TRANSMISSION ELECTRON MICROSCOPY OF PYROXENES IN THE ALMAHATA SITTA UREILITE.

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We performed FIB-TEM investigations of pyroxene in the Almahata Sitta (hereafter Alma) ureilite (sample #7), which is the first recovered asteroidal fall [1]. The pyroxenes (mg#=~0.92) in the Alma studied are present as minute individual grains (10-20 μm in size) showing a mosaicized texture, and they are both low-Ca and high-Ca pyroxenes [2]. The equilibration temperature of these pyroxene grains is very high (1240-1280 ^{o}C), which is consistent with other results on this meteorite and previous studies on many ureilites [e.g., 3,4]. Although their Ca contents are as low as Wo_{2-3}, the EBSD analysis shows that low-Ca pyroxenes are clinopyroxene ($P2_1/c$) [2]. Our FIB-TEM study revealed that some areas in the pyroxene of Alma show an exsolution texture at the nm scale. In low-Ca pigeonite, augite exsolution lamellae of 10-15 nm wide develop in the pigeonite host of 20-45 nm wide, which is parallel to (001). Similarly, low-Ca pigeonite lamellae were observed in the augite host. The exsolution wavelength of pyroxene (typically 30-60 nm) gives the cooling rate of 0.2-5 ^{o}C/hour [5], which is in agreement with that estimated by the Fe-Mg diffusion profiles of pyroxene and olivine due to reduction [3]. The pyroxene exsolution texture gives an equilibration temperature of approximately 1000 ^{o}C, which probably records the equilibration temperature after the rapid cooling history. Such a rapid cooling probably records quenching from high temperature (1240-1280 ^{o}C) down to 1000 ^{o}C due to the impact break-up of the Ureilite Parent Body (UPB) while it was still hot [e.g., 6,7]. Exsolution of pyroxene is rare among ureilites, and has been reported only for a few samples [e.g., 8]. The pyroxene microstructure of Alma is within the known range of ureilites and is most similar to that of ALHA81101 with the affinity of mosaicized texture of pyroxene and olivine [8]. Because ALH81101 shows a coarser exsolution texture [8], it experienced a slower cooling history than Alma. ALH77257 is a ureilite whose pyroxene does not show visible exsolution lamellae, but shows a compositional gradient due to spinodal decomposition. Thus, it should have cooled faster than Alma. Rapid, albeit variable cooling rates observed in these ureilite samples may suggest that they originated from UPB fragments of different size. The fine-grained nature of asteroid 2008 TC_3 implies that even intermediate sized fragments were pulverized to small grains in later collisions that produced the daughter bodies now present in the asteroid belt [e.g., 6,7].

References: [1] Jenniskens P. et al. 2009. *Nature* 458:485-488. [2] Mikouchi T. et al. 2010. Abstract #2344. 41st Lunar & Planetary Science Conference. [3] Herrin J. et al. 2010. Abstract #1095. 41st Lunar & Planetary Science Conference. [4] Takeda H. et al. 1989. *Meteoritics* 24:73-81. [5] Weinbruch S. and Müller W. F. 1995. *Geochimica et Cosmochimica Acta* 59:3221–3230. [6] Goodrich C. A. 2004. *Chemie de Erde* 64:283-327. [7] Downes H. et al. 2008. *Geochimica et Cosmochimica Acta* 72:4825-4844. [8] Tribaudino M. 2006. *Meteoritics & Planetary Science* 41:979-988.