EJECTA FORMATION AND DEPOSITION AFTER THE MJØLNIR IMPACT.

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Introduction. The Mjølnir submarine crater (40 km in diameter and located in the Barents Sea) is interpreted as formed by the impact of an 1.5 to 2 km in diameter asteroid [1,2] into a 200–400 m deep epicontinental paleo-Barents Sea [3]. The target area consisted of a sedimentary sequence of Devonian to Jurassic age, at least 6 km thick, overlying older, well lithified sedimentary strata. The simulation of Shuvalov et al. [4] modeled the formation of the Mjølnir Crater, but the ejecta formation and distribution were not discussed in detail. In a case as that of the Mjølnir Crater, being buried beneath sediments and water in the Barents Sea, understanding the ejecta formation may be particularly important since ejecta are the most easily accessible crater products. In this study we consider the influence of water layer and impact angle on ejecta distribution and apply the results for the Mjølnir Crater.

Numerical approach. The 3D version of the SOVA multi-material hydrocode [5] is used to model the initial stage of the Mjølnir impact. The SOVA simulation terminates at the end of the excavation stage, when ejection velocity falls below 100 m/s (approximately at 5 s for the Mjølnir impact). The farther flight and deposition of the ejecta are calculated with ballistic approximation. Based on previous results [4] we consider the projectile to be an 800 m in radius spherical asteroid consisting of granite and with an impact velocity of 20 km/s. The target is considered to consist of wet tuff overlain by a 400 m thick water layer.

Numerical results. Numerical simulations of the Mjølnir impact showed that the 400 m water layer only slightly influenced the cratering process and the parameters of the final crater [4]. Nevertheless, even such shallow sea has a considerable influence on the formation and distribution of distal ejecta (Fig.1a,c). Our results demonstrate that the fastest (and consequently extending to high distance) ejecta are ejected from the uppermost target layers. In our case the upper target layer consisted of water. Hence, the water ejecta had the highest velocities, and solid ejecta (being ejected from deeper target layer) were characterized by lower velocities and consequently extended to shorter distances than in the case of similar subaerial (on land) impacts.

Although most craters (even resulting from oblique impacts) are near circular, the impact angle can strongly influence ejecta deposition [6]. This influence for craters resulting from subaerial impacts was first demonstrated in experiments by Gault and Wedekind [7]. They found that the ejecta deposits remained near circular for impact angles down to 45°, however, an area of the deposits was slightly offset downrange. As the impact angle decreases below 45°, ejecta deposits become strongly asymmetrical, and the so-called “forbidden” azimuthal zones appear first uprange and then downrange of the crater. Recent experiments by Schultz [8] show that high-velocity ejecta move preferably in the downrange direction, whereas the low-velocity ejecta are distributed more evenly around the crater.

Our results demonstrate that the distribution of ejecta deposits of the vertical impact, strongly differ from the distributions of oblique impacts (fig.1a,b). Primarily the ejecta blanket area strongly increases as impact angle decreases from vertical down to 45°. This increase of ejecta blanket is the result of a significant increase in the downrange ejecta velocity. A central part of the ejecta deposits (at a distance of a few crater radii) looks very similar to experimental data (Fig.10, page 3854 of [7]). However a decrease in impact angle strongly increases the area of distal ejecta deposits and makes it strongly asymmetrical, although close ejecta are only slightly asymmetrical (Fig.1a,b). “Forbidden” azimuthal zones do not appear neither uprange nor downrange, however, a region of relatively lower thickness of ejecta deposits can be seen downrange at distances above 1000 km (i.e., 50 crater radii) (Fig. 1b).

The ejecta distributions for impacts into 400 m deep water at different impact angles substantiate both tendencies presented above: a decrease of ejecta deposits in the presence of water layer and an increase of area of ejecta deposits with a decrease of impact angle (Fig. 1c,e). In the vertical impact of a Mjølnir like projectile into 400 m deep water, the area of deposits is restricted by approximately 600 km. A decrease of impact angle leads to increase (only in downrange direction) of this area up to 3000-4000 km, exceeding ejecta deposits after the vertical impact even without water, but smaller than compared to the case with oblique impact without water. The structure of this downrange zone of deposits depends on both water depth and projectile shape, however, these particular distributions illustrate where to find the deposits: downrange, in a cone with angle 60° at a

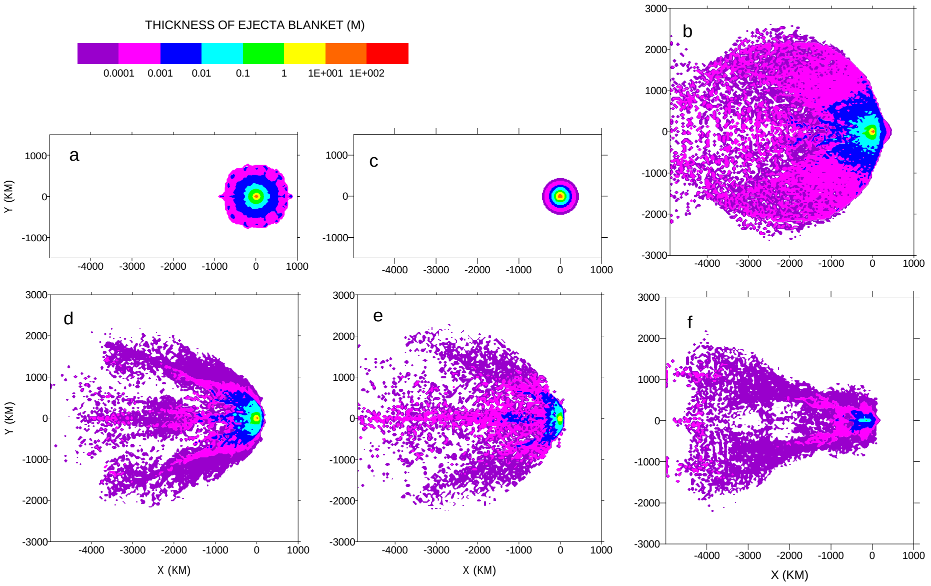

Fig.1 Distributions of the basement ejecta deposits after the vertical impact without water (a), 45^{o} oblique impact without water (b), vertical impact into 400 m deep sea (c), 45^{o} (d) and 30^{o} (e) oblique impacts into 400 m deep sea. Plate f shows distribution of projectile material after the 45^{o} oblique impact into the sea 400 m deep. Impact direction is from right to left.

distance less than 3000-4000 km. Note that we neglected a spherical shape of the Earth, which is of minor importance at distances less than Earth's radius 6300 km.

The projectile ejecta for a 45^{o} oblique impact into the sea (Fig.1f) have a larger velocity and are even more asymmetrical (move in a more narrow angle) than the target area ejecta. Due to high velocity the projectile ejecta deposits have a local maximum at a distance of about 4000 km, where there is almost no target ejecta.

Discussion. Tsikalas [9], by applying criteria suggested by Schultz and Anderson [10] and detailed geophysical data, suggested the Mjølnir crater to have been formed by an oblique impact coming from south/southwest direction at a 45^{o} angle. With an impact direction from SSW towards NNE and the ejecta distribution modeled here, the occurrences of Ir enrichments in both the Svalbard and Nordvik (Siberia) sections are likely. It is also clear that searching for distal ejecta southwards may be a more dubious task. Likewise we note that the thickness of ejecta may increase in thickness even farther away (4000 km) from the crater than the Nordvik location [11] (2500 km away). It is also evident that such uneven distribution may create some problems in getting the best sampling locations. In the Mjølnir case, however, the secondary redistribution of the returning waters, waves and currents of the paleo-Barents Sea probably smeared out some of these distributions and reduce the original variations some.

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