FINE-GRAINED EQUANT TROILITE IN THE CM CHONDRITE SHIDIAN: POTENTIAL EVIDENCE FOR LOW TEMPERATURE POST-HYDRATION HEATING. L. E. Jenkins[*1], M. R. Lee[1], L. Daly[1,2,3], and S. Li[4], [1]School of Geographical and Earth Sciences, University of Glasgow, Glasgow, Scotland [2] Space Science and Technology Centre, School of Earth and Planetary Sciences, Curtin University, GPO Box U1987, Perth, WA, 6845, Australia [3]Australian Centre for Microscopy and Microanalysis, The University of Sydney, NSW, 2006, Australia [4]Lunar and Planetary Science Research Center, Institute of Geochemistry, Chinese Academy of Sciences, Guiyang 550081, China [*]Corresponding Author: *l.jenkins.1@research.gla.ac.uk*

Introduction: CM chondrites have all undergone aqueous alteration, which occurs at temperatures less than 150 °C [1]. Some CM chondrites have also experienced heating at temperatures greater than 150 °C after aqueous alteration in a process known as post-hydration heating [2]. For post-hydration heating occurring at temperatures exceeding 300 °C, there are several textural indicators, however in the temperature range of 150-300 °C there are few indicators. This makes identification of meteorites that have experienced low-temperature post-hydration heating difficult [2]. One of the signs of post-hydration heating that occurs below 300 °C is tochilinite dehydrating and forming troilite, at temperatures around 245 °C [3].

Shidian has experienced extensive aqueous alteration (subtype CM2.2) and fell in 2017 [4]. It still contains tochilinite and therefore has not experienced post-hydration heating exceeding 245 °C. However, Shidian's tochilinite has a peculiar textural relationship with troilite (Fig. 1). This work aims to evaluate this textural relationship, as it could be due to the incomplete recrystallization of tochilinite into troilite during low temperature post-hydration heating.

Methods: A polished section of Shidian was studied by Backscattered Electron (BSE) imaging and Energy Dispersive X-ray Spectroscopy (EDS). BSE images and EDS chemical maps and data were acquired with a Carl Zeiss Sigma Variable Pressure Analytical SEM at the ISAAC lab at the University of Glasgow.

Results: Several tochilinite-troilite globules occur on chondrule edges and have fractures radiating out from their edges. They often show more extensive fracturing than the matrix (Fig. 1A and 1C). Sulphides often occur along fractures inside the globules (Fig. 1A). Some sulphides also form semi-concentric layers within a few of the globules (Fig. 1B). In one instance, sulphides rimming a tochilinite globule were associated with Fe-bearing serpentine (Fig. 1C). The sulphides are all fine grained and equant, no more than 5 µm in size. The Ni content of the sulphides varies (Fig. 1 and 2B). Most are troilite, however pentlandite also occurs.

In BSE images, the tochilinite near the sulphides is darker (had a lower atomic number) than the tochilinite farther away (Fig. 1). The tochilinite varies in composition (Fig. 2A), with darker areas usually being depleted in S compared to brighter areas (Fig. 2A). One exception was a globule of tochilinite that was enriched in Fe (Fig. 1C and 2A).

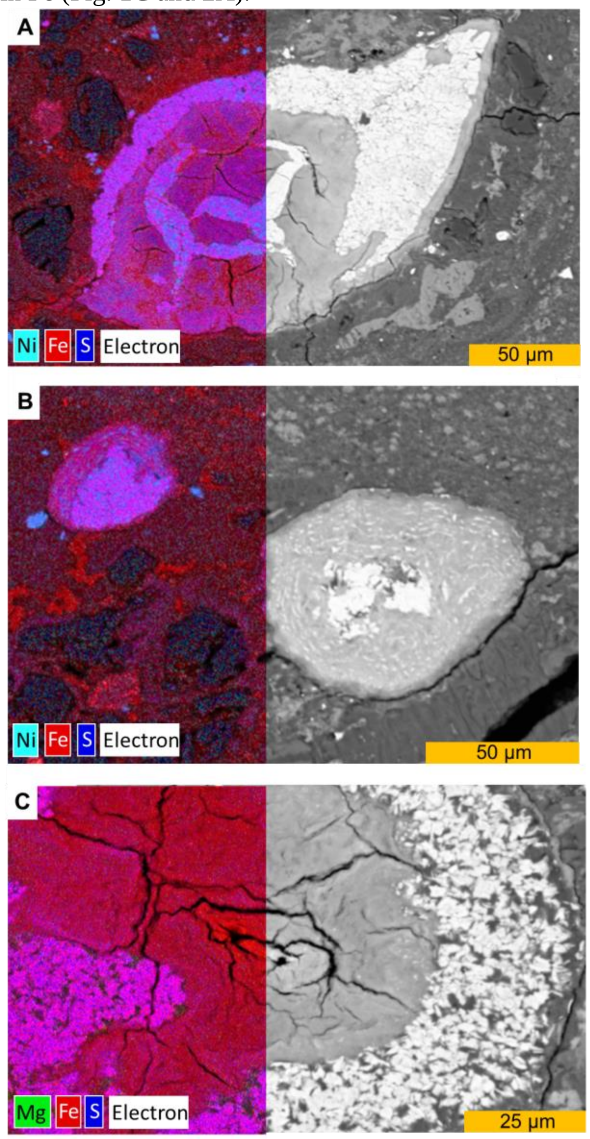

Fig. 1. EDS chemical maps (left) and BSE images (right) of tochilinite-sulphide globules. In BSE images tochilinite is light grey, sulphides are white, and silicates are dark grey. A) Globule showing sulphides occurring along fractures. Sulphides are primarily troilite, but pentlandite is also present. B) Globules showing sulphides occurring in semi-concentric layers in tochilinite. Sulphides are mainly pentlandite. C) Fe-rich tochilinite globule with troilite-serpentine rim.

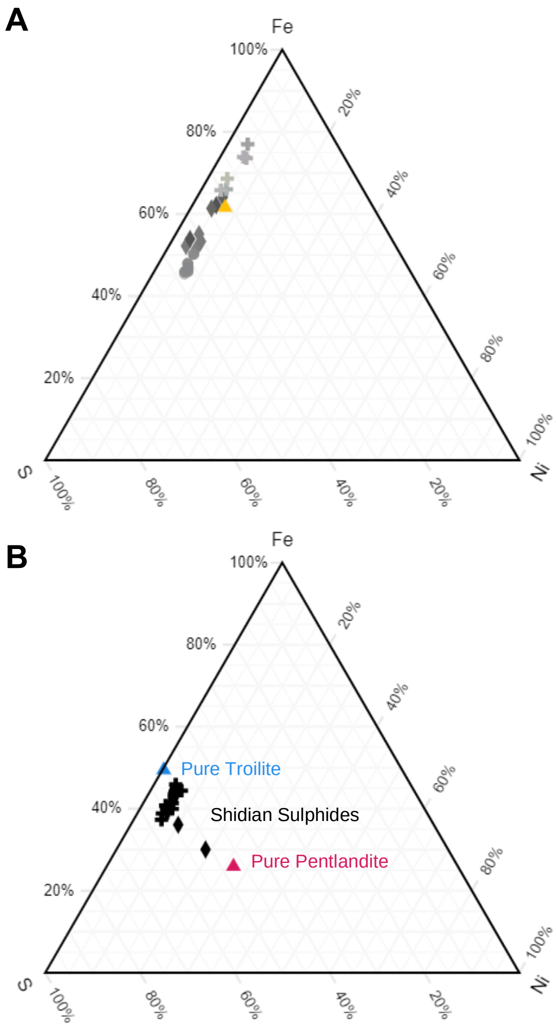

Fig. 2. Fe-Ni-S ternary diagrams. A) Ternary diagram for tochilinite. The shade of grey each point is identical to the shade of grey the tochilinite is in the corresponding BSE image. Points of the same shape are from the same globule. An average tochilinite composition calculated by [5] is shown in yellow. B) Ternary diagram for sulphides. Points corresponding to Shidian's sulphides are shown in black. Points of the same shape came from the same globule. Idealized troilite and pentlandite are blue and pink, respectively.

Discussion: There are two possibilities for the presence tochilinite-associated troilite in Shidian. One is that the troilite is primary, originally present as inclusions in kamacite globules that were replaced with tochilinite during aqueous alteration. The other possibility is that the sulphide is secondary, recrystallizing from tochilinite during heating.

Troilite occurs as euhedral to subhedral crystals that differ to primary troilite inclusions in kamacite [6]. Troilite tends to occur in patterns typical for fractures, but atypical for troilite inclusions (Fig. 1A), implying the fractures pre-dated troilite. Troilite also occurs in semi-concentric layers within tochilinite, also atypical of inclusions [6]. These could be sulphides crystallizing within tochilinite. Sometimes, troilite occurs alongside Fe-bearing serpentine in a rim around Fe-rich tochilinite (Fig. 1C). Tochilinite-cronstedtite intergrowths occur in CM chondrites [7], however the Fe-bearing serpentine has 12 wt.% Mg and cannot be cronstedtite. Cronstedtite can react with Mg-rich serpentine to form Fe-bearing serpentine [7]. The troilite-serpentine intergrowths are likely the result of tochilinite-cronstedtite intergrowths reacting with serpentine followed by tochilinite dehydrating into troilite.

The tochilinite close to troilite is often depleted in S compared to tochilinite farther away, appearing darker in BSE images (Fig. 1 and 2A). This could be due to the tochilinite losing S to the troilite when the troilite crystallized. This observation also implies that the troilite formed after the tochilinite. The crystallinity of tochilinite in Shidian is currently unknown. If the troilite formed from the dehydration of tochilinite, then the tochilinite is likely to be amorphous or at least highly disordered. Because there is still S and Fe in tochilinite, if the troilite formed from recrystallization from tochilinite, this recrystallization would be incomplete. This would mean that either the temperatures experienced were lower than 245 °C or that the heating event was short lived (e.g. few days).

Conclusions and Future Work: The textures displayed by both the tochilinite and troilite indicate that the troilite is secondary and recrystallization of tochilinite is incomplete. This means Shidian experienced low temperatures or short-duration heating on its parent asteroid. We predict secondary tochilinite would be amorphous and/or disordered. This would need to be confirmed with either X-ray Diffraction or Transmission Electron Microscopy. Further evidence for low temperature post-hydration heating, such as disordered serpentine, would also need be found. Heating experiments on tochilinite are planned to characterize the recrystallization process of troilite at various peak temperatures and durations.

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