EXPERIMENTAL STUDY OF SERPENTINIZATION REACTIONS B. A. Cohen[1], A. J. Brearley[1], J. Ganguly[2], H.-P. Liermann[3], and K. Keil[4]. [1]Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131 (bcohen@unm.edu), [2]Department of Geosciences, University of Arizona, Tucson AZ 85716, [3]CeSMEC, Florida International University, Miami, FL 33199, [4]HIGP, University of Hawaii, Honolulu, HI 96822.

Introduction: Current carbonaceous chondrite parent-body thermal models [1-3] produce scenarios that are inconsistent with constraints on aqueous alteration conditions based on meteorite mineralogical evidence, such as phase stability relationships within the meteorite matrix minerals [4] and isotope equilibration arguments [5, 6]. This discrepancy arises principally because of the thermal runaway effect produced by silicate hydration reactions (here loosely called serpentinization, as the principal products are serpentine minerals), which are so exothermic as to produce more than enough heat to melt more ice and provide a self-sustaining chain reaction. One possible way to dissipate the heat of reaction is to use a very small parent body [e.g., 2] or possibly a rubble pile model. Another possibility is to release this heat more slowly, which depends on the alteration reaction path and kinetics.

The pathways and kinetics of serpentinization reactions are poorly constrained as previous work is limited [7, 8]. The most commonly used source for thermal model inputs, [9] reported values for a reaction pathway that produces a large amount of brucite (MgO), a product not observed in meteorites in the same proportion as serpentine. In either case, the reaction rate must be extrapolated to the temperatures and pressures of the parent body, which are low compared with typical experimental conditions. Recent work describing the phase relationships within the system MgO-SiO-H_2O [10,11] show that extrapolation of high-temperature kinetic work to low temperatures may present serious problems because the serpentine stability field is limited to low temperatures and pressures. In particular, talc appears as the stable phase at intermediate pressures and temperatures, and it is possible that the serpentinization reaction may produce talc as a metastable intermediary.

Experimental Conditions: We have conducted a series of three experiments to investigate the kinetics and pathways of serpentinization. The base experiment investigates the reaction $Mg_2SiO_4 + MgSiO_3 + 2H_2O \rightarrow Mg_3Si_2O_5(OH)_4$ at temperatures and pressures within the serpentine stability field based on the phase diagram of [10], or below 450ºC and 10 kbar. Ward's forsterite (San Carlos, AZ; Fo_{90}) and orthoenstatite (Bamble, Norway; $Wo_{0.5}En_{89.0}Fs_{10.5}$) were hand-ground with an agate mortar and pestle and dry-sieved to the ≤150 mm fraction. A starting mixture of 20 mol En + 13 mol Fo (a mix calculated to produce stoichiometric serpentine as the reaction product) was packed into gold tubes and injected with enough distilled water to provide >1 kbar overpressure in the tube at 450ºC. The tubes were welded and placed in cold-seal hydrothermal bombs, where they were kept at experimental conditions for 1, 2, and 3 months, respectively. Although these conditions are extreme compared with alteration conditions estimated for most carbonaceous chondrites, they provide a starting point for evaluating the mechanisms of serpentinization. The resulting charges were emptied from the gold tube, dried in a 50ºC oven for 1 day, ground lightly to disaggregate them, and stored in glass vials. Grain mounts were prepared from 1/2 the powder by pouring epoxy over a pile of powder in a Teflon mold, then polishing and carbon coating the grain face. The mounts were not extensively polished due to plucking of the weak alteration products.

Results - Microprobe: Grain mounts were analysed at the University of Hawaii using a JEOL JSM-5900 scanning electron microscope (SEM) and a CAMECA SX-50 electron microprobe (EMP). SEM imaging shows that enstatite has preferentially altered to one or more fibrous phases, while forsterite grains remain relatively intact (Fig 1). An EMP three-element X-ray map of a large region of the 3-month grain mount (Fig. 2) shows that the majority of small grains have fully reacted, and only the cores of enstatite grains remain in addition to large forsterite grains. Additionally, the Fe X-ray map shows small specks of high iron, possibly an indication of redistribution and/or oxidation of iron and reluctance to be taken up in the alteration minerals.

Results - XRD: The remainder of the charges were analyzed by X-ray diffraction (XRD) at the University of New Mexico, using a Scintag Pad V diffractometer with Jade 5 Software using the ICDD database for phase identification. The XRD patterns are only qualitative at this time, but show that talc is the major alteration phase. Forsterite is also present but enstatite is only a minor phase in all charges. Even in the 3-month charge, antigorite or other forms of Mg-serpentine are not identified by XRD.

Conclusions: The reaction pathway of olivine and pyroxene to serpentine minerals may be complex, with talc as an intermediate product: En + $H_2O \rightarrow$ talc, talc

+ Fo → serpentine. The ΔH for these reactions is x and y, respectively. Though the formation of talc proceeds rapidly, it doesn't release enough heat to sustain a thermal runaway. The further reaction to serpentine, if it proceeds sufficiently slowly, may solve the heat problem in thermal models.

These preliminary data indicate that overall kinetics of the reaction to produce serpentine at relatively elevated temperatures are controlled by the sluggish breakdown of forsterite. The involvement of talc as an intermediate phase contrasts with the alteration behavior of olivine and pyroxene in carbonaceous chondrites, where both phases appear to react directly to serpentine without the involvement of talc. This may reflect the fact that talc is not stable at the lower temperatures of alteration experienced by these meteorites, i.e. the reaction path to form serpentine is different, further underscoring the problem of extrapolating high temperature kinetic data to low temperatures. Future work will examine this question in detail and will also focus on the effect of iron on the alteration reactions.

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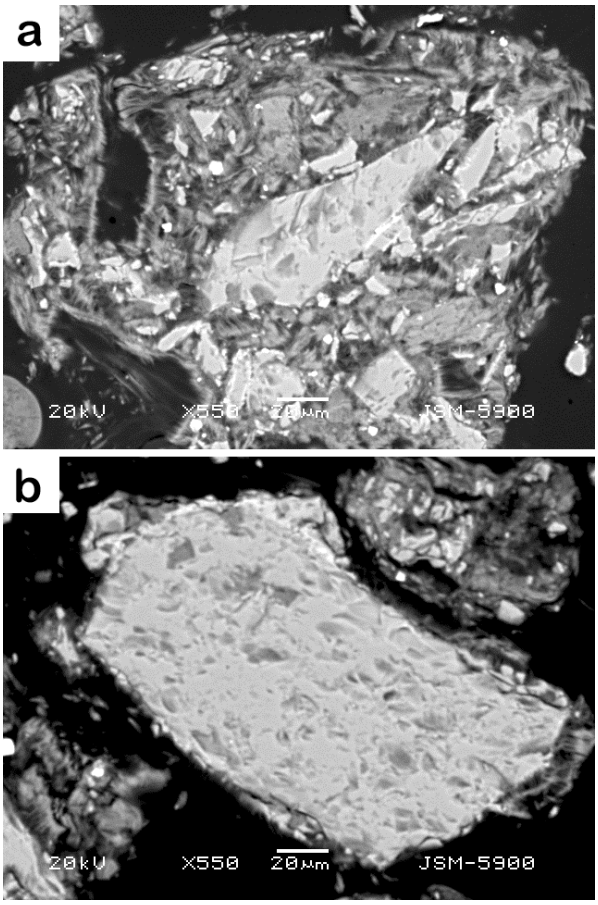

Figure 1. Back-scatter electron (BSE) images of grains in the 3-month charge (scale bar in both images is 20 μm); a) enstatite has been nearly consumed and alteration products are visible; b) forsterite grains retain their euhedral shape.

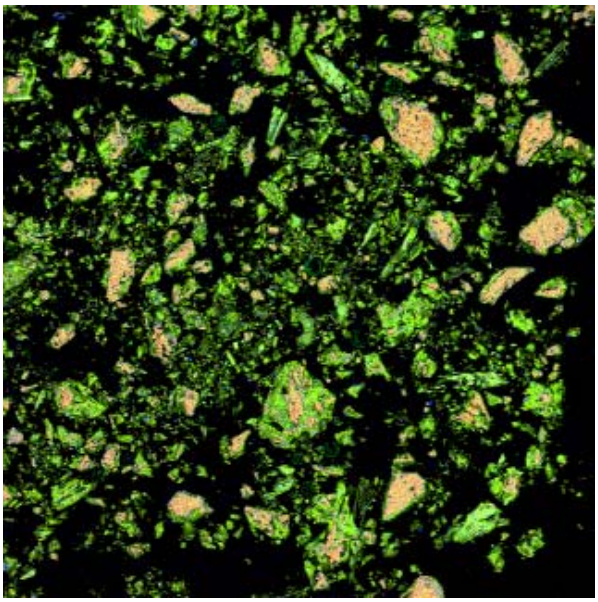

Figure 2. Combined EMP elemental X-ray map of a section of the 3-month grain mount (red=Mg, green=Si, blue=Fe). In this representation, forsterite and enstatite are orange and talc is green. This image shows the extent of alteration of the smaller grains. In the upper right, several forsterite grains still appear unaltered while the large grain near the lower center shows its disintegrating enstatite core.