# PART D

# "D-CALDERA": NEW PHOTOGRAPHS OF A UNIQUE FEATURE

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A unique D-shaped structure at latitude 18°40′ N, longitude 05°20′ E was discovered during the Apollo 15 mission within one of several smooth, dark patches in the hilly region between Montes Haemus and Montes Apenninus. Its unusual shape and interior morphology have generated much interest among selenologists (refs. 30-10 and 30-11). Orbital photographs and visual observations (sec. 28) were planned for the Apollo 17 mission to acquire additional information pertaining to the setting and detailed characteristics of this structure. Photographs of the area were obtained by using the metric and Hasselblad cameras (with both color and high-speed black-and-white film); no panoramic camera photography of the region was planned because the area had been adequately covered with the same camera during the Apollo 15 mission. The purpose of this report is to give a brief description of the Apollo 17 photographs of the D-shaped structure and its surroundings.

The patches of dark material between Montes Haemus and Montes Apenninus are separated by hilly and rugged units that are segmented by fractures radial to Mare Imbrium. Two of these fractures bound the area of the D-shaped structure. The Apollo 17 low-Sun photographs of the area indicate that a horst, at least 150 km long and 30 km wide (fig. 30-11), has been uplifted relative to the surroundings. The fault on the western side of the horst continues southward into eastern Mare Vaporum, as suggested by a prominent mare ridge system (fig. 30-11).

The dark patches filling the valleys between the foothills of the mountains have been previously mapped as Imbrian mare material (ref. 30-12). Flow structures and collapse depressions evident in the Apollo 17 low-Sun photographs further suggest that they may be basalt flows (fig. 30-12(a)). Thus, the units are most probably volcanic in origin and younger than the surrounding and underlying highlands (ref. 30-13).

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The D-shaped structure is a depression, 2 km wide and 3 km long. The feature is approximately 300 m deep and displays a raised rim that is 1.5 km wide. The floor is occupied by two different morphological units:

1. A flat unit that is subdivided into two albedo units, gray and white; the latter forms an annulus around the gray unit (ref. 30-11). Apollo 17 visual observations (sec. 28) and color photographs indicate that the whole floor has a bluish tone.

2. Approximately 50 disconnected, smooth, bulbous structures of various sizes; these structures produce a blister-like appearance.

There is a 1-km-diameter crater west of the D-shaped structure that, before the Apollo 17 mission, was believed to have a dark halo. The Apollo 17 low-Sun photographs indicate that the darkening is probably due to slope effects; the crater is near the border of an 18-km-wide dome that encircles the D-shaped structure (fig. 30-12(b)) and that appears to have fewer craters on it than on the surrounding mare (fig. 30-12(c)). It is proposed that the D-shaped structure is a collapse caldera atop an extrusive volcanic dome. It is further proposed to adopt the informal name "D-Caldera" to designate the feature.

From the preceding description, the following sequence of events may be reconstructed to explain the formation of observed features (fig. 30-13).

1. The Imbrium event clearly affected the triangular-shaped region between Montes Haemus to the east and Montes Apenninus to the west. Pre-Imbrian terrain was faulted, most of the major faults being radial to the Imbrium basin. Deposition of Imbrium ejecta is evidenced by the linear ridge units, also radial to the basin. The ejecta is probably kilometers thick because it masks preexisting structures (fig. 30-13(a)).

2. Faulting must have continued as a result of adjustment of the crust after formation of the Imbrium basin. At some later date, basaltic lavas migrated to the surface along the fractures and formed relatively thin mare patches; older highland

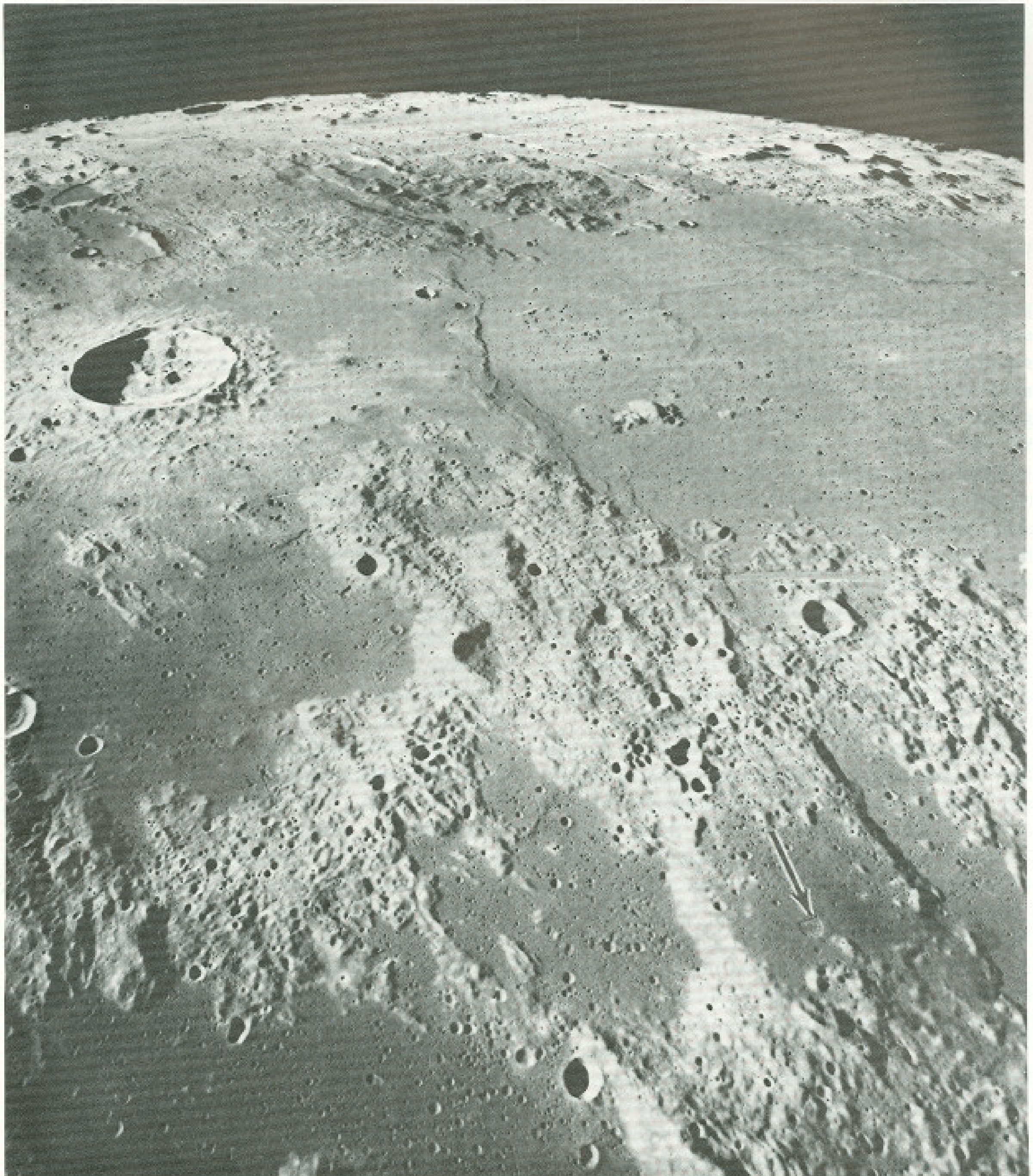

FIGURE 30-11.–Oblique view (looking southward) showing most of Mare Vaporum (upper right) and the 40-km-diameter crater Manilius (upper left). Four of the dark patches of mare material between Montes Haemus and Montes Apenninus are in the lower half of the photograph. The D-shaped structure is indicated by an arrow. The fault that separates the two patches in the lower right continues into Mare Vaporum, as indicated by the mare ridge in the upper middle portion of the photograph (Apollo 17 metric camera frame AS17-1671).

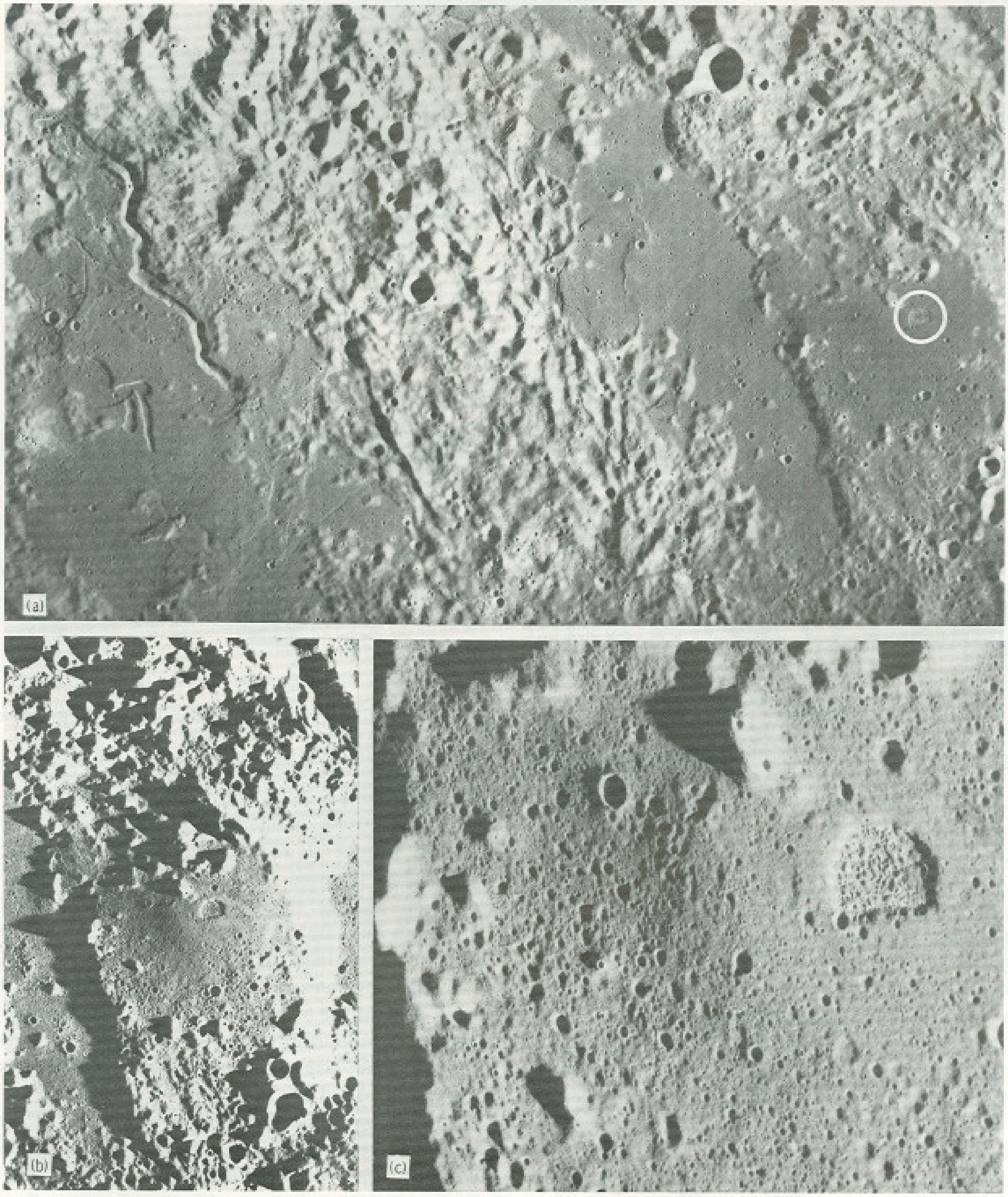


FIGURE 30-12.–Three views of the D-shaped feature. (a) Dark patches atop highland units have flow scarps and mare ridge structures (right of center) and collapse depressions and flow channels (left edge) similar to basaltic lava flow. The straight part of the D-shaped structure (circled) is 3 km long (Apollo 17 metric camera frame AS17-1822). (b) Low-Sun-angle view of the area surrounding the D-shaped structure, showing the dome that encircles it (Apollo 17 metric camera frame AS17-1237). (c) The small, bulbous domes in the floor of the D-shaped depression are shown in this view taken during the Apollo 17 mission using the Hasselblad camera with very-high-speed black-and-white film. The dome that encircles the structure displays fewer craters than does the surrounding mare surface (AS17-154-23672).

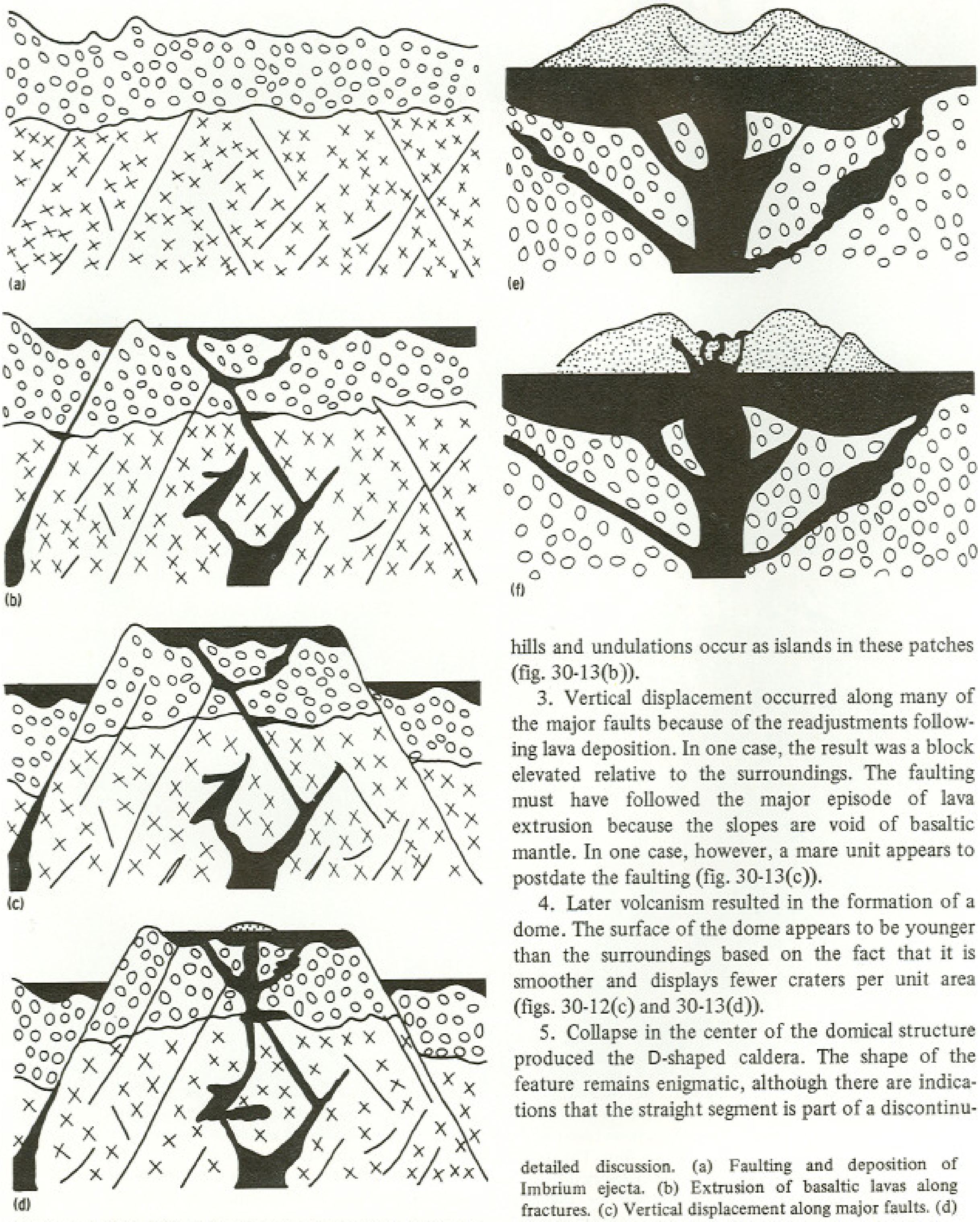


FIGURE 30-13.–Schematic illustration of the stages of faulting and subsequent volcanism that led to the formation of the D-shaped collapse caldera. See text for detailed discussion. (a) Faulting and deposition of Imbrium ejecta. (b) Extrusion of basaltic lavas along fractures. (c) Vertical displacement along major faults. (d) Formation of dome by late-stage extrusion. (e) Formation of D-shaped caldera by collapse. (f) Formation of bulbous floor structures by minor extrusions.

hills and undulations occur as islands in these patches (fig. 30-13(b)).

3. Vertical displacement occurred along many of the major faults because of the readjustments following lava deposition. In one case, the result was a block elevated relative to the surroundings. The faulting must have followed the major episode of lava extrusion because the slopes are void of basaltic mantle. In one case, however, a mare unit appears to postdate the faulting (fig. 30-13(c)).

4. Later volcanism resulted in the formation of a dome. The surface of the dome appears to be younger than the surroundings based on the fact that it is smoother and displays fewer craters per unit area (figs. 30-12(c) and 30-13(d)).

5. Collapse in the center of the domical structure produced the D-shaped caldera. The shape of the feature remains enigmatic, although there are indications that the straight segment is part of a discontinu-

ous fault in the mare unit (fig. 30-12(b)). It is probable that the depression would have been circular had that fault not existed (fig. 30-13(e)).

6. The collapse appears to have been followed by numerous small extrusions that formed the bulbous structures in the caldera floor (fig. 30-13(f)). These positive features appear to be small domes, and several seem to have repeated the collapse sequence as they display apex craters (ref. 30-11).

The preceding sequence, which is deduced from the characteristics of the region studied, may be pertinent to lunar volcanic processes that result in the formation of small-scale domes and collapse depressions.

## PART E

## ERATOSTHENIAN VOLCANISM IN MARE IMBRIUM: SOURCE OF YOUNGEST LAVA FLOWS

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Orbital photographs taken at low-Sun illumination during both the Apollo 15 (ref. 30-14) and Apollo 17 missions have provided excellent data on the lava flows in southwestern Mare Imbrium. These photographs have been used recently to present a detailed photogeologic evaluation of these flows and their role in mare volcanism of Eratosthenian age in the basin (ref. 30-15). Eruption of these flood basalts apparently took place in at least three major episodes with suggested dates of 3.0 ± 0.4 billion years (phase I), 2.7 ± 0.3 billion years (phase II), and 2.5 ± 0.3 billion years (phase III) using the mare age-dating method described by Soderblom and Lebofsky (ref. 30-16) and recent data by Soderblom and Boyce (ref. 30-17).[1]

The lavas of the Eratosthenian eruptive phases flowed directly toward the center of the Imbrium basin with the earliest (phase I) materials pooling, in what must have been the lowest portion, near the breached southeastern rim of the Sinus Iridum Crater (fig. 30-14). Present topography of the basin shows that this region is still the lowest point (ref. 30-20). The average surface slopes from the volcanic source region southwest of Euler Crater to the basin center are estimated to be between 1:100 and 1:1000. Lavas assigned to the three eruptive phases extended for 1200, 600, and 400 km, respectively, indicating a marked decrease in lava volume available for extrusion between 3.0 and 2.5 billion years. Flow thicknesses and areal extent indicate that a minimum of $4.0 \times 10^4$ km$^3$ of mare material covering an area of $2.0 \times 10^5$ km$^2$ was probably deposited in the Imbrium basin during this 0.5-billion-year interval.

The youngest lavas (phase III) have been traced to a possible source fissure at latitude 22°50′ N, longitude 31°20′ W (fig. 30-15, lower left). A very-low-albedo, linear cinder cone complex on the southeastern end of the island Euler $\beta$ trends northeast-southwest and may be structurally related to the inferred eruptive vent (fig. 30-16). The presence of a distinct linear fissure cannot be visually documented on the Apollo photographs, but its approximate location and northeast-southwest trend were suspected after photogeologic mapping showed that the phase III flow lobes narrow sharply southwestward

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[1]The method involves visual examination of an orbital photograph to determine the maximum diameter $D_s$ of craters the internal slopes of which have been reduced to slopes less than the Sun elevation angle $S_s$. Using the Soderblom (ref. 30-18) model of small crater impact erosion, measurements of $D_s$ are converted to an equivalent diameter $D_L$ of a crater eroded to an interior slope of 1° under the same flux that has eroded a crater of diameter $D_s$ to a slope of $S_s$. Values of $D_L$ are considered synonymous with relative age, which is directly proportional to the total number of craters that have accumulated on the surface. The $D_L$ values measured for the three phases of Eratosthenian basalts in Mare Imbrium are 235 ± 20, 175 ± 5, and 160 ± 5 m, respectively. The $D_L$ value for the youngest flows is in agreement with that of Boyce and Dial (part C of sec. 29).


FIGURE 30-18.–Nikon 35-mm photograph showing a low-albedo volcanic plateau within the regional volcanic source province of the Eratosthenian lavas in the Imbrium basin (AS17-155-23736). See figure 30-17 for location of this area in the regional volcanic province.

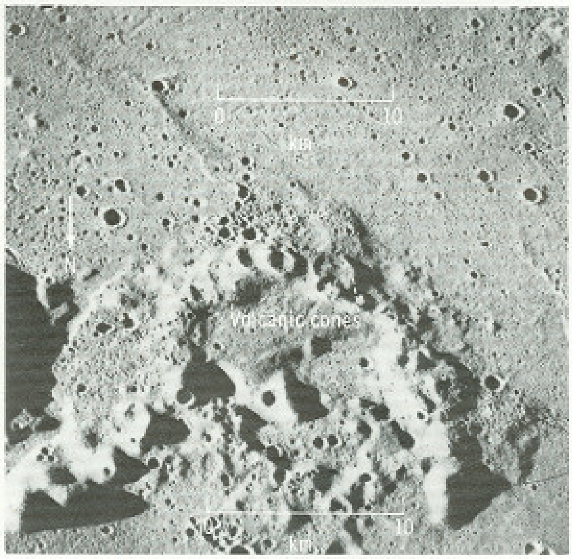


FIGURE 30-19.–Nikon 35-mm photograph showing arcuate volcanic cinder cone complex with associated lava flows (AS17-155-23738). See figure 30-17 for location of this area in the regional volcanic province.

ridge. The largest ridge northeast of Mons La Hire best illustrates the evidence for pre-phase II ridge topography with the dike-like, sinuous features on the ridge crest probably formed in the post-phase III period (figs. 30-20, 30-21(a), and 30-21(b)). Growth of this particular ridge may have begun in Imbrian time. Present photogeologic evidence indicates that the flows surmounted slopes of at least 0.5°. Postflow normal faulting with displacements of at least 145 m is present in the ridge system approximately 60 km north of Euler $\beta$ (fig. 30-15).

Subdued, 1- to 2-km-wide and 40- to 50-m-deep, leveed channels are present lengthwise along the center of the most extensive phase III flows (fig. 30-15). This type of lava channel is common in terrestrial basalt flows, but the lunar channels are several orders of magnitude larger. The braided lava channels in a complex series just north of the suggested phase III source vent are on the order of 400 to 800 m wide and 40 to 70 m deep (fig. 30-22). Lunar application of the equations of Shaw and Swanson (ref. 30-23) and Daneš (ref. 30-24) has shown that, even on nearly horizontal slopes, the lunar flow heights and extreme lengths are in accord with calculated values when the reduced-gravity environment and the higher density of the basalt melt are considered (ref. 30-15). In addition, the high rates of lava extrusion appear to be the primary cause of extreme flow lengths; the reduced viscosity of lunar basalts (ref. 30-4) probably plays a secondary role.

The orbital photographic documentation of southern Mare Imbrium begun by the Apollo 15 crewmen and completed by the Apollo 17 crewmen has enabled photogeologists to understand more clearly at least those volcanic processes that resulted in late-stage mare flooding. The distinct lava flows in the Imbrium basin were recognized as perhaps the best preserved result of such processes (ref. 30-25); until the Apollo missions, however, photographic resolution and quantitative topographic data were insufficient for a thorough evaluation.

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