Cooling rates of shock veins in chondrites: Constraints from Fe-FeS eutectic textures

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Asteroidal impacts in protoplanetary disks lead to formation of proto-planets, destruction and excavation of asteroids, thermal and pressure effects on asteroids, and formation of debris disks. The evidence of asteroidal impacts in the early solar system was recorded in shocked meteorites. Some of heavily shocked chondrites have melted veins containing quenched high-pressure minerals and numerous metallic iron-troilite (FeS) assemblages. Such Fe-FeS assemblages have rounded textures, indicating that they were molten during shock events, and some of them show solidification textures from eutectic melts, where numerous thin iron rods are present in the matrix of troilite. Eutectic solidification textures are known to be dependent on cooling rates of the system, and thus they should have recorded a cooling history of shock vein, which may put some constraints on physical conditions of asteroidal impacts.

Solidification experiments of Fe-Ni-S melt were performed in sealed, evacuated silica tubes. Natural pyrrhotite and Fe-Ni metal were mixed with different mixing ratios and were pressed into pellets. The pellets were placed in a silica tube and sealed after evacuating a tube with a rotary pump. The tubes were kept at 1050^{o}C for 0.5 hour, and cooled to 350^{o}C linearly at the rates of 3, 10, 50, 100, 200, 500, and ~5000 (air quench) K/h. Some samples cooled at 100 K/h were annealed for 1200 h at 350^{o}C

Pellets containing only pyrrhothite show a small amount of metallic iron grains after experiments, indicating that a small amount of sulfur evaporated. However, evaporated sulfur is estimated to be only a few %, and the bulk compositions of pellets would not change significantly. Eutectic solidification textures, where numerous thin iron rods (several to ten micron in diameter) were present in the matrix of iron sulfide, were observed for all the samples. We also found that annealing at 350^{o}C had no effect on textures. Power-law relationships were found between the metal rod spacing and the cooling rate (the rod spacing is predicted to be proportional to the supercooling by the Zener-Tiller diffusion model, which should be correlated with the cooling rate in this study). For instance, the average rod spacing (d) for the Fe-FeS eutectic composition can be expressed as d (micron) = 37.1 $R^{-0.35}$, where R is the cooling rate (K/h).

We applied the cooling speedometers to metallic iron-troilite assamblages within shock veins in Sahara 98222 (L6) chondrites, which experienced a shock event with pressure of 13-15 GPa and temperature of hgher than 2000^{o}C at 4467 +/- 22 Ma (Ozawa et al., 2007, AGU fall meeting). The typical spacing of metallic iron rods was sub to 1 micron. The cooling rate of the shock vein was estimated to be ~10 K/s at ~1000-800^{o}C based on the speedometers and bulk compositions of assamblages. The cooling rate of 10 K/s at 1000-800^{o}C and preservation of eutectic solidification textures indicates that the impact occurred on the parent body of Sahara 98222 should have occurred after thermal metamorphism, which is consistent with the U-Pb age of ~4470 Ma, and suggests that the recorded impact was that during the proto-planet forming stage.