Crystallography of minute minerals in meteorites by using FEG-SEM equipped with electron back-scatter diffraction (EBSD) detector

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Electron back-scatter diffraction (EBSD) analysis is a newly emerged analytical technique, which enables us submicron area crystallography on thin sections when combined with field emission gun scanning electron microscope (FEG-SEM). This technique is extremely useful to identify minute minerals in extraterrestrial samples that has been impossible to be identified by conventional X-ray diffraction techniques. FEG-SEM/EBSD can also reveal orientation relationship of constituent phases on submicron scale, which offers important information to understand their formation history. In this abstract, I will show examples of FEG-SEM/EBSD analysis applied for several minute phases in meteorite thin sections, two of which were approved as new minerals.

Governador Valadares is a nakhlite Martian meteorite mainly composed of 80% augite and 10% olivine. Augite shows broad twin bands and some twin bands are then polysynthetically twinned with spacing of a few to tens of micrometers. FEG-SEM/EBSD showed that the broad (100) twin and polysynthetic (001) twin share *b* and *c* axes and *a* and *b* axes in common, respectively. Such twin bands were probably formed by moderate shock, which is consistent with the shock metamorphism of nakhlites (10-20 GPa). Olivine grains in Governador Valadares often contain symplectite inclusions composed of submicron intergrowth of augite and magnetite. The obtained EBSD patterns showed that [001] and [010] of olivine are parallel to [110] and [112] of magnetite, respectively. These relationships are identical to the analysis performed by TEM.

QUE93148 is a small (1.1 g) achondritic meteorite mainly composed of Mg-rich olivine with lesser amounts of orthopyroxene, kamacite, troilite and chromite that shows a genetic relationship to pallasites. Olivine contains several different types of symplectic inclusions. FEG-SEM/EBSD analysis revealed that they were composed of diopside and chromite mixtures on submicron scale. The orientation relationship was basically similar to that of symplectites in Governador Valadares olivine.

Kaidun is a unique brecciaed meteorite containing an unprecedented variety of fragments. An unknown Fe-Cr phosphide (FeCrP) was found as individuals and linear array grains with a maximum dimension of 8 micrometers within two masses of Fe-rich serpentine from the C1 and C2 chondrite lithologies. FEG-SEM/EBSD analysis showed that the observed patterns well matched with those of allabogdanite, florenskyite, and synthetic FeCrP, and it was approved as a new mineral (andreyivanovite: IMA No. 2006-003).

NWA470 is a CH3 chondrite containing numerous small CAIs of different mineralogies as typical of this meteorite group. One of these CAIs contains a Ca-Al oxide whose composition is close to the stoichiometric $CaAl_2O_4$. This Ca-Al oxide occurs as about 10 micrometers subhedral grains intergrown with grossite, perovskite, and melilite. FEG-SEM/EBSD analysis revealed that the obtained pattern well matched with that of the high-pressure polymorph of synthetic $CaAl_2O_4$. Probably, the high-pressure polymorph was produced during shock metamorphism after the CAI formation because NWA470 shows weakly developed shock features (shock stage: S1). This phase was also approved as a new mineral (dmitryivanovite: IMA No. 2006-035).

As demonstrated above, FEG-SEM/EBSD enables us submicron area crystallography of regular thin sections without difficulty in sample preparation. It is a powerful analytical technique for meteorite studies such as identification of submicron-size minerals and characterization of microstructure. It is also useful when only a small amount of samples is available (e.g., sample return mission).