No. 134 CRATER OVERLAP ON THE NEAR-SIDE OF THE MOON

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ABSTRACT

An investigation of the overlap of craters on the front side of the moon shows a well-defined anomalous area around Tycho. This Tycho Association of craters may have originated as a result of the collision of a cometary shower, the nucleus of which formed Tycho itself. Alternative explanations are also considered. No full explanation is possible without additional research.

1. Introduction

The catalog of lunar craters by Arthur *et al* (1963, 1964, 1965, 1966) lists the diameters, selenographic positions, and other information, for craters with d > 3 km on the frontside of the moon. In addition to these data on crater-overlap, manuscript information is available at LPL recorded on punchcards. It includes the number and diameters of craters overlapping a given host crater.

In the present investigation all craters with d > 11 km, 5576 in number, were examined for the presence of "parasite" craters. A crater is called parasitic when it obviously overlaps another crater. Of the craters examined, 2400 are overlapped by one or more craters, yielding a total of 7100 parasite craters.

The number of parasite craters per host crater will be some indication of the age of the host. Two extreme groups are studied in detail, (1) craters without any overlap, and (2) those for a certain diameter range and in a given quadrant, with at least *twice* the average number of parasite craters.

The origin of lunar craters is still being debated. Arguments in favor of both impact and endogenic origin have been given. The information provided by space probes tremendously adds to ground-based information. Here Lunar *Orbiter IV* records were used to supplement and check ground-based records. Surprising results are derived for the Southern Highlands. Ronca (1968) had stated about this area, "Either the craters are predominantly volcanic or some endogenic control on the size of an impact crater exists." The present study seems to exclude the second alternative.

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2. *The Statistical Data*

The Arthur catalog entries were available at LPL on computer cards. Several printouts were made, each time in four parts, by quadrant. A first printout selected all craters with parasites and listed all overlapping craters for a given host crater. A second printout listed all craters in order of diameter. To avoid losses by incompleteness, a lower limit of 11 km was set for the host-crater diameter. For parasite craters the lower limit is set by the resolution of earth-based photographs. The Arthur catalog is fairly complete down to 3 km, but incompleteness is expected for the limb regions.

With both printouts, lists were made of both host craters and undisturbed craters larger than 11 km. Table 1 gives the results for each quadrant. There is a difference between Quadrants 1 and 2 (mostly maria) and Quadrants 3 and 4 (mostly highlands). The highlands have not only a larger percentage of host craters, but the average number of parasite craters (N_p) per host crater is larger. For simplicity, all craters in Table 1 are considered host-craters, with undisturbed craters having 0 parasites.

TABLE 1

STATISTICS FOR ALL CRATERS WITH d > 11 KM

	REAL HOST CRATERS	TOTAL CRATERS	PERCENTAGE HOST CRATERS	NUMBER PARASITE CRATERS	AVERAGE PAR. PER CRATER
Quadrant 1	282	926	30.4	473	0.51
Quadrant 2	149	486	30.6	430	0.88
Quadrant 3	727	1654	43.9	2763	1.67
Quadrant 4	1242	2510	49.5	3434	1.37
Total	2400	5576	42.0	7100	1.27

The difference noted is even more pronounced in a graph of a number of parasite craters per host crater (N_p/N_H) plotted against host-crater diameter; cf. Fig. 1 (undisturbed craters are again included). If instead only the real host craters are counted, the difference between the quadrants remains, while the spread in each plot widens. The host craters with d > 60 km are shown in Fig. 2. Again, the difference between maria and highlands stands out. The consistency of Quadrant 1 being below Quadrant 2 and of the Northern hemisphere below the Southern is remarkable. The graphs for Quadrant 3 and 4 are very similar. In combining all four quadrants, we obtain the fairly smooth average for the whole frontside, Fig. 3, a roughly quadratic curve, as expected. Graphs were also made for each quadrant of the percentage of craters being overlapped vs. diameter. These graphs are not significantly different. The average for all quadrants runs from 20% at 11 km, to 50% at 27 km, 80% at 68 km, to 100% at d > 135 km.

3. *Exceptional Craters*

It is of interest to consider the two groups of extreme or "exceptional" craters: (a) those having no overlap craters at all; and (b) those having at least twice the average number of overlap craters. This reference average can be taken either from the graph for one quadrant (which will show exceptional craters in the local sense) or the average for all quadrants (Fig. 3).

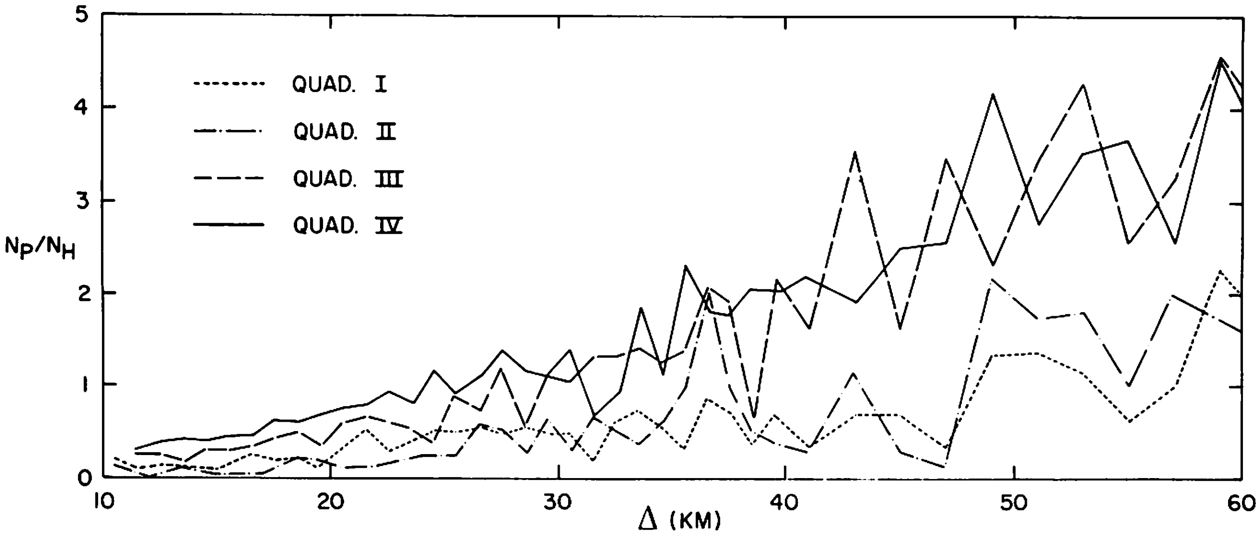

Fig. 1 Mean number of parasite craters per host center plotted against host diameter (in kilometers) for host craters smaller than 60 km. Separate curves are presented for each quadrant.

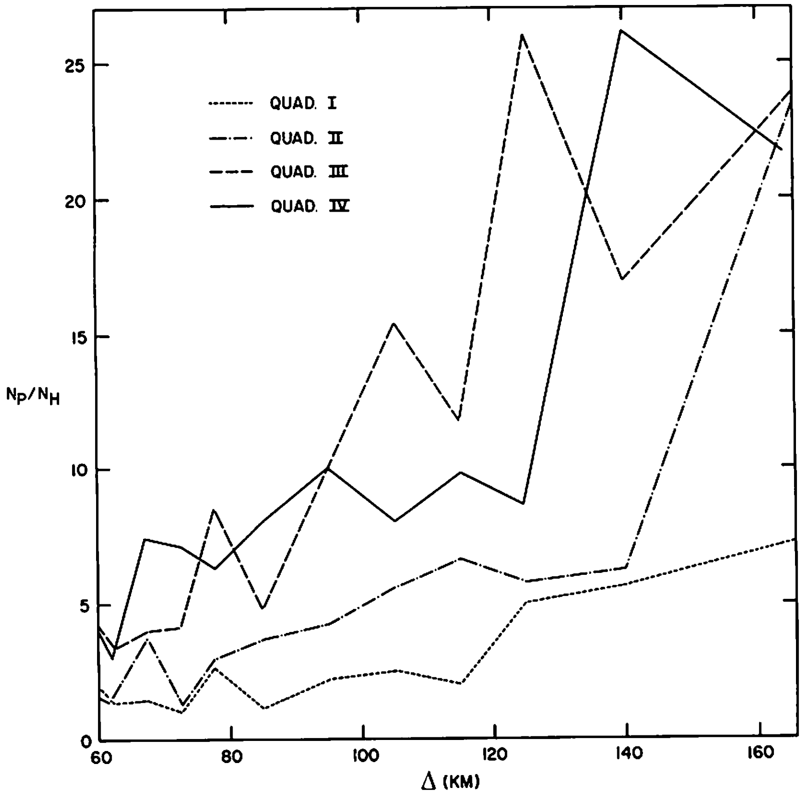

Fig. 2 Mean number of parasite craters per host crater plotted against host diameter (in kilometers) for host craters larger than 60 km. Separate curves are present for each quadrant.

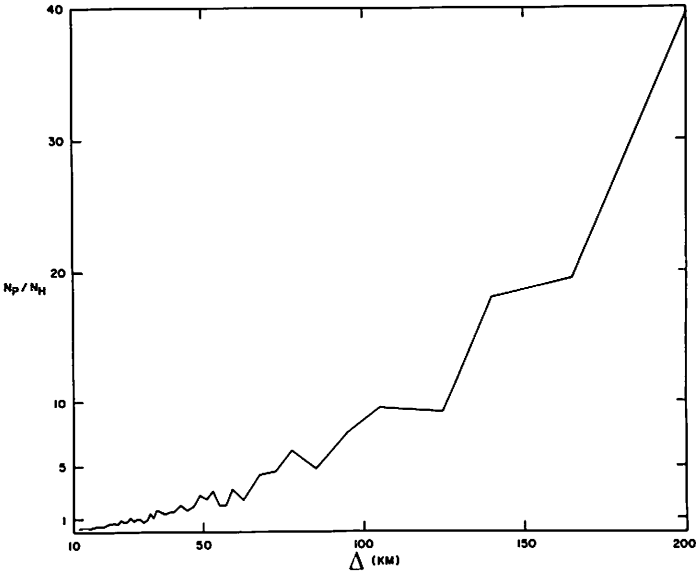

Fig. 3 Mean number of parasite craters per host crater plotted against host diameter (in kilometers) for all quadrants combined.

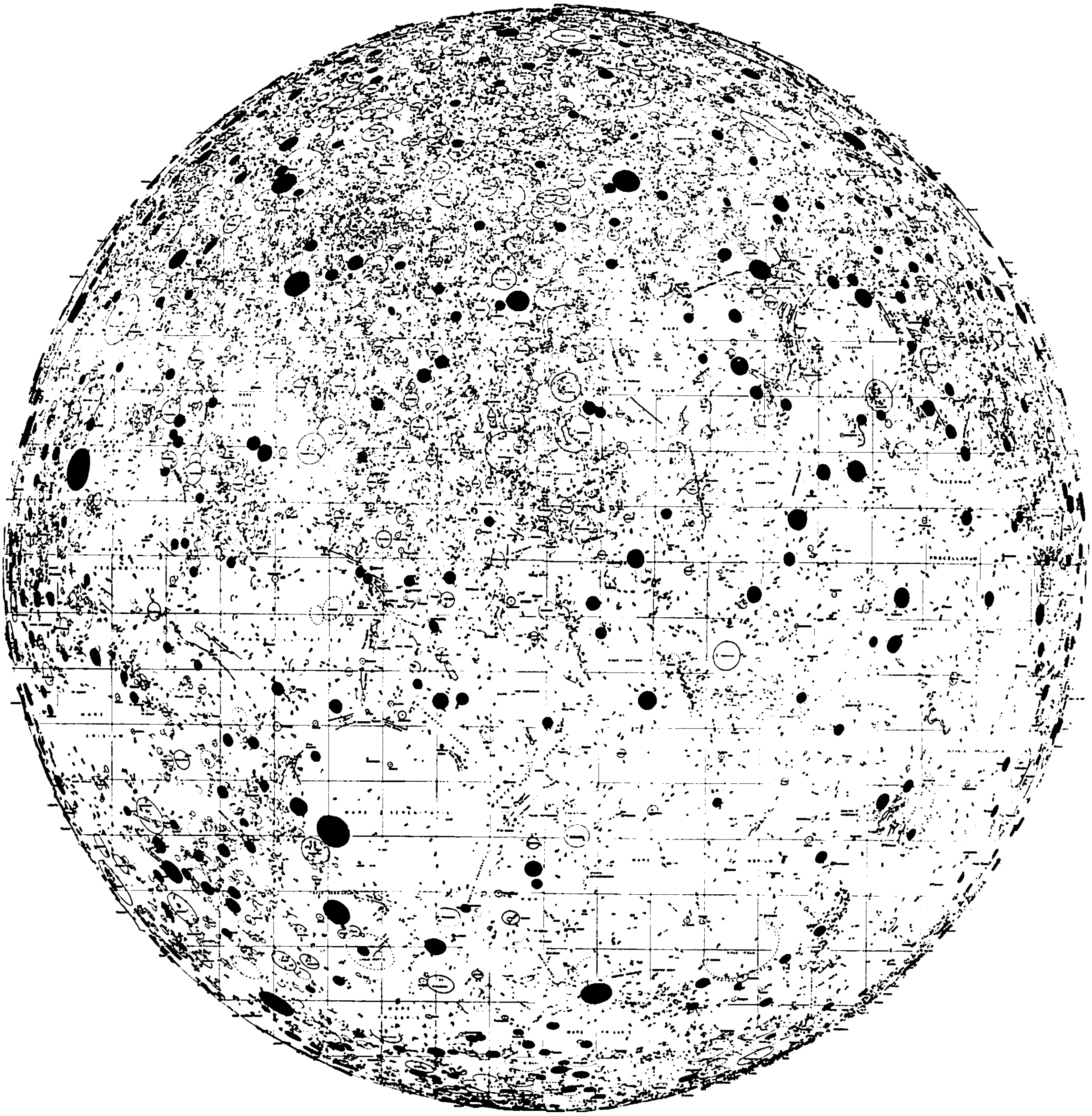

Fig. 4 Distribution of undamaged craters larger than 30 km. diameter. South is up.

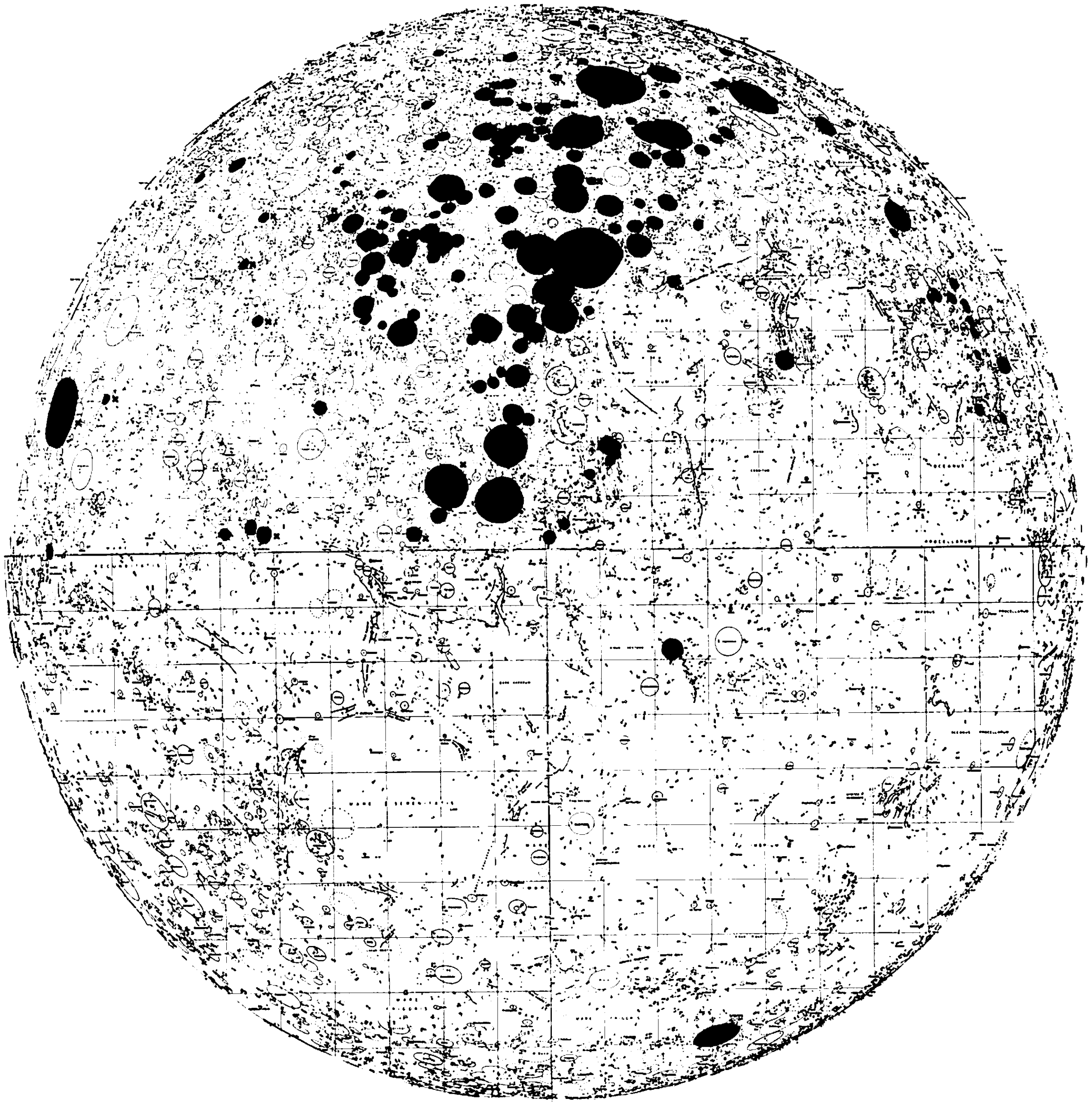

Fig. 5 Distribution of host craters having at least twice the mean number of parasite craters on the front side of the Moon. Examination of *Orbiter* photographs indicates that those craters marked with a cross probably do not exist. South is up.

Both extreme groups were examined for craters with d $\geqq$ 30 km, a limit chosen to exclude very small overlap craters and ambiguous statistics.

To determine how many parasite craters of 3 km in diameter had been lost in a typical area, Lunar *Orbiter* IV, high-resolution photograph No. 82, was examined. The results are given in Table 2.

TABLE 2

LOSS IN $N_p > 3$ KM NEAR LIMB

CRATER	ARTHUR CAT.	ORBITER	REMARKS
Hommel	11	18	Many 3 km-size parasite craters.
Mutus	7	9	
Boguslawsky	4	5	Quality of Orbiter photograph low.

The crater losses shown in Table 2 are perhaps less than expected. Nevertheless, we have excluded all areas within 20° of the limb from the discussion in Sec. 4 in order to make the data more homogeneous.

The surface distribution of undisturbed craters is shown in Fig. 4. Allowing for the marked differences in lunar surface structure, the crater distribution is remarkably random. By contrast, Fig. 5 shows the surface distribution of craters with at least twice the "average" number of parasites; the "average" used is that of the quadrant in question. Because of the similarity noted above, Quadrants 3 and 4 were combined.

If instead we adopt the "average" graph given in Fig. 3, the number of excess craters on the southern hemisphere is slightly increased. In Quadrant 1 there are 21 excess craters if the local average is taken, which all disappear when the overall average of Fig. 3 is used. Thus, there are no strongly overlapped craters in this entire quadrant. The same conclusion is found for Quadrant 2: compared with the local graph, there are 26 excess craters; but compared with Fig. 3, there are only 2, namely,

23808	J. Herschel	28 parasites
22138A	Stadius	10 parasites.

In Sec. 4 the distribution differences are discussed.

The cumulative diameter-frequency curve (Fig. 6) reveals a large difference in population distribution of the two classes. Fig. 6 is further discussed in Sec. 4.

It is interesting to determine how the heavily-overlapped craters are distributed among the classes as defined in Arthur's catalog:

Class 1: Very sharp and fresh-looking
2: Sharp but blurred rims
3: Craters with more broken rims
4: Craters usually described as ruins
5: Ghost craters and sometimes hardly recognizable

We did not confirm the Catalog classification in all cases. Some discrepancies are given below. We must also warn about interpreting these classes as an age-scale. E.g., ghost craters may be very young instead of very old (Fielder 1967; Fryer and Titulaer 1969).

Fig. 7 shows the distribution by Arthur class of both the craters without overlap and those with at least twice the average overlap. As expected, the peak for undisturbed craters is at Arthur class-2, as there are many more class-2 than class-1 craters in the catalog. It is surprising that there is also a high percentage of class-4 and -5 craters, though this may be explained in part by craters recently flooded with lava. Of the 82 class-4 craters, 50 (61%) are marked "F" (flooded interior) by Arthur.

As expected, the peak for craters with above average parasites is in the higher Arthur classes. No class-1 craters are represented in this group and only 8 class-2 craters. These are 15437 (Römer A), 21849 (Fontenelle), 32837 (Scheiner), 33835 (Weigel), 40882 (Lilius A), 41786 (Baco B), 40757B (Heraclitus D), 40773 (Licetus). These class-2 craters seem to have many secondary craters from nearby large craters.

4. *Interpretation and Conclusions*

The main result of this investigation is the discovery of a well-defined grouping of highly disturbed craters in the southern highlands which we shall call the Tycho Association. In Quadrant 1, not a single crater of this kind exists; and in Quadrant 2, only two craters, one of which (Stadius) can be explained by secondary impact craters from nearby Copernicus.

Some comments may be made at this point on the Arthur classifications mentioned in Sec. 3. I have noted that some of the class-5 craters are not real. I have used the Lunar *Orbiter IV* photographs to check each crater that was listed as having numerous parasite craters. The cases marked with a cross in Fig. 5 were not confirmed; i.e., the small craters were present but there was no host crater. With these corrections, the clustering of the Tycho Association is even more clearly defined and unique.

In explanation of this Association, it does not seem possible to explain it by random impacts ex-

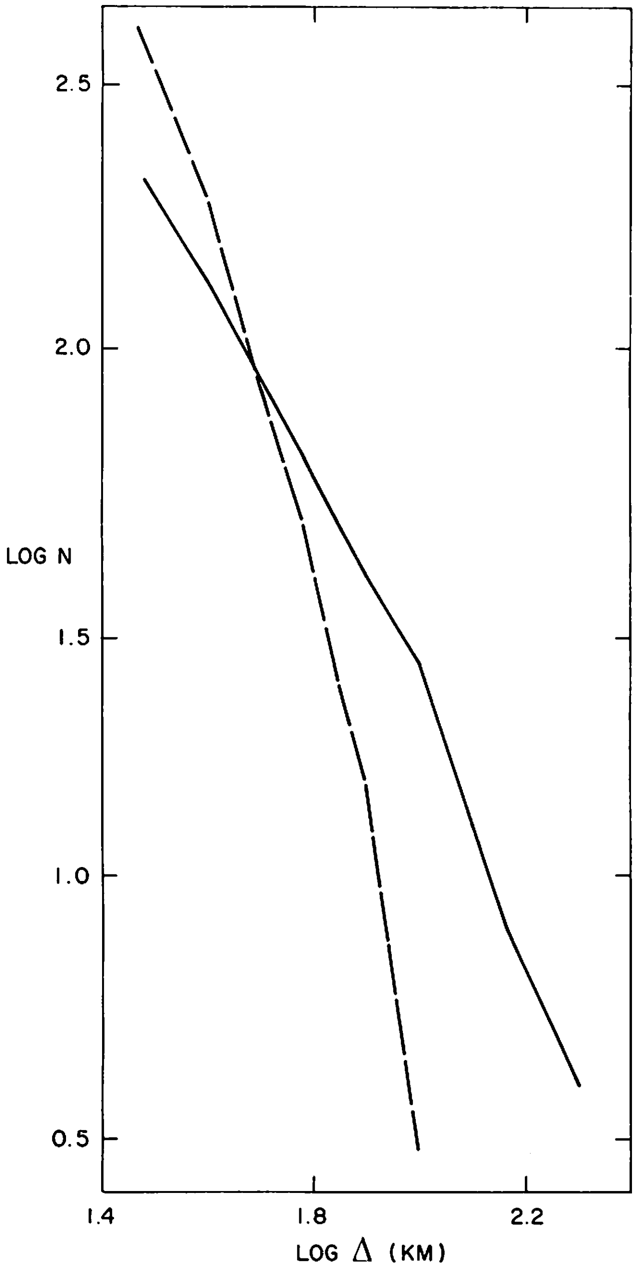

Fig. 6 Cumulative frequency, N, of undamaged craters (dashed line), and of craters with at least twice the mean number of parasites (solid line), greater than diameter Δ km plotted against Δ.

tending over a long period of time, nor can one conceive of a focusing process limiting the extent of the impact area. The nearly central location of Tycho within the Association suggests examining a possible relationship. Kuiper (1965) and Whitaker (1965) have concluded that Tycho may have been formed by the impact of a comet and have adduced much evidence in support of this hypothesis. Dr. Kuiper suggested to the author the possibility that the comet might have consisted of a main central mass, responsible for Tycho itself, accompanied by a swarm of lesser masses that could conceivably have been responsible for the Association. An apparent gap west of Tycho might then be accidental; in this area only a few large craters are present which would have been affected by the bombardment. It is true that other ray craters exist on the moon likely to have been caused by cometary impact; but these impact masses may have been more concentrated so that only one prominent crater formed in each case. If this explanation of the Tycho Association is correct, it would require that the composition of the attendant masses was different (less volatile) than that of the central mass, which is not impossible. The main check of this hypothesis must come from its compatibility with the relative ages of the members of the Association. It may well be that these ages will rule out a near-simultaneous origin.

An alternative explanation might be that the Association is the oldest area on the near-side of the moon and that the other highland regions are more mare-like and thus less populated by craters. This hypothesis would require verification through the discovery of other physical differences between the two highland regions. An examination of the photographs in the *Consolidated Lunar Atlas* does not reveal such a difference, except possibly a slight albedo difference on one full-moon photograph. More work is required to pursue this question.

A third possibility would be that exceptional endogenic activity occurred in the area of the Association. It is difficult to see, however, that a large roundish area as shown in Fig. 5 would result instead of the narrow belts normally so produced.

The author hopes to return to these problems in a later paper.

The distribution of undisturbed craters in Sec. 4 merits further attention. With allowance for the foreshortening toward the limb (all plots are made on Arthur's *Map of the Moon in Four Quadrants*), the distribution is roughly uniform. If we consider the classes of Arthur's catalog, almost all class-5

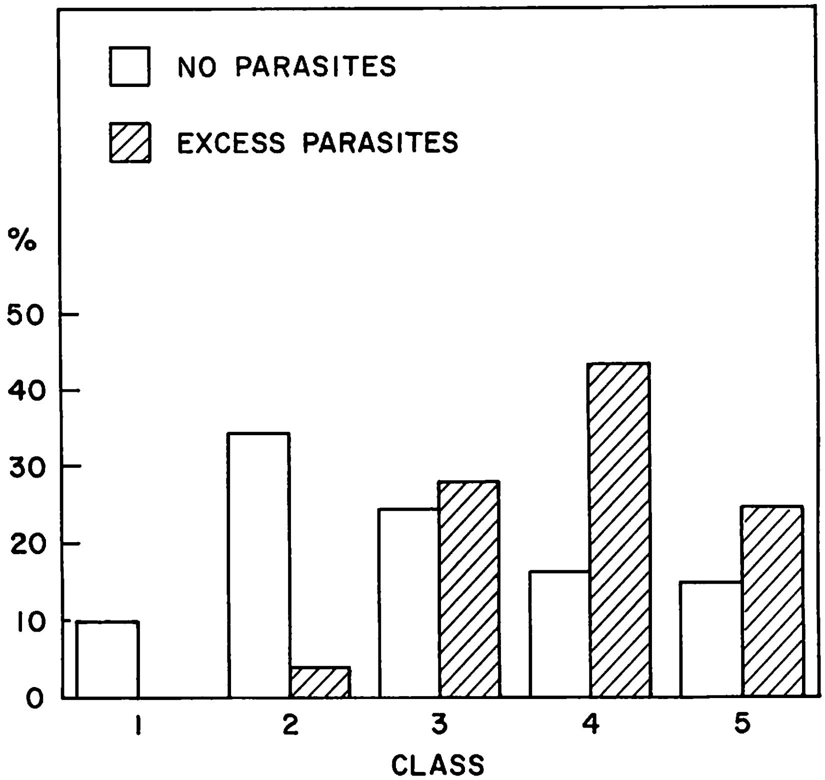

Fig. 7 A comparison of the distributions of both extreme types of crater over the classes of Arthur's Catalog.

craters are in the highlands, whereas of the class-1 craters a substantial percentage occurs in the maria. But even for them, twice as many occur in the highlands as in the maria. By contrast, the clean craters (Fig. 4) are distributed quite uniformly. If Arthur's classification measures age, then the clean craters must be younger than Arthur's class-1 craters with parasites. The highly-damaged craters all occur in the highlands (cf. Fig. 5). This would suggest that they are among the oldest lunar features.

The distribution in Fig. 4 does not show a difference in impact rate between the poles and the equator. Several non-overlapped craters may be young volcanic structures. None of the excess-parasite craters has a ray system, and most of the ray craters have no parasites.

The distribution of both clean and highly-damaged craters has been compared with the figures published by Ronca (1968). No similarities were found.

The slope S of the population curve for clean craters is 2.5, where

where $$S = \frac{d\,(\log F)}{d\,(\log D)}.$$

This is comparable with that quoted by Hartmann (1964) who found the average $S = 2.1$. For the highly-damaged craters (Fig. 6), $S = 1.25$, completely different. This may be due to a destruction of smaller craters by parasite craters.

It would be useful to extend this investigation to the farside of the Moon. So far, no overlap information in a suitable form is yet available.

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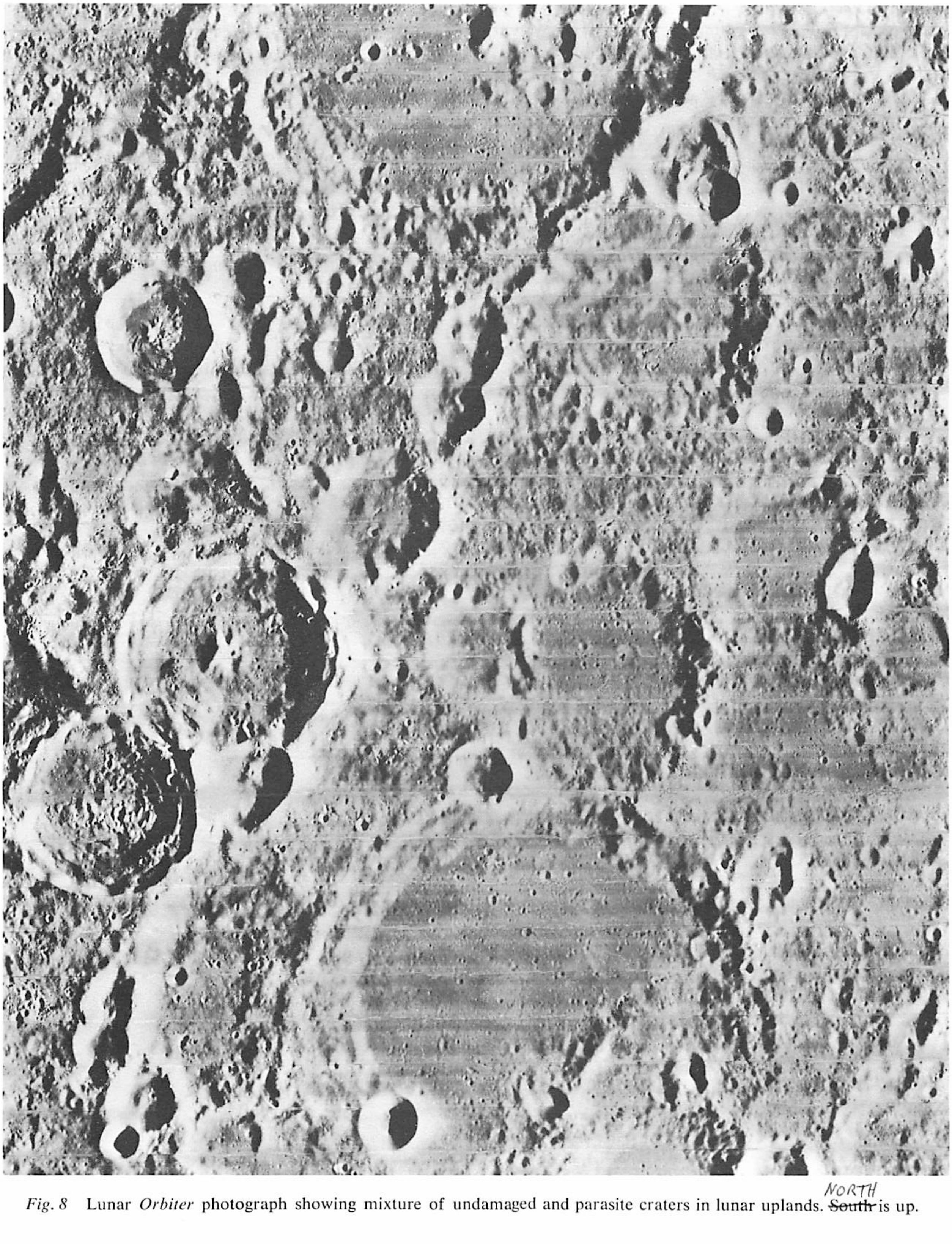

Fig. 8 Lunar *Orbiter* photograph showing mixture of undamaged and parasite craters in lunar uplands. ~~South~~ NORTH is up.

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