Paleomagnetic problems to be solved by IODP beyond 2013

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Abstract

The most significant progress in the geomagnetism and paleomagnetism since the present ISP was written is numerical simulations of the geodynamo. Paleomagnetic observations that can strongly constrain simulations are required now. Such observations attainable by the next phase of IODP are (1) global data for construction of a continuous paleomagnetic field model, (2) paleointensity data to understand relationship between reversal frequency and the strength of the field, in particular paleointensity during the Cretaceous Normal Superchron, and (3) data from high latitudes to clarify similarities and differences of geomagnetic field variations inside and outside the tangent cylinder. Other important issues that should be addressed by IODP are a possibility for the orbital modulation of the geomagnetic field, a possible link between climate and the geomagnetic field, and hotspot motion vs. True Polar Wander. Proposals of paleomagnetism often request to occupy widely distributed sites for global data coverage, which does not fit the conventional ODP-style expeditions. The next-phase IODP should have more flexibility of implementation. Improvement of drilling technology is necessary for maximizing scientific output. Cores (APC, XCB, and RCB) without drilling induced magnetic overprint are strongly required for paleomagnetism. Also accurate orientation of cores is desired.

1. Introduction

In the present Initial Science Plan (ISP), the importance of the paleomagnetism is recognized as the statement that "a more complete understanding of the variability of Earth's magnetic field through time, in both magnitude and direction, is an important component of drilling studies of the Earth system", although no paleomagnetic theme is included in the eight initiatives. The two specific paleomagnetic problems, source of marine magnetic anomalies and a possible relationship between the frequency of change in the polarity of Earth's magnetic field and major geodynamic events including that of the Cretaceous normal superchron and superplume, are pointed out in the ISP. These problems have not yet been settled, and will continue to be the issues to be solved beyond 2013.

The most significant progress in the geomagnetism and paleomagnetism since the ISP was written is numerical simulations of the geodynamo. The first result that succeeded to make a geomagnetic polarity reversal was published in 1995 by Glatzmaier and Roberts. At that time, however, parameters used for the simulation were far from the conditions in the core of the real Earth. Since then, simulations have become closer to the Earth in accordance with the development of super-computers like the Earth Simulator. In 2005, Takahashi et al. attained a simulation in a quasi-Taylor state, the Earth-like dynamo. When considering new and revised strategies for paleomagnetism beyond 2013, it is important to aim for merging observations and simulations. By IODP drilling, paleomagnetic data that give strong constraints to simulations can be obtained. The present ISP lacks this viewpoint.

2. Paleomagnetic problems to be solved

2.1. Constraining geodynamo models

From the modern geodynamo simulations, the following observations are in particular important for further progresses.

First, it is required to construct a continuous paleomagnetic field model that includes non-dipole components for the last few million years, like the CALS7K model for the last seven thousand years (Korte and Constable, 2005). From the model, we can examine, for example, whether the high-latitude flux patches that are known to have persisted at least for the last 400 years from historical observations are stable on longer timescale. Such information is necessary for understanding spatial stability of core convection and its dynamics. For constructing the model, global data coverage is essential, and thus paleomagnetic data from the southern oceans are in particular desired.

Second, it is necessary to understand the strength of the geomagnetic field in the past (paleointensity), which is an indicator of dynamo activity. A relationship between reversal frequency and the strength of the field has been suggested. Paleointensity during the Cretaceous Normal Superchron (CNS) is particularly important as an extreme case of a stable polarity, but paleointensity data obtained so far are controversial. A possible approach to the problem is to combine marine magnetic anomaly observations using deep-towed magnetometer and paleointensity determination of basalts drilled at closely-spaced several sites along a deep-tow survey line within CNS.

Third, it is important to examine similarities and differences of geomagnetic field variations inside and outside the tangent cylinder (a virtual cylinder aligned with the rotation axis in touch with the inner core at the equator). Numerical dynamo models tell us that convection and dynamo action occur differently inside and outside the tangent cylinder (e.g., Kono and Roberts, 2002). The Arctic Sea and Ross Sea are the target areas to take sediment cores for this purpose.

2.2. Possibility for orbital modulation of the geomagnetic field, and a link with paleoclimate

Understanding geomagnetic field variations within context of the whole Earth system is an important viewpoint. The possibility of orbital modulation of the geomagnetic field has been a matter of debate for ten years or more (e.g., Yokoyama and Yamazaki, 2000; Yamazaki and Oda, 2002; Fuller 2006; Xuan and Channell, 2009). If this is true, it has fundamental implications for the geomagnetism because it means that an energy source of the geodynamo resides outside the core. The current points of the arguments include a possibility of lithological contamination to paleointensity records and statistical significance. To settle the problem, it is required to obtain high quality paleomagnetic records, both paleointensity and direction, during the last ca. 10 m.y. with global site distribution, which can be a target for the next phase of IODP.

Another interesting topic is a possible connection between paleoclimate and geomagnetic field, which also has a long history of debate. Recently, a possible connection between influx of galactic cosmic rays and climate has been argued (e.g., Svensmark, 1997). If so, the geomagnetic field might affect climate because the strength and shape of the geomagnetic field control influx of galactic cosmic rays. It is expected for IODP to take a suite of sediment cores suitable for studying cosmogenic nuclides and paleomagnetism.

2.3. Hotspot motion and true polar wander

Arguments for the fixity of hotspots and the True Polar Wander (TPW) are a fundamental issue of the geodynamics, and paleomagnetism can provide essential data to settle the problem. The drilling of the Hawaii-Emperor seamount chain suggested southward migration of the Hawaii hotspot (Tarduno et al., 2003). Alternatively it could be explained by TPW. Implementation of the IODP drilling proposal of the Louisville seamount chain (636-Full3), which is currently at the OTF and waiting for being scheduled, will be the first step. It is necessary to drill several hotspot tracks to solve the problem. In particular, the location of the Tristan hotspot track is favorable for distinguishing the hotspot motion and TWP models. This may not be completed before 2013, and be carried over to the next phase of IODP.

3. Implementation strategy

Paleomagnetic themes often require global data coverage, and hence many paleomagnetic IODP proposals request to occupy widely distributed sites. These do not fit the conventional ODP-style expeditions: about two months for one proposal. We paleomagnetists request that the next-phase IODP has more flexibility of implementation. Occupation of widely distributed sites should be organized under a long-term program, and implemented as a piggy-back style; a few days are devoted to a paleomagnetic proposal when nearby sites are drilled for other objectives.

4. Technology to be developed

Improvement of drilling technology is important for paleomagnetic objectives. Drilling induced remanent magnetization has often been annoyed paleomagnetists. Coring with APC sometimes produces artificial remanent magnetization that cannot be removed by alternating-field (AF) demagnetization (e.g., ODP Leg 154). Such cores are unfortunately useless for paleomagnetism. The artificial remanent magnetization is probably acquired by deformation of sediments in a strong magnetic field of drilling strings: core-barrel, cutting shoe, and so on. A non-magnetic core-barrel reduces the problem, but far from perfect yet. Coring hard rocks with RCB also often induces secondary remanent magnetization. This can usually be erased by AF demagnetization, but for understanding sources of marine magnetic anomalies, recovering in situ magnetization before partial demagnetization is essential. Improvement of drilling technology for avoiding drilling induced magnetization should be seriously considered in the next phase of IODP for maximizing scientific output.

A demand of fully oriented cores is not only for paleomagnetism but also for other fields including structural geology. Orientation of APC cores with the FLEXIT tool (a magnetic compass) available at present is not satisfactory; it can be used for judging the magnetic polarities, normal or reversed, but not enough for studying secular variations of declination partly due to a magnetic field produced by a drill-string and twisting of a core liner. Introduction of up-to-date technology will enable accurate orientation of cores including RCB.

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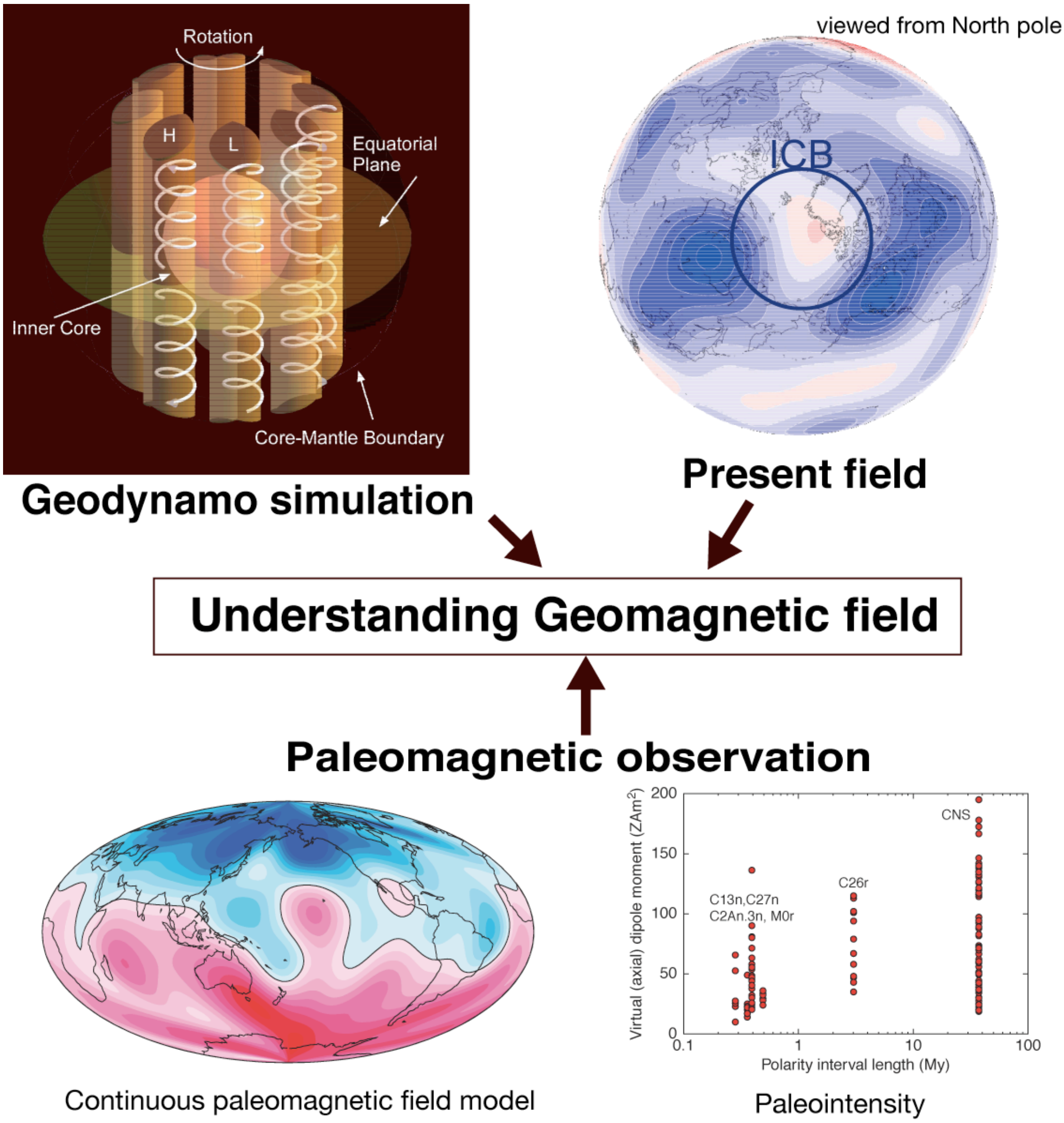

Rotation
H
L
Equatorial Plane
Inner Core
Core-Mantle Boundary
Geodynamo simulation
viewed from North pole
ICB
Present field
Understanding Geomagnetic field
Paleomagnetic observation
Continuous paleomagnetic field model
Virtual (axial) dipole moment (ZAm²)
Polarity interval length (My)
0
50
100
150
200
0.1
1
10
100
CNS
C26r
C13n,C27n
C2An.3n, M0r
Paleointensity