ON THE FORMATION OF BRUCITE AND CRONSTEDTITE ON CERES
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Introduction: Ceres is the largest body (diameter, $D = 944±23$ km) in the asteroid belt with density of $\sim 2.1$ g/cm$^3$ and a dark rocky surface. Some models imply a layered rock-icy mantle-rock internal structure [1,2], and others argue for a hydrated porous body [3]. Ceres’ spectra in near- and mid-infrared range indicate the occurrence of brucite, cronstedtite, magnetite and Mg carbonates in surface materials [4]. Spectra of 10 Hygiea ($D \approx 420$ km) and 324 Bamberga ($D \approx 235$ km) imply somewhat similar compositions [5]. We modeled chemistry of water-rock interactions to constrain ancient environments on these bodies.

Results: Cronstedtite forms at temperature ($T$) below $\sim 120^\circ$C at moderately oxidizing alkaline conditions and at an elevated activity ($a$) of dissolved SiO$_2$, consistent with observations in CM chondrites [c.f. 6]. It becomes much more stable at lower $T$. Magnetite, Mg carbonates and cronstedtite could form together. Brucite does not form with cronstedtite. Formation of brucite requires very low $a$SiO$_2$, low fugacity of CO$_2$, elevated $a$Mg$^{2+}$ and highly alkaline pH. Although brucite forms through serpentinization of olivine-rich rocks on Earth, it does not form in altered chondrites where the low bulk Mg/Si ratio accounts for an elevated $a$SiO$_2$.

Discussion: Although aqueous solutions are needed for the formation of the observed minerals, low-pressure and low-$T$ conditions in the vicinity of body’s surfaces were unfavorable for aqueous fluids. In one setting, the observed minerals could have formed through subsurface alteration followed by impact stripping of unaltered surface rocks. This scenario may imply heating by $^{26}$Al and dehydration of the deep interior, which could be inconsistent with the low densities of those bodies. Another scenario suggests formation of major secondary minerals on planetesimals [3] followed by post-accretional aqueous processes that added new phases (e.g., brucite, extra Mg carbonates). As in CM chondrites, cronstedtite, magnetite and carbonates could form through low-$T$ alteration. Formation of brucite and additional Mg carbonates could involve distinct action(s) of high-pH fluids which did not equilibrate with preexisting silicates and oxides. As an example, brucite could form through interaction of Mg salts (chlorides, carbonates, sulfates) with OH-rich solutions (NaOH, NH$_4$OH) percolating from beneath. The NaOH type fluids [7] are consistent with the lack of saponite in surface assemblages [4]. In another setting, precipitation of Mg carbonates and brucite could be driven by CO$_2$ degassing from subsurface fluids. Fluid motions and the apparent lack of isochemical alteration may reflect large sizes of Ceres, Hygiea and Bamberga [8]. All considered scenarios do not require icy mantles on these bodies.