorted with relatively even distributed throughout size ranges. These rock fragments are equant to rectangular, with trapezoidal or polyhedral outline, relatively smooth edges, angular to subangular corners. 10% semi-transparent, indistinct outline: 0.1 to 0.4 cm, moderately well sorted, average size about 0.3 cm, overall effect is of elongate particles or clumps of equant lumps disposed into elongate rock fragments.

Unit 4 Depth: 50.5 - 53 cm Thickness: 2.5 cm

Fine-grained unit with "thin" matrix, bimodal opaques

Matrix: 80%, less dense than below, finely granular, with 2% opaques, limit of resolution to 1.8 mm diameter, noticeably bimodal, with most fragments well sorted, about 0.4 mm diameter, the remainder 1.3 to 1.8 mm diameter with none in-between. Finest-grained opaques are equant, rounded to subrounded blocky, coarser fragments are equant lumpy-shard like.

Coarse Fraction: 20% semi-transparent rock fragments with moderately distinct outline: 0.2 to 0.5 cm diameter, fairly well sorted; equant polygonal with subrounded to subangular corners; sides slightly curved to straight, not irregularly rounded or lumpy. Fragments scattered through matrix, and do not form framework.

Unit 5 Depth: 44.5 - 50.5 cm Thickness: 6 cm

Zone with large rock fragments, angular opaques

Matrix: 40%, denser than below, medium to finely granular; with 2% opaques, limit of resolution to 1.7 mm, average 0.5 mm, moderately to poorly sorted.

Shape: 10% spherical, 5% shards, remainder equant to slightly elongate, blocky to lumpy, with subrounded to subangular corners.

Framework: 20% semi-opaque rock fragments with distinct outline: 0.2 to 2.3 cm diameter, poorly sorted with all sizes approximately equally represented. Fragments are blocky and equant, with straight to slightly curved (some appear conchoidal) edges, angular to subangular corners. 40% semi-opaque to semi-transparent, indistinct outline: 0.1 to 1.3 cm, moderately well sorted, with most fragments about 0.3 cm diameter, lumpy to nodular appearance with many elongate particles comprised of multiple aggregates.

Unit 6 Depth: 38.5 - 44.5 cm Thickness: 6 cm

Fine-grained interval, abundant granule-sized fragments

Matrix: 60%, moderately dense in appearance, with density noticeably increasing toward top of interval, medium to finely granular; with about 3% opaque, limit of resolution to 1.8 mm, average grain size about 0.5 mm, and moderately poorly sorted, with about 10% spherical fragments, 10% angular fragments and the remaining fragments equant to slightly elongate, blocky subangular to lumpy subrounded.

Framework: 10% semi-opaque rock fragments with distinct outline: 0.2 to 0.5 cm diameter, well sorted with most fragments about 0.4 cm. Fragments are polygonal with relatively straight to slightly curved sides, subangular corners. 30% semi-transparent with indistinct outline: 0.1 to 0.5 cm, mostly about 0.3 cm, equant or elongate objects comprised of clumps of equant particles, giving lumpy texture.

Unit 7 Depth: 36.5 - 38.5 cm Thickness: 2 cm

Concentration of centimeter-sized rock fragments

Matrix: 30%, moderately dense, medium to finely granular; with about 2% opaque, limit of resolution to 1.8 mm, generally coarse, but bimodal with one mode about 0.3 mm, the remainder of fragments 1.2 to 1.8 mm, equant to slightly elongate with 50% of particles ovoid to spherical, 25% lumpy equigranular, 15% elongate and smooth-sided, and 10% angular. Matrix is much denser than matrix of overlying unit.

Framework: 50%, semi-opaque rock fragments with distinct outline: 0.2 to 1.0 cm mostly about 0.7 to 0.8 cm, well sorted, blocky to irregular, straight to slightly curved sides, some edges look conchoidal, angular to subangular. 20% semi-transparent with indistinct outlines: 0.1 to 0.4 cm, well sorted with median diameter about 0.2 cm. Fragments appear as equant density concentrations, or arranged into elongate lumps as composites of individuals.

Unit 8 Depth: 38.5 - 18.5 cm Thickness: 20 cm

Massive fine-grained unit with sparse rock fragments

Matrix: 70%, thin (vs. dense), finely granular, 3% opaque, limit of resolution to 2.2 mm, poorly sorted, averaging about 0.5 mm. About 1/3 of the particles are spherical, about 1/4 are elongate-dendritic, and the remainder are blocky to lumpy, tending to be equant, with subangular to subrounded corners.

Framework: 10% semi-opaque rock fragments with distinct outline: 0.2 to 1.1 cm diameter, mostly on coarse side, with median about 0.8

cm. Rock fragments in this zone differ from other horizons in being noticeably elongate, irregularly rectangular to wedge shaped with slightly irregular edges, subangular corners. 20% semi-opaque with indistinct outline: 0.1 to 1.1 cm diameter, with median in lower part of bed about 0.3 cm, gradually increasing upward to about 0.6 at top of bed. Particles appear as density concentrations, tending to be equant and nodular, to lumpy appearing where individual particles coalesce.

Unit 9 Depth: 18.5 - 0 cm Thickness: 18.5 cm

Massive fine-grained unit, sparse equant rock fragments

Matrix: 60%, light appearing, not densely granular, medium to finely granular, with 3% opaques, limit of resolution to 3 mm, but with bimodal distribution, with the coarser fragments, all 2-3 mm fragments all under 1 mm, mostly 0.6 mm, all tending to be equant, with about 1/3 spherical, 1/10 elongate dendritic, and the rest blocky to lumpy equant with subangular corners.

Framework: 15% semi-opaque rock fragments with distinct outline: 0.1 to 0.9 cm diameter, median about 0.5 cm. These rock fragments are equant, mostly with a lumpy to rounded-irregular outline, and only a few with relatively straight margins and subangular corners. Many are concentrated in an indistinct layer at 12 cm depth. 25% semi-transparent with indistinct outline: 0.1 to 0.8 cm diameter, mostly about 0.2 to 0.3 cm, moderately well sorted, density concentrations which give appearance of compound lumps.

General:

This core sample was taken on the eastern margin of a 50 to 60 cm shallow, subdued crater, about 100 m southwest of the LM site. Though the core was taken on the rim of a crater it appears that there is no visible ejecta from the crater, and that the surface of the area is covered with relatively fine-grained material, including fines, granule-size fragments, and other rocks, none larger than a few centimeters (Figure 45).

The basal unit of the core, 8 cm thick, is noticeably finer grained than any other interval in the section and consists of 80% matrix. Within the matrix, opaques, approximately 1%, are less abundant than in the rest of the core and the coarse fraction consists of indistinct mottles. In contrast, unit 2 is extremely coarse-grained, with abundant large rock fragments, a greater percentage of opaques (2%) than the underlying unit, and anomalous sorting between the coarse rock fragments and the mottles and opaques. Interestingly enough, the matrix of this interval (60%) is unusually high for a coarse-grained unit, and there is a size-gradation of the coarse material, which becomes finer-grained upwards. Unit 3 seems to be largely a repetition of unit 1, with a small percentage of rock fragments mixed in. Correspondingly, unit 4 appears to be a fine-grained repetition of unit 2, with a lesser abundance of very coarse material. At the top of unit 4 is the most distinctive stratigraphic break in the section, consisting of a gently rolling, slightly irregular surface, emphasized by the density contrast between the matrix of units 4 and 5.

The matrix of unit 5 and all overlying units, is much less densely compacted than that of the underlying beds, and contains a higher percentage of opaques, which tend to be finer-grained but less well sorted than in the underlying interval. Some of the opaques are relatively large ovoid objects. Units 5 and 6 form a massive bed, graded normally, from coarse at the bottom to finer at the top. Additionally, rock fragments with distinct outline in x-radiograph are much more abundant at the base of the bed, and disappear toward the top, to be replaced by material with indistinct outline. There is an indistinct density break at the top of units 5-6, and unit 7 is similar in nearly all respects to unit 5.

Units 8, as unit 2, is classified as a pebbly mudstone, with a relatively low percentage of variable, poorly sorted, but coarse rock fragments. This surficial unit penetrates the highest point on the rim of a small crater, and the 5 cm of material probably represents ejecta from the crater.

5) ALSEP Area, Deep Drill Core

Samples: 60001 through 60007

Detailed Core Log: (See Figure 46)

No detailed core log is available as to date, however, the x-radiographs are illustrated in Figure 46 . A total of 57 units could be recognized during a preliminary survey. Detailed descriptions will be given later.

General:

The deep drill stem was taken about 175 m southwest of the LM and 25 m south of the ALSEP site in a generally flat spot in an area of rolling topography with numerous 2 to 6 m craters and relatively loose, uncompacted soil, Figure 45 . Two other core samples and seven penetrometer stations were taken within 100 m of the drill stem (Figure 45), enabling the most detailed correlation and reconstruction of lunar soil strata to date.

The upper section (60007) and the bit (60001) have been dissected and described; other information herein is from x-radiographs. The surficial 15.7 cm of the drill stem is relatively fine-grained, contains an abundance of glass, and has been subdivided into four subunits. Of these, the uppermost 2 cm are relatively dark and crumbly, and are underlain by a 3.5 cm zone that is high in whitish aggregates. Indistinct, massive bedding characterizes the next 10 cm, with a rock concentration at 10.5 cm marking a break in bedding. The massive zone tends to be poorly sorted, and contains a coarse fraction dominated by glass fragments, droplets and feldspar fragments. The lowest 6.4 cm of 60007 is reverse-graded, coarse-grained, and contains a diversity of rock fragment types. X-radiographs indicate that the coarse material of the base of 60007 continues down into the regolith for a total of about 50 cm. Bedding is thicker and more massive toward the top of this coarse-grained interval, but there are more large, semi-opaque rock fragments in the thinner beds at the base of the zone. As explained below, section 60005, with 76.1 gm of sample, was only 1/3 full, and 60006 was partially void; on the basis of density calculations, these two core tubes probably contain about 49 cm of actual section. The basal sections of the drill stem are fine-grained in comparison to the upper sections. The top 11 cm of 60004 is very fine-grained, followed by 25 cm of lumpy, coarse material with few distinct rock fragments. The basal 85 cm of the drill string is fine-grained with a rock layer only in the middle of 60003, at a depth of approximately 135 cm below the lunar surface.

The absolute depth of soil materials from the deep drill core, however, cannot be given with confidence at present, because the core was not filled completely. The drill was broken on the lunar surface into two sections of three joints each, the lower one containing in addition the drill bit. X-radiographs indicate that this section (60001 through 60004) is completely filled, however, the bottom (60005) of the upper section (60005 through 60007) is only partially filled and so is 60007; stem 60006 is completely full. While the condition of 60007 could be explained by the final penetration depth of the entire core, the interpretation of stem 60005 is highly problematic and thereby also that of 60007. Stem 60005 contains only 76.1 gr of material strung over the entire length of the stem in an obviously highly perturbed condition.

To date, three hypotheses have been proposed: The first possibility is that the entire three stem section was not completely filled by the sampling process allowing the contents to slip within the tube. Secondly sampling could be complete, but with material lost from the upper section while breaking the entire drill core on the lunar surface. Thirdly there could have been complete sampling but with material dropping from the base of the core while extracting it out of the lunar surface.

Because the astronauts noted the loss of only a few grams (at the most) of material during capping operations, hypothesis two is unlikely to account for the entire void space in 60005 and 60007, i.e. the potential loss of 2/3 of the contents of 60005 or 60007. At present it is impossible to discriminate between hypotheses 1 and 3. Either hypothesis requires an essentially complete regolith section with no material missing in the middle.

COMPARISON OF DRIVE TUBES 60010/09 and 60014/13 WITH DEEP DRILL STEM 60007/60001

The three cores in the ALSEP area were taken at apices of an isoceles triangle. Drive tubes 60013/14 were taken 95 m due north of the drill stem; and 60009/10 was taken at the eastern apex of two 60 m legs. Despite irregularities of the lunar surface, it was possible to correlate major units between cores.

Basal units of all three core sections are fine-grained in x-radiograph, with 80 to 95% matrix (much higher than in overlying units) and a very low percentage of opaques. What opaques there are tend to be relatively large (average diameter about 0.6 mm) equant, and with a high percentage of spherical particles.

Overlying the basal fines is a coarse-grained interval 55, 59, and approximately 50 cm thick in 60009/10, 60013/14 and the drill stem, respectively. In each core, the coarse interval can be further subdivided into a basal, thin-bedded portion and an upper, massive portion. The basal zone contains an abundance of large, semi-opaque, blocky rock fragments with distinctly straight to conchoidally curved margins, and with angular to subangular corners; the interval also tends to have a relatively "dense" matrix with a significant percentage of shard-like opaques. 20 to 25 cm thick, the interval takes up units 2 through 4 in 60009, 2 through 7 in 60013, and 39 through 44 in 60006.

In the drive tubes, the upper units, about 35 cm thick, tend to be more massive and have a matrix that tends to be less compacted and less dense appearing. In all cores, these upper massive units contain finer, more poorly sorted opaques with a distinctive trace percentage of large, oval fragments. Additionally, rock fragments in this upper interval show a lumpy to ragged outline, in contrast to mottled or distinctly outlined rock fragments of lower zones.

Relatively fine-grained, poorly sorted surficial soils may or may not be present, depending on the core site. Surficial soils are thickest in the drill stem, intermediate in 60009/10 and absent in 60013/14.

Because major units reflect principal events of the area, it may be hypothesized that the coarse-grained units in the cores represent North Ray and South Ray ejecta. The lower, coarse-grained unit is believed to be North Ray ejecta, with the thinner layering a result of micro- and small-scale meteoritic reworking of the ejecta blanket. The less compact, more massive upper units are assigned to the more recent, and presumably less reworked, South Ray event. Accordingly the basal fine-grained soil in all cores may represent the regolith before the North-Ray cratering event.

Major horizons between the drill stem and drive tubes 60009/10 were further correlated with the aid of penetrometer sections (Figure 47). In each penetration, a hard zone was encountered at about 8 to 15 cm below the surface, corresponding to an increase in rock fragments and soil density in the drill stem, and the 60010/09 drive tube section. Below the hard zones is a soft, finer-grained interval with maximum development at penetrometer station #4. The next lower zone is harder to penetrate because it contains more rock fragments, and is underlain by a bed which halts penetration, probably an indication of the lowest rock bearing unit in the cores.

TABLE I

STATION	LRL SAMPLE NO.	RETURNED SAMPLE WEIGHT, g	RETURNED SAMPLE LENGTH, cm	BULK DENSITY g/cm3	TUBE DEPTH (PUSHED), cm	TOTAL DEPTH (PUSHED AND DRIVEN), cm	HAMMER BLOWS, NO.	CORE RECOVERY %	RETURN CONTAINER
4	64002[a]	584.1	31.7	1.38 - 1.40[c]	32.6 ± .5	65 ± 6[d]	>> 3	103 ± 10%	SRC 2[e]
	64001	752.3	33.9[b]	1.66					SRC 3[f]
8	68002	583.5	27.4	1.59	17.8 ± .5	68.6 ± .5	~56	91%	SRC 2[e]
	68001	840.7	34.9	1.80					SRC 3[f]
9	69001	558.4	-	-	20.6 ± .5	27.5 ± 2[d]	8	-	CSVC[e]
10	60010	635.3	32.3	1.47	17.9 ± .5	71 ± 2[d]	~53	95 ± 3%	SRC 2[e]
	60009	759.8	33.1[b]	1.72					SRC 2[e]
10'	60014	570.3	28.8 - 28.4[c]	1.48	28 ± 2	70.5 ± 1	27	90 ± 1%	SCB 7[f]
	60013	757.2	34.7[b]	1.63					SCB 7[f]
10	60007	105.7	22.2	1.46	DEEP DRILL	223 ± 2	-	88 - 100%	CORE SAMPLE BAG [f]
	60006	165.6	35.5 ± .5	1.43 ± .02					
	60005	76.1							
	60004	202.7	39.9	1.56					
	60003	215.5	39.9	1.66					
	60002	211.9	42.5 (60002 and 60001)	1.75					
	60001(bit)	30.1							

[a] Crew neglected to insert Keeper

[b] The nominal length of the sample in a lower core tube is 34.9 cm; for those tubes in which the actual sample length is less, either some sample fell out, or the keeper compressed the top of the sample. The former is considered the more likely explanation and the densities have been calculated accordingly. The internal diameter of the core tubes is 4.13 cm.

[c] Corrected for void

[d] Measured from kinescopes

[e] In vacuum sealed ALSRC No. 2, i.e. not exposed to spacecraft environment

[f] In open sample bags, i.e. exposed to spacecraft environment

Figure 1. Contact Soil Sampling Device (CCSD) as deployed on the lunar surface. The sampler is essentially an Aluminum-box (12 x 10 x 2,5 cm) in which an aluminum collector plate is inserted. The containers are carefully sealed before and after deployment to prevent contamination. The collector plates are draped with nylon fabrics; one has properties similar to Beta-cloth (left) and is freely floating within the container; therefore, no load other than its own weight is applied during sampling. Thus (ideally) it picks up a layer in the order of about 100 microns. The plate on the other sampler (right) is draped with a velvet like nylon fabric and it is spring loaded. A force of 1 pd is applied during sampling and a layer roughly .5 mm is recovered. In both cases, however, the orientation of individual soil grains is not preserved. Though the potential collector surface is about 110 cm^2, the relief of the soil results essentially in three contact points, making a prediction of total surface area collected difficult. Additional technical details and pre-mission documentation of these devices may be obtained from document LEC-645D.21.081.

Figure 2. Lunar surface documentation of soil surface samples. a) Station 9 boulder field related to S-Ray Crater; view approximately to South. b) Locator-shot of sampling area (roughly to NE). c) After shot of beta cloth sampler (right) velvet cloth sampler (middle) and "skim" sample (left). Before "scoop"-sample. d) After shot of scoop-sample.

Figure 3. Lunar surface documentation of "shielded" soil. a) After boulder was turned over, but before soil sample was taken. b) After "shielded soil". According to astronaut descriptions, the soil area underneath the boulder was unusually compacted. Note also the fillet developed around the parent boulder.

Figure 4. CSSD (velvet sampler) as received in the LRL. Note that the closing latch and the additional velcro-strap are in nominal condition, however, outside of sampler is heavily dust coated.

Figure 5. "Padded bag" used to preserve pristine nature of rock surfaces. The bag is double-walled with knitted teflon between the walls to provide padding. The inner wall of the bag which is in contact with the rock has a knobby relief to keep the cross-sectional area of contact at a minimum and to decrease relative motion, which is further restricted by tightening a circumferential velcro-strap.

Figure 6. Stereo-surface documentation of sample 67215 (padded bag No. 1). It appears that the sample was slightly moved, before being picked up. However, the original surface orientation and exposure geometry is essentially the same. No "after" photo exists.

Figure 7. Stereo-surface documentation of sample 67235 (padded bag No. 2). This sample was also slightly displaced before being collected.

Figure 8. Padded bag samples during cursary inspection of bag contents (only top was opened, rocks were left untouched). Sample 67215 (bag no. 1) appears to be a moderately tough, polymict breccia

and considerable dust accumulate on the inner walls of the bag and on the bottom. Sample 67235 (bag no. 2) is a hard breccia, probably of the recrystallized dark matrix type. Some soil was present on bag walls, though considerably less than in padded bag No. 1. Both rocks are dust covered, which prevents a more detailed description at the moment. The rocks await special processing.

Figure 9. Fillet sample at rim of Plum Crater (Station 1). a) Locator shot across Plum Crater, view to NE. b) Down-sun shot with Flag Crater in background. Note well developed fillet around entire boulder. View approximately to WNW. c) Details of boulder before sample collection. d) Boulder after sample collection; note missing boulder-chip and scoop-marks for fillet-sample. e) Detail of boulder area, where boulder-chip (61295) was taken (see Figure 10).

Figure 10. Reconstruction of exposed and shielded surfaces, i.e. fresh fracture surfaces, of boulder chip 61295 according to micrometeorite crater distribution. The surface orientation is presented in the FGE Report. All subsequent orientation pictures are arranged in the same orthogonal manner. Numbers in insert indicate NASA photo numbers.

Figure 11. Fillet samples taken at boulder a at Station 8. a) Overall location of boulder 8a. View approximately to S. b) Close-up of boulder; view approximately to SW; note breccia nature of boulder. c) Close-up

of same boulder, view approximately to ESE. d) Before "fillet sample". e) After "fillet sample". f) After "boulder-chip" 68115 (see Figure 12).

Figure 12. Reconstruction of exposed and shielded surfaces of boulder-chip 68115. The surface orientation is presented in the FGE Report.

Figure 13. Surface orientation of rock 60135. This well rounded rock was very probably completely covered by a thin glass-coating. On the exposed sides the glass coating is completely removed due to micrometeorite impact. A small area is completely uncratered and interpreted to be buried in the regolith throughout its lifetime. A clear cut gradient in absolute microcrater density as a function of the solid exposure angle is present.

Figure 14. Boulder chips from Boulder 8b. a) General location of boulder field at Station 8 emanating in a ray like, linear fashion from S-Ray Crater. View: approximately to S., b) Close up of boulder 8b after chips 68415 and 68416 were taken (see FGE Report). c) Side view of boulder 8b, view approximately to WNW. d) Side view of boulder 8b, view almost due S. Note the breccia nature of boulder 8a and compare with Figures 15 and 16.

Figure 15. Reconstruction of exposed and shielded surfaces of rock 68415. The surface orientation is presented in the FGE Report.

Figure 16. Reconstruction of exposed and shielded surfaces of rock 68416. The surface orientation is presented in the FGE Report.

Figure 17. Boulder chip from Boulder 8c. a) General location of boulder 8c; view to SE. b) Close up of boulder 8c after samplg 68815 was taken from the very top (see FGE Report). c) View (towards S) of entire boulder 8a. d) View of boulder 8c toward NNW (see 17b).

Figure 18. Reconstruction of exposed and shielded surfaces of rock 68815. The surface orientation is presented in the FGE Report.

Figure 19. Breccia boulder at Station 9 as viewed from different directions. a) View to NE. b) View to SE. c) View to SW. d) View to NW. Note the scoop for scale, which may aid in reconstructing the overall boulder geometry (the distance from scoop/soil contact to black marker-line on extension handle is 65 cm.

Figure 20. Documentation of location of a) chip 69935 of top of boulder and b) bottom of boulder (69955) after boulder was turned over.

Figure 21. Reconstruction of exposed and shielded surfaces of rock 69935. The surface orientation is given in the FGE Report.

Figure 22. Detailed "micro-geology" of top surface of rock 69935. Note the presence of rejuvenated surfaces, i.e. rocks of different exposure histories. The "cratered" surface (A) is densely and homogeneously covered with microcraters. The "production" (B) surface displays only few microcraters and was therefore generated more recently. The "freshly broken" surface (C) is very likely created by the hammering action of the astronauts; it is the most recent surface and contains no microcraters.

Figure 23. Reconstruction of "exterior" and "interior" surfaces of chip 69955. This reconstruction is based on the presence or absence of a conspicuous soil cover on the "exterior" sides. However, none of the surfaces displays microcraters, indicating that the parent boulder did not tumble and very likely was sitting in the same position since being ejected by the S-Ray cratering event.

Figure 24. Parent boulder of breccia-chip 60018 collected in the ALSEP-LM area. a) Boulder before chipping. b) Boulder after chipping.

Figure 25. Reconstruction of exposed and shielded sides of rock 60018. The surface orientation is given in the FGE Report.

Figure 26. Location of samples taken from "White Boulder" at Station 11. a) Sample 67475, b) Sample 67455 (see also FGE Report). c) and d) Close-up stereo photographs of white breccia boulder. Note breccia nature of boulder and extremely friable matrix.

Figure 27. Broken pieces of boulder chip 67455. The materials essentially represent the matrix of the white boulders. Note cube in bottom of tray to reconstruct orientation. Because of the highly abraded surfaces and of a thick dust cover, no exposed surfaces could be identified with high confidence.

Figure 28. Reconstruction of exposed and shielded sides of rock 67475. White areas represent matrix of parent boulder adhering to clast.

Figure 29. Photo documentation of samples collected on 5 m boulder next to "House Rock". a) Overall view of boulder. b) Close up view of area where rock 67915 was taken. c) and d) Stereo close up

photos of recent impact event on 5 m boulder; within the spall zone of this event, two additional samples (67935 and 67955) were collected. (For detailed sample location see FGE Report.)

Figure 30. Reconstruction of exposed and shielded sides of rock 67915. The "exposed" surfaces were oriented roughly vertical and pointed approximately E.

Figure 31. General photography of "shadow boulder" at Station 13. (For general sample location see FGE Report). a) Overall view of "shadow boulder", view approximately to N. b) Overall view of shadow boulder, view approximately NW; the "geopher hole" where the shadowed soil sample (see below) was taken is located at the left side of the boulder. c) Close up photo of area where samples 60017, 63335 and 63355 were collected.

Figure 32. Reconstruction of exposed and shielded sides of rock 60017. The exposed sides were approximately vertical and pointed E.

Figure 33. Sample 63335. Due to the tough nature of the parent boulder, individual chips could only be dislodged after several hammer blows. No surface orientation can be established and the formerly exposed parts may be severely degraded for a variety of studies, because of removal of the surface.

Figure 34. Reconstruction of exposed and shielded sides of rock 63355. The actual surface exposure geometry cannot be reconstructed.

Figure 35. Reconstruction of exposed and shielded sides of rock 62235.

Figure 36. Reconstruction of exposed and shielded sides of rock 62295.

Figure 37. E-W gap between "House Rock" and 5 m boulder to the south (see also Figure 29). Note astronaut for scale.

Figure 38. Pre-mission photograph of Core Sample Vacuum Container (CSVC). After a core stem is extracted, it is capped with two teflon caps and the entire assembly is inserted into the CSV. The inside dimensions of the CSVC are such that a tight fit of the stem is ensured, preventing unnecessary relative motion. Then the top of the CSVC is vacuum-sealed by screwing a stainless-steel knife-edge into an indium seal.

Figure 39. Drive tube taken at Station 9 immediately before extraction and before insertion into CSVC. The depth of penetration was approximately 27 cm.

Figure 40. Preliminary stratigraphy of Apollo 16 double drive tubes based on interpretation of x-radiographs. (For detailed description of individual units see text.)

Figure 41. Lunar surface documentation of double drive tube taken at Station 4. (Solid circle indicates precise sample location.)

Figure 42. Correlation of penetrometer resistance and stratigraphy of double drive tube 64001/64002.

Figure 43. Lunar surface photodocumentation of double drive tube taken at Station 8. a) General location. b) A first attempt to sink the

double drive tube failed and the sample was actually taken where indicated with a solid circle. Note the 10-15 m sized crater in the vicinity of the sample location. c) Second and successful attempt, halfway in. d) Second attempt completely in.

Figure 44. General location of drive tube 60013/60014 approximately 120 m WSW of the LM.

Figure 45. Lunar surface photodocumentation of deep drill core, double drive tube 60009/60010 and penetrometer tests in the ALSEP area. a) General location (C = drill core, D = drive tube, P = penetrometer tests). b) Detailed view of drive tube location. c) Detailed view of drill core location.

Figure 46. Survey of x-radiographs of Apollo 16 deep drill core. The "0" level of each stem is normalized to the actual sample surface within each core. More detailed information is necessary before absolute depths of individual strata can be given.

Figure 47. Lateral extent of stratigraphic units in the ALSEP area as indicated by the stratigraphy of drive tube 60009/60010, deep drill core and penetrometer resistance.

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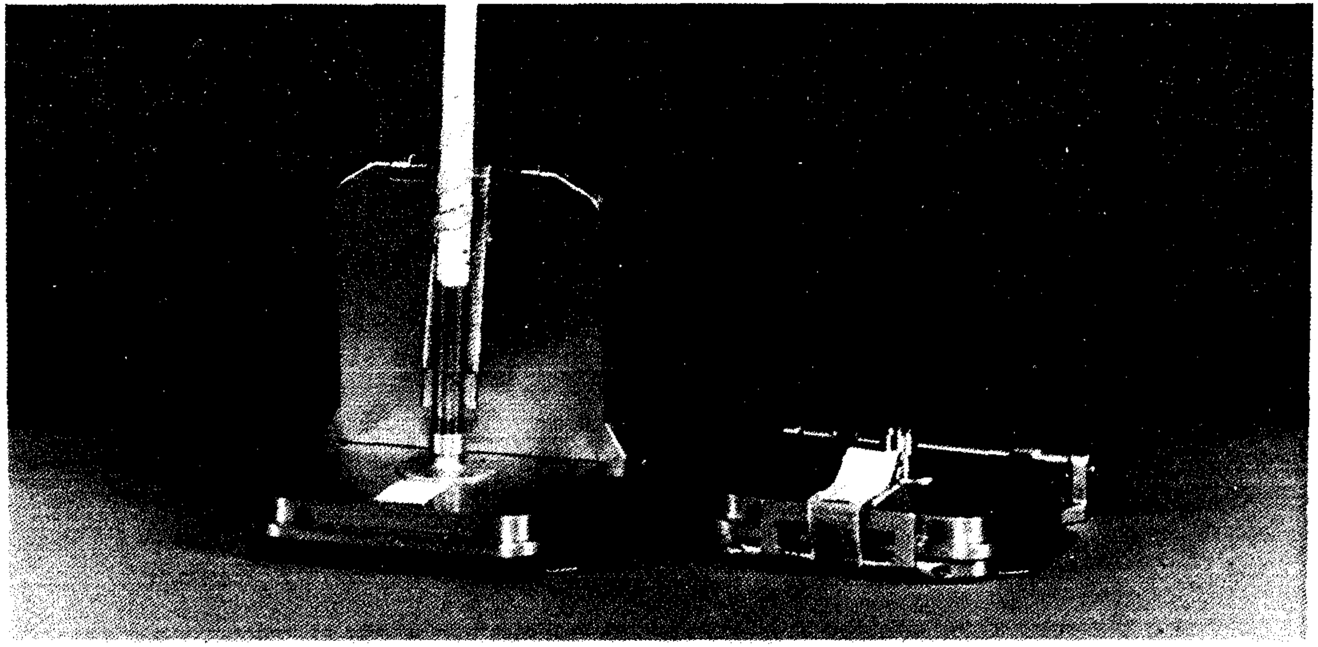

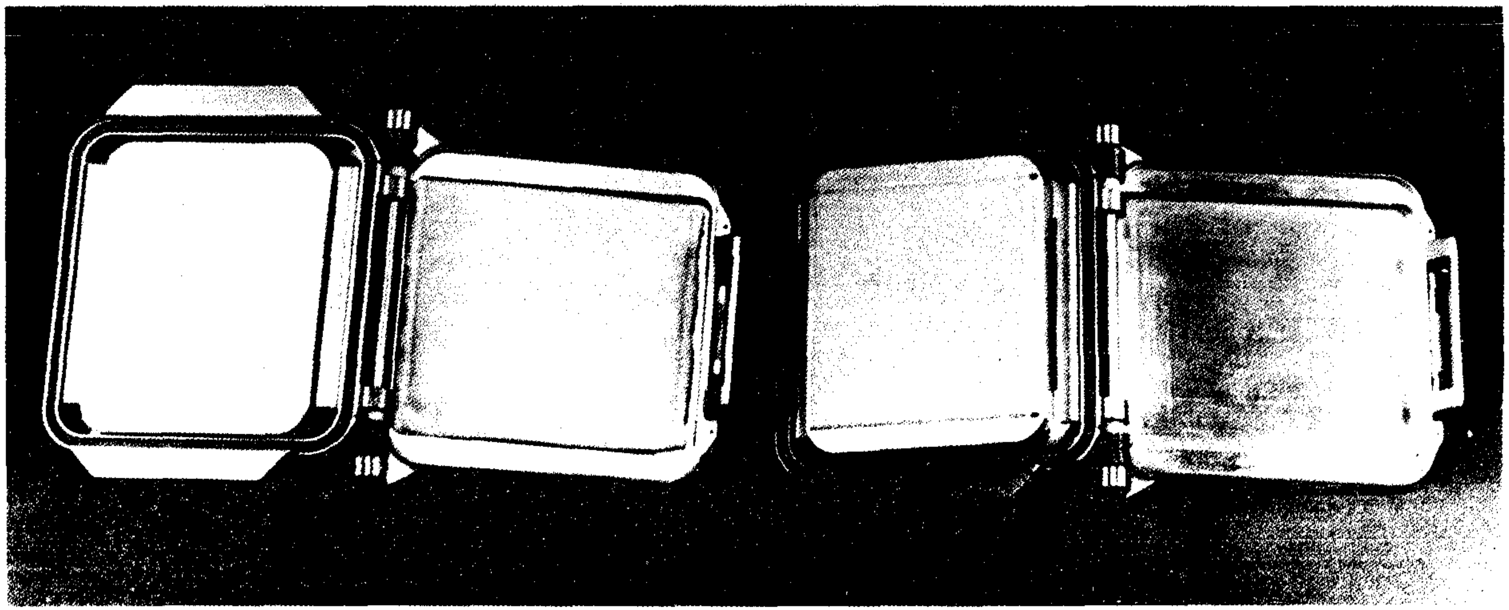

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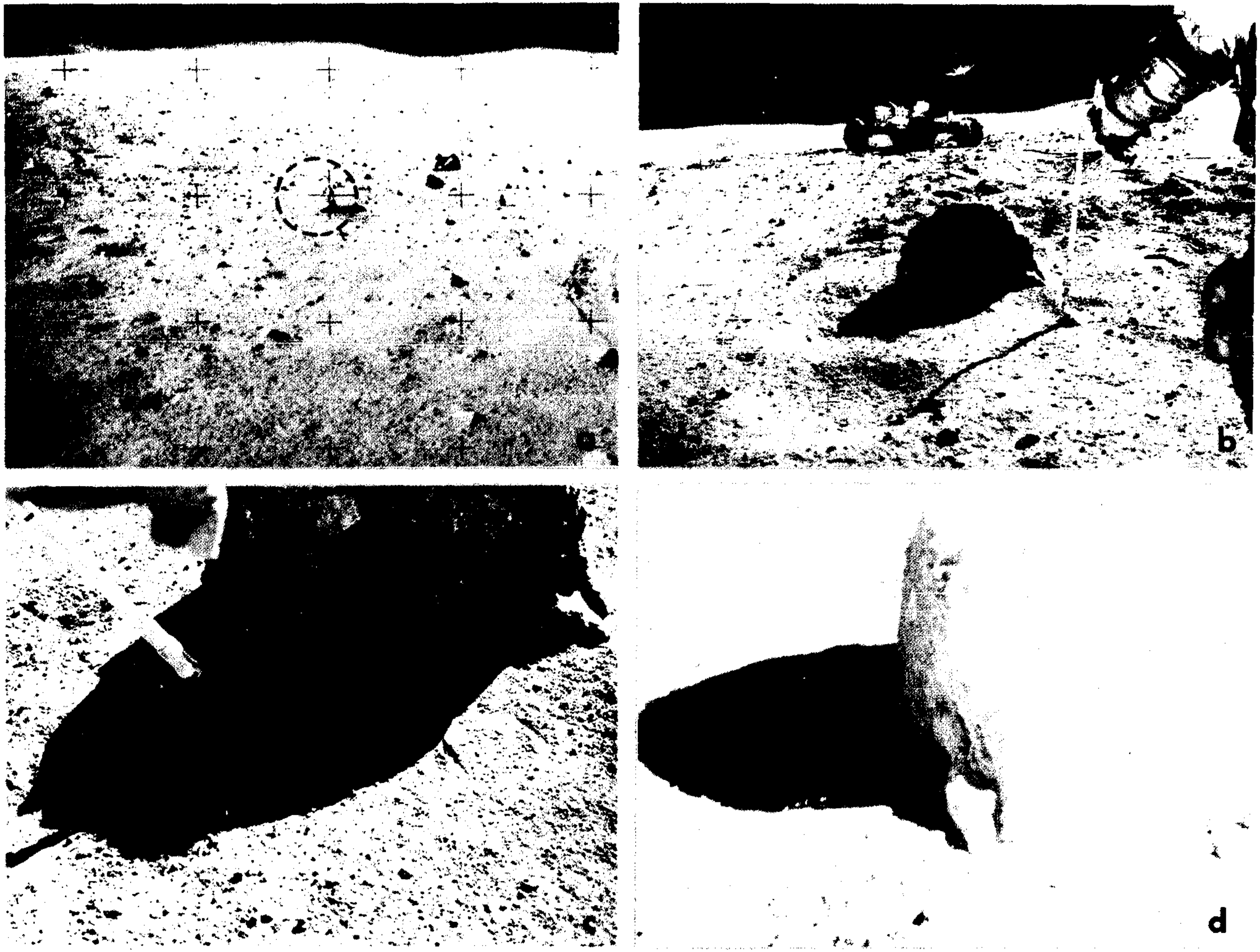

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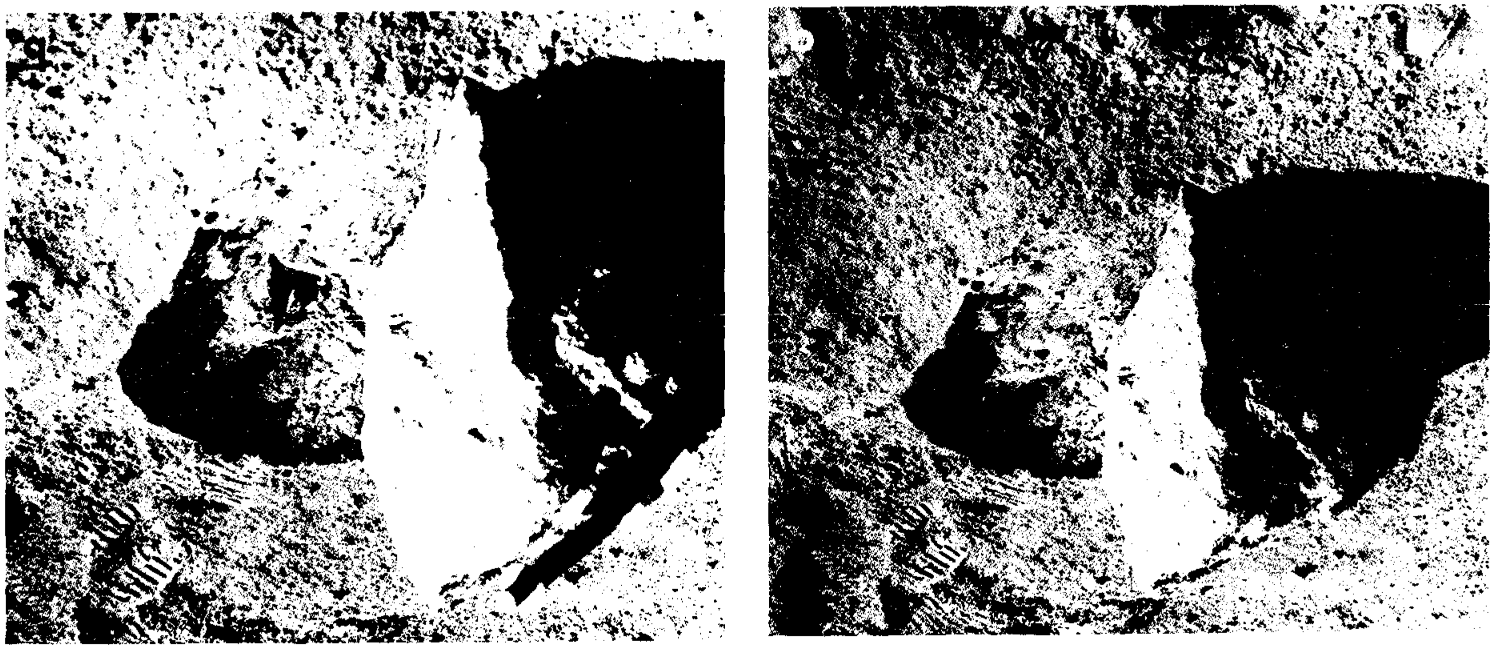

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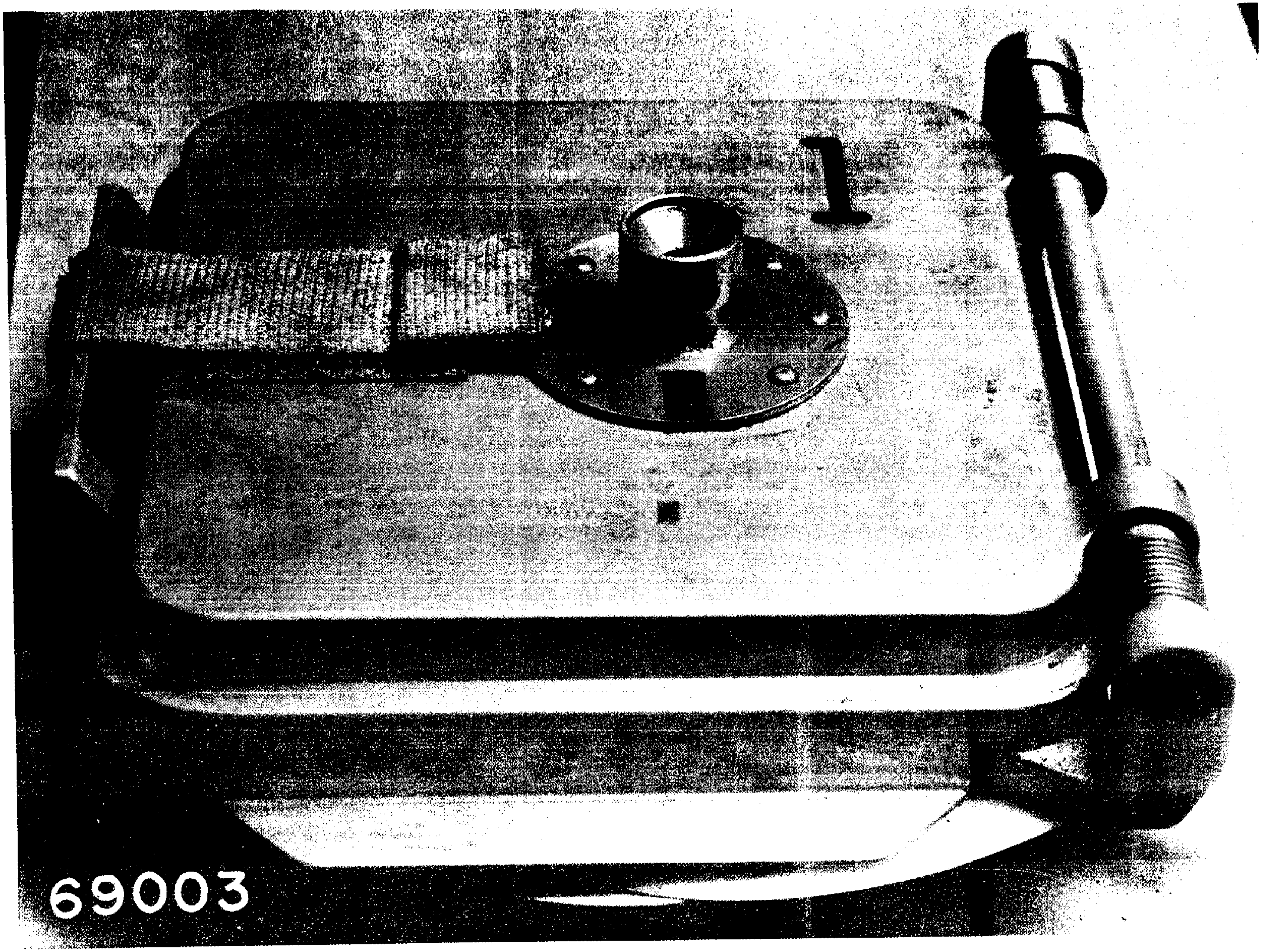

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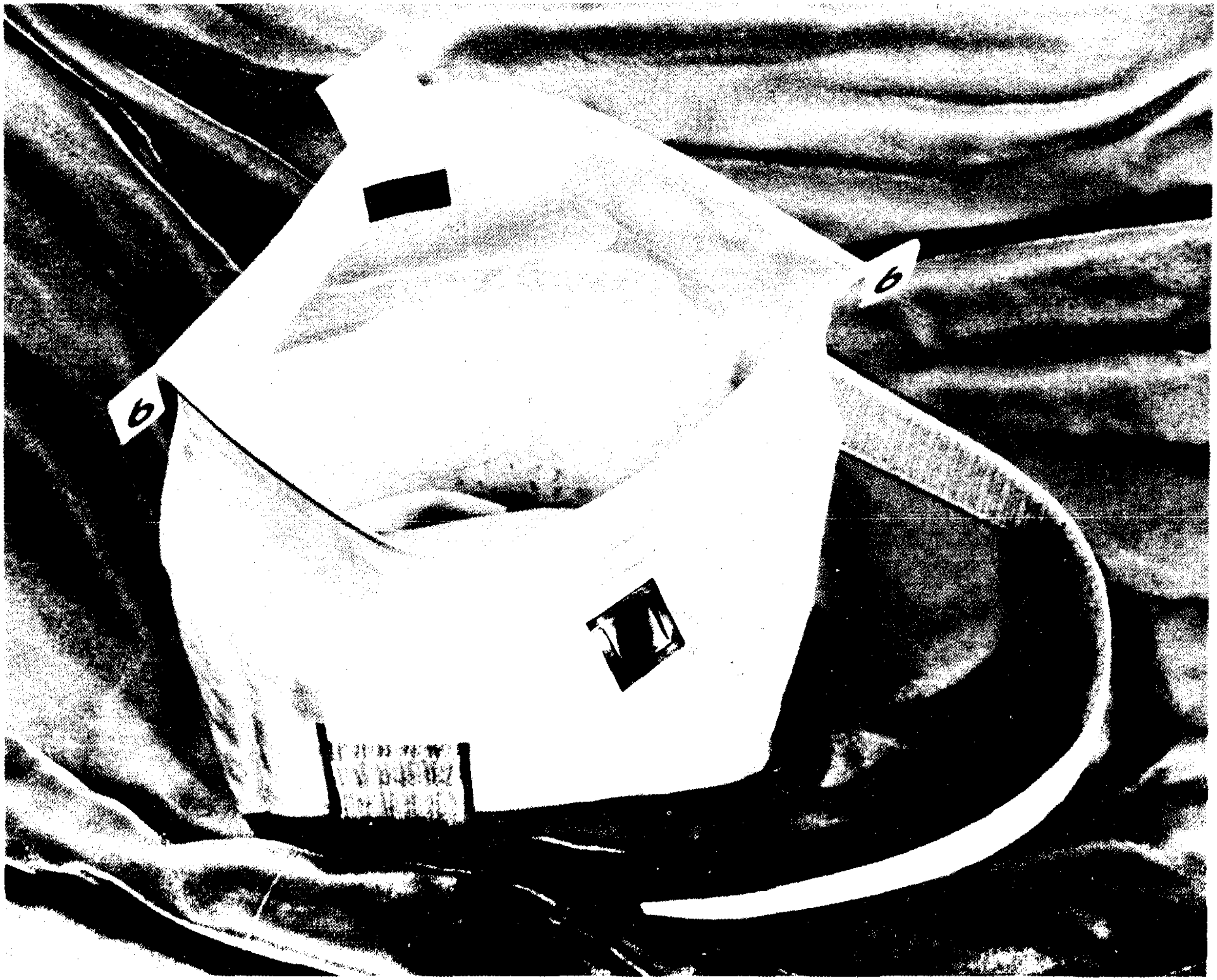

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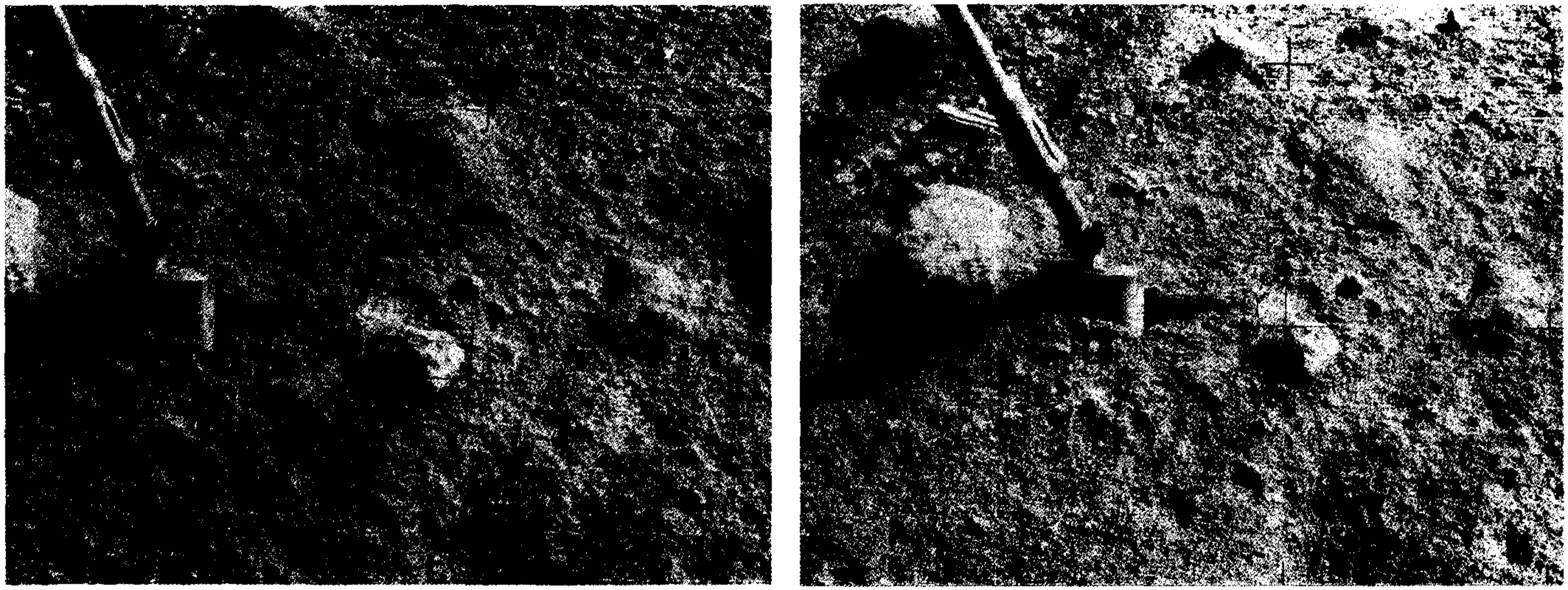

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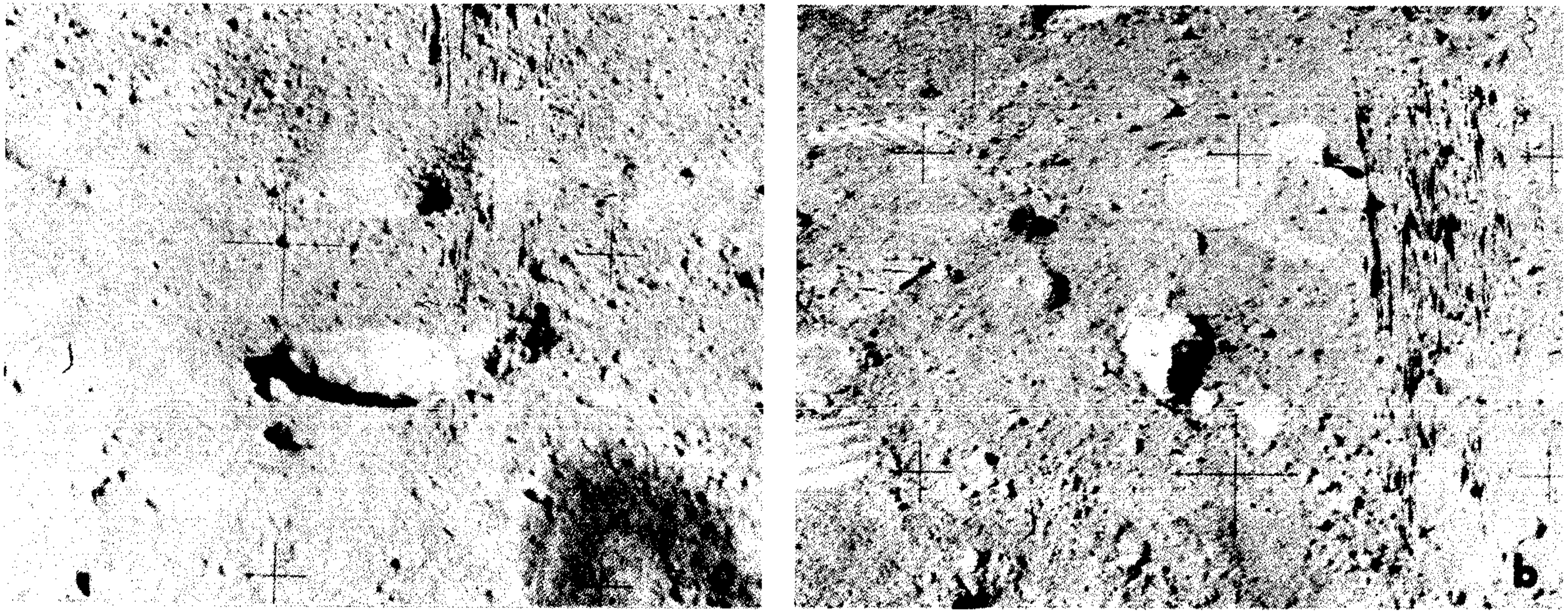

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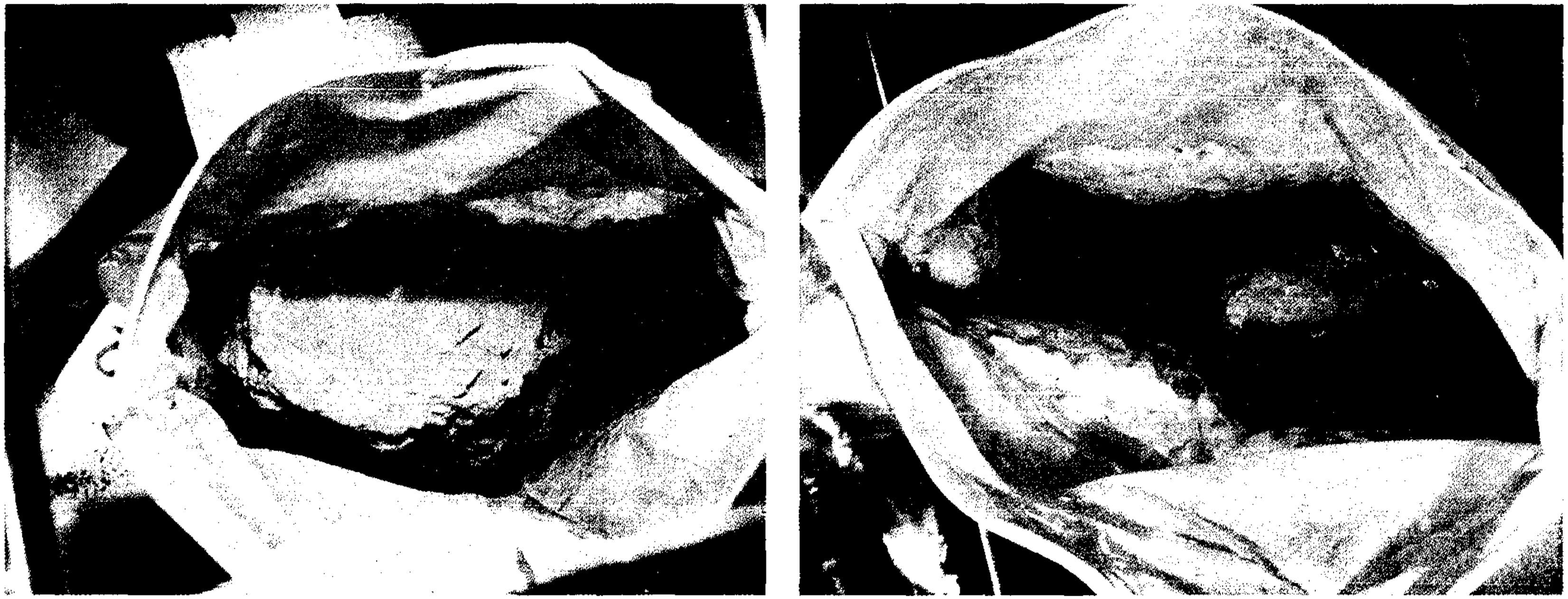

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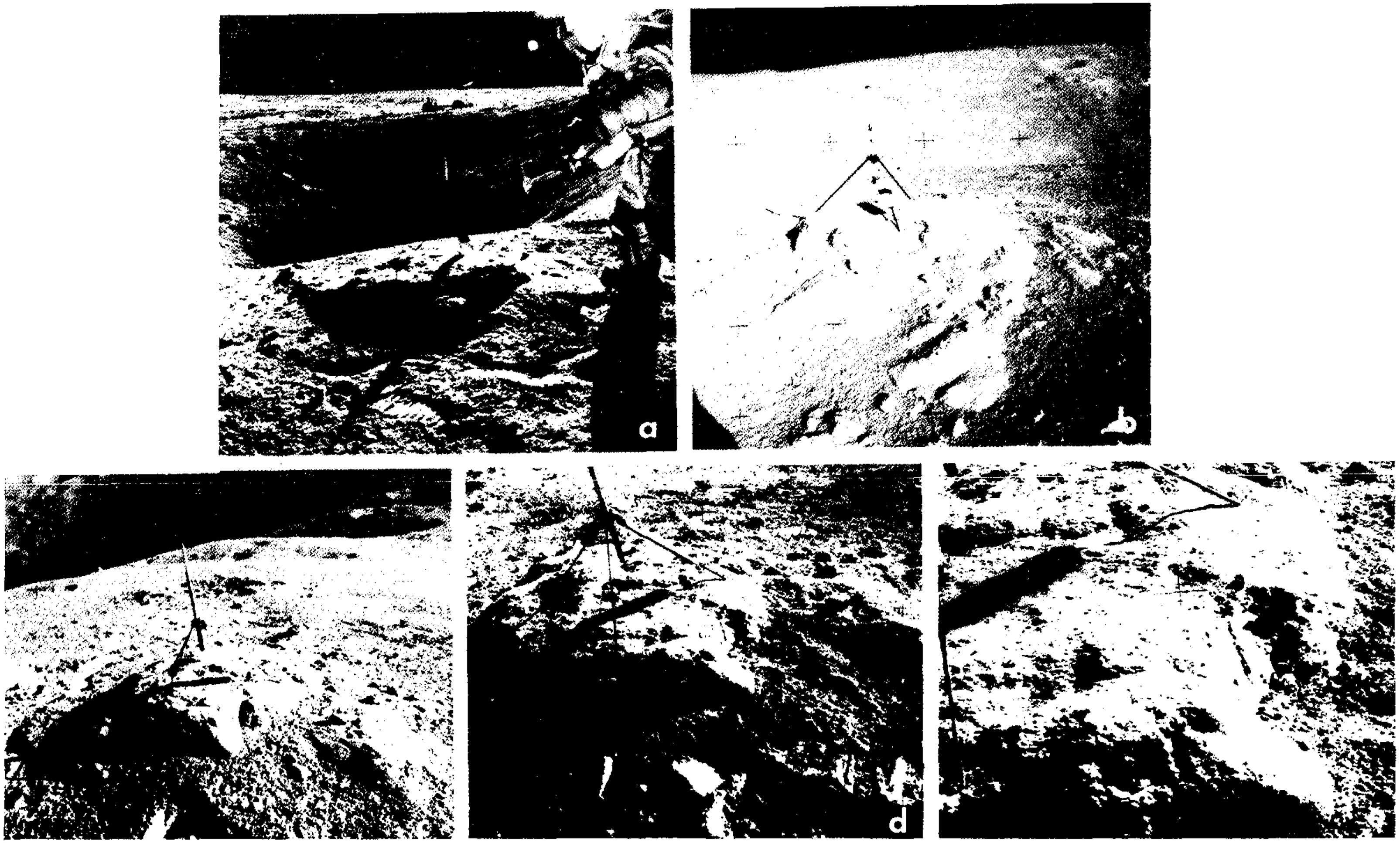

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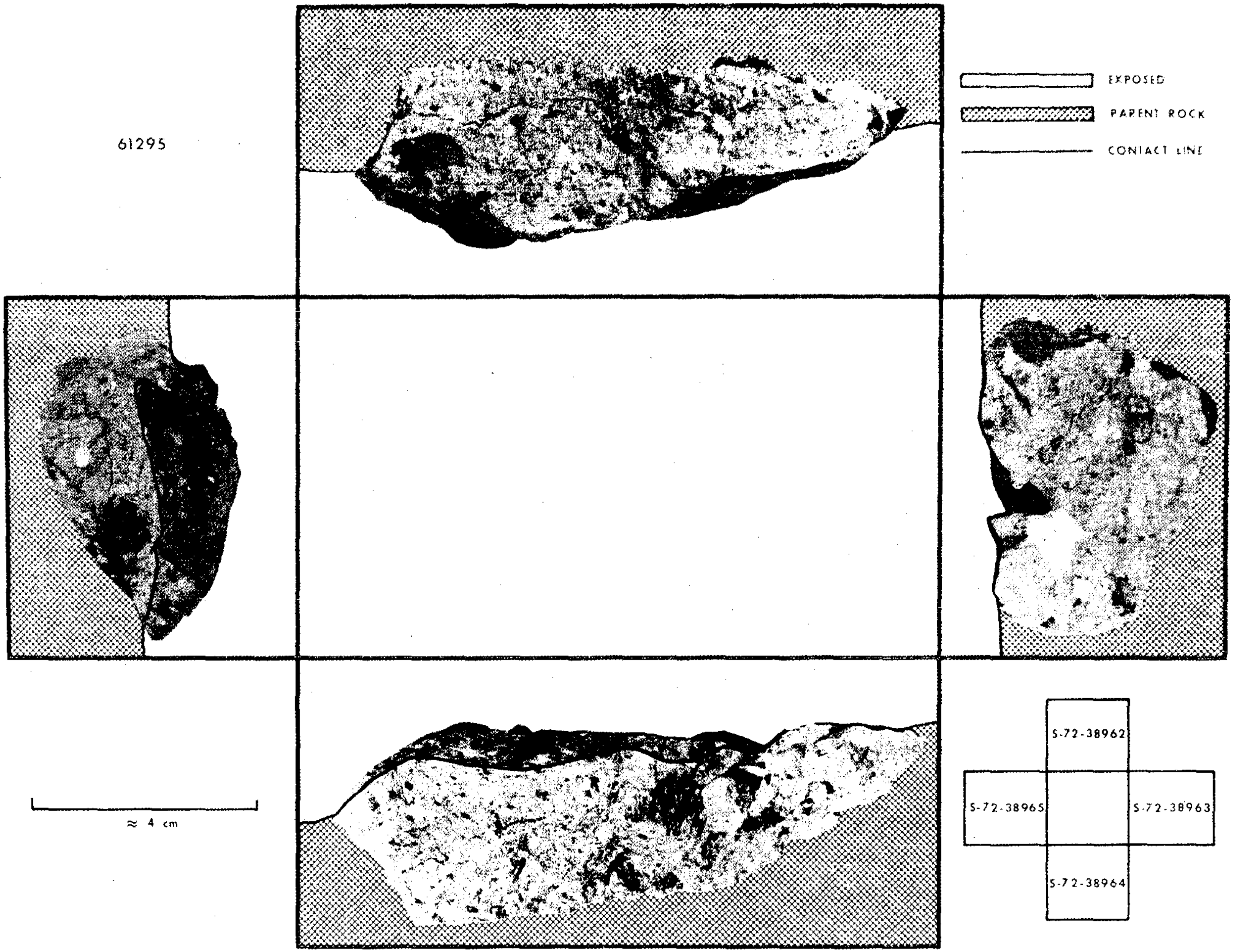

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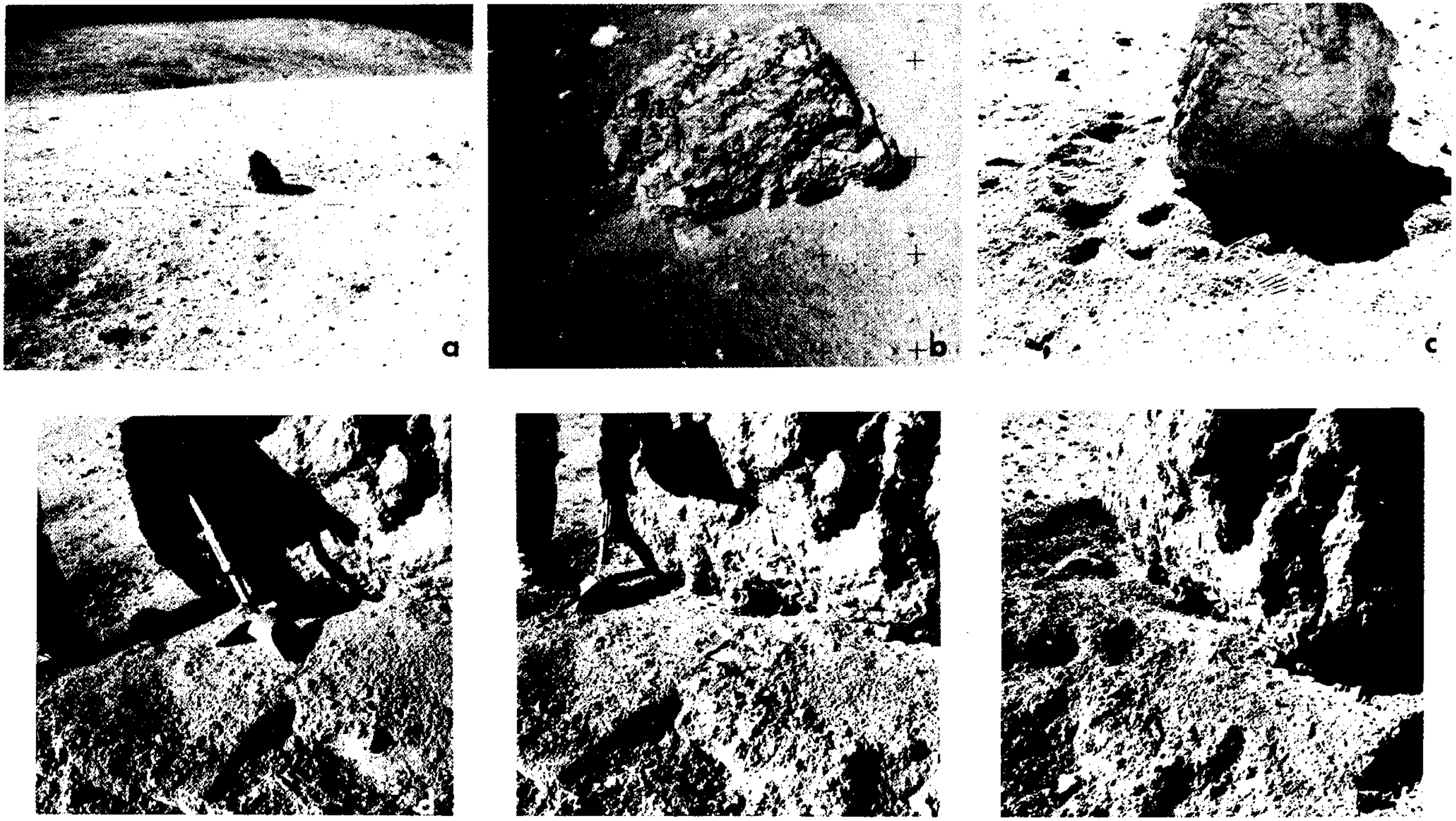

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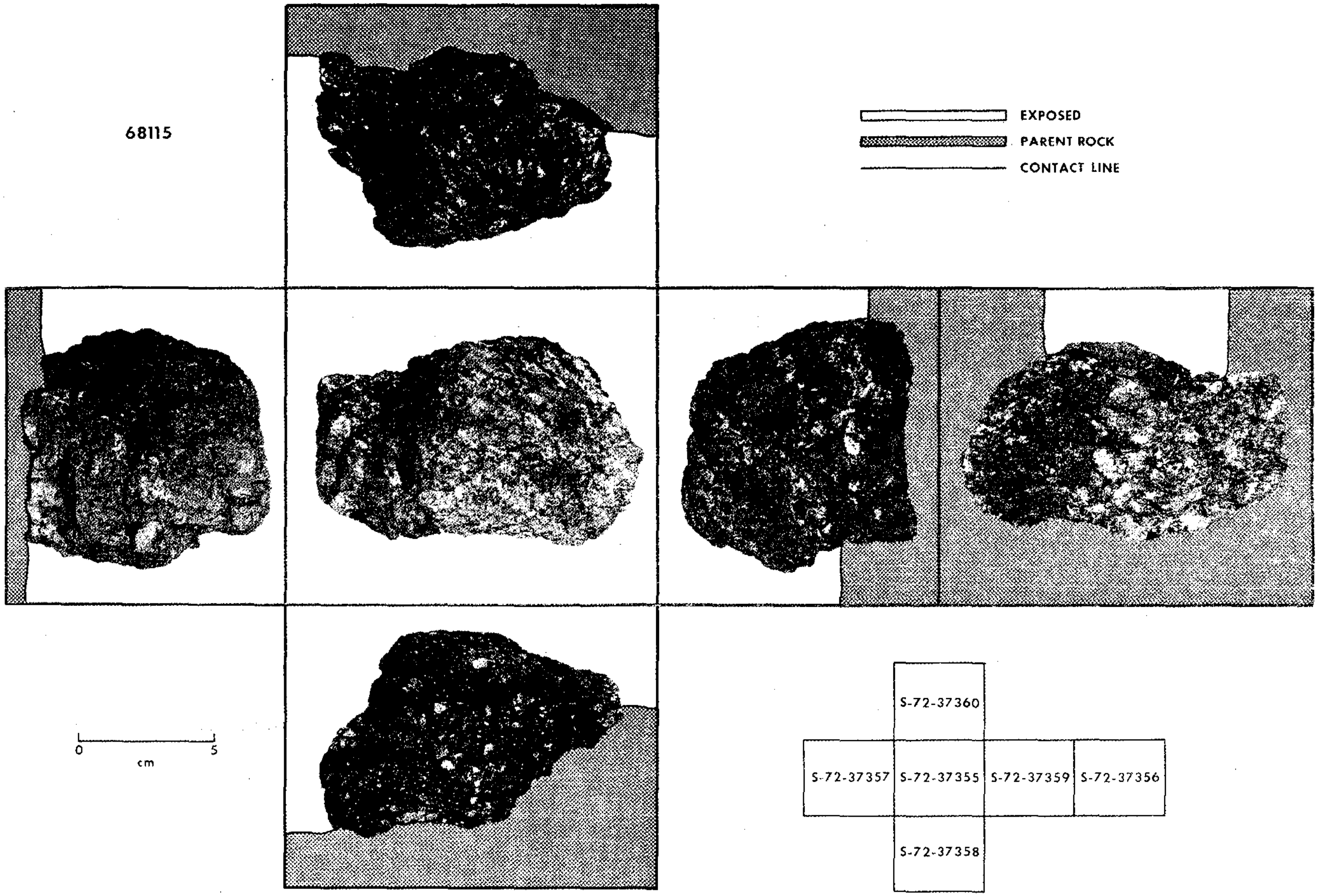

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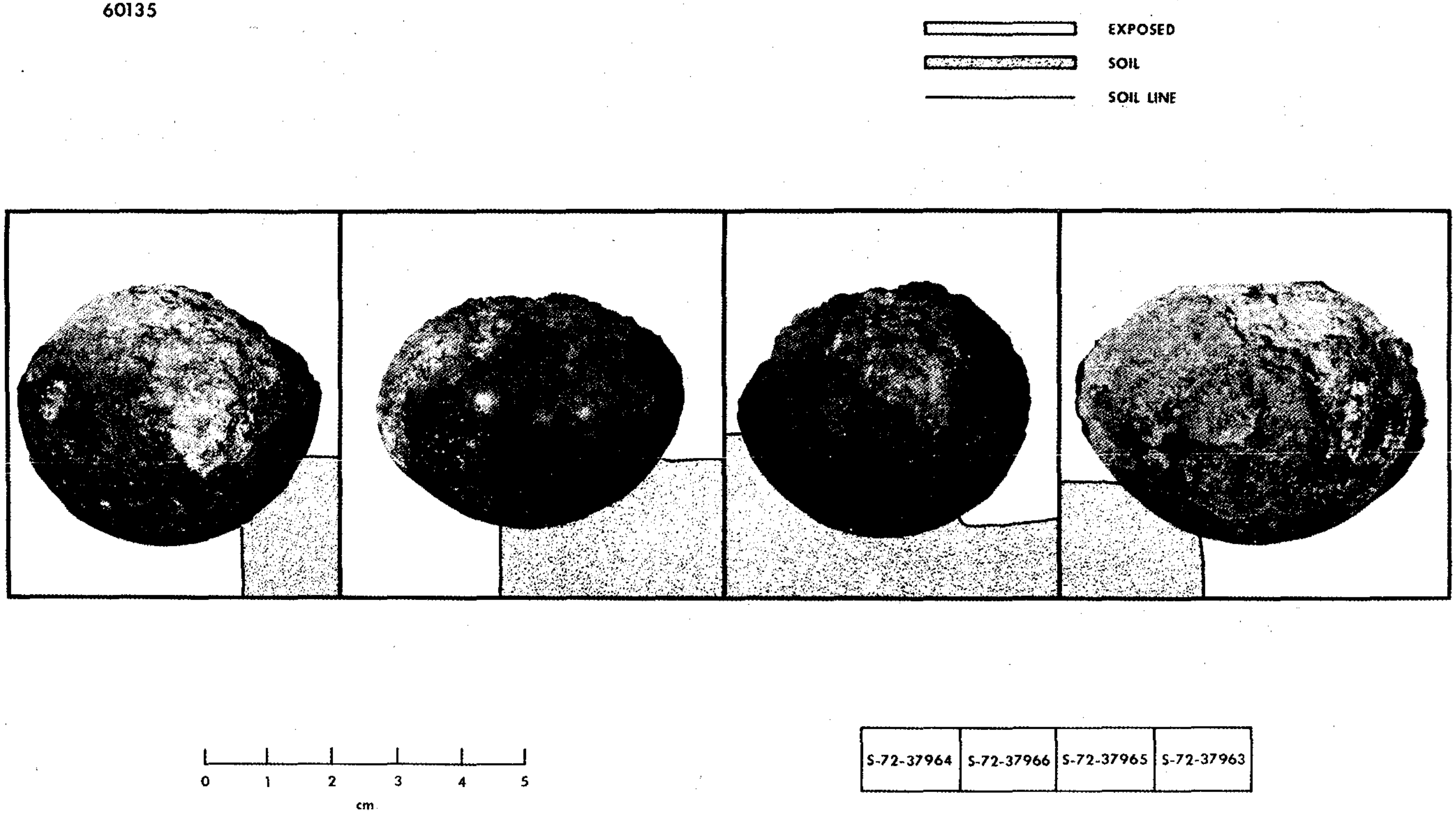

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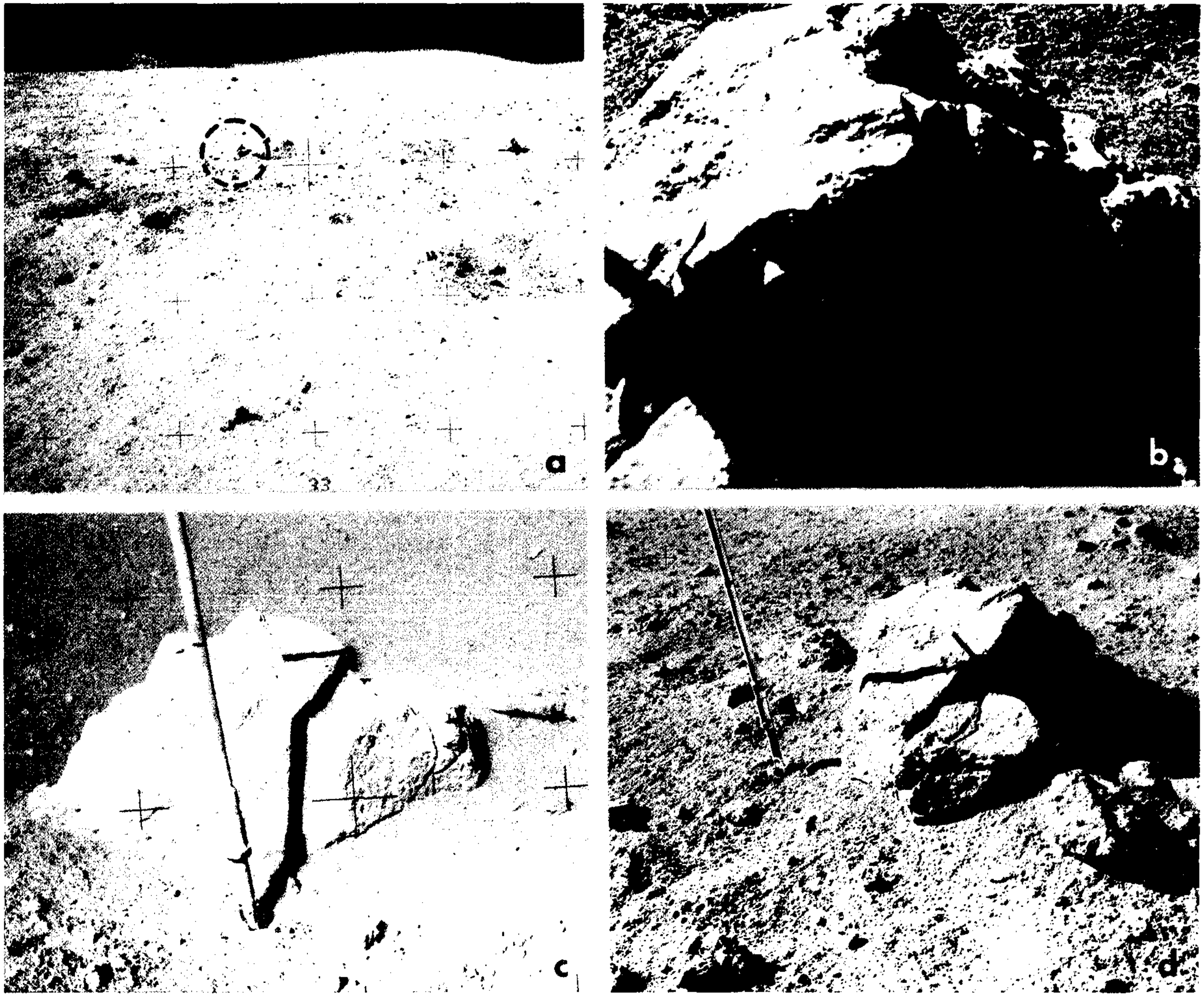

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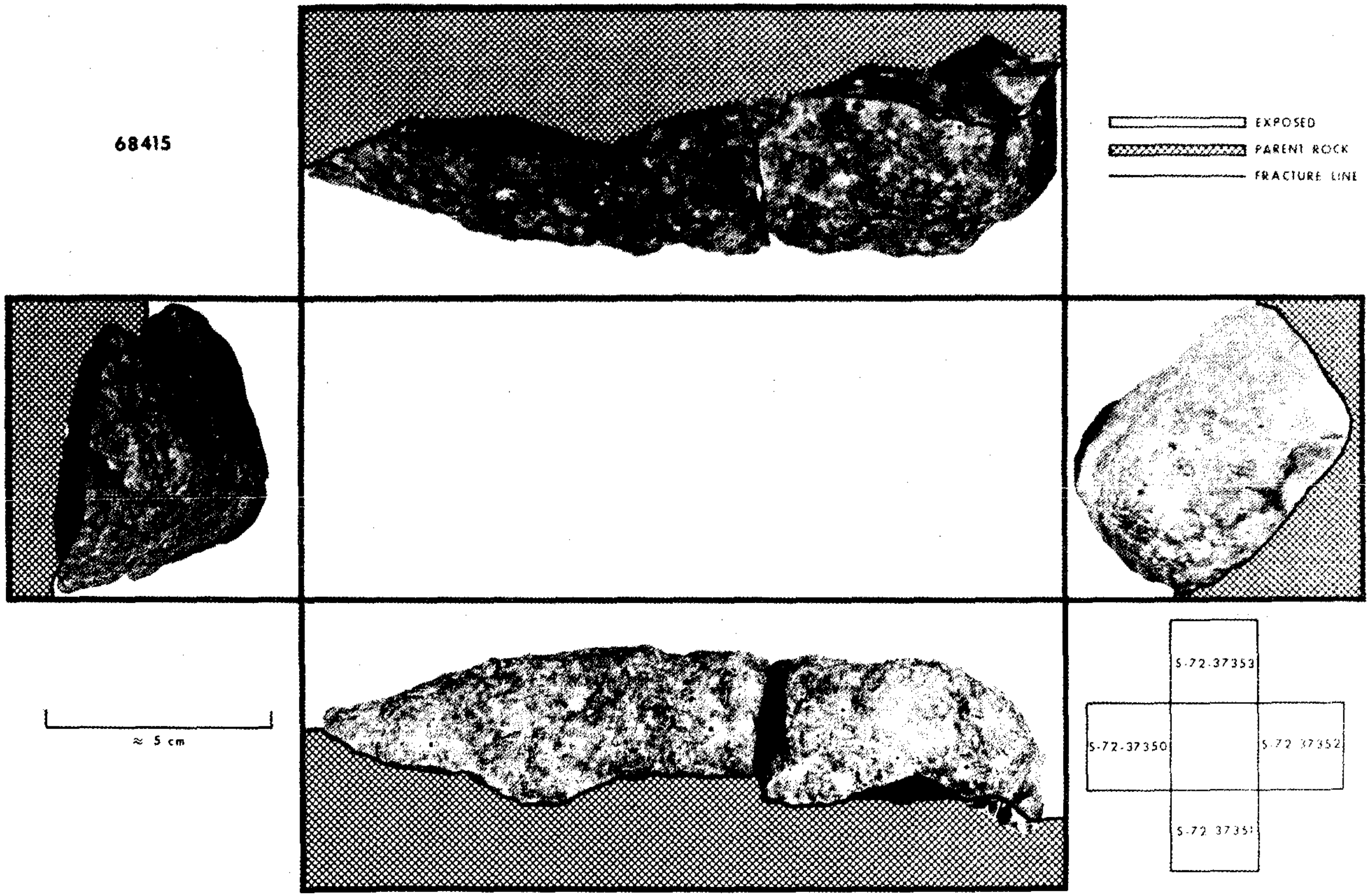

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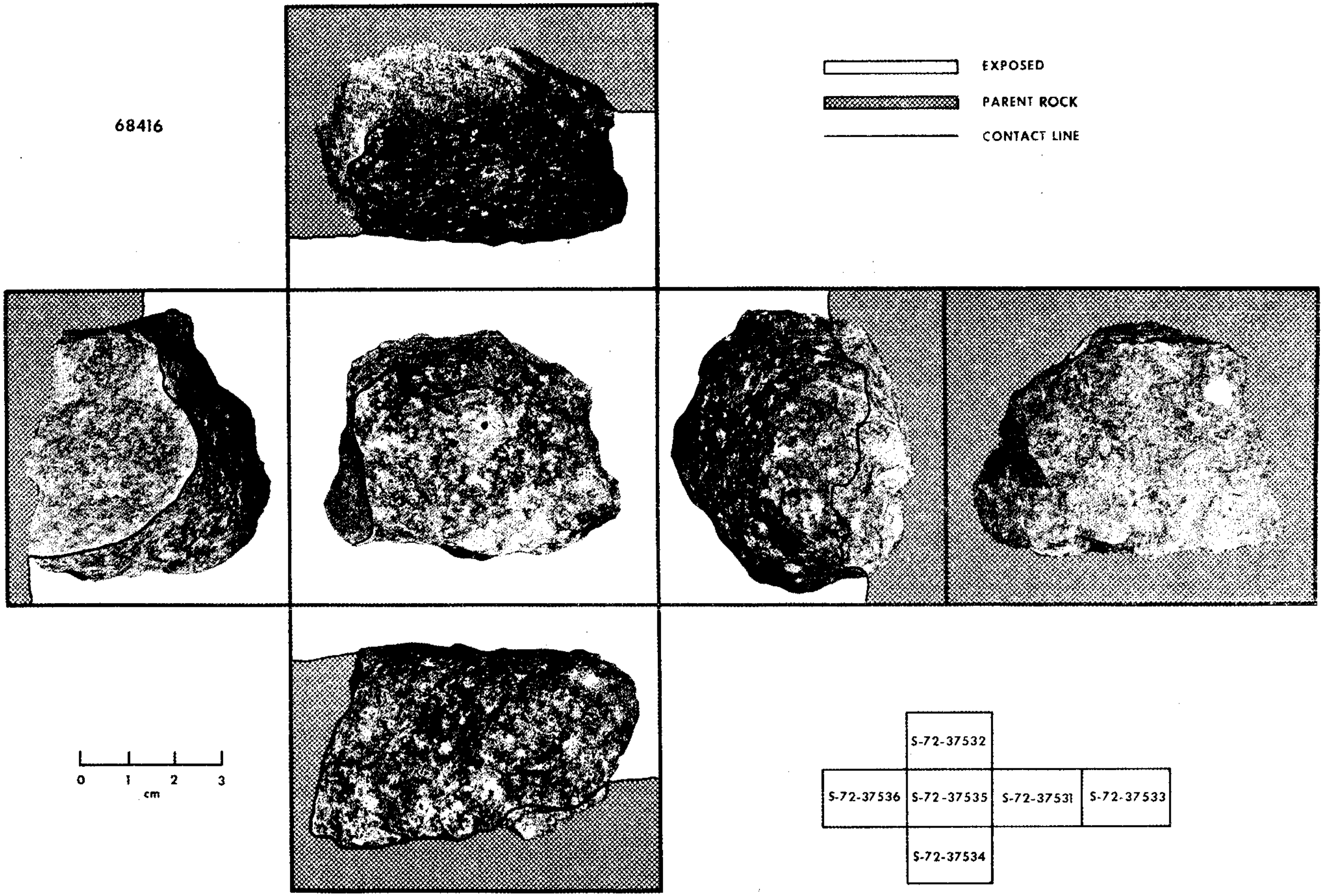

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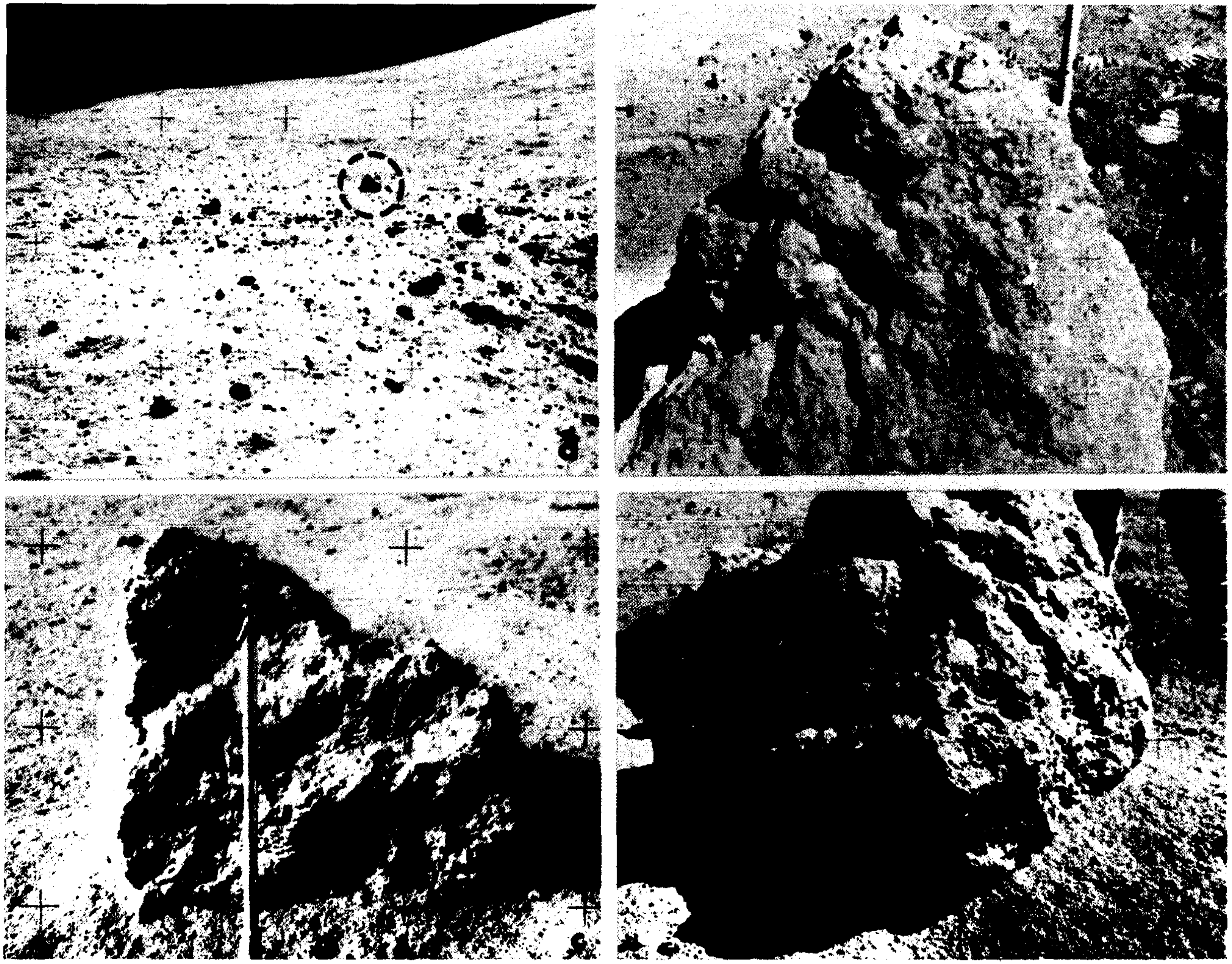

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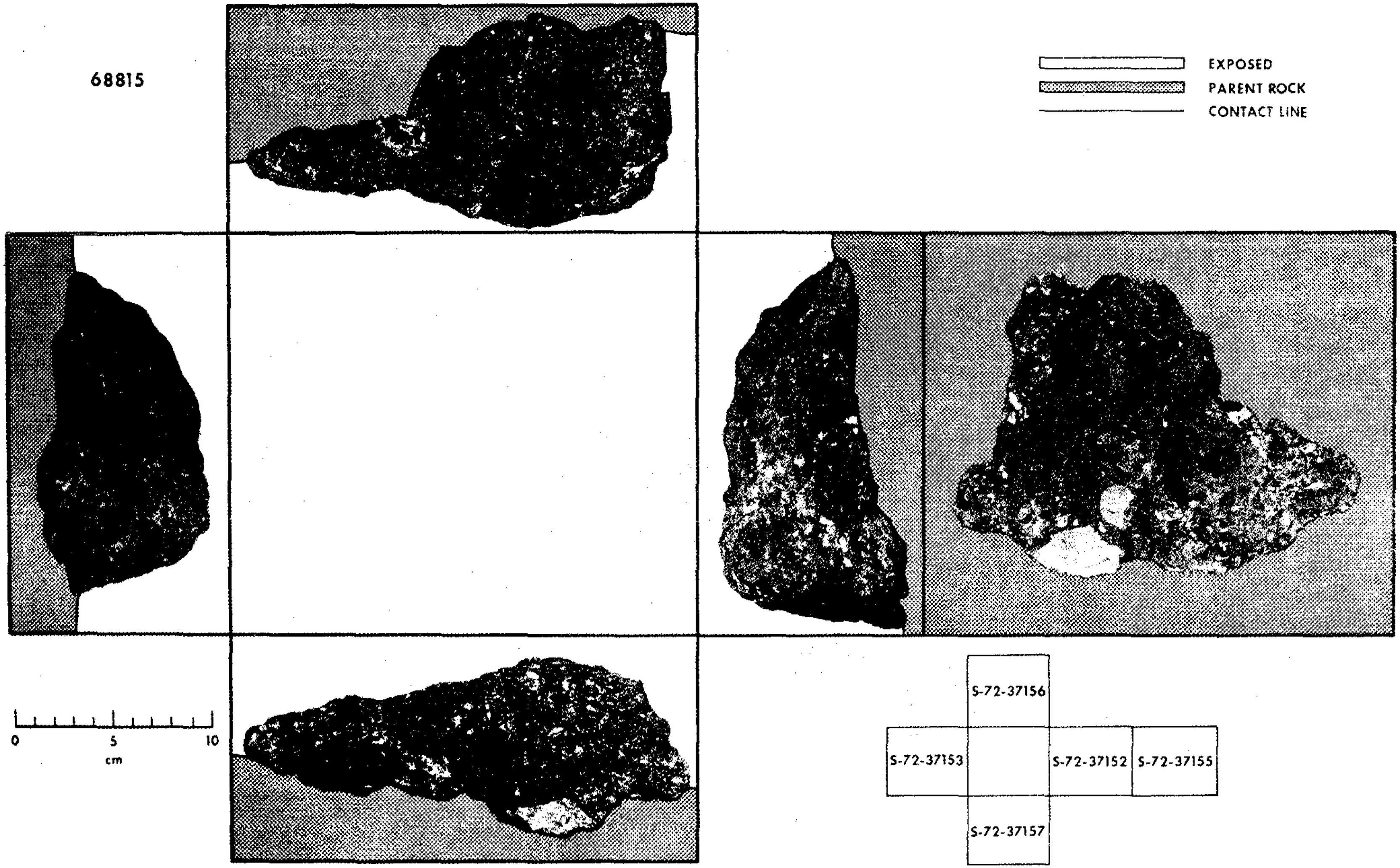

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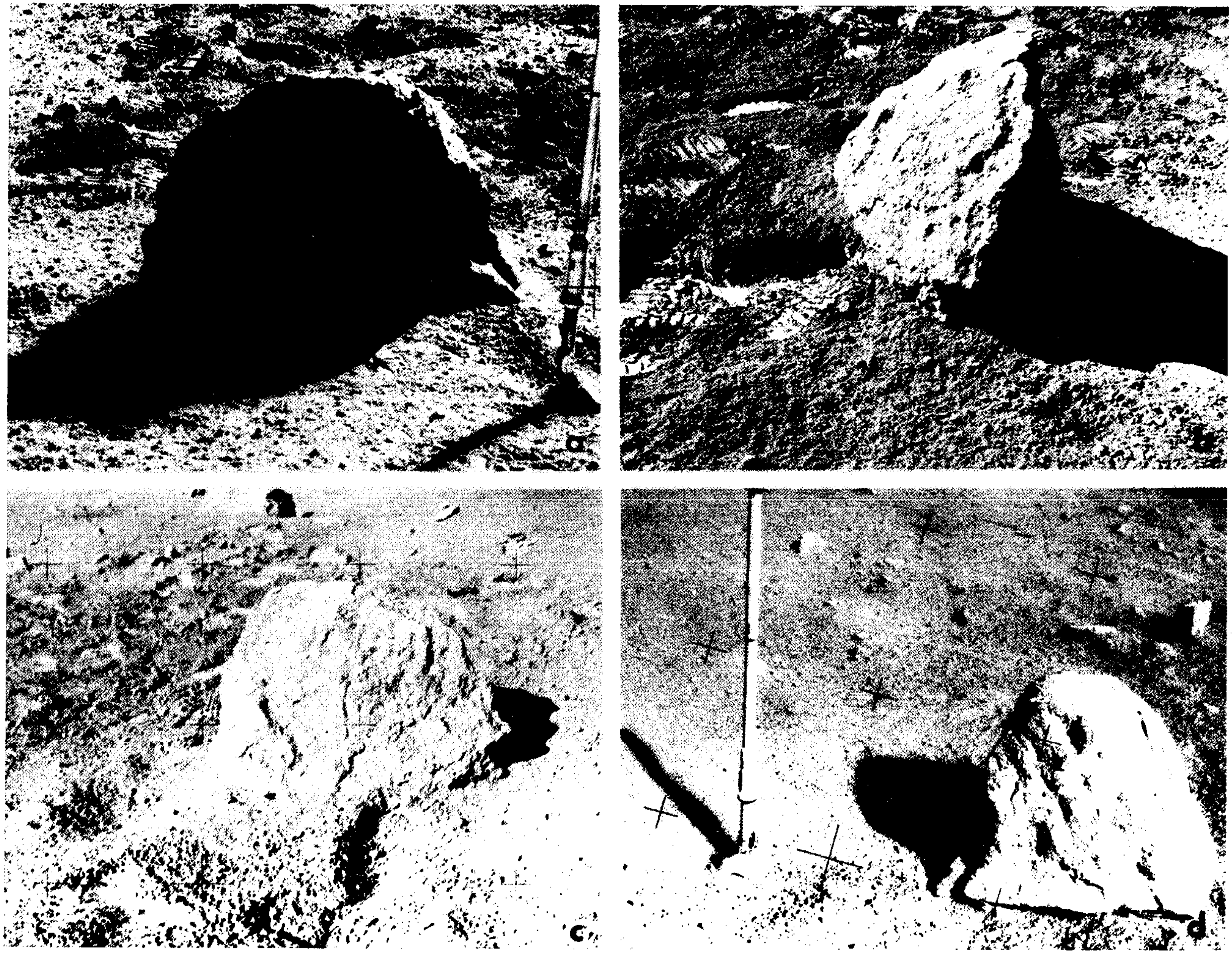

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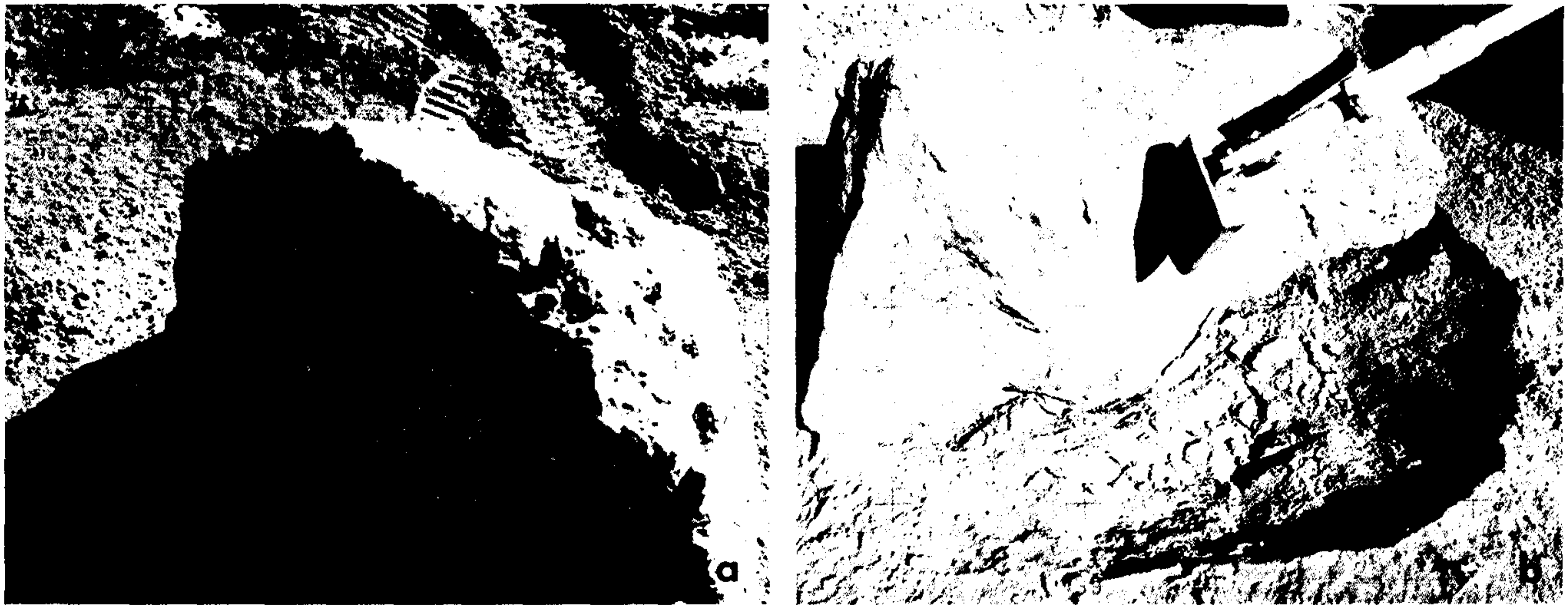

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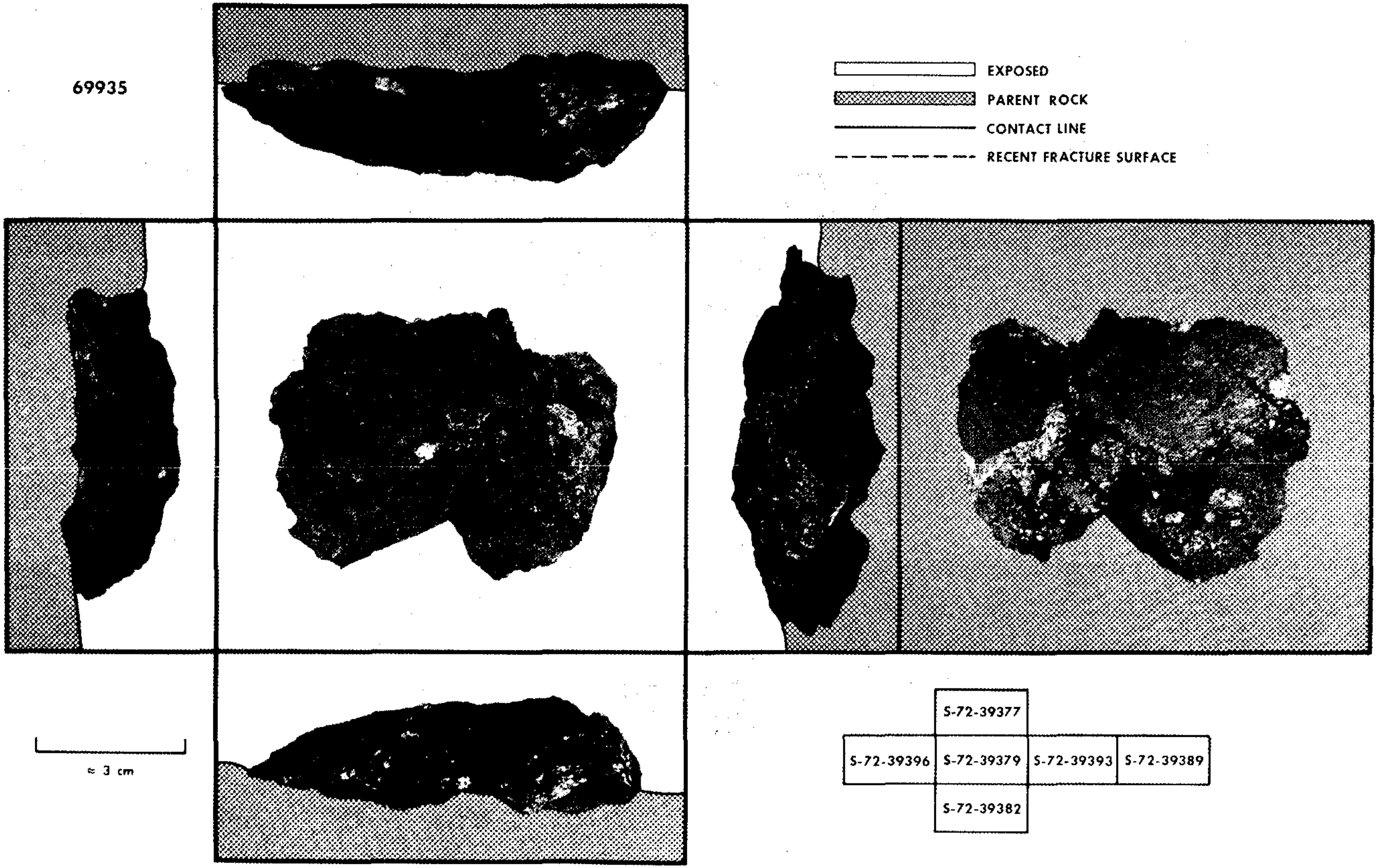

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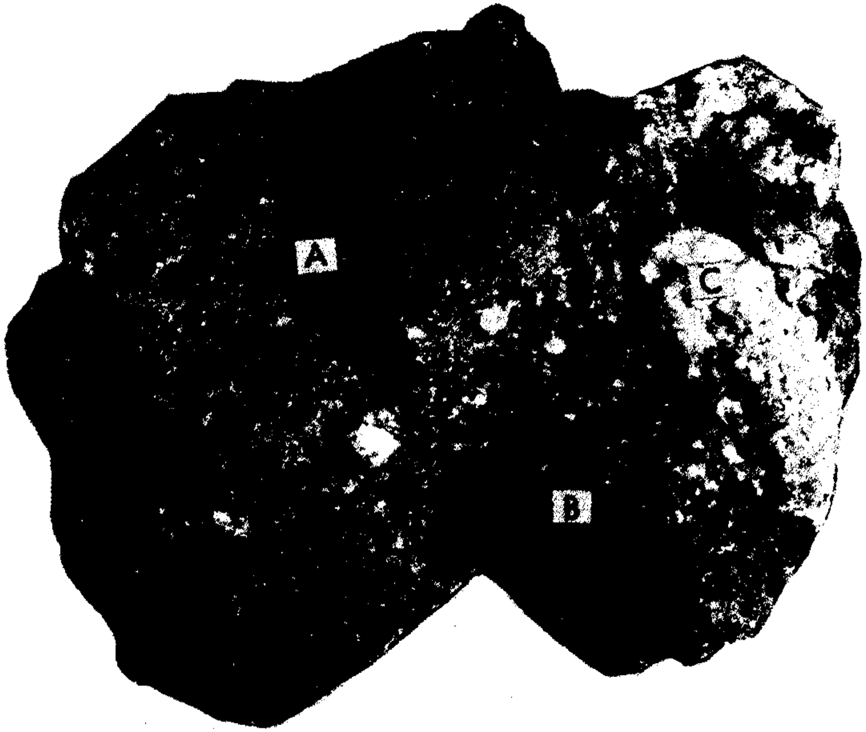

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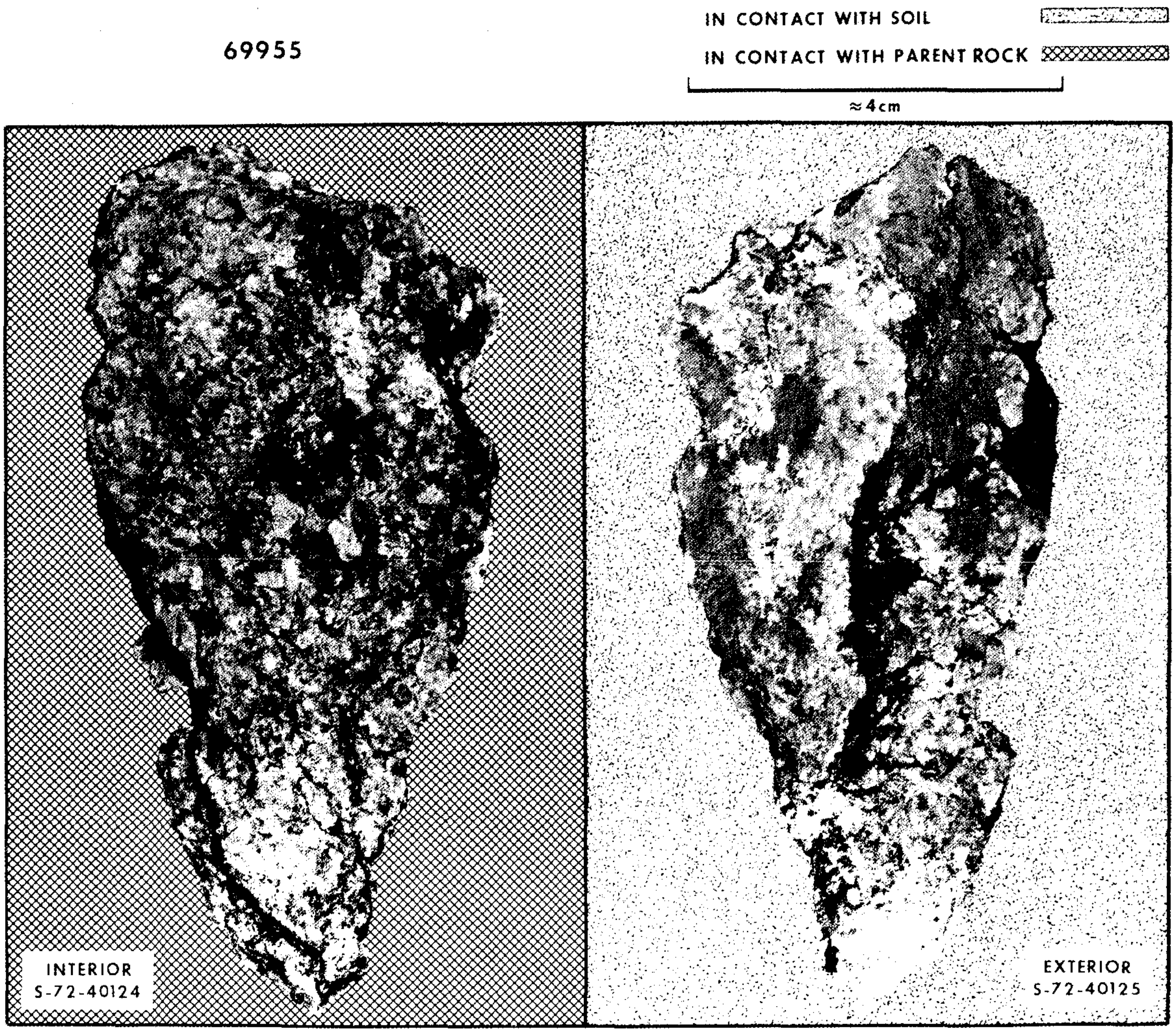

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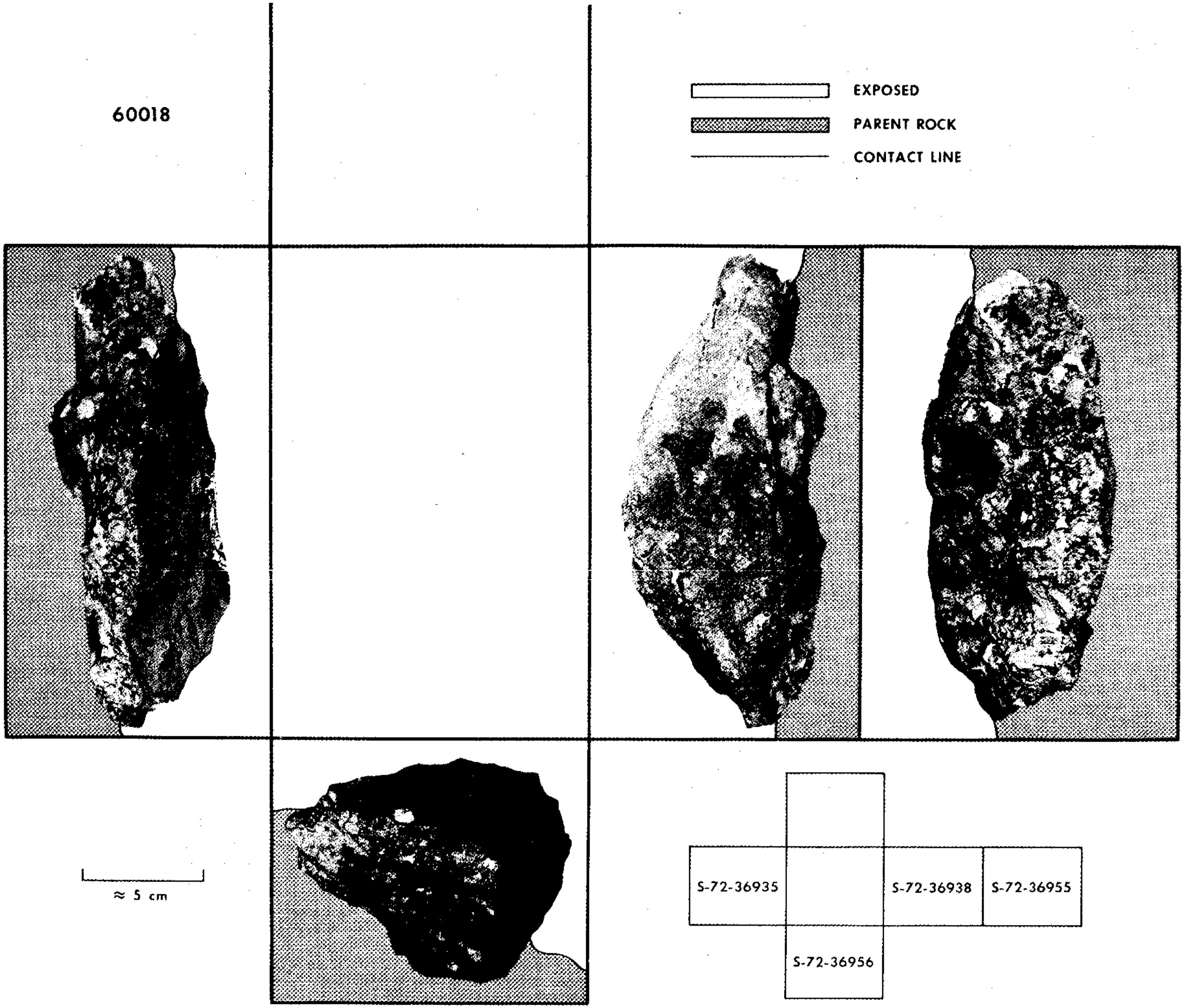

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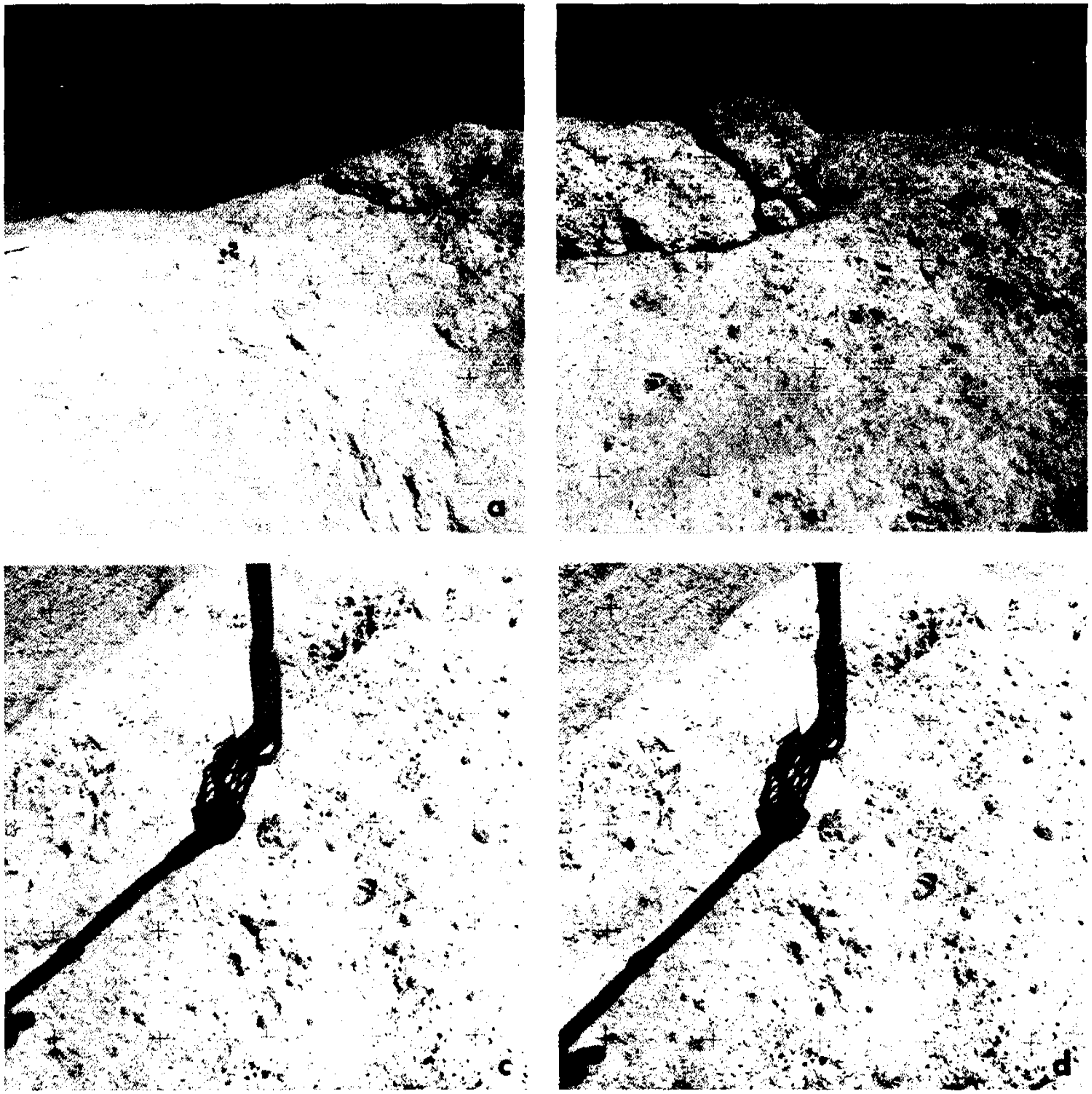

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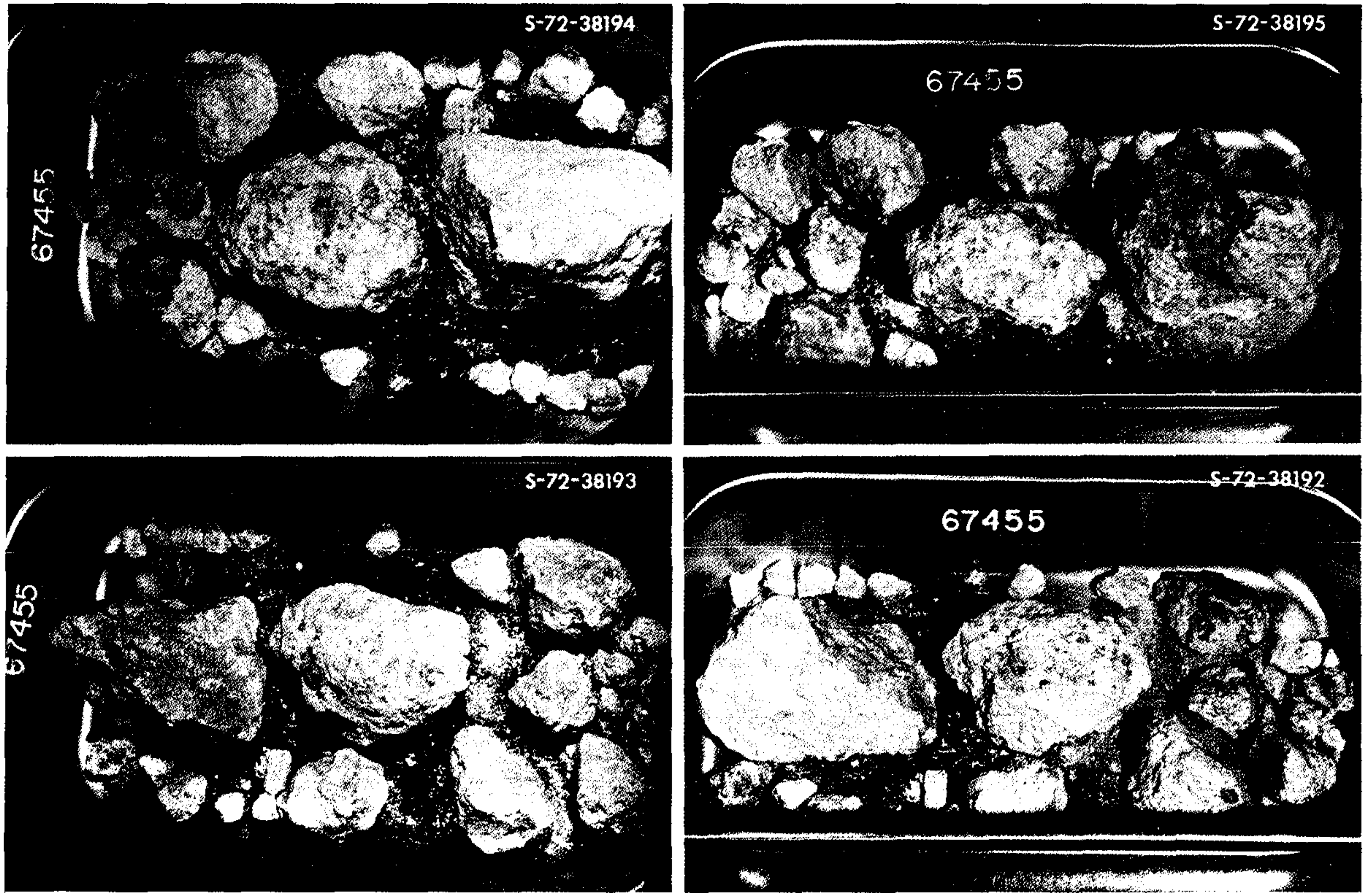

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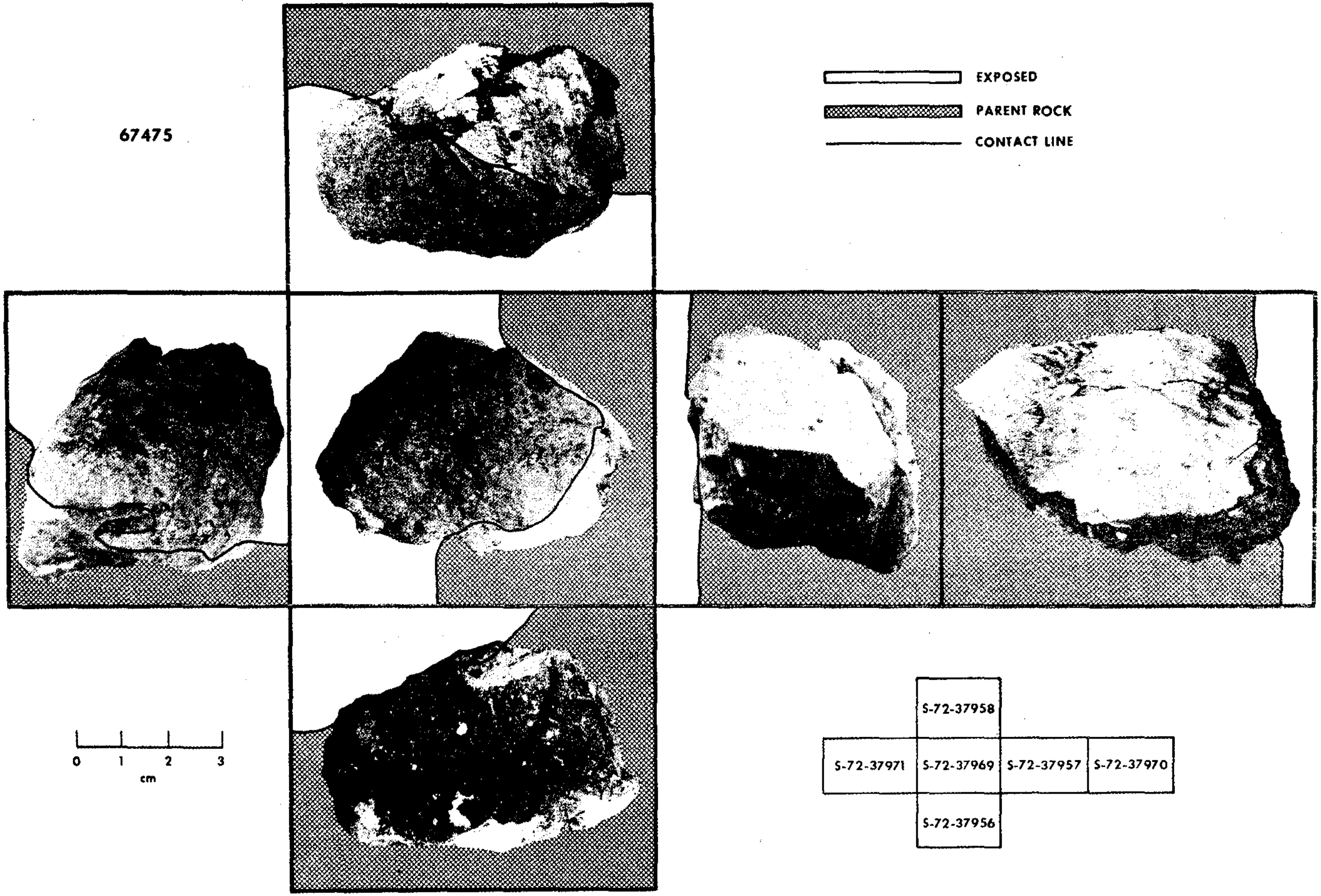

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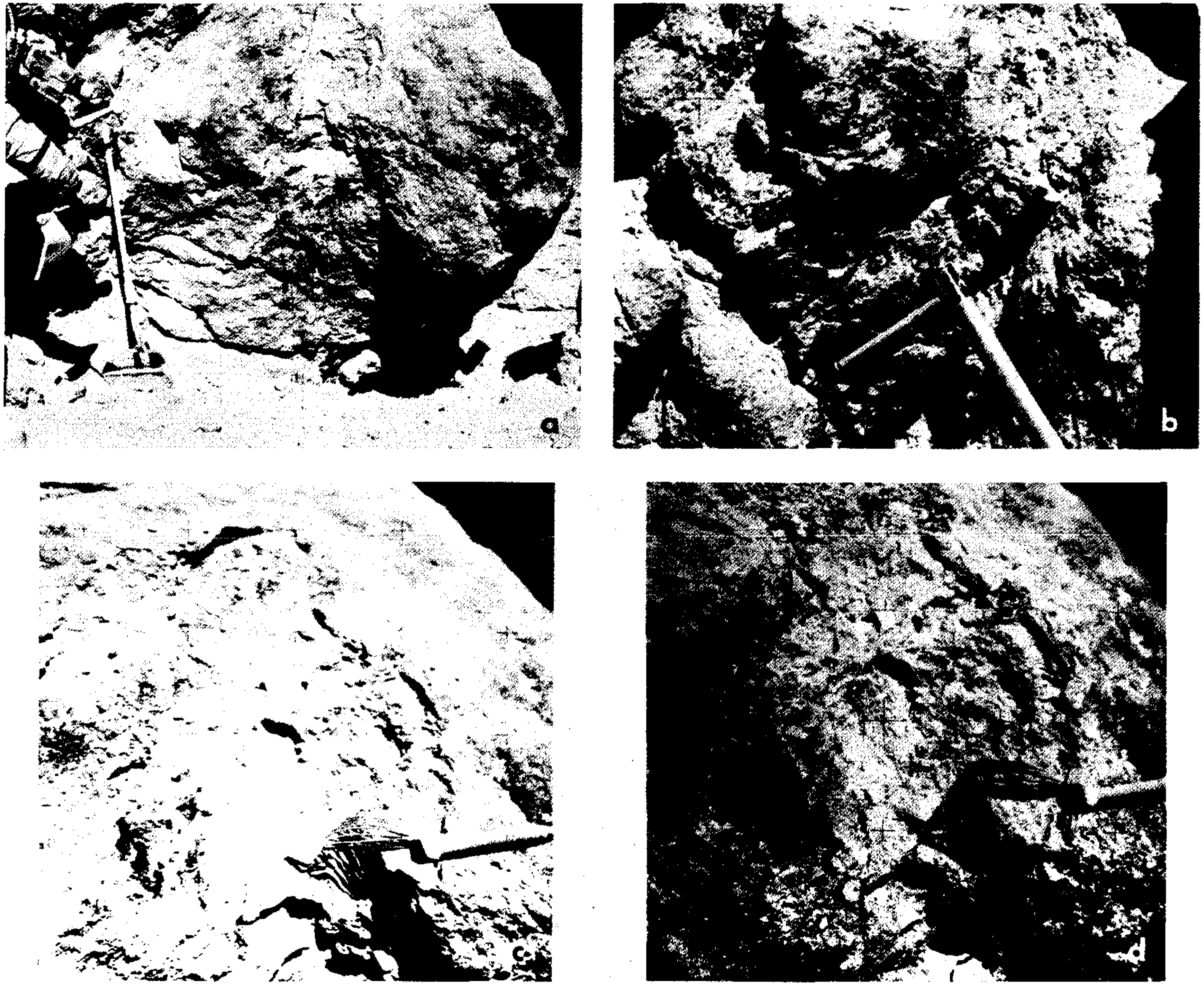

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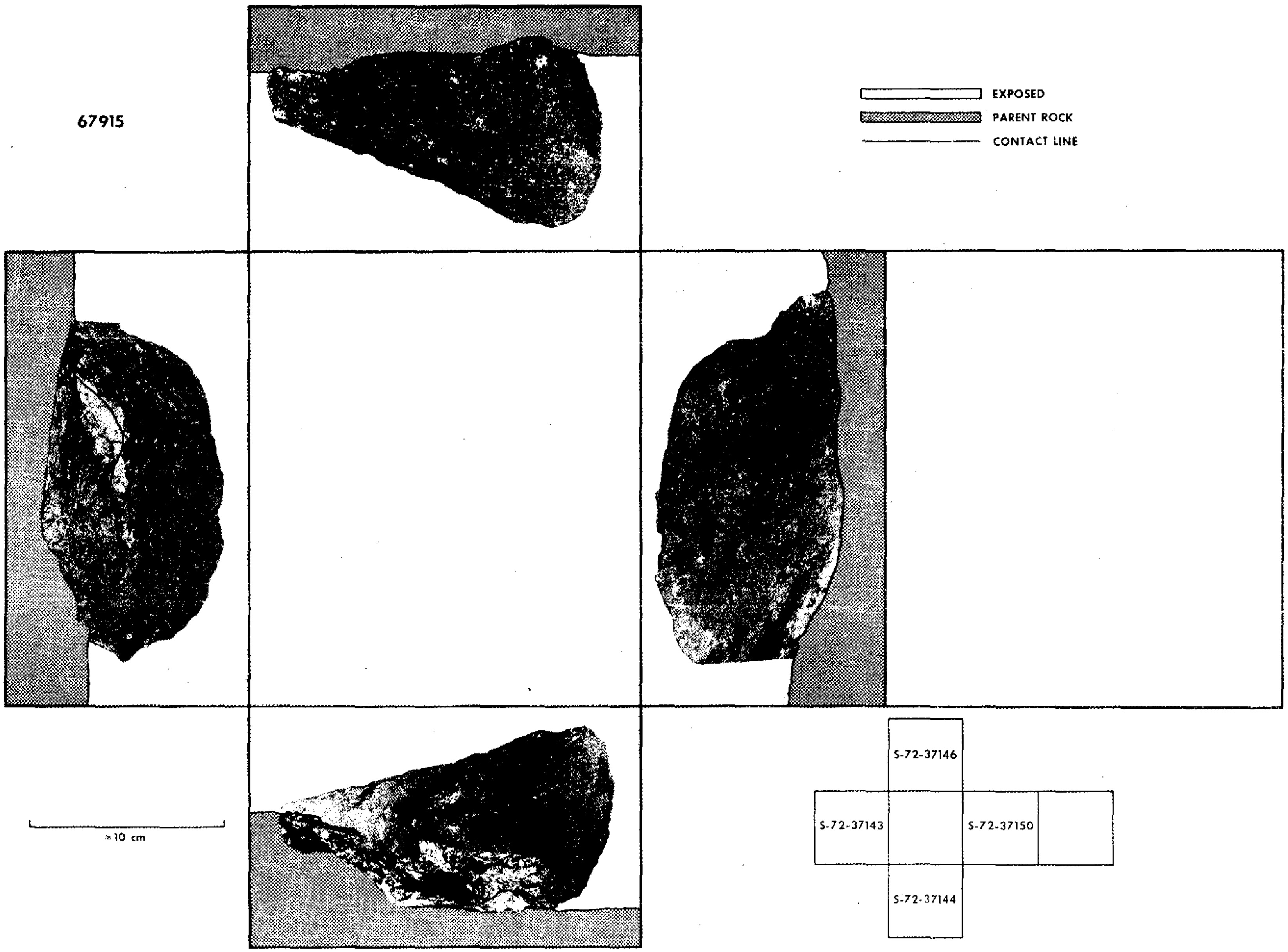

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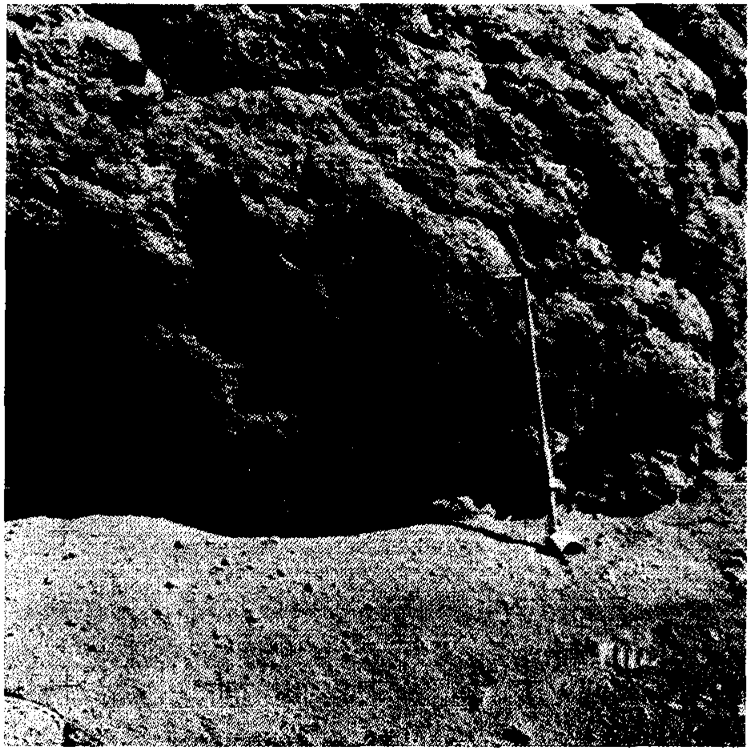

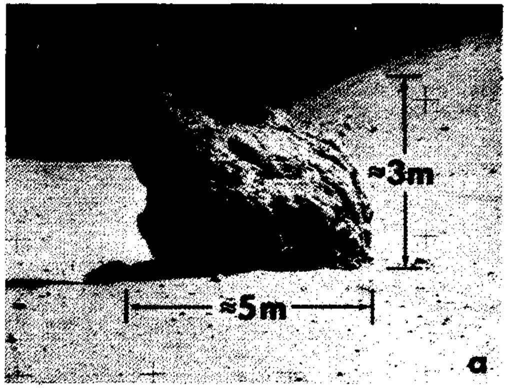

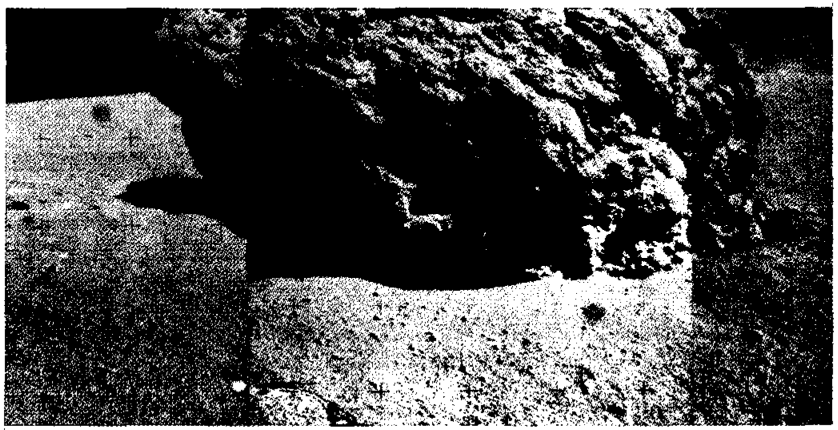

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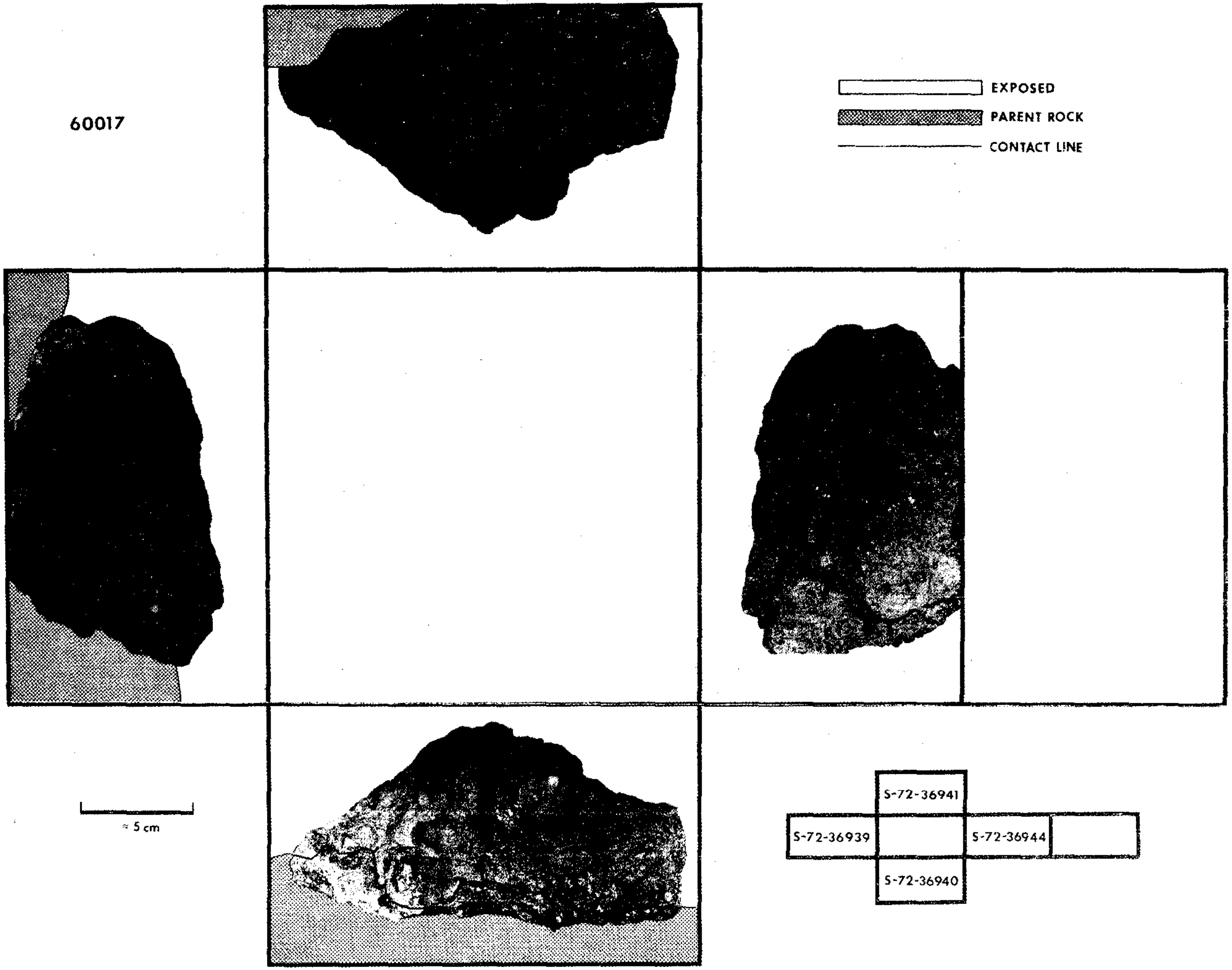

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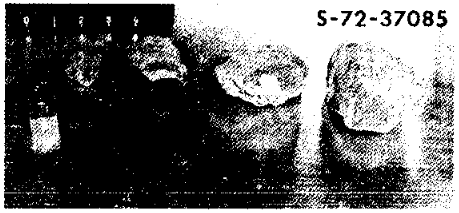

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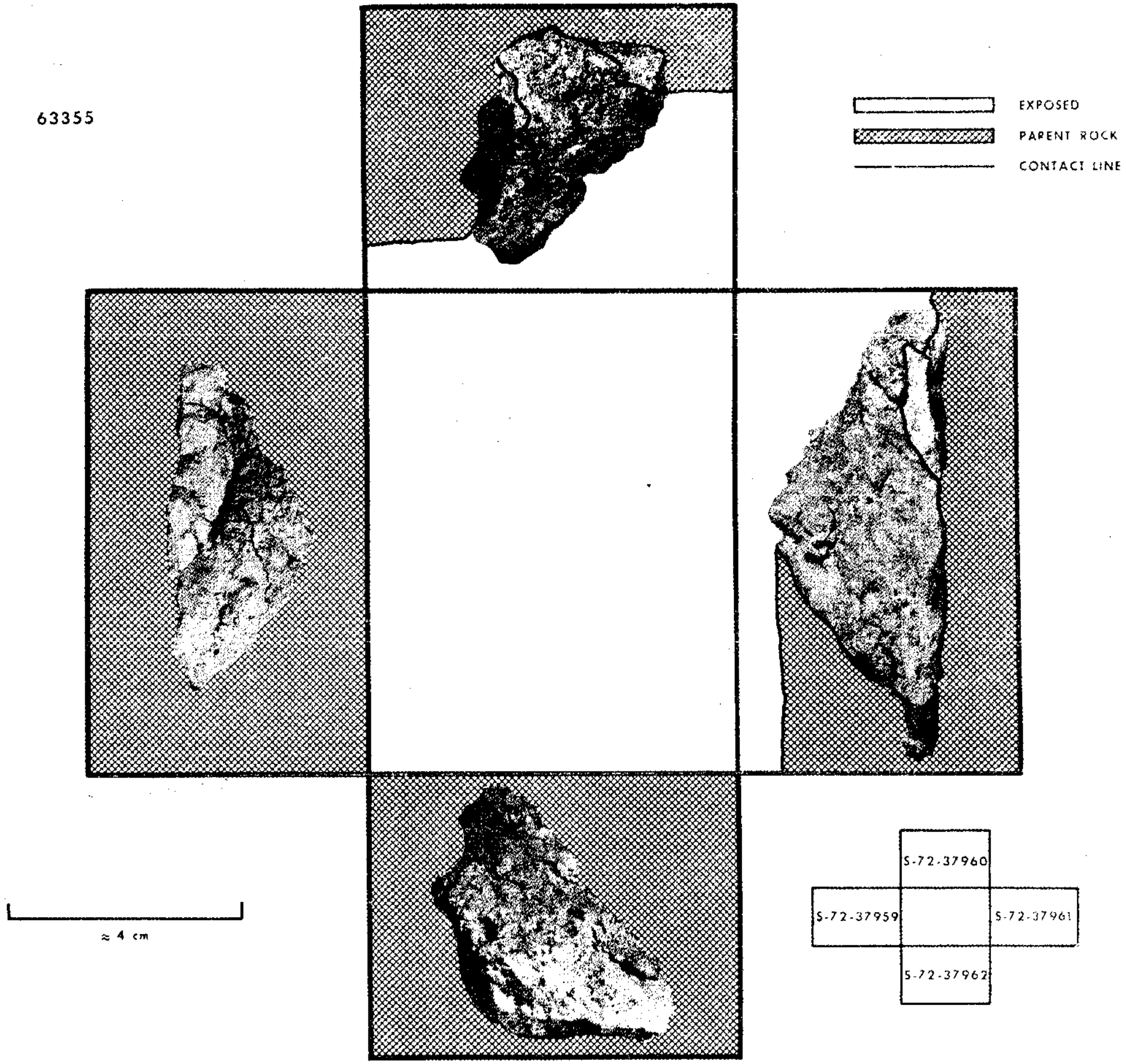

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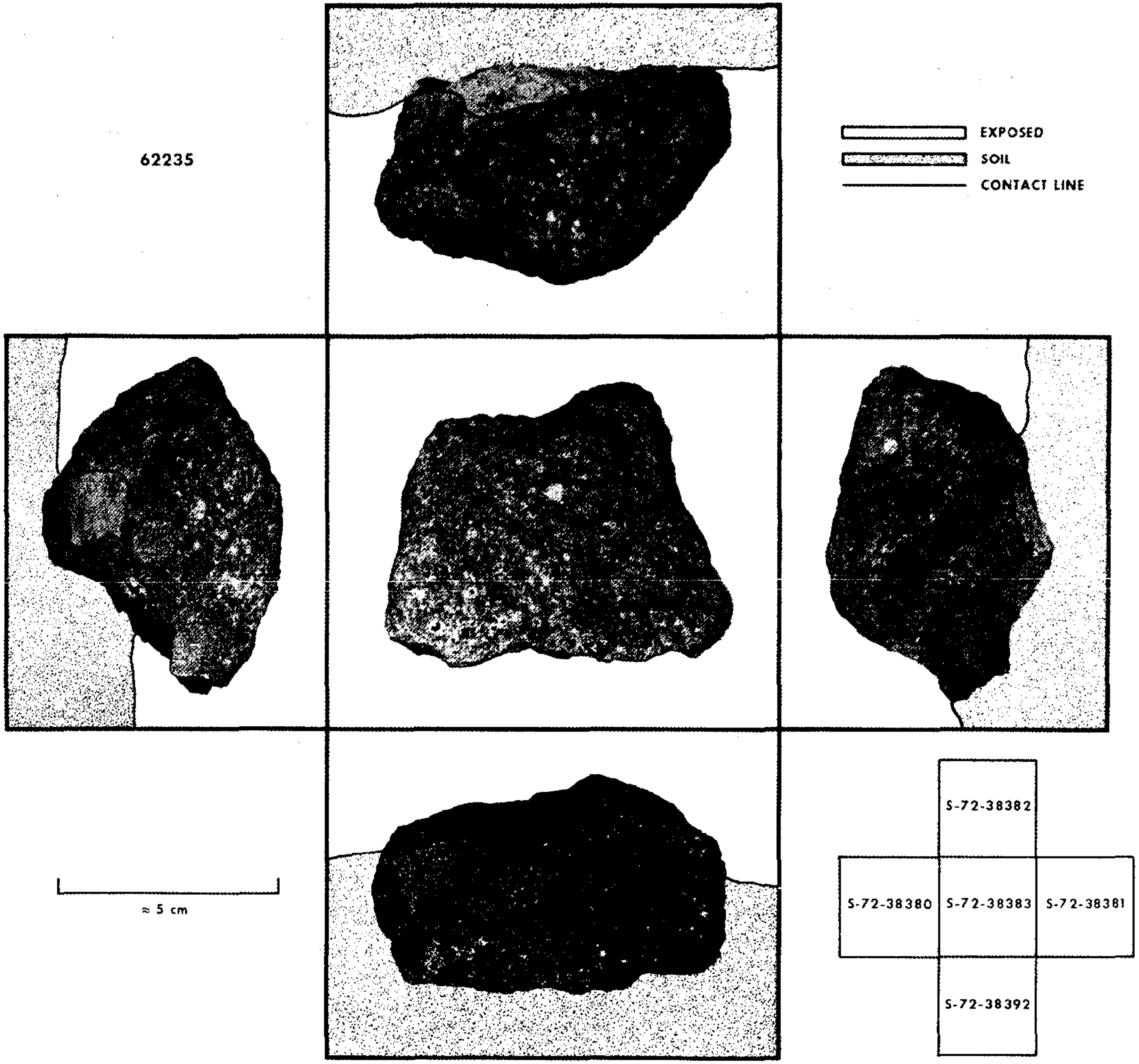

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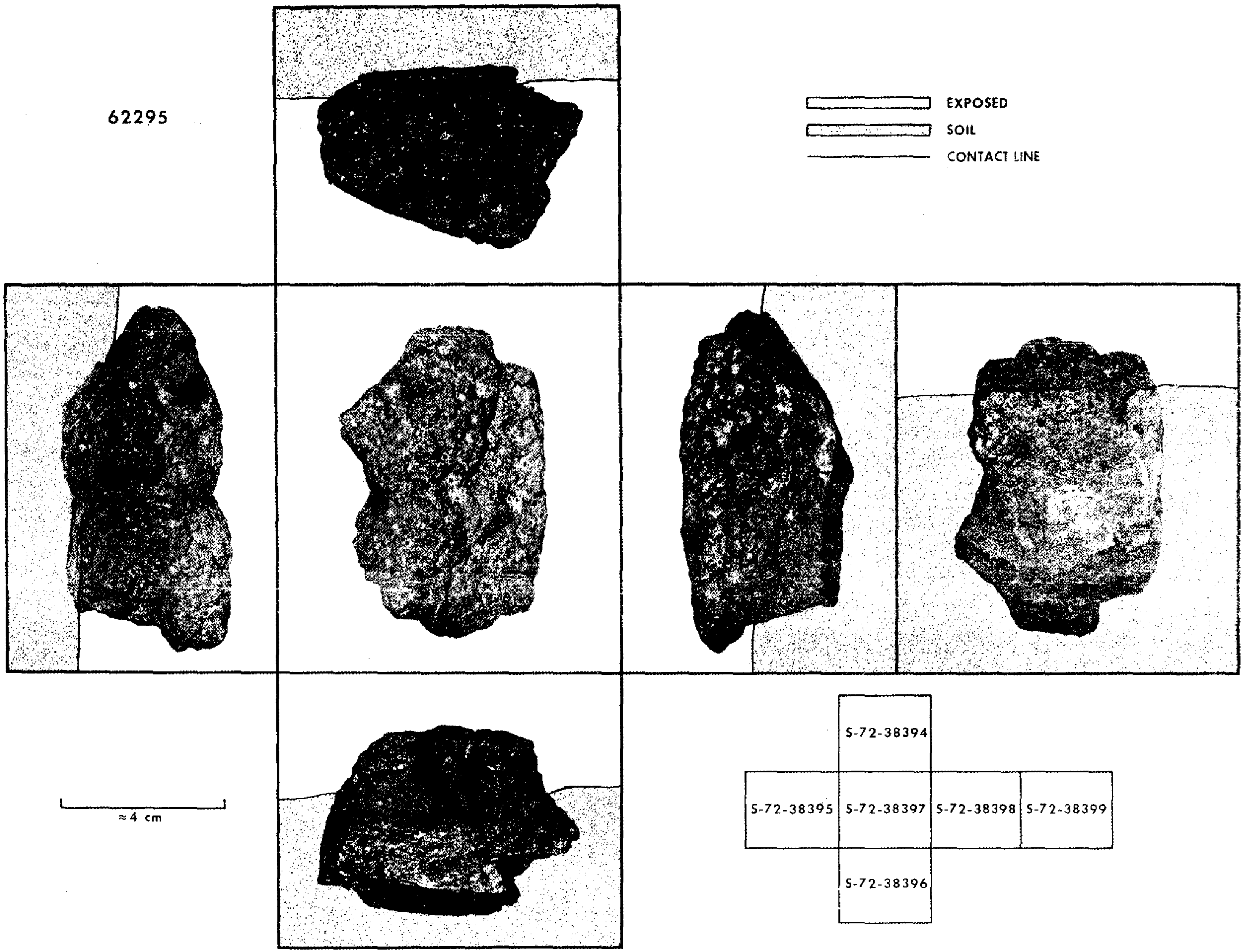

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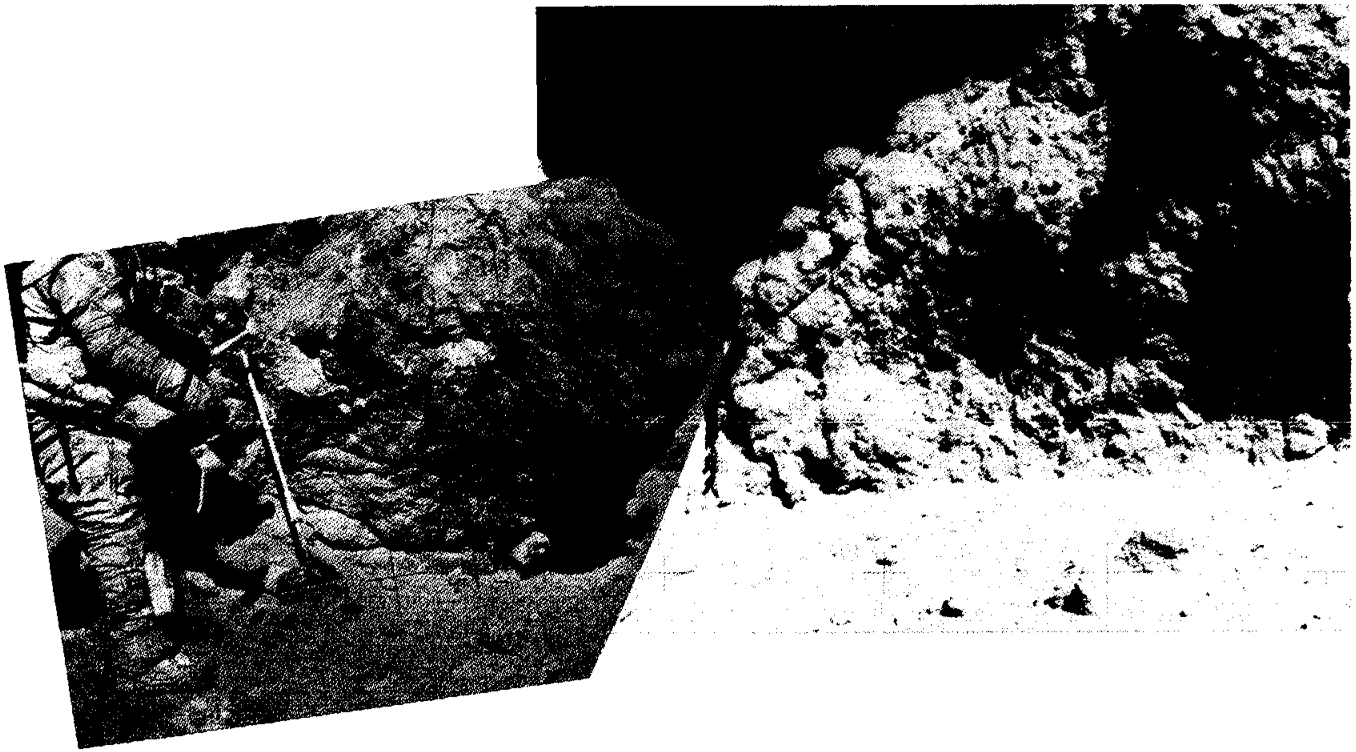

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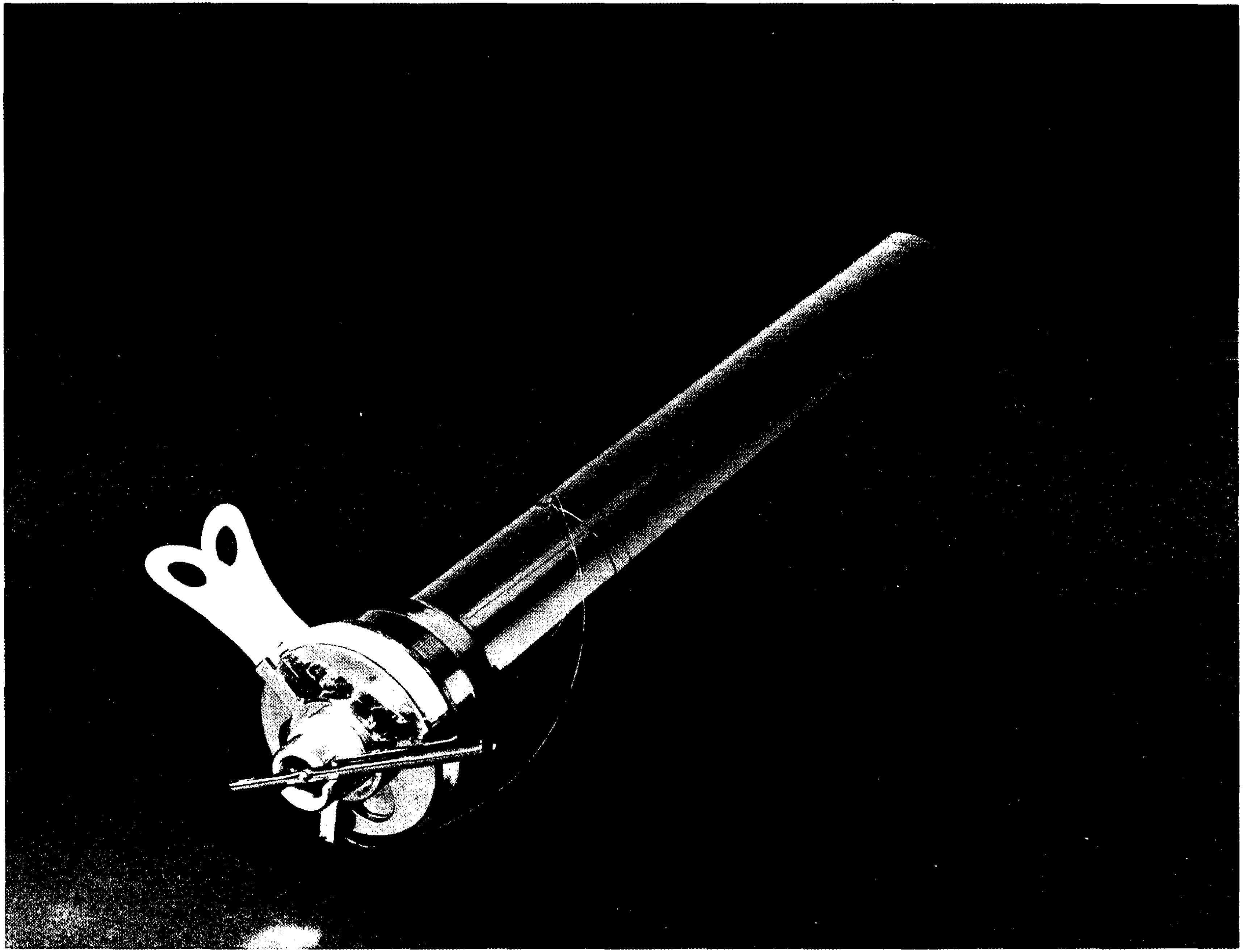

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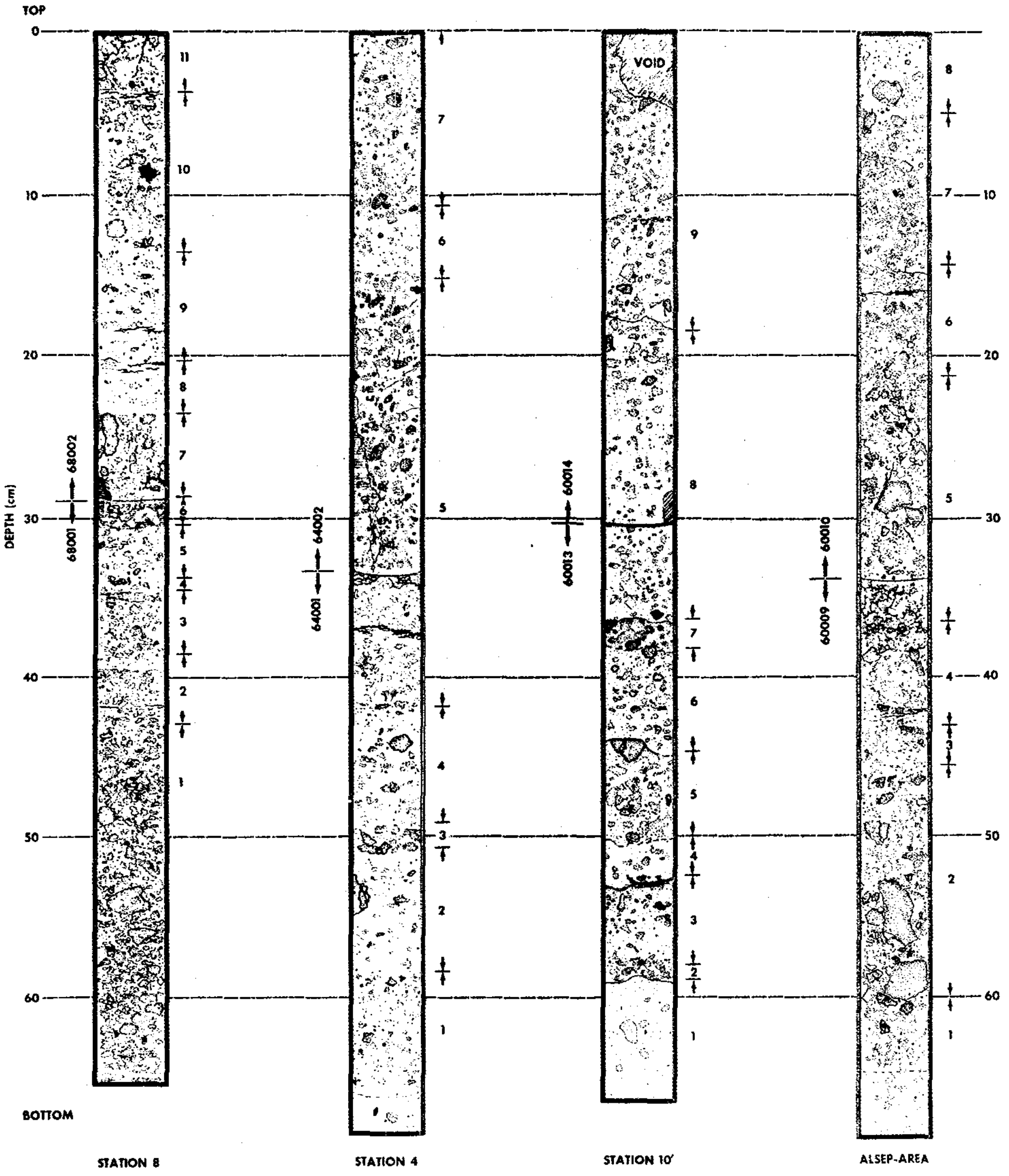
NASA
S-72-43794

X-RADIOGRAPHS
APOLLO 16 DRIVE TUBES



NASA S-72-44433

40

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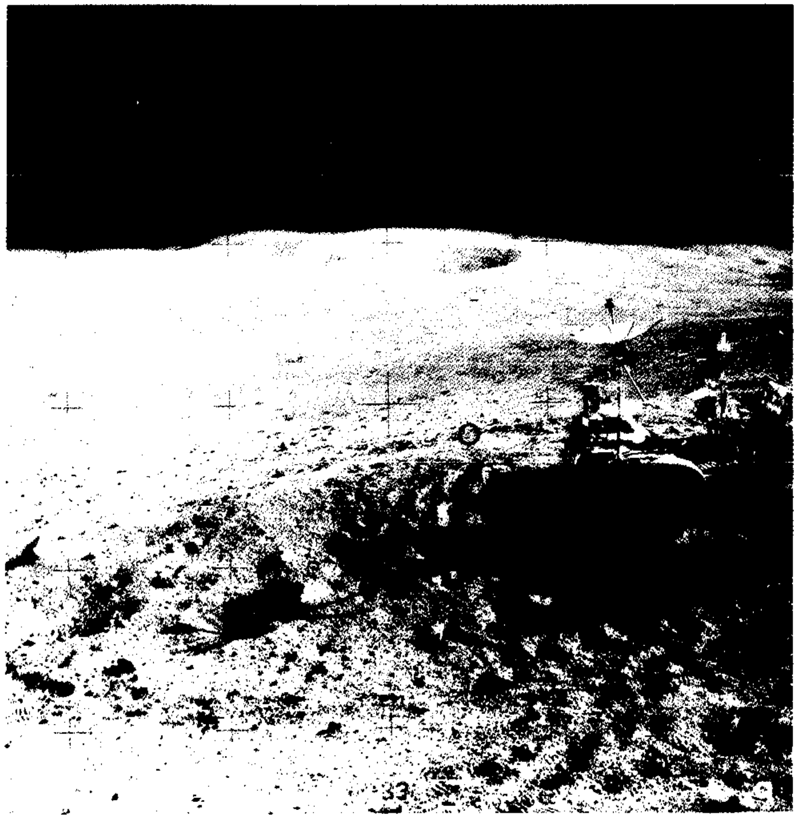

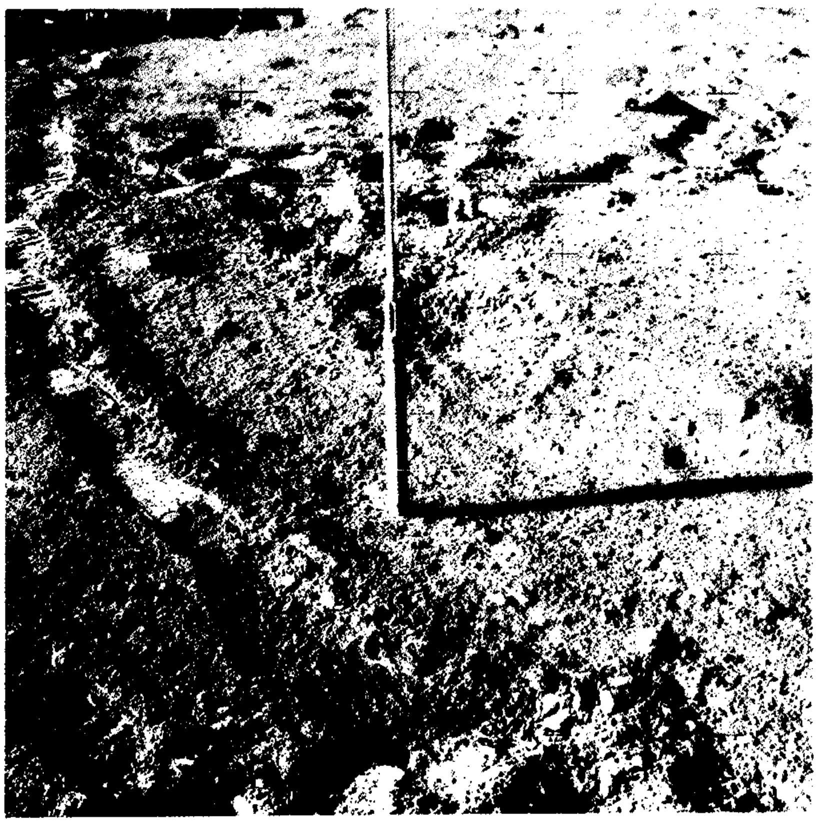

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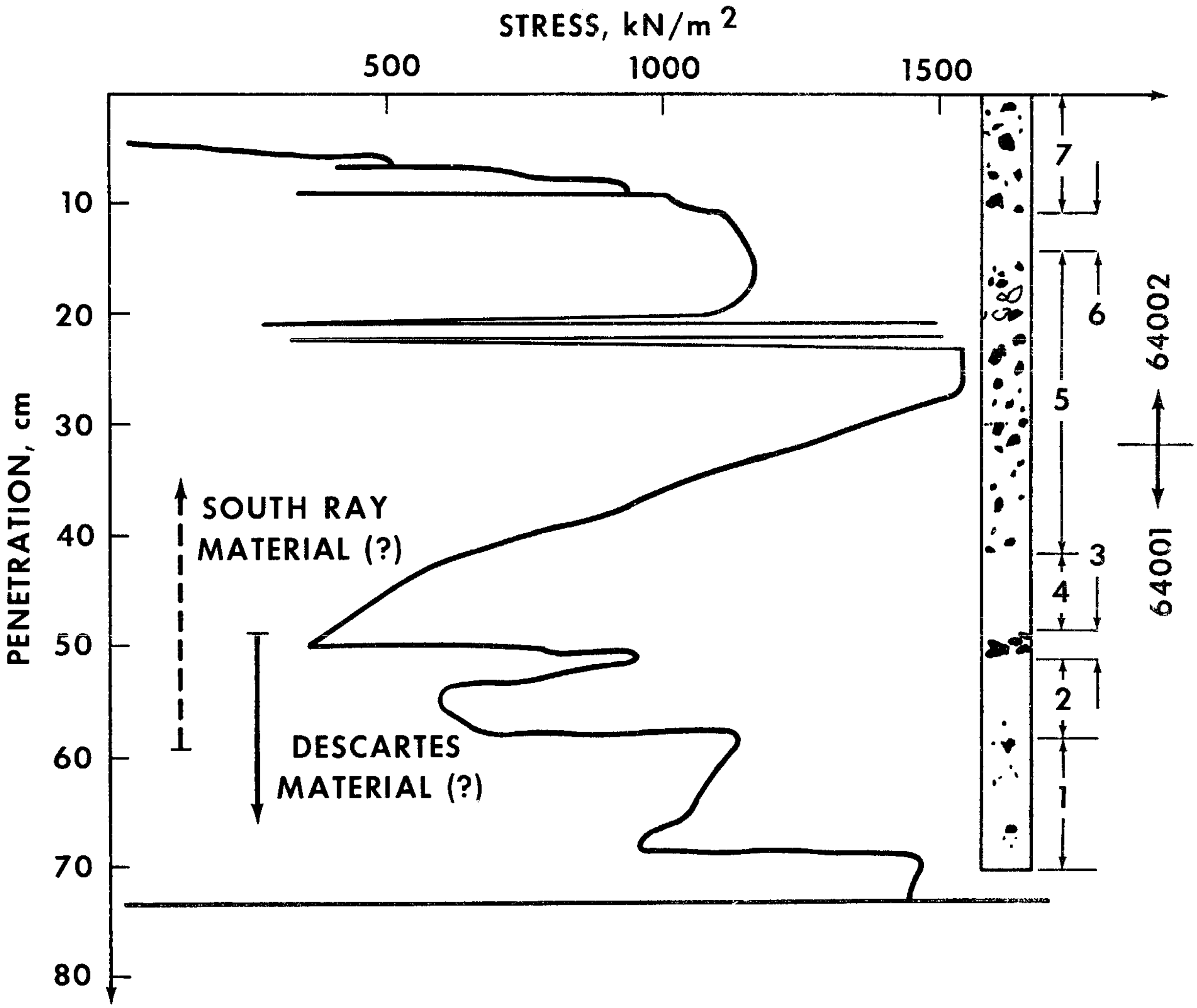

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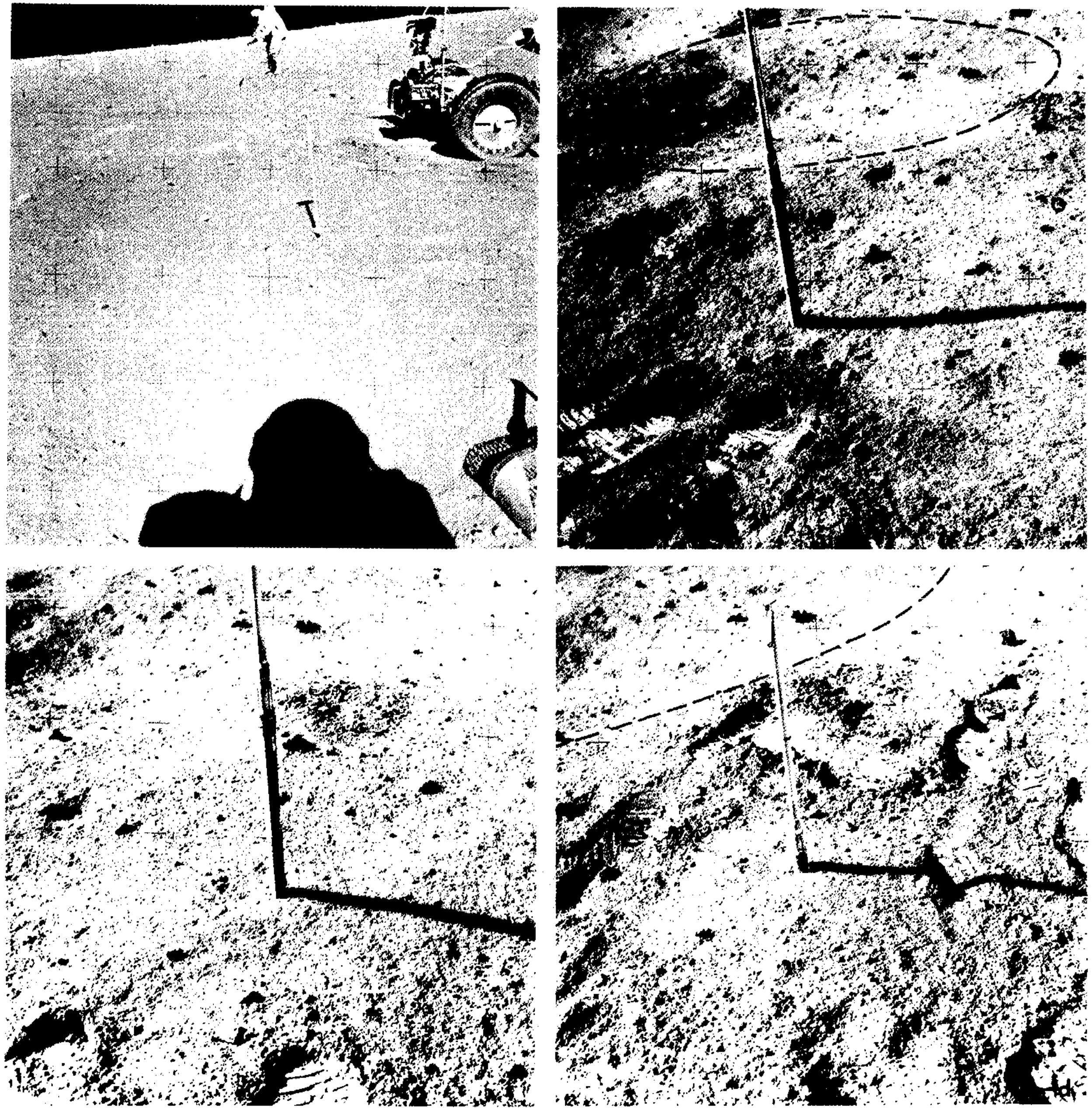

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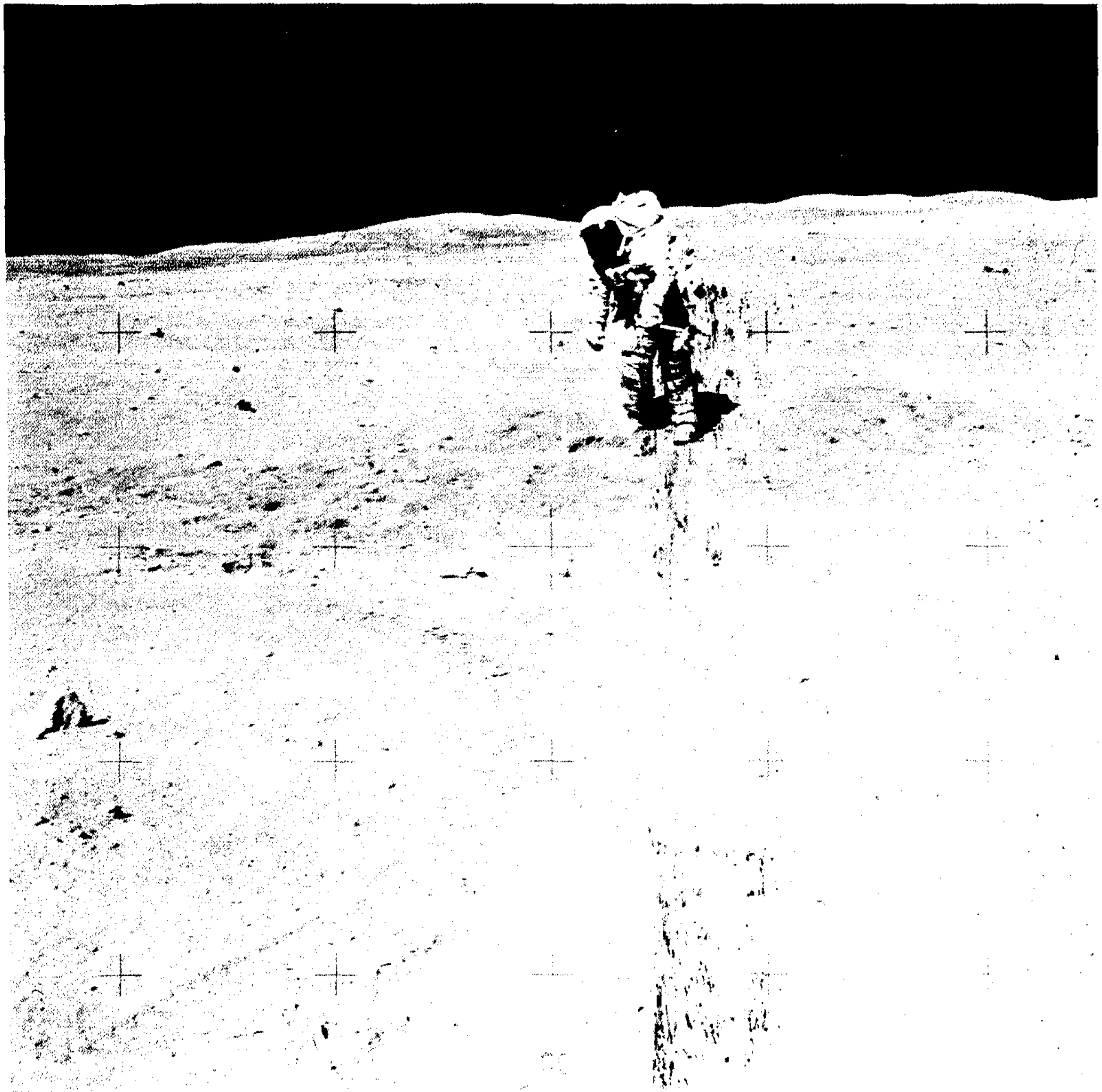

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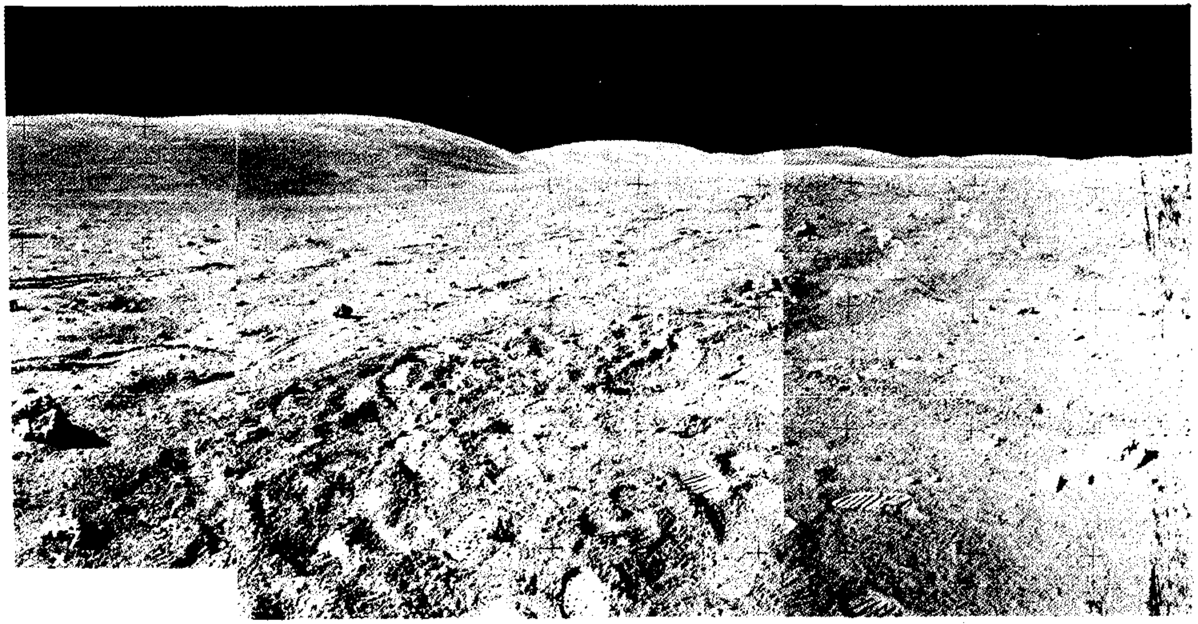
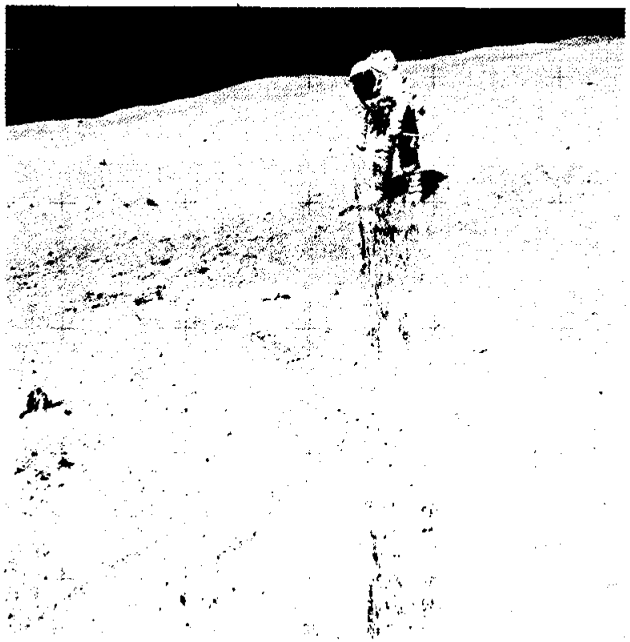
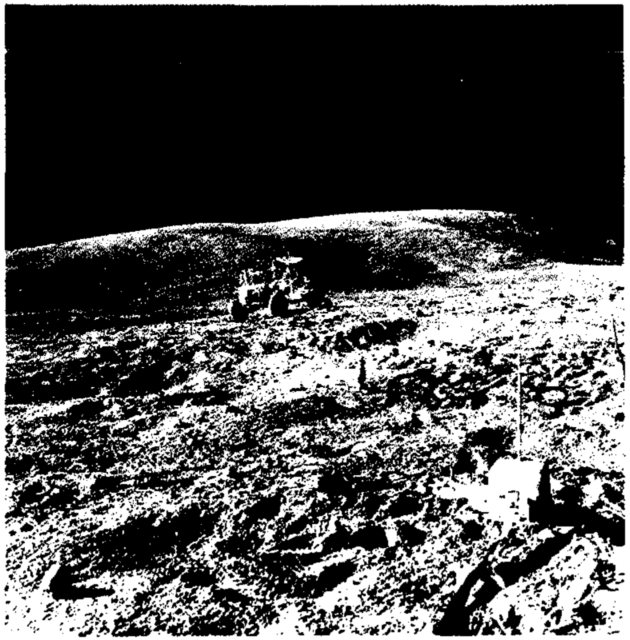
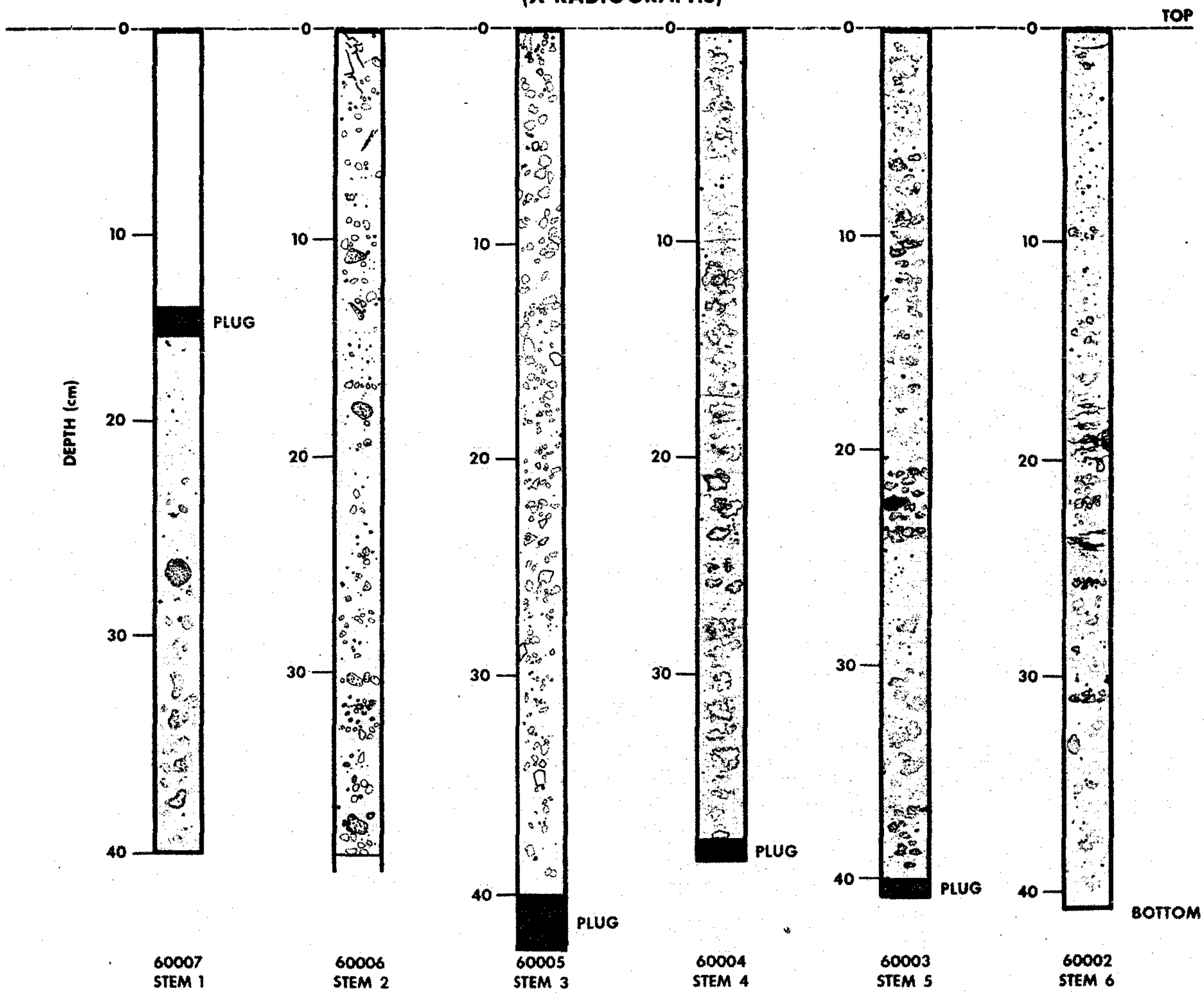






APOLLO 16 DEEP DRILL CORES
(X-RADIOGRAPHS)



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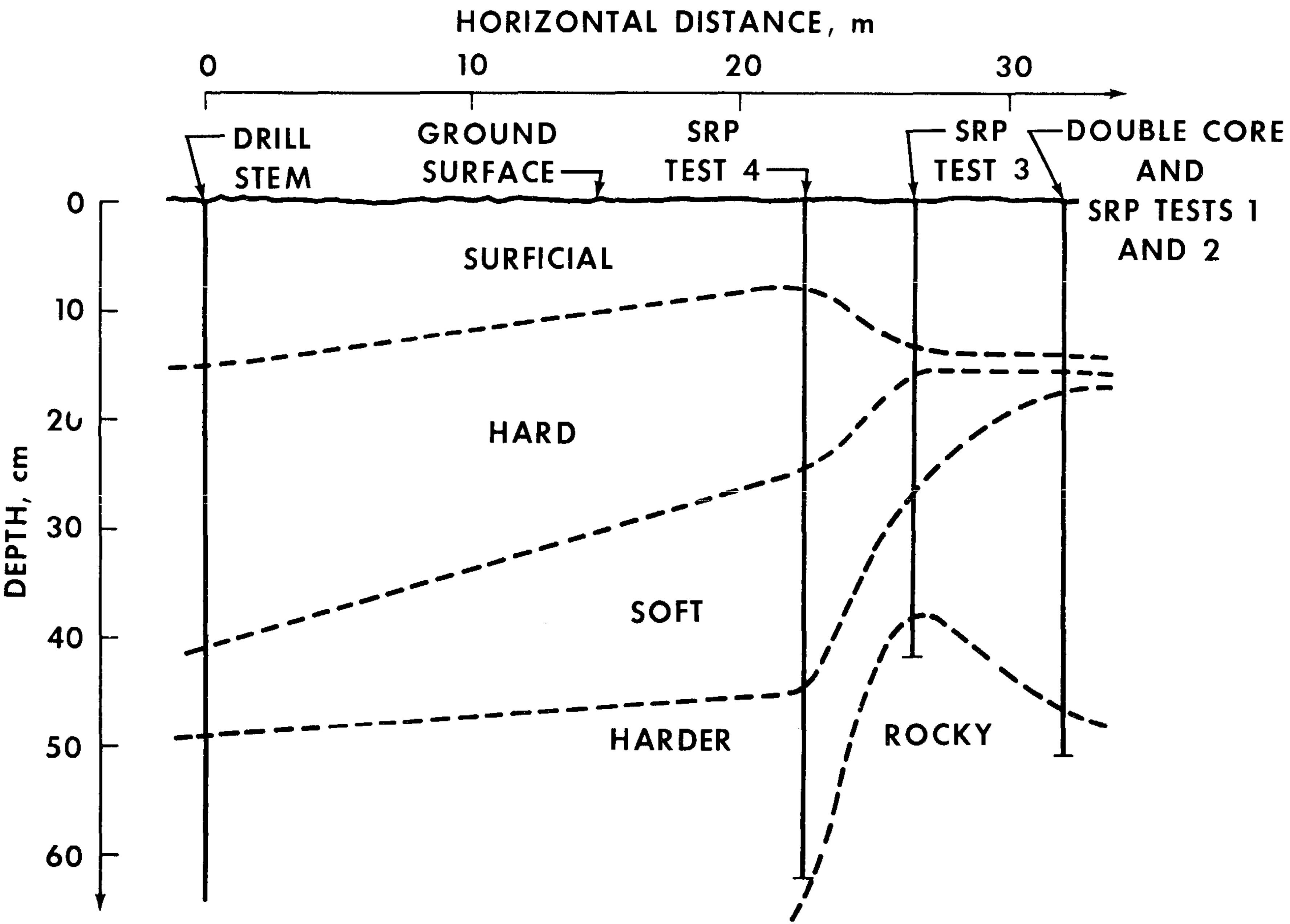

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