Goldschmidt 2021 Abstract
https://doi.org/10.7185/gold2021.6275

Metamorphic brine generation and the density of Ceres' mantle

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We investigate the thermal evolution of Ceres' mantle in order to interpret the density data inferred from the Dawn spacecraft. [1] derived an average mantle density of ~2430 kg/m^3, but accounting for slight departure from hydrostatic equilibrium [2], [3] inferred a mantle density of ~2800–2900 kg/m^3. Both values are lower than rock density inferred from theoretical modeling. This discrepancy is likely due to brine-filled porosity in the mantle [4]. We show that even for a cool internal thermal evolution, Ceres' rocky material releases water as a consequence of low-grade metamorphism. Metamorphism leads to the devolatilization of minerals, pore compaction, and densification of the interior, e.g., the reaction antigorite → olivine + talc + water proceeds from ~670 K to 970 K.

We applied the thermal evolution model from [5] on plausible compositional building blocks: CI chondrites, CM chondrites, and comets, with varying amounts of initial water, and assuming different vertical maximum porosities (Φ_{max}), using Rcrust [6]. Figure 1 shows selected results for a CM chondrite Ceres. Fig. 1a) shows the mean density at selected points in time for various amounts of initial water, and Φ_{max} of vertical layers from the surface to the interior. Allowable densities (2400–2900 kg/m^3) are outlined in black; a major fluid releasing event is outlined in green at 2 Gyr. Fig. 1b) shows solvents (CO_2-CH_4-H_2O) released as a function of PT; dashed black line and solid black line are the pressure-temperature profiles at 100 Myr and at present, respectively. Dashed orange line is the isobaric slice shown in 1c). Fig. 1c) shows mineral phases along the 50 MPa isobaric slice as a function of temperature.

[1] Ermakov et al. (2017). J. Geophys. Res. Planets 122, 2267–2293. [2] Park et al. (2016). Nature 537, 515–517. [3] Mao & McKinnon (2018). Icarus 299, 430–442. [4] Raymond et al. (2020). Nature Astronomy 4, 741–747. [5] Castillo-Rogez & McCord (2010). Icarus 205, 443–459. [6] Mayne et al. (2016). J. Metamorph. Geol. 34, 663–682.

Part of this work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract to NASA.