

**THE IMPLICATIONS OF CRONSTEDTITE FORMATION IN WATER-RICH PLANETESIMALS AND ASTEROIDS.** K. A. Dyl<sup>1</sup>, C.E. Manning<sup>1</sup> and E. D. Young<sup>1,2</sup>, <sup>1</sup>Department of Earth and Space Sciences, UCLA, Los Angeles, CA 90095 ([kdyl@ucla.edu](mailto:kdyl@ucla.edu)), <sup>2</sup>Institute of Geophysics and Planetary Physics, UCLA, Los Angeles, CA 90095.

**Introduction:** Water-rock reactions can produce the building blocks of life (amino acids, nucleotides, and sugars) [1]. These molecules are found in CM chondrites and form via parent body processes [2]. The probability of life elsewhere in the solar system is significantly enhanced if these molecules are widely produced on planetesimals. A thorough characterization of aqueous alteration reactions in these meteorites from the asteroid belt can be used to constrain the production of organics on other solar system bodies like Ceres, a main-belt asteroid containing significant water that interacted with the rocky interior [3].

Cronstedtite ( $\text{Fe}^{2+}_2\text{Fe}^{3+}(\text{Fe}^{3+}\text{Si})\text{O}_5(\text{OH})_4$ ) is potentially a unique monitor of water-rock interaction in early planetesimals. This  $\text{Fe}^{2+}$ ,  $\text{Fe}^{3+}$ -bearing serpentine group mineral is rarely found in terrestrial environments but is the dominant component of CM chondrite matrix [4]. It forms in the early stages of water-rock interaction and its abundance depends on salinity, pH, C concentration and time-integrated flux of aqueous fluid [5].

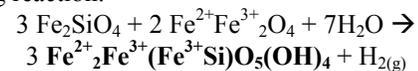
This study explores the implications of cronstedtite as a major constituent of CM chondrites. Its rarity in terrestrial environments suggests that its ubiquity in meteorites resulted from specific chemical conditions. We investigated its stability in simple systems to identify the first-order constraints and consequences imposed by the presence of this mineral. We conclude that abundant water, implying fluid flow, and a significant reservoir of oxidized carbon are required for cronstedtite formation on carbonaceous chondrite parent bodies.

**Computational Modeling:** We used the Geochemist's Workbench<sup>®</sup> program suite to constrain the stability field for cronstedtite in activity-activity space. Thermodynamic constants are provided by the LLNL database.  $\text{FeO}_{(c)}$ , antigorite, and quartz are kinetically inhibited and thus suppressed in our calculations. We performed all calculations at a temperature of 25°C, consistent with estimates for the temperature attending aqueous alteration in CM parent bodies.

We explored the stability of cronstedtite in three initial mineral assemblages in the Mg-Fe-Si-O-C-H system. They are a pure olivine assemblage of forsterite and fayalite, olivine and enstatite, and an assemblage of olivine, enstatite, and iron metal. All initial assemblages were reacted with fluids with carbon contents ranging from pure water to 0.1 m [ $\text{HCO}_3^-$ ].

**Results:** The production of cronstedtite in all reactions necessitated high water:rock ratios (W/R). In

pure water,  $\text{W/R} \sim 10^6$  for all assemblages. A [ $\text{HCO}_3^-$ ] = 0.01 m requires a minimum W/R of  $\sim 28$ ; this is achieved in the olivine- and enstatite-bearing assemblage. W/R is in excess of 500 when iron metal is included. When [ $\text{HCO}_3^-$ ] = 0.1 m, W/R decreases to  $\sim 1.2$  in the case of olivine-enstatite and  $\sim 50$  for olivine-enstatite-iron. High W/R is dictated by the chemistry of cronstedtite; the incorporation of equal amounts of both ferric and ferrous iron imply that iron must be oxidized. In the case of pure water, this occurs via the following reaction:



This reaction results in the production of copious amounts of  $\text{H}_{2(g)}$ . This fact has been noted in previous attempts to model CM chondrites [6]. However, the presence of oxidized carbon suppresses  $\text{H}_{2(g)}$  formation in favor of  $\text{CH}_{4(g)}$ :

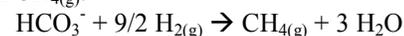


Figure 1 plots the abundance of aqueous carbon-bearing species in the reaction between a [ $\text{HCO}_3^-$ ] = 0.1 m fluid and the olivine-enstatite assemblage. Methane is the dominant C-species in the fluid; furthermore,  $\text{CH}_{4(g)}$  is produced in large amounts. This would require removal of methane gas from the system. While it is impossible to verify the existence of this reservoir, recent models of carbon isotopes in CM chondrites require methane generation to explain their values [7].

The other aqueous carbon-bearing species in equilibrium with cronstedtite are  $\text{CO}_3^{2-}$ ,  $\text{HCO}_3^-$ , and ethane at much lower abundance. However, at low temperatures redox reactions between carbon bearing species must be kinetically modeled to obtain a more accurate picture of carbon chemistry in these environments.

**Discussion:** The conclusions of this study have important implications to consider when investigating water-rock interactions in the solar system.

*Implications for Asteroid Belt.* Carbonaceous chondrites are thought to derive from or be related to C-class asteroids [8]. Ceres, the largest of these objects, may contain not only significant water, but also iron-rich clays [3,9]. If our assumptions about the link between meteorites and asteroids are valid, cronstedtite may be present in significant quantities. Evidence for a large reservoir of reduced carbon may therefore exist near the surface of this object due to the generation of  $\text{CH}_{4(g)}$  and  $\text{H}_{2(g)}$ . Furthermore, we can use models of water evolution and differentiation of Ceres to test the conclusion that carbonaceous chondrites did, in

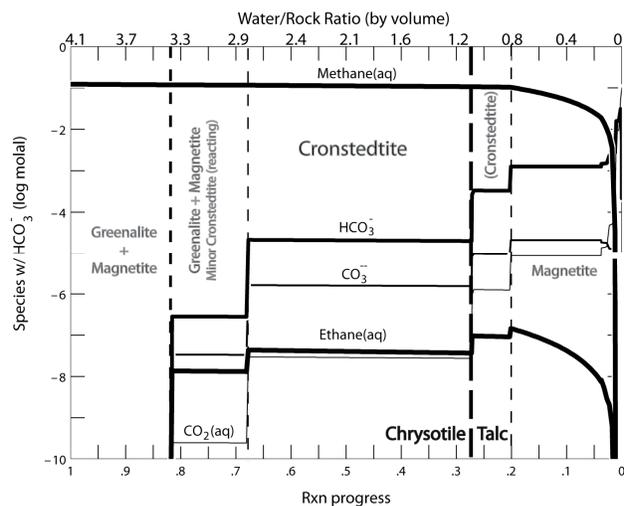
fact, see significant quantities of water through the course of their evolution in the early Solar System.

**Astrobiological Significance.** The oxidation of iron required to form cronstedtite has important implications for the production of prebiotic molecules. It would allow, and in fact require, that copious amounts of carbon be released as methane or other organic molecules. If this process occurred on all water-rich asteroids in the early solar system, it could have consequences for the delivery of early organics, especially during the proposed Late Heavy Bombardment of trans-Neptunian objects (objects we know to have abundant water reservoirs).

**Future Work:** We explored simple chemical system to identify the factors controlling cronstedtite stability. To refine these conclusions, elements such as sulfur and calcium must be incorporated to ascertain their role in hydrothermal systems on early planetesimals. Chemistry must also be incorporated into thermal and physical models of water-rich asteroids to better characterize these environments and better understand the formation of organics during solar system formation.

**References:** [1] Schulte M. and Shock E. (2004) *Meteoritics and Planet. Sci.*, 39, 1577-1590. [2] Gilmore J. et al. (2003) *Treatise on Geochemistry* 269-290. [3] Thomas P.C. et al. (2005) *Nature*, 437, 224-226. [4] Browning L.B. et al. (1996) *GCA*, 50, 2621-2633. [5] Dyl K.A. Manning C.E. and Young E.D. (2006) *LPSXXXIV*, Abstract #2060. [6] Wilson L. et al. (1999) *Meteoritics & Planet. Sci.*, 34, 541-557. [7] Guo W. Eiler, J. M. (2007) *GCA*, 71, 5565-5575. [8] Hiroi T. et al. *Meteoritics & Planet. Sci.*, 31, 321-327. [9] Rivkin A.S. Volquardsen E.L. Clark B.E. (2006) *Icarus*, 185, 563-567.

ates the boundary between the Mg-bearing phyllosilicates chrysotile and talc. Iron bearing phases present are labeled in regions of stability.



**Figure 1:** Aqueous C-bearing species as a function of reaction progress and W/R. The dark dashed line indi-