No. 80 LUNAR CRATERS COUNTS. I: ALPHONSUS

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ABSTRACT

Figures 2 and 4 show the diameter distributions of craters on the east inner wall, the central ridge, and the floor of Alphonsus in the diameter interval 125 m $< D <$ 8 km. The surface density of craters on the floor is about three times that on the wall, and the diameter distributions are parallel over much of this range. Two tenable working hypotheses are discussed to account for this. It is suggested that the central ridge may represent a horst-like structure created during flooding of the floor.

1. Introduction

This paper initiates a series of notes describing results of a crater counting program. The series represents work subsequent to *Comm. LPL,* No. 38, "On the Distribution of Lunar Crater Diameters," (Hartmann 1964*b*). To date, crater diameter distributions have been prepared in LPL for various lunar regions using earth-based, Ranger, Zond III, and Orbiter photography.

Unless otherwise noted, the counts in this series are incremental, the crater frequency F as a function of crater diameter D defined as

$$F(D) = \frac{\text{no. craters in } \Delta\log D \text{ increment}}{\text{km}^2}, \quad (1)$$

where the $\Delta\log D$ increment corresponds to the factor $\sqrt{2}$. Thus, each increment constitutes a 40 percent increase in D, a compromise between construction of highly, perhaps overly, detailed frequency distributions and rapid reduction procedures. Incremental counts have the advantage that counts in each size interval are independent, and the frequency distributions so defined, if linear, have the same slope as cumulative counts. The frequency distributions are plotted as histograms. The individual bars of the histogram typically represent counts of ten to two hundred craters. Dashed bars show counts of lesser statistical weight.

In view of the present state of understanding of the lunar craters, I believe that under-interpretation is preferable to over-interpretation. Therefore, I have avoided, so far as possible, dividing craters by supposed modes of origin and interpreting "fine structure" in the crater distributions.

2. Alphonsus Wall — Observations

Figure 1 shows the region of the Alphonsus east wall photographed with moderate resolution by Ranger IX. Counts were made from a number of frames with both higher and lower resolution than Figure 1. It was found that although all craters with $D < 1$ km were well defined, among larger diameters there were a number of ill-defined, crater-like depressions. If they appeared on other background terrains, they would be mapped as heavily damaged craters. These unusual types were counted separately. Many are included in Figure 1, although they are difficult to detect because they are more prominent at lower resolution. As the resolution increases, the circular structure is lost in the chaos of hummocky rim structure.

Figure 2 shows the distribution of crater diameters in the resolved regime on the Alphonsus wall. Counts of the ill-defined craters are marked with circles; they appear to be overabundant with respect to the smooth curve for the well-defined craters.

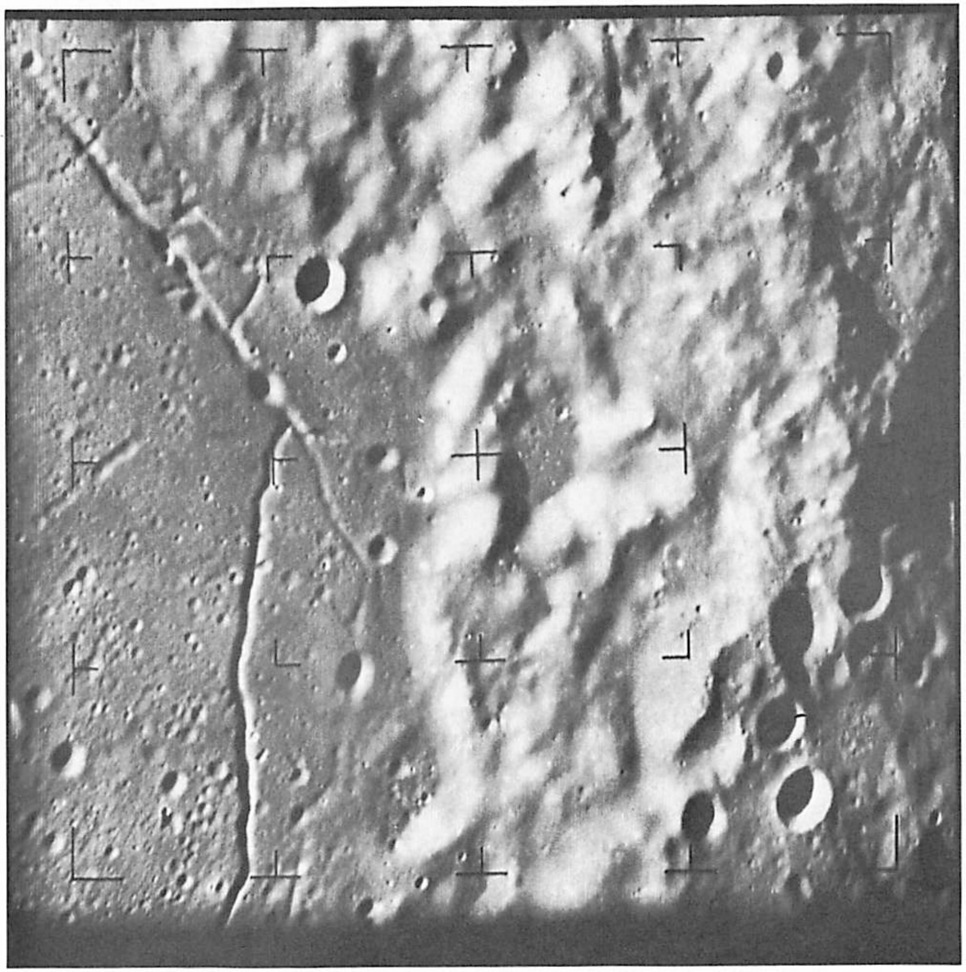

Fig. 1 Inner wall of Alphonsus and a portion of the NE floor. Ranger IX, frame B67.

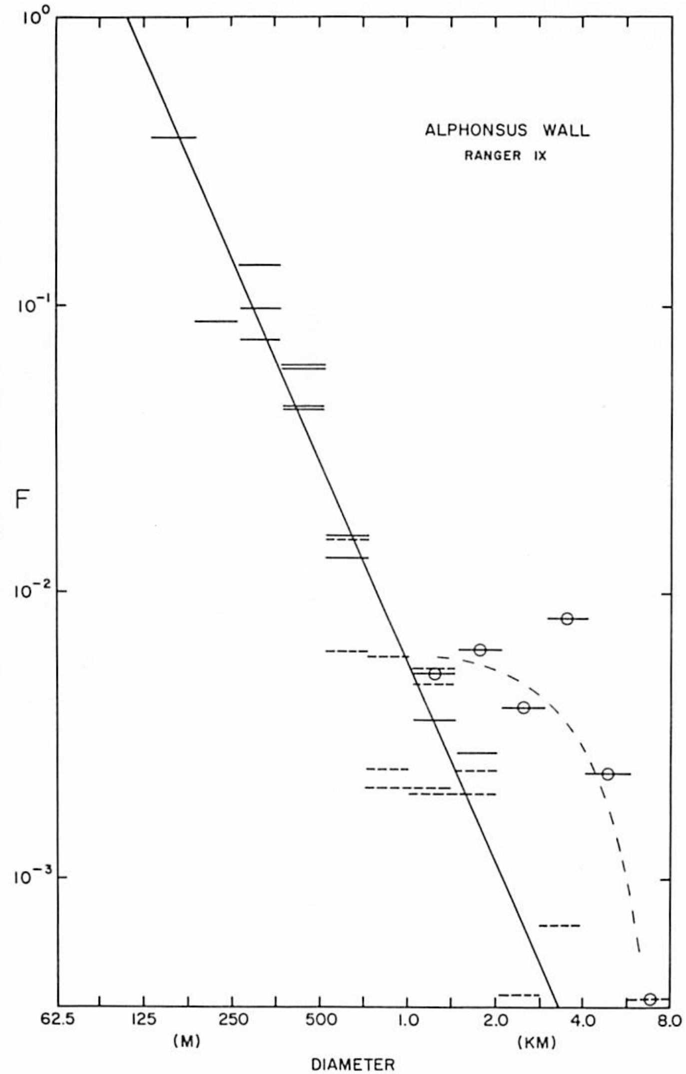

Fig. 2 Diameter distribution of craters on the Alphonsus NE inner wall. Dashed bars are of lesser weight (absolute count ≤ 5 craters). Circled bars include a number of ill-defined crater-like objects, tentatively interpreted as remnants of early craters nearly destroyed by major crater wall slumping. Straight line has slope —2.3.

The distribution of the latter appears to be quite well determined, and a linear relation is satisfactory in this diameter range (125 m to 4 km). The straight line fit in Figure 2 has a slope −2.3.

3. *Floor and Central Ridge — Observations*

Figure 3 shows a moderate-resolution view of the floor and central ridge of Alphonsus. A clear asymmetry in crater density can be seen between the east and west side of the crater floor, divided by the ridge. Closer examination shows smaller anomalous areas.

These asymmetries were neglected in the preparation of Figure 4, which compares the wall, floor, and ridge crater counts, made from many photographs. Among the larger craters (from the lower resolution frames) are some counts from the west side, although Figure 4's crater diameter distribution is an average primarily over the eastern part of the floor. Making counts of craters on the central ridge was difficult because of the small area and moderate ground resolution, but it appears that the ridge contains systematically fewer craters than the floor, yet more than the wall.

From $D = 500$ m to 2 km, the range of the best data, the ridge exhibits about 2.2 times the crater density of the inner wall, and the floor, about 3.0 times the density of the inner wall. These values are thought to be correct to within 15 percent. It should be emphasized that these counts include all identifiable craters, regardless of morphology or origin. At $D = 200$ m there appears to be a convergence of wall and floor counts.

The curve corresponding to the floor craters in Figure 4 parallels that of the wall craters over the range 350 m $< D <$ 3 km, having the slope −2.3. This is in good accord with the data of Shoemaker, *et al.* (1966), who report a value of −2.0 for $D < 500$ m and −2.7 for $D > 500$ m. However, the absolute density of craters counted by Shoemaker, *et al.* is systematically higher than that reported here (after converting to the cumulative format of Shoemaker, *et al.*); the cause of the discrepancy is uncertain.

4. *Interpretation*

The floor of Alphonsus has undoubtedly been flooded in the same sense that the maria have been flooded. Not only in photographs with low (earth-based) resolution, but also in those with moderate to high resolution down to meter scales, the Alphonsus floor structure is nearly indistinguishable from the mare surface structure. The only differences are the well-known higher albedo and a somewhat greater crater density in the kilometer-diameter range. Both of these differences — i.e., a thin veneer of secondary high-albedo material and a longer impact-recording time — suggest a somewhat greater age for the Alphonsus floor than the mare surface. Furthermore, the whole Alphonsus structure appears to be older than the average mare (Alphonsus is classed as pre-mare in the Arthur catalog, Arthur, *et al.* 1965). Alphonsus appears to be one of the typical, very old, damaged, large upland craters. One would expect that immediately after the formation of Alphonsus, the interior surface represented a clean slate for recording impacts. One might also assume that the wall is this same original surface and that the floor has been wiped clean again by the flooding. Hence, if we are here counting primarily impacts, one expects to see a high crater density on the old wall and a lesser density on the younger, mare-like floor. Instead, just the reverse is shown by Figure 4.

Apart from hypotheses requiring extraordinary conditions (walls younger than floor or unusual, thick deposits on the walls), two principal working hypotheses, consistent with the observations, may still be drawn from the literature resulting from the Ranger and Orbiter photography (e.g., Kuiper, Strom, and LePoole 1966; Shoemaker, *et al.* 1966; O'Keefe, Lowman, and Cameron 1967). These will be discussed in turn.

Hypothesis 1. Both the floor and wall of Alphonsus have a steady-state distribution of primary impact craters. The wall has fewer craters because downslope movement of material, or mass wasting, is constantly causing (or has in the past caused) crater erasure. Only the floor represents a sample of craters undisturbed by mass wasting, and it is in a near-saturation state for craters in the size range considered here.

A difficulty with this hypothesis is that the kind of slow mass wasting widely discussed would be expected to erase smaller craters preferentially. Fewer small craters would thus be found than expected from extrapolation of the large-crater counts. This would reduce the steepness of the slope of the wall counts. There is no evidence of this in Figures 2 and 4. The dotted wall curve in Figure 4 parallels or is steeper than the floor counts at all points; thus, there appears to have been no preferential erasure of small craters on the wall.

A related process that may have played a role in the history of the wall is slumping on a large scale.

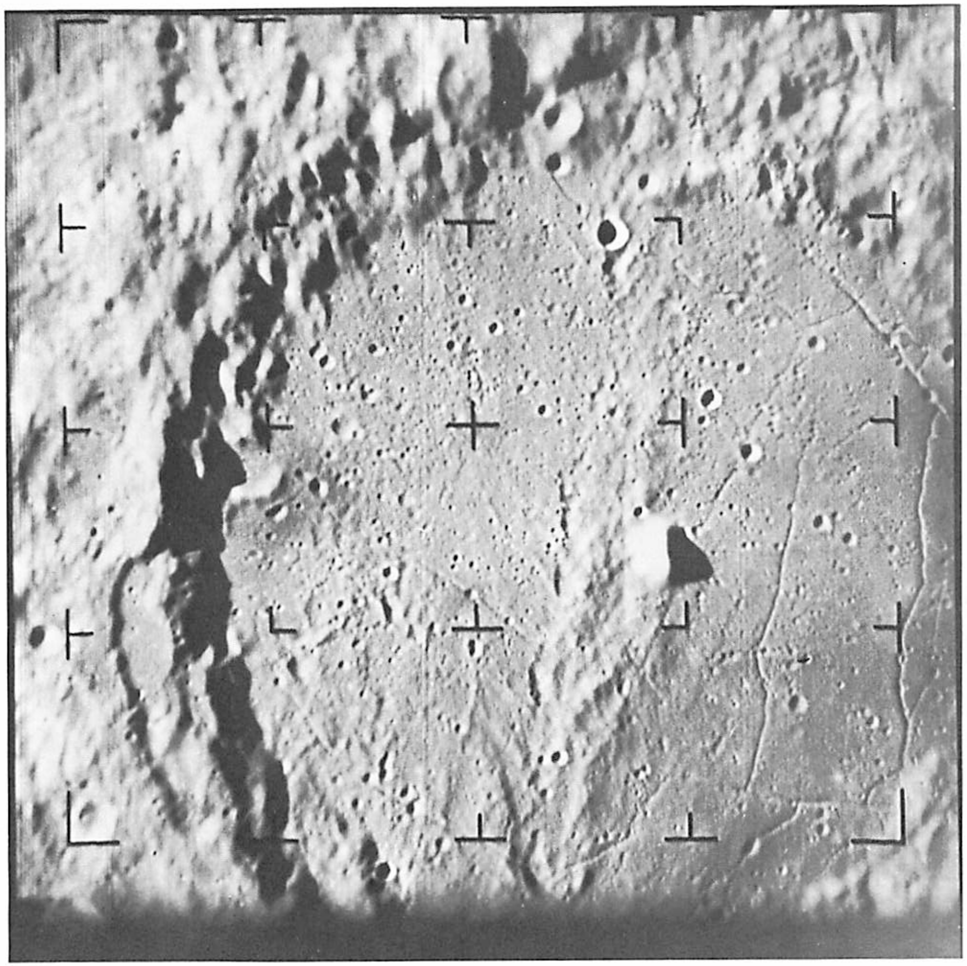

Fig. 3 Interior of Alphonsus, showing the central ridge and asymmetry in crater density between the E and W side. North up. Ranger IX, frame A52.

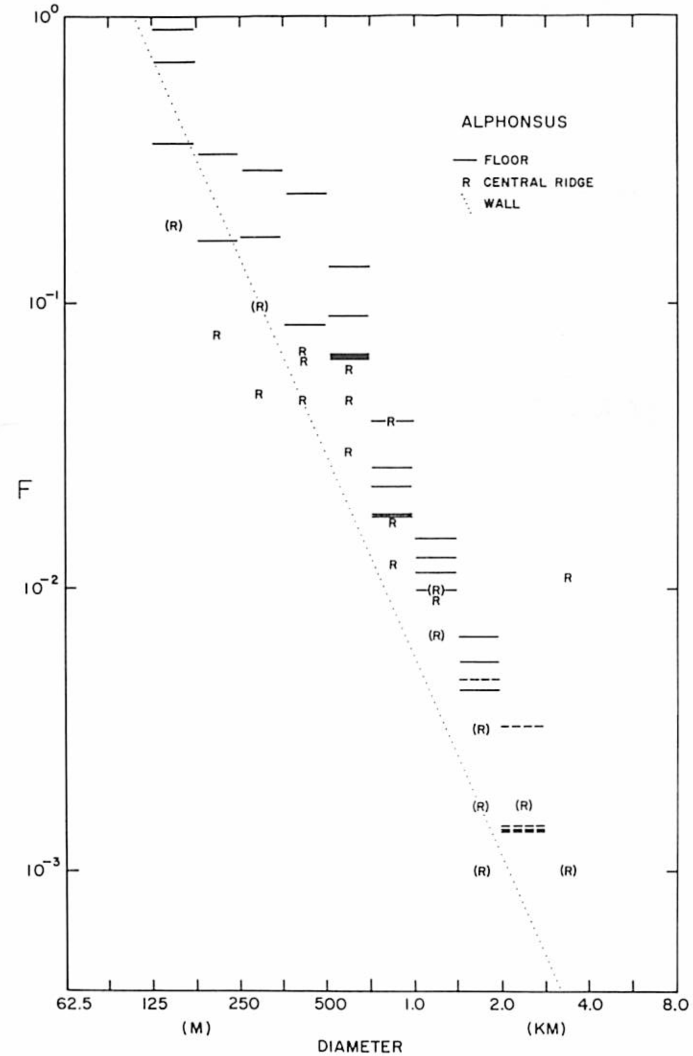

Fig. 4 Diameter distribution of craters inside Alphonsus. Dashed bars and parentheses denote lesser weight (absolute count ≤ 5 craters). Dotted line (wall; after Fig. 2) has slope -2.3.

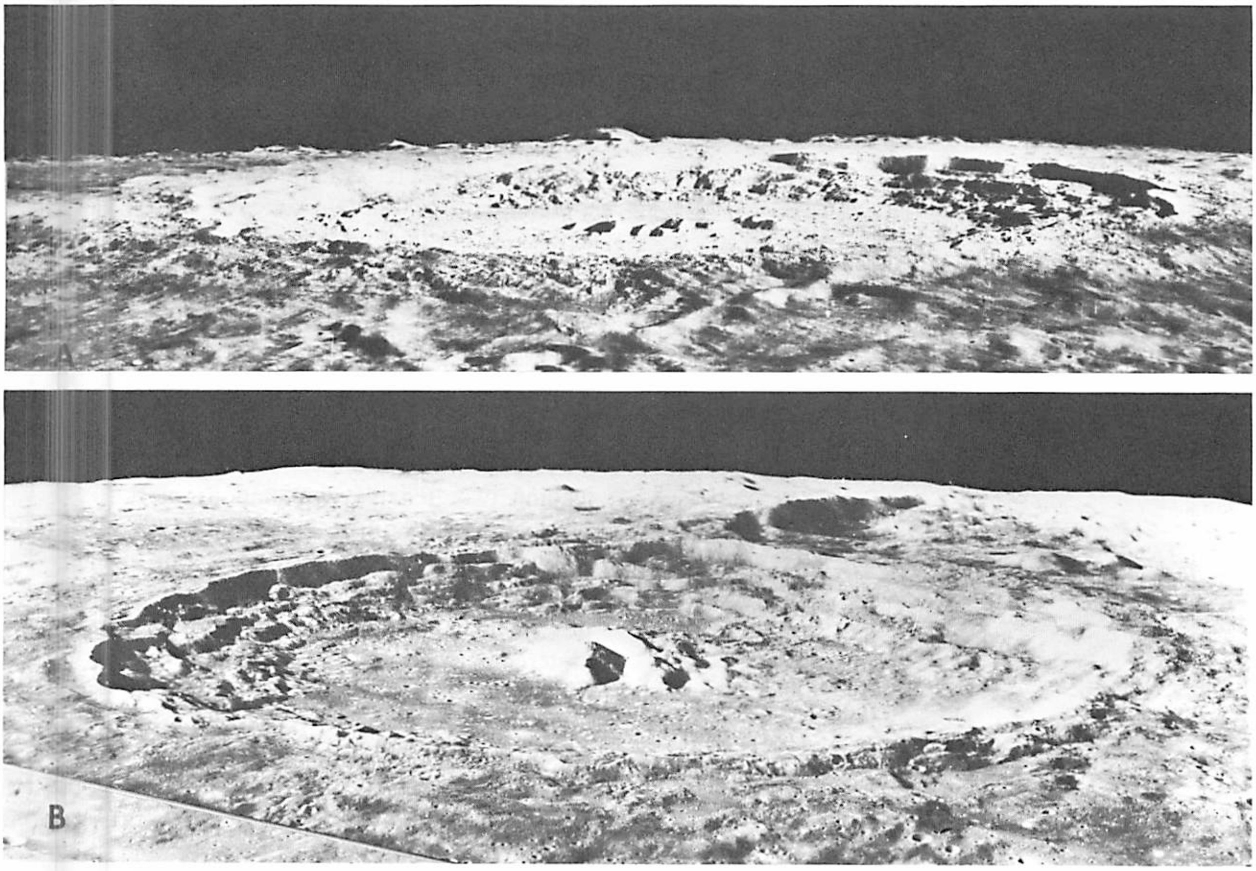

Fig. 5 Terraces and scarps, apparently due to crater wall slumping, in Copernicus (*A*, Orbiter II) and Theophilus (*B*, Orbiter III). (Photographs courtesy of NASA.)

This phenomenon has apparently occurred in Copernicus and Theophilus, producing the well-known steep scarps and flat terraces (Fig. 5). It is pictured as more catastrophic than mass wasting. It would account for the deformed crater-like structures on the Alphonsus wall (as pre-slump craters) and for the overabundance of these craters in Figure 2. Such slumping is not unexpected in large-crater walls, since these mark initially steep relief and loci of isostatic discontinuities produced by crater excavation and rim deposition. However, the sides of well-defined lunar hills also appear to be deficient in craters with respect to adjacent mare regions, even in cases where obvious catastrophic slumping has not occurred, and hence, such slumping does not alone account for the marked crater deficiency.

Hypothesis 2. The wall of Alphonsus represents a slate wiped clean at the formation of Alphonsus, a recorder of impacts ever since. The floor represents another recorder, formed shortly thereafter, but contaminated with a great number of craters of some other mode of origin, presumably internal and peculiar to the mare or mare-like material. Since the floor craters outnumber the wall craters by the factor 3, we would conclude that 67 percent of the floor craters are of non-impact origin. Mass wasting has had only a minor or negligible effect in erasing craters.

This hypothesis is illustrated in Figure 6. The shaded band represents the range of crater densities found in normal large maria. The bars represent the Alphonsus floor and show an excess (by a factor of about 2.5) of craters of $D > 500$ m. Mare craters of $D < 2$ km, which vary in density on different mare surfaces, are interpreted in this hypothesis to be mostly of internal origin peculiar to the maria. The true impact craters are supposed to follow a curve similar to that shown by the dashed line (after Kuiper, Strom, and LePoole 1966). They constitute only a fraction of the total crater densities at diameters $D < 2$ km.

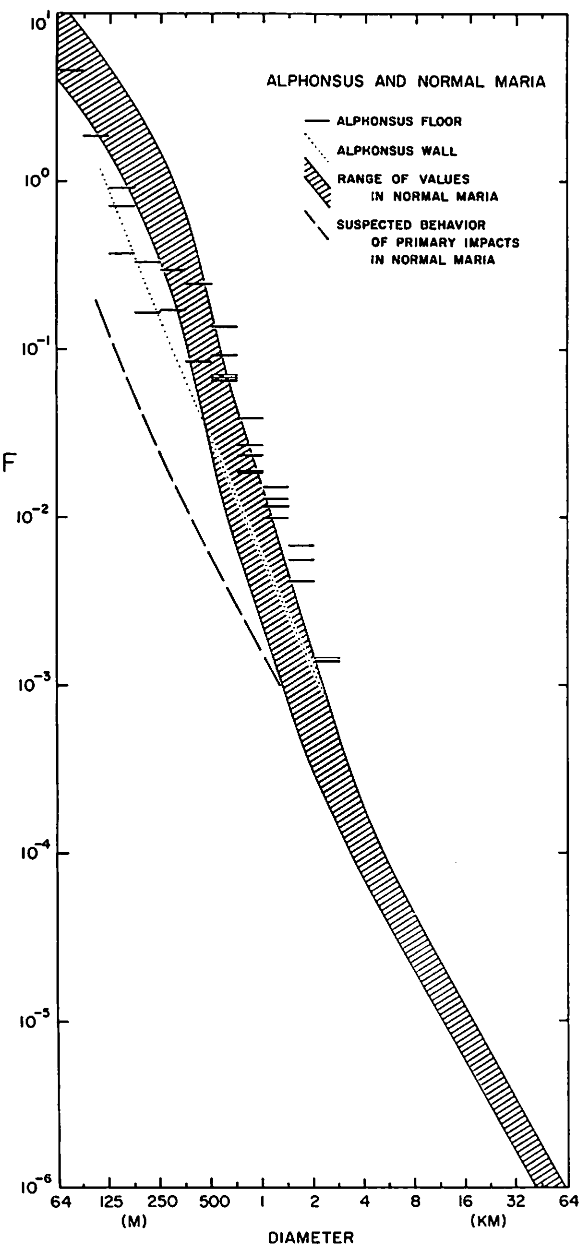

Fig. 6 Comparison of crater diameter distributions in Alphonsus and normal maria. Dashed line schematically shows values proposed by Kuiper, Strom, and LePoole (1966) for primary impacts. Its parallelism with observed counts of all craters on the wall of Alphonsus (dotted line) supports the hypothesis that primary impact craters indeed show this distribution.

Important support for hypothesis 2 comes from the rough parallelism between the wall counts and the dashed line in Figure 6. That is, the craters on the Alphonsus wall have a diameter distribution in the 125-m to 3.5-km range very close to that expected for the supposedly primary impact craters.

On the other hand, a number of observations (Shoemaker, *et al.* 1966; Gault 1967, private communication) indicate that the mare surfaces display near-saturation impact cratering in a loosely consolidated layer of rubble several meters deep. The "sharp" and "soft" craters are held to show merely a continuum of different states of erosion and blanketing. According to this view, the craters on the floor of Alphonsus are nearly all of primary and secondary impact origin in various states of erosion and blanketing, rather than a mixture of endogenous and exogenous craters. Such a view is incompatible with the interpretation of hypothesis 2 and would force one toward some variant of hypothesis 1.

These two hypotheses seem the only two, or the leading two, tenable explanations of the observations of the Alphonsus floor and wall, but it is difficult to choose between them without further data.

The small anomalous regions, illustrated in Figure 7, appear to be deposits superimposed on the cratered background. Two observations support this: (1) in cases where the anomalous region is not distinguished by albedo, it is distinguished by a fuzzy appearance as if camera resolution has failed in a certain area; (2) rilles crossing the anomalous area are filled in. Crater counts attempted in these regions gave no meaningful results because of the small area and insufficient resolution. The areas are associated with prominent single craters of $D \sim 1$ to 3 km. Craters apparently wiped out by the deposits range up to $D \simeq 600$ m. For fresh craters of this size, the depth d is estimated to be 70 m, in accord with the geometric data reported by Heacock (1966). The data of Jaffe (1965) indicate that to erase such a crater by deposition of material, starting from typical, already smoothed morphologies in non-anomalous regions, one would have to add a layer roughly 40 m thick. These figures apply to the example shown in Figure 7*b*, where the volume of the deposit (an elliptical patch 6 x 3.5 km) would be about 3 km^3, while the volume of the main crater would be only about 0.6 km^3. In view of the fact that most ejecta from an impact crater of this size should be piled up in a rim, we conclude that the ejecta blanket is several times more voluminous than could be accounted for in an impact. Hence, the ejecta blanket must be eruptive. The deposited volume estimated above is comparable to that of a large, terrestrial eruption, and is several orders less than the total volume of a magma chamber under a typical terrestrial volcano of moderate size (Williams 1942; Rittmann 1962). The asymmetry of some of these

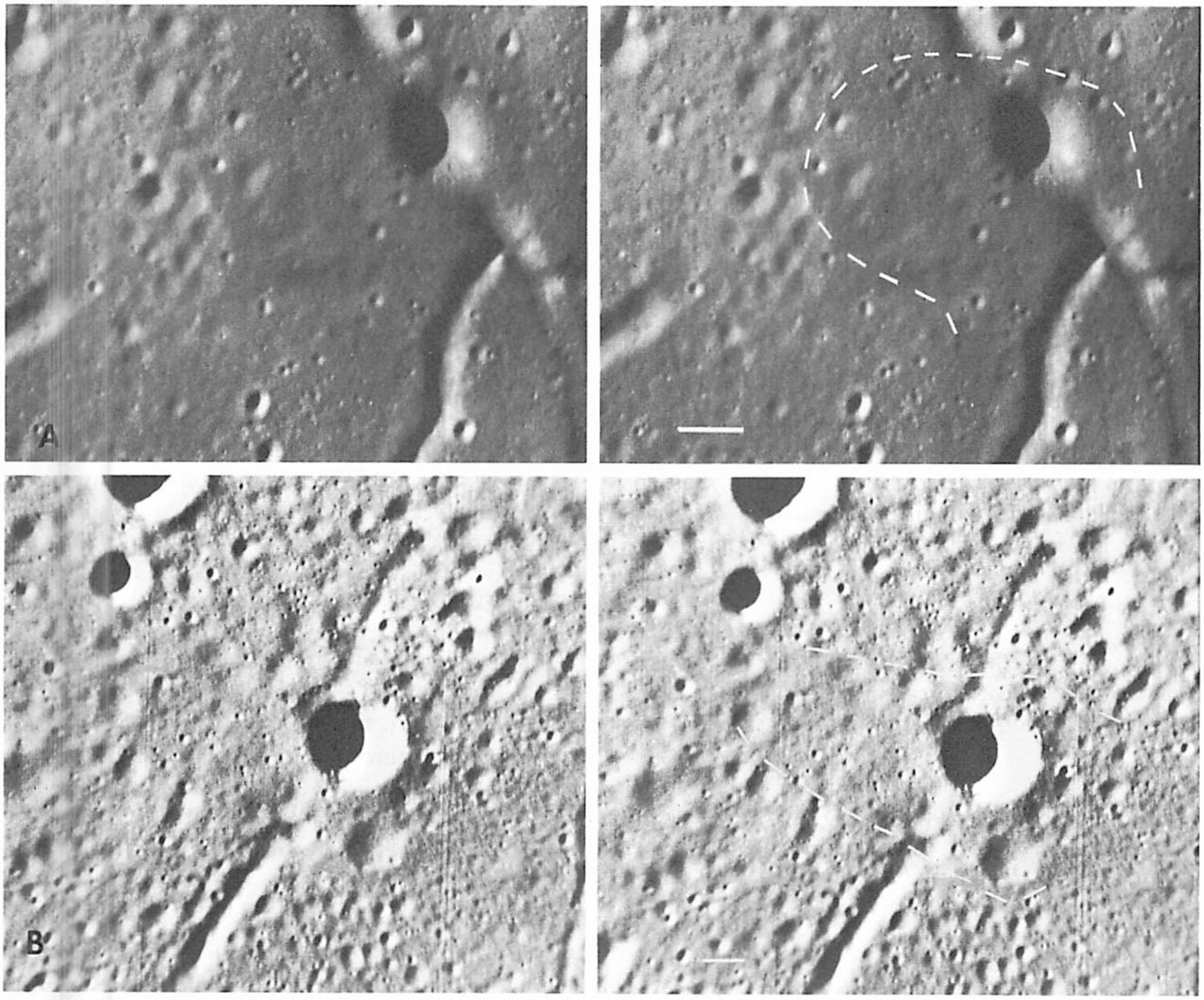

Fig. 7 Local anomalous regions on the floor of Alphonsus. *A*. Dark halo crater. *B*. Region of apparent blanketing with no albedo anomaly. These are interpreted as regions of local eruptive deposition. White bars at bottom indicate 1 km scale.

apparent deposits with respect to the associated crater is also characteristic of an eruptive origin. Finally, the close association of the dark-halo craters with rilles in Alphonsus has long supported the supposition that the halo craters are endogenous (cf. Kuiper, Strom, and LePoole 1966, p. 134).

These evidences for scattered endogenous craters of substantial size on the mare-like floor of Alphonsus support hypothesis 2 — that there is an admixture of endogenous craters there.

Finally, we will consider the central ridge of Alphonsus, which has been interpreted in many different ways. It is accurately aligned with, and considered a part of, the Imbrium radial system as described earlier in these *Communications* (Hartmann 1963, esp. Plate 24.21). Among others, Urey (1966) has described the ridge as consisting of exogenous material dropped onto Alphonsus "from the Imbrian collision itself or of material driven from the wall of Alphonsus by ejecta from the Imbrian collision." He believes that "when it fell it depressed the floor of the crater."

Certain observations suggest to me an endogenous origin. First, along parts of the west side of the ridge stretches a crater chain (see Fig. 4), suggesting that the ridge is defined on at least one side by a fracture. Second is the alignment with the Imbrium radial system, which is held to be primarily tectonic. Third, the ridge divides two provinces of different crater densities, indicating a division in the flooding histories. Hence, it is suggested that this ridge is in the nature of a horst. It has been argued (Hartmann

1963, 1964*a*) that the basin-forming impacts created families of radiating fractures, along which tectonic events occurred, and that subsequent flooding was controlled in part by these fractures. In Alphonsus, the two halves of the floor flooded and subsided somewhat independently. The ridge may have once been partially flooded, but has been left above the subsided units. The herring-bone pattern of the ridge, visible at certain illuminations, suggests the possibility of some shearing.

The interpretation of the central ridge as an old, partially flooded horst is consistent with either hypothesis 1 or 2. In case 1, its crater density intermediate between the wall and floor is ascribed to an intermediate degree of mass wasting on the gentle slopes of the ridge. In case 2, partial flooding has led to the formation of a number of endogenous craters characteristic of the maria, but not as many as on the deeply flooded floor.

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