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Mineralogical characterization and formation process of shock-induced melt veins in the Efremovka CV3 chondrite

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An understanding of shock effects is important to bring out the impact history of the solar system. A shock-induced melt vein is one of the typical textures caused by impact; the vein is considered to be formed by rapid shear melting and be solidified along the shearing plane in extremely short times. Mineralogy of the shock-induced melt veins have been well studied in highly shocked ordinary chondrites so far, while there are few studies of carbonaceous chondrites which are usually considered to have been experienced relatively weak shock metamorphism.

Efremovka, grouped as a CV3 carbonaceous chondrite, is known to be experienced a strong shock metamorphism classified with a shock stage of S4. Although the previous studies on Efremovka mainly focused on the chemical/isotopic properties, the detailed mineralogical and petrographic characteristics remain to be known. We made a SEM observation of the Efremovka thin sections with a total area of about 200 mm^2, and found distinguish veins or puddles including spherical globules of Fe-Ni metal, Fe-sulfide in the matrix. In order to clear whether these objects have been actually experienced melting or not, and to clear its formation process, we undertook a mineralogical study regarding on the veins (tentatively called "melt vein") compared with the other area of the matrix (called "normal matrix") using transmission electron microscopy (TEM) and synchrotron radiation X-ray diffraction (SR-XRD).

The veins are often observed near chondrule-matrix boundaries, and sometimes penetrate into the adjacent chondrules or matrices. For site-specific samplings, the melt veins and the normal matrix were lifted up from the thin section and were trimmed to feasible shapes for SR-XRD and TEM experiments using a focused ion beam (FIB) technique. The SR-XRD and TEM experiments show the clear differences between the melt veins and the normal matrix, especially as to the constituent olivines. The unit cell volume data from SR-XRD and the TEM-EDX analyses consistently indicate that the olivine of the melt veins (Fo_{73}) is poorer in Fe contents than that of the normal matrix (Fo_{45}). A clear difference is also seen in the grain size; the olivine size in the melt veins is significantly larger (~300 nm) than that in normal matrix (~100 nm). Moreover, appearances of lattice defects in the olivines is different; from TEM observation, dislocation densities in the melt vein's olivines are much lower than those in normal matrix in spite of the evidence of the heavy shock impact.

These results indicate that the melt veins have certainly experienced a different formation process from that of normal matrix, which are apparently affected by melting and quenching processes. During these processes, olivine in the veins grew larger in size and become poorer in Fe contents than those in original matrix. On the other hand, as for most parts of Efremovka matrix escaping from melting, the shock wave effect can be found in compaction of matrix and high dense dislocations in the constituent minerals. The present study reveals that chemical and mineralogical disproportions are caused by melting and quenching process. Such shock-induced process may be one of the factors generating a diversity of meteorites.

Keywords: carbonaceous chondrite, melt vein, shock metamorphism, Efremovka, TEM, SR-XRD