CERES: EVOLUTION AND PRESENT STATE. J. C. Castillo-Rogez[1], T. B. McCord[2], and A. G. Davies[1]. [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109-8099 United States, Julie.C.Castillo@jpl.nasa.gov; [2]Bear Fight Center, Space Science Institute, P.O. Box 667 22 Fiddler's Road, Winthrop, WA 98862 United States, mccordtb@aol.com.

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 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.

Modelling 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 ^{26}Al and ^{60}Fe, 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 (see Figure 1). Currently, hydrothermal cooling is not included in our algorithm.

Model Results: Results are shown in Figure 1. Conditions were present for full differentiation of Ceres if accretion time $t_{0\text{-}CAIs}$ was less than 7 My and/or if ammonia was accreted. For times of formation $t_{0\text{-}CAIs}$ 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 relies 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. 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 (Figure 2), that also produce the observed shape.

Observations by the Dawn Mission: The *Dawn* Mission is capable of determining Ceres's internal density distribution (*e.g.*, with radio science measurements). The shape of Ceres will also be accurately determined from imaging. *Dawn* will additionally constrain surface composition from visible-near infrared spectra from 0.35 to 5.0 µm.

The internal density distribution will provide constraints on the conditions at the time of Ceres' accretion.

As volume changes are expected to have occurred within Ceres as a result of differentiation, hydration, and the evolution of the outer icy shell [4], surface imaging might detect features that would provide information on the geological evolution of the body. Imaging should also permit surface dating, from crater counts, on global and regional scales, thereby possibly identifying sites of endogenic activity.

If hyrothermal activity once, or is still taking place, surface mapping in the infra-red might identify salts, minerals and chemical products resulting from such endogenic activity.

Conclusion: Future work will address the thermal and chemical evolution of the deep ocean, volcanic activity due to the evolution of the core, modeling of the differentiation of the inner core, the effect of hydrothermal activity on internal cooling, and will explore mechanical and thermal exchanges between the core and the surface.

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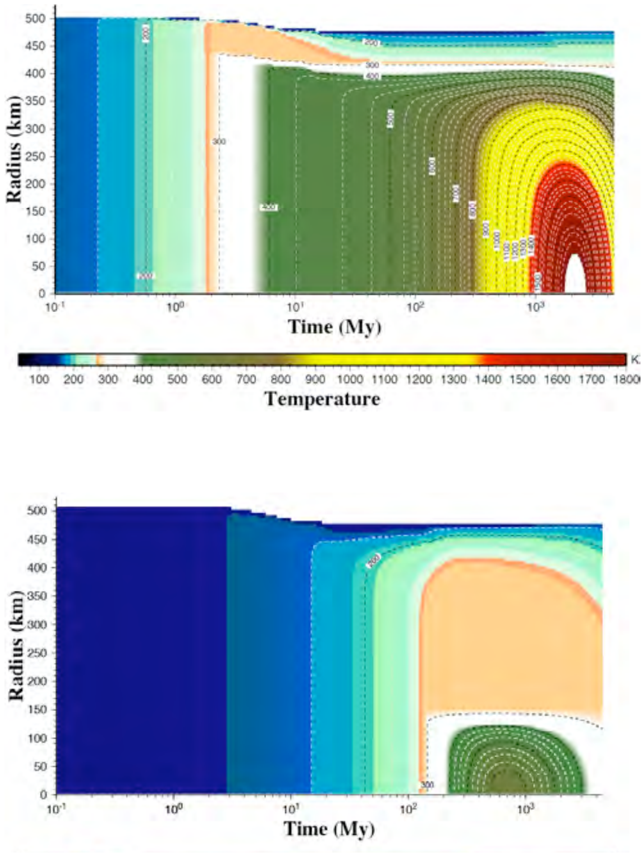

Figure 1: Thermal evolution for Ceres' models characterized by different initial conditions, especially composition and time of formation with respect to CAIs ($t_{0\text{-}CAIs}$): Top: 3 My; Bottom: 10 My. The other initial parameters (porosity, initial temperature) prove to play a less important role on the thermal evolution of the protoplanet. The dashed line marks the top of the silicate core.

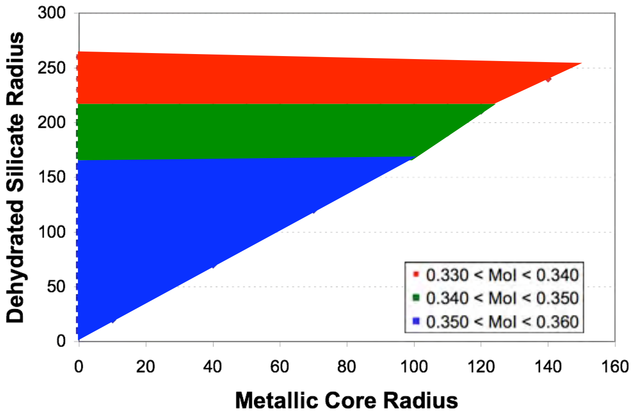

Figure 2: Main characteristics of Ceres' core for models matching the observed moment of inertia as inferred from shape measurements (after Thomas *et al.* 2005). Other characteristics of the models regard the core density, between 5500 and 8000 kg/m^3, deep ocean density (between 1000 and 1300 kg/m^3 to account for the presence of salts), the hydrated silicate phase density (between 2500 and 2800