No. 116 LUNAR CRATER COUNTS. III: POST MARE AND "ARCHIMEDIAN" VARIATIONS

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ABSTRACT

Figures 1 and 2 and Table 1 present data on inter-mare crater density variations which further support statements made in Paper II. The extreme crater densities (Mare Serenitatis and Mare Tranquilitatis) vary by a factor of approximately 2.5. Table 2 presents quantitative and qualitative estimates of the post-basin crater densities, as well as post-mare crater densities for various basin systems, arranged in order of basin age. The "Archimedian" craters considerably outnumber the post-mare craters. "Archimedian" time periods were finite and variable from basin to basin, thus excluding impact-induced melting as a source of mare material. These data demonstrate a working approach for future crater count programs.

1. Inter-Mare Variations

In the preceding paper (Paper II; Hartmann 1967), I mentioned the variation by a factor roughly 2.5 for the crater density of the larger (D > 2km) craters on mare surfaces. Figure 1 and Table 1 in that paper present the data on which this statement was based.

From a survey of the more accessible front-side mare surfaces, Mare Serenitatis and Mare Tranquillitatis were chosen as representative of lightly and heavily cratered mare surfaces, respectively. Mare Cognitum, recently named and well-photographed as a result of the Ranger VII mission, was also studied and found to be moderately cratered (Hartmann 1966*b*). The counts from these three maria are included in Figure 1. The conclusion that Ranger VII landed in a dense cluster of secondary craters associated with the rays of Tycho (Kuiper 1965; Shoemaker 1965; Whitaker 1965) — an area with density over and above the cratered background — is quantitatively confirmed by the excess of smaller craters (D < 500 m) shown in Figure 1. The greater density of large craters in Mare Tranquillitatis than in Mare Cognitum is confirmed by the counts published by Shoemaker, *et al.* (1965, p. 264).

An average mare count, as presented in Paper II, is included in Figure 1; it is a count of all mare craters divided by the total mare area. As expected, the distribution so defined lies between the Tranquillitatis and Serenitatis counts.

Figure 2 presents more clearly the distributions found in Figure 1, without the datum points, and shows the finite band that represents the maria on the log F-log D diagram.

Table 1 synthesizes data relating to this problem. The various authors have published data on cumulative numbers of craters in a variety of maria. These data suffer from various uncertainties: if the limiting diameter is too large, too few craters are available to give good statistics; if it is too small, observational errors become significant. It will be seen that there are inconsistencies among the data, probably due to these uncertainties, but the trend toward increasing density is clear, and it is believed that the final column does reflect significant and detectable differences. This material is slightly modified from an earlier presentation in my Ph.D. dissertation (1966*b*).

I concluded that significant inter-mare variations in crater density, by a factor of roughly 2.5, exist among the larger, presumably *primary impact craters* (D > 2 km), and that these variations reflect true age differences (by unknown factors in time since the cratering rate as a function of time is unknown). At the same time, it is important to note that there is a definite lower limit to the relative crater density on maria. None is below 0.6, although some young craters, e.g. Tycho, fall below this limit (cf. Paper VI). Hence, the mare-formation period, ranging

TABLE I. PROVISIONAL CRATER DENSITIES ON DIFFERENT MARE SURFACES

Reference:	RBB	RBB	WKH	DSS	RBB	GF	RBB	
Lower limit D: (KM.)	1.6	3.2	4	4	6.4	10	12.8	ADOPTED VALUE
M. Serenitatis	1.03	.76	0.40	.61	.34*	.28*	.24*	0.6
P. Epidemiarum	.77	.76			.71		.71*	0.8
M. Humorum	.77	.76			.71	.53*	.71*	0.8
M. Nubium	.77	.76			.71	.54*	.71*	0.8
M. Crisium	.92	.70			.74*	.91*	.94*	0.8
O. Procellarum						.73		0.9
M. Imbrium	1.01	.95		1.06	.74	.78	.72*	0.9
M. Orientale †			1.0					1.0
M. Cognitum			0.94					1.0
M. Nectaris	1.11	.96			.38*	.86*	.40*	1.0
M. Frigoris	1.10*	1.26		1.57	1.52	1.13	1.69	1.4
M. Foecundit.	.99*	1.14			1.52	1.62*	.97*	1.5
L. Somniorum	1.10	1.26			1.52	2.10	1.69*	1.6
M. Tranquill.	1.20	1.37	1.11		1.73	2.16*	1.73*	1.6
Appendix (DSS)								
M. Seren., outer dark zone				.54				.6
M. Seren., central portion				.69				.7

Notes:

Values in this table are $\frac{\text{crater density observed}}{\text{average crater density, all maria}}$

*Values given less weight because of paucity of craters, foreshortening, etc.

†See paper IV

RBB: Baldwin 1963, p. 296
DSS: Dodd, Salisbury and Smalley 1963
GF: Fielder 1963

from 0.6 to 1.6 on a relative crater density "time scale," represents a *restricted epoch* in lunar history.

2. *Post-Basin, Pre-Mare Intervals*

The interval between the formation of lunar basins and their associated mare surfaces can be judged by counts of the post-basin pre-mare, "Archimedian" craters. Though often highly damaged, Archimedian craters having diameters above some critical diameter should, in principle, be detectable where the mare cover is thin enough. Thus, counts were made for zones around the outer edge of various maria, in some cases essentially the inner edge of the rim only. The width of the zone was chosen according to the apparent degree of preservation of Archimedian craters.

The post-mare count, in some cases neglible, is added to the Archimedian count to get a measure of the interval between basin formation and the present. This measure is in terms of the crater numbers only, because a time-measure can be deduced only if we know the cratering rate, which is believed to have been changing rapidly at this epoch. (Kuiper 1954, pp. 1104, 1110; Kuiper 1966 p. 217; Hartmann, 1966*a*).

Secondary criteria of a more subjective nature were also used to order the basins by age, since in some cases no good crater statistics could be obtained. Morphological differences, such as rim sharpness, rim height, distinctness of ejecta blankets and preservation of radial and concentric systems, are useful in this context.

Table 2 presents the results expressed as the estimated ratio post-basin/post-mare crater density as well as data on post-mare craters. The table, though incomplete and subject to revision provides a rationale and serves as a guide for further studies of lunar crater counts. The present data are modified from an earlier presentation in my Ph.D. dissertation (1966*b*), and it is desirable to fill in as well as possible the remaining unknown data, which indicate the history of certain lunar regions.

An important conclusion that follows at once from Table 2 is that the "Archimedian" cratering intervals were finite and highly variable from one basin system to another. The large amount of cratering in many cases indicates an extensive time interval and rules out the hypothesis that the mare material is a result of impact-induced fusion, laid down contemporaneously with basin creation (Urey 1960).

Furthermore, the relative constancy of post-mare crater densities and variability of Archimedian densities favors the view that while the maria were formed more or less contemporaneously, during a restricted epoch, the underlying basins were distributed throughout a period during which most of

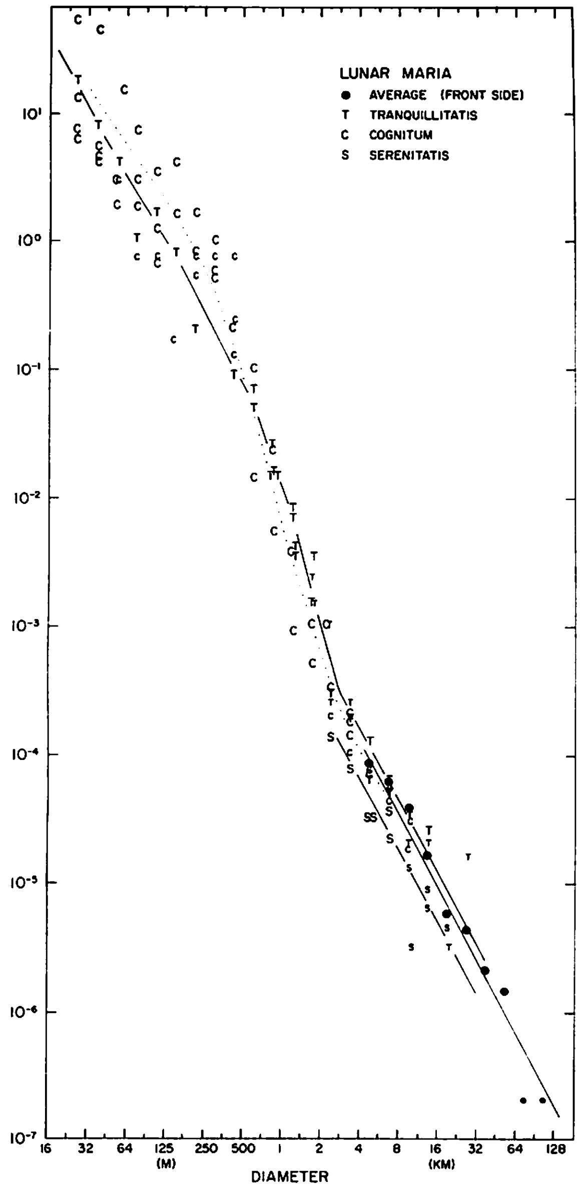

Fig. 1 Diameter distributions of craters on Mare Serenitatis, average mare, and Mare Tranquillitatis, showing significant variations between the latter and the former. F is incremental number of craters/km².

the pre-mare ("continental") craters formed. That is, the quantitative data of Table II are consistent with the model which has been presented earlier in these Communications and elsewhere (Hartmann 1964; Kuiper 1966; Hartmann 1966*a*) that the basins formed during an early intense cratering close to the end of which most of the major maria were laid down as a result of lunar melting. Much of the variation in inter-mare ages is attributed to the tail-end of the intense bombardment phase, which may have involved a different population of cosmic

TABLE II. PROVISIONAL POST-BASIN CRATER DENSITIES AND RELATIVE BASIN AGES

BASIN* (IN ORDER OF INCREASING AGE)	ESTIMATED POST-BASIN CRATER DENSITY**	POST-MARE CRATER DENSITY***
(Average mare)		1.00†
Orientale ‡	2.4	1.0
Imbrium	6	0.9
Crisium	16	0.8
Humboldtianum		
Nectaris	27	1.0
Near Schiller	28	
Humorum	28	0.8
Grimaldi		
Serenitatis		0.6
S. E. Limb		
Janseen		
Cognitum		1.0
(Pure Upland)	30	

*Cf. Hartmann and Kuiper (1962). Recently discovered far side basins not included.
**Estimated P. E. ≃ 25%
***Estimated P. E. ≃ 20% (See Table I)
†By Definition
‡See paper IV

bodies than those presently striking the earth and moon.

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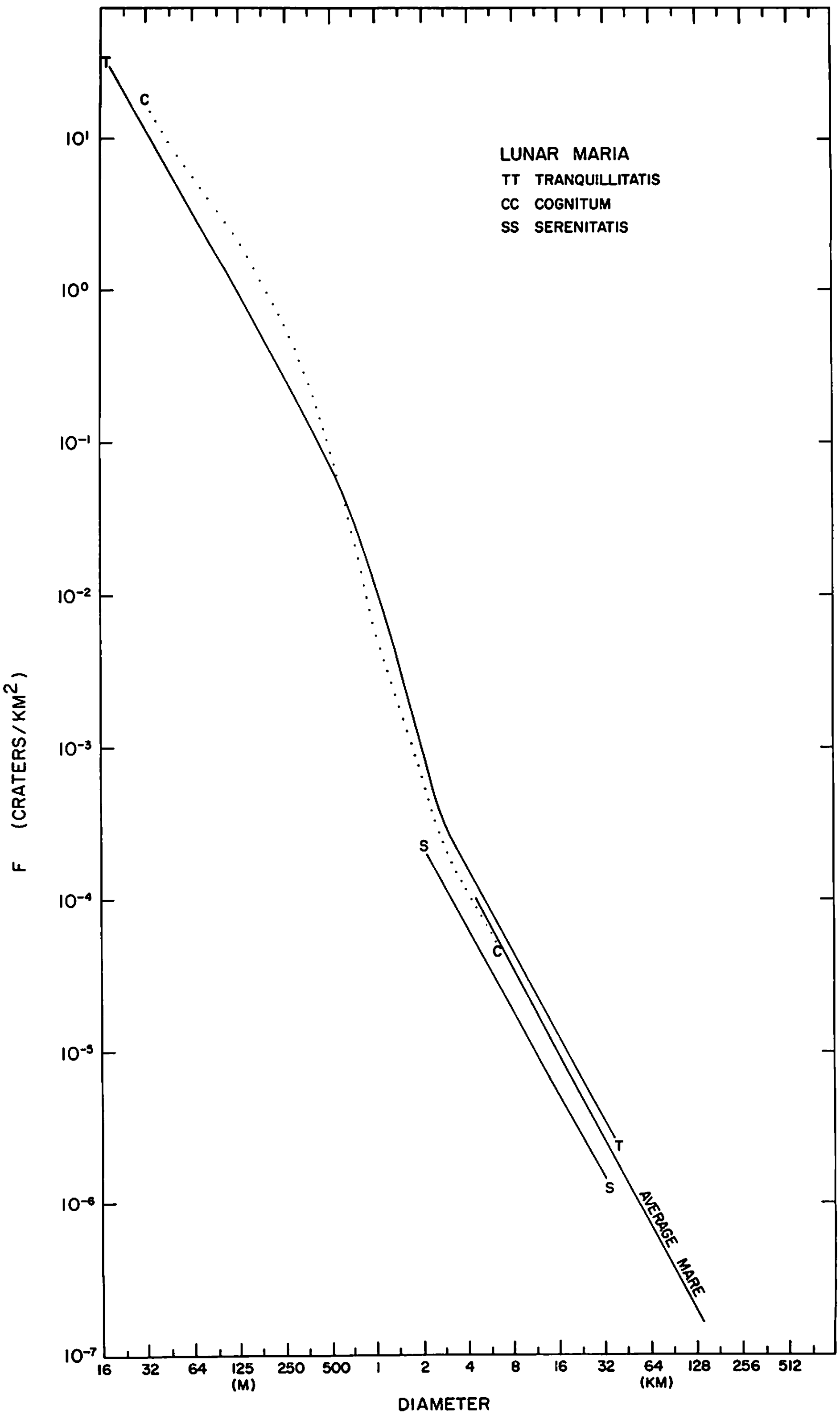

Fig. 2 Diameter distributions of craters on Mare Serenitatis, average mare, and Mare Tranquillitatis with datum points removed for clarification.

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