NON-NEWTONIAN CONVECTION MODELING AND THE POSSIBILITY OF PRESENT DAY INTERNAL ACTIVITY ON CERES?

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Introduction: The largest body in the asteroid belt, Ceres is believed to have experienced evolution process similar to planets. The comparatively small size of Ceres suggests that it should have cooled early in its formation and should be geologically inactive. The surface of Ceres is mainly covered with impact craters [1]. However, recent spectral studies show the presence of hydroxide brucite, magnesium carbonates and serpentine on the surface suggesting that there may have been recent geological processes [2]. Active internal activity could be the result of convection processes on the dwarf planet.

Studying Ceres is also important in planetary evolution, because it is considered to be a protoplanet that existed since the formation of the solar system [1]. It would also explain the importance of volatiles, early on in the solar system [1]. Hence, modeling the mantle of Ceres and understanding the internal process would shed light on the convection process on Ceres.

We implement a 3D temperature, stress dependant rheology, spherical shell convection model. We compare these models with a non-stress dependent model. We vary the percentage of rock in the outer mantle and the size of the core. Our results indicate a wide-range of parameters where convection within Ceres persists to present day. We estimate surface deformation, topography, geoid, and heat flow from our models, which can be compared with observational data when the DAWN mission arrives at Ceres in 2015.

Modeling: Mantle convection models can be used to study the evolution of Ceres through time. The parameters governing the conservation equations are Rayleigh number and rate of internal heating. Previous work involved a 1D finite difference spherically symmetric code [2]. McCord et al, 2005, analyzed different internal structures, differentiated and undifferentiated. They implemented decaying, short and long lived, heat sources in their models and also varied the timing of formation of their models.

In this work, mantle convection simulations were performed using finite element code CitcomS in a 3D spherical shell. We integrate forward in time from a warm but solid interior using a non-Newtonian rheology for the ice-silicate mantle dominated by the viscosity of ice (strain-rate dependent). We implement a temperature dependant viscosity, which is given by equation 1

$$\eta = \exp\left[\frac{E + PV}{nRT}\right]\varepsilon^{\frac{1-n}{n}} \qquad (1)$$

We consider the interior of Ceres to have a solid rock core with an ice-silicate mixture mantle, which is given in figure 1.

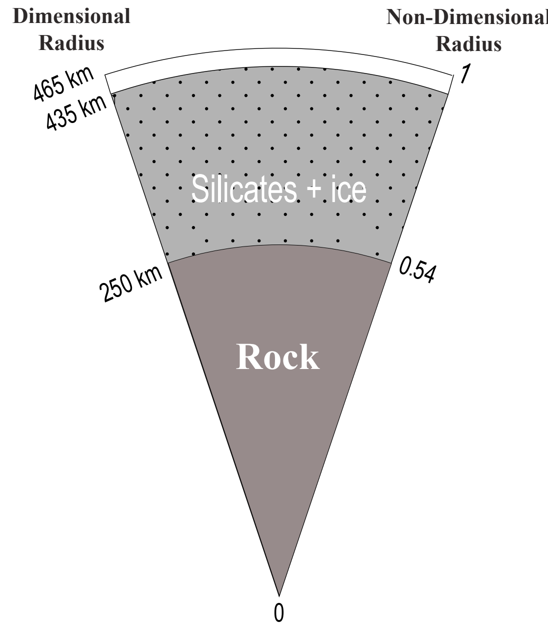

Figure 1: Internal structure of Ceres consists of a rock core of 250km and a silicate-ice mantle mixture of 215km depth. Dimensional depth values are on the left side and the non-dimensional values are on the right side

We use parameters based on a 50% silicate and a 50% ice mixture mantle rheology. Based on this mixture, the Rayleigh number varies between 6.85×10^6 and 1.65×10^9. Rate of internal heating varies between 38 and 15, based on 50% silicate. We vary the temperature difference across the mantle and the viscosity of Ice-1.

We consider a stagnant lid model, with a cold thermal boundary at the surface, an isothermal mantle and a hot thermal boundary at the core mantle boundary. Temperature and radius are non-dimensional values varying between 0 and 1, where 0.54 defines the core-mantle boundary and 1 defines the surface, for depth.

Results: The temperature-depth profile for a non-Newtonian rheology with a Rayleigh number of 5.26×10^6 and an internal heating value of 45 is given in figure 2.

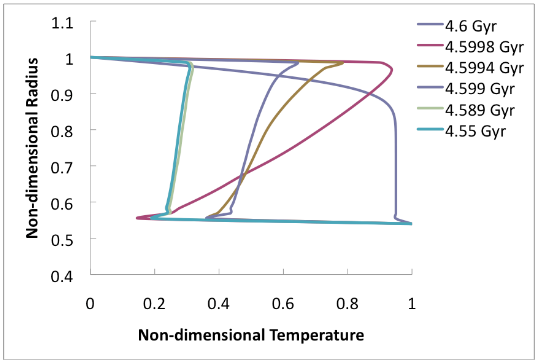

Figure 2: Temperature depth profile for a non-Newtonian rheology.

The evolution of Ceres with a constant heat source for a non-Newtonian rheology results in a convective solution. The solution remains convective and approaches a steady convective state early on, approximately 20 Myrs after the formation.

Models with different Rayleigh numbers and internal heating values were also considered. Comparisons between Newtonian and non-Newtonian rheologies were also considered. The comparison is given in figure 3.

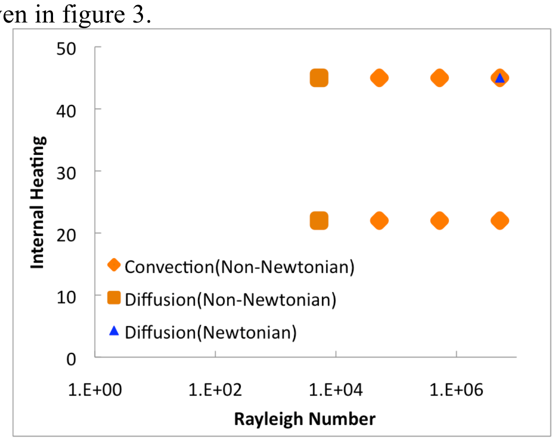

Figure 3: Comparison of Newtonian and non-Newtonian rheologies for different internal heating values and Rayleigh number.

For a high Rayleigh number, the Newtonian rheology (blue) results in a diffusive solution (triangle). On the other hand, non-Newtonian rheology (orange) results in both a diffusive and convective. For Rayleigh values greater than 10^3, the model arrives at a diffusive solution (square), irrespective of the internal heating value. For higher Rayleigh values, the model arrives at a convective solution (diamond).

Discussion: We analyze how and when the solution changes from convection to diffusion for a non-Newtonian model. As we have higher Rayleigh numbers, the models convect vigorously and reach a steady state very early on. As we reduce the Rayleigh number, the models convect more slowly, in turn, taking longer to reach a steady state. Lowering the Rayleigh number from 10^4 to 10^3 defines the point when it becomes a diffusive solution. It is observed that for high Rayleigh number, the internal heating value does not affect the convective solution. But as the Rayleigh number decreases, the internal heat plays a more important effect in the solution.

Conclusion: Convection appears important on present day Ceres if convection is controlled by Ice 1 rheology. Convection in the mantle of Ceres would help explain the presence of brucite on the surface because this suggests that the interaction of silicate and water in the mantle would make it to the surface through the process of convection.

For future work, varying the ratio of silicate and ice ratio in the mantle will be implemented. In addition, we need to implement decaying heat sources, both short lived and long-lived radioactive nuclides. These elements decay with time producing internal heat that contributes to a convective or conductive mantle. 3D spherical model will also be analyzed for varying Rayleigh numbers and internal heating rates. The geoid, topography and heat flow from the 3D model will be analyzed with the data from the DAWN mission, which will prove very important to understand the interior of Ceres.

References:

[1] Benoit Carry et al. (2008) *Astronomy and Astrophysics,* ESO 2008.

[2] Thomas B. McCord and Christophe Sotin (2005) *JGR, 110,* E05009.