The Relationship between CI Falls and CI Finds. A. J. King[1], P. F. Schofield[1], K. T. Howard[2] and S. S. Russell[1], [1]Department of Earth Sciences, Natural History Museum, Cromwell Road, London SW7 5BD, UK. [2]Kingsborough Community College of the City University of New York, USA. E-mail: a.king@nhm.ac.uk

Introduction

The CI chondrites are some of the most hydrated meteorites available to study, making them ideal samples with which to investigate the nature of water in the early Solar System. However, they are extremely rare. Over the last ~200 years only five CI chondrites, Alais, Orgueil, Tonk, Ivuna and Revelstoke, have been recovered after being seen to fall to Earth. They consist of a fine grained (<1 µm) phyllosilicate-rich matrix, oxides, carbonates and sulphides that were produced by extensive aqueous alteration of anhydrous precursor materials.

In the last ~30 years a further five meteorites with CI characteristics, Y-82162, Y-86029, Y-86737, Y-980115 and Y-980134, have been found in the Yamoto mountains of Antarctica. The mineralogy of the CI finds is similar to the falls but they typically have unusual O isotopic compositions and contain less H_2O [e.g. 1]. In Y-82162 and Y-86029 there is abundant fine grained olivine that likely formed through partial dehydration of phyllosilicates at temperatures of >500°C [1–3]. These meteorites have therefore been classified as CI-like chondrites that experienced both aqueous alteration and thermal metamorphism.

Unravelling the effects of secondary processing on the mineralogy of the CI chondrites has important implications for understanding the formation and evolution of the CI parent body(ies) and assessing their potential as a source of volatiles to the Earth. Here, we have used position sensitive detector X-ray diffraction (PSD-XRD) and infrared (IR) spectroscopy to determine the extent of aqueous and thermal alteration in the CI falls and CI finds, and examine the relationship between these groups of meteorites.

Experimental

For PSD-XRD analysis chips (~0.05 – 0.2 g) of Alais, Orgueil (*n* = 3), Ivuna (*n* = 2), Y-82162 and Y-980115 were powdered (<37 µm), packed into Al-wells, and then measured for up to 16 hours. Pure mineral standards were analyzed under the same conditions for 30 minutes. Modal abundances were determined for each phase present in the CI chondrites at >1 wt% using the method of [4], with uncertainties of <5 %. Following the PSD-XRD analyses, ~3 mg aliquots of the Orgueil, Ivuna, Y-82162 and Y-980115 powders were mixed with 300 mg of KBr and compressed to form pellets. The pellets were heated to 300°C for 3 hours to minimize the effects of adsorbed water before transmission mid-IR spectra were obtained in low vacuum using a Bruker Vertex 80V FTIR interferometer.

Results

The CI falls Alais, Orgueil and Ivuna contain high abundances of a mixed serpentine/saponite phyllosilicate (>80 vol%), plus magnetite (6.8 – 9.2 %), and minor sulphides (3.6 – 6.6 %) and carbonates (1.8 – 3.4 %) (Fig. 1). The CI finds Y-82162 and Y-980115 contain lower abundances of poorly diffracting serpentine/saponite (68.1 – 70.9 vol%), and significant amounts of sulphide (18.6 – 19.1 %) and olivine (8.3 – 10.6 %).

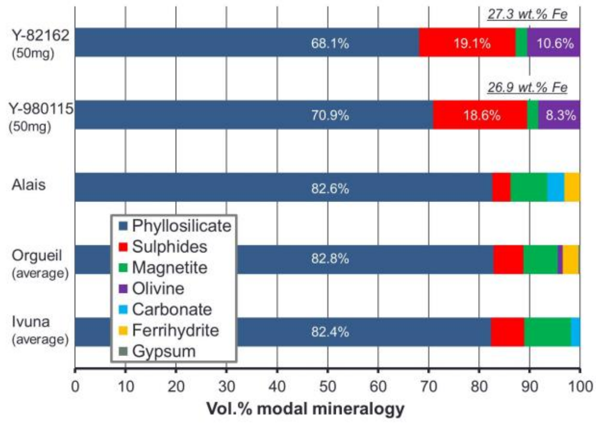

Fig. 1. Modal mineralogy of the CI falls and CI finds determined by PSD-XRD.

The main features in the IR spectra of Orgueil and Ivuna are a broad peak at ~9.9 µm and a doublet at ~23 µm from the Si-O stretching and bending modes (Fig. 2). At ~2.71 µm the CI falls display a sharp peak from the OH stretching mode, which can be attributed to hydroxyl ions structurally bound within disordered, serpentine and saponite rich phyllosilicates (Fig. 3). We note a good match between the IR spectra of the CI falls and a mixed serpentine/saponite standard from our laboratory. For Y-82162 and Y-980115 we again observe a broad peak at ~9.9 µm, which we attribute to the highly disordered serpentine/saponite phyllosilicate. However, the doublet at ~23 µm is less prominent and the 2.71 µm feature is absent in these meteorites. Instead we find intense peaks at ~11.2 µm, ~16.5 µm and ~19.5 µm that are consistent with the presence of olivine.

Discussion

The dominant component in both the CI falls Alais, Orgueil and Ivuna, and the CI finds Y-82162 and Y-980115, is a serpentine/saponite phyllosilicate that formed during a period of severe hydration on their parent body(ies). Phyllosilicate compositions in the CI finds are comparable with those in the CI falls suggesting that the starting mineralogy and aqueous alteration process was similar for each group [1–3]. Nevertheless, the XRD patterns, modal mineralogy and IR spectra of the CI finds are distinct from the falls, indicating that they experienced a different alteration history. In particular, the CI finds contain less phyllosilicate (~70 vol% vs. ~80 vol%), much higher abundances of olivine (~10 vol%) and sulphide (~20 vol%), and lack the 3 μm band in the IR spectra. These features can all be attributed to the CI finds having suffered post-hydration thermal metamorphism. From our XRD patterns we infer that Y-82162 and Y-980115 were heated to temperatures of 500 – 750°C [5], in good agreement with estimates by trace element chemistry [2, 3]. In contrast the CI falls were never heated above ~150°C suggesting that thermal metamorphism of a single CI parent body was a heterogeneous process, or the CI falls and finds are derived from different sources.

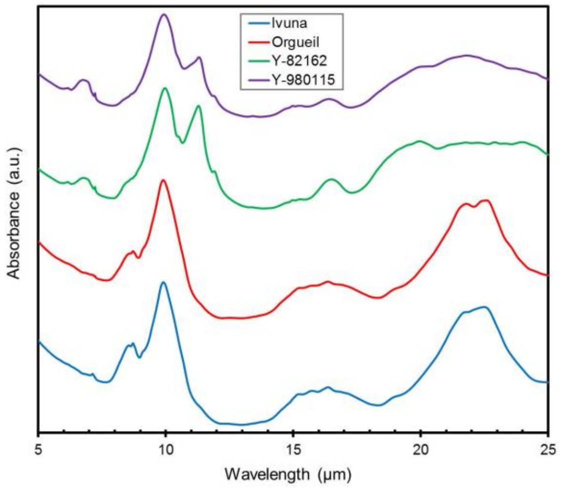

Fig. 2. Transmission IR spectra (5 – 25 μm) of the CI falls Orgueil and Ivuna and the CI finds Y-82162 and Y-980115.

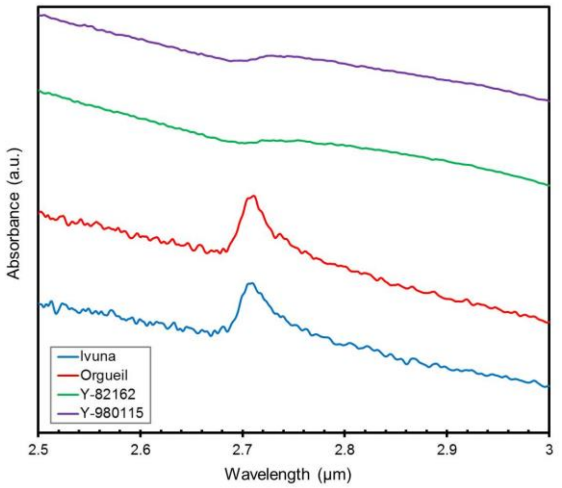

Fig. 3. Transmission IR spectra (3 μm region) of the CI falls Orgueil and Ivuna and the CI finds Y-82162 and Y-980115.

Oxygen isotopic compositions hint that the CI finds are from the same parent body as the CI falls. Y-82162 (and Y-86029) has a heavier O isotopic composition ($\delta^{17}O$ ~12 ‰, $\delta^{18}O$ ~22 ‰) than Alais, Orgueil and Ivuna ($\delta^{17}O$ ~9 ‰, $\delta^{18}O$ ~16 ‰) [6], which has been explained as mass-dependent isotope fractionation driven by thermal metamorphism. The predicted fractionation is as much as 6 – 8 ‰ in $\delta^{18}O$ suggesting that prior to heating the O isotopic composition of the CI finds could have been close to that of the CI falls [6].

Astronomical observations have tentatively linked the CI chondrites to low albedo asteroids [e.g. 7], although comets have also been proposed as a possible source for these meteorites [e.g. 8]. If the CI parent body was large enough (>20 km), internal temperatures of 500 – 700°C could have been produced by the radioactive decay of ^{26}Al [9]. However the timescale for this process, 10^6 – 10^8 years, is inconsistent with studies showing that thermal metamorphism of carbonaceous chondrites took place on the order of hours to several years [e.g. 10]. Shock heating from impacts could generate suitable temperatures but is predicted to last only seconds [11]. Alternatively, small bodies approaching within <0.1 A.U. of the Sun are heated to >500°C by solar radiation over a period of days to years [12].

Perhaps the CI finds are meteoroids from the disruption of a larger single CI parent body that passed close to the Sun before arriving on Earth? Or they come from a separate, although similar, parent body with a low perihelia orbit, such as some near-Earth objects (NEOs)?

References

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Acknowledgements

We are grateful to the beamline scientists of B22 at the Diamond Light Source, UK, for access to their offline FTIR spectrometer. This work was funded by the Science and Technology Facilities Council (STFC), UK.