

MG-FE-MN CARBONATES IN THE CARBONACEOUS CHONDRITES. M. R. Lee¹, P. Lindgren², L. E. Jenkins¹ ¹School of Geographical and Earth Sciences, University of Glasgow, Glasgow G12 8QQ, UK (Martin.Lee@Glasgow.ac.uk), ²Geological Survey of Sweden, Kiliansgatan 10, 225 50 Lund, Sweden (paula.lindgren@sgu.se).

Introduction: Carbonates are a volumetrically minor yet highly informative constituent of carbonaceous chondrite (CC) meteorites. Their chemical and isotopic compositions have been used to determine: (i) the chronology of parent body aqueous alteration [1, 2]; (ii) the temperature of crystal growth [3]; (iii) the provenance and evolution of aqueous fluids [4, 5]; (iv) the parent body's location in the protoplanetary disk [6]. Furthermore, the petrographic context of carbonates can provide important insights into the physical properties of the parent body such as the flow of aqueous solutions (from the presence of mineral veins [7]), and the intensity of post-aqueous alteration shock (from mineral petrofabrics and microstructures [8]).

Carbonate minerals differ in relative abundance between CC groups. Calcite is dominant in the CMs, and dolomite in the CIs; minor calcite also occurs in the CRs and CVs [5, 9]. Mg-Fe-Mn carbonates (i.e., minerals of the magnesite (MgCO_3)-siderite (FeCO_3)-rhodochrosite (MnCO_3) solid solutions) are relatively scarce but owing to their wide compositional range they are potentially highly informative about the physico-chemical conditions of aqueous alteration. For the same reasons they may be helpful in constraining the affinity of unclassified carbonaceous chondrite lithologies, for example clasts within meteorite breccias, and materials returned from the asteroids Ryugu and Bennu. Here we have sought to describe and understand the compositional range of Mg-Fe-Mn carbonates in the CC meteorites through the analysis of a sample of Ivuna (CI) and using published analyses from other meteorites.

Methods: Carbonates were studied in a carbon coated thin section of Ivuna (P12627) loaned by the Natural History Museum, London. Backscattered electron (BSE) images and X-ray maps were obtained using a Zeiss Sigma SEM at the University of Glasgow, and chemical analyses were acquired with a CAMECA SX100 electron probe at the University of Edinburgh. Published data of Mg-Fe-Mn carbonates are available from the CIs Orgueil, Ivuna, Alais and Tonk [10, 11], the CMs Queen Alexandra Range (QUE) 93005 [12] and Lonewolf Nunataks (LON) 94101 [13], and the C2 ungrouped meteorite Tagish Lake [14, 15]. Elemental compositions have been compiled from tables of analyses, and approximate compositional ranges have been measured from data plotted in ternary diagrams in these papers.

Carbonate terminology: The solid solution between magnesite $\text{Mg}_{>95}\text{Fe}_{<5}\text{CO}_3$ and siderite ($\text{Mg}_{<5}\text{Fe}_{>95}\text{CO}_3$)

has three variants of intermediate composition: breunnerite ($\text{Mg}_{95-50}\text{Fe}_{5-50}\text{CO}_3$), pistomesite ($\text{Mg}_{50-30}\text{Fe}_{50-70}\text{CO}_3$) and sideroplesite ($\text{Mg}_{30-5}\text{Fe}_{70-95}\text{CO}_3$).

Results: The Ivuna thin section is a breccia composed mainly of rounded mm-size clasts that have a phyllosilicate-magnetite mineralogy (Fig. 1). One relatively large and angular clast is depleted with respect to both Mg and Si (Fig. 1). Three Mg-Fe-Mn carbonate grains were analysed. All are breunnerite, and one is enriched in Mn: $\text{Mg}_{62-66}\text{Fe}_{15-18}\text{Mn}_{16-22}\text{Ca}_{0-1}\text{CO}_3$ ($n=10$), $\text{Mg}_{62-73}\text{Fe}_{26-36}\text{Mn}_{0-1}\text{Ca}_1\text{CO}_3$ ($n=7$), $\text{Mg}_{70-72}\text{Fe}_{26-28}\text{Mn}_{1-2}\text{Ca}_{0-1}\text{CO}_3$ ($n=4$). The Mn-rich breunnerite grain is 650 μm on its longest dimension (Fig. 2). It contains inclusions of Ca-phosphate and Fe-sulphide, and its angular shape shows that it has broken from a larger grain along cleavage planes (Fig. 2). One grain of dolomite in the Ivuna sample that was analyzed has the composition $\text{Ca}_{45-47}\text{Mg}_{44-47}\text{Fe}_{3-5}\text{Mn}_{3-6}(\text{CO}_3)_2$ ($n=6$).

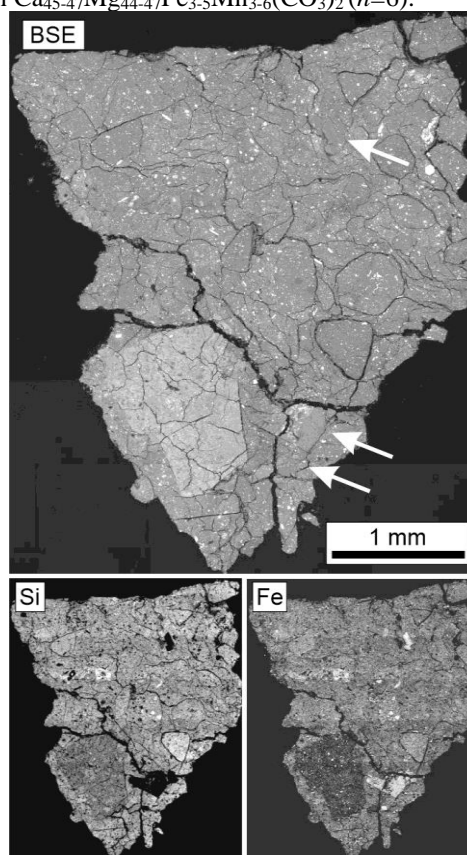


Figure 1. BSE image and X-ray maps of Ivuna P12627. Arrows indicate the breunnerite grains analysed. The Mg- and Si-poor clast is in the lower left-hand side.

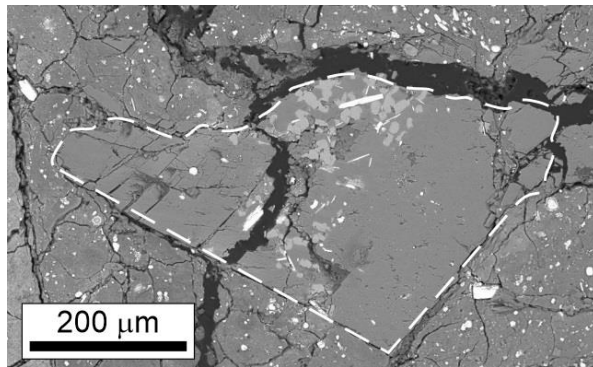


Figure 2. BSE image of the Ivuna Mn-rich breunnerite grain (margins outlined) with inclusions of Fe-sulphide (tabular, white) and Ca-phosphate (equant, light grey).

The Mg-Fe-Mn carbonates in the CIs Ivuna, Alais, Orgueil and Tonk that were analysed in two studies [10, 11] are all breunnerite; they have low Ca whereas Mn ranges up to ~20 mole % (Fig. 3). One grain of Ca-rich pistomesite was found in Ivuna with the composition $\text{Mg}_{38}\text{Fe}_{47}\text{Mn}_0\text{Ca}_{15}\text{CO}_3$ [11]. Mg-Fe-Mn carbonates occur in two CMs. QUE 93005 is a highly aqueously altered meteorite and contains calcite, dolomite (average composition $\text{Ca}_{52}\text{Mg}_{36}\text{Mn}_5\text{Fe}_8(\text{CO}_3)_2$ with some analyses being ankerite), and breunnerite with relatively low Ca and Mn [12] (Fig. 3). LON 94101 is a CM breccia that contains a clast with 46 vol. % carbonate. This clast has dolomite ($\text{Ca}_{52-56}\text{Mg}_{38-42}\text{Fe}_{5-7}\text{Mn}_{0-1}(\text{CO}_3)_2$), and carbonates ranging from Fe-rich breunnerite to pistomesite that has low Mn, and CaCO_3 of up to 7 mole % [13]. Tagish Lake carbonates are pistomesite and sideroplesite, and again with low Mn but up to 8 mole % CaCO_3 [14, 15].

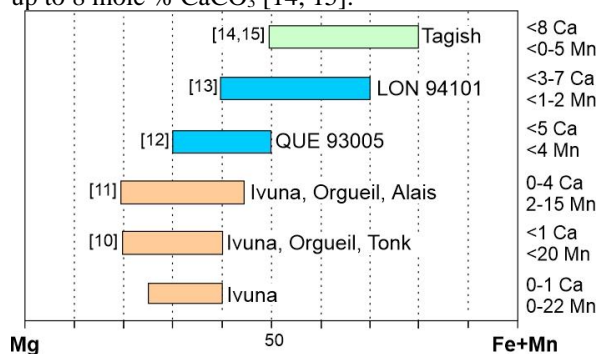


Figure 3. Compositional ranges of Mg-Fe-Mn carbonates analysed here (Ivuna) and in previous studies of CIs (light brown), CMs (blue) and C2 ungrouped (green). The x-axis is from 100 mole % MgCO_3 to 100 mole % $\text{FeCO}_3+\text{MnCO}_3$. The compositional ranges of Ca and Mn on the y-axis are in mole % carbonate.

Discussion: Breunnerite grains in the Ivuna sample studied here are comparable to the clastic carbonate fragments described from the CIs by [10] that are probably fragments of carbonate veins [11]. The sub-

stantial differences in Mn concentrations between individual breunnerite grains in the Ivuna sample demonstrates that the aqueous solutions from which the veins precipitated varied in composition spatially (with pieces of different veins then being mixed by brecciation) or temporally (making compositionally zoned veins). The sulphide and phosphate inclusions in the grain in Figure 2 indicate that aqueous alteration continued after vein formation.

Mg-Fe-Mn carbonate compositions differ considerably between meteorite groups (Fig. 3). Those in the CIs are almost exclusively intermediate to Fe-rich breunnerite with low CaCO_3 , and MnCO_3 ranging up to 22 mole %. Although there is overlap in Mg/Fe ratio with QUE 93005, its breunnerite is distinctive in having low Ca and Mn. Carbonates in the LON 94101 clast and Tagish Lake differ from the CIs, although there is some overlap with QUE 93005 in breunnerite compositions. The provenance of the carbonate-rich clast in LON 94101 was not determined by [13], but the compositional similarities with Tagish Lake carbonates point to a similar parent body.

Conclusions: Mg-Fe-Mn carbonates can be a valuable tool to better understand the conditions of aqueous alteration of CCs, and LON 94101 shows how they can also help to constrain the affinity of xenoliths in meteorite breccias.

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