# A METHOD TO DETERMINE THE END OF IMPACT-RELATED SEDIMENTATION AT MARINE-TARGET CRATERS: GEOCHEMISTRY AND MICROPALEONTOLOGY OF THE TRANSITION FROM RESURGE- TO SECULAR DEPOSITS AT THE LOCKNE, TVÄREN, AND CHESAPEAKE BAY IMPACT STRUCTURES.

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**Introduction:** The cessation of the formation of impact-related sedimentation is for land-target craters, generally, rather abrupt as the ejected material settles on the ground and crater collapse ceases. The timescale of crater collapse is similar to that of excavation [1], and thus the impact-related materials represent but a moment in the geological record. At marine-target craters, however, the settling of both ejecta and collapse materials commonly occurs in an aquatic environment which can impose a prolonged period of deposition. In this scenario, ejecta deposition and collapse of the seafloor crater are, in part, dependant on the target water depth, and are affected by the collapse of the water cavity and the adherent resurge of water to varying degrees. This water resurge can vary in force. The resurging water brings back both ejecta and rip-up material representing much of the impact-affected parts of the target succession. With decreasing transport energy of the waning resurge, secular sedimentation will again dominate the deposition in the area. The transition from resurge deposits to secular sediments may appear rather abrupt (e.g., Chesapeake Bay impact structure [2]) or gradual (e.g., Lockne [3] and Tvären [4] craters) in visual inspection. However, a distinct grain-size boundary does not necessarily represent the compositional boundary between the resurge and secular sediments. It merely reflects the shift in transport energy. In the case of a gradual transition the boundary can be difficult to distinguish visually. Here we have used stable isotopes of oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$), as well as variations in major element composition, to trace the resurge/secular sedimentation boundary at the Chesapeake Bay (CBIS), Lockne, and Tvären craters with the *a priori* assumption that the bulk composition of the mixed resurge deposits (i.e., mainly target materials) will have different values than the sediments deposited out of the water column after the onset of secular sedimentation. The targets of the studied craters consisted of seawater and sediments covering a crystalline basement, all of which were extensively excavated during cratering. The geochemical investigation is complemented with ongoing studies of planktonic microfossils to see if the resurge-secular transition is reflected in the paleontological record and, if this is the case, how the local biota was affected by (or possibly affected) the sedimentary environment within the crater.

**Method:** Bulk samples were taken across the previously estimated boundaries [2, 3, 4] between resurge deposits and secular sediments. For the CBIS we sampled the Eyreville-A core, for the Lockne crater the Lockne-1 and Lockne-2 cores, and for the Tvären crater the Tvären-2 core. The Lockne-1 core was sampled only for isotopes. The petrography of Lockne-2 was also studied using thin sections. All cores have nearly complete recovery in the analysed intervals.

**Results and discussion:** Due to limitations in space we can here only present the graphs for the Lockne cores (Fig. 1). For all craters we plotted major elements that can be strongly linked to the composition of the crystalline basement and, thus, will have been exclusively deposited by the resurge. For all the studied craters the major elements show a significant rise followed by an abrupt drop in weight percent either at the visually estimated boundary (CBIS, possibly also Tvären) or significantly above that boundary (Lockne). The major element shift is accompanied by an equally abrupt change in $\delta^{18}O$ and $\delta^{13}C$. Below this level the isotope data are interpreted to show the expected blend in the nearly instantaneously deposited resurge sediments followed by an increasing influence from the normal seawater (secular) sediments (approx. 45-30 m depth in Lockne-1 and 110-125 m depth in Lockne-2, Fig. 1). Although calcareous nannofossils indicate some reworking for some 10-15 m above the apparent end of resurge sedimentation at the CBIS (~443.9 m), the geochemical data support the very abrupt change obvious at visible inspection of the core. The Tvären core exhibits a number of more or less distinct visual boundaries of which one (~149 m) has been presented as the preferred top of resurge deposition based on lithologic and paleontologic data [4]. In this case, as at the CBIS, the geochemical results confirm the previously estimated boundary and, infact, further support an impression of a very rapid transition. At Lockne, however, the transition between resurge and secular sedimentation appears gradual over tens of meters and is visually impossible to distinguish even in thin section. The boundary was previously identified as the approximate top of the occurrence of sand sized clasts (i.e., “resurge arenite”) [3]. Therefore, at Lockne it was unanticipated that the geochemical data would show such a distinct change (on cm-scale), in sediments lacking any visible change in grain size or composition.

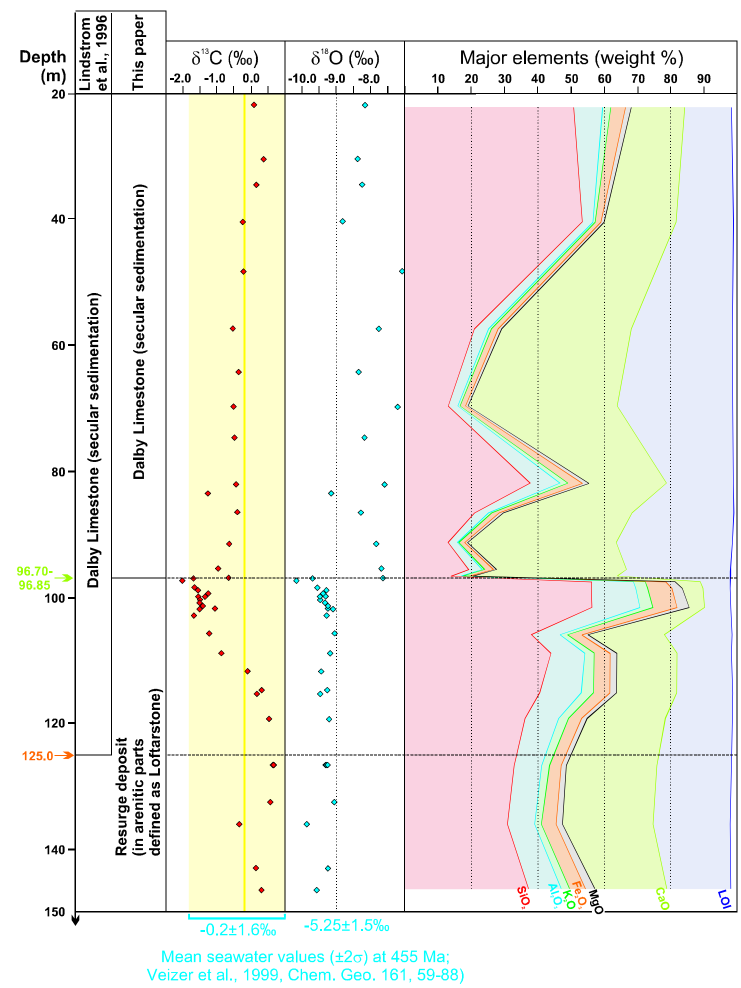
This change occurs approximately 30 m above the previously recorded boundary in Lockne 2 (Fig. 1).

At a few metres below the abrupt shift in the diagram (Fig. 1), in both Lockne-1 and Lockne-2 the $\delta^{13}C$ values drop below the expected mixing line (yellow) between basement-derived material and secular sediments (Fig. 1). We propose that although the water column was nutrient rich the sediment-rich water would have attenuated sunlight and, thus, decreased the photic zone preventing normal primary production rates. During the final stage of settling of the sediment particles, then possibly a colloid, an optimum combination of nutrients (i.e., the peak in basement-derived elements at 102 m, Fig.1) and insolation into the water column was reached. This is one possible explanation for the relatively negative $\delta^{13}C$ values. $\delta^{13}C$ and $\delta^{18}O$ values then abruptly returning to normal secular seawater ratios signifying a return to normal rates of primary production. The final deposition of sediment particles from the water column thus appears to have occurred during one rapid event, possibly as a flocculation of the colloid. Whether this event was chemically or biologically forced, or some combination of both, is the cause of ongoing micropaleontological and geochemical (including bio-geochemical) investigations.

**Conclusions:** Stable isotope and major element analysis is proving to be a useful method for distinguishing the end of impact-related sedimentation at marine-target craters. At the Chesapeake Bay and Tvären craters the transition from resurge to secular sedimentation seems to be a physical process only, but at the Lockne crater there may be a combination of both physical and biological/chemical processes. It is evident that visual inspection alone cannot always identify the break between resurge and secular sedimentation.

**References:** [1] Melosh H. J. (1989) *Oxford Monographs on Geology and Geophysics 11,* 245pp. [2] Gohn G. S. et al. (2009) *GSA Spec. Pap. (In press),* [3] Lindström M. et al. (1996) *GFF 118,* 193–206. [4] Lindström M. (1994) *Geol. Mag. 131,* 91-103.

## Lockne-2 drillhole




## Lockne-1 drillhole