Earth and Planetary Science Letters 397 (2014) 67–79

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

Geomagnetic, cosmogenic and climatic changes across the last geomagnetic reversal from Equatorial Indian Ocean sediments

Jean-Pierre Valet[a,*], Franck Bassinot[b], Alexandra Bouilloux[a], Didier Bourlès[c], Sébastien Nomade[b], Valéry Guillou[c], Fernand Lopes[a], Nicolas Thouveny[c], Fabien Dewilde[b]

[a] *Institut de Physique du Globe de Paris, Université Paris Diderot, Sorbonne Paris-Cité, UMR 7154 CNRS, 1 rue Jussieu, 75238 Paris Cedex 05, France*
[b] *Laboratoire des Sciences du Climat et de l'Environnement (CEA-CNRS-UVSQ), Domaine du CNRS, Avenue de la Terrasse, 91198 Gif-sur-Yvette, France*
[c] *Aix-Marseille Université, CNRS-IRD-Collège de France, UM 34 CEREGE, Technopôle de l'Environnement Arbois-Méditerranée, BP80, 13545 Aix-en-Provence, France*

ARTICLE INFO

Article history:
Received 6 December 2013
Received in revised form 22 March 2014
Accepted 24 March 2014
Available online 5 May 2014
Editor: L. Stixrude

Keywords:
reversals
geomagnetic field
beryllium
astrochronology
magnetization

ABSTRACT

High-resolution records of beryllium (^{10}Be) production and relative paleointensity have been obtained across the Matuyama–Brunhes (M–B) reversal from the equatorial Indian Ocean (Maldives area). Both magnetic and geochemical analyses were performed from the same discrete samples to avoid any artificial depth offset. The authigenic ^{10}Be concentrations were normalized with respect to ^{9}Be in order to correct for potential environmental effects, while the relative paleointensity was derived from the remanent magnetization intensity after accounting for changes in magnetic concentration within the sediment. The relative paleointensity and the ^{10}Be/^{9}Be records are both characterized by large deviations, which culminate in the middle of the reversal. In contrast to most previous studies, and despite relative high deposition rate (4.7 cm/ka), we observed a perfect synchronism between the ^{10}Be/^{9}Be peak, the lowest value of relative paleointensity and the switch in direction, which indicates that bioturbation and post-depositional processes did not affect the magnetic record. This leaves no ambiguity for the stratigraphic position of the reversal located within Marine Isotopic Stage 19 as revealed by the planktonic δ^{18}O record from the same core. The magnetic data depict a two-phase process with a precursory event preceding the rapid polarity switch, while only the second phase is present in the ^{10}Be record, similarly to other low latitude records from the Indonesian area. Using an orbitally-tuned age model, we obtain an age of 772 ka ± 5 ka for the middle of the transition, while the precursory event occurred almost 20 ka before. We believe that the bimodal distribution emerging from the compilations of the ages of the M-B reversal results from the succession of these two events. Microtektites from the Australasian impact were found at 0.6 m below the transition (790 ka ± 5 ka B.P.) and confirm that this large event occurred 12 ka prior to the polarity transition. The distribution of tektite abundance was used to deconvolve the ^{10}Be/^{9}Be signal. The results confirm that the beryllium changes are concentrated during the transitional period, thus likely in presence of a multipolar geomagnetic field (or in the vicinity of a geomagnetic pole) that favored the penetration of cosmic rays and consequently increased the ^{10}Be production. The absence of ^{10}Be during the precursor indicates that the present site and the Indonesian ones were far away from a geomagnetic pole and that interlatitudinal atmospheric mixing was limited. The geomagnetic pole positions above the Indonesian sites during the precursor would thus be incompatible with the corresponding inclined dipolar field during this period, and suggest the dominance of low-degree harmonics.

1. Introduction

The paleomagnetic data contain a broad spectrum of dipole moment fluctuations. The largest changes occur during polarity reversals and excursions and these major field instabilities are always associated with periods of low field intensity. Detailed knowledge of the rapid fluctuations and long-term changes of the dipole field intensity helps us understand why it fluctuates, what causes polarity reversals and ultimately informs us about the evolution of the geodynamo in the Earth's liquid core. Much information has been gained during the past 30 yr from a large number of paleointensity records, which rely on natural remanent magnetization (NRM)

---

* Corresponding author.

http://dx.doi.org/10.1016/j.epsl.2014.03.053

of sediments (Valet, 2003; Tauxe and Yamazaki, 2007). However, various factors constrain the response of magnetization to the field and their variability can generate discrepancies among records of Relative Paleointensity (RPI). Given the complex processes involved in the magnetization of sediments, it is delicate to understand the origin of differences between parallel records and thus in some cases to estimate their reliability. This problem can be partly solved by stacking a large number of distinct individual records into a composite curve (Guyodo and Valet, 1996; Laj et al., 2000; Valet et al., 2005). Another approach is to refer to the production of cosmogenic nuclides with a long decay life such as ^{10}Be, which provide an alternative and promising tool to decipher past changes in geomagnetic intensity.

During periods of low geomagnetic dipole strength, and thus low shielding by the field and greater penetration of cosmic ray protons, the flux of galactic rays to the atmosphere increases and produces more collisions with atoms, which subsequently enhance the production of radionuclides. The relationship between geomagnetic dipole strength and cosmogenic nuclides production is relatively well understood and has been quantitatively determined (Masarik and Beer, 1999). The cosmonuclide ^{10}Be has a long radioactive decay (half-life of 1.38×10^6 yr), a rather short residence time in the atmosphere (about 3 yr) and it is not damped by reservoirs (like for ^{14}C). The penetration of galactic rays is strongly modulated by the shape of the magnetic field lines so that particle access to the atmosphere varies strongly as a function of the cut-off rigidity, which is a quantitative measure of the shielding effect by the magnetic field and thus used to calculate the ^{10}Be production rate. Due to the dipolar dominant field geometry, most ^{10}Be production is concentrated at high latitudes and almost absent at low latitudes, but meridional mixing of the atmosphere favours the redistribution of ^{10}Be atoms attached to aerosols. It is usually considered that the atmospheric residence time of these particles would not exceed one-two years before being precipitated in some form to the surface.

Because the largest field intensity changes occur during geomagnetic reversals, these periods are particularly appropriate to document and compare records derived from relative paleointensity and ^{10}Be analyses. The last Brunhes/Matuyama (B/M) transition is unambiguously identified in sedimentary sequences and evidently the best candidate. A precursory study (Raisbeck et al., 1985) conducted on the last reversal confirmed that the signals of ^{10}Be production and relative paleointensity were effectively anti-correlated. A subsequent record (Carcaillet et al., 2004a) from core MD97-2140 collected on the Eauripik ridge (West Equatorial Pacific) concerned the 600–1300 ka interval while the recently published record from core MD05-2930 in the Gulf of Papua (Ménabréaz et al., 2014) presents the best resolution dataset for the 250–800 ka interval. The changes in ^{10}Be production reconstructed from these records match relatively well the pattern of the Sint-800 composite curve of relative paleointensity (Guyodo and Valet, 1999) over this time period as well as that of the Piso-1500 composite curve obtained from a subset of records from northern Atlantic (Channell et al., 2009). However, the intensity lows revealed by the relative paleointensity and the ^{10}Be variations measured in the same core are offset from each other. Another study was conducted on core MD92-2187 in the western equatorial Pacific Ocean (Suganuma et al., 2011). It was restricted to the interval surrounding the B/M transition recorded 12.85 m below sea floor with a mean deposition rate lower than 2 cm/ka. Similarly, the authors have reported a significant offset between the ^{10}Be and paleointensity signals, which has been interpreted as the consequence of post-depositional remanent magnetization.

Apart reversals, excursions are also accompanied by a large drop of field intensity which makes these events other interesting candidates for comparing relative paleointensity reconstruction and changes in ^{10}Be production. The most recent events were documented in the ^{10}Be database built for the past 200 ka using records from multiple Atlantic and Pacific cores stacked into a composite curve (Frank et al., 1997). The results revealed a pattern globally similar to that of the composite Sint-200 curve of relative paleointensity (Guyodo and Valet, 1996). More recently, the period surrounding the Laschamp excursion (40 ka B.P.) has been extensively investigated (Carcaillet et al., 2004b; Muscheler et al., 2005; Leduc et al., 2006; Nilsson et al., 2011; Ménabréaz et al., 2012). These high resolution ^{10}Be records show a great deal of similarities with the NAPIS composite curve of relative paleointensity for this period (Laj et al., 2000), but also some differences outside the Laschamp interval that remain still unexplained.

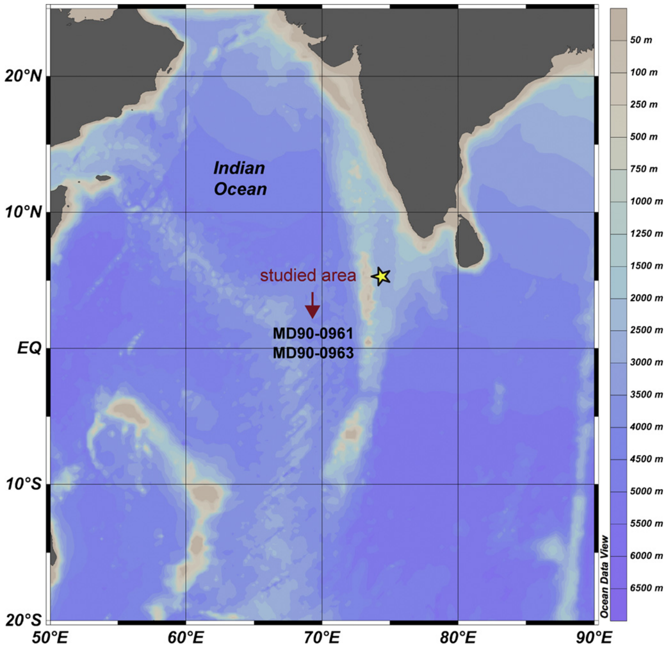

Fig. 1. Site location. Schematic map of the site location in the Maldives area.

In the present study, we focus on a high-resolution record from the Maldives area (Indian Ocean). We selected an equatorial site to study the changes in ^{10}Be production at low latitude during periods of strong and low dipole activity. The selected core, MD90-0961, was retrieved on the exact same location as core MD90-963, which provided a reference isotopic record which has been used to improve late Pleistocene orbital stratigraphy (Bassinot et al., 1994). A first objective was to investigate the relationship between the ^{10}Be and RPI signals within the time framework given by high-resolution isotopic stratigraphy. In order to minimize artificial offset linked to sampling problems, we systematically measured all magnetic, geochemical and mineralogical parameters from the same discrete samples.

2. Site, lithology and stratigraphy

Core MD90-0961 was collected during the Seymama cruise of the French R/V *Marion Dufresne* in 1990. The coring site is located in the Indian Ocean, east of the Maldives platform (05°03.71 N, 73°52.57 E) at 2446 m of water depth (Fig. 1). The sediment thickness retrieved is 45.7 m. Lithology is dominated by calcareous nanofossil ooze with abundant foraminifers.

We sampled the core at a 10-cm interval from 16.5 m to 40.9 m and measured the oxygen stable isotopic composition of planktonic foraminifer *Globigerinoides ruber* white (sensu stricto) picked in the 250–315 μm size fractions. Analyses were performed on