E113-P001 Room: Poster Session Hall Time: May 19

Magnetization due to the Verwey transition of magnetite

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Recent explorations of the terrestrial planets have revealed that there are many magnetic anomalies which probably recorded their ancient environments of the magnetic field. Many authors pointed out the relationship between magnetic anomaly patterns and geological features, especially impact craters. For example, it has been emphasized that the lunar magnetic anomalies might be caused by the large impact to have resulted in acquisition of shock remanent magnetization (SRM) under some ambient field. It is also suggested that there are several basins absent from crustal magnetization which were probably demagnetized due to the impact under almost null field, namely, zero SRM. Such a demagnetized basin indicates no core dynamo field at its formation. Although the impact-origin magnetic signatures can give key information of the planetary dynamo activity, acquisition process of SRM has not been understood yet. It is thought that one of the plausible mechanisms of SRM is the transformation remanent magnetization (TrRM). However, there have been only a few systematic studies of TrRM concerning the planetary magnetism. Thus we have conducted the experiments of TrRM to know its basic properties.

There are many kind of magnetic minerals contained in the crust of the terrestrial planet: magnetite, kamacite and so on. In the present study, we focus on magnetite and its TrRM due to the Verwey transition at about 120 K (T_V) and atmospheric pressure, since experimental conditions of pressure and temperature are easily controlled in laboratory. The Verwey transition is considered as the first order transformation from cubic to monoclinic phase. We first tested rock magnetic properties of several synthetic and natural samples, and consequently adopted a natural granite sample which contains a lot of multi-domain (MD) magnetite. The sample was cooled down to 77 K or 10 K and warmed back to room temperature in a weak DC field or no field. there are three types of transformation remanences: (1) transformation remanent magnetization (TrRM) by cooling and warming in a certain DC field, (2) transformation warming remanent magnetization (TrWRM) by cooling in zero field and warming in a DC field, and (3) transformation cooling remanent magnetization (TrCRM) by cooling in DC field and warming in zero field. We measured all types of transformation remanences and examined the basic rules of the paleomagnetism.

The conclusions in the present study are:

(1)We observed a drastic change of magnetization at temperature of T_V, and it is confirmed that transformation remanences are acquired at T_V.

(2)The remanent magnetization of our sample due to the Verwey transition have coercivity spectra less that about 20 mT, indicating that transformation remanences are carried by MD grains. Since this TrRM is much larger than IRM, our sample is useful for the transformation remanence experiment.

(3)The observed directions of TrRM, TrWRM, and TrCRM are parallel to the ambient field. Thus the parallelism to the ambient field is satisfied with the transformation remanences.

(4)The observed intensities of TrRM, TrWRM, and TrCRM are proportional to the ambient field. Thus the proportionality to the ambient field satisfied with the transformation remanences.

(5)The observed intensities and coercivity spectra of TrRM are almost the same as the anhysteretic remanent magnetization (ARM) of the MD grains. This suggests that acquisition mechanism of TrRM is analogous to that of ARM. This may be caused by the domain structure is completely reset in both acquisitions of TrRM and ARM.

Our results imply that the magnetic anomaly originated from the transformation remanence could record the ancient magnetic field of the terrestrial planets similarly to thermoremanent magnetization (TRM) of igneous rocks.