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Ceres: Evolution and current state as a water-rich silicate protoplanet

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Ceres is the largest (~1000 km dia.) of the only three remaining intact proto-planets in the inner Solar System [1]. Ceres is especially interesting because its bulk density suggests that it contains considerable water in addition to silicates (~25% water, ~75% silicates), unlike Vesta, which seems without water. Pallas is intermediate in density and water content. The presence of water and energy is likely to have promoted rich chemistry comparable to that observed at carbonaceous chondrites. Ceres is also important to study because the Dawn spacecraft is scheduled to orbit and map Ceres after it visits Vesta.

Ceres' likely thermodynamic evolution scenarios have been modelled [2, 3], and it appears that Ceres likely differentiated into a core stratified in hydrated and dehydrated silicates layers and a water mantle that might even today be partially liquid, even considering only long-lived radionuclides as the main internal heat source throughout Ceres' history. The surface/crust remains solid throughout the history, but likely turning over several times as a result of endogenic activity to become contaminated by the underlying icy mantle and in-falling materials. Hubble telescope observations of Ceres' shape tend to confirm that Ceres is differentiated and it is in hydrostatic equilibrium, within the measurement uncertainties [4].

This dynamic history would involve several dimensional changes, strong mineralization, and exchange of materials among the core, mantle and surface. These processes should have resulted in the presence of geological features on and the supply of materials onto the surface visible by Dawn to help in restricting the possible evolution scenarios.

Several major processes are under study to help understand Ceres, including mineralization, the hydration-dehydration process in the core, transport of material and energy by convection, chemistry in the ocean, and exchange of materials between the ocean and the surface.

We present here some of the more likely thermal evolution scenarios (e.g., Fig. 1) and discuss some of the major processes involved and their uncertainties.

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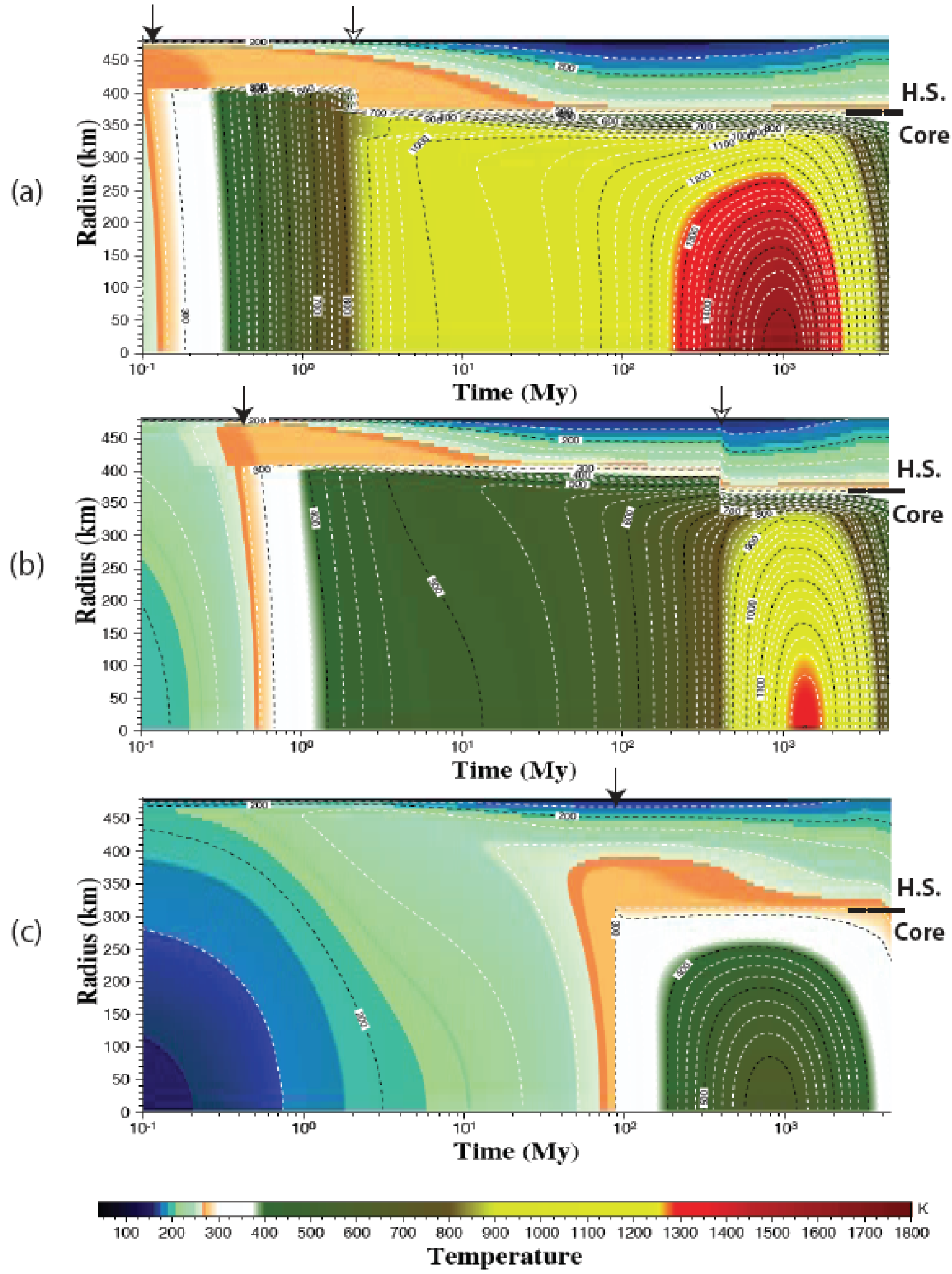

Figure 1. Temperature-depth-time plots for Ceres evolution [3]. Temperature is plotted as a function of radius and time (on a log scale) since accretion. The time at the extreme left is the start of the model. The time at the extreme right is the present. The temperature contours are every 25 K. Numerical call-outs temperature are in Kelvins. The color scheme indicates geophysically significant temperatures. Times of formation are (a - top) 2 My after CAIs, (b - middle) 3 My after CAIs, (c - lower) 5 My after CAIs. For all models the surface temperature is 180 K, the initial temperature is 150 K, the initial concentration in $^{60}Fe/^{56}Fe$ is 1×10^{-7}. All models assume a gradual increase in surface temperature in order to reflect solar luminosity evolution.