UNRAVELING THE RECORD OF NEBULAR AND ASTEROIDAL PROCESSES IN THE MURCHISON (CM2) METEORITE: PENTLANDITE FORMATION AND ITS ASSOCIATION WITH ZINC MOBILITY. K. A. Dyl[1,2], P. A. Bland[1], and J. S. Cleverley[2]. [1]Department of Applied Geology, Curtin University, GPO Box U1987, Perth, WA 6845, Australia. Email: katie.dyl@curtin.edu.au. [2]CSIRO Earth Sciences and Resource Engineering, 26 Dick Perry Avenue, Kensington, Perth, WA 6151, Australia.

Introduction: Carbonaceous chondrites (CCs)- primitive, undifferentiated rocks- preserve a complex record of nebular and asteroidal processes in the Early Solar System. CM meteorites have been of noted interest due to the range of alteration they seem to preserve [e.g. 1] as well as the presence of prebiotic molecules and their astrobiological implications. Nevertheless, the mechanisms and character of this alteration are poorly constrained. While several models argue for fluid flow and extensive water-rock interaction at large scales [e.g. 2,3], the elemental signatures preserved in these meteorites suggest limited element mobility [4].

By understanding the behavior of trace elements at both micron and cm-scales, we are able to better constrain the conditions of water-rock reactions as well as discern the preservation of nebular signatures. Zinc is a particularly important element, as it is both mobile during aqueous alteration and considered a volatile element [5,6]. However, its low abundance in CCs has prevented detailed studies of its chemistry in these rocks. Here we have utilized novel instrumentation to map [Zn] in a Murchison thin section, revealing important insights into both its behavior during aqueous alteration and its condensation from the Solar Nebula.

Methods: High-resolution (pixel size = 2 μm) element mapping of an 85 μm thick Murchison thin section was performed on the X-ray Fluorescence Microscopy beamline at the Australian Synchrotron, Victoria, Australia [7]. The detailed experimental design, data reduction, and complete suite of elements analyzed can be found in [8]. Subsequent mapping was undertaken at Centre for Microscopy, Characterization, and Analysis at the University of Western Australia using a Zeiss 1555 FESEM.

Results: While a complete data set (high-resolution maps for ~20 elements) has been obtained, the results we report here deal primarily with the distribution of Zn. While there appears to be Zn enrichment within several chondrule rims, the highest levels are associated with Ni-rich features.

Of these objects associated with high [Zn], we examined 14 of them; 12 of these had clear associations with pentlandite. We have selected 4 that represent commonly observed textures and an evolution in mineralogy. These are seen in Figure 1 accompanied by composite RGB images illustrating the association of Zn, Ni, and Fe with the object. All have a "halo" of Zn extending into the matrix. Additionally, these opaque nodules have a (partial) pentlandite rim or are entirely composed of pentlandite. The interiors vary: Object 1; pyrrhotite (displaying exsolution textures of pentlandite indicative of low-temperature cooling as described in [9]); Object 2, both pyrrhotite and magnetite; Object 3, magnetite; and Object 4, pentlandite. The concentration of Zn at the rim of these features varies from a maximum of ~0.6 wt% (Objects 1,2, 3) to 1.4 wt % in Object 4.

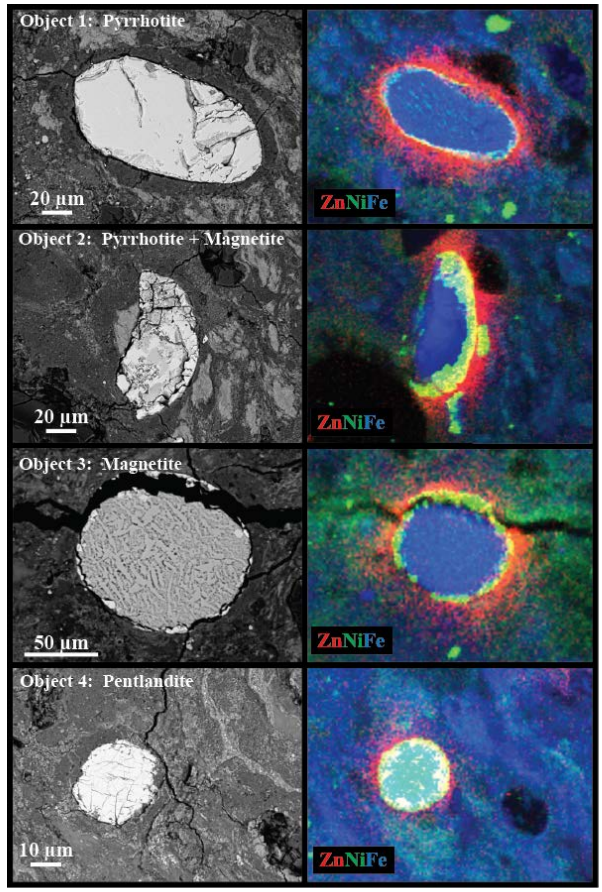

Figure 1: BSE imgase for 4 objects, all of which display pentlandite rims and Zn "haloes" into matrix. To their right are the corresponding x-ray fluorescence (XRF) maps obtained. Colors are: RGB=Zn, Ni, Fe.

Object 4 is also unique, as we have located what we believe to be a sphalerite grain in association with an Os-bearing refractory metal particle within its interior. This assemblage is shown in Figure 2, where both BSE

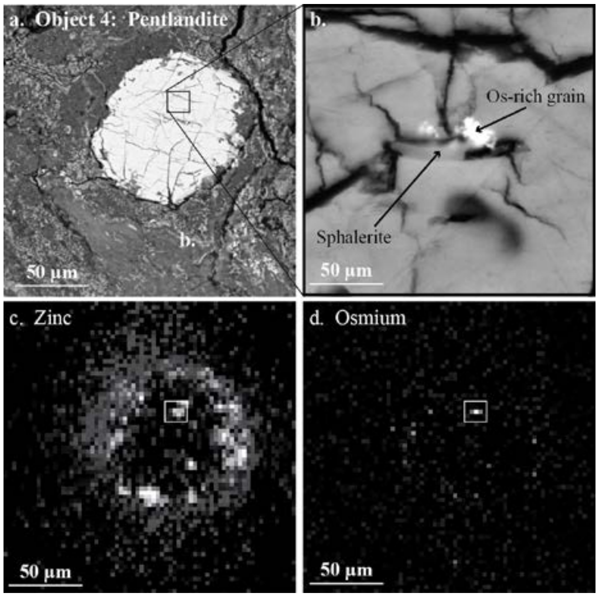

Figure 2: a. BSE image of Object 4 as seen in Figure 1. b. BSE image from interior of the pentlandite grain (as indicated by the black box in (a)). The grains of sphalerite and Os-bearing metal are identified. c. Zinc distribution as mapped at the Australian Synchrotron showing both a Zn-enriched rim and a Zn "hotspot" within the object that corresponds to the grain in (b) (the area is indicated by the white box). d. Os distribution as mapped at the Australian Synchrotron. The Os "hotspot" corresponds to the grain in (b).

and X-ray fluorescence data confirm their presence. Prior to this, sphalerite had been detected in a Stardust track associated with Ni-poorpyrrhotite [10]. To our knowledge, it has not been identified in CCs.

Implications: *Aqueous Alteration.* The textures we observe indicate that Zn condensed within this opaque phase and was later mobilized via aqueous alteration on the parent body. This is supported by the decreasing [Zn] further away from these objects, as well as its association with pentlandite. As observed in Figure 1 (Object 3), an opaque inclusion where only one half appears to have a pentlandite rim, Zn is only associated with that side of the object. The other half appears to be undergoing alteration to magnetite (within the object) and tochilinite/ cronstedtite (at the interface with matrix).

While it has been shown that pentlandite may be a nebular byproduct of reactions between metal and H_2S, those experiments resulted in fine-grained pentlandite inclusions in pyrrhotite due to the sluggish diffusion of Ni in metal [11]; this is not consistent with the rim textures we observe, the association with magnetite, or the sulfide assemblages containing solely pentlandite. Thus, we favor a model where pentlandite, in addition to the Zn mobility associated with this phase, both result from aqueous alteration in a parent body setting.

This is consistent with work on CI chondrites, which concludes that pyrrhotite and pentlandite are products of troilite alteration [12]. It has also been demonstrated that both Ni and Zn are mobile under acidic conditions, reprecipitating as sulfides when conditions become more reducing [13]. We see this mobility in both elements across the thin section; however, it indicates a more complex alteration history, as we expect serpentinizing fluids to be basic in character.

Condensation Phase of Zinc. It is not clear whether these objects were originally metals or sulfides prior to parent body alteration; however, many lines of evidence suggest that they accreted as primary sulfides. Condensation models predict Zn will form in solid solution with olivine and pyroxene [5,6]. But the condensation temperature predicted for Zn-sulfides is only marginally lower than that of silicates (724K vs. 704K) [6]; thus, in an unequilibrated, rapidly cooling system, Zn could be incorporated into troilite [7].

Furthermore, studies of metal alteration in CMs find that tochilinite and cronstedtite are the primary phases formed; while magnetite and pentlandite can form as well given different fluid chemistries, pyrrhotite is not documented. [14].

Conclusions: We have shown that Zn in the Murchison meteorite, and potentially other CMs, displays short-scale mobility in association with sulfides, particularly pentlandite. The features are the result of aqueous alteration in the parent body, as we see decreasing [Zn] extending into matrix. Zinc therefore likely condensed into sulfides in the Solar Nebula prior to parent body incorporation.

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