INA, A LUNAR CALDERA? P. L. Strain and Farouk El-Baz, National Air and Space Museum, Smithsonian Institution, Washington, D.C. 20560

Ina, an unusual D-shaped depression, is located in Lacus Felicitatis, north of Mare Vaporum (Figs. 1, 2). Its floor is covered with many small protrusions and it lies on a gently-sloping dome which rests on a basalt plateau. The feature was first noticed on Apollo 15 panoramic camera photographs by E. A. Whitaker (1) who pointed out its apparently unique character. El-Baz (2,3) proposed that it was a collapse caldera displaying evidence of episodic volcanic activity. Using detailed topographic data from Lunar Topographic Orthophotomaps (LTO's) at 1:250,000 and 1:10,000 scale, it is now possible to more accurately depict the morphology and structure of the feature and the surrounding region.

Ina lies in a region between the Apennine Mountains of the Imbrium basin and the Haemus Mountains of Serenitatis. The area is characterized by highland materials dominated by NW-SE trending lineations that are radial to Imbrium (3). A pattern radial to Serenitatis is also evident although less pronounced. Irregular patches of maria are present and are often bordered by scarps radial to the basins. Ina is located in one of these patches, atop a basalt plateau that bisects Lacus Felicitatis (Fig. 1). Scarps bordering the plateau have slopes of about 9^{o} and reach heights of as much as 600 m. The western scarp extends into the highlands to the south and appears to emerge as a mare ridge that crosses Mare Vaporum (3) and terminates northeast of Sinus Medii in a region marked by dark mantle material (4). In Mare Vaporum the ridge marks a change in elevation in the order of 100 m.

Lacus Odii, northeast of Felicitatis, exhibits an increase in elevation of more than 400 m from west to east. A lobate flow front (Fig. 1) indicates that during the latest episode of extrusion of mare lavas, flows in Odii traveled from west to east. This suggests the original topographic slope was different from that of the present day and indicates subsidence or uplift of part of Odii subsequent to mare emplacement. This evidence, coupled with the existence of the relatively raised Felicitatis plateau suggests the vertical displacement of much of the maria in the region.

Topographic maps indicate that Ina rests on a dome which is about 15 km in diameter and which rises more than 200 m above the surface of the plateau (Fig. 3). The dome exhibits a lower crater density than the surrounding mare (3). Along Ina's rim is a raised "collar", about 1.6 km wide marked by a crater density even lower than the rest of the dome. Overlapping flow fronts indicating a flow direction away from Ina exist on the collar and nearby. In addition, a possible lobate flow on Ina's north side suggests that material may have flowed from the rim into Ina.

Ina measures about 2.8 km along its straight edge and is about 60 m deep. Four units can be distinguished on its floor (Fig. 2):

Unit 1--a light-colored, rough-textured unit covering most of Ina's floor. The surface displays interlocking subdued hummocky forms.

Unit 2--a dark-colored, hilly unit found predominantly along the eastern edge of the floor, and apparently overlying unit 1. This dark material is characterized by small hills with summit depressions and may represent a pyroclastic deposit.

Unit 3--smooth-textured, sparsely cratered, protrusions on the floor. Many of these structures, here referred to as mounds, are somewhat flat-topped while others are more rounded. The individual mounds have heights ranging from about 5 m to more than 25 m and areas from .003 km^2 to .26 km^2. Some appear to have summit craters. However, there is no consistent relation

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between crater diameter and mound diameter, as has been noted in mare domes (5). Many of these craters may, therefore, be fortuitous impacts. There seems to be, however, a tendency for the craters to favor the tallest mounds. 80% of the mounds over 15 m high have the large summit craters, while less than 20% of those below 15 m do. At the margin of Ina's floor the mounds are discrete, whereas in the center they coalesce to form one large complex, parts of which exhibit a concentric plan. The preferential location in the lower central part of the depression and the concentric pattern which may reflect a fracture system support the idea (3) that the mounds are extrusive features. In addition, the material constituting the mounds is often indistinguishable from the mare material on the rim and walls. This similarity is substantiated by observations by the Apollo 17 astronauts that the mounds and the material surrounding Ina are the same color (6).

Alternatively, these mounds may be analogous to the features called Dimmuborgir (Dark Castles) found near Mývatn, northern Iceland, as was suggested by Wood et al. (7). The Dark Castles are "lava pillars" 10-20 m high which are found in a circular depression about 1-2 km in diameter and about 15 m deep (8). Barth (8) suggested the area was a lava lake that had drained leaving the pillars (areas that had already solidified) standing. In support of this theory he cited vertical grooves similar to slickensides, and horizontal markings at different levels on the pillars as evidence of the sinking of the lake's crust. Wood (pers. comm.) suggests similarly that the often flat tops and relatively steep slopes indicate that the Ina mounds may represent the remnants of a former surface which has partially collapsed. However, a difficulty exists in that the Ina mounds are not all at the same level, their summits at times differing in elevation by as much as 20 m. Van Bemmelen and Rutten (9) state that rather than consisting of layered lava, the Dimmuborgir pillars are scoriaceous material, perhaps the result of turbulence and eddies in the lava lake. This hypothesis would suggest a different origin for the features in Ina if the Ina mounds are composed of material much the same as that found on the rim.

Unit 4--bright annuli (Fig. 2) found around the mounds and hummocks, and outlining Ina's floor. The material was interpreted as sublimates by Whitaker (1). Alternatively it may represent light-colored scoria collecting in annular depressions. A similar unit exists on the lava lake in Keanakakoi Crater southeast of the Kilauea caldera (10, plate 105B).

We propose that extensive fracturing of the area, caused by its proximity to two of the largest nearside impact basins, allowed the abundant extrusion of mare lavas and the later collapse and subsidence of much of the region. During the last stages of extrusion the 15-km dome was formed on the plateau in Felicitatis. The extrusive origin of this feature is supported both by its low crater density and by its distinct color on the IR-UV photographs of Whitaker (11). It is considerably bluer than any of the surrounding mare materials. This is in keeping with the observation by Apollo 17 astronauts that the Ina structure has a "bluish tint" (6). Ina's location at the summit of an extrusive dome suggests that it is indeed a caldera. Eruptions in Ina are indicated by the different units on its floor. Flow structures on the young "collar" that suggest flow both toward and away from the crater, as well as small dome-like features on the rim suggest a late-stage episode of volcanic extrusion along rim fractures.

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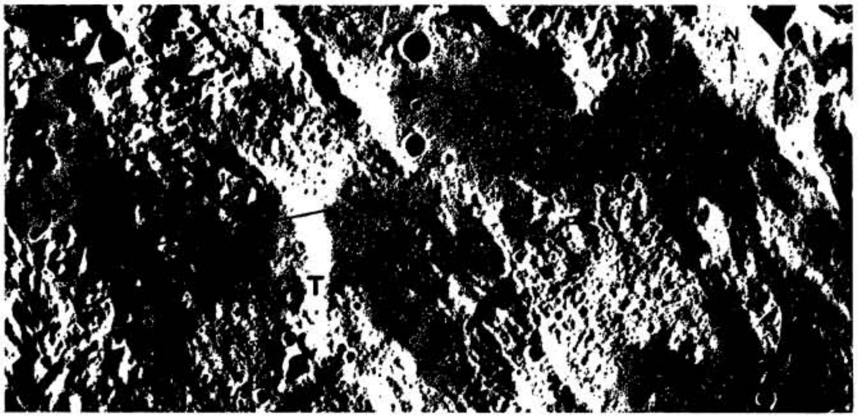


Fig. 1. Ina and surrounding region. Scale is about 1:1,400,000. I marks Ina. F marks lobate flow front. Line is trace of profile in Fig. 3a. AS17-M-1517.

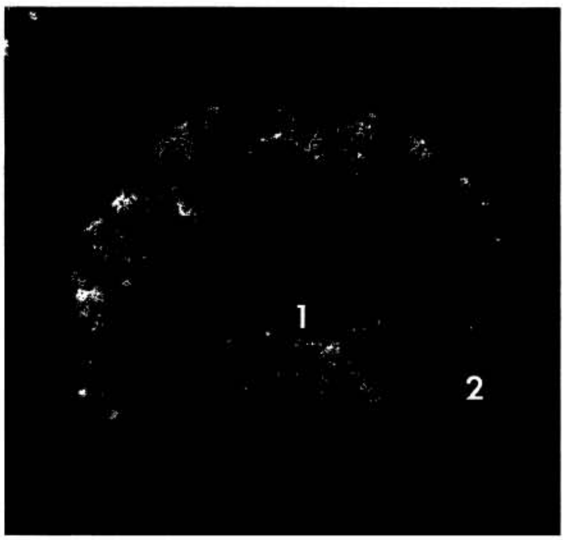
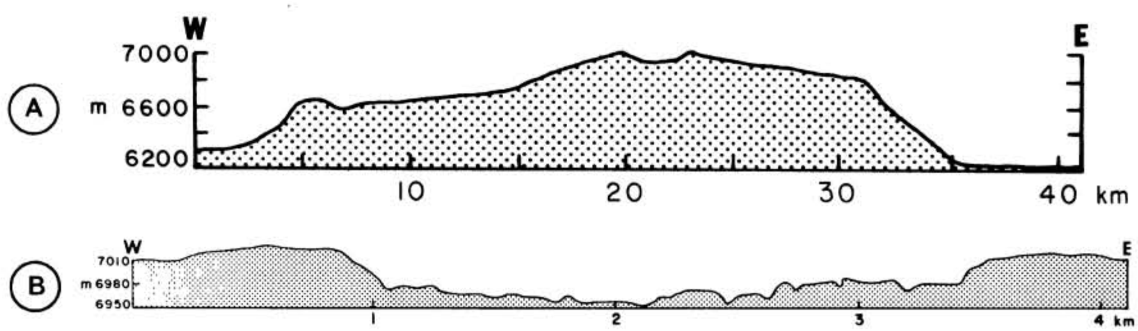


Fig. 2. Panoramic photograph of Ina. Scale is about 1:52,000. Arrows mark examples of units 1 and 2. Line is trace of profile in Fig. 3b. A15-181.

Fig. 3(a) Profile across plateau, dome, and Ina. Trace in Fig. 1. Data from LTO's 41C3,4. Vert. exag. about 6X. (b) Profile across Ina. Trace in Fig. 2. Topographic data supplied by Defense Mapping Agency. Vert. exag. about 3X.



References
1. Whitaker E. (1972) Apollo 15 Prelim. Sci. Rept., NASA SP-289, p. 25-84 to 25-85. 2. El-Baz F. (1972) Proc. Lunar Sci. Conf. 3rd, p. 39-61. 3. El-Baz F. (1973) Apollo 17 Prelim. Sci. Rept. NASA SP-330, p. 30-13 to 30-16. 4. Wilhelms D.E. and McCauley J. F. (1971) USGS Map I-703. 5.Head J.W. and Gifford A.W. (1980) The Moon and Planets, in press. 6.Evans R.E. and El-Baz F. (1973) Apollo 17 Prelim. Sci. Rept. NASA SP-330, p. 28-1 to 28-24. 7. Wood C.A. et al. (1977) Iceland Field Itinerary. Basaltic Volc. Study Proj., Contr. 6, Brown Univ., Providence RI. 8. Barth T.F.W. (1950) Volc. geology, hot springs, and geysers of Iceland Publ. 587, Carnegie Inst. Wash. 9. Van Bemmelen R.W. and Rutten M.G. (1955) Tablemountains of Northern Iceland, Leiden, E.J. Brill, Netherlands. 10.Green J. and Short N. M. (1971) Volc. Landforms and Surface Features. Springer-Verlag, NY. 11. Whitaker E. (1972) The Moon 4, pl 348-355.

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