Precise determination of Fe species in plagioclase crystals

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Silicate minerals such as plagioclase and pyroxene sometimes contain fine-grained magnetite crystals; such silicates are called magnetic silicates. Magnetic silicates are often appeared in plutonic rocks and are also appeared in lava flows. Natural remanent magnetizations (NRM) carried by magnetic silicates should play an important role in paleomagnetic records of whole rock and single crystal. Therefore, to elucidate crystallization mechanism of magnetite in silicate minerals and to understand origin of the NRM is of prime importance in paleomagnetism, while the mechanism has been poorly understood. In this study, to precisely determine the chemical species of Fe in the plagioclase crystals and to better understand the crystallization mechanism of magnetite, magnetic measurements combined with microscopic observation and synchrotron radiation study were conducted for single grain plagioclase crystals.

We prepared plagioclase crystals from a gabbroic anorthosite of the Duluth complex, a layered gabbro of the Oman ophiolite, and a medium-grained gabbro of the Murotomisaki gabbroic complex. The plagioclase crystals were collected under a stereoscopic microscope and used for the measurements after a hydrochloric acid leaching. The main series of measurements for the single grain plagioclase crystals were as follows: (1) To estimate a content of magnetic mineral in the plagioclase crystals, magnetic hysteresis loop was measured using an Alternating Gradient Magnetometer. (2) To investigate the average valence state of Fe, L_{III}-edge X-ray absorption near edge structure (XANES) measurement was performed at BL27SU of SPring-8. (3) To investigate chemical compositions of the plagioclase crystals, microscopic observation was conducted using electron microprobes. In addition to these single crystal measurements, low-temperature remanence measurements (field cooling remanence, zero field cooling remanence, and room temperature saturation isothermal remanence) were conducted for plagioclase grains using a Magnetic Property Measurement System.

The saturation magnetization value of plagioclase samples were 6-68 mAm^2/kg, 2-27 mAm^2/kg, and less than 1 mAm^2/kg for the gabbroic anorthosite, layered gabbro, and medium-grained gabbro, respectively. The low-temperature remanence curves of gabbroic anorthosite and layered gabbro plagioclase samples showed pronounced remanence reductions at around 100-140 K, indicating that the plagioclase crystals contained nearly pure magnetite. Assuming the saturation magnetization value of pure magnetite, we estimated the magnetite content. As a result, the magnetite content in plagioclase crystals were 60-740 ppm, 20-300 ppm, and less than 10 ppm for the gabbroic anorthosite, layered gabbro, and medium-grained gabbro, respectively. The XANES analysis showed that the average valence states of Fe in the bulk plagioclase crystals were 2.32-2.79, 2.69-2.92, and 2.72-2.94 for the gabbroic anorthosite, layered gabbro, and medium-grained gabbro, respectively. The microscopic observation showed that the Fe contents as FeO for the plagioclase crystals were nearly constant with an average of 2800 ppm and 1800 ppm for the gabbroic anorthosite and layered gabbro, respectively. Among these parameters there was inverse relationship between the magnetite content and average valence states of Fe, suggesting that the valence state of Fe could be a key factor in the crystallization mechanism of magnetite.