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Magnetic hysteresis measurement of magnetite under high pressure: Implication for source of the Martian magnetic anomaly

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Mars Global Surveyor observed the magnetic field of Mars, and revealed that there are many strong magnetic anomalies [1]. The strong magnetic anomalies suggest an active core dynamo of early Mars (about 4 billion years ago), and some mechanism of crustal formation in the dynamo field. Since magnetic properties of crustal rocks depend critically upon the mineralogical form of magnetic particles, the strong magnetic anomalies can give crucial information about the chemical composition and oxidation state prevailing in the early Martian crust. However, source of the magnetic anomalies have been poorly understood yet because of the lack of basic information concerning magnetic properties of deep crustal rocks. Here, we report laboratory magnetic experiments to interpret the source of the Martian magnetic anomaly.

According to previous analyses of the Martian anomalies [2,3,4], sources of the anomalies have to satisfy the following requirement: (1) the crustal rock on average is more intensely magnetized than terrestrial continental crust, (2) there may be a continuous non-magnetized layer at the surface (about 10 km), and (3) the magnetic layer is thick (about 30 - 40 km). Moreover, it is well known that remanent magnetization of the magnetic mineral gradually decays in a null field and at a temperature lower than the Curie point [5]. Thus, magnetic minerals of the Martian crust, probably magnetite [6], should have retained their magnetizations under high pressure and temperature for about 4 billion years.

In this study, we have conducted in-situ magnetic hysteresis measurement of magnetite under high pressure up to 1 GPa by using the high-pressure cell specially designed for a Magnetic Property Measuring System (MPMS). Based on the experimental results, systematic rock magnetic properties of multi-domain (MD), pseudo-single-domain (PSD), and single-domain (SD) magnetite were first obtained for high pressure up to 1 GPa. The results show that magnetite exhibits various pressure dependences with respect to magnetic domain states. Both MD and PSD magnetite particles, the coercivity monotonously increases with pressure at a rate of +90 %/GPa. On the other hand, the coercivity of SD magnetite is almost constant in the pressure range by 1GPa.

Taking into account new results of pressure dependences of hysteresis parameters, relaxation time of remanent magnetization in the Martian crust was calculated as a function of depth and age. As a result, remanent magnetization carried by MD and PSD magnetite would have been demagnetized within 4 billion years, except very shallow crustal part (shallower than 5 km). On the other hand, the SD magnetite could stably retain its magnetization in the entire crust. Therefore it is concluded that source of the Martin magnetic anomaly is probably elongated SD magnetite with submicron size, suggesting that chemical composition and oxygen state in the Martian crust was suited for bearing fine grains of magnetite about 4 billion years ago.

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