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Preliminary geologic analysis of the Apollo 17 site

by

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PRELIMINARY GEOLOGIC ANALYSIS OF THE APOLLO 17 SITE

by

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This manuscript is the Apollo Lunar Geology Investigation Team (S-059) report as submitted for the Apollo 17 Preliminary Science Report. It has not been edited by Lyndon B. Johnson Space Center personnel for conformity to NASA Special Paper standards. Citations should be to the NASA Special Paper now in preparation. Scientific questions should be referred to W. R. Muehlberger or E. W. Wolfe.
ERRATA

p. 12 - Figure 1. For Mare Serentatis, read Mare Serenitatis.

p. 18 - Figure 3. First sentence of caption should read: Index map of traverse area.

p. 27, 28 - Table 2 - Field stratigraphic sequence in the Taurus-Littrow area should precede Table 3 - Field and laboratory classification of samples.

p. 35, line 15. For are, read is.

p. 69 - Figure 28. For 7-3, 7-4, and 7-5, read 30, 31, and 32.

p. 107 - Figure 47. Add to caption:

open squares - vesicular porphyritic coarse-grained basalts;
closed squares - vesicular coarse-grained basalts;
open circles - vesicular fine-grained basalts;
closed circles - dense aphanitic basalts;
triangles - vesicular aphanitic basalts;
x - number of sampled large boulders;
y - number of sampled loose rocks larger than 5 cm.;
z - number of sampled 1-5 cm fragments.

Change in figure: At station 8, frequency of sampled vesicular aphanitic basalts (triangle) should read 0, 0, 1.

p. 112, line 6. For North Massif, read South Massif.
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SUMMARY OF RESULTS

Apollo 17 landed on the flat floor of a deep, narrow valley that embays the mountainous highlands at the eastern rim of the Serenitatis basin. Serenitatis is one of the major multi-ringed basins on the near side of the moon and the site of a pronounced mascon. The Taurus-Littrow valley, which is radial to the Serenitatis basin, is interpreted as a deep graben formed by structural adjustment of lunar crustal material to the Serenitatis impact.

During their stay on the lunar surface, the astronauts traversed a total of about 30 km, collected nearly 120 kg of rocks and soil, and took more than 2,200 photographs. Their traverse, sampling, direct observations, and photographs span the full width of the Taurus-Littrow valley.

The highlands surrounding the valley can be divided on the basis of morphology into 1) high smooth massifs, 2) smaller, closely spaced domical hills referred to as Sculptured Hills, and 3) materials of low hills adjacent to the massifs and Sculptured Hills. Massifs north and south of the valley were sampled by means of boulders that rolled down their slopes. These boulders are composed of complex breccias that are generally similar to those returned on Apollos 15 and 16.

Materials of the valley fill were sampled at many stations. Ejecta around many craters on the valley floor consist of basalt, showing that the graben was partially filled by lava flows. A relatively thick layer of unconsolidated material overlies the subfloor basalt; this debris consists largely of finely comminuted material typical of the lunar regolith.
The material at the surface over much of the Taurus-Littrow region has a very low albedo and was believed to be a thin young mantle, possibly pyroclastic, that covered the valley floor and parts of the adjacent highlands. No clear evidence of the existence of such a mantle as a discrete layered unit has yet been found, but it may be mixed in with the more typical debris of the lunar regolith.

An unusual bright deposit extends across the valley floor from the foot of the South Massif. It consists of breccias similar to those of the massif and is interpreted as a landslide generated on the massif slopes.

South Massif materials were collected from three breccia boulders that are thought to have rolled down from a blue-gray unit overlying tan material near the top of the massif. The first boulder is a unique foliated layered breccia, the only one of its type seen by the astronauts. Four samples were collected from it. All are composed of variable, but high proportions of subangular to subround, dark gray, fine-grained lithic clasts in a friable to moderately coherent medium to light-gray or light-gray matrix. A small percentage of white clasts occurs both in the matrices and in the dark-gray clasts. The dark-gray clasts have a seriate distribution, and range in size from several millimeters to about 0.1 mm. All of the samples contain light-gray clasts with thin dark-gray selvages. One sample contains a 4 cm gray and white banded fragment partly enclosed in a dark selavage, and another has a crude foliation formed by alternations of pulverized gray and white material.
Boulder 2 from the South Massif is a fractured rock from which 5 samples of vuggy, annealed, greenish-gray breccia were collected. These consist of a small percentage of mineral and lithic clasts in a fine-grained, sugary matrix. Lithic clasts, rarely larger than 10 mm are mainly fine-grained hornfelses, but a few are composed of either cataclastically deformed plagioclase-rich rocks or plagioclase and yellow-green mineral aggregates. Mineral clasts are, for the most part, angular plagioclase fragments and a yellow-green mineral.

A breccia clast and its host were sampled from boulder 3 at the South Massif. The clast is light greenish-gray breccia with abundant mineral clasts and sparse lithic clasts in a moderately coherent, fine-grained matrix that is probably annealed. The matrix of the clast consists largely of angular fragments of a yellow-green mafic silicate embedded in a very fine-grained, sugary groundmass. The host material is a blue-gray breccia that contains about 10 percent lithic and mineral clasts in a tough, finely crystalline, deep bluish-gray matrix with scattered vesicles. Lithic clasts in the sample of host material include cataclastic and sugary white rocks with hornfels texture; mineral clasts are dominantly angular plagioclase and a subordinate yellow-green mineral.

Materials of the North Massif were sampled primarily from a 6 x 10 x 18 m fragmented boulder at station 6 and a 3 m boulder at station 7. The station 6 boulder, which broke into 5 pieces, is at the lower end of a boulder track whose apparent beginning is in an area of light boulders about 1/3 of the way up the massif. Dark boulders are abundant higher on the mountain, and light boulders occur again in
its upper part. Thus there may be a layer or lenses of darker rock high on the mountain, with lighter rocks both above and below. The source of the station 7 boulder on the North Massif is unknown, but it contains rock types like those of the station 6 boulders.

Four of the five large pieces of the station 6 boulder were sampled. The boulder consists of two major breccia types, greenish-gray and blue-gray. They are in contact in a 1/2 m-wide zone that appears to be an area of mixing between the two rock types.

The greenish-gray breccia is tough and annealed, with sparse lithic and mineral clasts set in a vuggy, fine-grained, sugary matrix. Lithic clasts, all smaller than 1 cm in the samples, include granoblastic intergrowths of plagioclase and yellow-green mineral. Mineral clasts are mostly plagioclase and yellow-green mineral that grade into the matrix.

Samples of blue-gray breccia from the station 6 boulder contain a high proportion (40 to 60 percent) of blue-gray breccia fragments in a vuggy greenish-gray matrix. The matrix is a tough, finely crystalline material composed principally of angular mineral debris and small fragments of blue-gray breccia that grade upward to clast size. The breccia clasts are dominantly finely crystalline breccias that themselves contain sparse finely recrystallized white clasts.

Large friable inclusions ranging from 1 cm to 1 m across are in sharp irregular contact with the blue-gray breccia. Samples of one of these are very light gray cataclasites composed of angular mineral debris that includes mafic silicate minerals and plagioclase.
The station 6 boulder is intricately sheared. Comparison with the oriented returned samples shows that movement along some of the shear planes has deformed clasts.

Major events recorded in the station 6 boulder are formation of the light cataclasite, its incorporation in the blue-gray breccia, and subsequent enclosure of the blue-gray breccia in the greenish-gray breccia.

The station 7 boulder is similar to the station 6 boulder in that the two major rock types, greenish-gray breccia and blue-gray breccia, are present. A large white clast (1.5 x 0.5 m), similar to those in the station 6 boulder, is penetrated by narrow blue-gray breccia dikes. The blue-gray breccia is in sharp irregular contact with the younger greenish-gray breccia. Like the station 6 boulder, the station 7 boulder is intricately fractured. At least two fracture sets are confined to the large white cataclasite inclusion and the blue-gray breccia.

Smaller chips collected at stations 6 and 7 include the major rock types of the two large boulders, as well as a few other breccia types, one coarse-grained gabbroic rock, and one light-colored, fine-grained hornfels. A few basalt fragments, that are probable ejecta from the valley floor, were also collected.

South Massif boulders most probably came from the highest part of the massif, and the stations 6 and 7 boulders probably came from within the lower 1/3 of the North Massif. Hence two different stratigraphic intervals may have been sampled. On the other hand, the lithologies of the South Massif boulders closely resembled those of the North Massif boulders in many respects. The similarity seen in early examination
suggests the possibility that only one stratigraphic unit is represented. Whichever the case, the massifs are comprised of intensely shocked breccias reasonably interpreted as ejecta from ancient large impact basins.

Fine-grained regolith is nearly ubiquitous on the accessible part of the Sculptured Hills, and no boulders that clearly represent Sculptured Hills bedrock were found. Small fragments of basalt, probably ejected from the valley floor, and regolith breccia dominate the samples, which consist mainly of chips collected with soils or by raking. Samples of friable feldspathic breccia from the wall of a 15 m crater and of a glass-covered gabbroic boulder that is almost certainly exotic were also collected. The greater dissection, lower slopes, lack of large boulders and limited sample suite suggest that the Sculptured Hills may be underlain by less coherent breccias than the massifs.

Subsequent to the formation of the Taurus-Littrow graben by the Serenitatis impact, the valley floor was inundated and leveled by basaltic lava flows. Geophysical evidence (Talwani and others, in press; Kovach and others, in press) suggests that the prism of basalt filling the valley is more than a kilometer thick. The uppermost 130 m was sampled in the ejecta of craters on the valley floor.

In general the subfloor basalt blocks seen at the landing site were not visibly shocked or even intensely fractured. The most notable exception was an intensely fractured 5 m boulder on the rim of Shorty crater. The predominant types described on the lunar surface were coarse-grained, vesicular, relatively light-colored basalts composed of clinopyroxene, ilmenite, and 30-40 percent plagioclase. Vesicles up to about 1 cm diameter typically comprised 10-15 percent of these rocks. In some
rocks, planar partings paralleled bands expressed as differing concentra-
tions of vesicles. Fine-grained and less vesicular varieties of basalt were recognized locally. Almost all returned samples of basalt can be divided into 5 classes: 1) vesicular, porphyritic, coarse-grained basalts; 2) vesicular, coarse-grained basalts; 3) vesicular, fine-grained basalts; 4) dense aphanitic basalts; and 5) vesicular aphanitic basalts.

Radiometric dates (Fourth Lunar Science Conference) suggest that this episode of basalt extrusion was completed about 3.8 b.y. ago. Subsequently, but prior to final accumulation of the Serenitatis mare fill, broad arching east of the Serenitatis basin tilted the subfloor lavas to the east forming the present 1° eastward tilt of the valley floor.

The subfloor basalt is overlain by fragmental debris on the order of 15 m thick. For the most part this is impact-generated regolith similar to that developed on mare basalts elsewhere on the moon. The central cluster ejecta, the light mantle, and the ejecta of Shorty and Van Serg craters are discrete deposits recognized within the regolith.

The lower part of the regolith is thought to be represented in the abundant dark friable breccias in the ejecta of the 90 m Van Serg crater. The breccias contain scattered light-colored lithic clasts as well as abundant dark glass, mineral and lithic fragments derived from basalts, and variable percentages of orange glass spheres and fragments. They are interpreted to be regolith breccias indurated and excavated from the deeper, older part of the regolith by the Van Serg impact. Basalt bedrock is not known to have been excavated by Van Serg.

The central cluster ejecta is derived from the cluster of craters south and east of the LM. It is distinguished by the abundance of
blocks in the unit, and the unit is too young for the blocks to have been reduced much in size by later impacts. All sampled blocks in the central cluster ejecta are subfloor basalt.

The young pyroclastic dark mantle that was anticipated before the mission was not recognized in the traverse area as a discrete surface layer. Strong photogeologic evidence for the existence of such a mantle on the valley floor and in parts of the highlands still exists. Albedo measurements show that abnormal surface darkening, consistent with the concept of introduction of exotic dark material--the "dark mantle", increases to the east and south in the Taurus-Littrow area. If the "dark mantle" is younger than central cluster ejecta, it must be so thin in the landing site that it is thoroughly intermixed with the younger part of the regolith. Such mixed "dark mantle" may be represented by the dark glass spheres that abound in the soils of the valley floor. An alternative hypothesis is that the "dark mantle" may have accumulated shortly after the extrusion of the subfloor basalt. This is suggested by the 3.7 b.y. age for the orange glass spheres (Schaeffer, Fourth Lunar Science Conference) which are associated with black glass spheres on the rim of Shorty. In this case the deposit would be intimately mixed with subsequently formed regolith.

The light mantle is an unusual deposit of high-albedo material with finger-like projections that extend 6 km across dark plains from the South Massif. Rock fragments collected from the light mantle are similar in lithology to the breccias of the South Massif. This supports the hypothesis that the light mantle is an avalanche deposit formed from
loose materials on the face of the South Massif. A cluster of secondary craters on the top of the South Massif may record the impact event that initiated the avalanche.

Size-frequency distribution and morphologies of craters on the light mantle suggest that its age is about that of Tycho, on the order of 100 m.y.

Shorty is a 110 m impact crater penetrating the light mantle. Unusual orange soil occurs in two places on the Shorty rim and in the ejecta of a small crater on the inner wall. A trench on the crater rim exposed an 80 cm wide zone of orange soil, now known to consist largely of orange glass spheres. A double drive tube showed that the orange soil overlies black fine-grained material, now known to consist of tiny, opaque, black spheres, at a depth of about 25 cm.

The old age for the orange glass material implies solidification during or shortly after the period of subfloor basalt volcanism. Hence the black and orange glass material, whatever its origin, must have been present in the Shorty target area; it was excavated or mobilized by the Shorty impact.

Fine-grained soil, darker than the underlying unconsolidated debris was recognized at the surface at Shorty, Van Serg, on the light mantle, and on the massif talus. It is thin (e.g., 1/2 cm at Shorty; about 7 cm on the flank of Van Serg). It probably represents the regolith that has formed on these young ejecta or talus surfaces.

Relatively young structural deformation in the landing area is recorded by the Lee-Lincoln scarp and by small fresh grabens that trend northwest across the light mantle. The sharp knickpoint at the base of the
North Massif may indicate that some fairly recent uplift of the massif has kept the talus slope active.
INTRODUCTION

Pre-mission geologic setting

The Taurus-Littrow region lies on the southeast rim of the Serenitatis basin (fig. 1) in an area of mountains, low hills, and plains. Serenitatis is one of the major multi-ringed basins on the near side of the moon and the site of a pronounced mascon.

The landing spot (lat. 20°10'N; long. 30°46'E) is located on the gently inclined floor of a narrow, flat-floored valley. The walls of the valley rise 2,000 m above the floor. The valley is interpreted as a deep graben formed at the time of the Serenitatis impact.

The highlands surrounding the valley can be divided on the basis of morphology into 1) high smooth massifs, 2) smaller, closely spaced domical hills referred to as Sculptured Hills, and 3) materials of low hills adjacent to the massifs and Sculptured Hills (Scott and others, 1972; Wolfe and others, 1972). They were interpreted in pre-mission studies as deposits of ejecta derived from surrounding basins with major uplift occurring in the Serenitatis event. A possible volcanic origin was also considered but thought to be less likely (Scott and others, 1972). The reason for the morphologic difference between the massifs and the Sculptured Hills was not clear; possibly, the difference reflects different responses to the Serenitatis event and to later tectonic forces. The low hills unit was considered to be downfaulted and partly buried blocks of massif or Sculptured Hills material.

The nearly level valley floor was apparently formed by deep filling of the graben by fluid plains-forming material. The material at the surface of much of the Taurus-Littrow region has a very low
Figure 1. Index map showing Apollo 17 landing site and major geographic features of the Taurus-Littrow region. (AS17-M-447).
albedo and was believed to be a thin mantle, possibly pyroclastic, which covered the valley floor and parts of the adjacent highlands. Overlap relations with the typical mare material of Mare Serenitatis and an apparent deficiency of small craters indicated that the dark mantle might be very young in the lunar geologic time scale (Scott and Pohn, 1972; Scott and others, 1972). Although quantitatively a minor deposit, its significance lay in its apparent young age and presumed volcanic origin. No volcanic rocks younger than 3.1 b.y. had been returned prior to the Apollo 17 mission. Similar dark mantling deposits occur in relatively small tracts on the southwest rim of the Serenitatis basin, at the outer edge of several other circular maria (Wilhelms and McCauley, 1971), and in other isolated patches on the lunar frontside.

A contrasting unit of bright mantling material occurs in a limited area of the valley. This unusual deposit extends from the south wall of the valley northeastward in finger-like extensions across the dark valley floor. The material was interpreted as a landslide from the steep slopes (Scott and others, 1972).

Geologic objectives and general results

The geologic objectives of the Apollo 17 mission may be divided into orbital and lunar surface data collection. The orbital objectives in the Taurus-Littrow area were to add to our knowledge of the regional geology of the site through direct visual observation and photographs, and to assist in locating the LM on the surface. Additional aid in traverse location by panoramic camera photographs of LRV tracks and astronaut-disturbed areas was anticipated. The principal objectives of
the ground crew were to deploy the Apollo lunar surface experiments (ALSEP) and surface electrical properties (SEP) packages, to record gravity data on the traverse gravimeter, to describe the kinds and proportions of rocks in the various map units, and to collect samples of them; to observe, describe, and collect samples of regolith and dark mantle that were thought to cover most of these units; to look for outcrop, and if found, to describe, photograph, and sample it; to describe structures, including lineaments, layers, faults, in various units; and to observe and describe, where possible, the attitudes of and contacts between the major geologic units.

In detail, ground objectives were planned around groups of stations with the potential of yielding varied geologic information (fig. 2). The prime massif and Sculptured Hills units sampling areas were located in the station 2, 6-7, and 8 areas, as well as between stations 2 and 4 on the assumption that the light mantle unit was composed of materials derived from South Massif. This broad station coverage was designed to yield maximum information about the lateral continuity of massif lithologies. The principal sampling areas for valley materials were planned at stations 1, 4, 5, 9, and 10b. This coverage was designed to allow detailed stratigraphic studies of both the dark mantle and the subfloor unit. Craters that were to be visited on the valley floor potentially offered samples of subfloor material from depths as great as 150 m. Regolith was, of course, expected throughout the traversed regions, but an unusually small thickness was anticipated because of the low crater density on the dark and light mantle units.
Figure 2. Preplanned traverses and geologic objectives.
Massifs north and south of the valley were sampled by means of boulders that rolled down the faces of the slopes. These boulders are composed of complex breccias; their general similarity to breccias returned on Apollos 15 and 16 indicates that they are very ancient materials as anticipated. Their relation to the circular basins on the lunar nearside is discussed below. Astronaut observations and photographic evidence suggest that the materials of the massifs are layered, and that at least two separate layers were sampled.

Materials of the valley fill were sampled at numerous stations around the LM and en route to and from the massifs. Ejecta around many craters on the valley floor consists of basalt, confirming that volcanic materials underlie the Taurus-Littrow valley floor. A relatively deep layer of unconsolidated material overlies the subfloor basalt; this debris consists of finely comminuted material typical of the lunar regolith. It may also contain the dark mantle mapped in pre-mission studies. No clear evidence for the existence of a dark mantle as a discrete layered unit has yet been found, but it may well be mixed in with the more typical debris of the lunar regolith.

The bright deposit extending across the valley floor from the foot of South Massif consists of breccias similar to those of the massif; the interpreted origin of this deposit as a landslide thus appears to be confirmed.
Traverse data

The Apollo 17 crew traversed approximately 2 km in EVA 1, 18 km in EVA 2, and 10 km in EVA 3 for a total of about 30 km. Nearly 120 kg of rocks and soil were collected and more than 2,200 photographs were taken on the lunar surface. Figure 3 is an index map of the traverse area. Figure 4 shows the traverse path and stations in detail, and Table 1 lists map coordinates for traverse points. Appendix B contains panoramic views and detailed planimetric maps for the traverse stations.
Figure 3. Index of the traverse area. Lettered boxes (A through F) show boundaries of detailed traverse maps (Figs. 4A through 4F). (Apollo 17 panoramic camera photograph 2309).
Figure 4(A-F). Detailed maps of traverse path and stations. See figure 3 for locations of individual sheets. (Apollo 17 panoramic camera photograph 2309).
Figure 4. Continued.
Table 1. Map coordinates of traverse points. Coordinate system is that used in the pre-mission data package.

<table>
<thead>
<tr>
<th>Station</th>
<th>X</th>
<th>Y</th>
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<td>83.4</td>
<td>DN.3</td>
</tr>
<tr>
<td>SEP</td>
<td>84.1</td>
<td>DN.4</td>
</tr>
<tr>
<td>ALSEP</td>
<td>82.5</td>
<td>DN.5</td>
</tr>
<tr>
<td>1</td>
<td>85.5</td>
<td>DH.1</td>
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<td>EP-7</td>
<td>85.3</td>
<td>DK.5</td>
</tr>
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<td>LRV-1</td>
<td>71.3</td>
<td>DK.7</td>
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<td>DM.1</td>
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<td>CY.4</td>
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<td>2a (LRV-4)</td>
<td>51.7</td>
<td>DA.1</td>
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<tr>
<td>3</td>
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<tr>
<td>LRV-12</td>
<td>88.8</td>
<td>DF.3</td>
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</table>

LRV-1, LRV-2, etc., refer to stations where samples were collected from the LRV with a long-handled sampling tool. Station 2a (LRV-4) was an unplanned station at which the crew dismounted from the LRV. EP-7 was the only explosive package that was not located at a sampling station.
STRATIGRAPHY AND PETROGRAPHY

Introduction

The studied and sampled geologic units are described in approximate stratigraphic order. However, some parts of the sequence, such as the relative ages of massifs and Sculptured Hills units, are not well known. Similarly, regolith units and surficial deposits on the highlands and on the valley floor overlap in time. In neither case is rigorous chronology of development implied by the order of discussion.

Table 2 summarizes the stratigraphy as seen in the field by the crew. Names of geologic units are those currently in use by the crew. Table 3 relates the field terminology to sampling areas, representative samples, and laboratory terminology.
<table>
<thead>
<tr>
<th>Geologic entity</th>
<th>Geologic unit</th>
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<th>Station</th>
<th>Type sample</th>
<th>Laboratory designation</th>
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<tr>
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<td>Van Serg ejecta</td>
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<td>Shorty rim core</td>
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<td>73240, 73140</td>
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<td>Coarse grained basalt</td>
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<td>Light gray breccia</td>
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<td>North Massif</td>
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<td>Exotics on Sculptured Hills and North Massif</td>
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<td>Cataclasite and hornfels</td>
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<td>LUNAR EVENT</td>
<td>TAURUS - LITROW AREA</td>
<td>UPLANDS</td>
<td>VAN VUG AREA</td>
<td>SHORTY AREA</td>
<td>LIGHT NAPLE AREA</td>
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<td>0.025 B.Y.</td>
<td>CONE CRATER</td>
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<td>3.7 B.Y.</td>
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<td>DARK Floor Material</td>
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</tbody>
</table>

Table slightly modified from H. H. Schmitt (4th Lunar Science Conference).

Dark floor material includes all regolith units of the valley floor except for the light mantle.

Units shown in italics are extrapolated from beyond the immediate observation area.

Internal stratigraphic sequence is not implied among bracketed units.
South Massif

Introduction

South Massif materials were collected from just above the break in slope at the base of South Massif at station 2. The astronauts described the massif as composed of light tan materials stratigraphically overlain by blue-gray materials (fig. 109, Appendix B). A concentration of boulders occurs at and near the break in slope at the foot of South Massif (fig. 5). Those with visible tracks on the massif slopes (fig. 6) were emplaced after the avalanche that formed the light mantle, and probably emplacement of all of the boulders postdates the light mantle. If they were a part of the avalanche itself, the boulders would be more uniformly distributed across the surface of the light mantle, rather than concentrated near the base of the massif.

Most of the boulders probably rolled from blocky areas that may be outcrops high on the massif (fig. 7); no apparent source for the boulders is visible on the lower two-thirds of the massif. These bouldery areas are mostly in the blue-gray unit. None of the three boulders sampled at station 2 have visible tracks on the massif slope. However, the boulders in the station 2 area are directly below a blocky area just above the contact (figs. 5, 6). The three boulders are about 50 m above the break in slope at the base of South Massif in the field of boulders strewn near the base (fig. 5).

Station 2, boulder 1

Boulder 1, the first boulder sampled at station 2, is a layered and foliated rock (fig. 8). It is the only one of this type that was seen by the astronauts, and no others have been identified with certainty in the
Figure 5. Part of South Massif showing area sampled at station 2. Boulders are numbered in order of sampling and text discussion. Bright-rimmed crater (20 m diameter) above and to left of sample area is identified on figure 6. Probable source of boulder track shown on figure 6 is boulder field centered on the skyline in this view (AS17-138-21072).
Figure 6. Boulder tracks on South Massif in the vicinity of station 2. (AS17-135-20672).
Figure 7. Boulder concentrations near top of South Massif from which most of the boulders at the base of South Massif may have rolled. Telephoto mosaic. (AS17-144-22051, 52, 54, 55, 57).
EXPLANATION

Contact between layered zones

5 Hackly, moderately coherent, poorly developed foliation planes
4 Hackly, friable, poorly foliated; similar to zone 5
3 Moderately coherent, discontinuous, fairly well-developed foliation planes
2 Moderately coherent, well-developed, continuous foliation planes
2a Friable zone
1 Finely spaced discontinuous foliation planes

Trace of foliation along bedding planes (Sα)
Trace of cleavage planes (Sβ)

Figure 8. Sketch map of boulder 1 at station 2. Insets show lunar orientation of samples. (AS17-137-20901; insets listed clockwise from upper right: S-73-17963, 17987, 17989, 17988.)
photographs. The boulder is about 2 m across by 1 m high above the ground surface. It has a well developed fillet about 30 cm high on its uphill side, and no fillet on its downhill side. It appears to be highly eroded, and has a hackly and knobby surface. The knobs range from less than a centimeter to 15 cm across, and were reported by the astronauts to be mostly fine-grained clasts eroded from a more friable fine-grained matrix. The astronauts also reported dark, elongate clasts parallel to the bedding planes ($S_a$ in figure 8); these are not discernible in the photographs.

Based on the degree to which the bedding foliation is developed, and on the erosion-produced characteristics, which are presumably related to the friability of the matrix, the boulder is divided into five crudely layered zones (fig. 8). A fairly well developed set of cleavage planes ($S_b$ in figure 8) that are roughly at right angles to the bedding planes are visible across the middle of the boulder, and a similar set with the same orientation occurs in sample 72255. These are probably shear planes.

The eroded nature of the boulder and well developed fillet on its uphill side suggest that it has been in its present position for a considerable period of time.

Four samples (72215, 72235, 72255, 72275) were taken from boulder 1 (fig. 8). All are breccias with light-gray matrices (called tan breccia by the crew). These rocks are composed of variable, but high proportions of subangular to subround, dark gray, fine-grained lithic clasts in a friable to moderately coherent medium to light-gray or light-gray matrix. Samples 72215 and 72255 have more coherent matrices than the other samples, and the clasts in these rocks show less tendency to stand out from the matrix on weathered surfaces. Sample 72215 is possibly itself a clast,
eroded from the friable matrix of the zone in which it occurred within the boulder. A small percentage of white clasts occurs both in the matrices and in the dark-gray clasts. The dark-gray clasts have a seriate distribution, and range in size from several millimeters to about 0.1 mm. All of the samples contain light-gray clasts with thin dark-gray selvages; sample 72235 contains a 4 cm gray and white banded fragment partly enclosed in a dark selvage, and sample 72255 has a crude foliation formed by alternations of pulverized gray and white material.

Station 2, boulder 2

The second boulder sampled at station 2 is about 2 m across and 2 m high above the ground surface. It is rounded, but smoother than boulder 1. This suggests that boulder 2 is more uniform than boulder 1.

A poorly developed set of fractures ($S_a$) trends from upper left to lower right as seen in figure 9. This set dips gently at about 5° into the surface of the rock, and probably controls the shape of the rock face in the right hand side of figure 9. A second set ($S_b$) dips from upper right to lower left across the rock surface, and appears to be nearly normal to the surface of the rock. A set of lineaments that appears to be traces of a third set ($S_c$) trends horizontally across the face of the boulder. The third set, or $S_c$, is visible in sample 72395. Several irregular joints are present. No evidence of bedding, or of a fracture set parallel to bedding, can be seen in the photographs.

The boulder has a moderately well-developed fillet about 0.25 m high on its uphill side, but overhangs the ground surface on its downhill side.

Five samples (72315, 72335, 72355, 72375, 72395) were taken from the second boulder at station 2 (fig. 10). Two of these samples (72315, 72335)
EXPLANATION

Lines denoting planar structures:

--- $S_a$

--- $S_b$

--- $S_c$

--- Trace of joint

Dotted lines outline large clasts.

Figure 9. Sketch map of boulder 2 at station 2. (AS17-137-20912-14, 20919-20).
Figure 10. Boulder 2 at station 2. Insets show lunar orientation of samples (sample 72375 not oriented). (AS17-137-20913; insets listed counterclockwise from upper right: S-73-, S-73-, S-73-17799, S-73-).
were taken from a 0.5 m clast, and the remaining three samples were taken from the matrix of the boulder. Two relatively friable zones are visible in the photographs (fig. 9), and may also be clasts. These were not sampled. All five samples are vuggy, greenish-gray breccias and, except for having smaller cavities, appear to be very similar to rocks called anorthositic gabbro by the crew at station 6. The two clast samples are somewhat lighter-colored than two of the matrix samples, but closely resemble the third (72395). All five samples are annealed breccias composed of a small percentage of mineral and lithic clasts in a fine-grained sugary matrix. The matrix is porous with irregular cavities ranging in size from about 0.1 mm to 8 mm; many cavities are slit-like and locally aligned. Most of the larger cavities are lined by plagioclase and brown pyroxene, with or without an opaque mineral and a yellow-green mineral. Smaller cavities are lined by a fine drusy intergrowth of minerals or, in some cases, are unlined. Lithic clasts, rarely more than 10 mm in diameter, are principally fine-grained, pale blue-gray, white or purplish-gray hornfelses, but a few are cataclasically deformed plagioclase-rich rocks or plagioclase and yellow-green mineral aggregates. Mineral clasts are, for the most part, angular fragments of plagioclase as large as 4 mm; and a yellow-green mineral as large as 3 mm.

Station 2, boulder 3

Boulder 3 is an equant, subangular breccia boulder about 40 cm across. Its surface is rough on a scale of about 1-2 cm, and, like boulder 2, its friability is probably uniform.
Several 2-4 cm clasts and one 10 cm light-gray clast in a gray matrix are visible in the photographs (fig. 11). No well-developed fracture or cleavage sets are visible, but two well-developed planar fractures at approximately 90° to one another are visible. A third fracture that is approximately parallel to the upper rock surface is also visible.

The boulder has a poorly developed fillet, which, together with its subangular shape, suggests that it has been in its present position for a relatively short period of time. Two samples, 72415-72418 and 72435, were taken from the third boulder at station 2 (fig. 12). Samples 72415-72418 represent a clast, and sample 72435 represents the matrix of the boulder. Sample 72435 is a blue-gray breccia that contains about 10 percent lithic and mineral clasts in a tough, finely crystalline, deep bluish-gray matrix. The rock has a local concentration of slit-like cavities in its matrix that are elongate parallel to a weak alignment of lithic clasts. Smooth-walled, ellipsoidal vesicles as large as 12 mm in diameter are also scattered irregularly through the matrix. Lithic clasts include cataclastic and sugary white rocks with hornfels texture. Mineral clasts are, for the most part, angular plagioclase and a yellow-green mineral in subordinate amounts. The clast from this boulder (represented by samples 72415-72418) is a light greenish-gray breccia composed of abundant mineral clasts and sparse lithic clasts set in a matrix that is moderately coherent, fine-grained, and probably annealed. The matrix of this rock is composed of about 35 percent angular fragments of yellow-green mafic silicate that is seriate below 1 mm, and less than 1 percent identifiable plagioclase, opaque minerals, and spinel(?); these minerals are embedded in a very fine-grained, sugary groundmass. Clasts are dominantly angular fragments of the same
Figure 11. Sketch map of boulder 3 at station 2. (AS17-137-20963)
Figure 12. Lunar orientation of sample 72435 from boulder 3 at station 2. (AS17-138-21049; inset: S-73-- ).
yellow-green mafic silicate as large as 3 mm in diameter, sparse plagioclase as large as 2 mm, and sparse lithic clasts composed of sugary plagioclase and yellow-green mineral aggregates with hornfels texture.
North Massif

Introduction

Stations 6 and 7 were designed as sampling sites for material which had been mass wasted from the North Massif. Station 6 lies on an 11° slope approximately 20 m above the break in slope between the massif and the valley floor. Station 7 is about 500 m east of station 6, on a 9° slope just above the break in slope (figs. 3 and 4). The surface in the area of the stations is covered by many large blocks and smaller fragments, most of which were derived from higher on the massif. There appears to be a bimodal distribution of fragments in the area. Fragments smaller than 2-3 cm and larger than 15-20 cm are abundant, whereas fragments between these two sizes are relatively sparse. Fragments smaller than 50 cm are scattered randomly over the surface; larger ones are generally in clusters that may be fragments from a single larger rock that had rolled or been thrown into that area. Where the soil was disturbed by the crew it is medium gray on the surface and lighter gray beneath (fig. 13).

Station 6 boulder

Most of the samples at station 6 are from a large (6 x 10 x 18 m) fragmented boulder (fig. 14) lying at the end of a boulder track (fig. 15) that extends about one-third of the way (approximately 500 m) up the face of the massif. Two other boulder tracks appear to originate at approximately the same level (fig. 16). From this level up to the top of the massif boulder concentrations are common. These boulder concentrations are probably derived from near surface bedrock.
Figure 13. Area of disturbed soil between boulders 3 and 4 at station 6. Soil is lighter beneath the thin gray surface layer. Letters indicate planar surfaces onto which boulder 4 may fit. Face A is most likely fit. See text for discussion. (AS17-140-21434).
Figure 14. Diagram of station 6 boulder showing relationships of large fragments, their reassembly, and locations of samples.
Figure 15. Footprint of 500 mm mosaics of part of North Massif that are shown in figs. 16 and 18. Features identified by letters are visible on figs. 16 and 18; primed letters denote objects visible on fig. 18 only. The origin of the 500 m grid is the LM. Elevations of grid corners (in parentheses) given in meters were taken from the National Aeronautics and Space Administration Lunar Topographic Photomap, Taurus-Littrow, 1:25,000, 1st ed., Sept. 1972, by the Defense Mapping Agency. The elevation of the landing point according to this map is 4,510 m, and the summit of the North Massif is 6,178 m. Photo base is Apollo 17 panoramic camera frame 2309.
Figure 16. Mosaic of 500 mm photographs taken from LM area showing boulder tracks on the North Massif. Dashed lines indicate boulder concentrations. The perspective grid is the same as that in fig. 15. Elevations of the 500 m grid intersections are shown in parentheses. (AS17-144-21991, 22119 through 22122, and 22127 through 22130).
At lower elevations the bedrock in the massif is covered by an increasingly thick regolith and talus cover. At higher elevations, the massif is covered by a much thinner layer of fine material which allows the underlying bedrock to be easily excavated by the more abundant smaller craters. This is suggested by the change in slope from 25° in the upper two-thirds (upper 1,000 m) of the massif to 21 1/2° in the lower one-third of the massif (about 500 m above the base). One boulder track visible in figure 16 extends nearly 1,000 m up the slope. At the lower end of this track is a large boulder that is darker than most of the other boulders on the lower one-third of the massif (fig. 17) and which is also darker than the station 6 boulders. A concentration of dark boulders occurs near its apparent source, and similar concentrations are scattered at about the same level elsewhere on the mountain face. Thus there may be a layer or lenses of darker rock high on the mountain. Lighter boulders occur above and below. The lower light zone was sampled at the station 6 boulder.

The station 6 boulder broke into 5 pieces which are aligned downslope. The largest is about 8 m across. The original boulder can be pieced back together, generally with only a small amount of rotation of any of the blocks. Several large fragments that may have broken from the boulder as it rolled downhill can be seen in and around the boulder track (fig. 18). Boulders 4 and 5 can be reassembled by minor rotation until similar appearing faces fit together (fig. 19). When this is done, vesicle foliation is in a similar orientation in each boulder, and non-vesicular inclusions in both pieces also fit across the break. Boulders 1 and 2 also fit without substantial manipulation. It appears
Figure 17. View of North Massif showing principal elevation data on prominent boulder tracks. Samples were collected next to Turning rock (station LRV-10). The light color of Turning rock and station 6 boulders in contrast to the dark color of the large rock that rolled from high on the North Massif is well displayed. (AS17-141-21550).
Figure 18. Telephoto view of prominent boulder tracks on lower North Massif showing probable source area of station 6 boulder. Lower case letters indicate fragments which may have broken from station 6 boulder. The large boulder in the lower left, at the end of the prominent track that heads at an elevation of 5,550 m, is distinctly darker than ant others in this area; its darkness is characteristic of some boulder concentrations high on the mountain as seen in figure 16. (AS17-144-21252, 21254, 21262, and 21263).
Figure 19. Boulders 4 and 5 at station 6. Arrows indicate probable match points between the two boulders. (AS17-140-21414, 21416, 21418, 21429, 21432, 21433).
that boulder 1 can be raised and placed against boulder 2 (fig. 20).
Boulders 2 and 3 are fitted together in much the same manner (fig. 21).
Relations across the split between boulders 1, 2, 3 and 4, 5 are not as
obvious, and the fit is still tentative. Figure 21 shows a nearly
planar surface (A) on boulder 2, which dips approximately the same as
the north face of boulder 4, as shown in figure 19. When boulder 4
is placed on this surface, the foliation which appears to be planar
concentrations of vesicles in boulder 2, is parallel with the foliation
in boulders 4 and 5. Also, a series of widely spaced joints in
boulder 4 are then aligned with similar joints in boulder 2. A second
possibility, less likely, is to place the north face of boulder 4 on
planar surface (B) on boulder 2, adjacent to the one just described
(fig. 13). However, structures seen in both boulders do not align as
well, and the shape of the fractured face of boulder 2 does not conform
well with that seen on boulder 4.

Four of the five numbered boulder fragments were sampled. Two
major types of breccia can be distinguished: greenish-gray breccias
and blue-gray. The third, fourth, and fifth boulders, and part of the
second, are greenish-gray breccias, described by the crew as anorthositic
gabbros. In boulder 2, there is an irregular contact between the
greenish-gray breccia and a blue-gray breccia. This zone, approximately
50 cm across, appears to be an area of mixing between the two rock types.
Boulder 1 is also blue-gray breccia.

Two samples were collected from the greenish-gray breccia. Sample
76215 is part of a larger rock which spalled from boulder 4, and 76015
is from the top of boulder 5 (fig. 19). These rocks are tough, annealed
Figure 20. Boulders 1 and 2 at station 6. Arrows indicate probable match points between boulders. (AS17-140-21497).
Figure 21. Boulders 2 and 3 at station 6. Arrows indicate fractures which line up when boulders are fit together. Letters indicate planar faces onto which boulder 4 may fit. Face A is most likely fit. See text for discussion. (AS17-146-22293).
breccias with sparse lithic and mineral clasts set in a vuggy, fine-grained sugary matrix. The vugs, which range in size from 0.1 mm to about 9 cm, are flattened and locally aligned. Vug interiors are coated by drusy intergrowths, and their walls are studded with scattered euhedral crystals of troilite, metal, and a translucent yellow-green mineral. Around the larger cavities, the sugary intergrowth of minerals that forms the matrices of these rocks gradually coarsens over a distance of about 1 cm. At cavity walls individual minerals of the matrix become distinguishable, and the rock has a poikiloblastic texture. Lithic clasts, all less than 1 cm across, include granoblastic intergrowths of plagioclase and a yellow-green mineral, and rare aggregates of dark yellow-green and finely recrystallized brownish-gray material. Mineral clasts are, for the most part, plagioclase and a yellow-green mineral that grade evenly into the matrix.

Two unsampled rock types are present within the greenish-gray breccia. Several baseball-sized light gray clasts are scattered randomly throughout the rock. They appear non-vesicular and are in sharp irregular contact with the greenish-gray breccia. On boulder 5 (fig. 22) is a large (0.5 x 1 m) gray non-vuggy area within the greenish-gray breccia. Photographs suggest that the non-vuggy rock may differ only in texture, not composition, from the host breccia. The dense area is sharply bounded by vuggy breccia on two sides and grades into it on a third side. It may be an inclusion that was incorporated in the greenish-gray breccia, which vesiculated along the margins, or a locally non-vesiculated interior of the boulder. The former is
Figure 22. Boulder 5 at station 6 showing non-vuggy area in vuggy greenish-gray breccia. Dashed lines show planar structures in the non-vuggy portion. Solid lines are joints. (AS17-140-21432).
preferred because of the sharpness of the contact on two sides. A set of planar structures occurs within the dense material parallel to the fracture face between boulders 4 and 5. It is not clear what these structures are, but they do not appear to be compositional layers. They do not continue into the vuggy part of the boulder, which further suggests that the non-vesicular rock is an inclusion rather than a central non-vesiculated core of the boulder.

Two samples from the blue-gray part of boulder 1 (fig. 23) (samples 76275 and 76295) are composed largely of blue-gray breccia fragments in vuggy greenish-gray matrices. The proportion of clasts in these two rocks is high (40 to 60 percent), and the matrix is somewhat browner and darker than the typical vuggy greenish-gray rocks. Vugs, which are about 2 to 5 mm across, are in most cases lined by rich-brown pyroxene and plagioclase with or without ilmenite plates. These minerals project as euhedral crystals into the larger cavities. In sample 76295 the matrix is also laced by thin, irregular veins composed of the same minerals that line the vugs. In sample 76275, the lined vugs occur locally in the blue-gray clasts as well as in the matrix. The matrices of these rocks are tough, finely crystalline material composed principally of angular mineral debris (plagioclase, yellow-green mineral, brown pyroxene) and small lithic fragments of blue-gray breccia. These breccia fragments grade evenly upward to clast size. The clasts in these samples are dominantly finely crystalline blue-gray breccias that themselves contain sparse finely recrystallized white clasts; scarce isolated finely crystalline white clasts, a few of which have thin dark selvages are also present. One dark-gray clast in sample 76275 is vuggy and finely crystalline; it encloses a small light-gray metaclastic fragment.
Figure 23. Locations of samples removed from boulder 1 at station 6. Known orientations shown in insets. Heavy solid lines indicate traces of shear planes, $S_3$, $S_4$, etc. Dashed lines outline inclusions and samples. A and B denote fracture surfaces bounding boulder. (AS17-140-21443).
In the blue-gray breccia of boulder 1 there are white friable inclusions ranging in size from 1-2 cm to 1 m across which are in sharp, irregular contact with the blue-gray breccia. Eight small samples (76235-76239 and 76305-76307) are chips that represent one of these inclusions (fig. 24). These samples are very light-gray cataclasites composed of angular mineral debris that includes yellow-green and pale grass-green mafic silicates and plagioclase. Mafic silicate fragments make up at least 25 percent of the rock. It is possible that thin gray veinlets occur in some pieces.

There are two other types of inclusions in the blue-gray breccia which were not sampled. There are a few inclusions (fig. 23, lower left) which are not as friable in appearance and are a darker gray than the light-gray inclusions sampled. A second type, which is rare, is medium gray and vesicular with sharp, irregular boundaries (fig. 23, upper left).

One sample (76255 collected from boulder 1) is breccia that contains clasts of blue-gray breccia set in a friable light-gray to brownish-gray matrix. The rock is prominently foliated, with alternating layers of abundant or sparse blue-gray breccia clasts. The tough blue-gray clasts stand out in relief on weathered surfaces. The clasts include not only blue-gray breccia, but fine-grained white hornfels and coarser granoblastic plagioclase hornfels. The blue-gray breccia clasts themselves contain sparse sugary white hornfels clasts and moderately abundant yellow-green mineral fragments. The largest blue-gray clast in the rock has a string of vuggy patches of plagioclase and rich-brown pyroxene along one edge; the patches are 3 to 12 mm across. A clast of this vuggy material with a small patch of the blue-gray matrix
Figure 24. Large light gray clast in blue-gray breccia of boulder 1 at station 6. Solid lines show traces of shear plane sets $S_a$ and $S_b$. (AS17-140-21445).
adhering to it is isolated in the light-gray matrix of the rock. The matrix of sample 76255 is unusual in having a high proportion of angular honey-brown mineral debris, with lesser amounts of identifiable plagioclase and yellow-green mineral debris.

Sample 76315, collected from boulder 2 near the contact, appears to be transitional between blue-gray breccia and the type represented by 76255. The rock is mainly blue-gray breccia with a few white clasts; a large (3 x 8 cm) white clast at one end of the specimen is veined by blue-gray material. Both components were subsequently weakly brecciated so that pieces of blue-gray rock are now encased in a white matrix.

In boulder 1 several throughgoing planes ($S_a$ through $S_g$) can be recognized in stereoscopic study of the photographs (figs. 23 and 25). The lettering sequence does not imply a sequence of development in the rocks. When comparing these with the oriented returned samples, it can be seen that they represent shear planes along some of which movement has occurred. Two types are evident. $S_a$ is a plane along which shearing has deformed the clasts to create discontinuous compositional banding. The zoning in sample 76255 is parallel to the $S_a$ shears. This type of shear is closely spaced (a few centimeters or less) but it is not a plane that had any substantial control on the shape of the boulder because the fracture surfaces are discontinuous and the rock is coherent across these surfaces. $S_b$ and $S_f$ are also this type. $S_c$ and $S_d$ are typical of the second type, and they appear to be somewhat more widely spaced planes which form fracture faces on the surface of the boulder. Sample 76295 parted along $S_d$ when sampled. $S_e$ and $S_g$ are also this type.
Figure 25. View of boulder 1 at station 6 after removal of samples; shows shear sets, \( S_a, S_b \), etc. Dashed area is a crushed zone, with mixing between light-gray and blue-gray breccia. Note the large fracture face of blue-gray breccia with light-gray clasts. (AS17-140-21456).
Most, if not all, of the shears appear not to be surficial, but rather penetrate the boulder. $S_a$ and $S_b$, for example, can be seen in two places on the boulder over a meter apart.

Movement along the shears does not appear to have been uniform throughout. In the area from which 76255 was sampled, one of the large light-gray clasts has been intensively sheared. The large clast from which samples 76235-76239 and 76305-76307 were collected has not been substantially deformed. The direction of shearing is the same in the two areas, but the amount of movement is different. Two fracture sets (A and B in fig. 23) which have not been identified in the samples are major mutually perpendicular fractures which shape the south and east faces of the boulder.

At least one and possibly two of these sets of shears can be seen in boulder 2. Sample 76315, which came from near the contact in boulder 2, shows some evidence of shearing. In figure 26 the face shown on boulder 2 is parallel with the $S_c$ structures of boulder 1. Figure 27 shows this face, along with what is probably an expression of the $S_d$ planes. Probably the other structures are in this boulder also, but because of the lower resolution and the direction from which this photograph was taken, they are not visible. It does not appear that the $S_c$ planes penetrate boulder 2 completely. They appear to die out as the contact between the two breccia types is approached. Assuming that the boulders have been reassembled correctly, it is not evident that these shears are present in the greenish-gray breccia. Some planar structures can be seen on boulders 4 and 5 but they neither coincide with nor look the same as the shear planes seen in boulders 1 and 2. They are generally spaced
Figure 26. Similar shear surfaces ($S_c$) on boulders 1 and 2 at station 6. (AS17-141-21633).
Figure 27. Boulder 2 showing shear planes ($S_1$, $S_d$) similar to boulder 1 at station 6. (AS17-148-21436).
several centimeters apart, and appear to be fractures rather than shear planes. No evidence of shearing is seen in samples 76015 and 76215 collected from these boulders.

One of the first events represented in the station 6 boulder was the formation of the light-gray to white cataclasite. This breccia was enclosed by the blue-gray breccia, either during the same event or a later one. The other two clast types in the blue-gray breccia probably have similar histories. The blue-gray breccia was heated enough to allow minor vesiculation. The blue-gray breccia was then incorporated by the greenish-gray breccia, which must have been heated enough to allow intensive vesiculation. The vesicles define a foliation parallel to the contact with the blue-gray breccia. The shearing seen in the blue-gray breccia portion of the boulder which caused the banding seen in sample 76255, apparently took place before and/or during its incorporation into the greenish-gray breccia, because no extension of these shears is evident in the greenish-gray breccia. The blue-gray breccia may, however, be more susceptible to shearing than the greenish-gray breccia.

It is not clear whether the vesicular patch seen in boulder 1 is of the same generation as the greenish-gray breccia, because its relation to the contact cannot be seen in three dimensions. The color and vesicularity of it suggest that it is the same. Whether it was injected into the blue-gray zone during this time is not known.
Station 7 boulder

Sampling in the station 7 area consisted of collecting four samples from a 3 m boulder (fig. 28), and grabbing several samples from the surface of the adjacent regolith. The boulder is similar to the station 6 boulder in that the two major rock types, greenish-gray breccia and blue-gray breccia, are present. A 1.5 by 0.5 m white clast, similar to those seen at station 6, is penetrated by blue-gray breccia dikes that are 2-3 cm across.

One sample (77135) was collected from the greenish-gray breccia (fig. 29). Sample 77135, which most likely represents the youngest matrix of the boulder, is a vuggy greenish-gray breccia that contains a few percent of small clasts of yellow-green mineral and finely recrystallized plagioclase set in a tough, vuggy matrix. The cavities in this rock range from about 0.1 mm to 10 mm in diameter and range from irregular vugs to nearly spherical, smooth-walled vesicles. Mineral debris contains a high proportion of yellow-green mineral and is seriate below 1 mm. Angular mineral fragments are enclosed in a fine-grained, sugary, annealed matrix. The contact between the blue-gray breccia and the greenish-gray breccia is a sharp irregular boundary. Sample 77115 may contain the contact between vuggy greenish-gray breccia and blue-gray breccia. However, the greenish-gray part of the sample differs from sample 77135 in containing a very high proportion of honey-brown and yellow-green mineral debris, and in containing scattered large, distinctive clasts of a dark-gray mineral. The greenish-gray material appears to invade the blue-gray breccia, but clast-matrix relations in the rock are not clearly evident. The finely crystalline, tough
Figure 28. Boulder sampled at station 7. Lines indicate areas covered in figures 30, 31, and 32. (AS17-146-22352).
Figure 29. Showing contact between greenish-gray breccia and blue-gray breccia on station 7 boulder. (AS17-146-22338).
blue-gray breccia portion of sample 77115 itself contains sparse lithic clasts, the largest of which consists of recrystallized plagioclase with a single yellow-green mineral grain and a single brown pyroxene attached. One fragment of the distinctive dark-gray mineral that occurs in the greenish-gray rock was seen in the blue-gray breccia.

The 1.5 x 0.5 m white inclusion is cut by several small dikes of blue-gray breccia. Samples 77075-77077 and 77215 represent the white clast, and the blue-gray dike that cuts through the clast (fig. 30). Sample 77215 is friable white cataclasite composed of approximately equal proportions of pale yellow mafic silicate and plagioclase. The cataclasite is cut by an irregular network of dark gray, fine-grained veins. The vein-cataclasite complex was weakly brecciated to isolate small pieces of the vein in the white matrix. Samples 77075-77077 also include portions of the white clast and of the blue-gray dike. In these rocks, irregular thin blue-gray veinlets branch from the main dike into the white cataclasite.

At least two well-developed fracture sets visible in the boulder seem to be confined to the blue-gray breccia and the white clast within it. A strongly developed set of fractures is essentially parallel with the bottom of the rock. A second less well-developed set, which appears to be a conjugate set, dips about 45° to the east. The fracture sets are spaced a few centimeters apart in the blue-gray breccia (fig. 31) and become very closely spaced (1 cm or less) in the white clast (fig. 32) indicating its comparative brittleness. These fracture sets are not seen in the greenish-gray breccia. This suggests that the fracturing occurred in the blue-gray breccia prior to its incorporation.
Figure 30. A. Dikes of blue-gray breccia in light gray clast within blue-gray breccia. (AS17-146-22305).
B. Sketch map. Except for labeled dikes and outline of boulder, solid lines indicate traces of fractures. Station 7 boulder.
Figure 31. A. Fractures in blue-gray breccia and light-gray inclusion in station 7 boulder. Note differences in spacing of fractures. (AS17-146-22310).
B. Sketch map.
Figure 32. A. Closely spaced fractures in light-gray clast in station 7 boulder. (AS17-146-22306).
B. Sketch map. Unlabeled lines show fracture traces.
in the greenish-gray breccia. Foliation of the vesicles in the greenish-gray breccia is parallel to the contact with the blue-gray breccia. The fracturing occurred after incorporation of the white clast, for the dikelets of blue-gray seen in it do not parallel the fracture sets, but are cut by them. As in the station 6 boulder, the youngest event is represented by the greenish-gray breccia, and the oldest by the large white clast in the blue-gray breccia.

Although there is no visible boulder track, there is little doubt that the station 7 boulder was derived from the North Massif because of its similarity in composition and structure to other materials collected from the massif. Since it is considerably smaller than the station 6 boulder, it probably bounded downslope, as did those of comparable size down the South Massif (fig. 6), rather than rolled. It appears that it has been in its present position but a short while, because only a small fillet is developed on the upslope side.

Other samples collected at stations 6 and 7

Several other samples, including soil, drive tube, grab, and rake samples were collected in the stations 6 and 7 areas. Sample 76240 is permanently shadowed soil, taken from about 1 meter under the north overhang of boulder 4 (fig. 33). It probably has not been shadowed for a great length of time, because the freshness of the boulder track indicates that the boulder has not been in its present position very long. Two other soil samples were taken from just outside the shadow. Sample 76260 is a 2 cm deep skim and 76280 is a 6 cm deep scoop of soil. Another soil sample, 76320 (fig. 20), was collected from the
Figure 33. North face of boulder 4 at station 6 and location of permanently shadowed and reference soil samples. (AS17-140-21406).
north face of boulder 1. This soil was probably picked up by the boulder as it fell into its present position. Sample 76220 is a soil sample collected from the center of the boulder track approximately 10 m northwest of boulder 1. Approximately 5 m south of the LRV a single drive tube, 76001, was collected. All of these samples probably represent a mixture of breccia fragments from the massif and subfloor material, with the major contribution derived from the massif.

Rock samples from stations 6 and 7 other than those collected from boulders and other than basalts include five white cataclasites (76355, 76536, 76558, 76559, 77017); fourteen greenish-gray breccias (76055, 76556, 76557, 76577, 77035, 77515, 77517, 77518, 77519, 77525, 77526, 77637, 77539, 77545); five blue-gray breccias (76036, 76035, 76555, 76569, 76575); two light gray breccias (76505, 77538) with small blue-gray clasts in a moderately coherent matrix; six dark matrix breccias with small white clasts (76506, 76545, 76546, 76547, 76548, 76549, 76565, 76566, 76568); one coarse-grained gabbroic rock with about 35 percent pyroxene (76535), one light gray regolith breccia (76567), and one light colored fine-grained hornfels (76576). The cataclasites are both chalky white rocks, but 77017 is laced by dark glass veins and one side is covered by a thick coating of dark glass with many inclusions of cataclasite. The greenish-gray breccias include two large rocks (76055, 77035) with irregularly distributed small slit-like cavities that are locally aligned. The matrices of these rocks are tough, finely crystalline intergrowths that include scattered plagioclase and yellow-green mineral debris. Clasts in the greenish-gray breccias include cataclasite with crushed plagioclase and yellow-green mineral,
granoblastic intergrowths of plagioclase and yellow-green mineral, scarce, fine-grained blue-gray hornfels, and scarce greenish-gray clasts with poikiloblastic textures. A smaller sample grouped with the greenish-gray breccias (77517), and two small pieces (77525, 77526) that may have been broken from it, have abundant medium light gray to light blue-gray aphanitic clasts in a vug-free annealed light gray matrix. Sample 76035 is an unusual blue-gray breccia. It contains a shattered clast of finely crystalline light-gray hornfels. Blue-gray matrix completely envelopes pieces of the broken clast around its periphery, but the interior of the clast is incompletely penetrated by blue-gray matrix so that the fragments form a porous aggregate. The blue-gray matrix appears to be holocrystalline, fine-grained, and has a small proportion of smooth-walled vesicles and irregular vugs. Other clasts in the blue-gray matrix include a distinctive fragment that consists of 2 mm euhedral plagioclase crystals, interstitial light-brown pyroxene, annealed plagioclase-rich fragments, and mineral debris.

Several basalts were collected in the rake and grab samples at these two stations: four vesicular porphyritic coarse-grained basalts (76037, 76538, 77535, and 77536); two vesicular fine-grained basalts (76136, 77516); and two dense aphanitic basalts (76537 and 76539).

The presence of the basalts indicate there is some mixing of subfloor materials in the talus of the massif material. This area is also downrange from the central crater cluster that dominates the landing area and which probably threw debris onto the slopes of the North Massif and adjacent Sculptured Hills.
Sculptured Hills

The single location on the Sculptured Hills from which samples were collected (station 8) lies about 20 m above the valley floor on a south-west facing slope just southeast of Wessex Cleft and 4 km northeast of the landing point. The station is within the zone mapped as dark mantle by Wolfe and Freeman (1972) and by Lucchitta (1972). This unit locally mantles the lower slopes and linear valleys of the Sculptured Hills (fig. 34) and is likely to have been mixed with the underlying regolith. The terrain is undulating on a general slope of 10°-30°, being steepest above the station 8 area (figs. 35 and 36).

From a distance on earlier traverses the astronauts described these hills as being pockmarked (by small craters), darker gray, more hummocky and lineated, and as having lower slopes than the massifs. During late mission orbits under highest sun elevations (58°), the hills were characterized as incorporating "the albedo both of the North Massif and the (dark) mantle area...to give...an in between gray albedo, but the sculpturing is produced by the darker albedo that looks like the mantle, and the lighter albedo that looks like the massif." These observations are borne out by both the high sun orbital and by the surface photographs.

While approaching the hills the crew noted that rocks larger than 20 cm are very rare on the Sculptured Hills slopes compared with their relative abundance at the foot of the North and South Massifs. Most of the fragments are small clods and create a downslope pattern of small lineaments indicating youthful mass wasting on currently active slopes (fig. 121, Appendix B). However, the three boulders investigated on this slope showed no evidence of having moved downslope, and the only
Figure 34. Panoramic camera view of station 8 area showing distribution of dark mantle on Sculptured Hills, Wessex Cleft, and valley floor (Apollo 15 panoramic camera frame 9557).
Figure 35. Station 8 area at Sculptured Hills viewed from the LM, 4 km away (AS17-137-20876). Note the contrast between the hills on the right and the massif material directly above Wessex Cleft. Both slopes have similar orientation.
EXPLANATION

--- Approximate boundary of dark rubble patch.

--- Possible boulder track

□ Location of large block(s)

•••• Area of break in slope

Figure 36. Telephoto mosaic of Sculptured Hills slope above station 8 viewed from station 2a. Sun elevation is 28°. (AS17-144-22034, 22035)
other large rocks on the hill are described as farther upslope. These latter blocks are the fragments visible within the patches of "dark mantle" sketched in figure 36.

The few fragments seen on the local surface are subrounded to subangular; some are partly buried, but the two sampled boulders and most of the soil clods are perched on the surface. The lack of blocks around fresh craters up to 50 m in diameter indicates bedrock is more than 10 m below the surface slope material. The soil in this area, at least to the 20-25 cm depth of the trench samples, consists of fine-grained, cohesive clods and particles. It has a moderately dark appearance characteristic of the mantle throughout the valley floor.

No large craters are present in the immediate area; those up to several meters in diameter are common, however, and have a continuum of morphologies from fresh-appearing, topographically sharp features to highly subdued depressions. The craters have neither prominently raised nor blocky rims, although one secondary crater lower on the slope (fig. 37) forms a cloddy rim similar to that sampled from the Rover on the rim of SWP crater (LRV-11, fig. 34).

The sample suite collected at the foot of the Sculptured Hills is represented mainly by basalts. These are most likely ejecta deposited on the Sculptured Hills slopes by valley floor craters and subsequently concentrated by mass wasting toward the base of the hills. The samples are all from the subtle, dark-gray apron, interpreted on pre-mission maps as dark mantle (fig. 34).

One large basalt fragment (78135, fig. 38) was taken from near a half-meter wide boulder, probably also basalt, that was too hard to be sampled directly. Others were collected in the rake and soil samples.

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Figure 37. Cloddy secondary crater on slope below station 8. Break in slope is about 200 m from camera. (AS17-142-21741)
Figure 38. Basalt fragment (78135) collected from beside hard boulder at station 8. Cube = 1 cm. (S-73-15003)
The basalts are not obviously shocked or glass-veined and the crew indicated they looked like the basalts sampled at other localities on the valley floor.

Perhaps the more important samples for interpreting the lithologic nature of the Sculptured Hills are represented by the smaller rocks and soils. Unfortunately their relation to the underlying hills is not known. The friable feldspathic breccia (78155), collected from the wall of a 15 m crater is a particularly good candidate for Sculptured Hills material. Its friability and color are compatible with the more rounded topography of the Sculptured Hills, the general absence of boulders, and the light-colored, generally fine-grained ejecta seen in the largest fresh craters of this area. Samples larger than 1 cm from soil bags and the rake samples include 22 dark-matrix breccias, most of which have small white lithic fragments and clasts of mare basalt (78508, 78516, 78518, 78535-9, 78545-9, 78555-9, 78565-8), one rock composed of regolith clods loosely cemented by glass (78525), one dunite(?) (78526), one non-vesicular metaclastic rock (78527), and one white feldspathic breccia (78517).

The gabbroic rocks (78235-78238 and 78255-78256) are from the top and bottom of another half-meter size boulder. The rock is coarse-grained, composed of about 50 percent each of plagioclase and pyroxene. It is intensely shocked and heavily glass-coated and glass-veined (figs. 39 and 40). No fillet existed on the boulder in its original position. These properties and its strongly fluted, glassy surface suggest that it originated from outside the area and was relatively recently emplaced at station 8. The lack of blocky craters or related boulder tracks upslope argues against a local source.
Figure 39. Glass-coated coarse-grained gabbroic rock (78236) from shock-fluted, rolled boulder at station 8. Cube = 1 cm. (S-73-15394)
Figure 40. Locations and orientations of gabbroic rocks 78235-78238 from top of rolled boulder. Fluted surface is glass-coated, and fragments broke along glass veins. (AS17-146-22370). Inset photographs are, top to bottom: S-73-17817, S-73-17962, and S-73-17814.
The well-documented trench samples (78420-480) have not been described as of this writing, but they should typify the soils of the lower slopes of the Sculptured Hills. They are probably a mixture of valley floor debris and Sculptured Hills soils. The soil sample collected from a dark, cloddy crater on the rim of SWP crater (78120) at LRV-11 is just at the base of slope and may represent either deeper material from SWP or mass-wasted material from upslope (fig. 34). Perhaps the original composition of the hills can best be determined by subtracting from these soils the average composition of the typical valley floor.

Relationships between the massifs and Sculptured Hills

The North, South, and East Massifs are alike in morphology and outcrop occurrence on their upper slopes. The samples from the North and South Massifs are strikingly similar breccias. The Sculptured Hills, in this region at least, are notably different in their greater dissection, lower slopes, and lack of large boulders. These features in combination with the limited sample suite suggest that the Sculptured Hills are underlain by less coherent breccias than the massifs. They do seem to have more slope debris deposited at their base and a greater possibility of contamination from the thinly mantling dark material above and below the sample area. If the Sculptured Hills reflect a different structural history from the massifs, no evidence was developed during the mission to demonstrate it.

Outcrops on North Massif occur on the upper two-thirds (1.000 m) of the slope. On South Massif only the upper one-third (700 m) of the slope has exposed blocks. Sampled boulders are thought to represent the uppermost part of the South Massif and the lower one-third of the North Massif. Hence two distinct stratigraphic levels may have been sampled.
On the other hand, rocks collected from North and South Massifs closely resemble each other in many respects: 1) Vuggy greenish-tan breccias from both massifs are virtually identical, except that cavities in samples from station 2 are smaller than those in station 6 rocks. 2) Identical greenish-gray breccias that lack cavities occur on both massifs. 3) Blue-gray breccias are also identical, at least insofar as can be determined with the binocular microscope. In both places these rocks have small proportions of white clasts and fine-grained to aphanitic matrices. 4) Light-gray breccias from both massifs are also similar, although as a class these rocks are variable. The characteristics of friable matrices, dominance of dark over light colored clasts, and local occurrences of foliation are shared by samples from both massifs. Subordinate features of the breccias are also similar in samples from North and South Massifs: 1) The brown pyroxene-lined vugs occur in rocks from both areas, although they are much better developed in North Massif samples; 2) rare blue-gray breccias with vesicles were returned from stations 2 and 6; and 3) rare breccias with abundant honey-brown mineral and distinctive dark-gray mineral clasts were found at stations 3 and 7. Minor differences between North and South Massif breccias include: 1) vuggy metaclastic clasts occur only in station 2 breccias; 2) light gray breccia at station 2 occurs as a large boulder, whereas light-gray breccias from North Massif are known only as subordinate inclusions in station 6 boulders; and 3) a greater number of friable cataclasites were returned from North Massif.

The similarity of the rock types between North and South Massifs suggests that the samples may represent only one stratigraphic unit. The greenish-gray breccia, light-gray breccia, and blue-gray breccia, seen as
discrete boulders at station 2, are all components of the same boulder
at station 6. This evidence indicates that they may come from a single unit
in South Massif. There apparently is an unsampled type of dark rock that
occurs high on the North Massif. It may represent a layer or lenses in
the upper part of the massif.
Subfloor basalts

Field occurrence

Subfloor basalts occur in the dark portions of the valley floor both as scattered blocks and fragments and as concentrations of blocks on the walls and rims of the larger craters. The areas in which the basalts were most thoroughly sampled were on the rims of Shorty and Camelot craters, in the LM-ALSEP-SEP area, and at station 1.

Several varieties of basalt were described on the lunar surface. The predominant types were coarse-grained, vesicular, relatively light-colored basalts composed of clinopyroxene, ilmenite, and 30-40 percent plagioclase. Vesicles up to about 1 cm in diameter typically comprised 10-15 percent of these rocks. In some rocks, planar partings paralleled bands expressed as differing concentrations of vesicles. Finer-grained and less vesicular varieties of basalt were recognized locally.

Shorty crater.—Subfloor basalts were sampled on the rim crest of Shorty crater in the vicinity of a 5 m boulder (fig. 41). Debris that may have been shed from the boulder lies on the nearby surface, and blocks are abundant on this part of the inner crater wall. All of the rocks examined were basalts. They are commonly intensely fractured and some show irregular knobby surfaces that resemble the surfaces of terrestrial flow breccias.

Shorty is 110 m in diameter and is most probably a young impact crater. Its blocky floor is about 10-15 m below the general surface level near the crater, and its walls are largely composed of relatively fine fragmental material. The impacting projectile should have encountered hard rock at a depth of no less than 10 to 15 m, and
Figure 41. Northwest-looking photograph showing intensely fractured basalt boulder on rim of Shorty crater and locations of samples 74255 and 74275. (AS17-137-20990).
ejecta was therefore excavated from depths no greater than about 20 m (about 1/5 crater diameter). It is possible that basalt fragments on the crater rim may be ejecta derived from within the upper 5 to 10 m of bedrock of the subfloor basalt unit at the Shorty site. An alternative interpretation is that coherent bedrock was not excavated by Shorty and that the basalt fragments on its rim are blocks ejected from pre-Shorty regolith.

**Camelot crater.**--Subfloor basalts were collected from the rim of the large (650 m) crater Camelot. The blocks, which are partly buried by soil, are exposed near and along the low, rounded rim crest of the crater and extend downward into the crater walls (fig. 42) where, as in other craters, blocks are abundant. Outward from the rim crest the block population decreases rapidly within a few meters.

Within the block field individual rocks, varying from cobble to boulder-size, are subrounded to subangular, moderately to deeply buried, and cover about 30 percent of the surface. They tend to be tabular in shape (fig. 42) and no doubt preferentially broke along the well developed set of partings (fig. 43). The partings parallel bands formed by variations in vesicle concentration. Descriptions by the crew indicated that the rocks were predominantly coarse-grained subophitic pyroxene-bearing basalts with shiny ilmenite platelets in the vugs and vesicles. They appear to be notably uniform except for gray zones that may represent finer-grained or nonvesicular areas.

The large basalt blocks on the Camelot rim undoubtedly represent ejecta from the crater. Impact theory suggests that the stratigraphically lowest target materials will most probably be located in the ejecta nearest the crater rim, and that the maximum depth from which material is
Figure 42. North-looking photograph of part of station 5 area showing tabular basalt boulders on southwest rim and inner wall of Camelot crater. Prominent banding visible in large block in right near field. (AS17-145-22178).
Figure 43. Northwest-looking photograph of vesicles and prominent parallel partings in basalt boulder on southwest rim of Camelot crater. Bootprint treads (lower right) are about 2 cm wide. (AS17-133-20333).
likely to be excavated is about 1/5 crater diameter--130 m deep in the
case of Camelot. However, the crater is old, and its rim has been
eroded. The rocks sampled may not, therefore, represent the uppermost part
of the original ejecta, and 130 m should be regarded as the maximum
possible depth of their origin.

**LM-ALSEP-SEP area.**--Large boulders of subfloor basalt were observed
and sampled in the LM-ALSEP-SEP area. The crew described the rocks as
uniform, coarse, vesicular, porphyritic, clinopyroxene-bearing basalts with
about 30 to 40 percent plagioclase and with ilmenite platelets in the vugs
and vesicles. Vesicles commonly make up 10 to 15 percent of rock surfaces.
A foliated effect is created by partings that parallel bands of differing
vesicle concentration. The rocks are commonly fractured. A single set of
parallel fractures is visible in one boulder (fig. 44), whereas so-called
"Geophone Rock" is intricately fractured (fig. 45).

Blocks in the LM-ALSEP-SEP area belong to a population of boulders that
project through the dark floor material throughout the area east of Camelot
crater. Scarcity of such boulders west of Camelot suggests that the boulders
near the LM are probably not Camelot ejecta but rather ejecta from the
craters east of the LM in the central cluster.

**Station 1.**--Station 1 is located on the northwest flank of Steno
crater about 150 m from the Steno rim crest. Subfloor basalt was col-
lected as small fragments from the soil and as chips from two vesicular
1/2 m boulders on the rim of a 10 m crater (fig. 46). As at Camelot
crater, the large boulders are bounded in part by tabular faces and contain
parallel parting planes. A distinct planar boundary between coarsely
vesicular basalt and finely vesicular basalt is oblique to a set of
parallel fractures in one of the boulders.
Figure 44. South-looking photograph showing parallel fractures in 1/2 m-high boulder south of deep drill site. "Geophone Rock" in upper left. (AS17-134-20505).
Figure 45. Southwest-looking photograph of "Geophone Rock," an intricately fractured, vesicular, 3 m-high basalt boulder. (AS17-147-22535).
Figure 46. Northwest-looking photograph showing 10 m crater at station 1 with sampled 1/2 m boulders on its rim. Boulder in foreground contains distinct planar boundary (solid line) between zone of coarse vesicles (left) and zone of fine vesicles (right). Dashed lines show traces of planar fracture set dipping to right. (AS17-136-20741).
The 10 m crater presumably re-excavated basalt blocks from within the upper 2 m of the ejecta blanket of Steno crater. The crater is 600 m in diameter; maximum depth from which rocks might have been excavated in the Steno impact is approximately 120 m. The sampled blocks occur about 1/4 crater diameter out from the Steno rim, however, and probably were derived from some intermediate depth in the Steno target.

**Petrography.**--Returned samples of basalt may be grouped in hand specimen into five classes: 1) vesicular, porphyritic, coarse-grained basalts; 2) vesicular, coarse-grained basalts; 3) vesicular, fine-grained basalts; 4) dense aphanitic basalts; and 5) vesicular aphanitic basalts. Individual samples of types 1) and 2) above were generally termed "vesicular gabbro" by the Apollo 17 crew. Examples of 3), 4), and 5) above were described as "fine-grained basalt," "basalt," and "obsidian," respectively.

Rocks called vesicular porphyritic coarse-grained basalts are characterized by 3-4 mm blocky pyroxene-ilmenite intergrowths. Although these intergrowths have zoned pyroxene rims, the cores are evenly spaced throughout the samples, they have the general aspect of phenocrysts, and they clearly pre-date the groundmass minerals. They are not glomeroporphyritic clots in the strict sense because each consists of a single pyroxene crystal that contains a large number of euhedral ilmenite crystals. These composite phenocrysts are present in amounts ranging from 5 to 15 percent in the basalts of this class. Olivine is present in trace amounts in some of these rocks, and where present, it commonly occurs as partially reacted cores in the pyroxene phenocrysts. Pyroxenes are strongly zoned. Ilmenite content, while high for mare basalts as a whole, is relatively low compared to other Apollo 17 basalts, and averages somewhere between 15 and 20 percent. Plagioclase content averages 25 to 35 percent. Feldspar laths
and plates range up to 2 x 5 mm, and average about 1 x 3. Large plagioclase plates poikilitically enclose pyroxene and ilmenite. Groundmass size averages about 1.5 mm, and the texture ranges from variolitic through intergranular to trachitic. Some layering occurs in larger hand samples: in one case grain-size variations were noted; in others, feldspar and ilmenite laths are alternately foliated and randomly oriented. Vugs are more common than vesicles, although both may be present in the same rock. Vugs range up to 5 cm long, although the average size is 10 to 15 mm. Cavity content is variable but averages 10 to 15 percent; vugs are aligned in planes, clearly elongate, and layered by abundance. Vug and vesicle walls are rough, and, for the most part reveal only small projections of matrix crystals on their inner walls. In a few cases cavities are lined with an ilmenite-rich mineral assemblage, which is in all cases finer-grained than the groundmass. It may be that all cavities were lined, but that linings have been broken out of those on exterior surfaces by small-scale impact processes. The type example of this kind of basalt is sample 70035.

Vesicular coarse-grained basalts are very similar to those of the above class except that they lack the pyroxene-ilmenite phenocrysts, and their average grain size tends to be somewhat finer (about 1.0 mm). The ratio of vesicles to vugs is somewhat higher in phenocryst-free basalts of this kind, and the total cavity content, while still variable, is somewhat less (about 5 to 10 percent). Groundmass textures are, for the most part, intergranular, although locally plagioclase is poikilitic. This class of basalts is typified by sample 75055.
Vesicular, fine-grained basalts are characterized by a high proportion of vugs and vesicles with ilmenite-rich linings, and by a groundmass grain-size in the range 0.3 to 0.6 mm. Olivine is commonly present in rocks of this class as microphenocrysts in amounts of 1 to 2 percent. Pyroxene is not visibly zoned in hand specimen, and is generally amber in color. Plagioclase and ilmenite are uniformly lath-shaped. Ilmenite content tends to be greater than in the coarser-grained basalts, and probably exceeds 20 percent in most rocks of this class. These rocks are characterized by vug and vesicle abundances of more than 30 percent; some are frothy. Vugs and vesicles are invariably studded with mafic crystals—largely ilmenite and brown and yellow pyroxenes. The size of crystals in the cavity linings commonly exceeds the grain size of the groundmass of the basalt. The type example of this class is sample 71055.

Dense aphanitic basalts are characterized by their very low abundance of cavities, and their extremely fine grain size. These rocks are dense and tough. Olivine microphenocrysts are widely represented but not abundant. The average grain size of these rocks is on the order of 0.1 to 0.2 mm, and mineral abundances are not easy to estimate in hand specimen. Pyroxene and ilmenite contents, however, appear to be high. Cavities are present in amounts of less than 5 percent. They are generally small; some contain minerals that project from the groundmass, others are lined with felted ilmenite crystals. Sample 70215 is typical of this class of basalts.

Vesicular aphanitic basalts are characterized by abundant and exceptionally large cavities and very fine grain size. Small amounts of olivine are present in some samples, but the average grain size is so small as to preclude estimates of groundmass mineral proportions. Vugs are
commonly as large as a centimeter, and reach 3 to 4 cm. Cavities are typically lined with felted ilmenite crystals. Sample 74235 typifies this group.

It is possible that the two coarse-grained basalt types are gradationally related by decrease of porphyritic pyroxene-ilmenite aggregates, but our best judgment at present is that they represent separate flow units. It seems more likely that the vesicular fine-grained basalts are gradationally related to the vesicular aphanitic basalts through decrease in grain size and increase in vesicle size. The dense aphanitic basalts seem clearly to be fragments of a separate flow unit.

A few samples cannot at present be fitted into these five categories. Samples 71549, 71557, and 71568 are coarse-grained basalts, but we cannot at present say whether or not they are porphyritic. Sample 71597 contains 20 to 25 percent olivine--more than any other basalt in the collection.

Stratigraphy.--Table 4 is a classification of basalts by type and LRL number; rake samples are identified by an asterisk. Station numbers are implicit in LRL numbers\(^1\), and it is apparent from inspection of the table that the five types have a fairly wide distribution over the traverse area. It is also apparent that the distribution is asymmetric in detail: for example, only one coarse-grained basalt was collected at station 4, and no fine-grained types were collected at station 5. Since large \(^1\)LRV samples are given the station number to which the Rover was proceeding when the sample was taken.
Table 4. Hand specimen classification of Apollo 17 basalts.

<table>
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<th>Vesicular porphyritic coarse-grained basalts</th>
<th>Vesicular coarse-grained basalts</th>
<th>Vesicular fine-grained basalts</th>
<th>Dense aphanitic basalts</th>
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Not classified at this time: 71549*, 71557*, 71568*, 71597*

(?) indicates questionable classification
*indicates rake sample
a indicates chip from large boulder
b indicates loose rock larger than 5 cm
c indicates small fragment 1-5 cm
blocks are less likely to have been reworked than small ones, the
general relation of basalt fragments to their source craters is probably
better established from the larger blocks. The basalts in Table 4 are
therefore subdivided on the basis of whether they were collected from
sizable blocks, whether they were loose rocks on the surface, or whether
they were collected as small fragments in soil or rake samples. Sample
distribution by size and by classification type for all basalts examined
to date is plotted on a traverse map (fig. 47).

Figure 47 shows that large blocks were sampled only on the rims of
Shorty and Camelot craters, in the LM-ALSEP-SEP area, and at station 1.
Large blocks can be confidently related to specific source craters only
at Camelot and station 1, where some limits on depth of origin can be
inferred. In general, the small fragments appear widely mixed, and
their distribution seems to have little stratigraphic significance.

The large blocks on the rim of Camelot crater are, so far as we know,
all of vesicular, coarse-grained basalt. Maximum depth from which the
basalt boulders on its rim were excavated is about 130 m. Vesicular coarse-
grained basalt, represented by Camelot rim ejecta, may be the deepest
subfloor material sampled on the mission, and the contact between vesicular
course-grained material and the next shallower unit may be at some depth
less than 130 m.

At station 1, which lies about 1/4 crater diameter out on the flank
of Steno crater, the larger blocks and most of the loose rocks larger
than 5 cm in diameter are of vesicular fine-grained basalt. The station
is within the mappable continuous ejecta of Steno. If these are original
Steno ejecta, one would expect material from intermediate depths (<120 m)
in that part of the ejecta blanket.
Figure 47. Map showing distribution of subfloor basalt samples by size and type. (Apollo 17 panoramic camera photograph 2309).
In the LM-ALSEP-SEP area the large blocks are vesicular porphyritic coarse-grained basalts. They belong to the population of large blocks that characterizes the central cluster ejecta (see Regolith, Figure 51). Those in the LM area are difficult to relate to the continuous ejecta of any single crater and may, in fact, represent rays or ballistic ejecta from one or more central cluster craters. If so, they could have been derived from any depth within the sequence penetrated by the central cluster craters. The largest craters are about 600 m in diameter; hence maximum sampling depth is about 120 m (1/5 crater diameter). If this rock type intergrades with the vesicular coarse-grained basalt sampled at Camelot, it probably comes from a slightly higher stratigraphic level.

Except for the intensely fractured 5 m boulder at Shorty, which is vesicular, porphyritic, coarse-grained basalt, all fragments collected there are of dense aphanitic or vesicular aphanitic basalt. If the interpretation that the coarse basalts are related is correct, the large 5 m boulder may have been re-excavated by Shorty from the ejecta of some older large crater. The absence of this basalt among the other fragments that were collected at Shorty also suggests that it does not represent the upper part of the local bedrock, whereas the exclusive concentration of aphanitic basalt fragments suggests these may indeed represent shallow bedrock.

Sampled subfloor basalts were most probably derived from depths between about 20 and 130 m. The stratigraphically lowest basalt unit is interpreted to be the vesicular coarse-grained basalt sampled at the Camelot rim. This unit may grade upward into the coarse-grained porphyritic type sampled in the LM-ALSEP-SEP area. The next stratigraphic unit, proceeding upward, is the vesicular fine-grained basalt represented in
the Steno ejecta, and the aphanitic basalts of the Shorty ejecta may be the shallowest recognizable types. It should be stressed that this stratigraphic succession is speculative.

**Origin.**—The landing site valley is interpreted to be a deep graben formed at the time of the Serenitatis impact event. Geophysical data collected during the mission suggest that the graben floor is overlain by a kilometer or more of high density material (Talwani and others, in press; Kovach and others, in press). The sampled part of the subfloor basalt is interpreted to represent the upper part of the high-density graben-filling material, which may consist entirely of basalt. Radiometric age determinations (4th Lunar Science Conference) suggest that filling of the valley by lava flows may have been completed by about 3.8 b.y. ago. Prior to final accumulation of the Serenitatis mare fill, broad arching east of the Serenitatis basin tilted the subfloor lavas to the east as shown in the present 1° eastward tilt of the valley floor.
Highlands regolith and surficial deposits

The formation of a regolith of impact-generated debris has been a continuous process in the highlands of the Taurus-Littrow area as elsewhere on the moon. The amount of regolith formed on any surface is proportional to the length of time that the surface has been exposed to bombardment by impacting bodies, while the thickness of regolith now present is also a function of the rate of removal of the loosened debris. Theoretically there is no net loss of debris on flat surfaces because the debris ejected from a point of impact is balanced by the influx of debris from nearby and distant impacts. On slopes there is a net loss of regolith as impacts at lower levels fail to throw balancing amounts of debris to the higher levels. Such a net loss of debris, sufficient to expose bedrock, occurs at the lip of Hadley Rille, which was visited by Apollo 15 (Swann and others, 1972).

The rolling tops of the massifs and Sculptured Hills are considered very old surfaces with thick accumulations of regolith. On the generally flat surface above the Sculptured Hills in particular very thick regolith is implied by the close spacing of the many large craters. The regolith there is probably several tens of meters thick.

The upper slopes of the massifs are nearly free of regolith as is shown by exposures of bouldery zones that may represent near-surface bedrock. Such zones occur on the upper one-third of the South Massif, high on the East Massif, and on the upper two-thirds of the North Massif. These zones seem to have been the sources of most of the large boulders now resting lower on the slopes as indicated by boulder tracks. The slope of the Sculptured Hills just above station 8 is either mostly covered with thick regolith or is composed of material so friable that boulders or bedrock ledges are rapidly disintegrated by impact.
In addition to the net downslope movement of ejecta, loose material tends to roll, slide, or bounce down steep slopes in response to gravity. Such movements may be initiated by jarring due to impacts or seismic events or by oversteepening of slopes by cratering or faulting. Deposits formed by these processes are distinguished herein as surficial deposits.

The volumetrically most important surficial deposit is talus, a poorly sorted deposit composed of debris that has arrived essentially piece by piece at its place of deposition on the lower slopes. The boulders resting near the bases of slopes and at the ends of trails leading down the slopes are clearly visible parts of the talus. Impact fragments thrown onto the lower slopes also comprise part of the talus. At the bases of large slopes, the talus forms a continuous apron. Separate talus streaks rather than aprons are clearly visible on the inner slopes of some of the large fresh craters in the region.

Other surficial deposits, denoted herein as mass movement deposits, occur as masses of debris that lie beyond the bases of the slopes. These result when masses of loose debris, mostly regolith, move downslope as tumbling or sliding units driven by gravity and gathering sufficient momentum to carry beyond the steep slopes. These are commonly set in motion by some jarring event or when they become unstable on oversteepened slopes.

Surficial deposits are undoubtedly present on the lower parts and at the bases of all the large slopes of the highlands. In general the highland slopes meet the valley floor with smooth curves or there is a band of gentle slope between the valley and the steeper slope above. Although the gentle intermediate slopes may reflect the occurrence of a high-water mark of subfloor basalt, they are more probably talus.
deposits that may have been partially redistributed valleyward by impact. At stations 2, 6, and LRV-10, located on the gentle slopes immediately above the valley floor, fillets occur preferentially on the upslope sides of boulders. This indicates that debris is currently moving down the slope.

Along much of the base of the North Massif the talus intersects the valley floor at a sharp angle, which suggests that downslope movements have been renewed so recently, perhaps as a consequence of recent massif uplift, that impact processes have not had time to round the knickpoint. Part of this talus deposit has filled about 3/4 of Nansen crater. The Nansen impact undoubtedly caused oversteepening at the base of the talus slope. Probably the oversteepened, already fragmented rock debris started moving immediately to fill enough of the crater to re-establish equilibrium at the angle of repose.

Except for a few boulders with enough energy to climb slightly up the opposing slope of the north wall of Nansen, the debris merely slid into the crater but did not cross it. The present appearance of the massif slope into Nansen is that of an active talus apron that is slowly continuing to fill the crater.

The best documented mass movement deposit is the light mantle at the base of the South Massif, which is presumed to be a mass of debris that moved at a high rate down the face of the massif and obtained enough kinetic energy to spread out across the valley floor for a distance of about 6 kilometers.

In several places there is evidence for mass movement deposits older than the talus aprons. Subdued lobes extend from the highland slopes onto the valley floor along the base of the North Massif and along
the base of the South Massif between Nansen crater and Bear Mountain.

It is possible that some of these lobes are mass movement deposits overlying the subfloor basalt.

Mass movements and formation of talus deposits should date back to the earliest uplift of the massifs. If the bounding faults were, as we suppose, steeper than the angle of repose for loose fragments, there must have been a large transfer of material down the newly formed slopes until the angle of repose was reached. Thus mass movement deposits and thick talus aprons buried by subfloor basalt are inferred to overlie the still older rocks that formed the initial floor and walls of the Taurus-Littrow valley.
Regolith and mantle units of the valley floor

Introduction

The subfloor basalt is overlain by fragmental debris which is as much as 15 m thick where cut by Shorty and Van Serg craters. A complete understanding of this material must await detailed descriptions of the numerous soil and core-tube samples. Part of the material is undoubtedly impact-generated regolith similar to that developed on mare basalts elsewhere on the moon. Pre-mission geologic maps of the Apollo 17 site (Scott and others, 1972) indicated in addition to normal regolith, light and dark mantle units. The light mantle unit was identified and sampled at station 2, 2a, and 3 and at LRV sample stops 2, 5, and 6. The dark mantle was not recognized on the lunar surface as a distinct stratigraphic unit; a unique darkening component, if present, is apparently intimately mixed with the impact-generated regolith.

In this report, the fragmental material overlying the subfloor basalt is divided into an older regolith, information on which comes mainly from the Van Serg crater ejecta, and a younger regolith which occurs at or close to the surface. In addition, major crater ejecta blankets around the central crater cluster and Shorty and Van Serg craters are mapped and described as separate portions of the surficial debris layer. Figure 48 shows inferred stratigraphic relationships among these units.

Petrography of regolith breccias

A total of 15 samples of breccia (70018, 70019, 70175, 71515, 72135, 79035, 79115, 79135, 79175, 79195, 79225, 79226, 79227, and 79228) was collected from the valley floor at stations 1, 9, LM-ALSEP-SEP, and 114
Figure 48. Schematic diagram of stratigraphic nomenclature for valley floor deposits.
LRV-1. Most are probably soil breccias ejected from the older regolith. Some, however, such as 70019, are soil breccias formed by impacts in the younger regolith. These breccias are all dark- to very dark-gray, friable to moderately coherent with numerous penetrative fractures, and they typically have low clast populations. Samples 79115 and 79135 are layered, with alternating layers on the order of several centimeters thick that are distinguished by differing clast abundances. Similar layering is also visible in lunar surface photographs of breccia boulders at Van Serg crater (fig. 49). Surfaces of penetrative fractures are weakly slickensided, as was typical of regolith breccias returned by earlier Apollo missions. Slickensides are especially well-developed in sample 79135. The matrices of the breccias contain abundant dark glass and small lithic and mineral fragments derived largely from basalts. Most matrices appear to contain a small percentage of light gray, lithic debris (fig. 50) not of basaltic origin, and most contain variable percentages of orange glass spheres. Clasts larger than 1 mm make up from 1 to about 15 percent of the breccias; most clasts are smaller than 1 cm, although the crew reported clasts as large as 1/2 m in breccias of this type at Van Serg crater. Most clasts are fine- to medium-grained basalts, but some are feldspathic cataclasites containing yellow-green and grass-green minerals unlike those of the basalts. A small proportion of broken orange glass occurs as fragments larger than 1 mm.

Samples 70019 and 79175 are breccias composed of friable dark clods loosely cemented by dark glass; these also closely resemble rocks returned by earlier missions.
Figure 49. South-looking photograph of layered dark matrix-rich breccia in the ejecta of Van Serg crater. (AS17-142-21821)
Figure 50. West-looking photograph showing dark matrix-rich breccia boulders on rim of Van Serg crater. Note small white clasts in the foreground boulder and sheared aspect of the boulder to the right of the gnomon. (AS17-142-21791)
Regolith breccias were also found at two areas marginal to the valley floor. Five small breccia fragments (78508, 78515-78518) were found in a soil sample from station 8. Samples taken from SWP crater (78120) did not survive in pieces larger than 1 cm but appear to be similar to the other regolith breccias.

Older regolith

The ejecta of 90 m Van Serg crater includes a large proportion of soft dark matrix-rich breccias (figs. 49, 50) whose petrography is described in the preceding section. On the crater rim the breccias contain scattered light-gray lithic clasts that range up to about 2 cm in diameter. In the dark-matrix fragment-rich breccia on the crater floor, light clasts up to 1/2 m in diameter were seen.

The Van Serg breccias can be interpreted as regolith materials indurated by the impact that formed Van Serg crater. So far as we know, subfloor basalt was not excavated by the impact, although traverse gravity data (Talwani and others, in press) imply its presence in the subsurface. At least 15 m of regolith material is interpreted to have overlain the subfloor basalt in the Van Serg area when the crater was formed. The deepest part, represented by the Van Serg rim and floor rocks, is presumed older than the central cluster ejecta, and, hence, represents older regolith material.

Central cluster ejecta

The regolith is subdivided locally by recognizing as unique a portion considered to be the complex ejecta blanket of a cluster of craters that lie mostly to the south and east of the LM (fig. 51). This
Figure 51. Map showing the craters of the central cluster, related boulders, and the outline of the central cluster ejecta.
unit is termed the central cluster ejecta. It is distinguished by an abundance of blocks visible at the surface. Younger deposits are apparently too thin to bury the blocks in the unit, and the unit is too young for the blocks to have been reduced much in size by later impacts. The general distribution of blocks considered as central cluster ejecta is shown on figure 51. It is assumed that beyond a crater diameter from the nearest crater of the cluster, the fine-grained ejecta will be present in significant amounts only discontinuously. The unit probably does not extend as far as the LRV station at Tortilla Flat but may coat station 5.

The shape of the central cluster ejecta unit must be that of a very complex lens as it is composed of the ejecta, rim, and continuous blanket deposits of each of the craters within the cluster. At station 1, a 2 m deep crater does not appear to have penetrated the total thickness of the unit. This is expectable because station 1 is only about 1/4 crater diameter out from the rim of Steno, a member of the cluster. At the deep core site, about 40 m north of ALSEP central station, the central cluster ejecta is assumed to be thin because the site is more than a crater diameter away from any big member of the cluster. The deep core probably penetrated the entire unit; the change of soil appearance, seen in core-stem joints, at a depth of about 1 m probably indicates the base of the central cluster ejecta.

All blocks from the central cluster ejecta that were sampled are considered to be subfloor basalts. Smaller sampled fragments are more difficult to relate to a source, but the preponderance of surface rock fragments
from the LM-ALSEP-SEP and station 1 sites must have come from the subfloor basalt either directly or after re-excavation. Soil samples in the area must be considered as from the overlying younger regolith unit. The ejecta of the central cluster unit is inferred from crater depths and estimated regolith thickness to contain roughly three times as much subfloor basalt as older regolith. The older regolith itself contains a large percentage of fine basalt fragments, so the expected amount of basalt in the central cluster ejecta, or later re-excavated deposits is at least 80 percent. A net effect of the central cluster ejecta was to create an immature regolith surface layer overlying what must have been in general a very mature regolith. The immaturity is most easily seen in the common occurrence of blocks and rock fragments. It is also reflected in the lithologic composition by the high percentage of fragments newly derived from the subfloor basalt and but little mixed with exotic components such as impacting projectiles and ejecta from impacts in the highlands.

Samples collected from the central cluster ejecta, either directly from boulders protruding through the younger regolith, or from re-excavated parts of the unit adjacent to some recent crater, would be expected to consist mostly of subfloor basalts that originally came from the uppermost 120 m of that unit.

Younger regolith

Pre-mission mapping of the Taurus-Littrow valley showed the valley floor to be covered with a dark mantle unit considered younger than the subfloor basalts and older than the light mantle. With the recognition of the central cluster ejecta unit the definition of the dark mantle must
be modified. The surface layer of material that overlies the central cluster ejecta where it is present is herein considered as a unit, composed of both regolith and whatever "dark mantle" may be present, and is termed the younger regolith. The surface of this unit is what was traversed and all shallow soil samples should be part of it. The light mantle is considered as a local unit which is equivalent to some central part of the younger regolith. Regolith younger than the central cluster ejecta is certainly present at the landing site but a unique component that can be called "dark mantle" has not been identified. The reasons for having postulated a dark mantle unit during pre-mission mapping remain valid and will be briefly stated. The findings by Apollo 17 will then be summarized.

An area of very low albedo is present along the southeast edge of the Serenitatis basin as shown on full-moon photographs (fig. 52). The boundaries of this area have been mapped somewhat differently by different mappers and the interpretations of the very low albedo have differed, but the presence of an anomalous area has been recognized by previous workers (Scott and others, 1972; Wolfe and Freeman, 1972; Lucchitta, in press). Photographs taken during the Apollo 15 mission indicated that dark areas existed along the edge of Mare Serenitatis, in the valleys to the southeast, and as spots and discontinuous coatings in the highlands. This distribution seemed to require an interpretation of a thin mantling unit which conformed to underlying topography rather than a thick flow that obliterated underlying topography. Several experiments seemed to confirm the presence of a dark mantle unit, especially the spectral results that indicated a compositional difference (Pieters and others, in press).
Figure 52. Earth-based telescopic view of southeastern part of Mare Serenitatis showing light central mare, dark annular ring, and dark mantle. U.S. Navy photograph 5819.
Because it is widespread, the dark mantle was interpreted as most likely to be a volcanic pyroclastic deposit with many source vents located both in the highlands and in the valleys. The thickness was considered to range from as much as 20 m to as little as a few centimeters within the traverse area planned for Apollo 17.

The photographs taken from orbit during the Apollo 17 mission permit a re-evaluation of the very low albedo area seen on the full-moon photographs. The low sun angles of the Apollo 17 photographs permit individual mare units to be separated. A comparison of the Apollo 17 pictures with the full-moon picture shows that in the Mons Argaeus area the dark mantle edge cuts across mare unit contacts and is thus independent of the mare units. In the Mons Argaeus area, the dark mantle apparently overlies the high albedo, main mare unit of Mare Serenitatis. As seen in figure 52, the very low albedo of the dark mantle unit extends from the Mons Argaeus area eastward to include the landing site. Hills west of the landing site, in addition to having a very low albedo, have a more rounded and subdued appearance than adjacent brighter hills as though covered by a thin mantle.

In summary, the weight of evidence favors the formation of a dark mantle sometime after the deposition of the subfloor basalt in the Taurus-Littrow region. Evidence that the mantle is substantially younger than the subfloor is present in one area to the west of the landing site. The dark material is apparently very thin in the landing site and has been mixed with underlying material into a regolith unit.

The thickness of "dark mantle" that was suggested in pre-mission work ranged from several centimeters to 20 meters. The 20 m thickness was based on the hypothesis that Shorty crater had ejected only "dark mantle" from beneath light mantle. Most of the thickness at Shorty between
the light mantle and subfloor basalt is now considered older regolith and no distinct "dark mantle" layer was seen. If only several centimeters of "dark mantle" were present, it could be mixed with the regolith portion of the valley fill unit. Although no unique "dark mantle" component has been identified at the Apollo 17 site, the evidence for such a component at the edge of Mare Serenitatis seems inescapable. The low albedo may be caused by the presence of many tiny opaque black spheres found in the soils (Lunar Sample Preliminary Examination Team, in press).

New photographs from orbit reinforce another kind of evidence for the existence of a mantling component in the Family Mountain region just a few kilometers west of the traverse route. The evidence is the presence of areas of distinctly differently appearing surfaces. A triangular area between Family Mountain and the South Massif had been noticed on Orbiter V and Apollo 15 photographs to look as if it was slightly out of focus or fuzzy. The area includes the cone considered as a cinder cone by El-Baz (1972). On the Apollo 17 photographs taken at a low sun angle the area has many sharply defined small craters but larger features are definitely more rounded in appearance than they are in adjacent areas. A unit of mantling material of local extent seems the best explanation. Its area might include the west edge of the light mantle. Two other small areas of smooth surfaces nearby are adjacent to steep slopes and the smoothing unit could be debris derived from the nearby slopes.

The areas of smooth surface are considered as evidence for dark mantle, and their nearness to the traverse area suggests at least a few centimeters of dark mantle might exist in the traverse area. Such a thin unit with the degree of cratering seen in the smooth areas would be gardened by
impacts to a depth greater than its thickness; that is, it would not exist as a pure layer but would be mixed with underlying material into a regolith layer.

Light mantle

The light mantle is an unusual deposit of high-albedo material with finger-like projections that extend 6 km across dark plains from South Massif. The light mantle was interpreted from pre-mission photographs as a probable landslide or avalanche from the steep northern slope of South Massif (Scott and others, 1972; Howard, in press). The materials collected at stations 2, 2a, and 3 on the light mantle are similar to those that comprise South Massif, which supports this hypothesis. A cluster of apparent secondary craters that is visible on top of South Massif in the low sun angle panoramic camera photographs from Apollo 17 may record the impacts that initiated the avalanche.

Thirteen rock samples were collected from stations on the light mantle. Three of these (73155, 73217, 73235) are blue-gray breccias with light-gray clasts, and appear to be very similar to those collected at station 2. Sample 73217 is unusual in having a high proportion of a honey-brown mineral in the blue-gray portion of the breccia, and in having a veneer on one edge that is composed of blue-gray and white sugary clasts in a friable light-gray matrix. The main body of this rock may itself be a clast from light-gray breccia. Two samples (73215, 73255) are light-gray breccias composed of gray clasts in a light-gray friable matrix, and appear to be very similar to those sampled from boulder 1 at station 2. Sample 73215 has a crude foliation resulting from alternating bands of gray and white material. Three samples (73216, 73218, 73275) are greenish-gray breccias,
and appear to be similar to those collected from boulder 2 at station 2. These breccias are tough, sugary metaclastic rocks that contain a small proportion of irregular vugs with drusy linings. Typically they are composed of small proportions of clasts, mainly of plagioclase and yellow-green mineral debris; a few small lithic clasts composed of the same minerals may be present. Five samples collected at LRV-6 (74115-74119) are very friable, medium light-gray regolith breccias that contain a few white clasts.

The materials of the light mantle have an albedo of approximately 20 percent at the surface, which is slightly lower than the 25 percent of the massif slopes (fig. 63). This is probably due to the formation of a regolith and consequent darkening of the surface of the light mantle; continued downslope movement of materials of South Massif brings newly exposed materials to the surface of the massif, hence the darkening process is not so effective on the steep slopes.

At a distance the crew recognized that the bright aspect of the light mantle is primarily manifested by numerous small craters whose walls and rims are brighter than any in the dark plains. These craters probably expose fresh material.

The light mantle is mainly unconglomerated fines. Comments by the crew and photographs taken at stations 2a and 3, and while driving indicate that rocks greater than 25 cm across are sparse on the surface of the unit. Smaller rocks are fairly common but not abundant. A single large (3-4 m) boulder was encountered on the traverse. The scarcity of rocks suggests that the avalanche mainly consisted of regolith from the surface of the massif and did not involve the sliding of underlying bedrock.
The light mantle feathers out at its margins away from South Massif. Near the extremities of the mantle, Shorty crater and a smaller nearby crater appear to penetrate through the slide into underlying dark mantle material. Craters of this size nearer to South Massif do not penetrate to darker underlying material.

A greater thickness near the base of the massif is also suggested by the occurrence of numerous low ridges that become less distinct farther from the massif (fig. 53). The ridges are aligned in the apparent direction of movement of the avalanche away from the massif, and are spaced 25-100 m apart. On some orbital photographs, lineaments appear to form V's that open away from the massif. Similar lineament patterns are visible in areas of similar relief in an area just northwest of the light mantle. This suggests the V lineaments are not necessarily associated with the emplacement of the avalanche. The lineaments may be enhanced or created by the lighting condition, an effect that is not fully understood (Wolfe and Bailey, 1972; Howard and Larsen, 1972).

Descriptions by the astronauts at station 2a indicate that the upper portion of the light mantle is made up of 5-15 cm of medium-gray material underlain by light-gray material. The medium-gray material may be regolith which has been darkened by the formation of impact glass and from small contributions of dark soil from impacts occurring on the dark portions of the valley floor.

The trench (fig. 54) at station 3 was dug into the rim of a 10 m crater. The bottom of the trench exposed a marbled zone of light and medium-gray materials. The texture of the marbled material is similar to the textures and ejecta from terrestrial impacts such as Meteor Crater (fig. 55),
Figure 53. Panoramic camera photograph showing details of the light mantle and Lee-Lincoln scarp. (Apollo 17 panoramic camera photograph 2309)
Figure 54 A.  Pre-sampling view of trench wall at station 3, looking southwest.  (AS17-138-21148)

B. Enlargement of part of figure 54 A.  Hachured area is light-gray material; remainder is medium gray.  (AS17-138-21148)
Figure 55. Marbled texture in ejecta at Meteor Crater, Arizona. Compare with Figure 54. (U.S. Geological Survey, Center of Astrogeology photograph 76824)
and this material may be ejecta from the 10 m crater in which undiluted light mantle was mixed with pre-crater regolith. Overlying the marbled material is a 3 cm thick layer of light material, which may represent unmixed light mantle ejected from well below the pre-crater regolith. Where the trench was dug, on the rim of the 10 m crater, the upper part of the stratigraphic sequence had probably been eroded by impact of small meteorites (Soderblom and Lebofsky, 1972; Swann and others, 1972, p. 5-23). Thus the 3 cm layer of light material was probably significantly thicker at its time of deposition as crater ejecta. The uppermost layer in the trench is 1/2 cm of medium-gray material that is slightly lighter than the medium-gray component of the marbled zone. This is interpreted to be the regolith that has formed on the ejecta of the 10 m crater (fig. 56).

Using the turnover rates of the regolith calculated by Shoemaker and others (1970a), and modifying the result by assuming that the meteorite flux rate for the last $3 \times 10^9$ years has been about half what Shoemaker and others originally assumed (Shoemaker, 1971), we estimate that the 5 cm of regolith at station 2a has developed in the last $10^7$ years. It is not known, however, whether this is regolith developed upon the original surface of the light mantle, or if it is regolith developed on ejecta from post-light mantle deposition cratering. Therefore, 10 m.y. represents a minimum age for the light mantle, and other considerations, discussed below, suggest that the light mantle was deposited considerably earlier than 10 m.y. ago. The presence of regolith on the rim of the 10 m crater at station 3 indicates that the regolith is forming at a rate greater than the erosion of materials off the rim. It is probable, however, that the new medium-gray regolith would be thicker than 0.5 cm if it were not for this erosion.
Figure 56. Interpretation of stratigraphy as seen in trenches on the light mantle at stations 2a and 3.
One-half centimeter thickness of regolith on the surface of the 10 m crater at station 3 implies that the crater was formed about 1 m.y. ago, but because of the erosion of material from the rim of the crater, a 1 m.y. age for the crater is a more likely minimum age, and it is probable that the event occurred considerably earlier than 1 m.y. ago.

The size-frequency distribution and morphologies of craters on the light mantle suggest that its age is about that of the crater Tycho, or on the order of $10^2$ m.y. Crater counts show that the saturation crater size is 2-4 m. The saturation crater size at Tycho is 2.8 m (Morris and Shoemaker, 1968).

Another way to estimate age uses the crater degradation model of Soderblom and Lebofsky (1972). The diameter of the largest unshadowed crater (Dx) on Apollo 17 panoramic photograph number 2308 (sun angle SA = 16.3°) is $30 \pm 10$ m. From this, the age expressed as the diameter of a crater $D_L$ which would be eroded to 1° slopes was calculated as $13 \pm 5$ m. This compares with Tycho, where $D_L = <20$ (Soderblom and Lebofsky, 1972).

The light mantle is larger than most other lunar avalanches, and unlike many, has no conspicuous source ledge on the slope above. New evidence suggests that the avalanche was triggered by secondary impacts from a distant crater. This evidence is the recognition on Apollo 17 orbital photos at low sun of a cluster of 100 m craters on the top of South Massif and a similar cluster on the plains adjacent to the northwest side of the light mantle. The clustered craters appear to be secondaries from a distant crater to the south, such as Tycho. If impacts from the same cluster of secondaries impacted the northwest slope of South Massif,
they could have initiated the avalanche. Elsewhere on the moon are other avalanches that clearly were similarly initiated by the impact of crater ejecta on slopes facing away from the primary crater (Howard, in press).

**Shorty crater**

Shorty is a fresh 110 m crater located near the north edge of the light mantle. It resembles other craters that have been interpreted as young impact craters. The floor is hummocky, with a low central mound and with marginal hummocks that resemble slumps forming discontinuous benches along the lower parts of the crater wall. The rim is distinctly raised and is sharp in orbital views. The dark ejecta blanket is easily distinguished from the reflective surface of the surrounding light mantle, which it overlies. However, the low albedo of the ejecta is similar to that of the dark younger regolith elsewhere on the plains surface.

Sampling was carried out in a low place on the rim crest of Shorty just south of a 5 m boulder of fractured basalt (fig. 57). Debris that may have been shed from the boulder lies on the nearby surface, and blocks are abundant on this part of the inner crater wall. All of the rocks examined are basalt. Most are intensely fractured and some show irregular knobby surfaces that resemble the surfaces of terrestrial flow breccias. Rocks range from angular to subrounded; some are partially buried; some are filleted, including the upslope sides of a few of the larger boulders on the inner crater wall.

The floor material, exposed in the central mound (fig. 58), is blocky and extremely jagged. It may differ in lithology from the basalts of the rim. The hummocks or benches that encircle the floor as well as portions of the walls are also blocky. However, the wall, the rim, and the
Figure 57. Southwest rim of Shorty crater showing sampling area and areas of orange soil (dashed lines). Large sampled boulder on rim is 5 m wide. View is to northwest. (AS17-137-21009, 21011)
Figure 58. North view across 110 m diameter Shorty crater. Far crater wall, blocky benches encircling floor, and jagged rocks of central mound are visible (AS17-137-21001)
outer flank of Shorty crater consist largely of dark material that is much finer grained than the floor. On the crater rim, fragments ranging up to about 15 cm in diameter typically cover less than 3 percent of the surface. Scattered coarser fragments, ranging up to at least 5 m in diameter, are present.

The crater rim and flanks are pitted by scattered, small (up to several meters) craters whose rims range from sharp to subdued. Typically their ejecta are no blockier, except for clods, than the adjacent surfaces.

Although a volcanic origin has been considered for Shorty crater, no compelling data to support the volcanic hypothesis have been recognized. The type of pure accumulation of basaltic spatter or cinders that forms steep-sided terrestrial volcanic cones has not been recognized; nor does the steeply raised sharp rim of Shorty resemble the low rounded rims of terrestrial maar craters. Most probably Shorty is an impact crater. Its blocky floor may represent either impact-indurated soil breccia or the top of the subfloor basalt, which is buried by 10-15 m of poorly consolidated regolith, including light mantle (fig. 59). The predominantly fine-grained wall, rim, and flank materials are probably ejecta derived largely from materials above the subfloor, and the basalt blocks may be ejecta derived from the subfloor. Regardless of its origin the crater is clearly younger than the light mantle.

Unusual orange soil is known to occur in two places on the Shorty crater rim crest as well as in the ejecta of a small, fresh crater high on the northwest interior wall of Shorty (fig. 57). A trench exposed an 80 cm wide orange zone that trends parallel to the crater rim crest for several meters. The orange soil is markedly coherent as shown by the
Figure 59. Schematic cross-section through Shorty crater. Vertical scale exaggerated.
systematic fractures in the trench wall (fig. 60). It is also zoned; a wide central reddish zone, now known to consist largely of small red and orange glass spheres and fragments, grades laterally to marginal yellowish zones about 10 cm wide (fig. 61). The yellowish zones in turn are in sharp steep contact with light gray fragmental material that is probably typical of the Shorty crater rim. A double drive tube placed in the axial portion of the colored zone bottomed in black fine-grained material now known to consist of tiny, opaque, black spheres. The contact between orange and black glass occurs within the upper drive tube at a depth estimated from the debris smeared on the exterior of the tube to be about 25 cm.

The origin of the red and black glass materials is uncertain. A radiometric age determination of about 3.7 billion years for the orange glass material (Schaeffer, Fourth Lunar Science Conference) implies solidification during or shortly after the period of subfloor basalt volcanism. Shorty crater, of course, is much younger. Such glass, whether ejected from an impact crater or a volcanic vent, may have lain as a layer (or layers) either within the upper part of the subfloor basalt sequence or deep within the regolith overlying the subfloor basalt in the target area. If so, the orange and black glassy materials may represent clods of ejecta excavated by the Shorty impact. However, the symmetrical color zonation of the orange soil and apparent parallelism of the zone's steep boundaries with both the internal color banding and the axis of the rim crest are improbable features for a clod of ejecta unless the clod has undergone alteration subsequent to its emplacement, a process heretofore unknown on the moon. The color zoning and steep contacts might

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Figure 60. North-looking photograph showing orange glass material and light-gray fragmental material exposed in trench on rim crest of Shorty crater. Short lines show more prominent fractures in the orange glass material. (AS17-137-20986)
Figure 61. Cross-section showing materials in trench and double drive tube on Shorty crater rim crest.
be more readily explained if the glass material, derived from a layer of similar material in the target were mobilized by the impact and driven dike-like into concentric fractures. However, the occurrence of black glass material below the orange glass material in the double drive tube (fig. 57) and the absence of the black glass at the surface suggests the existence of horizontal or gently dipping layering, a geometric arrangement that would be reasonable in a clod of ejecta but is difficult to reconcile with injection of old glass material into a concentric fracture.

A 0.5 cm thick layer of dark fine-grained soil overlies both the orange soil zone and the adjacent light gray fragmental material. This dark surface material may represent the regolith that has formed since the formation of Shorty crater.

Van Serg crater

Van Serg is a fresh, 90 m impact crater. It has a blocky central mound about 30 m across, discontinuous benches on the inner walls, and a raised blocky rim with a distinct crest out from which slopes the blocky ejecta blanket. The bench is particularly well developed on the north wall, where the astronauts reported that materials in the crater wall above the bench were darker than those below. Its ejecta blanket is distinct in lunar surface views because of its blockiness, which is greater than that of the adjacent plains. The ejecta blanket can be recognized, at least in part, in orbital photographs as a distinct topographic feature, but it is inseparable from the adjacent plains on the basis of albedo.
Rocks in the Van Serg ejecta range up to about 30 cm, with a few boulders as large as 1 to 2 m in diameter. At the rim crest, fragments larger than 2 cm cover about 10 percent of the surface, but they cover no more than 3 percent of the surface on the outer flank of the crater. The predominant rock type at station 9 is soft or friable dark matrix-rich breccia. White clasts up to about 2 cm in diameter are visible in some rocks on the crater rim, and light-colored clasts possibly as large as 1/2 m in diameter were seen in rocks of the central mound. Some rocks are slabby. Closely spaced platy fractures occur in some, and a few show distinct alternating light and dark bands. Some frothy glass agglutinate was also sampled. In spite of their apparent softness, the rocks are typically angular. Many are partially buried, but there is little or no development of fillets even on the steep inner walls of Van Serg crater.

Soil at the surface is uniformly fine and gray with no visible linear patterns. The uppermost one or two centimeters is loose and soft. A trench on the outer flank of the crater exposed about 10 cm of light gray fragmental material below a 7 cm layer of dark surface material (fig. 62).

Craters younger than Van Serg are extremely rare in the station 9 area. A few small (about 1 m) craters are present. A large subdued depression immediately south of Van Serg may be an old crater now mantled by Van Serg ejecta. Frequency and angularity of blocks, paucity of craters, general absence of fillets, and uneroded nature of crater rim and central mound attest to the extreme youth of Van Serg crater. Evidence for its being younger than Shorty is equivocal. Its rim seems to be slightly sharper than the rim of Shorty in orbital photographs, and small craters may be slightly more abundant on the Shorty rim.
Figure 62. North-looking photograph showing trench on outer flank of Van Serg crater about 70 m from rim crest shows dark surface material overlying light gray fragmental material (AS17-142-21827)
There is no evidence that the Van Serg impact excavated subfloor basalt, and the fragment-rich breccias and dark matrix-rich breccias of its floor, rim, and outer flank are probably regolith breccias indurated in the Van Serg impact. Hence at least 15 m of regolith is inferred to overlie the subfloor basalt in the Van Serg area.

Near coincidence of the albedos of the blocky Van Serg ejecta blanket and the nearby smooth regolith surface is puzzling. Possible explanations are that the elusive "dark mantle" material is represented in the ejected older regolith as well as at the present regolith surface or that the dark surface material recognized on the crater rim and flank has masked any distinction between the Van Serg ejecta and the nearby undisturbed regolith surface.
STRUCTURAL GEOLOGY

Geologic structure of the landing site

The valley in which Apollo 17 landed is bounded by high steep-sided mountain blocks that form part of the mountainous eastern rim of the Serenitatis Basin. The blocks are thought to be bounded by high angle faults that are largely radial and concentric to the Serenitatis basin. Hence the valley itself is interpreted as a graben formed at the time of the Serenitatis impact. Some of the prominent faults are not concentric or radial to Serenitatis, although major displacements probably occurred along them when Serenitatis was formed. They may have been pre-existing zones of weakness related to older basins such as Tranquillitatis or to the so-called lunar grid.

Massifs and Sculptured Hills

Each massif block probably is a structural entity uplifted during the Serenitatis event. Rejuvenation of these older structural elements may have occurred during the Imbrian event as suggested by the elongation of the Taurus-Littrow valley, which is radial to both Imbrium and Serenitatis. Segmentation of the massifs may be an inheritance from the even earlier Tranquillitatis event.

The massifs adjacent to the landing site appear similar in slope, albedo, and degree of cratering. They contrast with the closely spaced domical hills of the Sculptured Hills, which also form fault block mountains. No unequivocal Sculptured Hills material has been recognized among the samples; hence the reason for the differing appearances of the massifs and the Sculptured Hills is not clearly understood. They may consist of distinctly different materials with more friable material.
occurring in the Sculptured Hills. For example, the massifs may consist largely of pre-Serenitatis ejecta uplifted in the Serenitatis event, whereas the Sculptured Hills may consist mainly of Serenitatis ejecta. Alternatively, each might consist mainly of a different facies of Serenitatis ejecta, with more thorough recrystallization increasing the coherence of the massif materials. On the other hand, the initial materials of the two units may be similar, but subsequent deformational history may have caused their different aspects. For example, relatively recent uplift selectively effecting the massif blocks may have rejuvenated slope processes to create the relatively uninterrupted steep slopes that distinguish the massifs from the Sculptured Hills.

Single, major bounding faults are inferred along the face of each mountain block. Such faults can be recognized at younger, less modified basin margins (e.g., Orientale, Imbrium). These faults are probably very steep - more than 60° and probably close to 90° for the radial faults. They are buried under the talus aprons and lie valleyward from the lowest outcrops visible on the massif faces. Sharp knickpoints at the massif bases suggest that additional later uplift may have reinitiated downslope movement of talus.

Valley

The Taurus-Littrow valley appears to be a long narrow graben radial to the Serenitatis basin. The graben probably is composed of several structural blocks and did not move as an entity. Its floor, now buried, is thus visualized as having steps between blocks whose separate tops are at different elevations. These buried tops probably resemble in roughness the present tops of the massifs and Sculptured Hills.
The present uniformity of the valley floor is due to the continuity of the valley fill surface. The fill probably consists of rubble created at the time of block faulting overlain by basalt (subfloor) and regolith material that are younger than any large differential movements of the structural blocks. The surface continuity must be due mainly to infilling by subfloor basalts which are interpreted from geophysical measurements (Kovach and others, in press; Talwani and others, in press) to be a kilometer or more thick.

The valley floor slopes about 1° toward its eastern end. This small dip is interpreted as structural rather than depositional because it is coincident with other regional surface slopes. The NASA Lunar Topographic Orthophoto Map (1972) shows an east-tilted belt that includes the Taurus-Littrow valley and the floor of the crater Littrow (fig. 1). The tilt is interpreted to record development of a broad arch formed by uplift along the mountainous Serenitatis rim after the subfloor basalt fill had accumulated in the Taurus-Littrow graben. Long shallow grabens largely concentric to the Serenitatis basin were created during this deformation. They were truncated by younger mare filling deposits that subsequently accumulated in the Serenitatis basin.

Younger deformational features on the valley floor include the Lee-Lincoln scarp, which is discussed subsequently, and several small sharp grooves that are visible on the surface of the light mantle in the low sun angle photographs taken with the Apollo 17 panoramic camera. These appear to be small grabens similar to the small graben rilles that are common on mare surfaces. They were probably formed by minor tectonic movements that occurred after the emplacement of the light mantle.
Lee-Lincoln scarp

The origin and nature of Lee-Lincoln scarp is still a puzzle. Its steep face nearly everywhere faces east, commonly in a pair of steps whose total relief reaches 80 m in the center of the valley. A few prominent smaller west-facing scarps are present, best seen from Lara crater northward where the shadowed highlighting is enhanced by the whiteness of the light mantle (fig. 53). Individual segments die out along strike as another picks up the displacement; in places, it appears almost braided. The trends of individual segments of the scarp appear to alternate between north and northwest as if controlled by an underlying prismatic fracture system. This same set of trends is identifiable in segments of the scarp along the west base of North Massif. Here, however, the scarp is single and always faces east--toward the massif, in the form of a reverse or thrust fault. Forty kilometers to the north the scarp passes out onto the dark plains surface where it cuts Rima Littrow I (fig. 1).

The overall length, trend, asymmetry and morphologic character of the scarp resembles that of the larger wrinkle ridges of the adjacent Serenitatis mare (Howard and others, in press). This suggests a common origin--possibly folding and thrusting of a thin plate (decollement sheet) eastward. Relative youth of this deformation is indicated by transection of fresh, Copernican craters by wrinkle ridges in the mare, by the fresh, possibly rejuvenated scarplets that may be younger than the light mantle, and by the good preservation of the scarp in the unconsolidated materials of the North Massif face. An alternative possibility is that the Lee-Lincoln scarp is the surface trace of a complex high angle fault that changes strike where it follows the old North Massif boundary fault immediately north of the valley.
ALBEDO MEASUREMENTS

Lunar surface and orbital photographs were used to map albedo in the Taurus-Littrow area. Down-sun 60 mm photographs at each traverse station in combination with high resolution 500 mm photographs of the mountain slopes provided the control for photometric measurements made from orbital photographs.

Relative film densities over Apollo 15 panoramic camera frames 9557 and 9559 were measured on a Joyce-Loebl microdensitometer. The scanning aperture was 50 μm square, equivalent to an integrated 9 m² of lunar surface. Film densities, after calibration to normal albedo as determined in down-sun lunar surface photographs in areas of fine-grained regolith, and after adjustment to remove the effects of topographic slopes, are proportional to albedos of lunar surface materials. Topographic corrections were derived from the preliminary topographic map, part of the Littrow region of the moon, NASA, 1972.

The resulting map (fig. 63) was smoothed to remove scanning noise and high frequency albedo variations. Important qualifications are that the usual lunar photometric function was applied for the Apollo 17 area and that the albedo adjustments for topography are approximate due to inaccuracies of slope orientations. Comparisons of albedo values are most reliable between areas with similarly oriented slopes.

The albedo map (fig. 63) can be compared with an orbital photograph of the area at similar scale (fig. 64). The east-west trending valley floor is the most continuous physiographic unit. Except for the light mantle, in which albedo ranges from 14 to 23 percent, the albedo of the valley floor is low. It ranges from 14 percent in the western part to
Albedo values were obtained by digitization of panoramic photographs AS-15-9557 and 9559. Albedo values were adjusted for local slope effects.

Figure 63. ALBEDO MAP OF APOLLO 17 LANDING AREA
Figure 64. Orbital photomap of area covered by figure 63. (Sun angle 55°)
Base map prepared by U.S. Army Topographic Command (TPC) under the direction of the Department of Defense for National Aeronautics and Space Administration, 1972.
9 percent over the eastern portion. The albedo of the floor generally
increases gradually (3-4 percent) along a 300 to 600 m wide outer zone
(generally depicted by unit 6) adjacent to the base of the surrounding
mountains. This zone is considered to represent mixing of lighter
highlands regolith with the much darker floor regolith, and it is
remarkably narrower than the 1 to 2 km width of a similar zone at the
Apollo 15 site (Swann and others, 1972). The lighter valley floor area
between South Massif and Family Mountain may represent a more extensive
mixing zone, perhaps related to the proximity of uplands material at the
surface or to its presence at very shallow depths in the subsurface.
Even so, the mixing zone at the foot of South Massif (depicted by map
unit 5) seems to be as narrow as along the north side of the valley
floor.

The massifs and hills surrounding the valley generally have albedos
ranging from 15 to 34 percent, as is normal for lunar highlands. However,
local small depressions contain dark material with albedo as low as 10
percent. The lightest regolith material occurs on the steepest slopes
and on top of some rounded domes. The slopes of South Massif are lightest
from 1/4 to 3/4 of the way down the slope front and darker near the top
and bottom of the slopes. The small undulating plains area on top of
South Massif (unit 5) is as dark as the valley floor between the massif
and Family Mountain (14 percent) with tongues of the material draping
over the edge of upper massif slopes and extending down the steeper
slopes. North Massif has lighter regolith on the tops of rounded domes
and down the upper 2/3 of the slopes. Small closed depressions on top
of the massif that are too small to be shown in figure 63 show slight
darkening in the western part and increasing darkening toward the

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eastern part. The Sculptured Hills show a general darkening toward the east with the regolith in similar small depressions ranging in albedo from 17 to 14 percent. The large upland basin to the northeast has extensive regolith with 12 percent albedo. The East Massif is similar to the North Massif, but the small closed depressions darken toward the southeast. Albedos as low as 10 percent occur immediately south of the map area.

The surfaces of the small intramassif and intrahill depressions are from 1,200 to over 2,000 meters higher than the floor of the Taurus-Littrow valley. These dark areas are considered to contain bedrock material similar to the surrounding massif or hill bedrock. There is no observed geologic evidence to suggest that any mare-like basalt could have flooded these small depressions. Yet the darker albedos of many depressions are similar to the albedos of the mare areas and of the Taurus-Littrow valley floor.

The lunar regolith is generally considered to be developed primarily by repetitive crushing of local bedrock by impact processes (Shoemaker and others, 1970). The product is a fine-grained layer which is darker than the original bedrock. Mare basalt fragments with albedos ranging from 13 to 21 percent occur with fine-grained regolith of 9 to 13 percent albedos (Swann and others, 1972). The ratio of the albedo of the fine-grained regolith to the contained rock fragments for mare surfaces ranges from 0.62 to 0.68 and for highland surfaces from 0.55 to 0.68. Thus, the percentage of regolith darkening with maturity is only slightly greater in the highlands, 32 to 45 percent, than for the mare, 32 to 38 percent.
On the floor of the Taurus-Littrow valley within the landing area, average normal albedos of the floor and the subfloor basalt blocks are 12 and 18 percent, respectively, yielding a ratio of 0.66, which is average for mare regolith darkening. In the vicinity of MOCR crater at the east end of the valley, albedos of the dark floor material and the crater wall are 9 and 18 percent, respectively, giving a ratio of 0.50, which is the greatest degree of mare regolith darkening ever measured on the moon. It is probable that some darker material (black glass?) has been deposited over and mixed with an original bedrock-derived regolith. The surface in this area, which coincides with the darkest albedo unit (8), also appears somewhat smooth and subdued, in contrast to the landing area.

North and South Massifs show average albedos of about 26 percent for fine-grained regolith and 34 percent for rocks, producing a ratio of 0.76 for regolith darkening, slightly less darkening than at Hadley Delta (Apollo 15 site). The Sculptured Hills and the East Massif show local maximum albedos that are similar to the maxima for the North and South Massifs. This suggests that bedrock with similar albedo occurs in all four mountain masses. The average albedo of the Sculptured Hills and East Massif is about 18 percent, which gives an average regolith darkening ratio of 0.53. This is considerably darker than 0.74 on Hadley Delta and 0.76 on the North and South Massif.

Careful study of the Sculptured Hills and East Massif revealed eleven small closed depressions with areas of smooth floors. The normal albedo of the regolith on the depression floors should show the maximum darkening effects since mass wasting processes tend to expose
fresher brighter material on slopes. The albedos of the depression floors decrease eastward in the northern part of the Sculptured Hills, ranging from 17 to 12 percent. The albedos of depression floors in the East Massif decrease southward beyond the mapped area from 14 to 10 percent. The regolith darkening ratio decreases from 0.50 to 0.29, which is much lower than any other measured area on the moon. A darkening ratio of 0.50 or less strongly implies addition of material darker than local regolith, but a ratio of 0.29 is unequivocal evidence for addition of dark material from another source.

The increased darkening to the south and east of regolith developed on different geologic materials, i.e. the east valley floor, Sculptured Hills, and East Massif, is best interpreted as the effect of addition of material darker than 9 percent normal albedo from sources to the east or southeast of the Taurus-Littrow valley. The absence of any apparent ballistic shadowing by the mountains indicates that the material was transported along high angle trajectories. The only lunar material known to possess such low albedo is dark to black glass or glassy material. A pyroclastic-like mantle of dark glassy material fits the observed geological relationships and albedo data.
GEOLOGIC HISTORY

Before the Serenitatis basin was formed, older major basin impacts should have covered the Taurus-Littrow area with sheets of ejecta derived from still older ejecta deposits and ultimately from igneous lunar crustal material. Because of their proximity, Tranquillitatis and Pecunditatis should have contributed large amounts of ejecta that may be exposed in the massifs. The older major basin impacts should also have developed radial and concentric fracture zones comparable to those around the younger, better preserved basins. Some of these fractures were presumably reactivated in the Serenitatis event.

The major physiographic units (e.g., massifs, Sculptured Hills, Taurus-Littrow valley) of this region were produced by the impact that formed the Serenitatis basin. Major radial faults bound the Taurus-Littrow valley and Mons Argaeus; major concentric faults bound the South Massif and the East Massif.

Deposits of Serenitatis ejecta must have been thick and widespread. By analogy with deposits around younger multi-ring basins such as Imbrium and Orientale, they are interpreted to comprise most of the Sculptured Hills terrain. Whether Serenitatis ejecta comprises a major portion of the massifs as well or occurs only as a veneer overlying older ejecta deposits is unknown. Deposits from the younger multi-ringed basins are probably also present but have not been specifically identified. Such deposits, which may be present on the highlands and beneath or intercalated with the lower part of the subfloor basalts could have been derived from the Nectaris, Humorum, Crisium, Imbrium, and Orientale basins, listed oldest to youngest (Stuart-Alexander and Howard, 1970).
Uplift of the massifs following the Serenitatis impact was probably rapid and occurred along high angle faults. Thus the graben walls are thought to have stood at angles steeper than the angle of repose. Rapid reduction of slope angles by accumulation of thick talus wedges on the lower slopes and of mass movement deposits on the graben floor must have occurred.

With the major physiographic features now formed, the next major event was flooding of the valley by lavas that filled it with about 1,200 m of basalt (Kovach and others, in press). Samples collected from the upper 130 m of the subfloor basalt show it to be similar to Apollo 11 mare basalt but slightly older with an age of about 3.8 b.y. (4th Lunar Science Conference).

Either as a late stage of the subfloor basalt volcanism or as totally separate slightly younger events, spherical orange and black glass particles were deposited in the area of Shorty crater and probably over much of the Taurus-Littrow region. Whether of volcanic or impact origin, the glass spheres, which solidified about 3.7 b.y. ago (Fourth Lunar Science Conference), were rapidly buried so as to be preserved for eventual excavation at Shorty crater.

After subfloor basalt extrusion was completed, warping around the Serenitatis margin produced a broad anticlinal arch with the Taurus-Littrow valley and Littrow crater on its east limb. Long narrow grabens such as Rima Littrow I formed along the Serenitatis basin side of the crest of the arch, which was eventually overlapped by younger mare basalts of the Serenitatis basin.
A long period of regolith formation and accumulation of surficial deposits ensued. Some of the earlier formed regolith may be represented by the floor materials of Van Serg, in which light-colored lithic clasts presumably derived from the uplands are common. Relatively late events recorded in the regolith sequence are the formation of an older crater cluster (Camelot, Henry, Shakespeare, Cochise), formation of the younger central cluster (Steno, Emory, Sherlock, Powell, etc.), and emplacement of the light mantle as an avalanche of debris that may have been triggered when ejecta from Tycho struck the North Massif.

Photogeologic evidence in the general Taurus-Littrow area indicates that an unusually dark mantling deposit was deposited on both the plains and upland surfaces during this long period of regolith formation. The unusual concentration of glass spheres in dark soils from the valley (Phinney, 4th Lunar Science Conference) may represent the "dark mantle" thoroughly intermixed with more normal impact-generated regolith.

Relatively young deformational events that took place during the long period of regolith formation include slight eastward tilting of the Serenitatis basin (Sjogren and Wollenhaupt, 1973) and development of wrinkle ridges in Mare Serenitatis and the Lee-Lincoln scarp in the landing area. Very recent deformation is suggested by the occurrence of small grabens on the surface of the light mantle and by the apparent youth of parts of the Lee-Lincoln scarp.

The youngest large events of special significance to the mission were the impacts that formed Shorty and Van Serg craters. Both are younger than the light mantle and penetrate deeply into the regolith.
REFERENCES


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APPENDIX A

Lunar orientations of some Apollo 17 rock samples at the time of their collection (see tables 5 and 6)

Figures 65 through 87 show the lunar orientations of rock samples. Orientations were determined by correlating lunar photographs of samples before collection with shapes and shadow characteristics of the same samples in the Lunar Receiving Laboratory under oblique illumination with nearly collimated light. The light source in the laboratory simulates the sun. It is important to stress that the orientations shown are those at the time of collection, and do not necessarily apply to the entire history of a rock's exposure on the lunar surface. Tumbling and turning of some rock fragments on the lunar surface has already been well documented.

The small lettered cube included in each laboratory orientation photograph is not meant to indicate the lunar attitude of samples but is designed to tie the lunar perspective orientations to documentary views of the same samples in orthogonal and stereoscopic photographs ("Mugshots") taken in the Lunar Receiving Laboratory using the same orientation cube.

Not all of the photographs showing sample orientations are in this section of the report; some have been included with the discussions of the South Massif, North Massif, and Sculptured Hills. Table 5 identifies the appropriate illustrations for these samples.
Table 5. Lunar surface orientations.

<table>
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<tr>
<th>Sample number</th>
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<td>E/N*</td>
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</tr>
<tr>
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<tr>
<td>70275</td>
<td>T</td>
<td>E</td>
<td>67</td>
</tr>
<tr>
<td>71035</td>
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<td>E/B</td>
<td>68</td>
</tr>
<tr>
<td>71055</td>
<td>S</td>
<td>E/T</td>
<td>69</td>
</tr>
<tr>
<td>71175</td>
<td>N/T</td>
<td>S/W</td>
<td>70, 71</td>
</tr>
<tr>
<td>72155</td>
<td>T</td>
<td>N/E?</td>
<td>72</td>
</tr>
<tr>
<td>72215</td>
<td>B</td>
<td>S</td>
<td>8</td>
</tr>
<tr>
<td>72235</td>
<td>N</td>
<td>B/W</td>
<td>8</td>
</tr>
<tr>
<td>72255</td>
<td>S/B</td>
<td>W</td>
<td>8</td>
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<tr>
<td>72275</td>
<td>B</td>
<td>S</td>
<td>8</td>
</tr>
<tr>
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<td>N/B</td>
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<td>N</td>
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*Letters (T, B, N, S, E, W) denote faces of the reference cube used in the laboratory photographs.
Table 6. Rocks for which lunar surface orientations are undetermined.

| 70017 (c) | 75015 (b) (unsuccessful attempt) |
| 70018 (c) | 76035 (c) |
| 70019 (b) | 76055 (c) |
| 70035 (c) | 76135 (d) |
| 70135 (c) | 76215 (c) (unsuccessful attempt) |
| 70175 (c) | 76235 (b) |
| 70215 (c) | 76315 (a) |
| 70295 (c) | 76335 (c) |
| 70315 (d) | 77017 (c) |
| 71036 (e) | 77035 (c) |
| 72135 (d) | 77075 (b) |
| 72415 (a) | 77115 (a) |
| 73215 (c) | 77215 (a) |
| 73216 (c) | 78235 (a) |
| 73217 (c) | 78255 (a) |
| 73218 (c) | 79035 (c) |
| 74235 (c) | 79115 (a) (unsuccessful attempt) |

Reason for undetermined orientation

(a) Size too small or rock not identified in lunar surface photographs.
(b) Breakage in transit.
(c) Insufficient lunar surface photographs.
(d) LRV sample: surface photography insufficient.
(e) Inaccessible because of special storage.
Figure 65. Sample 70185 compared to part of AS17-136-20721, looking north. Inset photograph: S-73-17797.
Figure 66. Sample 70255 compared to part of AS17-135-20537, looking southwest. Inset photograph: S-73-
Figure 67. Sample 70275 compared to part of AS17-135-20539, looking north. Inset photograph: S-73-
Figure 68. Sample 71035, chipped from a boulder, compared to part of AS17-136-20739, looking northwest, down-sun. Inset photograph: S-73-17804.
Figure 69. Sample 71055, chipped from the same boulder as 71035, compared to part of AS17-134-20394, looking north. Inset photograph: S-73-17798.
Figure 70. Sample 71175 compared to part of AS17-136-20741, looking northwestern, down-sun. Inset photograph: S-73-17803.
Figure 71. Sample 71175 compared to part of AS17-134-20399, looking north. Inset photograph: S-73-17802.
Figure 72. Sample 72155 tentatively compared with a rock that shows in part of AS17-135-20649, an LRV driving photograph, looking north. No post-sampling picture available. Inset photograph: S-73-
Figure 73. Sample 73155 compared to part of AS17-138-21098, looking northwest. Inset photograph: S-73-
Figure 74. Sample 73235 compared to part of AS17-138-21143, looking south. Inset photograph: S-73-16968.
Figure 75. Sample 73255 compared to part of AS17-138-21148, looking southwest, down-sun. Inset photograph: S-73-
Figure 76. Sample 73275 compared to part of AS17-138-21144, looking south. Inset photograph: S-73-16969.
Figure 77. Sample 74255 compared to part of AS17-137-20990, looking south-west, down-sun. The sample broke from the boulder along existing fractures. Inset photograph: S-73-
Figure 78. Sample 74275 compared to part of AS17-137-20982, looking north. The sample broke from the larger rock along a planar fracture. Inset photograph: 5-73-
Figure 79. Sample 75035, chipped from a boulder, compared to part of AS17-145-22138, looking northwest. Inset photograph: S-73-
Figure 80. Sample 75055, chipped from a boulder, compared to part of AS17-145-22148, looking north. Inset photograph: S-73-17796.
Figure 81. Sample 75075, picked from the top of a large boulder, compared to part of AS17-145-22154, looking south. Inset photograph: S-73-17800.
Figure 82. Sample 75075 compared to part of AS17-133-20337, looking west, down-sun. Inset photograph: S-73-17801.
Figure 83. Sample 76015, from a large boulder, compared to part of AS17-140-21411. Inset photograph: S-73-
Figure 84. Sample 77135, chipped from a large boulder, compared to part of AS17-146-22388, looking northwest, down-sun. Inset photograph: S-73-
Figure 85. Sample 78135 compared to part of AS17-146-22365, looking north. Inset photograph: S-73-
Figure 86. Sample 79175, in approximate lunar orientation, compared to AS17-146-22421, looking south. Inset photograph: S-73-
Figure 87. Sample 79215 compared to AS17-143-21837 looking north. Inset photograph: S-73-
During the sample orientation studies it became apparent that the special lighting used for orienting rock samples was also useful for enhancing structural and textural alignments, that, for some samples, could be correlated with mappable lineations in boulders from which the samples were broken. This is especially true for the breccias. Most of the lineations in breccia samples appear to be closely spaced, thin shears. Some of these have deformed pre-existing minerals and clasts or controlled recrystallization so as to form alternating light-and dark-colored streaks that offer variable resistance to lunar weathering on exposed surfaces. Other alignments are apparently covered by changes in composition, possibly representing initial layering in the breccias. Figures 88 through 96 are views of some samples that portray enhanced linear features.
Figure 88. Sample 72215 (see figure 8 for reconstructed lunar orientation) with enhancement of surface lineations by oblique lighting. (S-73-17987)
Figure 89 A. Sample 72255 in reconstructed lunar orientation as viewed cross-sun. (S-73-17989)

B. Surface lineations that may be the traces of shear planes in sample 72255. Reconstructed lunar orientation with camera lower than in A above.

C. Sample 72255 in same view as in B above with oblique lighting adjusted to enhance closely spaced shear traces on weathered surface.
Figure 90. Sample 72275, taken from the top of a foliated, stratified breccia boulder (fig. 8) at station 2. Compositional layering seen in the sample is apparently parallel to a set of lineaments in the boulder (S-73-17988)
Figure 91 A. Sample 72395 in reconstructed lunar orientation showing shears on weathered surface. (S-73-

B. Sample 72395 in same view as in A (above) with oblique lighting adjusted to accentuate surface streaks that may be the traces of thin shears.
Figure 92 A. Sample 76255 in reconstructed lunar orientation (S-73-

B. Sample 76255 with oblique lighting adjusted to accentuate traces of thin shear zones on freshly broken surface.
Figure 93. Sample 76275 (see fig. 23 for reconstructed lunar orientation) with oblique lighting adjusted to accentuate traces of shears on weathered surface.
Figure 94 A. Sample 76295 in reconstructed lunar orientation (S-73-
B. Sample 76295 with freshly broken surface obliquely lighted
to enhance linear shear traces.
C. Alternate view of sample 76295 with freshly broken surface
obliquely lighted to enhance linear shear traces.
Figure 95 A. Weathered surface of sample 77135 in reconstructed lunar orientation. (S-73-

B. Sample 77135 showing traces of shears in weathered surface in oblique lighting.

C. Sample 77135 showing freshly broken surface lighted obliquely to accentuate shear traces.
Figure 96. Sample 78235 in reconstructed lunar orientation with oblique lighting to enhance traces of shears on weathered surface (S-73-17962),
APPENDIX B

Panoramic views and detailed planimetric maps of the traverse stations

EXPLANATION

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<tr>
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<tr>
<td>□</td>
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<td>LEAM</td>
<td>Lunar Ejecta and Meteorites Experiment</td>
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<td>Lunar Mass Spectrometer Experiment</td>
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<tr>
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<td>Lunar Surface Gravimeter Experiment</td>
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<tr>
<td>LSP</td>
<td>Lunar Seismic Profiling Experiment</td>
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<tr>
<td>PAN Δ</td>
<td>60 mm Hasselblad panorama</td>
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<tr>
<td>RTG</td>
<td>Radioisotope Thermoelectric Generator</td>
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<tr>
<td>SEP</td>
<td>Surface Electrical Properties Experiment Transmitter</td>
</tr>
<tr>
<td>LRV</td>
<td>Lunar Roving Vehicle, dot shows front of vehicle</td>
</tr>
<tr>
<td>●</td>
<td>Boulder - letters refer to large blocks on maps and pans</td>
</tr>
<tr>
<td>○</td>
<td>Crater</td>
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Figure 97. Pan south of LM (AS17-137-20866 to 20893)

Figure 98. Planimetric map of the LM-ALSEP-SEP area
Figure 99. Pan northwest of ALSEP central station (AS17-136-20863 to 20710)

Figure 100. SEP partial pan (AS17-134-20437 to 20446)
Figure 101. Station 1 east pan (AS17-134-20408 to 20431)

Figure 102. Planimetric map of station 1

Figure 103. Station 1 west pan (AS17-136-20744 to 20776)
Figure 104. Station 2 northeast pan (AS17-138-21053 to 21073)

Figure 105. Planimetric map of station 2

Figure 106. Station 2 southwest pan (AS17-137-20926 to 20956)
Figure 110. Station 4 west pan (AS17-133-20229 to 20256)

Figure 111. Planimetric map of station 4
Figure 112. Station 5 east pan (A817-133-20339 to 20361)

Figure 113. Planimetric map of station 5

Figure 114. Station 5 west pan (A817-145-22159 to 22183)
Figure 115. Station 6 south pan (AS17-141-21575 to 21603)

Figure 116. Planimetric map of station 6

Figure 117. Station 6 north pan (AS17-140-21483 to 21508)
Figure 118. Station 7 north pan (AS17-146-22339 to 22363)

Figure 119. Planimetric map of station 7

Figure 120. Planimetric map of station 8

Figure 121. Station 8 west pan (AS17-142-21726 to 21745)

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Figure 122. Station 9 west pan (AS17-142-21798 to 21824)

Figure 123. Planimetric map of station 9