IMPACT INDUCED HEATING OF OCCATOR CRATER ON ASTEROID 1 CERES. T. J. Bowling[1], F. J. Ciesla[1], S. Marchi[2], B. C. Johnson[3], T. M. Davison[4], J. C. Castillo-Rogez[5], M. C. De Sanctis[6], C. A. Raymond[5], and C. T. Russell[7]. [1]University of Chicago, Chicago, IL (tbowling@uchicago.edu), [2]Southwest Research Institute, Boulder, CO, [3]Brown University, Providence, RI, [4]Imperial College, London, UK, [5]Jet Propulsion Laboratory, Caltech, Pasadena, CA, [6]National Institute of Astrophysics, Rome, IT, [7]University of California, Los Angeles, CA.

Introduction: Dwarf planet Ceres, the current target of NASA's Dawn mission and the inner solar system's last remaining 'wet protoplanet', is thought to be composed of a mixture of silicates and ices [1]. One of Ceres' most intriguing features revealed by the Dawn spacecraft is the 92-km diameter crater Occator [2]. This crater is expected to be 10s-100s Myr old and contains some of the highest albedo features on the asteroid, which are possibly salt deposits [2]. Occator's longitude is also compatible with the putative source region for previously detected H_2O outgassing from Ceres [3], and may contain a diurnally periodic dust haze [2] driven by near surface volatile sublimation. To better understand the nature and possibility of post-impact hydrothermal systems in Occator, which may determine the distribution of salts and water ice in the crater's near surface, we use a suite of numerical models to investigate the initial temperature structure and subsequent cooling of the crater.

Methods: We model the formation of Occator using the iSALE-2D shock physics code [4-6] in order to obtain an initial temperature structure for the crater. Ceres is represented as a half space composed of a 50%/50% intimate mixture of hydrated silicate [7] and H_2O ice [8]. Material thermodynamics are modeled using the ANEOS equation of state package, and material mixing assumes an intimate combination of species in thermal and physical equilibrium following [9]. Because the simple-complex crater transition on Ceres is consistent with an icy target [10], we employ an ice rheology [11] modified to include ice-like visco-elastic-plastic behavior [12,13]. The pre-impact thermal structure of the target is taken from [14] with a surface temperature of 200K. Spherical impactors, composed of dunite [15] and with diameters of 3.7 and 5 km, collide with this target at Ceres' mean (4.8 km s^{-1}) and above average (7.5 $km \cdot s^{-1}$) impact velocities.

Results: Both simulations result in the formation of an ~80-km diameter central peak crater with maximum depth of ~5 km. The initial central peak is tall enough to be gravitationally unstable, and subsequent collapse concentrates hot material into a subsurface locus at the base of the peak [Fig. 1]. This locus, with a maximum temperature of 305 K (4.8 $km \cdot s^{-1}$) and 340 K (7.5 $km \cdot s^{-1}$) is the only region of the target to meet temperature and pressure thresholds required to melt H_2O ice, although the inclusion of impurities may lower the melting temperature considerably [16]. In both simulations, the central peak is composed of material uplifted from considerable (15-30 km) pre-impact depth. Because of its provenance, this material may have been sheltered from heating and subsequent devolatilization from both previous impacts as well as the Occator forming impact, and subsequently may be more volatile rich than average for the crater. During the subsequent thermal evolution of the crater this unaltered, volatile rich material may be heated above the melting point of water by the conductive thermal pulse from the hot locus at the base of the central peak. Assuming a typical thermal diffusivity of 10^{-6} $m^2 \cdot s^{-1}$ and a characteristic length scale of 10 km, temperatures within the hot locus and central peak should decay below the melting point of water on a timescale of ~3 Myr, much shorter than the suspected age of the crater even when neglecting advective heat transfer within hydrothermal systems. Details of Occator's post-impact thermal evolution will be investigated numerically following [17] with thermal boundary conditions taken from [14, 18].

Discussion: Today, Occator does not have a central peak, but is instead fairly flat with a central pit [2]. The most commonly accepted explanation for the formation of central pit craters in icy targets relies on the formation of an impact-induced melt pond which subsequently drains into fissures in the crater floor [19]. Because our target is composed of an intimate mixture of ice and rock, as opposed to pure ice, the collapse process is likely slightly different: 1) the crater forms with a central peak of heated ice-rock mixture, some of which may exceed the melting point of H_2O. 2) subsequent outgassing of water [20], possible loss of water through liquid water eruptions, and drainage into the subsurface removes volume from the central peak. 3) as ice is lost the central peak begins to slump, which, along with visco-elastic relaxation of the crater [21] results in a relatively flat floor and central pit. It should be noted that the initial prominence of the central peak may be lower than seen in our simulations, as the acoustic fluidization [22] parameters for ice were derived for icy satellites at much higher impact velocities [23], so further simulations exploring this parameter space will be run.

The subsurface locus of >273K material seen in Fig. 1 represents the only region in which hydrothermal circulation may occur. Melted subsurface material may percolate or effuse onto the floor of the crater, where it will subsequently sublime and build a lag deposit (possibly involving dissolved salts). Such outflows may be the origin of the 'bright spots' observed within Occator. Bright spots observed elsewhere on Ceres [2] may be recently exposed material originating from a similar process in subsequently erased craters.

The possible detection of a diurnal dust haze within Occator by the Dawn spacecraft implies that subsurface H_2O is currently subliming within the crater and subsequently being lost from the body. Because the thermal skin depth of the diurnal wave should be extremely shallow (<0.1 m), the periodic nature of this haze implies a driving H_2O source in the very near surface. Assuming a daytime H_2O loss rate of 1 $kg{\cdot}s^{-1}$ [3], a 10 km diameter source region (comparable to the size of Occator's central pit) should become depleted of volatiles in ~2000 yr. A 100 m diameter source region (comparable to the highest resolution obtained by Dawn instruments [24]) should become depleted in ~0.2 yr, shorter than the temporal baseline over which water production has been observed on Ceres [3,25]. As such, the source region must be either very young or continually recharged via hydrothermal circulation. Because the current temperatures beneath Occator should have decayed well below the melting point of water, we consider the possibility of active hydrothermal recharge extremely unlikely. High resolution imagery currently being obtained by the Dawn spacecraft will determine if there is a sufficiently young source within Occator (such as a small, recent crater which has exposed fresh volatile rich material) to explain the presence of the putative haze.

References: [1] McCord, T. B. and Sotin, C. (2005) *JGR*, *110*, E05009. [2] Nathues, A. et al. (2015) *Nature, 528,* 237-240. [3] Küppers, M et al. (2014) *Nature*, *505*, 525-527. [4] Amsden, A. et al. (1980) *LANL Report*, LA-8095. [5] Collins, G. S. et al. (2004) *MAPS*, *39*, 217. [6] Wünnemann, K. et al. (2006) *Icarus*, *180*, 514. [7] Brookshaw, L. (1998) *Working Paper Series SC-MC-9813*, 12pp. [8] Turtle, E. P. and Pierazzo, E. (2001) *Science*, *294*, 1326-1328. [9] Pierazzo, E. et al. (2005) *GSA Special Papers*, *384*, 443-457. [10] Schenk, P. (2015) *AGU Fall Meeting*, P23E-2186. [11] Senft, L. E. and Stewart, S. T. (2008) *MAPS*, *43*, 12. [12] Elbeshausen, D., *personal communication*. [13] Durham, W. B. et al. (1992) *JGR*, 97, E12. [14] McCord, T. B. and Sotin, S. (2005) *JGR*, 110, E05009. [15] Benz, W. et al. (1989) *Icarus*, *81*, 113-131. [16] Stillman, D. E. et al. (2016) *Icarus*, *265*, 125-138. [17] Davison, T. M. et al. (2012) *Geochimica et Chosmochimica Acta*, *95*, 525-26. [18] Hayne, P. O. and Aharonson, O. (2015) *JGR Planets*, *120*, 1567-1584. [19] Elder, C. et al. (2012) *Icarus*, *221*, 831-843. [20] Fanale, F. P. and Salvail, J. R. (1989) *Icarus*, *82*, 97. [21] Bland, M. T. (2013) *Icarus*, *226*, 510-521. [22] Melosh, H. J. (1979) *JGR*, *84*, B13. [23] Bray, V. J. et al. (2014) *Icarus*, *231*, 394-406. [24] Rayman, M. et al. (2006) *Acta Astronautica*, *58*, 605. [25] A'Hearn, M. F. and Feldman, P. D. (1992) *Icarus*, *98*, 54-60.

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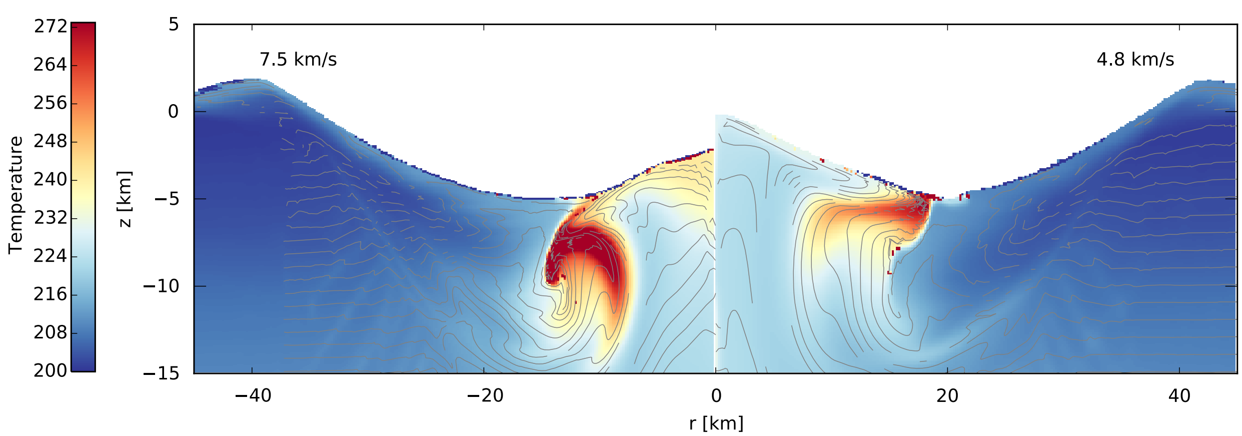

Figure 1: Thermal structure of an Occator-like crater 1500 s after impact for impact velocities of 4.8 and 7.5 $km{\cdot}s^{-1}$.