

**HYDROTHERMAL CONVECTION AND AQUEOUS ALTERATION IN CHONDRITIC PARENT BODIES.** J. Palguta<sup>1</sup>, B. J. Travis<sup>2</sup> and G. Schubert<sup>1,3</sup>, <sup>1</sup>Department of Earth & Space Sciences, UCLA (595 Charles E. Young Drive East, 3806 Geology Building, Los Angeles, CA 90095; jpalguta@ucla.edu), <sup>2</sup>Los Alamos National Laboratory (EES-2/MS T003, Los Alamos NM 87545), <sup>3</sup>Institute of Geophysics and Planetary Physics, University of California, Los Angeles.

**Introduction:** Carbonaceous chondrites (CCs) are among the most primitive materials in the solar system. They are the vestiges of planetesimals that contributed to building terrestrial planets, moons and asteroids. As a consequence of their primitive bulk compositions, carbonaceous chondrites can serve as an important source of information about the origin and early history of the solar system. Carbonaceous chondrites have been divided into several groups (CI, CM, CV, CO, CH, CR, CK, and CB) based on mineralogical, chemical, and isotopic characteristics [1,2]. Despite their apparent primitive bulk compositions, CCs display evidence of processing either by thermal metamorphism or low-temperature aqueous alteration [3,4,5]. Petrographic observations of CIs and CMs, in particular, suggest alteration by the interaction of liquid water and anhydrous minerals [4,5,6]. Furthermore, observations of alteration minerals lining fractures and forming veins, mineral textures, and alteration mineral intergrowths require aqueous alteration within a parent body.

Carbonaceous chondrite parent bodies (CCPBs) are the bodies in which CCs acquired their current chemical and mineralogical characteristics. Water in the form of ice would have accreted along with rocky material to form the original CCPB. Sufficient heating (e.g., from <sup>26</sup>Al) of the body would allow the ice to melt and hydrothermal convective flow to develop. Such flow would be heterogeneous with some regions of a CCPB experiencing warm upwellings [7]. Fluid flow and the resulting water-rock reactions in a CCPB can promote chemical redistribution, changes in petrologic relationships and isotopic fractionation. Accordingly, understanding the alteration processes that occurred in CCPBs is crucial to unraveling the information provided by CCs. The work presented here suggests that if large-scale, heterogeneous flow developed in CCPBs, then mineral alteration could vary with location. This raises the possibility that CCs of different chemical groups come from the same parent body.

**Computational Model:** We use the codes MAGHNUM [8] and PHREEQC [9] to consider the consequences of hydrothermal processing on CCPBs. The coupled hydrothermal-mineral alteration calculations have the ability to track the distribution of different minerals with time and determine the role flow patterns and flow rates have in controlling water-rock

interactions. MAGHNUM simulates the freezing and thawing of water in a CCPB and is responsible for modeling the thermal evolution of a body. MAGHNUM determines the thermal history of the body by solving the equations of mass and energy conservation together with Darcy's law for low Reynolds number flow in porous media. The governing conservation equations are approximated with finite differences. The accompanying water-rock reactions are modeled using PHREEQC.

PHREEQC is designed to perform a wide variety of geochemical calculations, including simulating chemical reactions in water. The program includes the capability to model kinetic reactions with rate equations that are completely user-specified. PHREEQC uses a Runge-Kutta algorithm to integrate reaction rates over time and determine the moles of reactant mineral converted. Presently, a general reaction rate based on transition state theory is used to model the reaction between minerals and the aqueous solution

$$r = k(1 - \Omega) \frac{A_o}{V} \left( \frac{m}{m_o} \right)^{2/3}$$

where  $r$  is the overall reaction rate,  $k$  is the rate constant,  $\Omega$  is the saturation ratio,  $A_o$  is the initial surface area of the solid,  $V$  is the volume of solution,  $m_o$  is the initial moles of solid, and  $m$  is the moles of solid at a given time. The temperature dependence of  $k$  is given by the Arrhenius equation

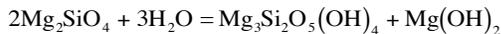
$$k = \mathcal{A} e^{-E_a/(RT)}$$

where  $\mathcal{A}$  is the pre-exponential factor,  $E_a$  is the activation energy,  $R$  is the gas constant, and  $T$  is the temperature in kelvins.  $E_a$  and  $\mathcal{A}$  are determined by fitting experimental data [10]. Furthermore, the rate of reaction is assumed linear with pressure [11], P.

**Discussion:** Grimm & McSween [12] previously considered the thermal histories of CCPBs and carried out a parameterized analysis for convective flow in a porous medium. Based on the laboratory experiments of Wegner and Ernst [10], which measured the time for hydration of olivine as a function of temperature, pressure, and grain size, Grimm and McSween [12] assumed aqueous alteration of CCPBs was fast and considered the reactions instantaneous in the context of their models. Consequently, aqueous alteration of CCPBs was completed early in a CCPBs' evolution and was homogeneous. However, rates measured in

the laboratory often do not match those seen in the field [13,14,15]. Reactions proceed as much as 5 orders of magnitude more slowly in the field than measured in the laboratory. Slower reaction kinetics allow heterogeneous convective flow patterns to develop before the body is completely altered. Slower rates then also allow non-uniform alteration of the parent body.

**Example Simulation:** We have investigated how varying body parameters and reaction kinetics affect aqueous alteration in a body experiencing hydrothermal convection. For illustrative purposes, we consider here a body with the following parameters: 20% porosity,  $10^{-11}$  m<sup>2</sup> permeability,  $^{26}\text{Al}/^{27}\text{Al}$  ratio of  $4.5 \times 10^{-6}$ , 40-60  $\mu\text{m}$  olivine grains, a rate expression of  $1.39 \times 10^{-9} * P * \exp(-3460/T)$ , specific heat of  $1000 \text{ J kg}^{-1} \text{ K}^{-1}$ , rock density  $3200 \text{ kg m}^{-3}$ , rock thermal conductivity of  $3 \text{ W m}^{-1} \text{ K}^{-1}$ , and a body radius of 50 km. The CCPB is considered to be composed of forsterite olivine [12]. The aqueous alteration is then characterized by the reaction



Figures 1 and 2 summarize the mineral alteration results of this simulation. Figure 1 shows the state of alteration at approximately 1.7 Myr. By this time, the CCPB is experiencing hydrothermal convection with four major warm-water upwellings. Alteration is not uniform and regions of maximum alteration follow along the upwellings while convection persists. As convective motions weaken, alteration smooths out but heterogeneous features still persist. Figure 2 illustrates the final state of the CCPB at 13 Myr. Temperatures in the CCPB have fallen below 0 °C and reactions can no longer progress. In the deep interior, water is depleted and the reactions go to completion. The body maintains heterogeneous alteration features.

**Conclusions:** The example simulation discussed above indicates heterogeneous alteration in CCPBs is possible under certain conditions. Choice of reaction kinetics is an important factor in determining the evolution of a CCPB. MAGNUM allows us to explore hydrothermal convection given different body parameters (e.g., permeability, porosity,  $^{26}\text{Al}/^{27}\text{Al}$  ratio, and body radius). The fact that PHREEQC permits its user to easily define rate expressions for kinetic reactions allows us to explore a wide range and combination of water-rock reactions and reaction rates in our simulations. The ultimate goal is to determine the rates and conditions required to match mineralization patterns, products and isotope ratios comparable to those seen in CCs.

**References:** [1] Van Schmus W. R. and Wood J. A. (1967) *GCA*, 31, 737-765. [2] Wasson J. T. (1974) *Meteorites: Classification and Properties*, 316 pp.

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Mass Fraction  
(Forsterite/Total rock)

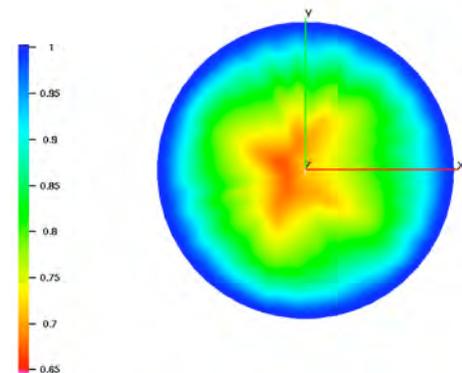


Figure 1. Aqueous alteration progress at about 1.7 Myr.

Mass Fraction  
(Forsterite/Total rock)

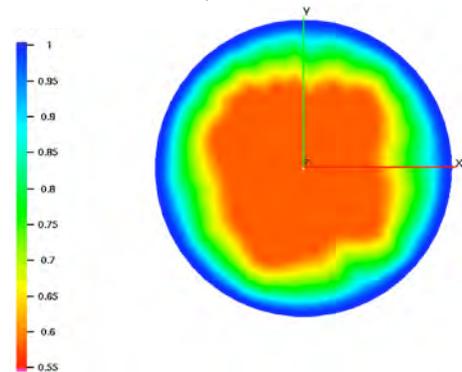


Figure 2. Aqueous alteration is complete by 13 Myr.