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AQUEOUS ALTERATION ON THE PARENT BODIES OF CARBONACEOUS CHONDRITES: COMPUTER SIMULATIONS OF LATE-STAGE OXIDATION:

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CI carbonaceous chondrites may be the products of hydrous alteration of CV- or anhydrous CM-type materials. The CIs typically contain veins filled with carbonates and sulfates, probably indicating a period of late stage aqueous alteration under oxidizing conditions. To test this idea, computer simulations of aqueous alteration of CV- and CM-type carbonaceous were performed. For this study, simulations were restricted to the oxidation of hydrous mineral assemblages produced in simulations reported previously [1] in order to determine whether further reaction and oxidation results in the phyllosilicate, carbonate, sulfate and oxide vein assemblages typical of CI carbonaceous chondrites. Our simulations were performed at 1, 25, 100 and 150°C (the appropriate temperature range) for the CV and CM mineral assemblages reported in [1] and using the computer code EQ3/6 [2].

For both the CV- and CM-type reactants, an oxidizing assemblage of phyllosilicates, sulfates, carbonates and oxide minerals is predicted to form from pre-oxidation hydrous mineral assemblages. The sulfide/sulfate fO_2 boundary is temperature dependent, located at 10^{-55} to 10^{-70} bars, at the temperatures of interest. Predicted phyllosilicates include chrysotile, greenalite, cronstedtite, saponitic smectite and chlorite-all minerals found in CI chondrites [3]. Calcium sulfates (gypsum and anhydrite) were predicted to form only in the CV-type reactant simulation, presumably because of the higher calcium concentrations in the CV source material [1]. The small amounts of calcium in the anhydrous CM-type reactants were preferentially incorporated into calcium silicate phases in the course of our simulations. The presence of primary gypsum rather than anhydrite indicates temperatures lower than 42°C during the oxidizing event, or at least the presence of liquid water below 42°C during the late stages of oxidation.

In order to get Mg-sulfate precipitates in the simulations it was necessary to inhibit the precipitation of several stable Mg-silicate phases. This may indicate that the oxidation event was rapid relative to the overall duration of the hydrous alteration and that the Mg-silicate phases were kinetically inhibited from precipitating. It could also indicate that the oxidizing fluid was enriched in sulfate, in which case Mg-sulfates would preferentially form. The simulations predict precipitation of several carbonate phases including dolomite, calcite and various carbonate solid-solution compositions that evolved from an early-formed Ca-rich to a later Mg-rich composition. No Fe-rich carbonates were predicted to form (although they are reported from CI chondrites).

Finally, magnetite and hematite were predicted to form at all temperatures in the CV and CM simulations except for the CM reactant at 1°C, where neither phase occurred. Only magnetite is reported in CI chondrites. However, even if the oxidation event was very rapid it is likely that the ferrihydrite observed in CI chondrites resulted from terrestrial oxidation. Observations of ferrihydrite on Earth indicate that it ages rapidly to more crystalline phases such as goethite.

We conclude that CI mineralogy is consistent with hydration and later relatively rapid oxidation of CV- or anhydrous CM-type mineralogies. More simulations using an improved thermodynamic data base will more narrowly define the conditions and sources of carbonaceous chondrites.

REFERENCES: [1] Zolensky, Bourcier and Gooding (1989) *Icarus 78*, 411-425; [2] Wolery (1979) Calculation of chemical equilibrium between aqueous solutions and minerals: the EQ3/6 software package. Lawrence Livermore Nat. Lab. *Report UCRL-52658*; [3] Zolensky and McSween (1988) in *Meteorites and the Early Solar System*, pp. 114-143..