

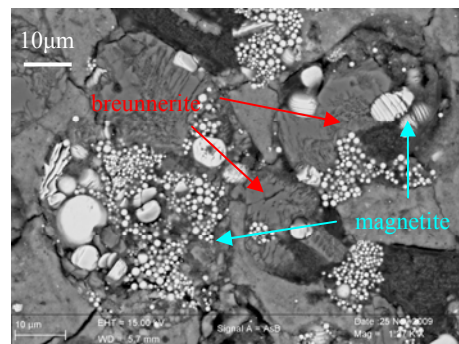
**MAGNETITE CONTENT AND CARBONATE MINERALOGY AS CONSTRAINTS FOR PARENT BODY HYDROTHERMAL ALTERATION.** M. Petitat<sup>1</sup> and M. Gounelle<sup>1</sup>, <sup>1</sup>Laboratoire de Minéralogie et Cosmochimie du Muséum (MNHN), UMR CNRS – 7202 Case 52 - 57 Rue Cuvier 75231 Paris Cedex 05. (petitat@mnhn.fr)

**Introduction:** Aqueous alteration of silicate primary minerals is an important process that occurred on the parent bodies of meteorites as evidenced by secondary mineralization such as the formation of carbonates and magnetite in primitive meteorites. The latter are classified into different groups showing different degrees of aqueous alteration (CI > CM > CR > CV, CO) (e.g. [1]).

After magnetite, carbonates represent the most abundant secondary minerals in the phyllosilicate-rich matrix of CI1s and CM2s [e.g. 2, 3]. Mineralogical observations proposed that carbonate and magnetite precipitated from an aqueous fluid on meteorites parent bodies [e.g. 2, 4]. Moreover, in CM2s and CI1s, carbonates are commonly intergrown with magnetite grains, phosphate and sulfides suggesting a related paragenesis (fig. 1) [2, this study]. Although a common origin is undisputable, previous studies showed that the O isotopic composition of magnetite and carbonates in CI1s [5] and in CM2s [6] are in disequilibrium. This suggests that the isotopic exchange between the fluid and the magnetite occurred on longer timescales than for carbonates [5], and that a succession of thawing and freezing episodes occurred [6]. Finally, the formation of carbonates and magnetite can be dated using different short-lived radionuclides such as the <sup>53</sup>Mn-<sup>53</sup>Cr (e.g. [7]) and the <sup>129</sup>I-<sup>129</sup>Xe (e.g. [8]) systems, respectively, thus giving precious chronological constraints for early solar system processes [9].

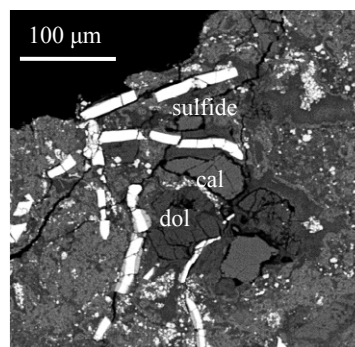
As magnetite and carbonates show mineralogical affinities and bear some important information for our understanding of early solar system processes, we present here a mineralogical study of these 2 types of secondary minerals present in CM2 chondrites, anomalous C2 chondrites and CI1 chondrites in order to improve our understanding of the relationships existing between these 2 minerals, and to determine whether or not the 3 meteorite groups aforementioned may have had evolved on a single and common parent body. Our mineralogical observations also help constraining the period during which magnetite formed.

**Experimental method and samples:** The mineral chemistry of individual carbonate grains was determined at MNHN and Université Paris 6 by using conventional SEM and EMPA techniques.



**Figure 1:** BSE image of magnetite (framboids, plaquettes and spherules) in association with breunnerite grains in the Orgueil meteorite.

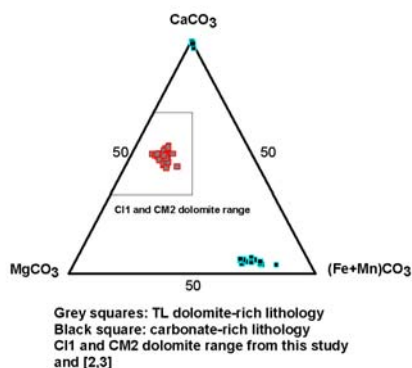
**Results:** Principal mineralogical observations are presented in the SEM backscattered electron images (figure 1-2). In Orgueil, intergrowths of magnetite and breunnerite (figure 1) were found for the first time. We also identified carbonate-carbonate associations in Nogoya and Boriskino (figure 2). Finally, in addition to the carbonate-rich (magneto-siderite) and carbonate-poor lithology (mostly Ca-carbonates) [10], Tagish Lake contains a dolomite-rich lithology with chemical compositions similar to the one measured for CM2 and CI1 dolomites (figure 3).



**Figure 2:** Dolomite (dol), calcite (cal) and sulfides intergrowth in the Boriskino meteorite (CM2).

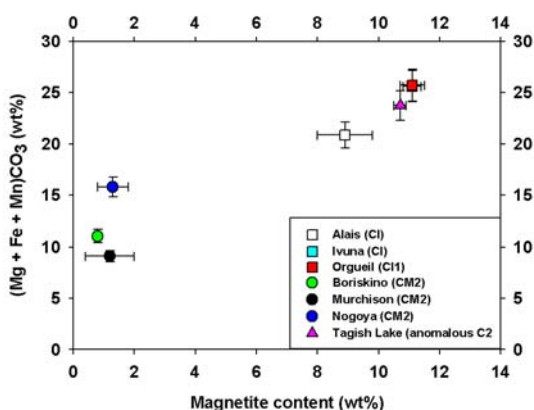
Figure 4 clearly shows that the total magnetite content of each studied meteorite ([11] for CI1s and CM2s and [12] for Tagish Lake) correlates with the average Fe, Mg and Mn composition of its respective carbonate ([7] and this study). In addition, figure 4

shows that magnetite and evolved carbonates are rarer in CM2 chondrites than in CI1s and anomalous C2 chondrites.



**Figure 3:** Chemical composition in wt% of the dolomite rich and the carbonate-rich lithologies of Tagish Lake.

**Discussion:** The correlation obtained in figure 2 indicates that the magnetite content and the average concentration of Mg, Fe and Mn of the carbonates in the meteorites analyzed is proportional to the degree of alteration of the meteorite. First, it corroborates other mineralogical studies demonstrating that Alais had been less aqueously altered than the other CI1s [e.g. 13]. Second, it confirms that Tagish Lake has been extensively exposed to aqueous alteration [10]. Third, it validates the sequence of carbonate crystallization (dolomites before breunnerites) suggested by the  $^{53}\text{Mn}$ - $^{53}\text{Cr}$  systematics [7] and finally it reproduces the sequence of alteration observed between CI1s and CM2s chondrites [1].



**Figure 4:** Correlation between the average Mg, Fe, Mn abundance of carbonates and their respective magnetite content in CI1s, CM2s and anomalous C2s.

The setting of aqueous alteration of CI1s and CM2s is subject to discussion. This correlation further suggests a progressive alteration model for explaining aqueous alteration of the CI1 and the CM2 chondrites

together on a single parent body. Thus it evokes a general progressive alteration between the CI1s and the CM2s, the anomalous C2 chondrites being the binding links [14, 15, 16]. The anomalous C2 chondrites such as Tagish Lake and Niger I, but also Essebi and Bells have indeed mineralogical [e.g. 17] and O isotopic compositions [15] in-between those of C2 and C1 chondrites. Their matrices resemble that of CI1 chondrites and contain amounts of magnetite similar to CI1s [e.g. 18].

This is consistent with the fluid flow model (e.g. [19]). It indeed predicts that different parts of the parent body and the water that they contain could have evolved to different oxygen isotopic compositions ( $\Delta^{17}\text{O}$ ,  $\delta^{18}\text{O}$  and  $\delta^{17}\text{O}$ ). This would then enable at least CI1s, anomalous C2s and CM2s to have evolved on the same parent body.

Finally, whether or not carbonates and magnetite formed at equilibrium, their association permits to constrain the timescales of magnetite formation. The  $^{53}\text{Mn}$ - $^{53}\text{Cr}$  chronometer has set the formation of dolomite and breunnerite at 3Myr and 10Myr, respectively [5]. Hence magnetite in these carbonates precipitated in average  $\sim 3\text{Myr}$  and  $\sim 10\text{Myr}$  after the start of the solar system. This is supported by the  $^{129}\text{I}$ - $^{129}\text{Xe}$  systematics which demonstrates that the magnetite content in Orgueil may contain various iodine carriers that recorded different stages of aqueous alteration [8, 20]. Finally, the sequence of carbonate precipitation [7, this study] suggests that the magneto-siderite found in the carbonate rich lithology of Tagish Lake should precipitate after breunnerites as they contain more Mn, Fe and Mg. Aqueous alteration on meteorite parent bodies might have thus been longer than thought.

**References:** [1] Brearley A. J. (2006), *MESS II*, 587-624. [2] Endress M. and Bischoff A. (1996), *GCA*, 489-507. [3] Johnson C. A. and Prinz M. (1993), *GCA*, 57, 2843-2852. [4] Kerridge J. F. et al. (1979), *Science*, 205, 395-397. [5] Rowe M. W. et al. (1994), *GCA*, 58, 5341-5347. [6] Benedix G. K. et al. (2003), *GCA*, 67, 1577-1588. [7] Petit M. et al. (2009) *LPS XL*. [8] Hohenberg C. M. et al. (2000), *GCA*, 64, 4257-4262. [9] Krot A. N. et al. (2006), *MESS II*, 525-555. [10] Zolensky M. E. et al. (2002), *MAPS*, 37, 737-761. [11] Hyman M. and Howe M. W. (1983), *LPS XIII*, 736-740. [12] Thorpe A. N. et al. (2002), *MAPS*, 37, 763-777. [13] Bullock E. S. et al. (2005), *GCA*, 69, 2687-2700. [14] Browning L. B. et al. (1996), *GCA*, 60, 2621-2633. [15] Clayton and Mayeda (1999), *LPS XXX*. [16] Brandon A. D. et al. (2005), *GCA*, 69, 1619-1631. [17] Brown P. G. et al. (2000), *Science*, 290, 320-325. [18] Costa T. V. V. et al. (1997), *ICAME*. [19] Young E. D. et al. (1999), *Science*, 286, 1331-1335. [20] Pravdivtseva O. V. et al. (2003), *LPS XXXIV*, 1863.