The Influence of a Deep Shelf Sea on the Excavation and Modification of a Marine-target Crater, The Lockne Crater, Central Sweden. Jens Ormö¹ and Maurits Lindström”, Centro de Astrobiología (CAB), Instituto Nacional de Técnica Aeroespacial, Ctra de Torrejón a Ajalvir, km 4, 28850 Torrejón de Ardoz, Madrid, Spain. (ormo@inta.es); Dept. of Geology and Geochemistry Stockholm University 10691 Stockholm, Sweden (maurits.lindstrom@geo.su.se)

Target environment: Comparisons between craters formed at different target water depth and in different strength and configuration of the rocks below the seafloor is a prerequisite for the understanding of the marine impact process. The Lockne crater is a well-preserved and well-exposed example of a crater that was strongly affected by the target water. Geologically well-constrained numerical modeling has showed that the water depth exceeded the impactor diameter: Approximately 800 m water, 600 m impactor diameter [1]. Below the water, about 80 m of limestone and loose, bituminous mud rested on the weathered Precambrian crystalline peneplain. Recently, improved outcrop has shown that its ejecta deposits and morphological features are better preserved than hitherto assumed. These new data have improved the interpretation of the formation of the crater.

Crater excavation: The thick layer of target water came to incorporate much of the zones where vaporization and melting normally occur during crater excavation. The difference in strength between the water and the rocks generated a concentric shape of the transient cavity with an at least 14 km wide crater in the water mass, and a 7.5 km wide crater in the basement. A brim with ejected crystalline rock surrounds the crater. There is no obvious uplift of the basement below the ejecta. The brim is about 2.5 km wide on the northern and western sides of the crater, but much smaller on the eastern side. This was previously thought to be due to irregular preservation from erosion, but outcrops exposed by a new forest road extending radially outwards through the eastern brim zone show that the irregularity is due to the obliquity of impact rather than erosion. Shuvalov et al [2] and Lindström et al. [3] show that the obliquity of impact caused more extensive ejecta downrange (western side) than uprange (eastern side). Interestingly, much of the crystalline ejecta of the brim appear to have been deposited in semi-coherent state as an anomalously wide flap. It rests on top of a surface stripped from much of the sediments by the excavation flow during formation of the water cavity. The target sediments are progressively more complete below the flap outwards from the crater. A combination of weak spallation along the seafloor during passage of the shock wave, the water cavity excavation, and the crushing and shearing during flap deposition have caused a brecciation of the target sediments below and near the flap (Ynttjärnen Breccia). This breccia is in some parts of the crater covered by resurge deposits.

Crater modification: The water rushing back towards the basement crater during water cavity collapse caused additional strong vibrations and easily eroded the brecciated sediments where they were not protected by the crystalline flap. On the eastern side, where the near absence of a flap gave no protection from the resurge erosion, resurge deposits rests directly on the crystalline peneplain. Preserved Cambro-Ordovician sediments below the small flap near the basement crater rim show that the removal of sediments on this side of the crater most likely was due to the resurge flow rather than the excavation flow. The western side of the crater, on the contrary, has almost no preserved sediments in the same proximal position below the flap. This indicates a stronger excavation flow in this direction prior to flap deposition. The modeling of oblique impact by Shuvalov et al. [2] shows an offset of the water cavity relative to the basement crater supporting the interpretation of a stronger shallow excavation flow downrange. It also shows that a stronger resurge flow can be expected on the uprange side, which appears to correlate well with the indications for strong erosion, but thin resurge deposits observed on the eastern side.

The semi-coherent behavior of the ejecta flaps may have caused tangential stresses with resulting wedge-shaped openings in the brim zone. These openings were canalizing the resurge flow so that kilometer long and hundreds of meters wide resurge gullies were formed. There are 4 known resurge gullies at Lockne extending radially out from the crater. The floors of the gullies are covered by resurge deposits and post impact...
sediments. The gullies do only cut through the flap, not into the underlying basement.

Collapse of the basement crater rim during crater modification generated terraces with a few tens of meters width and 5-10 m subsidence. At some locations in the brim zone, ring faults have likewise generated a few tens of meters wide grabens. On the eastern side of the crater, a small graben is filled with resurge breccia. On its sides, resurge arenites rest directly on the Precambrian basement. This may give information on the timing between the faulting and the resurge flow. The relation between the resurge breccia and the resurge arenites may also have been affected by the oscillations in the water movements indicated in the numerical modelings of the water cavity collapse. Evidence for such oscillations are found in repeated beds of coarser and finer resurge deposits on the northern side of the crater.

**Summary:** Lockne offers the possibility to, in the field, follow the spatial relations between different lithologies. This is valuable in the studies of the influence of water on the crater formation and resurge dynamics at other well-preserved, but less exposed marine-target craters such as Chesapeake Bay impact crater (CBIC). Together with colleagues working on the CBIC we have initiated a comparative study of resurge deposits at Lockne and CBIC. The study will be part of the International Continental Drilling Program’s planned core drilling at the center of the CBIC.

**References:**

Fig. 1. Geological map of the Lockne crater. Note that the patches of Cambrian shale visible on the south-western flap occur at "windows" through the flap.