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Dynamic models for formation of Occator bright spots

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Abstract

A prominent feature of the asteroid Ceres is the large crater Occator, and especially the bright spots seen in its interior. We describe possible mechanisms that could have formed the bright spots and the central pit.

1. Introduction

The Occator crater has a diameter of 92 km and a depth of 4 km. It is located at latitude 19.86 °N. A central pit has a diameter of 11 km and depth of 0.6 km. The age of the crater is estimated at 16-280 Myrs [1,2], while the bright spots are apparently much younger, potentially present-day. The bright spots appear to be rich in carbonate deposits [3]. A previous study [4] has proposed that the bright spots in Occator are the result of outflow to the surface from a subsurface brine reservoir. Build-up of gases (CO_2 and CH_4) in the reservoir according to [4] lead to explosive breaching of the surface. Impact energy is likely to have stimulated near-surface hydrothermal circulation [5], but the time-scale of that process would occur much closer to the creation of Occator, rather than tens of Myrs or more later. Post-impact hydrothermal systems tend to last no more than ~1 Myrs [5]. The time difference suggests that a considerably deeper reservoir is being tapped.

Numerical simulations of the evolution of Ceres from an unconsolidated cold mixture of rock grains and ice crystals to the present indicate that throughout much of Ceres' history, hydrothermal circulation can occur in the core and in a muddy ocean mantle [6]. Heat generated by radiogenic elements and heat of reaction from serpentinization drive fluid circulation. The initial size distribution of rock grains includes coarse particles and fine particles. When the interior warms sufficiently to melt ice, rock grains are freed up; they settle at size-dependent rates towards the core.

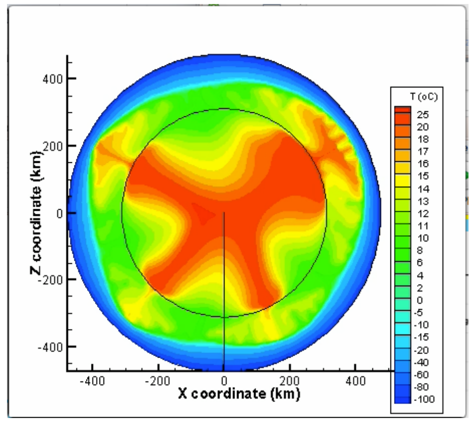

Figure 1: Snapshot of thermally driven convection showing multiple scales of circulation. The interior circle is the boundary of a porous Ceres core.

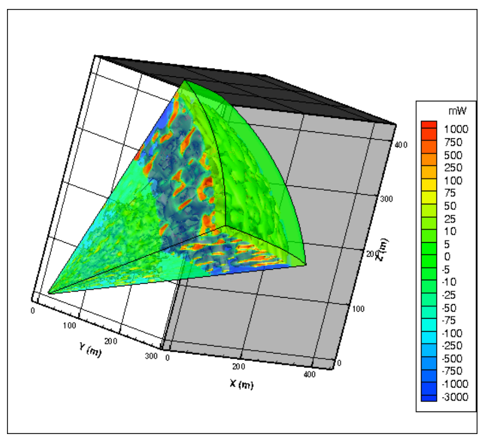

Figure 2: Higher resolution mud convection in a sector, showing clearly the many episodic plumes that rise toward the surface.

Resultant core size and core and mantle densities lie on the curve of possible solutions determined by gravity analysis [7], between CM and CI models. Fine particles (< 1 μm) remain suspended; the fluid is a mud. Despite the higher viscosity of mud compared to pure water, hydrothermal circulation is still possible. Figures 1 and 2 captures the very dynamic multi-scale circulation that could develop.

2. Tapping a deep reservoir

Several processes could transport brine from deep in Ceres to the surface or near surface, based on our model results [8]. (1) Flow through fractured mantle. Over time, the model mud mantle gradually freezes, but not uniformly in latitude or longitude, generating vertical and lateral stresses on the neighboring unfrozen upwellings. Compressibilities of water and rock are about 4.5×10^{-5} /bar. Applying that to the H_2O phase change (about 10% volume change x ~0.50 water volume fraction) generates about 1 kbar of overpressure, sufficient to fracture ice and rock and drive out-flow to the surface or near-surface, until excess volume is expelled. We envision a slow buildup of pressure and then a relatively sudden breakthrough when a critical pressure is reached and a fracture conduit is formed. Hydrothermal circulation is episodic meaning the process of freezing and fracturing would also be episodic. (2) As the mud layer freezes, cryo-convection (convection in the solid phase), will increase in strength (Figure 3). Occator crater is located at low

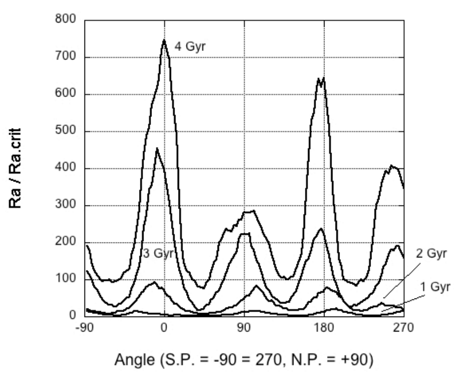

Figure 3: Possibility of cryo-volcanism increases over time as the mud mantle freezes. Further, the higher the Ra number, the more episodic the plume generation becomes.

latitude, just where convection, either hydrothermal or cryo, should be strongest. The base of a cryo-convective plume would lie at the top of a regional mud sea. Salts and other minerals in the sea mud would be entrained into the upwelling plume, and eventually brought to the near-surface. (3) Episodic porous flow through the overlying frozen mantle. Deep regional mud seas persist to the present time in our model. Further, experimental studies of slow freezing rates in particle rich solutions [9] indicate that a pattern of alternating layers of ice and particulates is likely to form, with vertical micro-fractures connecting the layers locally. The overlying frozen mantle could be somewhat permeable. An impact would also increase permeability through extensive fracturing. When the crater forms, there is a sudden pressure deficit of roughly 25 bars. This pressure difference could drive flow of brine on a **tens of** Myr time scale from a depth of ~100 km.

In summary, there are several mechanisms, acting either separately or simultaneously, that could bring H_2O and minerals from deep in Ceres to a near-surface reservoir.

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