A MECHANISM FOR THE PRODUCTION OF CRATER RAYS. V. Shuvalov, Institute of Geosphere Dynamics RAS, Leninsky pr. 38-1, 119334, Moscow, Russia, shuvalov@idg.chph.ras.ru

Introduction: Oberbeck [1] stated that "lunar rays emanating from only the freshest of the lunar craters are among the most impressive and puzzling of lunar surface features". The rays are long bright albedo streaks that surround about 12% of lunar craters. They also occur on other airless bodies and were recently observed on Mars [2, 3].

Most hypothesis of the origin of crater rays relate them to distant impact ejecta [4, page 110]. Hawke et al. [5] have shown that "lunar crater rays are bright because of compositional contrast with the surrounding terrain, the presence of immature material, or some combination of the two". However, a reason for the ray-like shape of these bright features is not clear yet.

Rays also form in the ejecta of near-surface explosions [4, page 110]. In series of small-scale explosion experiments Andrews [6] had shown that the rays in the ejecta pattern correlate with high-velocity jets of detonation products. The jets appear due to the development of Rayleigh-Taylor instabilities on the boundary of high-density detonation products decelerating in the low-density air. This mechanism does not work on the airless Moon.

The goal of this work is to propose and to study a possible mechanism of generation of the crater rays resulting from interaction between an impact induced shock wave in a target and nonuniformities of the target surface (target relief). Different types of a surface relief can be roughly considered as a superposition of elevations and depressions. Numerical simulations were used to study the influence of both of these features on the ejecta deposits.

Numerical model: A 3D version of the SOVA multi-material hydrocode [7] was used to model vertical and oblique impacts of a 5-km-diameter asteroid (with density 2.63 g/cm^3) against the Moon. Impact velocity was 15 km/s. These parameters roughly correspond to an impact that produced the 86 km diameter Tycho crater, well known for its rays. Tables obtained with the ANEOS equation of state [8] and input data for granite from [9] were used to describe thermodynamical properties of both target and projectile materials. The model of strength is based on the approach developed by Melosh and Ivanov [10] and takes into account acoustic fluidization in the treatment by Ivanov and Turtle [11].

As craters are the most typical relief features on airless cosmic bodies, the target surface consisted of crater-like depressions and some elevations. The depression shape was determined by equation

$$x^2+y^2+(2.5z)^2=r^2, \quad z<0,$$

where r is the crater radius. The crater depth was less than the crater diameter by a factor of 5 (typical for simple craters). The elevation was determined by the same equation at $z>0$.

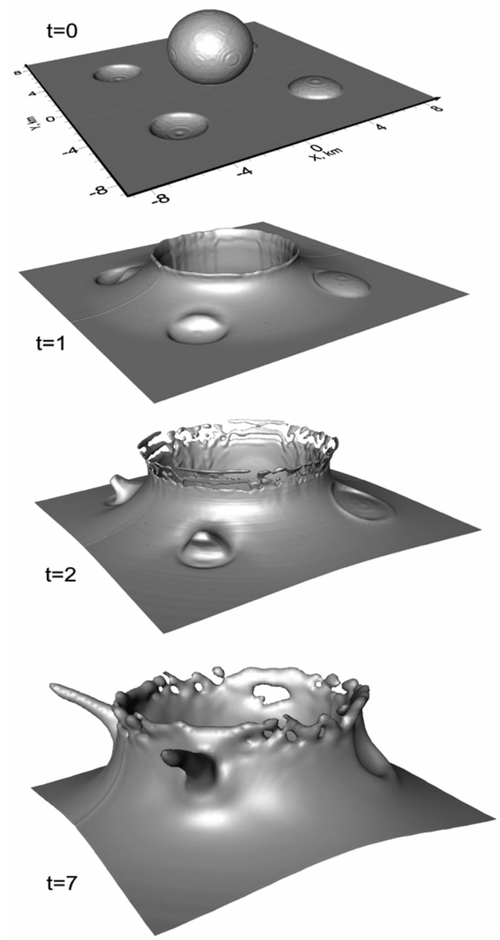

Fig. 1. An evolution of ejecta curtain after a vertical impact of a 5-km-diameter asteroid surrounded by a 2.5-km-diameter craters and 2.5-km-diameter elevations. Isosurfaces ρ=1 g/cm^3 are shown, where ρ is material density.

Numerical results: Figs. 1-3 illustrate the vertical impact near these surface features. An expansion of the shock wave through the depression results in the formation of a jet arising at the inward (nearest to the impact point) slope of the depression (Fig. 1). The jet appears due to spallation phenomenon at the slope and is enhanced by the cumulation effect. After deposition the jet produces a ray-like nonuniformity in the deposit distribution (see Fig. 2). In contrast, a presence of an elevation weakens the spallation effect at the target surface, decreases local ejecta velocity (see Fig. 1), and produces a forbidden zone in ejecta deposits (see Fig. 2). Fig. 3 shows how depressions and elevations influence ejection velocity. The additional mass of the elevation decelerates an expansion of the underlying target material whereas the depression facilitates an expansion of the deeper highly compressed target material.

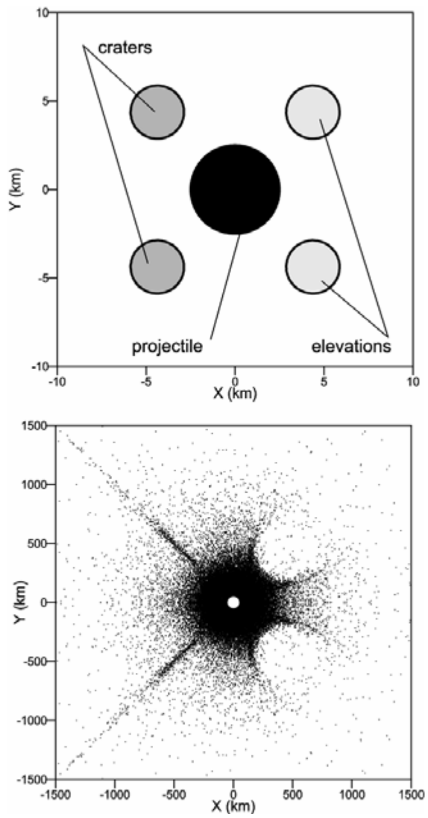

Fig. 2. An upper image shows initial configuration (top view) of 3-km-diameter craters (gray circles), 3-km-diameter elevations (light gray circles), and 5-km-diameter impacting projectile (black circle). A lower image shows a distribution of tracer particles ejected and deposited during the vertical impact. A distance between the impact point and depression/elevation centers is 6 km.

Conclusions: Numerical simulations suggest that crater rays surrounding about 12% of lunar craters (at least, some of these rays) and craters on other airless bodies could result from an interaction between impact induced shock waves and surface depressions. The numerous craters that occur on airless planetary bodies form these depressions. Larger depressions produce longer and more pronounced rays. The distance between impact point and the depression determines the initial and the final points of the ray.

Generally the ray-forming ejecta do not differ (by composition, shock compression, initial depth in a target, etc.) from the other ejecta (not specific ejecta, but specific distribution of typical ejecta). The numerical simulations also show that ray-producing depressions (old craters) should have a size approximately in the range from 0.2*D* to *D* and should be located at a distance less than 2-3*D* from impact point (within the newly formed crater), where *D* is a projectile radius. An average number *N* of craters of the necessary size (0.2*D* to *D*) in a circle of radius 2*D* can be estimated using the well-investigated size-frequency distributions for lunar craters [12]. For *D*=1 km one can obtain *N*=8. This very rough estimate shows that situations considered in the paper are very typical, at least for the Moon.

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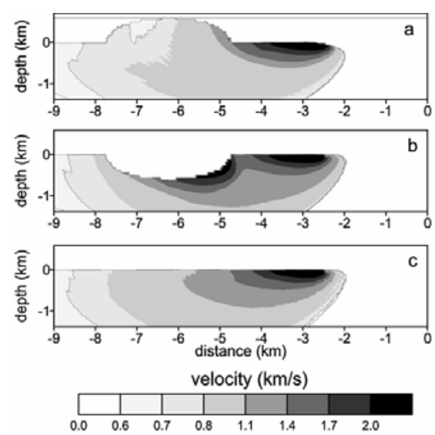

Fig. 3. Ejection velocity of target material in relation to its initial position: a - in the vertical plane passing through impact point and elevation center, b - in the vertical plane passing through impact point and crater center, c - in the vertical plane passing through impact point and undisturbed crater surface.

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