

ON THE ORIGIN OF THE LUNAR CRATERS

BY

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1. Introduction

The most conspicuous feature of the lunar surface is a crowd of regular shaped large and small craters. The surface of the Moon attracts our interest because of its curious appearance; it tells us even now something about the state of formation of the Solar System. Although some atmosphere must have existed in early times, there is neither air nor water, nor erosion and weathering on it.

There have been two hypotheses as to the origin of the craters. One supposes a bombardment of meteorites, while the other claims volcanic explosions were responsible. Regularity in the distribution and in the shape of numerous craters make it difficult for us to support these two hypotheses.

S. Miyamoto (1960 a, b) proposed an idea that the lunar craters were formed as the traces of a degassing process in the course of the lunar crustal formation. He attributed the form of the craters to the subsidence of molten spots on the crust, due to degassing from underground caverns filled with a highly volatile constituent. He discussed also the possibility of second boiling of magmas by further cooling, and of formation of underground gas caverns. It seems difficult, however, to explain the regular circular shapes of the ramparts and the smooth floors of the craters only in these terms.

Several years ago the author was studying the shape of water bubbles theoretically and experimentally. One day, seeds were planted in a flowerpot and water poured over the dry sand. As the water filtered into the sand, the air contained in the inter-space of sand rose, causing bubbles on the surface. As the bubbles burst, sand craters were formed that retained the shapes of the bubbles. They looked so much like lunar craters, that he felt the origin of lunar craters might have been from enormous bubbles formed on the lunar surface, when the Moon was solidifying.

At this point, he also recalled mud hot springs. There are many such hot springs in Beppu, a large spa in Japan. High temperature vapor bubbles rise from the bottom of mud ponds and burst at the mud surface. The traces of the bursting of the bubbles seem very similar to the lunar craters. Plate 1 shows some frames

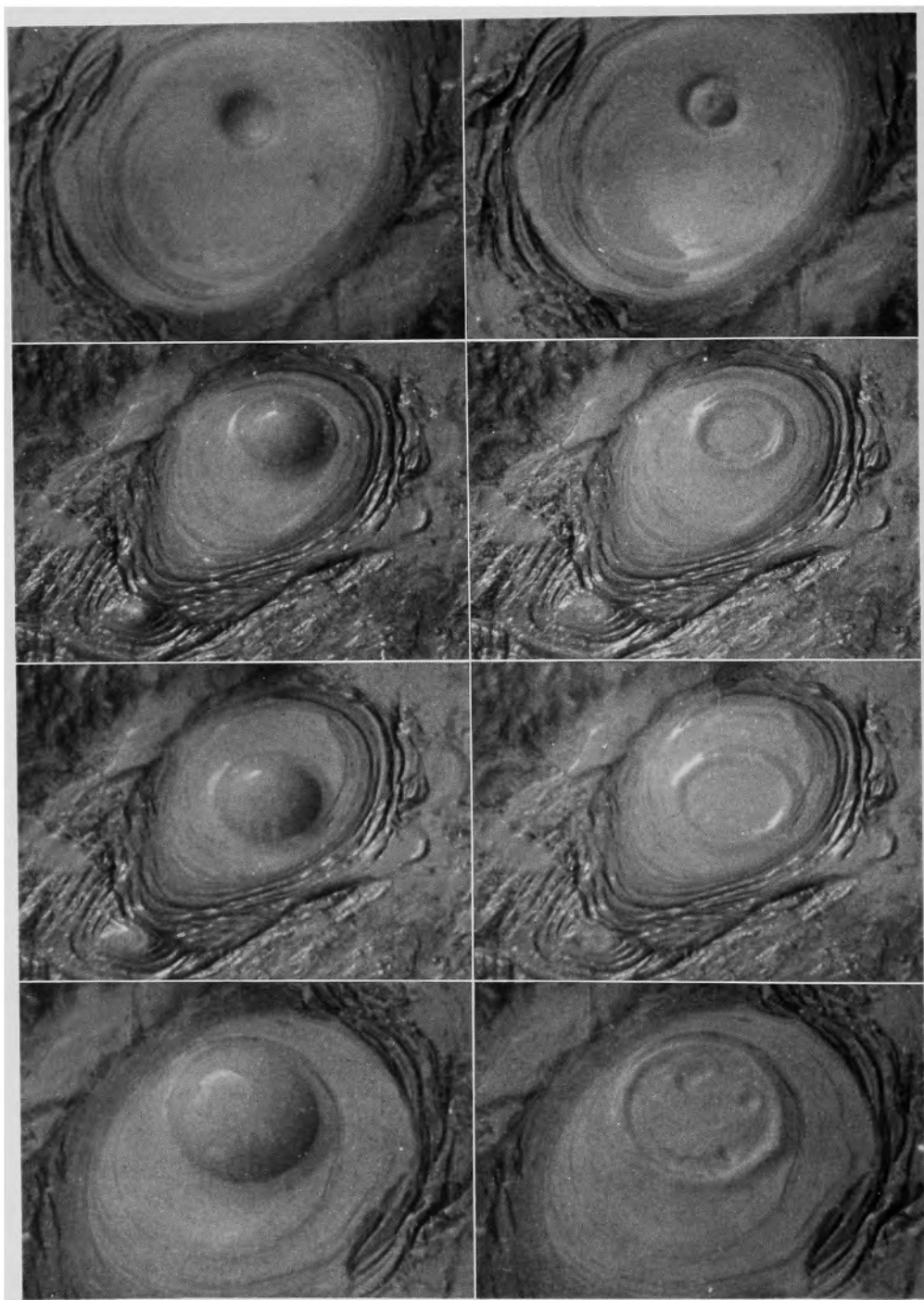


Plate 1. Vapor bubbles and the craters formed upon their collapse, at a mud hot spring in Beppu. Photographs on the left correspond to those on the right, respectively. (Photographed by Dr. K. Kikkawa.)

from a motion picture of them.

A recently published U.S. Air Force "Lunar Chart" has offered up-to-date materials useful in the study of the shapes of lunar craters. We compared the shapes of lunar craters with those of water bubbles and found some similarity between them. A report of this comparison is given in the following section.

2. Comparison between the shape of lunar craters and that of water bubbles

It has been established that there is a statistical relation between the height of the ramparts of lunar craters above their floors and the diameter of the respective craters. It is known as "Ebert's rule." Although it is based on early visual measurements subject to certain reservations, it states that the larger the diameter, the smaller the ratio of rampart height to diameter. The physical meaning of the rule, however, has not been known. Further, very small craters appear to have almost no ramparts at all, and represent mere depressions sunken in the lunar surface (Z. Kopal, 1961).

According to the study of Y. Toba (1959) the equilibrium shape of a bubble is, in small size, nearly spherical and exists almost entirely below the still liquid surface, but in larger size, it deviates from the spherical shape, then begins to protrude on the water surface, and finally, the bubble floor approaches a flat plain encircled by a rampart with a hemispherical cap of film. Fig. 1 shows the change in the shape of a water bubble with size. This characteristic seems to coincide with the above facts on the lunar craters.

To compare quantitatively the shape of the lunar craters with that of water bubbles, the diameter of craters (X) and the depth from the crater rim to its floor (Z) have been taken from USAF Lunar Chart (1961~), which was constructed from motion-picture studies on the travel of shadows across the lunar surface, and which reported the depths of craters larger than several km in diameter. Only the following five portions of this publication are available to us: LAC 58, 74, 76, 93 and LVC

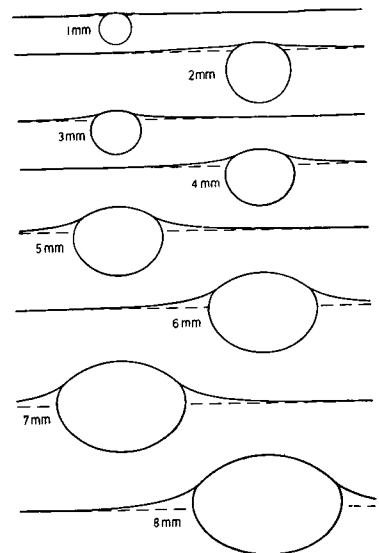


Fig. 1 Change in the shape of a water bubble with size. The size is entered as the diameter of a sphere having the same volume with the bubble. Two figures at the top are drawn in a twofold scale. (Y. Toba, 1959).

20, which present the solenography of the western equatorial region of the Moon. Values for the crater systems Copernicus with its surroundings (LAC 58), Kepler with its surroundings (a part of LVC 20), Sirsalis, Lansberg, and Damoiseau are plotted by white circles in Fig. 2. These craters reveal their outstanding figures in these regions and seem to be of similar solenographical situations. We may regard a water bubble as a hydraulic model experiment for the lunar crater formation. Factors such as gravity, density, viscosity, a kind of force corresponding to surface tension, etc. affected the crater forming processes, while the shape of a water bubble studied is for a equilibrium state, which means a limit stage in the crater formation. Consequently, a deformation of the horizontal and the vertical scales must arise in order to fulfil the condition of the similitude between the proto type (the lunar crater) and a model (a water bubble). We take the horizontal and vertical scales of the proto type (X, Z) and a model (x, z) as $X=\alpha x$ and $Z=\beta z$. If one takes the values of $\alpha=1.3\times10^7$ and $\alpha/\beta=15$, the shape of the model fits closely that of the proto type as shown in the lowest curve in Fig. 2 (cf. Y. Toba, 1959).

Next, we plotted the values for craters in LAC 93, which shows the region

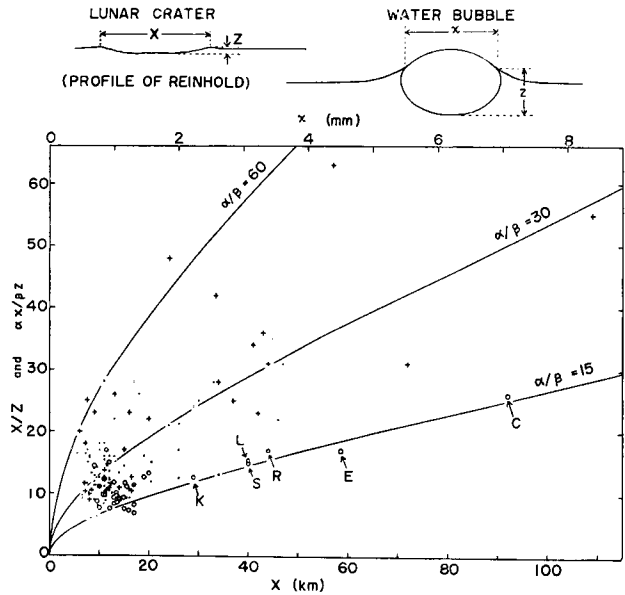


Fig. 2 Similarity between the shape of the lunar craters and that of water bubbles. Scales are expressed by $X=\alpha x$ and $Z=\beta z$, and the ratio α/β represents the deformation of the horizontal and the vertical scales.
C: Copernicus, E: Eratosthenes, R: Reinhold,
L: Lansberg, S: Sirsalis, K: Kepler

of Mare Humorum, by plus signs in Fig. 2. Points deviate upward from the line $\alpha/\beta=15$ and are distributed until near to the curve $\alpha/\beta=60$, for the same value of α . This seems to indicate that the condition of the crater formation in this region, for example, the nature of the magma, the stage of the solidification, etc., differed from that in the Copernicus region. The values for the rest of the craters reported in LVC 20, LAC 74 and 76 are entered in Fig. 2 by dots. Points are distributed along the curve $\alpha/\beta=30$. The problem of the variation of the scale ratio α/β with solenological situation may be investigated in detail after the complete publication of the USAF Lunar Chart. It appears impossible at this point, however, to give a detailed discussion on these values of α and α/β , because of the lack of acceptable knowledge about factors affecting the crater forming processes.

3. Supplement for lunar travelers

We do not know, at present, the depths of the numerous craters smaller than several km in diameter. But they may be predicted from Fig. 2. The depth of the crater floor below the rampart (Z in m) is related to the diameter of the crater (X in km), generally by the formula

$$Z=7070\frac{\beta}{\alpha}\sqrt{X}$$

for craters smaller than 20 km in X , where β/α varies from 1/15 to about 1/60 according to the location or the solenological situations of the respective craters. This formula becomes a criterion for the validity of this hypothesis.

A more appropriate subject for the criterion is found in another object on the lunar surface. We find some round hills called domes, which sometimes have an indentation at the top. They may have been bubbles that did not collapse due either to their small dimensions, or to the stage of the solidification of the lunar surface at the time of the bubble formation. If this is so, a large cavity will be found inside the domes. It may offer a good residence for lunar travelers.

However, whether this idea has merit or not will be ascertained by future space-craft travelers, who should arrive at the lunar surface within a very few years.

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