"FALSE-PEAK" CREATION IN THE FLYNN CREEK MARINE-TARGET IMPACT CRATER. V.J. Bray[1], J. J. Hagerty[2], G. S. Collins[3], [1]The University of Arizona, Tucson, AZ, 85721. [2A]Astrogeology Science Center, U.S.G.S. Flagstaff, AZ, USA. [3]Department of Earth Science and Engineering, Imperial College London, Exhibition Road, London, SW7 2AZ, United Kingdom. (vjbray@lpl.arizona.edu).

Impacts into marine targets are known to create abnormal crater morphologies, including 'inverted sombreros' and substantial central mounds [1, 2]. Flynn Creek is a ~3.8 km diameter impact crater, thought to have formed in a shallow sea [3, 4]. Confirmation of an impact origin for the Flynn Creek structure came with the discovery of shatter cones in exposures of the central uplift [5] in rocks from ≤ 450 m beneath the pre-impact surface. Higher-pressure indicators were not found, limiting peak shock pressure range to 3-5 GPa. Various works [e.g., 3-6] have suggested that the impactor likely struck a shallow sea before penetrating underlying Upper Ordovician limestone at relatively low impact velocities. We define the range of possible sea depths based on the thorough comparison of hydrocode simulation results with observational data.

Method: We conducted hydrocode simulation of vertical impact into a limestone target using iSALE2D [7-11]. The material models and equations of state used are presented fully in [12]. To explore the possible impactor velocity-size combinations that might have formed the Flynn Creek impact structure, we simulated spherical iron impactors striking the ocean surface with various velocities (1-30 km/s). A tracer particle was placed at 450 m depth to record peak shock pressure. Suitable results were chosen based on peak pressure of 3 - 5 GPa, in addition to suitable morphology. To determine the sea depth present at the time of the Flynn Creek impact, simulations were also performed with a shallow sea of varying depth (0 m – 1000 m). Results were compared to the post-resurge topographic profile of [1] to check for the correct morphology, and the drill core analyses of [13, 14] to confirm the correct amount of resurge breccia deposition. The third physical constraint on our simulations, was the exhumation of a tracer particle from 450 m depth to the peak surface, representing the shatter cone detections of [5].

Results: Only impact velocities between 2 and 5 km/s produced suitable shock pressures at the tracer particle. The shallow depth and overly large central peak of Flynn Creek crater were successfully produced in several ways, involving simulations with a 200m, 400m and >600 m ocean (Fig. 1). In all cases, the over-turning rim-flap deposited onto ocean, resulting in significant rim slump deposits within the crater cavity. In the case of the 200 m ocean, these slumps reached the crater center forming a large 'false peak' on top of the originally more modest uplift. The 400 m ocean simulation also produced a 'false peak', this time due to the collection of resurged ejecta at the crater center. This 'false peak' masked the 'inverted sombrero' morphology formed by the rim slump deposits. Once sea depth exceeded 600 m, enhanced uplift occurred, presumably due to the release of the additional over burned pressure of a deeper ocean.

Of these three morphological best-fits, the observed depths of resurge breccia (78 m on the flank and 14-21 m in the moat [13, 14]) were recreated best by a sea depth of 400 m: 75 (± 10) m deep on the central peak flank and 20 (± 10) m in the crater moat. The 700 m ocean simulation also produced an acceptable fit of resurge breccia at the peak-flank (55 ± 10 m), although crater moat resurge breccia could not be differentiated from the quickly collapsing rim breccia.

A tracer particle at an original pre-impact depth of 450 m, was uplifted to within 30 m of the peak surface only in the 700 m ocean depth simulation, and recorded a peak pressure of 3.09 GPa for an impact velocity of 5 km/s. The 200m and 400m ocean simulations likewise lifted to the tracer particle to near the peak surface, but were then buried by rim collapse deposits. Our best-fit ocean depth, based on a good match to crater morphology, breccia thickness, and peak pressure at the central peak surface is 700 m.

Implications: Our simulations, for water depths 150 - 400 m, create broad, shallow craters with a central depression as the result of large-scale rim collapse. The deeper sea simulations (250-400 m), include infilling of this central depression by resurge deposits. As we used a homogeneous sedimentary target it demonstrates that nested marine crater morphology does not require the presence of a stronger material at depth, as has been suggested for other marine-target craters [2].

The significant peak formed during some of our simulations suggests that extremely tall and broad peaks can be produced as part of the crater formation process when standing water is present at the surface. This result has implications for abnormally large central deposits such as those in Gale Crater, Mars, and the terrestrial marine impact crater Mjolnir – their peaks might have already been sizeable prior to post-impact tectonism or sediment deposition [2, 15].

An impact velocity of 5 km/s is significantly below the average terrestrial impact velocity (~18 km/s). Atmospheric drag can slow an impactor somewhat, but fragmentation and dispersion of the meteor in flight is a more likely explanation for a very low velocity at Flynn Creek crater [16]. The creation of a "false peak" at Flynn Creek has implications for the absence of high pressure impactites in drill cores, and the inferred low impact velocity. Our simulations reproduced the morphology of the Flynn Creek crater with significant rim slumps that covered the original crater floor in some cases – burying material which had experienced higher pressures. If drill cores around the crater were not deep enough to excavate through the low-shock material of slump deposits, it is possible that high shock pressure indicators exist at Flynn Creek, but remain undetected.

Acknowledgements and References: This work was funded by NASA PGG grant NNH14AY73L. [1] Adrian et al., 2019, MAPS 54(11):27558-27568 [2] Ormö & Lindström 2000. Geol Mag 137:67–80. [3] Roddy 1979, LPSC X Abs. 2519-2534. [4] Evenick 2006, Field Guide to Flynn Creek, Univ. of Tennessee. [5] Roddy 1966, Am. Min. 51:270, [6] Evenick & Hatcher, 2007, GSA Map and Chart Series 95. [7] Amsden et al. 1980, LANL Report, LA-8095. [8] Melosh et al. 1992, JGR 97:14735-14759. [9] Ivanov et al., 1997, Int. J. Imp. Eng. 20:411-430. [10] Collins et al. 2004, MAPS, 38:217-231 [11] Wünnemann et al. 2006, Icarus, 180:514-527. [12] Bray et al. 2022, MAPS: In Press. [13] Adrian et al., 2018, MAPS 53:857-873. [14] Demarchi et al., 2019, MAPS 54(11):2864-2878. [15] Corseri et al., 2020. J. Struct. Geol. 131:10395. [16] Artemieva & Pierazzo, 2009. MAPS 44:25-42.

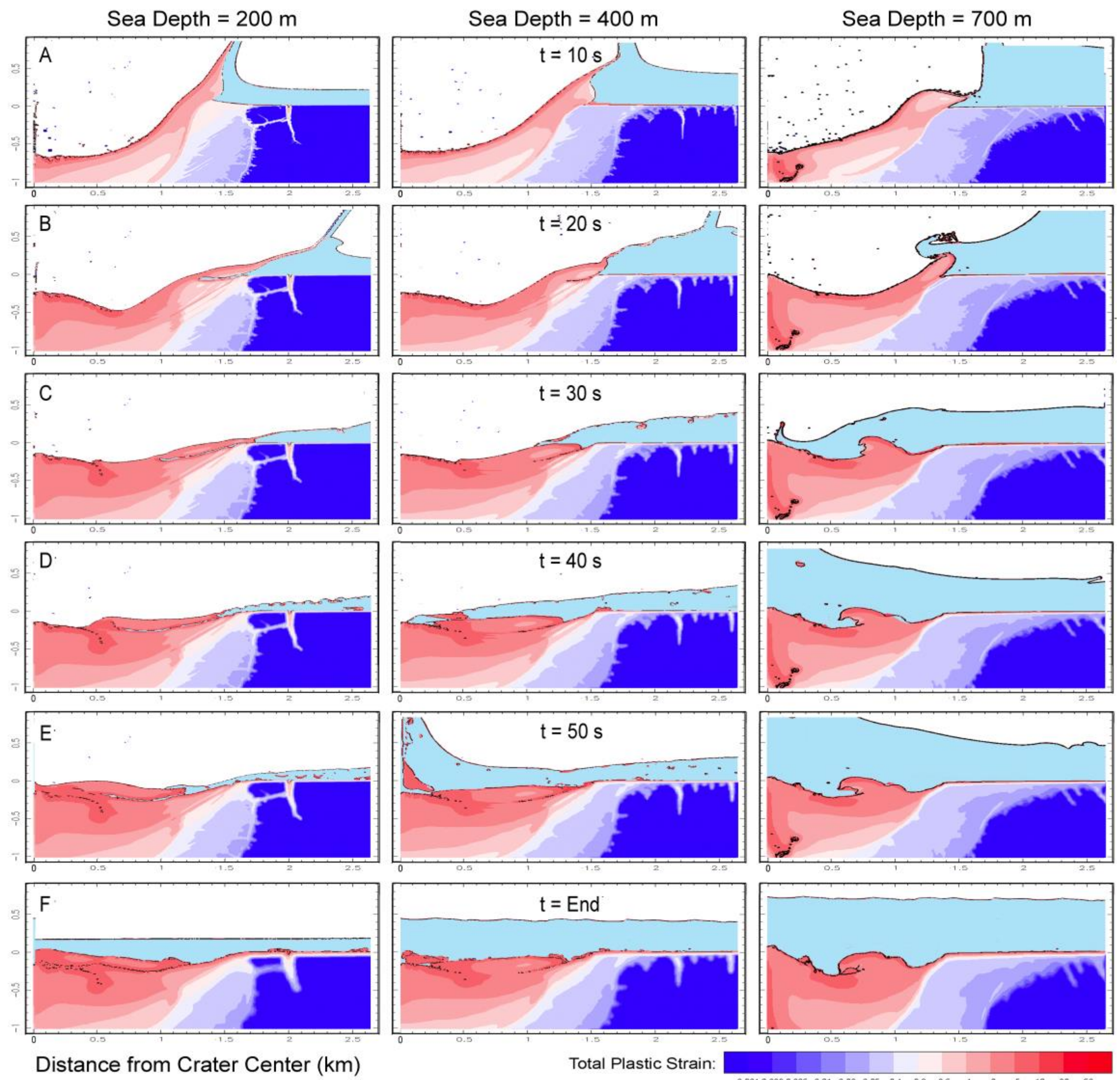

Figure 1: Simulation time-steps after impact for the three morphological best fits. 200 m water layer (left), 400 m water layer (centre), and 700 m (right). Colour shows regions of material that has been significantly moved from its initial position (high total plastic strain -TPS) in red, and material less removed from its original position (low TPS) in blue. These simulations present pristine impact crater morphology. Further erosion over time will have subdued this initial crater morphology, eroding the topographic highs and infilling the topographic lows.