Construction of the continuous global paleomagnetic field model for the last few million years

YAMAMOTO, Yuhji

(Center for Advanced Marine Core Research, Kochi University)

Abstract

We have now known that the time-average of the 'recent' geomagnetic field is a geocentric axial dipole field. As for the continuous time variation of the dipole moment, it has been reported as several well-known stacked curves from marine sediments. They are in relative values and cover the last few million years.

However, geomagnetic field is not solely the dipolar field and there is a not negligible amount of contributions from the non-dipole components. Both the dipole and non-dipole components are time-varying and the latter cause local variations. Thus, for a complete understanding of the global paleomagnetic field variation, it is important to construct global continuous models.

There have been three such models reported so far, but none of them cover time scale more than ~ 10^5 years. Considering the last five million years, a geologically recent period, average duration of a one geomagnetic polarity interval is about 2×10^5 years. We think it is important to construct a global continuous paleomagnetic field model covering more than a time scale of ~ 10^5 years, in order to comprehensively investigate the Earth's core dynamics.

One of the target periods should be the last few million years. For a construction of the model, we should need (1) few hundreds of volcanic paleomagnetic records and (2) few tens of sedimentary paleomagnetic records from all over the world. They particularly lack in the southern hemisphere at the moment. Geo-dynamo simulations are considered to be one of the most rigorous approaches to investigate the Earth's core dynamics, and recent advances in these simulations need better continuous global paleomagnetic field models for verifications of the simulations.

Body Text

Remanent magnetizations of igneous rocks and marine sediments reflect the past geomagnetic field at their formation or post-deposition. We can retrieve 'instantaneous' paleomagnetic field from igneous rocks while 'continuous' variation from marine sediments. In terms of the intensity of the paleomagnetic field (paleointensity), igneous rocks give absolute paleointensities whereas marine sediments provide relative paleointensities. Ideally, paleomagnetic records should be obtained both from igneous rocks and marine sediments and be integrated for a complete understanding of the ancient geomagnetic field. This understanding is important to investigate the Earth's core dynamics.

We have now known that the time-average of the 'recent' geomagnetic field is a geocentric axial dipole field. Although its magnitude estimated from volcanic rocks is still controversial (e.g. 7.26 x 10^{22} Am^2 for 0-1 Ma, Ziegler et al., 2008; 3.64 x 10^{22} Am^2 for 0.5-4.6 Ma, Yamamoto and Tsunakawa, 2005), continuous time variation of the dipole moment in relative value have been reported as stacked curves from marine sediments: for example, Sint-800 curve for the last 800 kyr (Guyodo and Valet, 1999), Sint-2000 curve for the last 2000 kyr (Valet et al., 2005), EPAPIS-3Ma curve for the last 800-3000 kyr (Yamazaki and Oda, 2005), and PISO-1500 for the last 1500 kyr (Channell et al., 2009). Paleomagnetic records recovered from ODP cores play important roles on these stacked curves: the Sint-800 and Sint-2000 curves include eight and five ODP records, respectively. Further efforts have been made to construct longer time series for an older era and high-resolution stacks for a younger period.

As for the young period, we should also make effort to increase 'spatial resolution'. Geomagnetic field is not solely the dipolar field and there is a not negligible amount of contributions from the non-dipole components. It is known that both the dipole and non-dipole components are time-varying and the latter cause local variations. For a complete understanding of the global paleomagnetic field variation, it is important to construct global continuous models. There have been three such models reported so far. One of the models is the CALS7K (Korte and Constable, 2005). This has been constructed using both published paleodirection and paleointensity data: the former data are from lake sediments of 41 areas, and archaeological material and volcanic rocks of 23 regions; the latter data are from archaeological material and volcanic rocks of 17 regions. From a view point of the Earth's core dynamics, for example, Wardinski and Korte (2008) analyze the core-surface flow over the last 7 kyr by inversion analyses of this model. Other two existing global continuous paleomagnetic models are for the last geomagnetic reversal (around 765-795 ka; Leonhardt and Fabian, 2006) and for the well-known Iceland Basin geomagnetic excursion event (178-202 ka; Lanci et al., 2008).

None of the three models cover time scale more than ~ 10^5 years. Considering the last five million years, a geologically recent period, average duration of a one geomagnetic polarity interval is about $2x10^5$ years, based on the geomagnetic polarity time scale by Cande and Kent (1995). We think it is important to construct a global continuous paleomagnetic field model covering more than a time scale of ~ 10^5 years, in order to comprehensively investigate the Earth's core dynamics. One of the target periods should be the last few million years, because there have been several stacked relative paleointensity records reported so far (e.g. Sint-2000 and EPAPIS-3Ma) which have already revealed dipolar variations.

For a construction of the global continuous model, we should need (1) few hundreds of volcanic paleomagnetic records and (2) few tens of sedimentary paleomagnetic records from all over the world. There have been relatively abundant type (1) data, but they are mostly from the northern hemisphere. We should need to obtain new data mainly from the southern hemisphere. As for type (2) data, only several 'usable' records seem to have been reported and they are also mostly from the northern hemisphere (e.g. Figure 1). Future IODP expeditions will collect many sediment cores from whole world. A part of them is thought to be potentially contributed to the type (2) data and they will probably accumulate as time advances. However, for a better construction of the model, we should probably collect some 'key' sediment cores purposefully from the Pacific and the Atlantic, particularly from the southern hemisphere.

Geo-dynamo simulations are considered to be one of the most rigorous approaches to investigate the Earth's core dynamics. Recent advances in these simulations (e.g. Takahashi et al., 2005; Kageyama et al., 2008) need better continuous global paleomagnetic field models for verifications of the simulations. The paleomagnetic model covering the last few million years will play an important role.

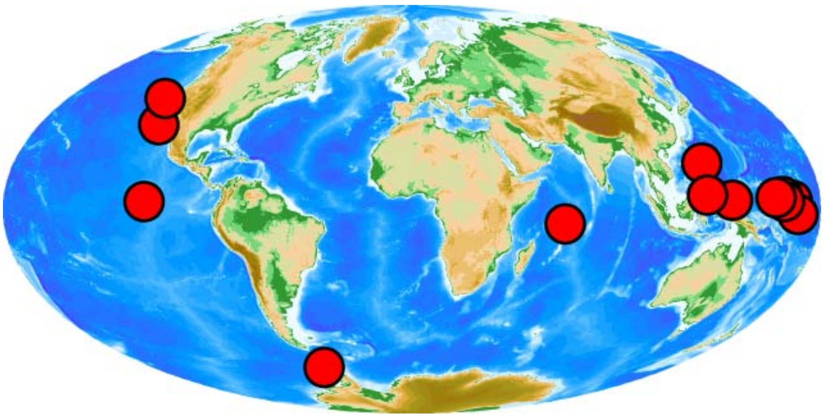

Figure 1: Map showing the locations of sedimentary cores used for a construction of the Sint-2000 curve (Valet et al., 2005). Five ODP records have been included. The curve represents a continuous time variation of the geomagnetic dipole moment in relative value and covers the last 2000 kyr.

References

Cande, S.C. and Kent, D.V., Revised calibration of the geomagnetic polarity timescale for the Late Cretaceous and Cenozoic, J. Geophys. Res., 100, 6093-6095, 1995.

Channell, J.E.T., Xuan, C. and Hodell, D.A., Stacking paleointensity and oxygen isotope data for the last 1.5 Myr (PISO-1500), Earth Planet. Sci. Lett., 283, 14-23, 2009.

Guyodo, Y. and Valet, J. P., Global changes in intensity of the Earth's magnetic field during the past 800 kyr, Nature, 36, 234-238, 1999.

Kageyama, A., Miyagoshi, T. and Sato, T., Formation of current coils in geodynamo simulations, Nature, 454, 1106-1109, 2008.

Korte, M. and Constable, C.G., Continuous geomagnetic field models for the past 7 millennia: 2. CALS7K, Geochem. Geophys. Geosyst., 6, Q02H16, doi:10.1029/2004GC000801., 2005.

Lanci, L., Kissel, C., Leonhardt, R. and Laj, C., Morphology of the Iceland Basin Excursion from a spherical harmonics analysis and an iterative Bayesian inversion procedure of sedimentary records, Phys. Earth Planet. Inter., 169, 131-139, 2008.

Leonhardt, R. and Fabian, K., Paleomagnetic reconstruction of the global geomagnetic field evolution during the Matuyama/Brunhes transition: Iterative Bayesian inversion and independent verification, Earth Planet. Sci. Lett., 253, 172-195, 2006.

Takahashi, F., Matsushima, M. and Honkura, Y., Simulations of a Quasi–Taylor State Geomagnetic Field Including Polarity Reversals on the Earth Simulator, Science, 309, 459-461, 2005.

Valet, J.P., Meynadier, L. and Guyodo, Y., Geomagnetic dipole strength and reversal rate over the past two million years, Nature, 435, 802-805, 2005.

Wardinski, I. and Korte, M., The evolution of the core-surface flow over the last seven thousands years, J. Geophys. Res., 113, B05101, doi:10.1029/2007JB005024, 2008.

Yamamoto, Y. and Tsunakawa, H., Geomagnetic field intensity during the last 5 Myr: LTD-DHT Shaw palaeointensities from volcanic rocks of the Society lslands, French Polynesia, Geophys. J. Int., 162, 79-114, 2005.

Yamazaki, T. and Oda, H., A geomagnetic paleointensity stack between 0.8 and 3.0 Ma from equatorial Pacific sediment cores, Geochem. Geophys. Geosyst., 6, Q11H20, doi:10.1029/2005GC001001., 2005.

Ziegler, L.B., Constable, C.G. and Johnson, C.L., Testing the robustness and limitations of 0–1 Ma absolute paleointensity data, Phys. Earth Planet. Inter., 170, 34-45, 2008.