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Ceres: Dawn visits a warm wet planet

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Abstract

Ceres likely contains considerable water, has differentiated, possesses a silicate core and water mantle, and has experienced major dimensional, thermal and chemical changes over its history, making it more a planet than an asteroid [1]. These factors created the present day body, its interior structure and composition, and its surface properties, which Dawn will visit. Here, I will summarize our current understanding of Ceres and suggest what Dawn will find, building on earlier attempts [2]. A major uncertainty is how processes, such as aqueous mineralization, impact and cratering, infall of external material, mixing, and viscous relaxation of surface features have altered the formation materials and current surface and hidden Ceres' secrets.

1. Ceres' evolution

Ceres' bulk density of 2100 kg/m3, suggesting a major water content, motivated McCord and Sotin [3] to model the thermodynamic evolution of Ceres. They calculated a water content of between 17% and 27% by mass and assumed radioactive heating. Assuming different times of formation after CAIs for the smaller ~1-km diameter ice-silicate objects that accreted to form Ceres, led to results ranging from a dry Vestal-like object (earlier, hotter formation) to retention and melting of the ice and differentiation of silicates from liquid water, even assuming only heating in the interior of Ceres from long-lived radionuclides. Mixing of liquid water and silicates led to exothermic hydration reactions, formation of a core and a liquid mantle. Large dimensional changes would be associated. A crust of order 10 km stays frozen, due to the external temperature at the current location of Ceres but founders at times due to gravitational instability, dimensional changes and impacts. The liquid mantle slowly freezes from the top down but a layer of salty liquid water could exist today near the core boundary. Telescopic observations of the difference between the equatorial and polar radii and modeling [4] tended to confirm the McCord and Sotin differentiated model. Later modeling studies by Castillo-Rogez and McCord [5] confirmed and extended these basic findings by exploring hydrothermal activity in the long-term evolution of Ceres and the evolution of its hydrosphere. They showed that 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 and complex range of chemistry and mineralization.

2. Observational evidence

Ceres, the larges body between Mars and Jupiter, is well described by an oblate spheroid with equatorial/polar diameters of 967/892 +/- 10 km [4] with an obliquity of near 3 deg. and has a spin period of approximately 9 hours. Only subdued spatial albedo variations have been observed at UV and IR wavelengths on Ceres' surface at the scale possible from Earth (~50-100 km) using HST and also groundbased adaptive optics [6]. Albedo maps confirm similar features, including a few that are circular: crater-like. Compositional evidence includes the long known similarity of Ceres' albedo and visual-IR reflectance spectrum to those for carbonaceous chondrite meteorites. Thus, the surface is thought to be made of carbon-bearing, hydroxolated materials [7]. Absorptions in the reflectance spectrum's 3-μ m region proved the presence of OH-bearing materials [8]. Candidate materials have included water frost, ammoniated phyllosilicates, iron-rich clays, carbonates and brucite. However, all these minerals can't form in the same environment, requiring multiple, complex formations or errors in the mineral identifications. These hydrated/hydroxolated materials in general are consistent with the results of the evolutionary thermodynamic models and infill of carbonaceous chondrite-like materials. Recently, water vapor was reported [9] originating from localized sources seemingly linked to mid-latitude regions of Ceres' surface. This followed a single early IAU observation of OH emission over the north polar region. This indicates H_2O as well as OH in the near surface and perhaps cryovolcanism, as an undisturbed stagnate surface should be dried out over geologic time.

3. Conclusions and predictions

Models and observations all point to a surface of hydrated/hydroxolated materials. These tend to be of complex and varying compositions and difficult to identity by remote sensing. Both infall and internal evolution contribute. Calculations for Vesta [10] indicated 1-2 m of low albedo material accumulating on Vesta and mixing into the surface in the last 3.5 billion years, which should not be enough to hide the indigenous Ceres material, especially considering the founderings and partial rejuvenations of the crust. It is difficult to avoid melting accreted ice during the evolution of Ceres' interior and injecting into/onto the crust some of the resulting altered silicates and salty water. There must have been huge tectonic movements during the evolution due to the thaw-freeze cycle and the serpentinization-like reactions, but a reformed crust may not preserve the evidence of these. The observational data suggest a relatively bland surface without easily identified mineral spectral signatures, other than OH and maybe H_2O. H_2O apparently venting from Ceres surface suggests internal activity. Higher spatial resolution may well reveal distinct compositional units at the surface, which probably is composed of desiccated forms of mostly indigenous materials. Ceres family members and meteorites, which would help with our investigation, are missing. This might be due to the icy nature of pieces of Ceres that might have been knocked off, which probably would have sublimed by now [11]. Limb observations suggest no large surface relief. There are a few circular features visible in the telescopic albedo maps that are consistent with craters. Calculations predict [12] that craters as small as 4 km diameter on a Ceres-like body with an icy mantle would viscously relax over short timescales except perhaps near the colder poles. So, Ceres' surface may also be relatively devoid of topography. Of major importance will be Dawn's ability to resolve small features on the surface that might reveal structures undetectable so far. Elemental and mineral analyses, used together, will be critical to differentiate material types. The gravity field measurements will reveal some internal structures. Ceres, the goddess of fertility, surely had a very exciting past for Dawn to investigate.

Acknowledgements

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