

Precise determination of Fe species in plagioclase crystals: a case study for gabbroic anorthosite of the Duluth complex

Masahiko Sato[1]; Masashi Ushioda[2]; Ryoichi Nakada[3]
[1] IGG, GSJ, AIST; [2] IEVG, GSJ, AIST; [3] ELSI, Tokyo Tech

Silicate minerals such as plagioclase and pyroxene sometimes contain fine-grained magnetite crystals; such silicates are called magnetic silicates. Magnetic silicates are ubiquitous in mafic and intermediate plutonic rocks (Dunlop and Ozdemir 1997; Gee and Kent 2007). As the middle and lower crust have greater mafic composition than the upper crust (Rudnick and Gao 2004), magnetic silicates should play an important role in controlling the magnetic properties of deep crustal rocks. For understanding the sources of magnetic anomalies, which are often originated from thick magnetized layers within the crust (Shive et al. 1992 and reference therein), it is crucial to investigate the exsolution mechanism of magnetite in silicate minerals.

In this study, to precisely determine the chemical species of Fe in the plagioclase crystals, magnetic measurements combined with microscopic observation and synchrotron radiation study were conducted for single grain plagioclase crystals. We prepared plagioclase crystals from gabbroic anorthosite of the Duluth complex at Forest Center, Minnesota, USA (FC1, Paces and Miller 1993). The plagioclase crystals were collected under a stereoscopic microscope and used for the measurements after a hydrochloric acid (HCl) leaching for two days.

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 (Micro-Mag 2900, Princeton Measurements Corporation) and magnetic hysteresis parameters (saturation magnetization M_s , saturation remanence M_{rs} , coercivity B_c , and coercivity of remanence B_{cr}) were calculated. (2) To investigate chemical compositions of the plagioclase crystals, microscopic observation was conducted using a field emission electron microprobe (JXA-8530F, JEOL) at Tokyo Institute of Technology and an electron microprobe (JXA-8900R, JEOL) at Geological Survey of Japan. (3) To investigate the average valence state of Fe, K-edge X-ray absorption near edge structure (XANES) measurement was performed at BL-12C of Photon Factory. 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 (MPMS-XL5, Quantum Design).

The magnetic hysteresis parameters resulted in the single-domain (SD) and pseudo-single-domain (PSD) range on the Day plot (Day et al., 1977), and the M_s values ranged from 3 to 63 mAm^2/kg . The low-temperature remanence curves showed pronounced remanence reductions at around 100-120 K, indicating the existence of low-Ti titanomagnetite. The presence of magnetite was also suggested by the linear combination fitting of XANES spectra, and thus, we confirmed that the plagioclase crystals contained nearly pure magnetite. We estimated the magnetite content assuming the M_s value of pure magnetite ($92 \text{ Am}^2/\text{kg}$, Hunt et al. 1995). As a result, the magnetite content ranged from 40 to 680 ppm with an average of 270 ppm in weight.

The microscopic observation showed that the FeO contents for the plagioclase crystals were nearly constant with an average of 2800 ppm in weight. Thus, about 76-99% of Fe was contained in the plagioclase crystal and the remaining Fe was exsolved as magnetite crystals. The XANES analysis showed that the average valence states of Fe in the bulk plagioclase crystals were 2.53 ± 0.10 . So far, there was no clear relationship between the magnetite content and the valence state.