

HYDROTHERMAL ALTERATION BEHAVIOR OF KAINSAZ (CO3) AT LOW TEMPERATURES UNDER REDUCING CONDITIONS: INSIGHTS INTO INCipient AQUEOUS ALTERATION OF CARBONACEOUS CHONDRITES Adrian J. Brearley and Paul V. Burger, Department of Earth and Planetary Sciences, MSC03-2040, 1University of New Mexico, Albuquerque, NM 87131, USA (e-mail: brearley@unm.edu).

Introduction: Water has played a very significant role on the mineralogical and cosmochemical evolution of chondritic meteorites [1,2]. Mineralogical, chemical and isotopic data for several different chondrite groups show that hydrous fluids have interacted, to varying degrees, with the primary mineral assemblages. The mineralogical effects of aqueous alteration include the formation of hydrous phases such as phyllosilicates as well as soluble phases such as carbonates and sulfates [3]. Hydrous phases are most extensively developed in CI, CM, CR and some CV carbonaceous chondrites and minor occurrences have also been reported in some CO and ordinary chondrites. The effects of aqueous alteration on the mineralogy of chondritic meteorites are now quite well understood. However, there are still a significant number of outstanding questions concerning the mechanisms of aqueous alteration reactions as well as the duration and location of aqueous alteration that have not been fully addressed. In particular, the rates of aqueous alteration reactions, especially during the earliest stages of reaction are not particularly well understood. We have undertaken an experimental program to explore the possible effects of aqueous alteration on various chondritic protolith materials. Results of experiments using Allende as a starting material [4], carried out under oxidizing conditions show that incipient alteration occurs on timescales of days to weeks at temperatures of 100-200°C.

Here we report new observations from a series of hydrothermal experiments using uncrushed samples of the CO3 chondrite, Kainsaz. The experiments were performed under much more reducing conditions than our previous Allende experiments and extend our previous work to protolith materials that contain significant amounts of Fe,Ni metal. Two sets of experiments have been performed at temperatures of 100 and 200°C for time periods of 7, 28, 90 and 180 days. The experiments were carried out in Parr reaction vessels in an inert atmosphere of nitrogen. Rather than being immersed in the aqueous fluid, the samples were suspended above the fluid reservoir and interacted with water vapor. After the experimental

runs the samples were examined by optical microscopy, SEM and TEM.

Results: Irrespective of experimental conditions, all the samples show evidence of alteration. The sample surfaces exhibit a red-brown coloration and crystals of white secondary phases are apparent on the sample surfaces. At both experimental temperatures and for all run times, SEM studies show that the dominant alteration phase on the sample surfaces is calcite which occurs as euhedral grains 5-100 μm in size. There is no systematic variation in the grain size of the calcite as a function of run time or experimental temperature. The sample surfaces show variable development of bulbous to fibrous Fe oxide, whose abundance is a function of both temperature and run time. TEM studies of samples removed from the surfaces of samples run for longer than 1 month show that magnetite is present and also show that fine-grained fibrous phyllosilicates with compositions and *d*-spacings consistent with Mg-rich serpentine are common.

The interior of one sample (KB1) run for 7 days at 100°C was selected for study by TEM. Ion milled samples of fine-grained matrix in this sample were examined for evidence of incipient aqueous alteration. The matrix of unaltered Kainsaz consists dominantly of abundant submicron olivine grains with a range of Fe contents (Fa_{38-62} [3]) with significant pore space between individual grains. However, even after only 7 days reaction evidence of pervasive alteration is present throughout all regions of matrix studied. HRTEM of matrix olivine grains indicate that localized pitting is present on the grain surfaces, suggesting that some olivine dissolution has occurred. However, the dominant characteristic of the alteration is the presence of a fibrous phase in the interstices between olivine and other matrix grains (Fig 1). High resolution TEM imaging of this phase suggests that it is amorphous. The fibers are usually about 10 nm in thickness and may be slightly curved, extending for up to 150 nm within the pore space. Analytical electron microscopy indicates that this phase is some kind of Fe-oxide or oxyhydroxide, which also contains a high concentration of Ni (up to 15 wt%). The most likely

candidate for this phase appears to be ferrihydrite. This Fe-rich fibrous phase is set in a groundmass of material which has lower electron contrast and is also amorphous. This material appears to fill essentially all the void space between the precursor crystalline phases and has a complex and variable composition from region to region (Fig. 2). In all cases, the composition is Fe-rich (28-50 wt% Fe), but with significant Si (7-15 wt%). Ni, Mg, Al and S are all present in varying, but lesser concentrations. Within this complex amorphous material, very rare, poorly ordered, fibrous nanocrystals with basal spacings of ~ 0.7 nm occur. It is possible that these grains may be phyllosilicates such as serpentine, but additional data are required to confirm this.

Discussion: Like our experiments using Allende, alteration occurs extremely rapidly even at 100°C and the reaction products bear close similarities to those that occur in altered carbonaceous chondrites. However, there are notable differences compared with our Allende experiments, which we attribute to the more reducing conditions. In particular, Ca-sulfates are absent in these new experiments, with carbonate dominating the alteration assemblage. This observation indicates that oxidation of sulfides in the protolith material has not occurred as a consequence of the more reducing conditions. In addition, the development of Mg-rich phyllosilicates on the sample surfaces appears to have occurred much more rapidly than in our Allende experiments. In the shortest duration experiments, it is clear that the alteration assemblage in the matrix is dominated by amorphous material that has filled all the pore space in the sample. These data further illustrate the importance of amorphous, non-stoichiometric phases in the earliest stages of fluid-mineral interaction. We are currently examining samples run for more extended periods of time and anticipate that we will see significant evidence of recrystallization of this amorphous material to form phyllosilicates.

Finally, although the experiments were carried out in the presence of water vapor, rather than liquid water, the presence of abundant Ca carbonate on the sample surfaces indicates that mass transfer of soluble material was still highly effective. It seems probable that even under these conditions, a film of liquid water must still have been present along grain boundaries within the sample and possibly along the sample surfaces that acted as a mass transfer medium.

References [1] Zolensky, M.E. and McSween, H.Y. (1988) *MESS*, 114. [2] Brearley, A.J. (2006) *MESS II*, 587. [3] Brearley, A.J. and Jones, R.H. (1998) *Rev. Mineral* v. 36. [4] Jones, C.L. and Brearley, A.J. (2006) *GCA* **70**, 1040.

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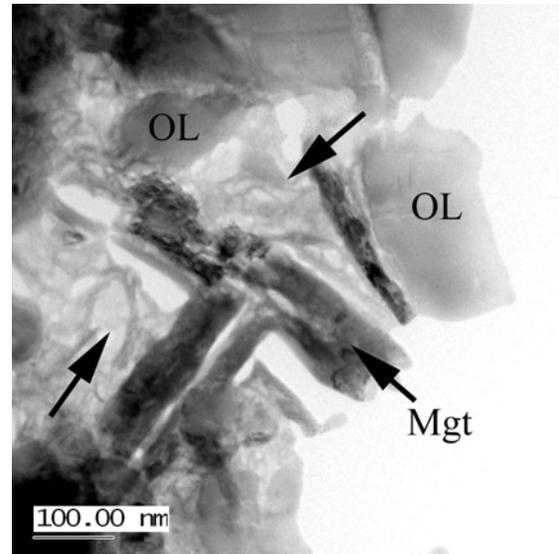


Figure 1. Bright field TEM image showing alteration textures in the matrix of Kainsaz after reaction for 7 days at 100°C . The interstices between the olivine grains are filled with a fibrous Fe-rich phase (blue stars in Figure 2), set in an amorphous groundmass of more Si-rich material.

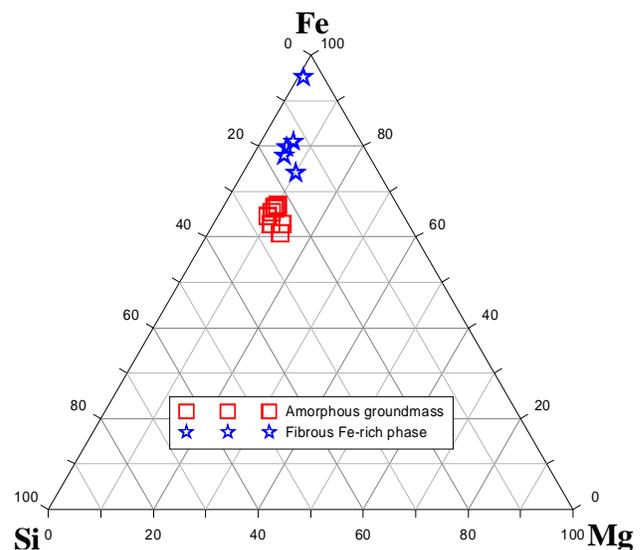


Figure 2. Ternary element wt% diagram (Fe, Si, Mg) showing the composition of alteration phases in the matrix of Kainsaz after reaction for 7 days at 100°C . Red squares represent the composition of the amorphous groundmass material that fills void spaces in the matrix. Blue stars are the compositions of Fe-rich fibrous phase that occurs within the groundmass material.