NO. 85 "EARLY LUNAR CRATERING"* (SYNOPSIS)

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ABSTRACT

The evidence for intense cratering early in the history of the moon is presented. This early cratering rate, averaged over the first seventh of lunar history, was about two hundred times the average post-mare rate, and may have had a peak still much higher. Surface crater densities are thus not proportional to surface age. The large, circular mare basins fit the diameter distribution of the early continental craters and are therefore identified with pre-mare cratering. This cratering is assumed to be due to a high early bombardment rate by objects of uncertain origin. Mars shows no such early intense cratering. Some considerations on the origin of the objects are given.

The evidence for an early intense cratering of the moon comes from the very high density of pre-mare craters in continental or upland regions and the probability that the formation of the maria occurred quite early. Kuiper (1954) proposed early intense bombardment both on the above grounds and on the basis of visual observations of smooth, intercrater upland regions, which he took to be parts of an original, accreted, uncratered crust. This raises the important possibility that the original surface was not marred by major impact features. More recently, the possibility has been raised that smooth upland areas might result from other causes, such as volcanic activity, overlapping ejecta blankets, or early flooding overlain by thin opaque ejecta layers. In 1963, Alter also found evidence that ancient upland features predate the craters, suggesting that the general background has not been due to impact.

During the last fifteen years, Urey has assumed an early intense bombardment for a different reason: that the maria are a mixture of dust and lava flows produced by fusion at the time of impact. This would require that all basin-forming impacts occurred within a time less than the cooling time of the lava fills, i.e., as short as "some thousands of years." The high density of "Archimedian" or post-basin, pre-mare craters, however, testifies that the interval between impact and flooding was appreciable.

Others hold that there is no evidence for early intense bombardment. Disregarding theoretical and meteoritic indications that the mare-forming period was confined to early lunar history, they choose the simplest possible interpretation of the data: the age of any surface is directly proportional to the crater density. This *ad hoc* assumption led Fielder in 1963 to conclude that no major mare is older than 7×10^8 years, thus confining mare formation to the last 15 percent of lunar history. This appears unacceptably recent, in view of the early melting of other planetary bodies.

Figure 1 shows a comparison of crater densities averaged over mare surfaces with crater densities in selected "pure continental" regions. The basins of the large, circular maria fit perfectly onto the continental crater curve, indicating that they are simply the large-diameter extension of continental craters and presumably were formed by the same basic process.

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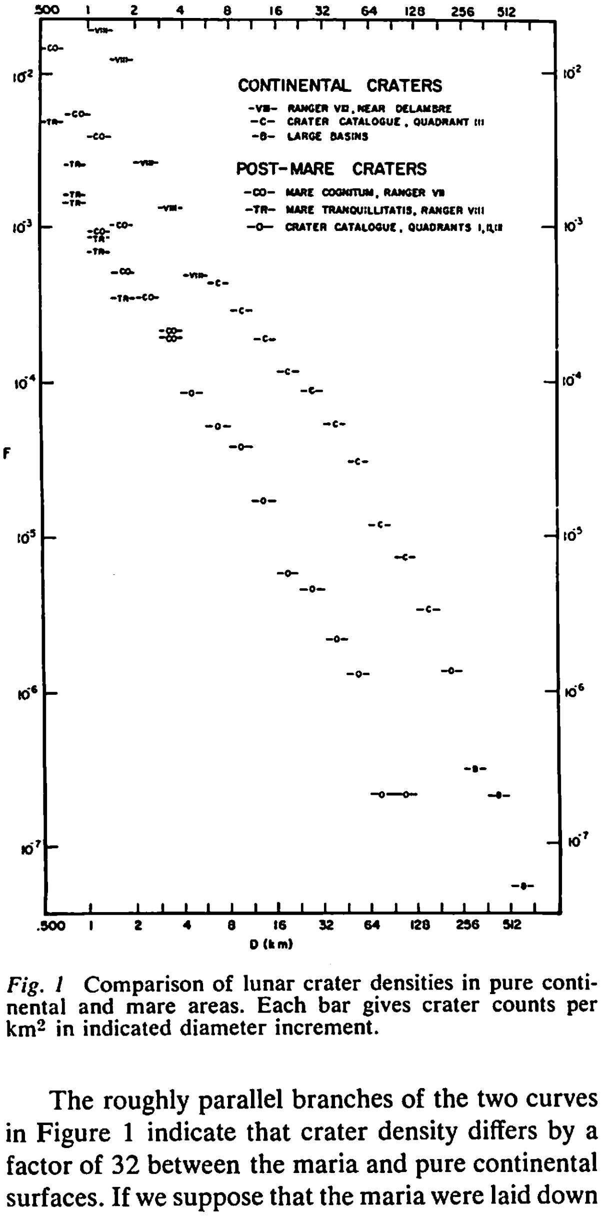

Fig. 1 Comparison of lunar crater densities in pure continental and mare areas. Each bar gives crater counts per km² in indicated diameter increment.

The roughly parallel branches of the two curves in Figure 1 indicate that crater density differs by a factor of 32 between the maria and pure continental surfaces. If we suppose that the maria were laid down just after the first seventh of lunar history — a supposition compatible with crater densities on earth and thermal histories of meteorites — we have an *average* cratering rate in this period about two hundred times the post-mare rate. If the maria were formed at a still earlier time, the peak rate would have been higher.

One possible explanation of the high early rate would be to suppose that the continental craters are mostly the result of intense volcanism and outgassing of the moon, i.e., they are of internal origin. But because these early craters are similar in dimension, morphology, and diameter distribution to the post-mare impact craters, an internal origin is tentatively rejected, and it is assumed that the craters were caused by impacts.

Figure 2 shows a schematic sketch of the situation for the very early stages of lunar history.† The "background" flux, labeled "cometary and meteoritic," may at first have declined from an early accretion rate. In later time, approaching the present day, the background flux has probably increased owing to the fragmentation of asteroids.

Within a framework of modern ideas about the early history of the solar system, one may conceive of six hypothetical causes of a high flux: (1) the objects represent the final, dwindling stages of lunar accretion; (2) they were planetesimals left in solar orbit after the formation of the planets; (3) they result from a much higher early ejection rate of comet nuclei from the cometary cloud; (4) they result from a much higher early ejection rate of objects from the asteroid belt; (5) the moon was captured by the earth after the objects struck it in another part of the solar system, for example, near the asteroid belt; (6) the objects represent circum-terrestrial debris swept up by the moon as tidal friction forced it outward from the earth.

There are objections to the first four hypotheses. One such objection is that the diameter distribution of large continental craters appears to be incompatible with the mass distribution of asteroids. The last two hypotheses concern the origin of the moon itself, and it appears likely that just as the earth-moon system is unique, so the early cratering history of the moon may be unique. Mars does not appear to show the two-phase surface characteristic of lunar pre-mare and post-mare terrains, yet Mars' surface appears to be very old in terms of crater-retention age. Hypothesis (6) is tentatively favored.

A powerful tool in distinguishing among these hypotheses will be high-resolution space probe photography of planetary surfaces. Mercury will be especially interesting in this respect as it may have both mare and continental regions.

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†Cf. Fig. 134 in Kuiper, G. P., *et al.* 1966, "Interpretation of the Ranger Records," *Ranger VIII and IX, Part II: Experimenters' Analyses and Interpretations,* JPL Tech. Rept. No. 32-800, p. 217.

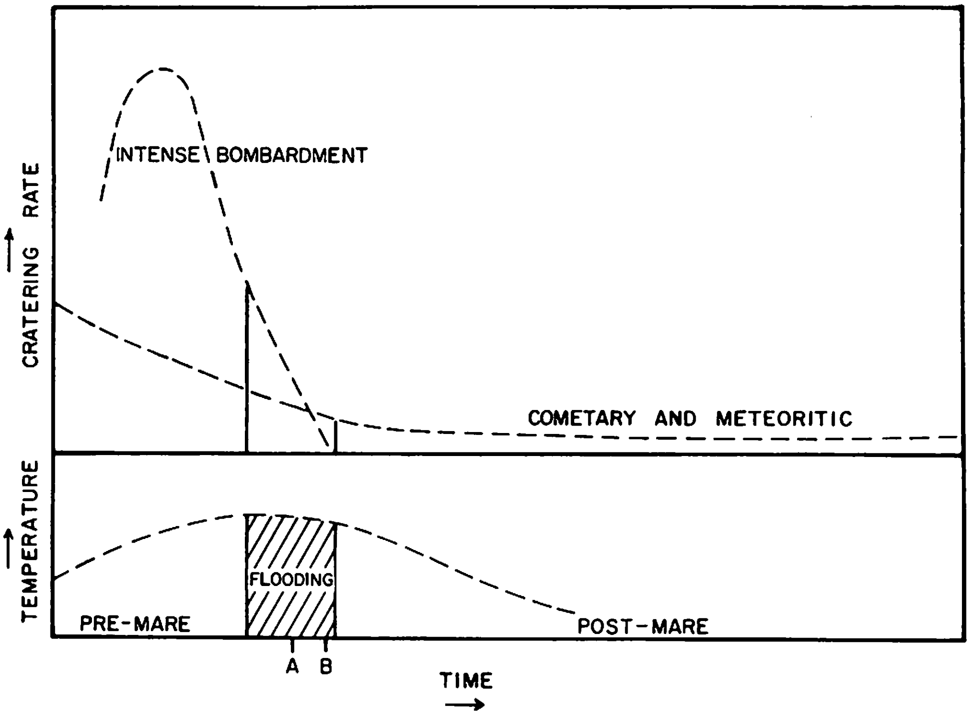

Fig. 2 Schematic diagram of early lunar history. Background flux is shown decreasing from an early accretion rate; it may have since increased as asteroidal fragments became available. Two mare surfaces, formed at *A* and *B*, could show markedly different crater densities as a result of the tail end of the early intense cratering.

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