METAMORPHIC EFFECTS IN THE MATRICES OF CO3 CHONDRITES: COMPOSITIONAL AND MINERALOGICAL VARIATIONS Adrian J. Brearley, Institute of Meteoritics, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, New Mexico 87131.

We are examing the mineralogical and compositional variations of fine-grained matrix through the petrologic sequence in the CO3 chondrites to assess possible metamorphic models for these meteorites. We have measured the major and minor element compositions of matrix and rims by electron microprobe and studied the fine-scale mineralogy by transmission electron microscopy. Our data show that there are systematic, but complex, compositional trends in the matrices of these meteorites through the metamorphic sequence. The major elements, Mg and Fe, become progressively more equilibrated with increasing petrologic type and the matrices become progressively enriched in Mg and depleted in Fe. The behavior of the minor elements, Ti, Cr and Al, contrast markedly with Mg and Fe and become increasingly heterogeneous through the metamorphic sequence.

Introduction. It has been recognised for several years that carbonaceous chondrites of the CO3 group define a metamorphic sequence, similar to that observed in the ordinary chondrites [1,2]. Scott and Jones [2] provided detailed petrologic subtypes for individual CO3 chondrites and showed that ALH A77307 (3.0) and Isna (3.7) represent the least and most equilibrated members respectively. The detailed compositional variations in chondrule silicates reported by [2] and [3] provide support for the model that equilibration in these meteorites occurred by diffusional exchange, principally of Fe and Mg, between Mg-rich chondrules and Fe-rich matrix within a parent body environment. The compositional systematics observed in chondrules are now well understood, but the chemical and mineralogical changes which occur in the fine-grained matrix of these meteorites as a response to metamorphism are poorly understood. We have carried out a detailed study of the compositions and mineralogy of these meteorites to examine variations which may develop during metamorphism. These data will provide insights into how fine-grained matrix materials respond to metamorphism in terms of their textures, mineralogy and compositions and will ultimately test the model of in-situ parent body metamorphism.

We have studied 3 CO3 chondrites, Kainsaz (3.1), Ornans (3.3) and Warrenton (3.6), all falls, which span the range of degrees of equilibration found in this group. We have previously obtained data on the least equilibrated CO3 chondrite, ALH A77307, for comparison [3]. Major and minor element compositions of fine-grained rims and matrix were measured by electron microprobe using a 10μm beam. These regions were then demounted from the thin sections and were studied by TEM techniques.

Results. Our electron microprobe data show systematic trends in the composition of matrix through the metamorphic sequence. The observed trends are complex and the behavior of different elements is variable, demonstrating that the response of these elements to metamorphism is controlled by several variables. A comparison of data for a number of rims and bulk matrix from each meteorite, normalized to Si and CI values, shows some of the major compositional variations which occur through the metamorphic sequence. The element ratio pattern for ALH A77307 shows strong depletions in Ca, Ti, Mg, Cr, Mn, and Na and a small depletion in S [3]. Al, K, Ni and Fe are all enriched. The element ratio patterns for Kainsaz are, in comparison, much flatter and the relative enrichments and depletions are smaller, with the exception of S, which shows a depletion 2 orders of magnitude larger than that for ALH A77307. Depletions of S of the same magnitude are also observed in Ornans and Warrenton. However, in general the patterns for these two meteorites are more fractionated than Kainsaz, with variable, but significant depletions in Ca, Na, K and Ni and an enrichment in Al. In moving through the metamorphic sequence, several points are clear: 1) there is a significant drop in the concentrations of S and Ni, 2) the Mg/Si ratios of matrix increase systematically through the metamorphic sequence, 3) the bulk Na/Si, K/Si, Ca/Si and Ni/Si ratios for individual rims become increasingly variable in the higher petrologic type chondrites, Ornans and Warrenton and 4) the unfractionated character of matrix in Kainsaz appears, in some respects, anomalous and requires further investigations.

METAMORPHIC EFFECTS IN CO3 CHONDRITE MATRICES: Brearley, A.J.

The elemental variations observed in individual microprobe analyses for matrix and rims have also been examined in detail. These data provide some important additional insights into the response of matrix to increasing degrees of metamorphism. The major elements, Mg and Fe show a sensitive response to increasing degrees of metamorphism. In ALH A77307 the range of Fe/Si and Mg/Si ratios observed is large, but there is no correlation between these two elements, indicating that the matrix is not a simple two component mixture of Mg and Fe-bearing phases. Mineralogically this is certainly the case, as the matrix consists of a complex unequilibrated assemblage of olivines, pyroxenes, amorphous material, sulfides, oxides and iron nickel metal. In Kainsaz, the matrix clearly has a higher Mg/Si ratio than ALH A77307, but the spread in Fe/Si ratios is still large, although, unlike ALH A77307 the bulk of the analyses are much more strongly clustered. Like ALH A77307 there is no correlation between Mg and Fe. In the higher petrologic types, Ornans and Warrenton, the range of Fe/Si and Mg/Si ratios decreases dramatically and there is a clear movement of the matrices to progressively higher Mg/Si and lower Fe/Si ratios. In addition, Mg and Fe progressively develop a positive correlation, which is especially well-developed in Warrenton, indicating that the matrix mineralogy is much simpler in this meteorite. Indeed, TEM studies of the rims and matrix analysed by electron microprobe show that Warrenton matrix consists largely of fine-grained, equilibrated olivine with common, Mg, Al-bearing Cr spinel and accessory kamacite.

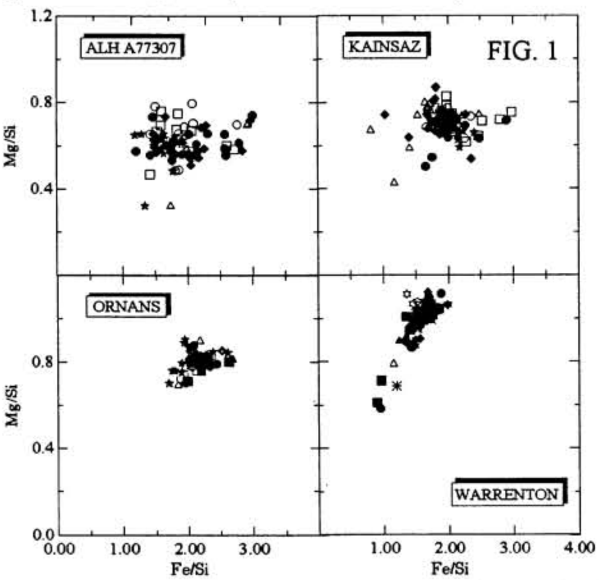

FIG. 1

Although Mg and Fe show increased homogenization in matrix through the metamorphic sequence, this is not the case for other elements. Cr, Ti and Al show the reverse trend to those observed for Mg and Fe. In ALH A77307, the variation in Cr/Si, Ti/Si and Al/Si ratios is limited throughout matrix and rims, but increases progressively, such that in Warrenton all these elements are highly variable. In addition, Cr and Ti and Cr and Al become progressively better correlated. In ALH A77307 there is no correlation between these elements, whereas in Warrenton Cr shows positive correlations with both Ti and Al. Mineralogically, the correlation of Cr and Al must be the result of the presence of a significant amount of Al-bearing Cr spinel in rims and matrix.

Discussion. The parent body metamorphic model for the CO3 chondrites requires elemental mass transfer between a compositionally homogeneous matrix with heterogeneous chondrule and inclusion silicates. In the CO3 chondrites the bulk of chondrules are Mg-rich varieties [1,2], which based on the data of [2] become progressively more Fe-rich as equilibration proceeds. Fe-Mg exchange between chondrules and matrix requires that the matrix becomes more Mg-rich, exactly what is observed in the CO3 chondrites studied here. In addition, the data for chondrule silicates reported by [2] suggest that their compositions are equilibrating towards a composition of Fa_{40}, exactly the compositions observed for rim olivines in Warrenton in this study. (For comparison [5] reported olivine compositions of Fa_{45-50} for Warrenton). All these data are consistent with an in-situ metamorphic model for the CO3 chondrites. The heterogeneities observed in the distribution of minor elements in the most equilibrated CO3 chondrites requires further investigation, but may be the result of the local crystallization of discrete phases which contain elements such as Ti, Al and Cr, for example Mg-Al-bearing chromite in Warrenton matrix. **Acknowledgments.** Funding was provided by NASA grant NAGW-3347 to J.J. Papike.

References. [1] McSween, H.Y. (1977) GCA 41, 477-491. [2] Scott, E.R.D. and Jones, R.H. (1990) GCA 54, 2485-2502. [3] Jones, R.H. (1993) 2853-2867 [4] Brearley, A.J. (1993) GCA 57, 1521-1550. [5] Keller, L.P. and Buseck, P.R. (1990) GCA 54, 1155-1163.