LINEAR GROUPS OF LUNAR CRATERS, L.D. Jaffe and E.O. Bulkley, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91103.

In an earlier paper (1), the authors found evidence that large lunar craters tend to lie in circular groupings. Locations of lunar craters 50-400 km in diameter were compared with those of randomized models (models matching the lunar crater density either overall or in the maria and highlands separately). Groups of four or more lunar craters were found to lie along circular arcs more frequently than did those in the models; the frequency differences are statistically highly significant. This was true both for groups of craters considered regardless of age, and for groups limited to late pre-Imbrian (Nectarian), middle pre-Imbrian, or early pre-Imbrian craters. The arcuate crater groups ("families") tend to center in the highlands and in different regions for Nectarian craters than for pre-Nectarian.

Several hypotheses for the origin of these families were considered in (1), none of which appeared satisfactory. Much of that discussion of possible origins concerned the compatibility of the hypotheses with the observed locations of the centers of the circles on which the craters lie. For example, one hypothesis considered was that a significant fraction of the large lunar craters are secondary to the impacts that created major basins. Reference (1) pointed out that the morphology of the craters considered is different from that typical of secondary impacts and that the arcuate families do not center in the maria. The latter point is weakened by the consideration that groups of secondary craters need not center about the primary. Shoemaker (2) noted that some of the secondaries tend to lie in "loops" or along near-linear rays extending out from the primary. The primaries to look for might accordingly lie <u>along</u> the arcuate groupings, rather than at their centers. For this reason, it seemed worthwhile to examine whether some of the arcuate families could also be interpreted as near-linear groups, extending out from possible primaries.

In this investigation, the lunar families found in (1) were sorted to identify those families having a diameter, measured along the lunar surface, larger than the lunar radius and, separately, those having a diameter larger than twice the lunar radius. The age classifications of (1) were retained. The locations of the first four craters in each family were then plotted by computer, for each age class, and a line drawn by computer between the two of these four craters that were furthest apart. Equiangle projections were used to preserve directional relationships.

A similar procedure was followed for four randomized models. In two of these ("random models"), the diameter and geologic classification of each lunar crater was preserved, but the longitude and sine of the latitude were obtained by random number generation. This should provide craters distributed at uniform density over the models. In two other models ("semirandom"), the locations of lunar maria were preserved in the models. Again the diameter and geologic classification of lunar craters were preserved, and the longitude and sine of the latitude were obtained randomly, but with the constraint that lunar mare craters were confined to mare portions of the models, and craters outside the lunar maria were confined to non-mare portions of the

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models. Families found for each age class with each model were plotted in the same way as for the lunar families.

A statistical analysis was made of the number of families found, using the t-test. A test was first made of the probability that the observed number of lunar families for each age class would be found if they were from the same population as the families in the semi-random models, from the same population as the families in the random models, or from the same population as the four randomized models. Also, a test was made of the probability that the observed number of semi-random families would be found if they were from the same population as the random families.

The number of lunar families having diameters greater than the lunar radius is significantly greater (0.05 significance level) than for the four randomized models, for every age class that included pre-Imbrian craters; for many of the age classes the difference is highly significant, statistically (0.01 significance level). Highly significant difference occurs for families consisting solely of late pre-Imbrian craters, solely of middle pre-Imbrian and solely of early pre-Imbrian, as well as for some classes including both Imbrian and pre-Imbrian craters. When family counts of lunar crater classes are paired with those of the corresponding randomized model classes and grouped, the differences are all highly significant.

The linear families of craters found on the moon lie almost entirely in the highlands. They do not, in general, lie tangential or radial to large circular basins. A few may do so: those lying north of Maria Imbrium and Serenitatis and roughly tangential to them, and those southeast of Mare Nubium. The families north of Imbrium and Serenitatis consist predominantly of pre-Nectarian craters. Since these craters are older than the Imbrium basin, they cannot be secondary impacts from the event which formed it. The Serenitatis basin is probably late pre-Nectarian. Some of the craters comprising the linear families to the north are probably older than this. Also, they are over 1500 km distant; their association with Serenitatis is tenuous.

The near-linear crater families southeast of Nubium include many craters of middle pre-Imbrian age. The Nubium basin is of early pre-Imbrian origin; parts of the original basin are probably overlain by some of these crater families. Thus, these families are apparently too young to be secondaries from the Nubium impact.

Thus, the near-linear families seemingly cannot be secondaries from the impacts that produced the mare basins. Also, there is no obvious association of near-linear families with the large unflooded circular basins of the far side. Rather, the craters constituting near-linear families are widely distributed over the highlands. They evidently are not genetically related to the basins.

The statistics indicate that the observed frequency of near-linear lunar crater families cannot be accounted for as a random effect of the total crater population distributed randomly over the moon or of the mare and highlands crater populations distributed randomly over these terrain types. It is still possible that random distributions over a larger number of smaller areas might account for the observed frequencies, and this should be investigated further. Any regional differences in crater density must pertain to

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highland regions if they are to account for the observations.

The near-linear families of lunar craters of each age classification constitute only a few percent of the arcuate families of the same age class. Though the frequency of near-linear families is highly significantly greater than that for random impacts, they may represent the high arc-diameter tail of the population of arcuate lunar craters. Rather than seeking the origin of the near-linear families, it seems appropriate to seek the origin of the much larger number of arcuate families. Reference (1) showed that they do not lie circumferentially to major circular basins; this work shows that they do not lie radially or tangentially to the basins. Together, these results appear to rule out the possibility that the arcuate crater families were produced by the impacts that formed the large circular basins, either directly by impact of secondaries or by obliteration of a circular region within the arc, or indirectly, through production of circumferential topographic rings or ring fractures, followed by selective obliteration through differences in erosion or flooding associated with the ring topography or fractures.

Thus, the more obvious explanations for the arcuate families of lunar craters appear ruled out. Since a great many arcuate families have been found, and their numbers are statistically highly significantly greater than expected for random craters (1), the need to find the process by which these groups were produced becomes more interesting and more important. Possible approaches include examination of regional differences in crater density among the highlands and their possible association to the arcuate families, analysis of the morphology of the craters constituting the families, the distribution of family diameters, determination whether small craters (< 50 km in diameter) tend to lie in arcuate families, and whether craters on Mars and Mercury also lie along circular arcs.

REFERENCES

(1) Jaffe, L.D., and Bulkley, E.O. (1976). Lunar crater arcs, The Moon 16, 71-114.

(2) Shoemaker, E.M. (1962). Interpretation of lunar craters. In "Physics and Astronomy of the Moon" (Z. Kopal, ed.), pp. 283-359. Academic Press, New York and London.

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