DIFFERENT DEGREES OF AQUEOUS ALTERATION IN SULPHIDES WITHIN THE CI1 CHONDRITES

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Introduction: It has been well documented that all of the CI1 chondrites have undergone extensive aqueous alteration, [1] which has modified the texture and composition of the minerals present. In this study, we look at the effect of aqueous alteration on Fe-Ni sulphides in four different CI1 chondrites, with a view to identifying variable degrees of aqueous alteration within CI1 chondrites.

Method: Images were obtained using a Jeol 5900LV SEM operating at 20kV and 1nA, with a working distance of 10mm. Quantitative analyses were performed using a Cameca SX50 EMP operating at 20kV and 20nA. Elemental mapping was done both on the SEM and the EMP. Two thin sections of Alais, two of Tonk, one of Ivuna and three of Orgueil were examined. The sections of Orgueil were prepared without using water, in order to try and preserve any water-soluble phases present. Looking at thin sections allowed us to study the sulphides *in situ*, and observe their spatial relationships to other minerals. This contrasts with the study of CI1 pyrrhotite and pentlandite performed by [2], in which they analysed hand-picked or magnetically separated grains.

Observations: The main type of Fe-Ni sulphide found in the CI1 chondrites is pyrrhotite. Occasional small (~10μm) irregular inclusions of pentlandite have been found within pyrrhotite grains in Alais and Tonk. These have not been seen in either Orgueil or Ivuna. The pyrrhotites are hexagonal or lath-shaped, and range in size from approximately 10μm in diameter to around 80μm. Those in Alais and Tonk are, on average, larger than those seen in Orgueil and Ivuna. Some of the pyrrhotite grains are extensively corroded (*fig. 1)*, particularly those in Orgueil and Ivuna. Corrosion occurs at the edge of grains, as well as the interior, with material similar in composition to the matrix filling the spaces, although it is difficult to obtain accurate analyses as the corroded areas are so small. Both Orgueil and Ivuna contain more magnetite than Alais or Tonk, with magnetite occurring as framboids, spherules and plaquettes.

These observations are compatible with the data and observations from previous studies [e.g. 2,3].

Discussion: From looking at the texture, morphology and composition of the sulphides in the four different CI1 chondrites, we suggest there are two subgroups within the CI1 clan. It has also been noted by several other authors that there are other petrological and mineralogical differences between Alais and Tonk, and Orgueil and Ivuna. For example, the CI1 chondrites display a range of aqueous alteration features, with Orgueil being the most extensively altered, followed by Ivuna, then Tonk, with Alais the least altered [3]. The degree of oxidation reflects this, with Orgueil containing the greatest proportion of Fe^{3+} (~95%), and Alais containing the least (~90% Fe^{3+}) [4]. Alais and Tonk contain many large (>100μm) coarse phyllosilicates, whereas Orgueil and Ivuna contain smaller (<60μm) phyllosilicate aggregates [5]. The differences in the quantity of magnetite between Alais and Tonk, and Orgueil and Ivuna, were first noted by [6], who quoted figures of ~8.5% and ~11% respectively. They were the first to suggest possible division of the CI1 chondrites into two subgroups.

Since the CI1's have a similar bulk chemistry [7], the differences between them appear to be due to the extent of remobilisation of elements during differing periods of aqueous alteration, rather than different starting materials.

The method of formation of the Fe-Ni sulphides in the CI1 chondrites is still unclear; whether they formed in the solar nebula or on the parent body is unknown. However we may begin to make tentative suggestions as to the effects of subsequent aqueous alteration on the sulphides on the CI1 parent body. Based on our own petrological and mineralogical studies, and observations by other authors, we propose the following for the sequence of alteration to the sulphides.

During, or after formation/emplacement of the pyrrhotite and pentlandite on the parent body, hydrothermal fluids began to circulate. In addition to alteration of the matrix, the fluids began to dissolve some of the pentlandite, producing the "corroded" texture

seen in many of the sulphides in the CI1's. After a period of time, the alteration to the region of the parent body from which Alais and Tonk were derived ended: either the fluid stopped circulating round the parent body, or it was too cool to dissolve any more pentlandite. The alteration to the Orgueil and Ivuna region continued however, dissolving the rest of the pentlandite and resulting in the more corroded texture of the remaining pyrrhotites.

The dissolved Ni was circulated by the fluid and re-deposited in the matrix. This would explain why Orgueil and Ivuna have noticeably higher matrix NiO content (~2.77 wt%) than either Alais or Tonk (~1.7 wt%). [8]. Some of the Ni in Orgueil and Ivuna might have combined with Na to form Ni-blodite, a sodium nickel sulphate (observed in Orgueil and Ivuna by [9]). This in turn would help to explain the lower Na content of the matrix in Orgueil and Ivuna (~0.06wt%, compared to ~1.46 wt% in Alais and Tonk) [8].

Summary: Our studies of the sulphides present in the four CI1 chondrites, combined with work undertaken by other authors, has led us to the conclusion that the CI1 chondrites could be divided into two subgroups, as has been done for the CV3 chondrites [10]. One sub-group, consisting of Alais and Tonk, has undergone a period of aqueous alteration, but some pre-alteration minerals such as pentlandite are still present. The other sub-group, consisting of Orgueil and Ivuna, appears to have undergone a longer period of aqueous alteration, which has dissolved any pentlandite, further altering the mineralogy of these two chondrites.

References: [1] Zolensky M. & McSween H. Y. (1998) *Meteorites and the early solar system* p114-143. [2] Kerridge J. F. *et al*. (1979) *EPSL* **43** p359-367. [3] Endress M. & Bischoff A. (1996) *GCA* **60** p489-507. [4] Bland P. A. (2002) Personal communication. [5] Endress M. & Bischoff A. (1993) *Meteoritics* **28** 345 *(Abstract)*. [6] Hyman M. & Rowe M. W. (1983) *Jour. Geophys. Res.* **88** p A736-A740. [7] Kallemeyn G. W. & Wasson J. T. (1981) *GCA* **45** p1217-1230. [8] Zolensky *et al* (1993) *GCA* 57 p3123-3148. [9] Frederiksson K. & Kerridge J. F. (1988) *Meteoritics* **23** p35-44 [10] McSween H. Y. (1977) *GCA* **41** p1777-1790.
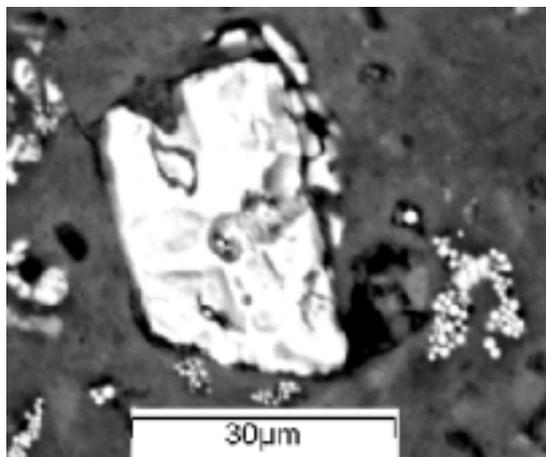

Figure 1. SEM image of a pyrrhotite grain in Orgueil. Note the corrosion occurs around the outside of the grain, as well as the interior.