SIZE OF LUNAR CRATERS AND THE CHRONOLOGY OF THE MOON

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SIZE OF LUNAR CRATERS AND THE CHRONOLOGY OF THE MOON

Hitoshi TAKEUCHI and Hitoshi MIZUTANI

Of late, research has been briskly progressing [1] in connection with determining the relative ages of the different terrains seen on the moon's surface, by application of rules modeled on those of terrestrial geology. For instance, the lunar chronological scale employed by research workers of the U.S. Geological Survey classes these terrains as follows (starting from the oldest): Pre-Imbrian Period; Imbrian Period; Procellarian Period; Eratosthenian Period; Copernican Period. One of the important conclusions from this research is that the dark parts of the lunar surface, the so-called seas or maria, originated from magma that issued from the moon's interior in the Procellarian Period. Elucidating the relationships between the lunar time periods thus determined and the terrestrial geological eras is, we may take it, an important task for planetary science. An important step in this direction is the recent study by Zdeněk Kopal of Manchester University, England [2]. Kopal has taken as his starting point Hawkins' findings (also of recent date) on the distribution of meteoritic matter in the solar system. From Hawkins' results, for instance, one can calculate the number N of meteoritic bodies of mass >m impacting upon the moon per unit area of the lunar surface and per unit time. The energy of motion, E, of such a meteoritic body is given by the expression $(1/2)mv^2$, where v is its velocity. On the other hand there has been, of late, a good deal of experimentation with regard to determining the diameter D of the crater produced when an explosion of energy E occurs in the earth's surface. The experiments have ranged from laboratory explosions to nuclear explosions. Accordingly, if it be provisionally assumed that v is independent of m, we may now, by proceeding sequentially from $m \rightarrow N \rightarrow E \rightarrow D$ as above, calculate how many craters of diameter greater than D will be produced per unit of lunar surface area per unit of time. The curves in Figure 1 show the relationship between D and the number of craters with diameters >D. Here the figures are for area 10^6 km^2 and time 4000 million years, and are calculated for two values of v, namely 2.38 km/sec, the moon's escape velocity, and 10 km/sec. The circlets and dots in Figure 1 represent the relationships, as found by Shoemaker and by Hartmann respectively, between diameter D of craters on the lunar maria and the number of craters of diameter greater than D (the number of craters being expressed per 10^6 km^2 of area). Basing himself on this result, Kopal concludes that the time elapsed from the Eratosthenian Period to the present is about equal to the age of the earth, 4500 million years. This is indeed an interesting conclusion. But for those who take the age of the moon to be about the same as the age of the earth, it is a disconcerting conclusion indeed, for Kopal's finding leaves no room for the lunar Periods prior to the Procellarian!

Let us look at Figure 2 [3]. Here the crater count of Figure 1 is plotted separately for the lunar "sea" areas (maria) and for the lunar "land" areas. For craters of the same diameter D, the land-area count is higher than the sea-area count by about 20 times. If we assume that the number of meteorite impacts is unchanged from the earliest times until today, then the age of the moon's land areas would be twenty times that of the maria and the age of the moon as a whole must be 90,000 million years. One way of escape from this conclusion is to suppose that in the initial period of the moon's history the number of meteorites falling on the moon was very much greater.

We decided to revise the above argument from the beginning. At the same time we were pondering over possible reasons why the lunar craters are so much larger than terrestrial meteorite craters or calderas. It immediately occurred to us that the force of gravity at the surface of the moon is only about one-sixth of what it is at the earth's surface. If we now consider the parabolic paths of bodies ejected by explosions (neglecting the presence of the earth's atmosphere) then it becomes clear to us that the diameters of lunar craters will be on the average six times greater than the diameters of terrestrial craters. And this holds not only for the diameters; the depths too are greater.

These facts suggest the following line of thought. Below-surface explosions occur when the explosive pressure exceeds the pressure in the rock at the depth in question. Putting ρ for the rock density, g for the force of gravity, and h for the depth, the rock pressure is ρgh. The explosive pressure is unrelated to g. We may assume that ρ is the same for the earth and for the moon. Then the crater depth h will be inversely proportional to g, and thus the depth of lunar craters, in the mean, six times the depth of terrestrial craters. With an atmosphere present, the theory is not so simple. But according to experimental studies recently conducted by NASA, the diameters of explosion craters are indeed approximately in inverse proportion to the force of gravity [4]. Now let us reconsider the process as found in Figure 1, arguing from m $\rightarrow$ N $\rightarrow$ E $\rightarrow$ D. Here the step from E to D depends on terrestrial experiments. Should our reasoning be correct, then if such experiments were conducted on the moon we should expect a six times greater D for a given E. In Figure 1 for the moon, the abscissae [of the curves predicting the relationship of crater count to diameter] will be multiplied by six, the coordinates remaining the same, and when this adjustment is made, the curves (always for the same two values of $\underline{v}$) will no longer agree with the plotted points representing the observed crater data for the lunar maria. In Figure 2 we show a scale length [the horizontal arrow] corresponding to multiplication by six. Now the fact to which we wish to draw attention is that when in Figure 2 the diameter values for the lunar maria craters are multiplied by six, the plotted points, thus displaced to the right, come just about into coincidence with the straight line representing the crater count for the lunar land areas. Now we may think as follows. It is not the lunar maria that have an age similar to that of the earth --- 4500 million years. Rather it is the lunar "land" areas that have this age. At any constant abscissa in Figure 2, the crater count (coordinate) for the lunar land areas is about twenty times that for the maria. Thus if we assume the age of the land areas to be 4500 million years, the age of the maria is one-twentieth of this, or about 230 million years. Here there may be some connection with the fact that no ages greater than 500 million years have been found for tektites, which are thought to be matter ejected from the moon.

Perhaps in a few years from now it may become clear whether our line of thought is correct. That is to say, we may be fortunate enough to obtain, by soft landings on the moon or otherwise, representative samples of rocks from the maria and from the land areas of the moon. Our suggestion is that the age of the land areas is a few thousands of million years, while the age of the maria is a few hundreds of million years. This is sharply at variance with Kopal's deduction that the age of the maria is close to that of the earth.

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REFERENCES

(1) E.M. Shoemaker: Scientific American, 211, 38 (Dec. 1964).

(2) Z. Kopal: Space Science Reviews, 4, 737 (1965). (This review paper recapitulates in detail other papers of which we have made use.)

(3) R.B. Leighton: Scientific American, 214, 54 (April, 1966).

(4) L.K. Moraski et al.: Trans. Amer. Geophys. Union, 47, 149 (1966).

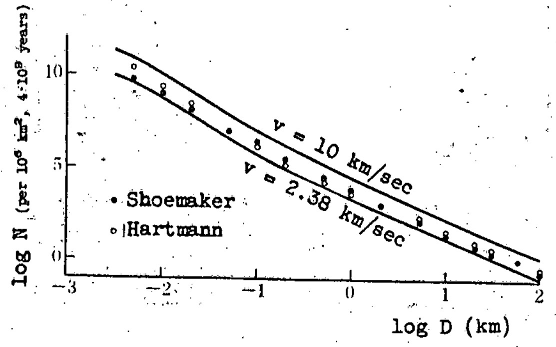
log N (per 10⁶ km², 4·10⁹ years)
10
5
0
−3
−2
−1
0
1
2
log D (km)
v = 10 km/sec
v = 2.38 km/sec
• Shoemaker
∘ Hartmann

Fig. 1

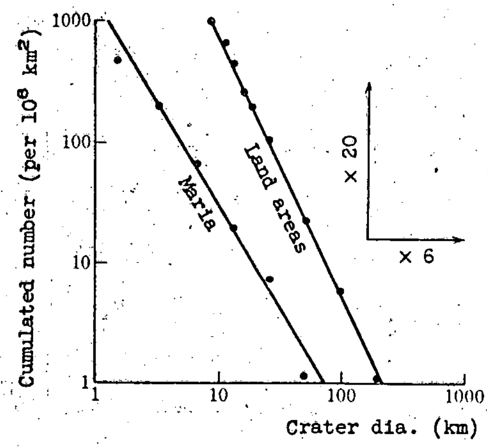
Cumulated number (per 10⁸ km²)
1000
100
10
1
1
10
100
1000
Crater dia. (km)
Maria
Land areas
× 20
× 6

Fig. 2

1867 Centennial of Canadian Confederation 1967
1867 Le Centenaire de la Confédération Canadienne 1967