A STUDY OF THE MORPHOLOGY, COMPOSITION AND MINERAL ASSOCIATIONS OF FE-NI SULPHIDES IN CM CARBONACEOUS CHONDRITES

E. S. Bullock[1], M. Gounelle[1,2], M. M. Grady[1], S. S. Russell[1], [1] Department of Mineralogy, The Natural History Museum, Cromwell Road, London SW7 5BD, UK. e-mail e.bullock@nhm.ac.uk. [2] CSNSM - Université Paris 11, Bâtiment 104, 91 405 Orsay Campus, France.

Introduction: The CM chondrites are a large group that show a wide range of aqueous alteration features [1]. Whilst a lot of attention has been paid to primary and secondary phases in the CMs, such as phyllosilicates [e.g. 2], carbonates [3], sulphates [4] and chondrule olivines and pyroxenes [e.g. 5], much less attention has been given to the opaque phases in these chondrites. The sulphides in particular are very interesting, as they might be products of sulphuration of metal grains by H_2S in the nebula [6]. Previous studies [e.g. 7] have tended to concentrate on sulphides in particular CMs; only one study [8] has looked for differences between the CM sulphides. Our study looks at some of the CMs included in that study, plus an additional group of CMs, to assess whether the observations noted by [8] apply to these samples.

Method: Five sections of the CM1 chondrite ALH88045 were studied, as well as a range of relatively pristine to extensively aqueously altered CM2's. The samples were primarily studied in a Jeol 5900LV Scanning Electron Microscope operating at 20kV and 1nA, and a WD of 10mm. This allowed us to look at the morphology and size range of the grains, and to obtain major element analyses of the sulphides. Accurate analyses of the minor elements present in the sulphides were obtained using a Cameca SX50 Electron Microprobe operating at 20kV and 20nA.

Results: Results from the CM2s are presented in order of increasing alteration according to [9]:

Murchison, the least altered CM2 of the group we studied, shows a range of Fe-Ni sulphide compositions from pyrrhotite, through intermediate sulphides to pentlandite (Fig. 1). Stoichiometric FeS (troilite) is also present. Most of the sulphides are pyrrhotite. The sulphides are large (>40µm in diameter, up to >100µm). They range in shape from rounded, "blobby" grains to euhedral grains in the matrix, and also form discontinuous rims around chondrules. Most are cracked across their surface, though not all. Some of the sulphides contain inclusions of matrix-like material: others have been partially oxidised to magnetite.

Bells, slightly more altered than Murchison, is less diverse in terms of its sulphide mineralogy. Again, both pyrrhotite and pentlandite are present, but there is no troilite, and no sulphide of an intermediate composition. (Fig. 1) The sulphides are rounded, cracked, and occur both as isolated grains in the matrix and as rims around chondrules.

Pollen, in contrast to the previous two chondrites, contains only pentlandite. The Ni content varies between 28 – 31wt% (Fig. 1). The grains in the matrix are around 10µm in diameter, rounded, and are dispersed sparsely throughout the matrix. Pentlandite is also found at one edge of a porphyritic olivine chondrule, within the fine-grained rim.

Mighei, like the majority of CM2s in this study, contains a range of Ni-poor to Ni-rich pyrrhotite grains, and Ni-poor and Ni-rich pentlandites. Few grains of an intermediate composition are found (Fig. 1). Pyrrhotite and pentlandite often occur within the same grain, but are not intergrown. A distinct boundary can be seen between the phases. Fe-Ni sulphide grains are rare in Mighei, but occur throughout the matrix as rounded, slightly cracked grains, and also as discontinuous rims around chondrules. The matrix grains can be up to 100µm in diameter. Rarely, Fe-sulphides and Fe-oxides form thick rims around metal grains (Fig 2).

Cold Bokkeveld, the most altered CM2, contains both pyrrhotite and pentlandite (Fig. 1). These two phases are rarely intergrown, and occur as small (10 - 30µm), irregular grains in the matrix. Some grains show alteration at the edges, others show no alteration but are extensively cracked along the surface. Two of the Fe-Ni sulphides show enrichment in Cu (0.15 and 0.38wt%) and Cr (0.13 and 0.12wt%) respectively.

We have also included in our study some CM2s that were not included in the alteration index of [9]. These are given below.

ALH81002: This chondrite, like Pollen, contains only pentlandite. The Ni content though is much more homogenous, between 31.5 – 33.7wt% (Fig. 1). The grains in the matrix are between 5 and 30µm, whilst the grains associated with chondrules are between 5 and 50µm.

Essebi: This unusually magnetite-rich CM2 also contains very interesting sulphide grains. Pyrrhotite and pentlandite (but not troilite or intermediate sulphide) are present (Fig. 1). The grains occur as irregular masses around silicate grains, as discreet grains in the matrix and as associated phases with chondrules. One interesting "flame-like" intergrowth of pyrrhotite and pentlandite has been noted (Fig. 3).

QUE99355: Pyrrhotite, pentlandite and troilite are found in QUE99355 (Fig. 1). Clear boundaries can be seen between the pyrrhotite and pentlandite where they occur in the same grain: the phases are not intergrown. The grains are found in the matrix, and associated with chondrules, where they are found inside the fine-grained rim.

The sulphides in the CM1 chondrite ALH88045 are the most diverse found in any single CM chondrite. The size of the sulphides ranges from <10µm to >300µm. They occur as rims around remnant chondrules and lumps of matrix, and also occur as isolated grains in the matrix. Some of the matrix grains are rounded: others are irregular, forming "tendrils" or "crosses" that taper out into the matrix (Fig. 4). The rims around Mg-rich matrix lumps and remnant chondrules are discontinuous and variable in thickness, between 10µm and 150µm. The grains are often porous. The composition of the sulphides in ALH88045 ranges from pyrrhotite ($[Fe,Ni]_{1-x}S$) to pentlandite ($[Fe,Ni]_9S_8$) with sulphides of an intermediate composition also apparently present (Fig. 1). The pyrrhotite and pentlandite are very finely intergrown. The intermediate sulphides are probably a result of beam overlap of the pyrrhotite and pentlandite in this case: high-magnification images show the level of intergrowth (Fig 5.)

Discussion: We agree with [8] that the alteration that has occurred to the Fe-Ni sulphides in the CM chondrites does not follow any simple direction. The number and texture of the sulphides does not change with increasing alteration. This supports a nebula origin for CM sulphides. Aqueous alteration of the sulphides has however had an effect on composition: the sulphides that have undergone most alteration have a lower Ni content in their pyrrhotite.

References: [1] Zolensky, M. E. *et al* (1997) *GCA* **61** p5099-5115. [2] Grady, M. M. *et al* (1997) Workshop on Parent-body and nebular modification of chondritic materials, *LPI technical report*, p17-18. [3] Benedix, G. K. *et al* (2003) *GCA* **67** p1577-1588. [4] Lee, M. R. (1993) *Meteoritics* **28** p53-62. [5] Hanowsi, N. P & Brearley, A. J. (2001) *GCA* **65** 495-518. [6] Zolensky, M. E. & Thomas, K. L. (1995) GCA 59 4707-4712. [7]Kerridge, J. F *et al* (1979) *EPSL* **43** p1-4 [8] Zolensky, M. E. & Loan, L. (2003) LPI XXXIV, 1235. [9] Browning, L. B *et al* (1996) *GCA* **60** p2621-2633. [10] Lauretta *et al* (1998) *MAPS* **33** p821-833.

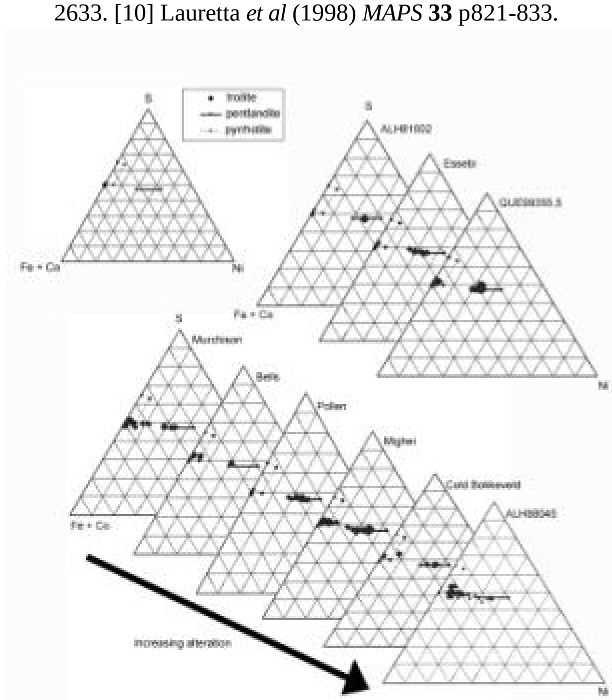
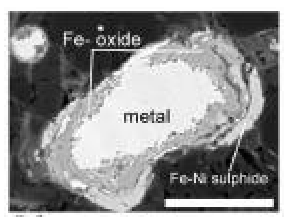
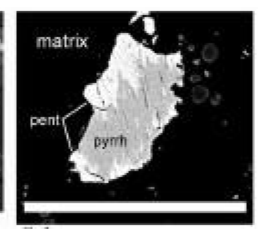
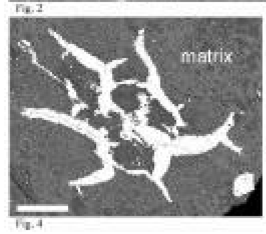


Fig. 1. Triangular diagrams showing the compositional range of Fe-Ni sulphides in CM1 and CM2 carbonaceous chondrites. Bottom row of diagrams shows increasing alteration, according to [8]; top row of diagrams shows CM2s not included in the study by [8].







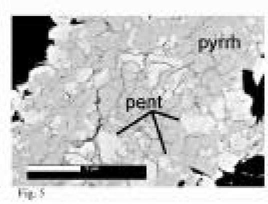


Fig. 2. Metal grain with Fe-oxide and Fe-Ni sulphide rims in Mighei. Scale bar is 30µm. Fig. 3. Intergrown pyrrhotite and pentlandite in Essebi. Fig. 4. BSE image of intergrown pyrrhotite and pentlandite (white) in matrix (grey) in ALH88045. Scale bar is 200µm. Fig. 5 High-contrast image of intergrown pyrrhotite and pentlandite in ALH88045. Scale bar is 5µm.