LONGEVITY OF THE CRYOMAGMA CHAMBER BENEATH OCCATOR CRATER ON CERES. M. A. Hesse[1] and J. C. Castillo-Rogez[2], [1]Department of Geological Science, The University of Texas at Austin, Austin TX 78712, USA (e-mail address: mhesse@jsg.utexas.edu), [2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA.

Introduction: Here we study the thermal evolution of the potential cryomagma chamber beneath Occator crater on Ceres that could form due to an impact 24 to 34 Ma ago [1,2]. The recent (< 1Ma) bright carbonate-rich surface deposits (faculae) in the center of Occator crater have been interpreted as deposits of subsurface brine formed from melt created by impact-induced heating [3,4,5]. This implies that subsurface brines in the cryomagma chamber persisted much longer than cooling time scale estimates < 3Ma, simulated so far [5]. This apparent discrepancy suggests either that Ceres crust is significantly less conductive than expected and/or that the cryomagma chamber was significantly larger than previously simulated, and potentially communicated with deeper brine reservoirs within Ceres [6,7,8]. Additional constraints on the source of the facula material comes from their composition. First, it suggests a predominant contribution from the crust [9,10]. Furthermore, the compositional gradient in Cerealia facula (ranging from a base dominated in sodium-carbonate to a top rich in ammonium chloride [11] suggests an evolution of the cryomagma chamber over time.

Owing to new insights into Ceres crustal composition and thermal evolution, we revisit the thermal evolution of the assumed cryomagma chamber beneath Occator crater in an attempt to reconcile simulations with the age data and to test the possibility of communication with a deeper brine reservoir.

Internal structure: Ceres is partially differentiated and the analysis of gravity and shape data suggest that Ceres has a strong, light (~1300 kg/m^3), largely isostatically compensated, outer crust of 40 to 60 km thickness [12,13,14]. The strength of the crust is attributed to the presence of significant amounts of low-density high-strength phases such as salt and clathrate hydrates [10,14,15]. The top of the silicate mantle below this crust is weaker by several orders of magnitude, which has been attributed to the presence of pore fluid [14]. The prospect for the persistence of a small fraction of brines until present was predicted by pre-Dawn models of thermal evolution. These suggested that the temperatures at the base of the crust would be between 240 and 250°K [6,16] and therefore close to the eutectic temperature of relevant salt-ice mixtures [10].

In either case, the Ceres' mantle provides a potentially over-pressured reservoir of subsurface brines that could contribute to cryovolcanism on Ceres [17]. If the impact generated cryomagma chamber beneath Occator communicates with this mantle brine, then it might increase the longevity of the crustal cryomagma chamber.

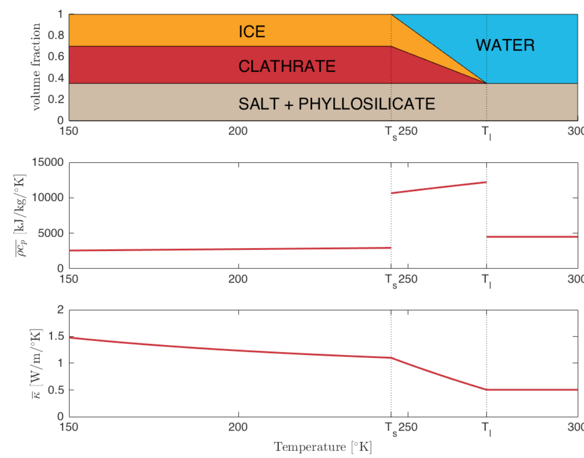

Figure 1: Thermal model properties. Top panel shows the volume fraction of phases as function of temperature. Middle panel shows the effective heat capacity of the multi-phase medium, including the latent heat term. Bottom panel shows the mean thermal conductivity of the multi-phase medium. Solidus temperature, T_s = 245°K, is the eutectic temperature of relevant salt-ice mixtures [10]. The liquidus temperature, T_l = 273°K, is the melting point of pure ice.

Crustal composition and thermo-physical properties: Previous analyses of the cooling of the thermal perturbation due to impact heating assumed a crust composed of ice and silicate [5] and a nearly constant crustal temperature of about 160°K. However, recent analyses suggest a crustal composition comprising approximately 30% ice, 35% clathrate, 15% hydrated salts and 20% phyllosilicates [10]. In comparison to the thermal conductivity of ice (2.5 - 3.7 W/m/°K) these phases have conductivities less than 0.7 W/m/°K (e.g., [18]).

This suggests that the crust of Ceres is significantly less conductive, which increases the longevity of the crustal magma chamber. Figure 1 shows the variation of the effective thermal conductivity and heat capacity of Ceres' crust with the composition given above. Below the eutectic temperature of the salt-ice-hydrate mixture, at 245°K, the effective thermal conductivity is less than 1.5 W/m/°K and the heat capacity is between 2500 and 3000 kJ/kg/°K.

Thermal evolution model: To study the effect of the new bulk composition we have developed a 2D thermal evolution model in cylindrical coordinates. The thermal properties of the phases are allowed to vary with temperature and the effective medium properties are volume fraction weighted averages. The models assumed eutectic melting of both the ice and clathrate begins at 245°K and is completed at 273°K (Figure 1). We assume the latent heat of melting is released uniformly and the volume fractions of the ice, clathrate and brine change linearly over the melting interval. The initial temperature field is patterned after the results of impact simulations [5] combined with a thermal evolution profile consistent with the presence of pore fluids (brines) at ~45 km [6,16]. This results in a 20 to 25 km deep region where the liquidus is exceeded with a radius of 4 to 5 km. This is surrounded by a region 30 to 35 km deep where the eutectic temperature of some salt-ice mixtures is exceeded.

Model results: The longevity of the cryomagma chamber is the maximum time for which the region beneath Occator crater exceeds the eutectic temperature of the relevant salt-ice mixture. This is an upper limit, as cryovolcanic activity likely ceases long before the last subsurface brine freezes [17].

Our simulations show that the lower conductivity of Ceres' crust can extend the longevity of cryomagma chamber with depth 30 km and width 12 km from 5 Ma to 8.5 Ma or by 70% for a given size. These results are limited to the particular initial condition, but it seems unlikely that any reasonable initial condition would extend the longevity of the cryomagma chamber to the 20 Ma required by observations, unless the lower crust already contains significant amounts of brine.

However, our simulations show that a partially molten connection between the cryomagma chamber and the base of the crust can be established if the chamber is sufficiently large (Figure 2). In this case, downward heat conduction raises the temperature of the initially solid lower crust beneath the cryomagma chamber above the eutectic temperature and induces low degrees of partial melting. Given that brine percolates through ice at very low melt fraction [19], this would establish a hydraulic connection with the deep brine reservoir below Ceres' crust.

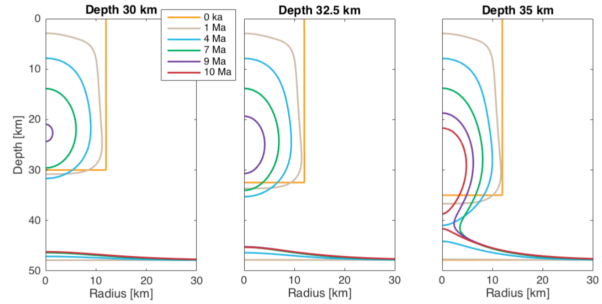

Figure 2: Evolution of impact induced cryomagma chamber beneath Occator crater. The solidus isotherm, bounding the magma chamber, is shown as function of time, see legend in left panel. Three panels show initial cryomagma chambers with increasing depth. The base of the crust below which deep brines are present is initially at 47.6 km.

If the brine reservoir beneath the crust is overpressured due to continued freezing of the interior [17], a porous and permeable lower crust would allow recharge of the crustal magma chamber. This could significantly extend the longevity of the crustal cryomagma chamber and hence explain geologically recent cryovolcanic activity in Occator crater.

The dynamics of such a hydraulically connected system are likely complex and beyond the scope of this contribution. Future work aims to extend the model to account for the induced mass and energy transfer in such a system to test if it can sustain cryovolcanism in Occator crater for 24 to 34 Ma.

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