A New Explanation for the Hexagonal Shape of Lunar Craters

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If a mechanical shock-wave expands symmetrically in a two-dimensional non-isotropic medium, then the amplitude of the radial displacements is directionally dependent. This has been demonstrated by a system of 1400 hexagonal plastic pillars, simulating the impact of a 10 km size meteorite on a frozen 50 km thick basalt crust in the earliest phase of the Moon's life.

Since various space missions have produced an abundance of photographs of the Moon's surface [1], as well as of Mercury [2] and Mars [3] we noticed a remarkable number of structures which have a polygonal, even a hexagonal structure, next to those with a more circular appearance. Straightforward counting of major objects in the south-west quadrant of the Moon, facing the earth, shows that craters with a diameter below 15 km are for 95% circular, whereas craters with a diameter between 50 and 150 km are for 50% hexagonal. Most of these hexagones have one or more 120° angles. On Mercury's surface one can observe similar features. Do such statistics perhaps tell something about the early period of the Moon when its surface began to solidify [4, 6], and regular impacts of rather big meteorites were taking place? We think of the period in which the crust was quite thin, more than 4 billion years ago.

In 1963 Fielder [5] tried already to relate prominent systems of lineaments with observed hexagonal outlines of "craters" in the Ptolemaeus group. After him Hartmann [6] deepened the insight enormously. The outlines of well-developed lunar "craters" and their surroundings show structures which suggest a radially expanding tidal wave, compressing the local topography in outward radial directions. Mascons upto 10^{18} kg underneath some of the bigger Mares [7] might be remains of very big meteorites hitting the Lunar surface at an early time of formation of the Mares. Analogous giant impacts are suggested by Voyager I's (December 1980) observations on Jupiter and Saturn moons.

Circular craters can be expected from the impact of smaller objects on a very thick underlayer [8]. Most smaller and younger lunar craters belong to that category.

In the earliest period of the Moon a layer of about 500 km thick molten lava covered its surface [9, 10]. Radiative cooling has caused a frozen top layer during all stages of development. The solid layer of lava reduced the heat loss enormously. Measurements of the growth rate of such crusts on liquid lava lakes of Kilauea, Hawaii [11] show a thickness of 30 cm after a day, 2 m after a month, and 8 m after a year. The present day heat flux Q at the Lunar surface is 1.8 micro Watts cm^{-2} [12]; 4 billion years ago this flux was about a factor 3.5 larger if we assume the same U, Th, K composition as in the earth crust. Hsui's model [13] gives a factor two. For Urey's stationary heat flow system [14]

$$\Delta X = \lambda \, \Delta T \, Q^{-1}$$

with $\Delta T = 1000$ K and $\lambda = 10^{-3}$ Watt cm^{-1} K^{-1} for solid basalt. We find ΔX about 2 or 3 km. Although the melting point is about 1500 K, the solidified layer will be appreciably thicker due to

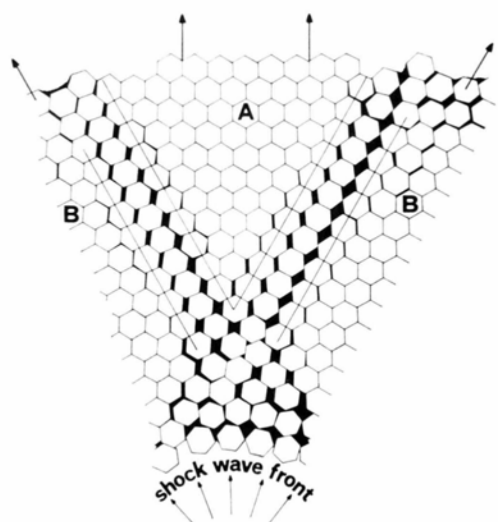

Fig. 1. A schematical demonstration of a shock wave in a system of hexagonal blocks.

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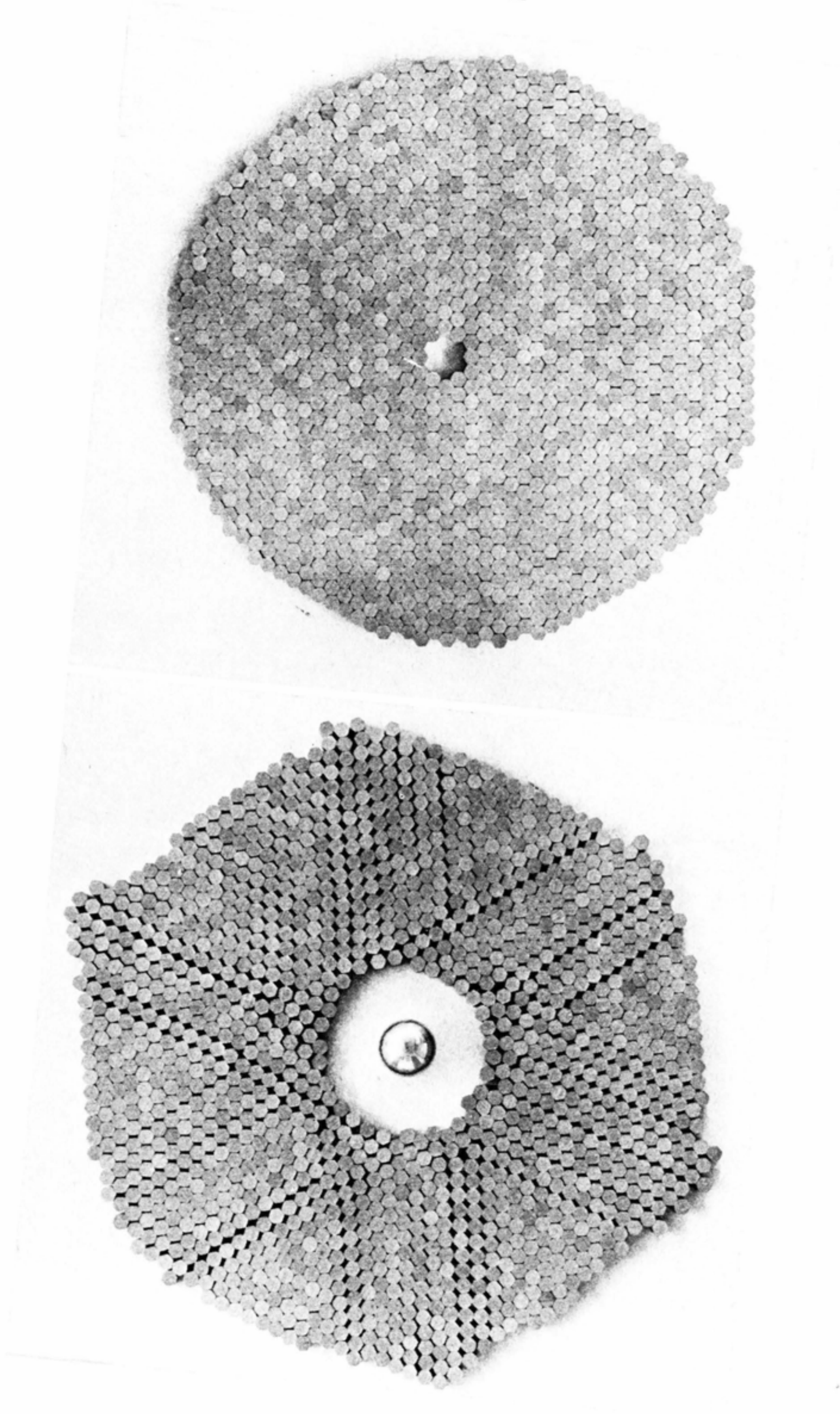

Fig. 2. The result of the dilatation.

the high internal pressure. Estimates go from 10 to 50 km for the earliest stage in the Moon's life [15]. The solidified basalt crust had a remarkable structure in itself, as basalt shrinks by 5% when it freezes. Shrinking increases when it cools from 1500 K to 500 K surface temperature. In the absence of surface erosion this causes characteristic macro-size hexagonal basalt pillars [11].

Now let us consider a meteorite of asteroïd size, with a diameter d of 10 km and with a mass of 10^{15} kg. Assume a speed V relative to the Moon's surface of 20 km per second. Then Summers and Charters' [16] penetration formula

$$P/d = 2.28[\varrho V/\varrho_t c_t]^{2/3}$$

gives a penetration depth $P = 80$ km, for $\varrho = 5000$ kg/m^3; $\varrho_{\text{target}} = 2700$ kg/m^3 and $c_{\text{target}} = 5$ km/sec. ϱ is the density and c_{target} the velocity of sound in the Moon lithosphere. This means that the frozen crust, 10 to 50 km thick, is pierced in a few seconds. The available kinetic energy (10^{23} Joules) is mainly transformed into hydrodynamic energy given to the basalt, which fluidizes under the enormous pressure. As calculated by Bryan c.s. [17] the hydrodynamic shock front moved radially at an initial speed of about 10 km sec^{-1} through the basalt crust and changes at a distance of about 5 meteorite diameters into a normal tidal wave.

The problem is how such a shock propagates through a nonisotropic medium. Certainly not with equal speed in all directions. To investigate this we did an experiment imitating a hexagonal structure. Figure 1 demonstrates schematically what will happen with a system of hexagonal blocks. The front of the shock pushes against the total system of oriented, correlated blocks and acts differently on the B groups than on the extended A field. Between the **A** and **B** groups we see a dilatation zone. The result is demonstrated in Figure 2. The blocks are pushed symmetrically away from the centre, imitating the shock front, by rolling around a polished 10 cm steel ball until the radius R of the inner circle is a factor 3 to 5 larger than the radius of the ball. One sees a spectacular demonstration how 1400 hexagonal plastic pillars, initially forming a circular disk, are radially pushed away into a hexagonal peripheral shape if they slide with low friction on a smooth or liquid underground. Some similarity with what happened on the Moon is suggested.

"Our" meteorite of 10 km size had enough energy to create a Mare of 100 km size. The formation of the ring-walls took a very minor fraction of the total energy available [18]. Pogressive cooling leads to "rille" systems connected with some Mares as a secondary result.

Acknowledgement

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