Formation process of Fe-FeS globules in melt veins in shocked ordinary chondrites

*Riho Tani[1], Naotaka Tomioka[2], Kaushik Das[1]

1. Hiroshima University Department of Earth and Planetary Systems Science, 2. Kochi Institute for Core Sample Research, Japan Agency for Marine-Earth Science and Technology

Heavily shocked stony meteorites contain optically black veins called shock veins. The veins consist of micron to submicron-scale grains of silicates, oxides, Fe-Ni metals and Fe-sulfide. During shock vein formation, metal-sulfide melt is not chemically mixed with silicate melt due to their mutual immiscibility. As a result, the metal-sulfide is crystallized as tiny globules in the silicate/oxide matrix in shock veins. Such globules are an unequivocal evidence for extensive melting of silicate materials. Previously, mineralogical studies of shock vein have been mainly focused on silicate and oxide minerals, since these minerals often occur as high-pressure phases. Pressure-temperature histories in shocked chondrites have been deduced from high-pressure mineral assemblages based on experimentally determined phase equilibria [1]. However, metals and sulfides in shock veins have not been well investigated. In the present study, we have examined the Fe-FeS globules in shock veins in two ordinary chondrites (NWA4719 and Tenham), which are considered to have experienced different shock pressures, [2–3] to obtain further information of the formation process of shock veins.

The trend of the globule size in the shock vein shows that it becomes larger from the vein wall to the center (up to 25 μm) due to the difference of cooling rate and local fluid dynamics. Following the previous study [4], cooling rates of shock veins were estimated from spacing of Fe-metal dendrites in the globules by a cooling-rate meter established for Fe-dendrites in alloys [5]. The widths of Fe-dendrites in NWA4719 and Tenham are in the range of ~300–600 nm, and estimated cooling rates of the shock veins in are extremely high (10^6 deg C/sec).

To evaluate such a seemingly unrealistically high cooling rate, we examined mineral phases of the globules in Tenham by TEM/STEM. Fe-FeS globules are surrounded by high pressure silicate minerals including aluminous majorite crystallized from chondritic melt at pressures above 14 GPa. Meanwhile, X-ray elemental mapping clarified that the globules consist of grains of kamacite, taenite and troilite (<2 μm in size). But, high-pressure phases of Fe-sulfide such as Fe_3S_2 and Fe_3S, which are stable above ~14 and ~21 GPa [6,7] respectively, were not found. The results suggest that shock pressure in Tenham was significantly dropped from >14 GPa when temperature of the shock vein was in between the liquidus temperature of silicate (~2000 deg C) and eutectic temperature of Fe-FeS (~1000 deg C). Therefore, only silicate minerals could have been crystallized as high pressure phases. The absence of high-pressure phases of Fe-sulfide is rather consistent with much slower cooling rate than that estimated by Fe-dendrite spacing. The cooling-rate meter established in metallurgical studies provides overestimated values for shock veins formed in a dynamic high-pressure process.

References: [1] e.g. Agee et al. (1995) J. Geophys. Res. 100, 17725–17740. [2] Kimura et al. (2007) Meteorit. Planet. Sci. 42, 5139.pdf. [3] e.g. Tomioka and Fujino (1999) Am. Mineral. 84, 267–271. [4] Scott (1982) Geochim. Cosmochim. Acta 46, 813–823. [5] Flemings et al. (1970) J. Iron Steel Inst. 208, 371-381. [6] Fei et al. (1997) Science 275, 1621–1623 [7] Fei et al. (2000) Am. Mineral. 85, 1830–1833.

Keywords: metal-sulfide globule, shock vein, ordinary chondrite, TEM

