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Transformation remanent magnetization due to the Verwey transition of magnetite

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Recent explorations of Mars and Moon have observed many magnetic anomalies which probably recorded ancient magnetic fields. Many authors have pointed out a correlation between magnetic anomaly patterns and geological features, especially impact craters (Acuna et al., 1999; Mitchell et al., 2007).
Although impact-origin magnetic signatures can give key information of the planetary dynamo evolution, details of shock remanent magnetization (SRM) acquisition mechanisms have not been revealed yet. One of the plausible mechanisms of SRM is transformation remanent magnetization (TrRM). However, there have been only a few systematic studies of TrRM concerning the planetary magnetism (Ozima et al., 1963; Dickinson and Wasilewski, 2000; Dunlop, 2007). Thus we focus on the Verwey transition of magnetite and have conducted experiments of TrRM to know its basic properties.
The Verwey transition is considered as a first order transformation from cubic to monoclinic phase at 120 K (Tv). In the experiment, natural rock samples which contain a lot of multi-domain (MD) magnetite grains are cooled down from room temperature to below Tv and then warmed back to room temperature in a weak DC field or zero-filed. In the present study, three types of transformation remanences are defined: (1) transformation remanent magnetization (TrRM) which is acquired by cooling and warming in a constant DC field, (2) transformation warming remanent magnetization (TrWRM) which is acquired by cooling in zero field and warming in a DC field, and (3) transformation cooling remanent magnetization (TrCRM) which is acquired by cooling in a DC field and warming in zero field. We measure all types of transformation remanences and checke the basic rules of the rock magnetism.
To evaluate accurate properties of TrRM, we make the experimental apparatus which can contain a 1-inch core sample and generate a weak DC field (< 400 uT). After cooling and warming of samples, remanences are measured using a spinner magnetometer combined with stepwise alternating field demagnetization.
For the purpose of understanding TrRM acquisition process, we also observe sample magnetization of chip samples continuously during cooling and warming in a slightly weak DC field (< 2 mT) or zero-field by using MPMS.
Major remarks concluded and suggested in the present study so far are: (1) Drastic changes in magnetization intensity are observed at Tv, and it is confirmed that transformation remanences are acquired at Tv. (2) The observed directions of TrRM, TrWRM, and TrCRM of magnetite are parallel to the ambient field. Thus the parallelism to the ambient field is satisfied with the transformation remanences. (3) The observed intensities of TrRM, TrWRM, and TrCRM of magnetite are proportional to the ambient field intensity. Thus the proportionality to the ambient field is satisfied with the transformation remanences. (4) The observed intensities and coercivity spectra of TrRM of magnetite 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; domain structures are reset in both acquisitions of TrRM and ARM.
Our results imply that the magnetic anomaly originated from the transformation remanences could

record the ancient magnetic field of the terrestrial planets similarly to thermoremanent magnetization of igneous rocks.

Keywords: transformation remanent magnetization, Verwey transition, magnetite, shock remanent magnetizatnio