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Ceres: Models, observations and what Dawn might find

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Abstract

Ceres likely contains considerable water, has differentiated, and has experienced major dimensional and chemical changes over its history, making it more a planet than asteroid [1]. These factors must have had major influence on the creation of the present day body, its interior structure and composition, and its surface properties. The sparse and often inconclusive observational data and the uncertainty of how and when these dimensional and chemical changes occurred make predicting the precise Dawn findings impossible. But, the models of evolution and the observational evidence plus the knowledge of Dawn's capabilities gained from its Vesta campaign are important in helping prepare for and understanding Dawn's observations. Here, I will summarize current understanding and predictions, building on earlier attempts [2].

1. Ceres evolution

Knowing and understanding the potential evolutionary tracks of Ceres is a major basis for predicting what the Dawn mission might find when it reaches Ceres in 2015. McCord and Sotin [3] began the "modern" literature by modeling the thermal evolution of Ceres and large, wet protoplanets in general. The density for Ceres is near 2.1, suggesting water content between 17% and 27% by mass. Short- and long-lived radioactive nuclide heating was considered. Even if only long-lived radionuclide heating is assumed, the water ice in Ceres melts and a water mantle forms, but an approximately 10-km crust does not melt because of its interface with cold space. The circulating warm water would alter the silicates during differentiation. As heat is lost by conduction through the frozen crust, water begins to freeze out at the base of the crust. Solid-state convection begins and transports heat as well as material dissolved or entrained in the water to or near the surface. Ceres' water layer eventually freezes, mostly but perhaps not entirely, forming a layered density structure with perhaps some liquid water remaining today near the core. They found that Ceres' existence and evolution depend critically on it containing water at formation, and this depends strongly on the combination of when it accreted and the amount of ^{26}Al present in the pre-Ceres 1-km-sized objects; slightly more ^{26}Al or earlier accretion produces a dry Vesta-like object. Telescopic observations of the difference between the equatorial and polar radii [4] tended to confirm the McCord and Sotin differentiated model, as did earlier but less precise measurements. Later modeling studies by Castillo-Rogez and McCord [5] confirmed and refined the basic McCord and Sotin findings and extended them by exploring hydrothermal activity in the long-term evolution of Ceres and the evolution of its hydrosphere. They showed that some hydrated material from the initial differentiation would likely dehydrate near the core center, producing a two-layer core. The time and spatial scale of the movement of warm liquid water through silicate minerals supports a wide range of chemistry and mineralization. Zolotov [6], however, argued that the density of Ceres could be due to prior mineralization of the material initially forming Ceres and to porosity in the current Ceres and that free water was not required to achieve the current density. Castillo-Rogez [7] countered, arguing that the models showed that a mixture of hydrated minerals is bound to compact and partly dehydrate as a consequence of long-lived radioisotope decay heat. Studies of the details of how the interior of Ceres evolves, the chemistry and mineralization and the hydration/dehydration cycle, show that the processes are complex and difficult or impossible to predict with certainty. Thus, a major chore for Dawn is to find evidence that helps to elucidate these processes.

2. Observational evidence

Observational evidence of Ceres' properties is also helpful for predicting what Dawn might find. Only subdued spatial albedo variations have been observed on Ceres' surface at the scale possible from Earth (~100 km). Ultraviolet and visual maps of brightness showing these variations were presented by Li et al. [8] from HST observations. These were confirmed by near infrared ground based adaptive optics observations [9]. Compositional evidence includes the long known similarity of Ceres' albedo and reflectance spectrum to those for carbonaceous chondrite meteorites. Thus, the surface has been thought to be made of carbon-bearing, hydroxolated materials. Absorptions in the reflectance spectrum's 3-μm region indicate the presence of OH-bearing materials. Candidates have included water frost, ammoniated phyllosilicates, iron-rich clays, carbonates and brucite [*c.f.* 10]. All this evidence can be argued to be consistent with both infall of carbonaceous chondrite material and with the expected results of the evolutionary models.

3. Dawn potential findings

It seems likely that some form of the evolution models is correct, but that infall also occurs. It is difficult to escape melting of water ice and differentiation unless Ceres' forming material, at condensation, was already hydrated/hydroxolated, a scenario most meteorite scientists discount. Infall of carbonaceous material was well demonstrated at Vesta [11]. So, Ceres' surface is likely a mixture of materials from the interior that are desiccated by exposure to space and debris from infill. Impact gardening will mix these. (How to tell them apart?) Hydrated and hydroxolated minerals probably form a major part of present day Ceres with some free water possible in the interior and even possibly near the surface. McCord and Sotin [3] predicted that the evolution of Ceres would have been violent, with major dimensional changes and energy transitions at several stages due to melting and freezing plus exogenic mineralization. Consider the well-know serpentinization reaction and the associated energy and volume changes. The body would have been massively disrupted, creating interior structures and zones of weakness and surface topographic features. This process alone would have disrupted the crust and facilitated mixing from the interior to the surface. Further, they also pointed out that the frozen icy surface would have been gravitationally unstable over a liquid water mantle causing it to collapse and reform. Infall of material from the asteroid belt and beyond would have contaminated and mixed with the surface, as was found by Dawn for Vesta. A major question is whether any of these major features created by this violent past still remain visible.

The lack of dramatic surface variations suggests a well-mixed surface to some significant depth at the scale of near-earth observations (~100 km). Of major importance will be Dawn's ability to resolve small features on the surface that might reveal materials, structures and contrasts undetectable from afar. Elemental and mineral analyses, used together, will be critical to differentiate material types and their locations. The gravity field measurements will reveal some internal structures. Following the rich return from Dawn's study of Vesta and an improved knowledge of Dawn's instrument capabilities, attacking the Ceres puzzle will be challenging but productive and very exciting.

Acknowledgements

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