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Paleointensity study of the middle Cretaceous Iritono granite in northeast Japan: Implication for high field intensity of the Cretaceous normal superchron

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ABSTRACT

Paleointensity of the Cretaceous normal superchron (CNS) has been studied using the middle Cretaceous Iritono granite of the Abukuma massif in northeast Japan. Our previous study [Wakabayashi, K., Tsunakawa, H., Mochizuki, N., Yamamoto, Y., Takigami, Y., 2006. Paleomagnetism of the middle Cretaceous Iritono granite in the Abukuma region, northeast Japan. Tectonophysics 421, 161–171] indicates that the Iritono granite retains a stable and primary component of high blocking temperatures and high coercivities which is characterized by the shallow inclination and carried mainly by single-domain magnetite. Applying Coe's version of the Thellier method and the LTD–DHT Shaw method, we have obtained 16 successful results with an average of 58.4 ± 7.3 μT. However, an effect of long cooling time of the granite on the paleointensity measurement should be taken into account. An estimate of cooling time to acquire the primary component ranges in 4×10^4 to 1.4×10^7 years from a thermal diffusion model of the granite body and the difference between $^{40}Ar–^{39}Ar$ biotite age of 101.9 ± 0.2 (1σ) Ma and U–Pb zircon age of 115.7 ± 1.9 (1σ) Ma. From single-domain theory, thermoremanent magnetization (TRM) of the Iritono granite samples in nature is estimated to be about 1.5 times as strong as the laboratory TRM. Applying this correction factor, the corrected paleointensity is 39.0 ± 4.9 μT and the virtual dipole moment (VDM) is calculated to be $9.1 \pm 1.1 \times 10^{22}$ A m^2. This VDM can be interpreted as representative of the middle CNS geomagnetic field since the individual granite samples with long cooling time can average out the paleosecular variation. The obtained VDM is a few times higher than mean VDMs averaged for 0–5 Ma (3.6×10^{22} A m^2) and 0–160 Ma (4.8×10^{22} A m^2) except for the CNS by previous studies. This suggests that the geomagnetic field intensity was high in the middle CNS.

1. Introduction

Polarity reversals of the geomagnetic field usually occur at intervals of less than a million years, and such frequent reversals are regarded as one of the intrinsic characteristics of the geodynamo. However, a very long polarity epoch sometimes appears, that is, a superchron with several tens of million years duration. The most recent superchron is the Cretaceous normal superchron (CNS) of 83–118 Ma (Kent and Gradstein, 1985; Cande and Kent, 1995), the cause of which has been studied with special reference to thermal conditions at the core–mantle boundary (CMB).

It has been proposed that hot superplume rising at the CMB caused intensive heat transfer from the core surface to generate a rigorous geodynamo without polarity reversals during the CNS (Larson, 1991; Larson and Olson, 1991). On the other hand, there has been another model of a weak geodynamo due to thick D″ layer (Loper and McCartney, 1986). Numerical results of the fluid dynamics and dynamo for the last two decades suggest that inhomogeneous thermal condition at the CMB heavily affects the geodynamo status and its reversal frequency (Zhang and Gubbins, 1992, 1993; Gallet and Hulot, 1997; Glatzmaier et al., 1999; Olson and Christensen, 2002; Courtillot and Olson, 2007; Takahashi et al., 2008). Therefore the CNS paleointensity study gives a crucial constraint on the core–mantle dynamics of the earth during the Cretaceous.

There is a difficulty to obtain reliable paleointensity of the CNS since fresh volcanic rocks of the pre-Cenozoic age are not abundant.

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Even if a fresh volcanic rock is sampled, it generally gives a spot-reading paleofield due to its rapid cooling, and then at least several temporarily independent units are needed to average out the geomagnetic secular variation. Therefore recent studies of the CNS paleointensity have been carefully conducted by using quenched-glass samples of submarine basalts (e.g. Pick and Tauxe, 1993; Tauxe, 2006) and single plagioclase crystals in volcanic rocks (e.g. Cottrell and Tarduno, 1999; Tarduno et al., 2006). Although those samples yielded both lower and higher virtual dipole moments (VDMs) than the present-day dipole moment, the average for the CNS is about twice higher than for other epochs of 0–160 Ma (Tauxe, 2006). Especially for the middle CNS, two paleointensity data from single plagioclase crystals of basalts show about 1.6 times as strong VDM as the present-day dipole moment (Tarduno et al., 2001). However, most of the CNS paleointensities are distributed at the beginning or ending stages of the CNS, and therefore more data should be accumulated for the middle stage.

Compared with pre-Tertiary volcanic rocks, fresh granite samples are more easily obtained since granite was formed as massive bodies in the deep crust, uplifted, eroded and finally exposed on the surface to result in good preservation against the weathering. Besides, long cooling time of granite could average out the secular variation of the geomagnetic field. This potential is useful for the study of long term variation in the geomagnetic field. In contrast to these advantages, it is thought that there are two major disadvantages in the paleointensity study using granite: (1) unstable component of natural remanent magnetization (NRM) of granite due to multi-domain (MD) magnetic grains, and (2) overestimation of paleointensity due to very long cooling time of granite bodies. Thus there have been few paleointensity data using granite samples (e.g. Biggin et al., 2009).

With the above advantages and disadvantages in mind, we have conducted the paleointensity study of the middle Cretaceous Iritono granite in the Abukuma region, northeast Japan (Fig. 1). Samples were collected in 1998 and 2002, and the tectonic study of the Abukuma massif was reported on the basis of paleomagnetic directions, rock-magnetic properties and ^{40}Ar–^{39}Ar ages (Wakabayashi et al., 2006). According to our previous study, the Iritono granite has a ^{40}Ar–^{39}Ar age of 101.9 ± 0.2 Ma, and the selected samples show a stable component of high blocking temperature (Tb) and coercivity (Bc) which is considered to be primary component carried mainly by single-domain (SD) magnetite. The cooling time is estimated from the thermal diffusion model to be longer than 4×10^4 years. In this paper we report paleointensity measurement results of Iritono granite samples and an estimate of cooling time further constrained by new U–Pb zircon ages. Based on the result, we discuss the geomagnetic field intensity of the middle CNS.

2. Sample selection

The Iritono granite shows a small body with a diameter of about 4 km, which is located at (37.1°N, 140.7°E; Fig. 1) and grouped into granodiorite of the young granitic rocks in a narrow sense (Hiroi et al., 1998). Samples used in the present study are sister samples of our previous tectonic study (Wakabayashi et al., 2006), the results of which are briefly reviewed below.

NRMs of the Iritono granite and associated dikes show two components of H and L. The H component is characterized by shallow inclination and westerly declination ($I = 29.9°$, $D = -49.0°$, $\alpha_{95} = 2.7°$), high blocking temperature (Tb > 350 °C) and high coercivities (Bc > 50 mT), while the L component is by moderate inclination and westerly declination ($I = 42.8°$, $D = -48.5°$, $\alpha_{95} = 3.3°$), lower Tb and lower Bc (Fig. 1). Based on the thermal, alternating field and low temperature demagnetization results, microscopic observations, EDS/EPMA measurements and magnetic hysteresis measurements of feldspar, biotite and whole rock samples, it is concluded that the H component is carried mainly by SD assemblage of magnetite inclusions in plagioclase and dominated by the primary component. On the other hand, it is thought that the L component is carried mainly by pyrrhotite and/or MD magnetite and affected by the Cenozoic remagnetization over northeast Japan (Otofuji et al., 2003).

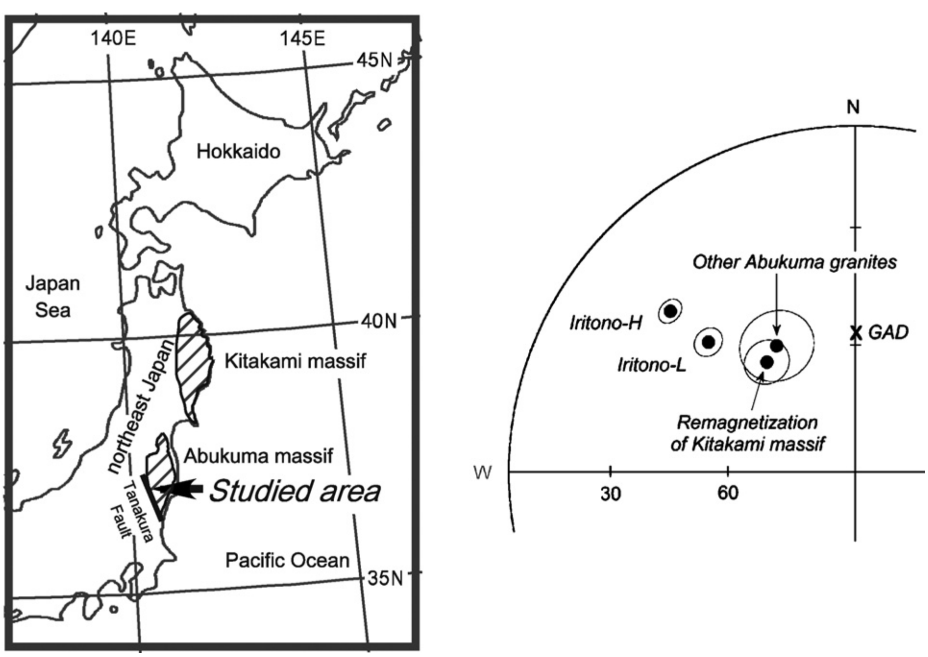

Fig. 1. Map of the Iritono granite of the Abukuma massif, northeast Japan (left), and the remanence directions on equal area projection (right). Iritono-H, a component of high blocking temperature and high coercivity; Iritono-L, a component of low blocking temperature and low coercivity; GAD, the geocentric axial dipole field at the sampling site. Related directions are also shown: mean NRM direction from other Abukuma granites after Ito and Tokieda (1986), and the Cenozoic remagnetization direction of the Kitakami massif in northeast Japan after Otofuji et al. (2003). Circles indicate 95% confidence limits of α_{95}. These are reproduced from the previous study (Wakabayashi et al., 2006).