

CARBONATE COMPOSITIONS IN CM AND CI CHONDRITES AND Mg-Fe-Mn PARTITIONING DURING AQUEOUS ALTERATION; Craig A. Johnson and Martin Prinz, Dept. of Mineral Sciences, American Museum of Natural History, New York NY 10024

INTRODUCTION: All chondrites which have undergone extensive aqueous alteration contain carbonate minerals. Calcite (or possibly its polymorph vaterite), dolomite and iron-bearing magnesite have been reported in CIs [1], calcite and aragonite in CMs [2,3], and calcite in CRs [4]. The carbonates are generally believed to have precipitated from carbonate- or bicarbonate-bearing aqueous solutions during alteration, and this interpretation is supported by mineral solubility modeling of the alteration process [5]. We have carried out electron probe analysis of carbonate minerals in 15 CMs (9 Antarctic, 6 non-Antarctic) and in the CIs Orgueil and Ivuna and have examined the Mg, Fe and Mn partitioning among carbonate and phyllosilicate phases. The results may reflect the temperatures of aqueous alteration.

RESULTS: All the CMs studied contain disseminated calcites discernable by optical microscopy. The calcites are up to a few 10s of μm in size, are polysynthetically twinned and are commonly rhombic in form. They are optically uniaxial negative which confirms that they are calcite; neither vaterite nor aragonite was found. (Calcites in the CM Bells are exceptions; they resemble those found in CIs.) Minor elements in 129 calcites have ranges of 0.07-0.61 wt% FeO, up to 0.33 wt% MgO and up to 0.83 wt% MnO. Nogoya, Boriskino, Cold Bokkeveld and ALH83100 also contain dolomite, a mineral which has not been previously reported in CMs. Dolomite makes up only one or two grains of the 10-20 carbonate grains analyzed in each meteorite. The phase may have gone unrecognized by us in other CMs. Dolomites are polysynthetically twinned, and some are elongate suggesting that they may have precipitated in fractures. Minor elements in 6 dolomites are 1.36-4.16 wt% FeO and 0.40-3.82 wt% MnO (Fig. 1).

In CIs, dolomite is the most abundant carbonate. It is disseminated in matrix and has 1.28-2.55 wt% FeO and 0.07-11.5 wt% MnO (21 grains) (Fig. 1). The broad range of MnO and nearly uniform MgO/FeO may reflect local variations in Mn^{++} activity in the altering solution and generally uniform Mg^{++} and Fe^{++} activities. Calcite is commonly associated with veins [6] and is neither rhombic in form nor twinned. It has been suggested [1] that the grains are actually the metastable vaterite polymorph. Analyses of 4 calcites in Orgueil and Ivuna show 0.16-0.42 wt% FeO, up to 0.63 wt% MgO and up to 0.53 wt% MnO. CI magnesite is also disseminated in matrix. A single grain analyzed by us has 13.5 wt% FeO and 11.2 wt% MnO.

There are few good analyses of individual phyllosilicate minerals in altered chondrites. Four analyses by Bunch and Chang [2] suggest that CM serpentines vary in composition over the range 13.8-25.3 wt% FeO (total Fe as FeO) and 16.8-33.0 wt% MgO. MnO is 0.10-0.20 wt%. Orgueil serpentine is more uniform in composition averaging 10.9 wt% FeO and 34.6 wt% MgO for coarser grains [7]. Kerridge's data [8] suggest that MnO is about 0.2 wt%.

DISCUSSION: By analogy with carbonate minerals formed in many terrestrial low-temperature environments, the mineralogy and composition of chondritic carbonates may have been controlled by kinetic factors. Aragonite, for example, almost certainly formed metastably in CMs [3]. On the other hand, equilibrium solubility models [5] have successfully reproduced the aqueous alteration assemblages observed in CIs and CMs which implies that mineral precipitation may not have departed dramatically from chemical equilibrium. Whether or not the carbonates are equilibrium precipitates can be evaluated by examining elemental partitioning among carbonate phases and between carbonates and phyllosilicates.

Data from terrestrial serpentinites, iron formations and ophicarbonate rocks [9] indicate that equilibrium Mn partitioning among coexisting minerals leads to decreasing MnO in the order magnesite>dolomite>calcite>phyllosilicates. For the meteoritic data, the comparison of phyllosilicate and calcite Mn-contents is somewhat uncertain due to analytical error at such low concentrations and to comparison of data from different laboratories. Comparisons involving magnesite and dolomite data, on the other hand, are free of these problems. In the CMs, Mn decreases in the order dolomite>phyllosilicates \geq calcite; in CIs the order is

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magnesite>dolomite>calcite/vaterite>phyllosilicates. Except for calcite, the order is as predicted for equilibrium partitioning.

Data from terrestrial occurrences also indicate that Fe is partitioned among coexisting minerals in the order serpentine>magnesite>dolomite>calcite [9], which is the same partitioning observed in the CMs and CIs. The terrestrial data further suggest that the Fe-Mg distribution between dolomite and serpentine varies with equilibration temperature. An empirical calibration of the exchange reaction ($K_d = (\text{Mg}_{\text{dol}}/\text{Fe}_{\text{dol}})/(\text{Mg}_{\text{serp}}/\text{Fe}_{\text{serp}})$) based on data from 5 localities [9] is shown in Fig. 2 as a sloping line. If one assumes that dolomite precipitated in equilibrium with serpentine during aqueous alteration, then the Fe-Mg distributions yield qualitative temperature estimates. The 4 CM serpentine compositions of Bunch and Chang [2] imply temperatures of about 130, 160, 170 and 340°C (Fig. 2). For Orgueil, the data imply a temperature of about 290°C. For comparison, the oxygen isotope fractionation between calcite and matrix phyllosilicates suggests 0-25°C for CMs and ~150°C for CIs [10]. Given the uncertainties in the thermometer calibration, the dolomite-serpentine temperatures are approximate. However, for most of the range of serpentine compositions observed in CMs, K_d is larger than that obtained for Orgueil. Thus despite the uncertainty in the temperatures, the data appear to support the conclusion of Clayton and Mayeda [10] that aqueous alteration occurred at lower temperatures in CMs than in CIs. The data appear to be inconsistent with the conclusions of Rietmeijer and Mackinnon [11] who inferred the reverse relationship on the basis of the ordering of poorly graphitized carbon.

CONCLUSIONS: The elemental partitioning data indicate that, although CMs and CIs are highly unequilibrated meteorites, some carbonate phases and some phyllosilicate phases may be near-equilibrium precipitates from the altering solutions. The Fe-Mg distributions suggest higher alteration temperatures for CIs than for CMs in agreement with conclusions based on oxygen isotope fractionations.

REFERENCES: [1] Fredriksson K & Kerridge JF (1988) *Meteoritics* 23:35, [2] Bunch TE & Chang S (1980) *GCA* 44:1543, [3] Barber DJ (1981) *GCA* 45:945, [4] Fredriksson K et al. (1981) *Meteoritics* 16:316, [5] Zolensky ME et al. (1989) *Icarus* 78:411, [6] Richardson SM (1978) *Meteoritics* 13:141, [7] Tomeoka K & Buseck PR (1988) *GCA* 52:1627, [8] Kerridge JF (1976) *EPSL* 29:194, [9] Klein C, Jr (1974) *Can Mineral* 12:475; Floran RJ & Papike JJ (1975) *GSA Bull* 86:1169; Klein C, Jr & Fink RP (1976) *Econ Geol* 71:453; Trommsdorff V & Evans BW (1977) *Contrib Mineral Petrol* 62:301; Sanford RF (1982) *Am J Sci* 282:543, [10] Clayton RN & Mayeda TK (1984) *EPSL* 67:151, [11] Rietmeijer FJM & Mackinnon IDR (1985) *Nature* 315:733.

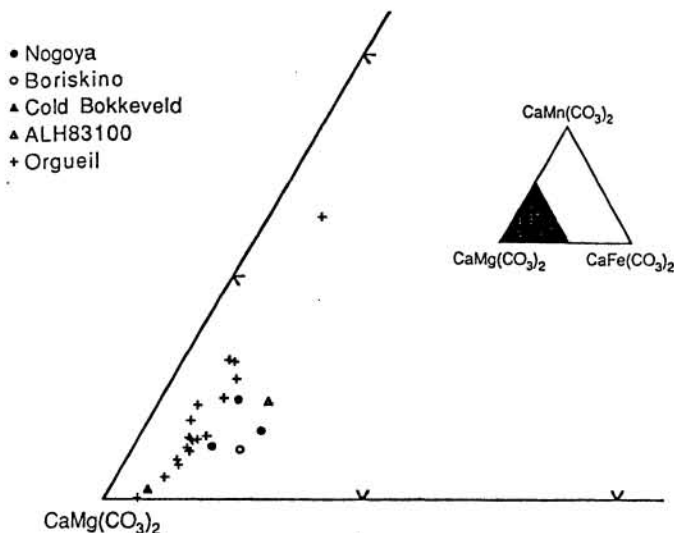


Fig. 1. Dolomite compositions in CM and CI chondrites.

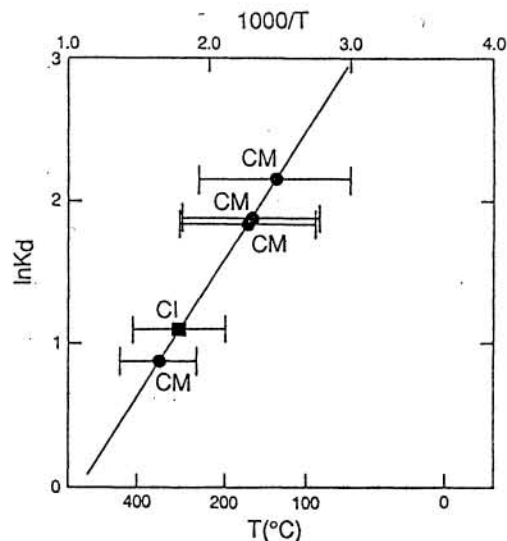


Fig. 2. Dolomite-serpentine thermometer (sloping line) with data from CMs and CIs.