ARE PHYLOSICATE CR CHONDRITE MATRICES GENERATED BY HYDROTHERMAL ALTERATION? N. M. Abreu, Earth Science, Penn State University – DuBois Campus, DuBois, PA, 15801, USA. Email: abreu@psu.edu.

Introduction: Most CRs are regarded very primitive CCs that have experienced a variable degrees of aqueous alteration, but have escaped thermal metamorphism [1]. FIB/TEM observations show there are five CR populations that contain increasing amounts of minerals generated by aqueous alteration: (1) QUE 99177, MET 00426, (2) EET 92062, LAP 02342, GRA 95229, (3) MIL 07525, EET 96259, MIL 090001, (4) LAP 04516, LAP 04720, (5) GRO 95577, with a large gap between (4) and (5). [2] observed that the water contents of CRs measured by [3] do not predict their secondary mineral abundance. Variations in the temperature of aqueous alteration have been suggested to explain the puzzling observation that some mineralogically pristine CRs have higher water content than more aqueously altered ones [3]. Recently, the degree of thermal metamorphism in 15 CRs has been determined [4], of which 5 had been studied for signs of aqueous alteration by [2]. Here, new EPMA observations of those and the remaining four CRs are used to investigate if there is a relationship between degrees of aqueous alteration and alteration temperatures.

Results: EPMA point analyses for Na, Mg, Al, Si, Fe, Co, Ni, Ti, Cr, Mn, P, S, Ca, and K and compositional maps for Na, Al, Ca, S, Ni, and Cr were collected from matrix, Fe-Ni metal and chondrules from each of the nine CRs listed above.

Matrix. 694 points and X-ray maps were collected from representative regions. S content decreases with increasing degrees abundance of hydrous minerals, except for LAP 04516. Na also monotonically decreases with increasing degrees of aqueous alteration for all CRs observed, except for LAP 04720. While LAP 04516 matrix contains abundant phyllosilicates, that are comparable in size and degree of crystallinity to those in LAP 04720 matrix [2], LAP 04516 matrix is more S-rich than any other CR matrix.

Fe-Ni Metal. 248 points were collected from 4-20 individual nodules in chondrite. Unlike data presented by [4], which showed a positive correlation between Co and Ni, CRs studied here have weak $R^2 = 0.43$, 0.42, 0.67 for GRA 95229, MIL 07525, and LAP 04516 respectively) or no correlation at all ($R^2 = 0.00$-0.05 –Fig. 1). All CRs display variable CI normalized average Ni/Co ratios ($<\text{Ni/Co}> = 0.67$-1.82), with large standard deviations, indicating that most individual grains have non-nebular Ni/Co ratios. Independent metal is depleted in Co with respect to metal in chondrule interiors in all but two CRs (GRO 95577 in which no interior metal was found and LAP 04720). It was not possible to assess if Ni-rich (Ni >20 wt.% metal has less Co than kamacite, because only one of the CRs studied (MIL 090001) has Ni-rich Fe-Ni.

Fig. 1. Co versus Ni contents of Fe-Ni metal in CRs.

Type IA Chondrules. 156 points were collected from representative forsteritic olivine and ~98 points were collected from 8 CRs – no anhydrous phenocrysts were identified in GRO 95577. A relatively weak linear ($R^2 = 0.5$) correlation between the average ferrosilite content in low-Ca pyroxene and the fayalite content in olivine in type IA chondrules is observed (Fig. 2). The least aqueously altered CRs have higher Fs and Fa contents and the more altered ones (with the exception of GRO 95577). There is no correlation with Cr of Ca in forsteritic olivine.

Type II Chondrules. 107 points and 9 X-ray maps were collected from fayalitic olivine in 8 CRs. Observations here are generally consistent with [4]. There is no evidence of chromite formation on the periphery of fayalitic olivines. There is no correlation between Cr content of fayalitic olivine and the abundance of hydrous minerals.

Chondrule Mesostasis. 320 points were collected from 5-8 type I and II chondrules in each of the 9 CRs. No compositional trends have emerged from either mesostasis in chondrule type. Ca, Na, K, Cr, and S are not related to the amounts of secondary minerals, to water content measured by [3], to their total oxide contents, or to their Antarctic weathering category.

Discussion:

Matrix. The least aqueously altered CR chondrites are richer in both S and Na than the more altered ones. [5] suggested that the matrix of the least heated chondrites is enriched in S and Na with respect to heated ones. These observations could suggest that the degree
of aqueous alteration of the CRs is related to how much heating they record. However, it is difficult to interpret the S and Na trends as exclusively caused by thermal metamorphism, because aqueous alteration may have modified the distribution of these elements. For example, [6] suggested that decreasing S content of matrix indicates increasing degrees of aqueous alteration. Dehydration and structural collapse of matrix phyllosilicates is an indicator of thermal metamorphism in low petrologic type CCs in which heating events occurred after aqueous alteration [e.g., 7-9]. This is not necessarily the case for the CRs. Based on TEM observations [2], it is clear that dehydration of phyllosilicates was not prevalent for most CRs.

Metal. [10,11] observed systematic changes in the distribution of Ni and Co and on the texture of Fe-Ni metal in CO, O, and CM chondrites. Unheated chondrites preserve solar Ni/Co ratios. Weakly heated chondrites retain a positive correlation between Ni and Co, which is lost as thermal metamorphism increases [10,11]. In type < 3.1 CO and OCs, isolated Ni-metal is enriched in Co relative to kamacite in chondrule interiors [10]. Fe-Ni metal was martensitic in unheated CMs and progressively developed plessitic intergrowths [11]. Coarse-grained assemblages of kamacite and Ni-rich metal are found in more thermally modified CCs, [10,11].

The distribution of Co and Ni in Fe-Ni grains suggest that CRs studied here underwent mild thermal metamorphism, equivalent to with petrographic type ~3.1 using indicators proposed for CO and OCs [10] and Category B for the CMs as defined by [11]. This is consistent with [12] who argued that CR metal recorded weak thermal metamorphism. It has been suggested that in the matrices of petrologic type 3.1 and above, nanosulfides coalesce into larger grains and silicates form fayalitic olivine [5]. In contrast, the matrices of all CRs studied here are dominated by amorphous silicates and nanosulfides. It is possible that chondritic matrices are not as susceptible to temperature-induced recrystallization as previously though. For example, Fe-Ni metal in UOC Semarkona, whose matrix is mineralogically pristine, displays plessitic intergrowths that indicates that it has undergone some heating [11].

Thermal metamorphism affected the distribution of fayalite content and minor elements in chondrules. In CO and OCs type IA chondrule olivines, fayalite contents increase and CaO contents decrease with increasing degrees of thermal metamorphism [13]. In addition the ferrosilite content of low-Ca pyroxene increased with thermal metamorphism [13]. Distinct trends in Fe content are recorded by phenocrysts in type IA chondrulce. Based on the fayalite content of olivines and the ferrosilite content of low-Ca pyroxenes, the least aqueously altered CRs show most signs of thermal metamorphism, which is the opposite of what would be predicted if thermal metamorphism drove the hydration of CR matrices.

The behavior of Cr in type II chondrules systematically changes with thermal metamorphism [5]. While the CRs study here record some evidence of mild heating, there is no relationship between these trends and the amounts of phyllosilicates CR matrices contain. CR chondrule mesostasis, which is thought to become more K-rich with thermal metamorphism [5], shows no compositional trends. As with the matrix, mobilization of alkalis is likely to occur as a result of aqueous alteration. Therefore if this process postdates thermal metamorphism, trends established during heating are likely to be erased.

Conclusions: Indicators of thermal metamorphism in CR chondrites record contradictory trends. The distribution of Ni and Co in Fe-Ni metal suggest that all the CRs have undergone metamorphism consistent with petrologic type ~3.1, which is generally consistent with results presented by [4]. If a relationship between thermal metamorphism and aqueous alteration exists (e.g., type IA chondrules), it does not appear that heating was a main driver in the formation of hydrated minerals. In fact, our data suggest that aqueous alteration postdated very mild thermal metamorphism.