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In-situ magnetic hysteresis measurement of magnetite under high pressure up to 1 GPa: Source of the Martian magnetic anomaly

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Evolution of the terrestrial planet is often clearly recorded by the magnetic anomaly of its crustal rocks. The Martian magnetic anomaly was observed and mapped by Mars Global Surveyor, indicating many strong magnetic anomalies on the Mars (˜100 nT at 400 km altitude). The strong magnetic anomalies suggest an active dynamo of early Martian core and some mechanism of crustal formation in the dynamo field. The high intensity of the Martian anomalies may be attributed to the strong dynamo field and/or a high susceptibility of thermoremanent magnetization of the Martian crust. However, it should be considered whether or not the magnetic anomalies of Martian crustal rocks could have retained those magnetic records for about 4 billion years. 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. Such magnetic properties of crustal rocks depend critically upon the mineralogical form of magnetic particles. Inversely, the strong magnetic anomalies can give crucial information about the chemical composition and oxidation state prevailing in the early Martian crust.

According to previous analyses of the Martian anomalies, sources of the anomalies have to satisfy the following requirement: the crustal rock on average is more intensely magnetized than terrestrial continental crust, and the magnetic layer is thick (˜30 - 40 km) and extending deeply (at least deeper than ˜10 km). Therefore, magnetic minerals of the Martian crust, probably magnetite, should have retained their magnetizations under high pressure and temperature for about 4 billion years. However, pressure dependence has not systematically been studied yet, since particular instrumental technique is required for in-situ magnetic measurement under high pressure.

The author has 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 in the present study. The results show that magnetite exhibits various pressure dependences with respect to magnetic domain states. Both MD and PSD magnetite particles, the coercivity Bc 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 time. As a result, remanent magnetization carried by MD and PSD magnetite would have been demagnetized within 4 billion years, except very shallow crustal part (depth <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 single-domain 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.