NUMERICAL MODELING OF THE ELTANIN IMPACT. V. V. Shuvalov, Institute for Dynamics of Geospheres RAS, Leninsky pr. 38-1, 119334 Moscow, Russia, e-mail: shuvalov@idg.chph.ras.ru

Introduction. Eltanin [1] is the only presently known impact structure formed during the fall of a cosmic body into a deep (4-5 km) oceanic basin. The evidence for the impact origin of this structure is the discovery in 1981 of an iridium anomaly in the bottom deposits [2]. Subsequent studies showed that the meteoritic material was present in three sedimentary rocks spaced at 500 km. Unmelted fragments of the impactor with sizes less than 2 cm were also found. According to the estimates made by Gersonde and Kyte [3], the impact structure of Eltanin was formed by the impact of an asteroid 0.5-2 km in size that occurred 2.2 Myr ago. No traces of crater have been discovered.

In this paper I used numerical simulations to estimate a probable impactor size, to follow the fate of a projectile, and to calculate an initial tsunami amplitude. To simulate the main stages of the impact I used the multi-material multi-dimensional hydrocode SOVA [4]. The SOVA code is close in its characteristics to the CTH code [5], which is widely used in the USA. To calculate the thermodynamic parameters I used the tabular equation of state [6] for air, the Tillotson equation of state [7] for water and basalt sea floor, and ANEOS [8] for the projectile (consisting of dunite). The ocean depth was considered to be 4 km.

Impactor size. In the first set of runs a vertical impact was considered for different impactor sizes. The purpose was to determine the range of impactor sizes for which a bottom crater does not form. The calculations show that a clearly pronounced crater about 2 km in depth is formed after the impact of a 1.5-km-diameter projectile at V=15 and 20 km/s. The mass of melt is about six times the impactor mass. The impact of a 1-km-diameter projectile causes only a weak deformation of the sea floor surface and does not produce melt. The conclusion can be derived that the impactor size (diameter) should have been no larger than 1 km for a vertical impact and no larger than about 1.5 km for a 45 degree oblique impact. On the other hand, projectiles with diameter less than 0.5 km do not produce water cavity reaching the ocean floor.

The fate of the projectile. In the second set of runs the 1-km-diameter projectile impacts the ocean at a=30, 45, 60, and 90^o (vertical) from the surface. Up to 10,000 tracer particles were regularly distributed inside the projectile to record the thermodynamic history of the projectile material. The tracers are massless particles that move through the mesh recording temperature and pressure of given material points. Fig.1 shows the distribution of the peak shock pressure inside the projectile. For comparison the results of numerical simulations for the impact against a dunite target (at 45^o) are also shown, these results correlate well with those of Pierazzo and Melosh [10]. Peak pressure distribution strongly depends on impact angle. The results presented in Fig.1 confirm the idea that the peak pressure is proportional to *sin2 a* [11, 10]. As expected, the peak pressure is approximately proportional to V^2. The main conclusion is that, contrary to land impacts, in all the cases under consideration a considerable part of the projectile (from 100% for V=15 km/s, a =30^o to 25% for V=20 km/s, a =90^o) remains unmelted.

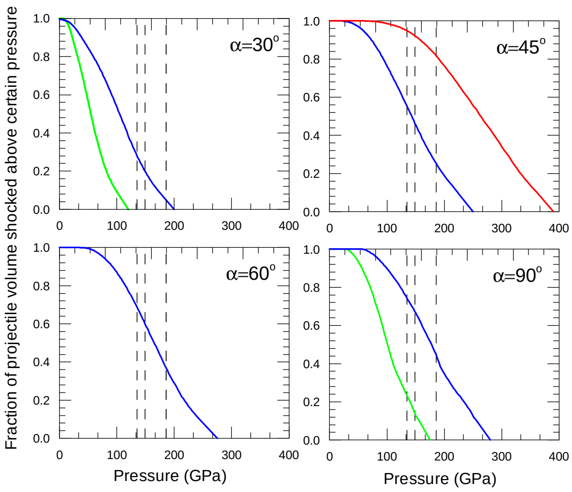

Fig.1. Maximum shock pressure distribution in the projectile for different impact angle a. Green lines show results for V=15 km/s, blue lines show results for V=20 km/s, red line shows results for the impact on dunite target. Dashed vertical lines indicate incipient melting pressure 135 GPa, complete melting pressure 149 GPa, and incipient vaporization pressure 186 GPa for dunite [9].

Pierazzo and Chyba [12] considered amino acid survival in large asteroidal and cometary impacts. Their results suggest that some amino acids would survive the shock heating of kilometer-radius cometary impacts. The results presented in Fig.1 show that some amino acids could also survive the shock heating of asteroidal impacts into deep water basins.

Fig.2 shows the evolution of a water transient cavity and the distribution of a projectile material after the 45° oblique impact of a 1-km-diameter dunite projectile at 20 km/s. Although the water transient cavity reaches ocean floor (-4 km), the projectile material does not descend below approximately -1.5 km. Later, a part of the impactor mass (both melted and unmelted) accelerates in an impact induced plume to velocities reaching 1-3 km/s. This high-velocity part of projectile ejecta could flight for a distance 100-1000 km. The other part of impactor material is involved into water motion and displaces with water before sedimentation.

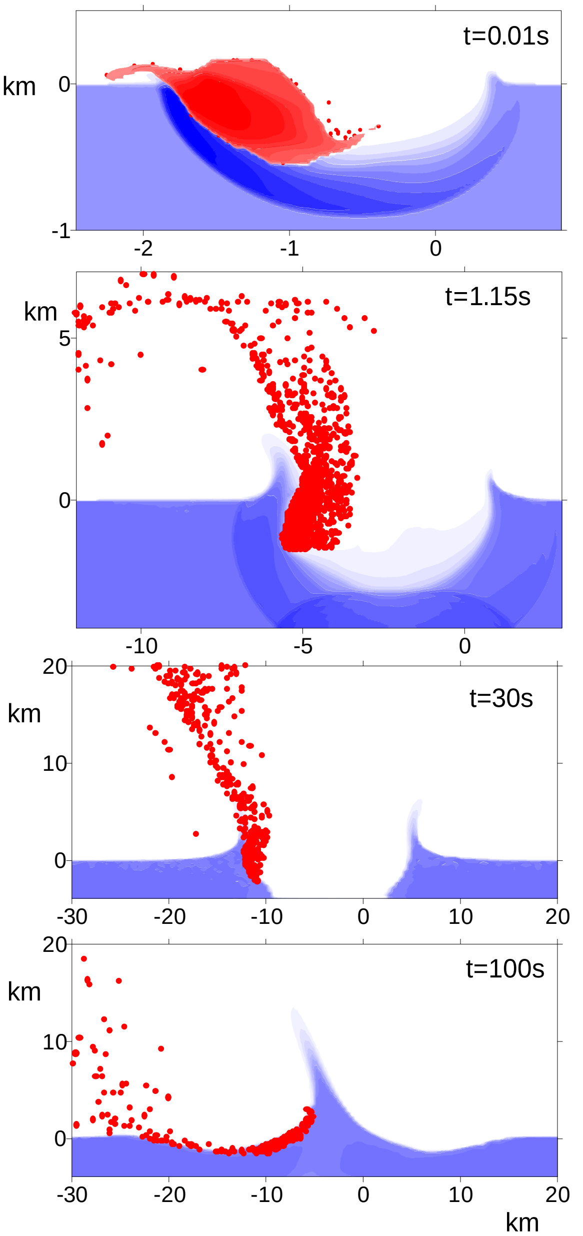

Fig.2. Distributions of water and impactor material after the oblique 45° impact of a 1-km-diameter projectile at 20 km/s. Impactor material is shown by red.

Tsunami generation. In the analysis of the consequences of tsunami arising after the marine impacts of cosmic bodies, the following formula is commonly used [13]

$$h = 45\frac{H}{L}(Y)^{0.25}, \qquad (1)$$

where H is the water basin depth, h is the wave amplitude in meters, L is the distance from the source, and Y is the released energy in kitotons TNT equivalent. This formula was derived from the analysis of data obtained at the Baker nuclear explosion in the 60-m deep lagoon on Bikini atoll; its energy was about 20 kt [13].

For the impact of a 1000-m asteroid (which is presumably responsible for the formation of the Eltanin underwater structure), formula (1) gives the wave amplitudes 850, 570, 340, and 240 m at distances of 20, 30, 50, and 70 km from the impact site. In the calculations of the vertical impact I obtained amplitudes 1200, 800, 450, and 320 m respectively. Since the difference does not exceed 30%, the agreement can be considered as satisfactory. Note, that in shallower water (when the ocean depth is comparable with impactor size or less) formula (1) considerably underestimates initial amplitudes of tsunami [14].

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