Fe-Ni Sulphides as Indicators of Alteration in CM Chondrites

Conference or Workshop Item

FE-NI SULPHIDES AS INDICATORS OF ALTERATION IN CM CHONDRITES Bullock E. S.[1], Grady M. M.[2], Gounelle, M.[3], Russell S. S.[4] [1]Department of Mineral Sciences, National Museum of Natural History, Smithsonian Institution, Washington, DC 20560 USA (BullockE@si.edu). [2]Planetary Space Sciences Research Institute, The Open University, Walton Hall, Milton Keynes, Bucks MK7 6AA, UK. [3] Laboratoire d'Étude de la Matière Extraterrestre, Muséum National d'Histoire Naturelle, 57, rue Buffon, 75005 Paris, France. [4]Department of Mineralogy, The Natural History Museum, Cromwell Road, London SW7 5BD UK

Introduction: There are more CM chondrites known than any other type of carbonaceous chondrite [1], and CM material often occurs as clasts within other types of meteorite [2]. The CM chondrites show varying degrees of aqueous alteration, from relatively pristine CM2 chondrites that contain abundant anhydrous silicates, through to highly altered CM1 chondrites in which all olivine and pyroxene grains have been altered to form phyllosilicates [3]. Various methods have been proposed to define a sequence to determine a sequence from least altered to most altered. Previous work has focused on phyllosilicate abundance and composition [4], oxygen isotopic composition of carbonates, [5] and chondrule olivine and pyroxene abundance and composition [6] to determine alteration sequences, but these have not been consistent as to the sequence of alteration. In addition the mineral alteration index (MAI) devised by [4] has been to shown to correspond well with the year of fall of the chondrite, suggesting that it may not be a reliable measure of pre-terrestrial alteration [7]. In this study, we look at the composition of Fe-Ni sulphides in a range of CM chondrites, to see if sulphide composition and/or abundance correlates with other alteration features, and so whether they can provide information on the alteration undergone by individual CM chondrites. Fe-Ni sulphides are found in all CM chondrites, unlike carbonates and anhydrous silicates, which are absent from CM1 chondrites. Previous work on Fe-Ni sulphides in CI1 chondrites has demonstrated that increasing alteration increases the proportion of Ni present in pyrrhotite grains [8], and it appears that the same may be true for CM2 chondrites [9].

Method: Sulphide grains in thick and thin sections of ten CM2 chondrites (ALH81002, Bells, Cold Bokkeveld, Essebi, Mighei, Murchison, Murray, Nogoya, Pollen, and QUE99355) ranging from relatively pristine to extensively aqueously altered, and two CM1 chondrites (ALH88045 & MET01070) were analysed. The samples were primarily studied using a Jeol 5900LV SEM operating at 20kV and 1nA, and a working distance of 10mm. This allowed investigation of the morphology and size range of the grains, and also element mapping of the sections. Accurate quantitative analyses were obtained using a Cameca SX50 Electron Microprobe operating at 20kV and 20nA.

Results and Discussion: The CM1 chondrites contain abundant sulphide grains (~4.5 vol% in MET01070 and ~6.5 vol% in ALH88045). The sulphide grains are finely intergrown mixtures of pyrrhotite and pentlandite (fig. 1), so overlap of the phases during analyses was inevitable. The sulphides are rich in Ni, and no troilite was identified (fig. 2) The average composition of pyrrhotite and pentlandite in each chondrite is given in Table 1. The CM2 chondrites, as would be expected for such a diverse range of meteorites, show varying abundances of sulphides, from ~0.05% to 0.6%. Most contain pyrrhotite and pentlandite, although only pentlandite was observed in Pollen and ALH81002, and several also contain a sulphide of an intermediate composition. Troilite was observed only in Murchison (fig. 2)

The original sulphide present in the CM chondrites was probably troilite: troilite is the sulphide predicted to have formed first from a cooling nebular gas [10]. With increasing alteration, the troilite grains in the CM chondrites lose iron and nickel, forming pyrrhotite. The closer the stoichiometry of the pyrrhotite grains to troilite, the less altered the CM chondrite. According to this, the alteration sequence would be, in order of increasing aqueous alteration:

Murchison $\leq$ *Murray < Mighei < QUE99355 < Essebi < Bells < Cold Bokkeveld< Nogoya < MET01070* $\leq$ *ALH88045*

This broadly agrees with previous proposed sequences [4, 5, 6]; however there are some complexities in the overall picture of the composition and abundance of sulphide grains, so that sulphides alone cannot be used to judge the degree of aqueous alteration undergone by a particular CM chondrite. However, the Ni content of pyrrhotite grains does increase with increasing alteration, and so, used in conjunction with other features, can provide clues as to the degree of aqueous alteration.

References: [1] Grady M. M. (2000) Catalogue of Meteorites; [2] Gounelle M. (2003) *GCA* **67** p507-527; [3] Zolensky M. E. *et al* (1997) *GCA* **61** p5099-5115; [4] Browning L. B. *et al* (1996) *GCA* **60** p2621-2633; [5] Benedix G. K. *et al* (2003) *GCA* **67** p1577-1588; [6] Hanowski N. P. & Brearley A, J. (2001) *GCA* **61** p495-518; [7] Benedix G. K. & Bland P. A. (2004) 67th MetSoc, #5184; [8] Bullock E. S. *et al* (2005) *GCA* **69** p2687-2700; [9] Zolensky M. E. & Loan L. *LPSC* XXXIV #1235. [10] Grossman L (1972) *GCA* **36** p597-619.

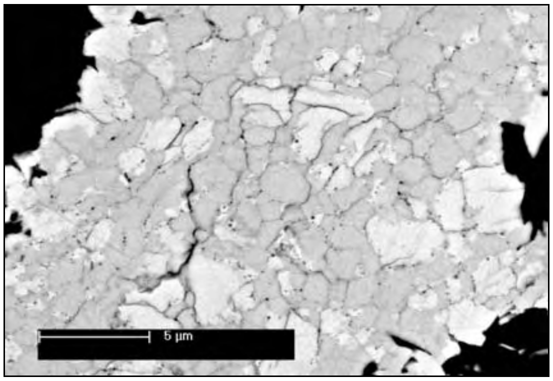
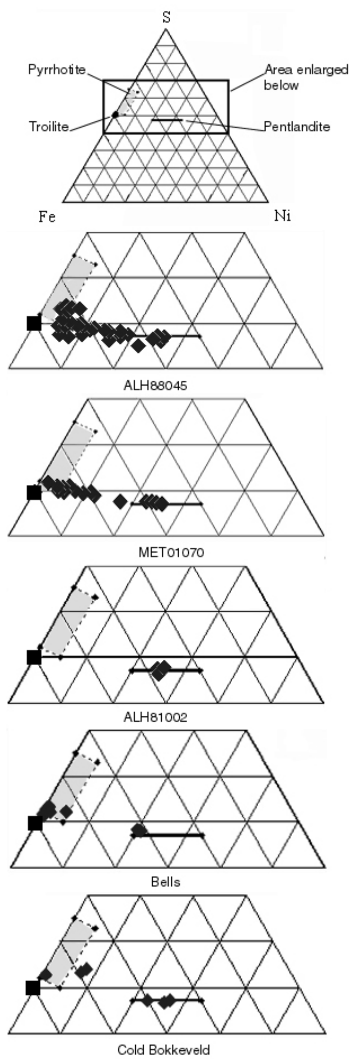


Figure 1. Intergrown pyrrhotite (dark grey) and pentlandite (light grey) in the CM1 chondrite ALH88045.

Meteorite	Sulphide content (%)	Average pyrrhotite composition	Average pentlandite composition
ALH88045	6.5	$(Fe,Ni)_{0.86}S$	$Fe_{4.87}Ni_{4.25}S_8$
ALH81002	0.1	N/A	$Fe_{4.67}Ni_{4.31}S_8$
Bells	0.5	$(Fe,Ni)_{0.9}S$	N/A
Cold Bokkeveld	0.05	$(Fe,Ni)_{0.9}S$	$Fe_{4.57}Ni_{4.40}S_8$
Essebi	0.3	$(Fe,Ni)_{0.91}S$	$Fe_{4.87}Ni_{4.14}S_8$
MET01070	4.5	$(Fe,Ni)_{0.86}S$	$Fe_{4.76}Ni_{4.20}S_8$
Mighei	0.4	$(Fe,Ni)_{0.93}S$	$Fe_{4.74}Ni_{4.22}S_8$
Murchison	0.6	$(Fe,Ni)_{0.99}S$	$Fe_{4.92}Ni_{3.96}S_8$
Murray	0.3	$(Fe,Ni)_{0.99}S$	$Fe_{4.89}Ni_{4.12}S_8$
Nogoya	0.4	$(Fe,Ni)_{0.88}S$	$Fe_{4.50}Ni_{4.50}S_8$
Pollen	0.5	N/A	$Fe_{4.90}Ni_{3.98}S_8$
QUE99355	0.1	$(Fe,Ni)_{0.93}S$	$Fe_{4.78}Ni_{3.84}S_8$

Table 1. Average pyrrhotite and pentlandite compositions within CM chondrites.



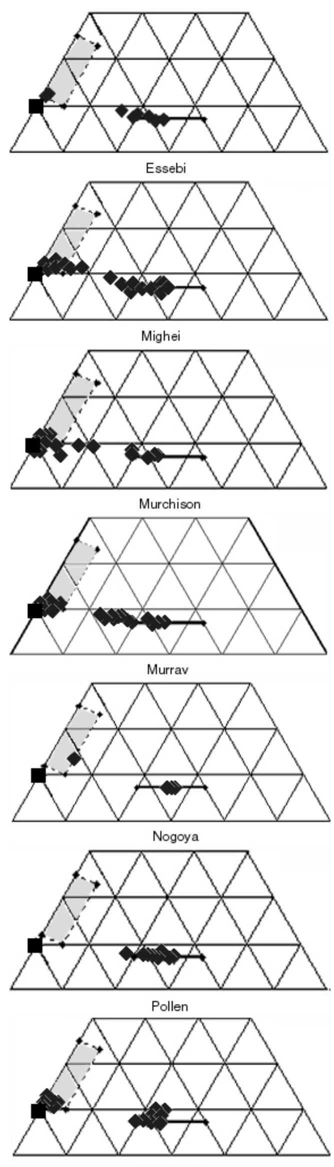


Figure 2. Composition of Fe-Ni sulphide grains in CM1 and CM2 chondrites, shown alphabetically.