GEOPHYSICAL EVOLUTION OF THE THEMIS FAMILY PARENT BODY.

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We model the geophysical evolution of the Themis family parent body. This study is motivated by the recent detection of water ice at the surface of 24 Themis [1, 2], the first detection of free water on the surface of an asteroid. The Themis family members display a variety of spectral properties and densities, a possible indication that their parent was differentiated at the time of break-up.

To test this hypothesis, we model the thermal evolution as a result of short- and long-lived radioisotope decay heat and conductive heat transfer after [3]. We consider two scenarios for Themis' initial composition: (1) as a homogeneous mixture of ice and silicate; (2) as an assemblage of hydrated silicates, after [4]. In the latter case, we want to test whether Themis' internal temperature could reach the silicate dehydration temperature, of about 530 K, leading to the separation, migration, and condensation toward the surface of water ice. The modeling takes into account the possibility that part of all of the silicate phase could have been hydrated, either prior to accretion, in the planetesimals, or during differentiation.

We also test the effect of the time of formation of Themis with respect to the production of calcium-aluminum inclusions (CAIs) taken as a reference for computing the amount of short-lived radioisotopes accreted in the asteroid. We range the time of formation from 3 to 10 My after CAIs. Other uncertainties on initial conditions are the composition of the volatile and of the rocky phases.

The figure below shows several possible thermal evolution models for the Themis family parent body. These models assume that Themis formed as a homogeneous mixture of ice and rock, except for model (c) that shows a model made up of hydrated silicates. Model (a) assumes a time of formation of 3 My after CAIs, while models (b) and (c) were computed for a time of formation of 5 My. Model (b) shows partial differentiation with at least 60% of the volume remaining undifferentiated. Model 1c undergoes little geophysical evolution. Only the model (a) displays significant geophysical evolution involving the melting of the volatile phase and the differentiation of a rocky core. Rapid cooling of the ice-rich shell occurs over a few tens My. Depending on the input parameters, especially the densities of the rock and brine-rich ocean, the rocky core radius ranges from 140 to 160 km. The nature of the silicate core is a function of the extent of hydrothermal activity that occurred during differentiation and possibly over the long term. Aqueous alteration could lead to the leaching of major elements that precipitated when the icy shell froze and the liquid phase became supersaturated in various compounds. Thus obviously the icy shell is not made up of pure water ice but should present some complex layering of organics, brines and other hydrated minerals, as well as oxides. That layer may have a density greater than 0.93 and up to $\sim$ 1.6 g/cm^3. The fraction of brines and other hydrated minerals is not quantified but could be significant.

The final internal structures and the products of their disruption are sketched in the middle and right columns of the figure. Disruption of undifferentiated model (c) yields fragments of porous silicate with a maximum density of $\sim$ 2 g/cm^3. For this model to be consistent with our knowledge of the Themis family, it requires the density of 24 Themis to be equal or smaller than $\sim$ 2 g/cm^3 and the water observed at various members of the family to have an exogenic origin, either as a result of surface chemistry, or from impactors. Disruption of partially differentiated model (b) would leave a main fragment with a small rocky core and abundance of water ice mixed to rock. Most other fragments would have an abundant content in water ice. Again, that model may be consistent with our knowledge of the Themis family only if the density of 24 Themis is less or equal to $\sim$ 2 g/cm^3.

Disruption of the parent body modeled in (a) would yield a main daughter of about the size of 24 Themis uniquely composed of silicate that could have raccreted some of the more volatile-rich material from the icy shell. Thus the density of 24 Themis would be that of the rocky material offset by macroporosity and some water-rich material. Since the icy shell occupied $\sim$ 50 vol.% of the parent body, there is a large chance that some of the large Themis family members are dominated by water ice and volatiles, for example the binary asteroid Antiope. Early accretion involving short-lived radioisotopes is consistent with observations at carbonaceous chondrites and models generally suggested for their parent bodies [5]. In this scenario, the Themis parent body core underwent mild temperatures and no thermal metamorphism. As such is may represent a good analog to the parent body of CI carbonaceous chondrites. Chemical evolution, beyond the scope of this paper, is of interest in order to better assess the place of Themis as a possible carbonaceous chondrite parent body.

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References

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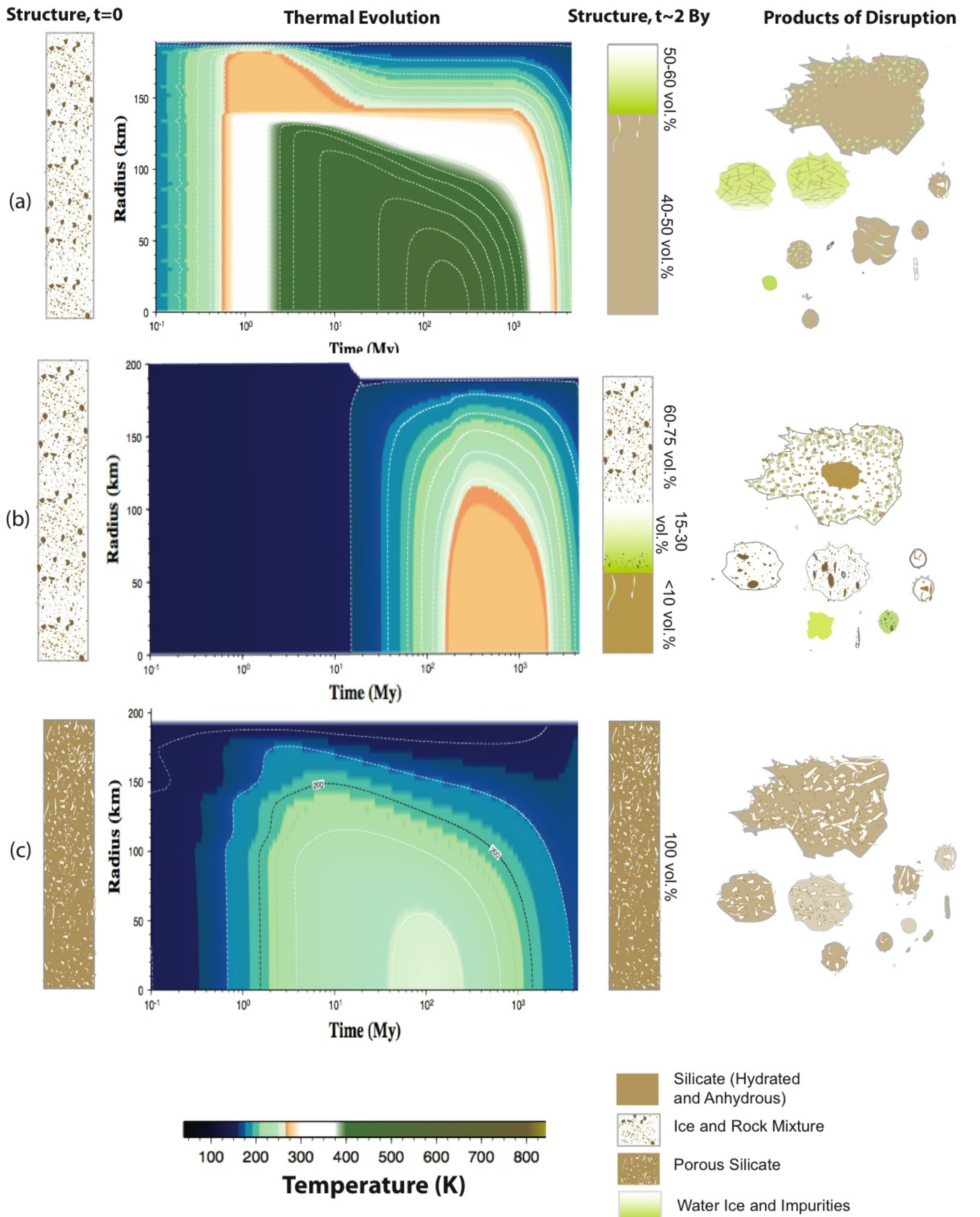
Structure, t=0
Thermal Evolution
Structure, t~2 By
Products of Disruption
(a)
(b)
(c)
Radius (km)
Time (My)
50-60 vol.%
40-50 vol.%
60-75 vol.%
15-30 vol.%
<10 vol.%
100 vol.%
200
Temperature (K)
100 200 300 400 500 600 700 800
Silicate (Hydrated and Anhydrous)
Ice and Rock Mixture
Porous Silicate
Water Ice and Impurities