A MODEL FOR THE FORMATION OF THE CHESAPEAKE BAY IMPACT CRATER AS REVEALED BY DRILLING AND NUMERICAL SIMULATION.

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Introduction: The Chesapeake Bay crater, Virginia, is the largest known impact structure in the United States [1]. It is well-preserved beneath ~500-m of post-impact sediments and has been investigated by seismic studies, as well as by several drill cores [e.g., 2-7]. Seismic data interpretation revealed that the basement structure of the crater an “inverted sombrero” morphology, with a deep inner basin (~40-km diameter) surrounded by a shallower brim (80-90 km diameter) [1-7]. The surface morphology of the crater, however, is almost entirely flat due to the presence of an unusually thick (several hundred meters) synimpact crater fill deposit, the Exmore breccia [1-7]. The structural and morphologic form of the Chesapeake Bay crater is similar to that of other marine craters on Earth, but is quite unconventional when compared with similar-sized subaerial craters on Earth.

Recent numerical simulations of the Chesapeake Bay impact using the iSALE hydrocode, which included a large contrast in material strength between the weak sedimentary and strong crystalline units, reproduced the unusual structural form of the Chesapeake Bay crater and many of the structural features interpreted from the seismic data [8]. According to this model of a 3.2-km diameter impactor colliding vertically at 17.8 km/s with a two-layer (water-saturated sediment over crystalline basement) target:

i. A deep basin in the crystalline basement is formed near the crater center that contains inwardly collapsed (resurge) sediments and is bounded by a ring of uplifted basement.
ii. Outside of this, the model predicts a shallower outer basin where deformation is confined to the sedimentary layer.
iii. The unusually thick impact breccia/resurge deposit that fills the entire crater is a direct consequence of the extremely weak sedimentary unit at the time of impact.

Petrographic analyses of drill core from the recent ICDP-USGS drilling project provide new constraints on the inner crater stratigraphy (Fig. 1) with which to test this model [e.g., 9-12]. Here, we compare a new 3-layer model of the Chesapeake Bay impact (Fig. 2), similar to [8], with ground truth data from the new drill core. In addition, we use the combination of drill core analysis and results from numerical simulation to provide new insight into the duration of different stages of the Chesapeake Bay and other marine target impacts.

Overview of ICDP-USGS-drilling results: The principal stratigraphy as revealed in the combined Eyreville cores (Fig. 1) is documented in [9-12]. It consists, from top to bottom, of 444 m post-impact sediments resting on 652 m of resurge deposits, the so-called Exmore beds [9]. Underneath this unit is a single, coherent 275 m granite block, which, in turn, overlies 22 meters of smaller sedimentary and granite blocks. Beneath this is 157 m of lithic impact breccia, suevites, and impact melt rocks [10, 11]. The lowermost sequence in the drill core comprises 215 m of basement-derived lithologies (Fig. 2) [10, 11]. Significantly, a shock metamorphic overprint is lacking in both the 275-m granite boulder and the lowermost basement blocks [12].

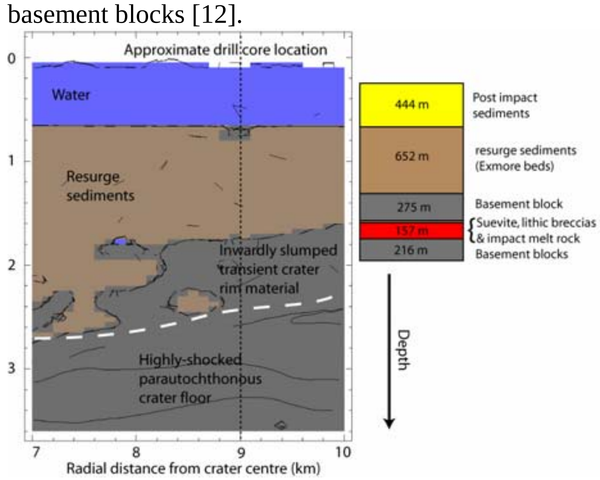

Figure 1 *Comparison between numerical model results and principal stratigraphy of the combined Eyreville cores [9-12], which were located ~9 km from the crater center.*

Comparison with numerical models: The best-fit model of [8] represented the water and sediments in the pre-impact target at Chesapeake Bay as a single weak layer. However, as it is difficult to meaningfully compare the detailed stratigraphy in the two-layer model with results from the drill-core, we performed new high-resolution 3-layer simulations of the Chesapeake Bay impact that show the same good agreement with geophysical interpretation and also enable better comparison between final modeled crater stratigraphy and the results of drilling. Figure 2 shows a radial cross-section through the final crater in our new numerical simulation of the Chesapeake Bay impact. The model is identical to that of [8] apart from separating the upper target layer into a 500-m water layer above a 1-km thick weak sediment layer. The impact velocity was also reduced from 17.8 km/s to 16 km/s.

The Eyreville drill site is situated at a radial distance of approximately 9 km from the crater center (marked on Fig. 2) [12]. The large-scale stratigraphy observed in the model is shown in Fig. 1 for comparison with the drill core observations. Comparison between the model and borehole suggests the following:

i. At 9-km radial distance, the numerical model shows a 1-kilometer thick sequence of heavily deformed sediments (see lack of tracer lines in Fig. 1&2). The recovered Exmore beds (652 m) in the drill core are thinner than this; however, the 275 m thick granite block and the underlying unit (22 m) of smaller sedimentary and amphibolite blocks are also part of this sequence, which has an aggregate thickness of 950 m.

ii. Below the heavily deformed sediments in the model is a ~600-m thick zone of deformed, predominantly basement material that collapsed (and was pushed) inward from the transient crater rim during resurge. This zone contains material exposed to a wide range of shock states. The corresponding unit(s) in the drill core may be the suevite-like unit and, perhaps, the basement blocks beneath. In the model, the highly-shocked, parautochthonous crater floor is located at a depth of 2.5 km (dashed white line); if this is correct, it implies that the drill core did not reach the crater floor.

iii. Modeling predicts that the sediment-laden resurge (Exmore beds) flowed back into the crater at speeds on the order of 100 m/s, and filled the inner basin in a matter of minutes after the impact. According to simple physical analysis [12], fluid flow on this scale and at this speed would be sufficient to "pluck" or drag a boulder up to several hundred meters in size from the transient crater rim area and carry it into the crater. This offers a potential explanation for the presence of a 275-m wide granite block, which shows no evidence of shock metamorphism, near the base of the resurge sequence in the drill core.

Insight into Chesapeake Bay crater formation: The combined results of numerical models and observations from the ICDP-USGS drill core provide insight into the timing and order of marine cratering processes during the Chesapeake Bay impact [12]:

i. The sequence of polymict lithic breccia, suevite and impact melt rock (1393-1550 m) must have been deposited prior to the arrival of, or concurrent with, the 950 m thick resurge and avalanche-delivered beds and blocks within 6-8 min after impact.

ii. This short period for transportation and deposition of impactites suggests that the majority of the impactites of the Eyreville core never left the transient crater and were emplaced by ground (re)surging. This is in accordance with observations of the impact breccia fabrics. However, the uppermost part of the suevite section contains a pronounced component of airborne material from the collapsing ejecta plume.

iii. Limited amounts of shock deformed debris and melt fragments also occur throughout the Exmore beds. A shard-enriched interval in the upper Exmore beds indicates that late ejecta plume deposits were incorporated and dispersed into the later resurge. Modeling indicates that the major resurge flow was concluded some 12 to 15 min after impact. This also marks a late stage of deposition from the ejecta plume.

References: [1] Poag, C.W. et al., (1994) *Geology*, 22:691-694. [2] Poag, C.W. (1996) *MAPS*, 31:218-226. [3] Powers and Bruce (1999) *USGS Professional Paper* 1612, 82 p. [4] Poag et al., (1999) *GSA Special Paper* 339: 149-164. [5] Poag et al., (2004) *The Chesapeake Bay crater—Geology and geophysics of a late Eocene submarine impact crater*, Springer, Heidelburg, 522 p. [6] Catchings, R.D. et al (2008) *JGR*, doi:10.1029/2007JB005421, in press. [7] Horton, J.W. et al (2005) *USGS Professional Paper 1688*. [8] Collins and Wünnemann (2005) *Geology*, 33(12): 925-928. [9] Gohn, G.S. et al. (submitted) *GSA Special Paper.* [10] Horton, J.W. et al. (submitted) *GSA Special Paper.* [11] Reimold, W.U. et al. (submitted) *GSA Special Paper.* [12] Kenkmann, T. et al. (submitted) *GSA Special Paper.*

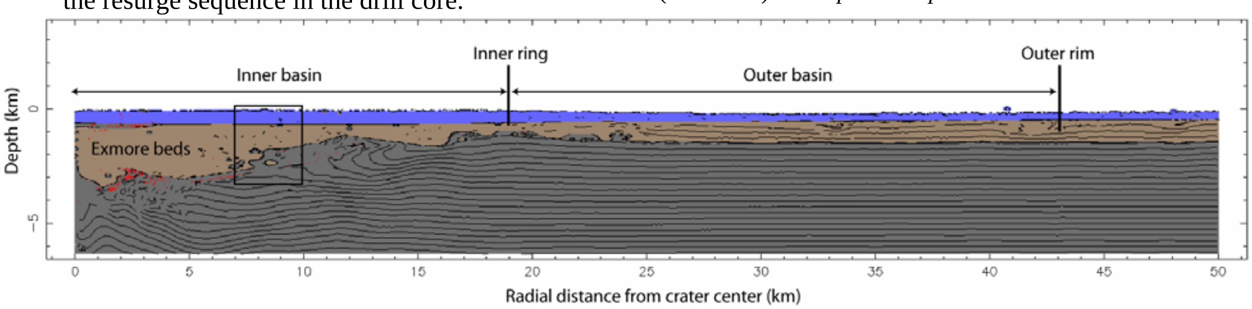

Figure 2 *Radial cross-section through final simulated Chesapeake Bay crater. Large-scale crater structure is consistent with seismic data interpretation. Rectangle corresponds to section of model in Fig. 1; the Eyerville drill core was located ~9 km from the crater center. Target deformation is illustrated by Lagrangian tracer lines. Tracers are only connected to form lines if their separation is less than twice their original separation; hence, regions of high deformation have few or no lines.*