No. 120 STATISTICS OF CENTRAL PEAKS IN LUNAR CRATERS

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ABSTRACT

Statistics of central peaks are drawn from the large catalog, "The System of Lunar Craters." Only about 3% of all cataloged craters have peaks (cf. Table 3); this value is much smaller than has been previously reported. However, the percentage of craters with observed central peaks increases markedly with size and approaches 100% for undamaged craters of diameter 70km and larger (cf. Fig. 2). Young (undamaged) craters have peaks more frequently than older craters.

MacDonald (1931) and Young (1940) initiated modern statistical studies of lunar crater heights, depths, and diameters. This paper intends to improve the statistical data on the occurrence of central peaks in lunar craters.

As a compiler of the catalog, "The System of Lunar Craters" (Arthur, *et. al.* 1963, 1964, 1965, 1966), the author was responsible for determining which of the approximately 17,000 entries possessed a central peak. This decision was based on the examination of the original prints of the *Photographic Lunar Atlas* (Kuiper, *et. al.* 1960) and newer photography, including the Ranger #7, 8, and 9 records. (Orbiter photographs had not yet been obtained when the catalog was completed.) Each of the central peaks was classified as "weak" or strong," and "single" or "multiple." Classification was qualitative: the category for each peak depended on its height, brightness, and size relative to the crater diameter. The catalog was put on punch cards and the IBM 407 accounting machine of the University of Arizona was used to sort central peak data with respect to other crater parameters.

The data in "The System of Lunar Craters" were used to determine what percentage of craters have central–peaks, and how such central-peak craters differ from craters without peaks. Some of the 17,385 craters in the catalog were so small that it was impossible to determine if they had a peak. Likewise some craters were so near the limb that the detection of central peaks was unreliable. To avoid these selection effects *we included in the statistics only those craters with diameter D larger than 10km, and whose centers were 70° or less from the center of the moon's face.* Within these limits only 6.8% of the lunar craters on the earthward hemisphere have central peaks. (Only 3% of *all* craters, $D \geqq 3.5$km, have peaks.) This may appear a startling result, for even a poor photograph will show many central peak craters: Copernicus, Aristillus, Tycho, Bullialdus, etc. Indeed, Goodacre (1931) found that 19.2% of lunar craters have central peaks, in close agreement with Young's (1940) percentage of 21.1. Recently Baldwin (1963) compiled central-peak statistics from a sample of 342 craters and concluded that 68% of craters larger than 8km have central peaks. This

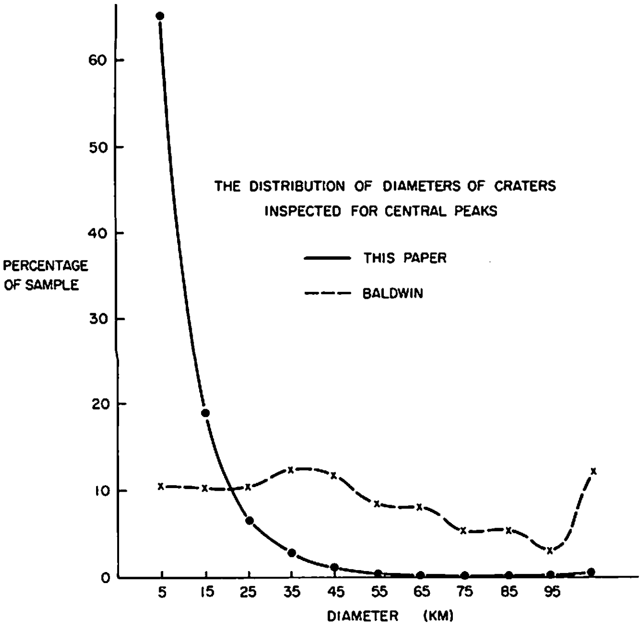

Fig. 1 Comparison of diameter distribution from the catalog, used in this paper, and that used in an earlier analysis of central peak statistics.

exceptionally high percentage is not representative, as may be seen by comparing the diameter distribution of Baldwin's 342 craters with the distribution of diameters in "The System of Lunar Craters." Figure 1 shows that *Baldwin's sample* is biased in favor of *prominent, named craters larger than 20km.* Similarly, the search for central peaks by members of the British Astronomical Association, reported by Goodacre, included "generally those [craters] of large diameters," so that his sample was not representative of the entire population of craters either. Young stated the diameter interval for his central peak statistics: 21.1% of 1126 craters between 16 and 208km, and 35.4% of 209 craters between 54 and 208km. At approximately the same intervals the values from "The System of Lunar Craters" statistics are 10% and 25% respectively. *The difference is due to Young's sampling procedure:* he included only craters conspicuous enough to warrant designations. Such craters are usually large or fresh looking and frequently possess central peaks.

Each crater in "The System of Lunar Craters" was classified on a 1 to 5 scale according to the sharpness and completeness of its rim. Class-1 craters have very sharp, complete rims, while craters whose rims are either blurred or broken are classed as 2 or 3. Ruins are class-4 objects, and class-5 is restricted to ghost craters and other structures so battered or fragmentary that they are not easily recognizable as former craters.

In Figure 2 the percentage of central-peak craters of each class is plotted against crater diameter. It is found that:

(1) The probability of a crater possessing a central peak increases with diameter.
(2) For any diameter interval, the percentage of peaks in class-1 craters is greater than for class-2 craters; the percentage of peaked class-2 craters is greater than class-3; etc.
(3) In each class of craters the percentage of peakedness reaches a maximum at a particular diameter and then remains nearly constant for larger diameters. Above 90km there is a slight decrease in the percentage of central peaks for classes 2, 3, and 4. At these large diameters, unless a crater is relatively "new," it has suffered the overlap of many newer craters which may in some cases have obliterated the peak. There is no decrease for class 1, and the falloff for class 2 is small.
(4) For all craters irrespective of class the maximum percentage of central peaks (30%) is reached at about 60km. This disagrees with Tyurk's finding (Sharonov 1964) that the maximum frequency of central peaks occurs at 25 to 30km.

If the classification series 1 to 5 indeed represents an age sequence (with class-1 craters being the most recent), and if most of the craters are due to a single process of formation, the implication of (2) could be that craters are normally formed with peaks, but the peaks are destroyed with time. Alternatively, peak formation may have been less likely early in lunar history.

Table 1 presents data bearing on these hypotheses. *The ratio of "weak" to "strong" peaks is found to increase with the age of craters (class).* This again suggests that weak peaks may have formed as strong peaks which have been "eroded" or that peak formation was favored during the "class-1" period of lunar history. Further, since crater classification is determined by *rim* sharpness, this result suggests that peak age is highly correlated with crater age.

Using fewer data, Fielder (1965) found that the ratio of weak to strong peaks was *not* correlated with crater class and concluded that "erosion" has *not* been an effective peak destroying agent. While this conclusion is not confirmed here, Fielder's observation that both weak and strong peaks occur in craters of various ages is accepted.

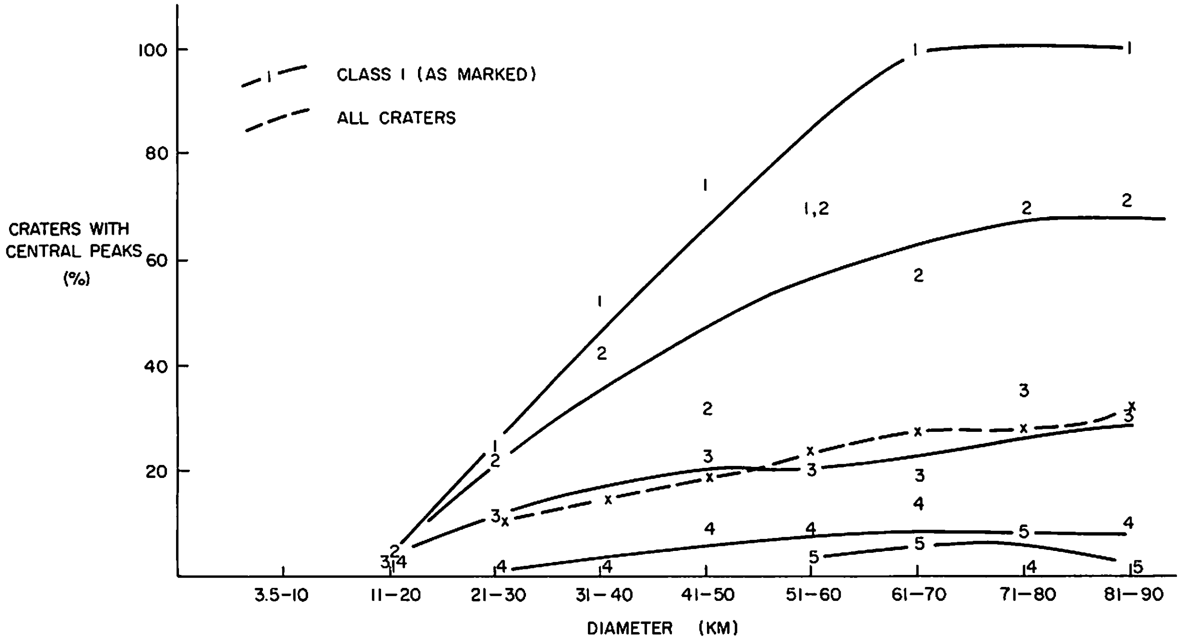

Fig. 2 Systematic trends in central peak frequency as a function of "class," based on crater preservation.

Statement (1) is not unexpected. If craters were formed by impact, the depth of brecciation would be proportional to crater diameter. If peaks are the result of volcanic activity they would be formed only if the fracture zone under the crater extended to an area of magma; hence large craters with their deeper zones of brecciation should have a greater percentage of central peaks than small craters. Similarly if peaks are thought to be rebound structures, the likelihood of peak formation would increase with the strength of the initial explosion, and hence crater diameter. If peaks were uplifted following gravitational slumping of rim material onto the crater floor, this effect also would be more pronounced if the initial explosion were greater, and the crater, larger and deeper.

The *percentage of multiple central peaks* varies only slightly with class, being 25%, 20%, 21%, and 29% for classes 1, 2, 3, and 4 plus 5. This indicates that single and multiple central peaks were produced in about the same ratio throughout lunar history. However, the multiplicity of peaks is correlated with crater diameter as Table II shows.

TABLE I
RATIO OF WEAK TO STRONG PEAKS

CLASS	WEAK	STRONG	RATIO
1	36	20	1.8
2	124	65	1.9
3	120	45	2.7
4	38	12	3.3
5	8	1	8.0

Table III compares the statistics of central-peak craters with those of all craters in "The System of Lunar Craters" for different age groups or "backgrounds." The figures indicate that the fraction of central-peak craters is uniform in different areas. However, this table does not have as much interpretive value as Fig. 2, in terms of lunar history, because *all* craters in the catalog were used ($D \geqq 3.5$km instead of the previous $D \geqq 10$ km). This dilutes the sample with small, non-CP craters, and the percentage of CP craters drops from the 7% found earlier to only 3% for *all* craters in the catalog. It does appear, however, that craters with central peaks do not have a unique location, age, or mode of formation. There may be a spread of ages, central peaks being most common in craters formed during the mare-forming epoch or early post-mare time (i.e. including most class-1 craters as found from Figure 2).

TABLE II

DIAMETER INTERVAL	% MULTIPLE CENTRAL PEAKS
0- 50 km	16
50-100 km	34
100-150 km	37
150-200 km	75

TABLE III

CRATER TYPE	TOTAL CRATERS	CP CRATERS	% CP CRATERS
Post-mare	2039 or 11.7%	60 or 12.3%	2.9
Ante-mare	964 or 5.5	26 or 5.3	2.7
Continental	14382 or82.7	403 or 82.6	2.8

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