CRATER DIMENSIONS FROM IMPACTS AT SEA.

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Introduction: Studies of marine-target impact structures indicate a significant difference in the cratering mechanism to the better known land-target crater, often used as standard in impact cratering. The marine-target crater develops, basically, in a target with layers of different strength. The resulting crater often shows an outer shallow crater surrounding an inner crater in the more rigid basement. Neither the outer, nor the inner crater does directly express the shape of the transient crater. It develops in both seafloor and water mass and, hence, differs significantly from land target impacts. So, how to compare the diameter of a marine-target crater with other impact craters? To answer this we need to clarify the terminology for the marine-target crater:

All impact structures get their initial appearance changed by processes affecting them after their formation. The crater we see today has often a different shape from the newly formed crater. The crater structure at this specific moment of the craters geological history is called the apparent crater [1]. A term occasionally used in oral reference to the newly formed crater is "fresh crater" (or transient apparent crater). To be able to calculate the energy expended in the formation of a crater that today may be old and eroded (e.g. for evaluation of environmental consequences), it is necessary to reconstruct the fresh crater. It is from this morphological structure that one can estimate the dimensions of the transient crater, which is the crater established at the end of excavation stage before the subsequent modification [1]. The dimensions of the transient crater are used to calculate the expended energy of crater formation. In the "standard" crater formation the fresh crater is equal to or wider, even much wider, than the transient crater. However, recent geological and numerical work on marine-target craters indicate a completely different situation:

Discussion: Here we restrict marine-target craters to craters that develops both in the upper layer consisting of water, and the substrate including sediments and a more solid basement. Lindström et al. [2] noticed that the Lockne crater, Central Sweden, has a morphology similar to small concentric experimental and Lunar craters [3]. Notwithstanding the differences in the cratering dynamics between these small craters and the much larger Lockne crater, Lindström et al. [2] adopted the terminology used for them [3]. Hence, the Lockne crater is described as a concentric structure with an inner (nested) crater in the basement and an outer crater where sediments have been stripped from the basement. If focusing only on today's topographic expression of the crater, the nested crater is most apparent for the viewer, thus, it is natural to call it the apparent crater. However, parts of the outer crater are clearly visible in the geology of the area, and should be part of the apparent crater. A strong connection is noticed between the outer crater and the shallow excavation forming the water cavity [4]. The situation with a concentric transient cavity consisting of a wide water cavity and a nested basement cavity is suggested to be typical for impacts at relatively great or intermediate water depth. A comparison with other craters showed that when the water depth instead is shallow compared to the amount of expended energy, a concentric transient crater does not develop. Shuvalov and Artemieva [5] came to the same results with numerical simulations and found a relation between concentricity and impactor diameter. This was recently used in a calculation of the target water depth at Lockne [6].

It is important to note that the outer crater can develop by other processes than the shallow excavation occurring at Lockne (see the craters in Table 1 in [4]). This must be considered when estimating the transient crater and the magnitude of the event. In addition, there is an inconsistency in the published apparent crater diameters of many craters (Table 1 in [4]). Some give the diameter of the apparent outer crater, others the diameter of the apparent inner crater.

Figure 1 shows a simplified cross-section of a marine-target crater based on the Lockne case. As the crater seen today (apparent crater) is also a result of later tectonism and erosion the figure represents the fresh crater as if we had seen it shortly after the early modification (i.e. resurge of water and slumping). The water cavity in the case of vertical impact [6], has been superimposed on the figure. In an oblique case the transient outer crater (sediment and water cavity) is offset relative to the center of the transient inner crater (basement cavity), which affects the crater dimensions and ejecta distribution [7]. Note that the transient crater in the case of a marine-target crater may be much larger than the apparent inner crater would indicate. Of interest is also that the main bulk of the solid ejecta is deposited within the realm of the outer transient cavity, a significant difference to the standard model where an ejecta blanket forms outside the transient cavity.

We consider the resurge to be one of the early modification processes. Thus, the diameter of the fresh crater should incorporate any part of the impact structure shaped by the resurge (similar to the incorporation of the terraced zone in a complex crater). Hence, in the case of Lockne, the fresh crater includes the whole crater as far as the end of the slightly inclined discontinuity surface that can be reconstructed to have run through the sedimentary succession to a distance of 12 km from the crater center [8]. Post-impact sedimentation, tectonism, and erosion have affected the surface. Therefore, it can only partly be included in the apparent crater visible today.

The diameter of the transient crater coincides with the maximum extent of the water cavity. Hence, for energy calculations one can not reconstruct the transient crater from the shape of the inner (basement) crater only (Figure 1). We have so far not found any morphological feature that directly give the maximum extent of the transient crater. We know the water cavity extended beyond the zone stripped of most of the sediments. Numerical modeling [6, 7] define crucial situations during the cratering that are recognized in the geology of the crater. Only the inner part of the discontinuity surface can be part of the transient crater. Strong outward and inward water movements are calculated to shape the seafloor outside the transient cavity, which provides an upper limit. The modeling also shows that the bulk of basement crater ejecta does not pass the wall of the water cavity. It gives a lower limit. At Lockne, the deposition of basement crater ejecta caused authogenic brecciation of the sediments in the floor of the transient crater [9]. At Lockne this breccia is found to a distance of 7 km from the center.

Conclusions: It appears that a combination of numerical modeling and geological fieldwork is the best way of determining the size of the transient crater for a marine-target crater and, hence, the magnitude of the event

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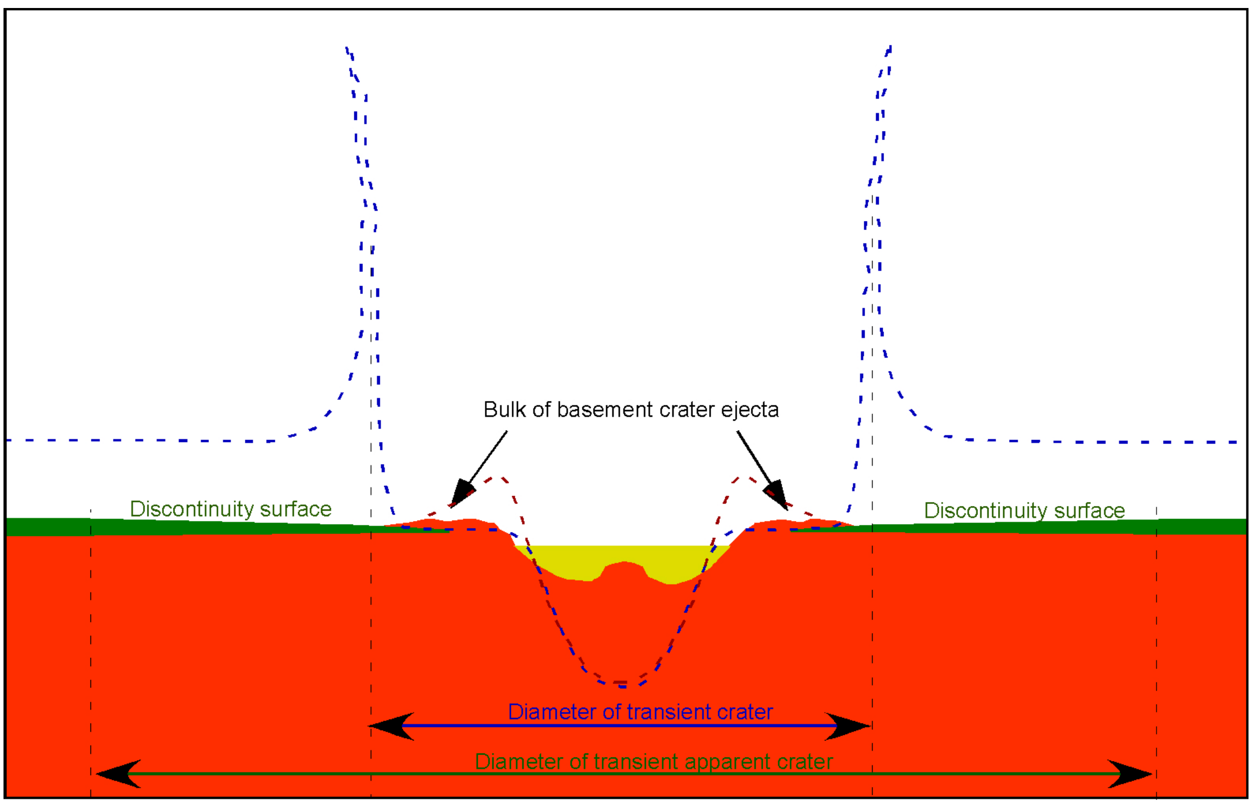

Figure 1. Schematic profile of the transient apparent crater of a marine-target crater. The figure is based mainly on data from the Lockne crater [2, 4, 6, 7, 8]. No length scale is introduced to emphasize the universal significance. Vertical scale is two times exaggerated. The transient crater is indicated with blue stippled line. Green color indicates target sediments, orange the crystalline basement, and yellow resurge deposits within the basement crater. Red stippled line indicates the, in this case erroneous, standard way of reconstructing the transient crater from the shape of the modified (slumped) crater depression.