EPSC Abstracts,
Vol. 2, EPSC2007-A-00466, 2007
European Planetary Science Congress 2007

Ceres: Evolution and Present State

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Introduction: We consider Ceres as a prototype for planetary evolution [1]. From thermal modeling by McCord and Sotin [2, 3, 4], Ceres was inferred to have differentiated into a rocky core of hydrated silicates, and an icy outer shell. Thomas et al. [5] confirmed such a model from direct observation of Ceres's shape from Hubble Space Telescope observations, and pervious occultation measurements. McCord and Sotin [4] also suggest that Ceres could have preserved a deep ocean, especially if ammonia or some other ice melting point depressant, such as salts, was incorporated during accretion. We continue to develop thermal modeling of Ceres, using increasingly sophisticated models and new observational information in order to match the observed shape. . In particular, we investigate the evolution of the core.

Approach: Our models require the following initial input: initial planetesimal temperature (after [6]); composition; time of formation with respect to Calcium-Aluminum Inclusions (CAIs); and an internal heat profile after initial accretion. Modeling begins with a porous Ceres (after [7, 8]). The rock phase has the composition of an ordinary chondrite (after [9]). Short-lived radiogenic isotopes, including 26Al and 60Fe, have initial concentrations as measured by [10, 11]. Conductive thermal evolution is computed for one-dimensional models following the approach of [4] and [12]. The silicate core evolves through hydration, then dehydration and melting stages. Currently, hydrothermal cooling is not included in our algorithm.

Model Results: Conditions were present for full differentiation of Ceres if accretion time t0-CAIs was less than 7 My and/or if ammonia was accreted. For times of formation t0-CAIs shorter than 2 My, the boiling point of water was reached within a few My after accretion, and may have led to major water loss.Under these conditions, hydrothermal activity was inevitable, and might still be taking place inside Ceres.

Whether a deep ocean is still present within Ceres or not depends on the initial conditions, especially the presence of ammonia. The core follows very different evolutionary paths, given the range of input values. Core evolution is most strongly affected by the time of accretion, with respect to inclusion of CAIs. With the inclusion of short-lived radioisotopes, pressure and temperature conditions in the core can lead to dehydration of the silicate phase [13], and layering of the core. An outer layer consisting of hydrated silicates, and a deep core consisting of dry silicate is the result, due to the equation of state of hydrated silicates. Explosive volcanism is expected to occur [14]. Conditions can even lead to partial differentiation of a metallic core.It is these model runs, resulting in the differentiation of Ceres's core into an outer hydrated layer, dehydrated inner layer and a tiny metallic center, that also produce the observed shape.

Acknowledgement: This work was supported in part by the NASA Dawn Discovery Program under contract to the Space Science Institute by the UCLA and funded by JPL/NASA. Part of this work was performed at the Jet Propulsion Laboratory - California Institute of Technology under contract to NASA.

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