DETERMINING THE GEOTHERMOMETRY OF A HAYABUSA-RETURNED SULFIDE PARTICLE.

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Introduction: Geothermometry of pyrrhotite-pentlandite intergrowths in meteorites, using compositional data from quantitative electron probe microanalysis (EPMA), shows that most of them formed during primary cooling from high temperature (i.e., during chondrule formation) or after thermal metamorphism [e.g., 1–5]. Sulfides in LL4 to LL6 chondrites equilibrated <600°C [2], likely <250°C [4], consistent with formation during cooling after thermal metamorphism [2,4]. However, geothermometry of pyrrhotite-pentlandite intergrowths from an LL5–6 impact melt-breccia indicated that the sulfides were annealed at ≤230°C, likely after an impact event [1]. In comparison, analyses of silicate-bearing Hayabusa-returned particles have identified asteroid 25143 Itokawa as LL4 to LL6 chondrite material (~10% LL4 and ~90% LL5 to LL6) [e.g., 6–9] that was thermally metamorphosed between ~780 and 840°C [6]. Sulfides in Hayabusa particles [e.g., 6,10,11] record additional and/or complementary information on the formation conditions of Itokawa [e.g., 12], however their pyrrhotite-pentlandite intergrowths are too small to analyze via EPMA [12]. Our goal is to further constrain the formation and alteration conditions of asteroid Itokawa by determining the geothermometry of sulfide-bearing Hayabusa-returned particles via quantitative energy-dispersive x-ray spectroscopy (EDS) using a transmission electron microscope (TEM).

Samples and Analytical Procedures: We identified pyrrhotite-pentlandite intergrowths in the sulfide-bearing Itokawa sample RB-CV-0234 and Saint-Séverin USNM2608-3 (LL6). We have described pyrrhotite-pentlandite intergrowths in sections from RB-CV-0234 [12] and Saint-Séverin [13] extracted with the FEI Helios NanoLab 660 focused-ion-beam-scanning electron microscope (FIB-SEM) at the University of Arizona (UAz), and analyzed using the 200 keV aberration-corrected Hitachi HF5000 scanning TEM at UAz. Prior to FIB-TEM, the pyrrhotite-pentlandite intergrowth in Saint-Séverin region of interest (ROI)A was analyzed for its elemental compositions via EPMA [2,13]. We obtained quantitative EDS data from FIB sections of both samples via TEM following [14].

Results: The compositions of RB-CV-0234 via quantitative EDS [14] are 35.2 wt.% S and 64.8 wt.% Fe for pyrrhotite, and 32.4 wt.% S, 49.4 wt.% Fe, and 18.2 wt.% Ni for pentlandite. The compositions of Saint-Séverin ROIA via quantitative EDS are 37.9 wt.% S and 62.1 wt.% Fe for pyrrhotite, and 35.7 wt.% S, 45.6 wt.% Fe, and 18.7 wt.% Ni for pentlandite. The compositions via EPMA of Saint-Séverin ROIA prior to FIB extraction are 36.8 wt.% S and 63.7 wt.% Fe for pyrrhotite, and 33.6 wt.% S, 43.9 wt.% Fe, and 21.0 wt.% Ni for pentlandite.

Discussion: The compositions of both pyrrhotite and pentlandite in Saint-Séverin ROIA determined by EDS are within ~1 to 2 wt.%, for Fe, Ni, and S, of the values determined by EPMA. These compositional differences could: (1) be due to EPMA analyzing the sample surface, whereas EDS measurements of the FIB section sample the subsurface; or (2) imply that the uncertainty in the EDS measurements relative to EPMA analyses is ~1 to 2 wt.%.

In [12] we showed that the pyrrhotite-pentlandite intergrowth in RB-CV-0234 is most similar to that found in Saint-Séverin (LL6, S2), indicating that RB-CV-0234 might be from LL6, ≤S2 chondrite material. However, the higher Fe-content of pentlandite in RB-CV-0234 compared to that in Saint-Séverin ROIA indicates they had different parent-body thermal histories. The chemical compositions of pyrrhotite and pentlandite in Saint-Séverin ROIA are most consistent with equilibrating <400°C, perhaps ~300°C (using phase diagrams in [15,16]). The compositions of pyrrhotite and pentlandite in RB-CV-0234 determined via EDS are consistent with equilibrating <300°C, perhaps as low as ~230°C. These temperatures are most similar to the closure temperatures of ≤230°C and <250°C for pyrrhotite-pentlandite intergrowths from NWA 4859 (LL5–6 impact melt-breccia) [1] and Stubenberg (LL6, S3) [4], respectively. This indicates that RB-CV-0234 is likely from LL6 chondrite material.

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Acknowledgements: We thank JAXA for the loan of the Hayabusa-returned particle used in this study, the Smithsonian Institution for the loan of the meteorite used in this study, and NASA grant NNX17AE53G (DLS PI, TJZ Co-I) for funding this research.