FE-SULFIDES IN EXPERIMENTALLY AND NATURALLY HEATED CM CHONDRITES

C. S. Harrison¹,2, A. J. King¹ and R. H. Jones²

¹ Planetary Materials Group, Natural History Museum, London. E-mail: c.harrison@nhm.ac.uk. ²Department of Earth and Environmental Sciences, University of Manchester, UK.

Introduction: A limited number of CM carbonaceous chondrites (CCs) experienced post-hydration heating (>300 ⁰C) on their parent body [1,2]. However, the timing, duration and mechanism of the dehydration event(s) remain poorly constrained. Constraining the thermal history of the CCs is an important step to understanding the distribution and transport of volatiles in the early solar system. The dehydrated CM chondrites contain Fe-sulfide grains, specifically pyrrhotite ([Fe,Ni]₃S) containing inclusions of pentlandite ([Fe,Ni]S₈), with compositions and textures that are diagnostic of their thermal history [3,4]. For example, at temperatures >610 ⁰C, pentlandite is expected to thermally decompose into a Ni-rich metal [3,4]. Here, we have experimentally heated chips of the unheated CM2 chondrite Murchison under conditions aimed to replicate those on the parent body of dehydrated CM chondrites [4]. We then investigate the composition and occurrence of pentlandite and Ni-rich metal in the coarse (>10 μm) Fe-sulfide grains within the experimental products, and compare results with unheated CMs and CMs of heating Stage II (peak temperature ~300 – 500 ⁰C), Stage III (peak temperature ~500 – 750 ⁰C), and Stage IV (peak temperature >750 ⁰C) [1].

Samples & Methods: Twelve Murchison (CM2) chips (~1 mm in size) were heated in a Deltech one-atmosphere furnace. The chips were wrapped in gold foil and placed in evacuated silica glass tubes along with pieces of Fe,Ni metal, pyrrhotite and pentlandite to maintain /fO₂ at the iron-wüstite buffer and /fS₂ at the iron-troilite buffer. Experiments were run at peak temperatures (T_max) of 500 ⁰C, 700 ⁰C and 900 ⁰C, and cooling rates of 100 °C/min, 10 °C/min, 1 ⁰C/min, and 0.1 ⁰C/min, resulting in runs lasting from 1 hour up to 101 hours.

We identified coarse (>10 μm) Fe-sulfide grains in polished sections of the experiment run products and in the unheated CM chondrites Murchison (CM2), Winchcombe (CM2), Kolan (CM1/2), and Cold Bokkeveld (CM2), the heated CM chondrites Jbilet Winselwan (CM2, Stage II), Dhofar (Dho) 1434 (CM_an, Stage III), Pecora Escarpment (PCA) 91008 (CM2_an, Stage III), PCA 02010 (CM2, Stage IV), and PCA 02012 (CM2, Stage IV). Sulfides were characterized using a ZEISS EVO 15LS scanning electron microscope with an energy dispersive X-ray spectrometer. Spot analyses were acquired at 20 kV and 1.5 nA. To exclude results that overlap multiple phases within a single Fe-sulfide grain, we classify analyses as pentlandite when S/(Fe+Ni+S) = 0.465 – 0.475.

Results: We find at least one occurrence of pentlandite within the Fe-sulfide grains of all unheated and naturally heated CM samples in this study. In the experimentally heated Murchison chips, we observe pentlandite in every experimental run with T_max of 500 ⁰C and 700 ⁰C, while at 900 ⁰C it is only present in the 100 °C/min run. Ni-rich metal is only observed in the Stage III and Stage IV naturally heated samples, while in our experimentally heated chips it is only observed in the 700 ⁰C and 900 ⁰C runs. The Ni content of pentlandite systematically decreases with increasing heating stage in the naturally heated CMs, and with increasing T_max in experimentally heated chips (Fig. 1). This trend is irrespective of the cooling rate in the 500 ⁰C and 900 ⁰C runs, while in the 700 ⁰C runs the Ni-content of pentlandite also decreases with slower cooling rates.

Discussion: Changes in Ni content of pentlandite with heating stage and with T_max in experiments suggests that pentlandite compositions could be used as an indicator of heating stage in unclassified samples or clasts. The occurrence of pentlandite alongside Ni-rich metal in the Stage III and Stage IV CMs suggests that while pentlandite has begun to thermally decompose at >610 ⁰C as expected [3,4], the heating events were too rapid for complete pentlandite thermal decomposition. Our experimental results constrain the rate of pentlandite decomposition to days with a T_max of 700 ⁰C or hours at a T_max of 900 ⁰C. The pentlandite-bearing Stage IV CMs were therefore likely heated on the order of hours to days, consistent with short-duration timescales inferred from the structure of organics [5] and heating estimates of ~100 hours at 900 ⁰C from minimal Fe-Mg interdiffusion between chondrule olivine and matrix [6]. Heating on the order of hours to days is more consistent with impact heating rather than heating via solar radiation or radiogenic decay [1,7].


Figure 1. FeNiS ternary diagram (at %) showing pentlandite compositions in a) CM chondrites and b) experimentally heated Murchison.