On the Question of Polygonality and Irregularities of Shape of Certain Craters on the Moon

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On the Question of Polygonality and Irregularities of Shape of Certain Craters on the Moon

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I. P. Puiseux noted at the beginning of the twentieth century that among lunar craters there occur angular ones, and even those having the form of regular polygons ([1]). G. Taziev, attempting to find the cause of such a feature, regards large polygonal craters as former convective cells ([2]). It is known that under laboratory conditions, when a layer of viscous liquid is heated from the side of its lower flat boundary, hexagonal cells are modeled, which are closed elements of convective heat transfer. However, even after the substance has cooled it is scarcely possible to obtain on the surface the profile of a lunar crater: the coefficient of thermal expansion of minerals common in nature does not give a sufficient difference in heights after cooling. Moreover, the edges of the cells always serve as boundaries between neighboring cells, whereas on the Moon isolated polygonal craters are encountered.

It appears possible to give another explanation of the polygonality of lunar craters of the most varied sizes from the standpoint of the hypothesis of their explosive (possibly meteoritic) origin. Let us turn to their observed properties.

On the basis of 160 examples found by the author, it may be asserted that incompletely polygonal objects predominate among quasipolygonal objects on the Moon (see Fig. 1). They usually consist of 3–4 sides, or of an incomplete number of sides of a hexagon, more rarely of a pentagon. The remaining part of the rampart enclosing the figure is arc-shaped or has irregular outlines. Thus, quasipolygonality is not necessarily encountered in all directions of the radius of the funnel, but in a limited sector, which may constitute any fraction of the full circle. There are varieties of craters as if intermediate between ring-shaped and hexagonal ones: their sides are arc-shaped and occupy an intermediate position between chords and a circumference. Examples of quadrangular and seemingly triangular forms are extremely rare, but they do exist. They belong chiefly to intermediate varieties—with arc-shaped sides. One may point to examples of more complex and irregular angularity. Along with these there are non-angular craters with pear-shaped outlines of the crest of the rampart, or with deformation of the opposite type.

Gilvarry and Hill showed (3, 4) that, at a velocity sufficient for an explosion as a result of impact, meteorites should form round craters in a half-space of isotropic material, even in oblique impacts. Obviously, in all cases of noncircular craters one may suppose anisotropy of the explosive destruction. There may be two causes: nonuniform strength of the ground over the area of destruction, and anisotropy of propagation of the explosive wave. Elongation or compression of individual craters in only one of the directions suggests that the explosion occurred near some inhomogeneity in the ground, or at the boundary of two grounds with different acoustico-mechanical properties, or near an obstacle, "positive" or "negative."

It remains to explain the periodicity of the quasi-polygonal dependence of the radius of the crater on azimuth.

In the spectra of the Moon' s γ-radiation recorded at the "Luna-10" space station, there is a component due to the decay of natural radioactive elements K^40, Th, and U. Comparison of the observed intensity of this component with the results of calibration of the instrument on terrestrial rocks makes it possible to ascribe to lunar rocks concentrations of K^40, Th, and U close to those for terrestrial rocks of basic composition (of the basalt type) (^5). Let us recall that every rock has its own characteristic system of jointing. Basalts are characterized by polygonal (most often six- and five-sided) columnar jointing. Each columnar joint, and their ordered aggregate, must possess anisotropic properties with respect to the propagation of a shock wave in the horizontal plane. First, polycrystalline basalts are anisotropic in the mass of each crystal. Second, deformation in a shock wave is not transmitted completely from one basalt joint to another through mutually adjacent faces. The component of deformation parallel to the cracking surface in basalt may be partly damped by interfacial sliding, to a degree determined by the angle between the wave front and the face. These causes generate a dependence between the energy of shock waves and the direction of their propagation. The anisotropy of the propagation of the explosion energy must evidently lead to an inequality of the crater radius in different directions.

Taking into account the dependence of the radius of destruction on the energy of the explosion, $R = R_s W^{0.3}$ (^6), we have: in the case of a regular hexagonal shape of the crater, the specific energy of the wave in the direction of the short radius is 65% of the energy in the direction of the corner. Such a difference can be provided by quite small, spatially extended ordered anisotropy.

Apparently, even in the case when the region of ordered anisotropy of the ground existed only at the site (or near it) of the central region of the future crater, it could determine its noncircular outlines along the entire perimeter (or on the corresponding part of it). Under such circumstances, the anisotropy of the shock wave may be partially smoothed as a result of diffraction or other causes, and in a different degree in different directions in the general case of nonconcentricity of the boundaries of the anisotropic region with respect to the epicenter of the explosion.

The long-noted correlation between the outlines of polygonal craters and the direction of fractures in their surroundings (^7) may speak in favor of the existence, in individual regions of the lunar surface, of comparatively large areas of ordered anisotropy of the ground.

II. There is an opinion that explosive destruction of an anisotropic substance must lead to isotropy of shock-wave propagation within the radius of destruction. We shall show the invalidity of this point of view.

1. Immediately behind the compression wave propagating from the epicenter of the explosion, in the case of a three-dimensional problem (i.e., a non-plane front), there follows a rarefaction wave (^8). It is precisely in the region of negative pressures that shock-explosive destruction of materials occurs (^9), while the front of the compression wave precedes it.
2. In the leading region of shock compression, at very large wave amplitudes, changes in the modification of the substance and phase transformations, in particular melting, may occur. The questions of melting in shock waves cannot be considered reliably studied either experimentally or theoretically (^8). Despite the fact that, according to calculations (^3), impacts of very large meteorites with velocities in the range 16–37 km/sec develop pressures of the order of 10^4–10^5 kbar and temperatures 10^4–$10^{5\circ}$ (which, according to modern concepts, exceeds the melting temperature of the ground

Fig. 1. Examples of polygonal craters. *a*—Lade and Saunder; *b*—Lacus Mortis; *c*—Encke

at the indicated pressures), traces of melting can be found in astroblemes (giant meteorite craters on the Earth) only extremely rarely. They have been found in the sandy soil of the Arizona crater (6). It is known that in a loose and porous substance an explosive wave gives a substantially greater possibility of melting than in a monolithic solid body (8, 9). In our problem, in the outer layers of the Moon, according to radio-astronomical observations, porous material is represented only in the very outermost cover, with a thickness of no more than a meter, whereas the effective depth of the epicenter of a meteoritic explosion is of the order of the diameter of the impacting meteoritic mass (10). This diameter, on the scales of the phenomenon that interest us, is hundreds of meters or more (for example, 1 km for a 10-kilometer crater with a TNT equivalent of 1 : 1).

Thus, in most (or at least in some portion of) meteoritic explosions on the Moon there are not sufficient grounds for confidence in the presence of melting.

3. The front of a shock wave in a solid body is usually considered infinitely thin, because in solving many problems its width may be neglected. In reality it has a finite (although very small) width in the direction of propagation. Indeed, a change in mass velocity without acceleration is physically inconceivable. Therefore the replacement of the concept of a hydrodynamic discontinuity by the concept of a mathematical discontinu-

ity can be made not as an equality, but only in a certain approximation. Across the width of the wave front there are, evidently, intermediate states through which the substance passes in the process of changes from the initial conditions to the maximum amplitude. Melting occurs not earlier than a definite, very high level of temperature increase, i.e., during the passage of some definite phase of the increase of the wave amplitude, and, consequently, lags behind the propagation of the preceding phases, which are in the region of elastoplastic matter still retaining the properties of anisotropy, if such were inherent in it initially. Therefore the influence of the wave itself on the mechanical properties of an anisotropic soil cannot completely eliminate the anisotropy of propagation.

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