Earth and Planetary Science Letters 278 (2009) 87–95

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

journal homepage: www.elsevier.com/locate/epsl

Geomagnetic field evolution during the Laschamp excursion

Roman Leonhardt [a,*], Karl Fabian [b], Michael Winklhofer [c], Annika Ferk [a,c], Carlo Laj [d], Catherine Kissel [d]

[a] Department of Applied Earth Sciences and Geophysics, Montanuniversity, 8700 Leoben, Austria
[b] NGU, Geological Survey of Norway, 7491 Trondheim, Norway
[c] Department of Earth and Environmental Sciences, Ludwig-Maximilians-University, 80333 Munich, Germany
[d] Laboratoire des Sciences du Climat et de l`Environnement, (CEA-CNRS-UVSQ), 91198 Gif-sur-Yvette Cédex, France

ARTICLE INFO

Article history:
Received 28 July 2008
Received in revised form 17 November 2008
Accepted 23 November 2008
Available online 10 January 2009

Editor: R.D. van der Hilst

Keywords:
geomagnetism
palaeomagnetism
excursion
Laschamp

ABSTRACT

Since the last geomagnetic reversal, 780,000 years ago, the Earth's magnetic field repeatedly dropped dramatically in intensity. This has often been associated with large variations in local field direction, but without a persistent global polarity flip. The structure and dynamics of geomagnetic excursions, and especially the difference between excursions and polarity reversals, have remained elusive so far. For the best documented excursion, the Laschamp event at 41,000 years BP, we have reconstructed the evolution of the global field morphology by using a Bayesian inversion of several high-resolution palaeomagnetic records. We have obtained an excursion scenario in which inverse magnetic flux patches at the core-mantle boundary emerge near the equator and then move poleward. Contrary to the situation during the last reversal (Leonhardt, R., Fabian, K., 2007. 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), these flux patches do not cross the hydrodynamic boundary of the inner-core tangent cylinder. While the last geomagnetic reversal began with a substantial increase in the strength of the non-dipolar field components, prior to the Laschamp excursion, both dipolar and non-dipolar field decay at the same rate. This result suggests that the nature of an upcoming geomagnetic field instability can be predicted several hundred years in advance. Even though during the Laschamp excursion the dipolar field at the Earth's surface was dominant, the reconstructed dynamic non-dipolar components lead to considerable deviations among predicted records at different locations. The inverse model also explains why at some locations no directional change during the Laschamp excursion is observed.

1. Introduction

The Earth's magnetic field has sporadically switched its polarity throughout the geological past. Between polarity transitions the field geometry at the Earth's surface is approximately that of an axial dipole. The periods of stable polarity have been interrupted by geomagnetic excursions of a few kyr duration (Laj and Channell, 2007). If the field intensity shows a pronounced low during an excursion, this can then result in large-scale fluctuations of local field direction, which are similar in magnitude to those observed during reversals, but without entailing a persistent polarity flip. The nature of geomagnetic excursions has been debated ever since their discovery and interpretations have ranged from aborted reversals to anomalous or enhanced palaeosecular variation (Cox et al., 1975; Hoffman, 1981; Merrill and McFadden, 1994). Several interpretations suggest that during excursions, the reversing field in the liquid outer core is held back by the influence of the solid inner core (Hollerbach and Jones, 1993; Glatzmaier and Roberts, 1995; Gubbins, 1999). Therefore, understanding the nature of geomagnetic excursions is considered essential for characterizing the geodynamo (Kono and Roberts, 2002).

The Laschamp excursion was first discovered in lava flows from the Chaine des Puys, France (Bonhommet and Babkine, 1967). It is the best examined geomagnetic excursion and has been confirmed to have occurred globally (Kristjansson and Gudmundson, 1980; Levi et al., 1990; Kissel et al., 1999; Kent et al., 2002; Oda et al., 2002; Lund et al., 2005; Channell, 2006; Laj et al., 2006; Mochizuki et al., 2007; Singer et al., 2008; Cassata et al., 2008), at about 41 ka (Guillou et al., 2004), roughly at the onset of the Upper Palaeolithic and the appearance of early modern humans in Europe “Cro Magnon” (Strauss, 1989) and eastern Eurasia (Barker et al., 2007). Due to the Laschamp excursion, atmospheric cosmogenic-radionuclide production, at the resolution-limit age of the ^{14}C-dating method, increased significantly (Laj et al., 2002a). Thus, details of the excursional field behaviour affect archaeological dating during this especially important period of human prehistory.

While earlier studies proposed enhanced non-dipole components at the Earth's surface during the Laschamp excursion (Levi et al., 1990), recent suggestions assume that the geometry of the excursional field state was rather simple, because strikingly similar patterns of

* Corresponding author.
E-mail address: roman.leonhardt@unileoben.ac.at (R. Leonhardt).

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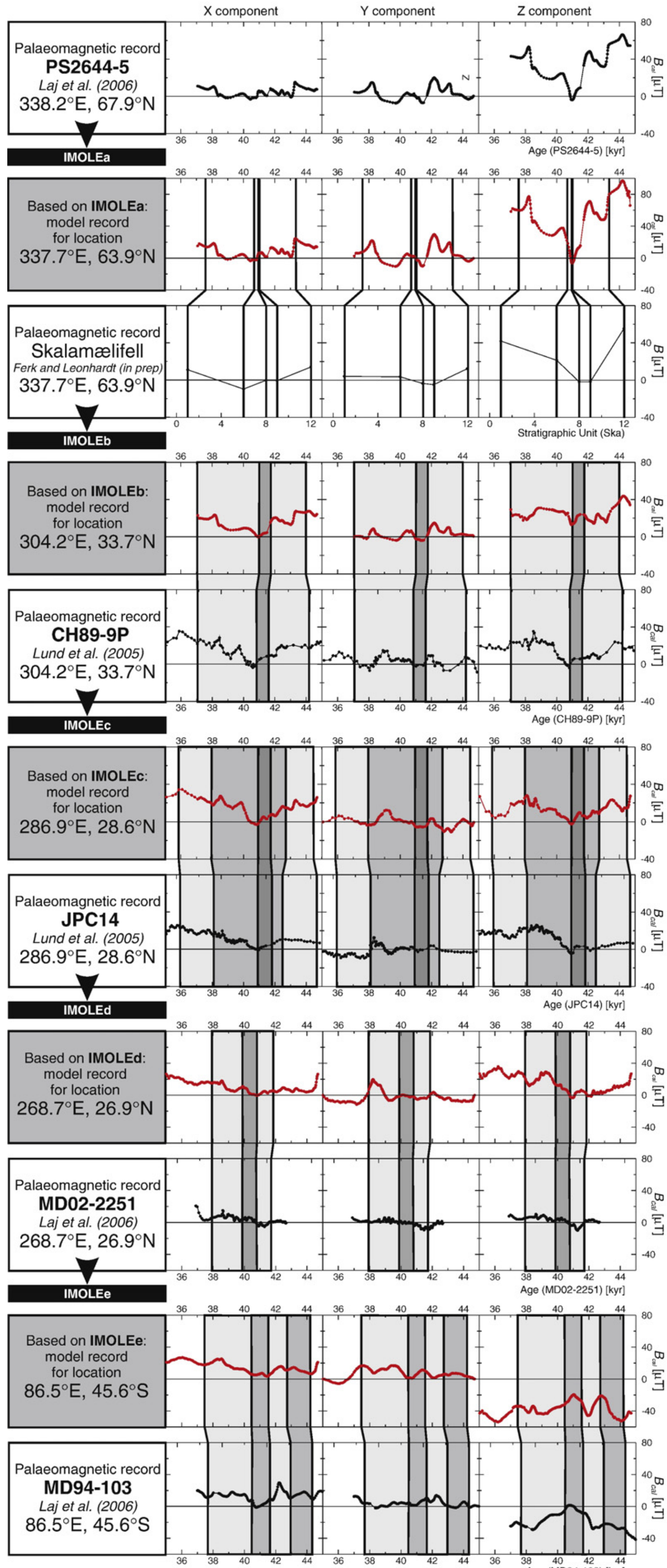
doi:10.1016/j.epsl.2008.11.028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for location
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Palaeomagnetic record
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Ferk and Leonhardt (in prep)
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Stratigraphic Unit (Ska)
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for location
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Palaeomagnetic record
CH89-9P
Lund et al. (2005)
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Age (CH89-9P) [kyr]
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IMOLEe
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model record
for location
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Palaeomagnetic record
MD94-103
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Age (MD94-103) [kyr]
B [µT]
B_cal [µT]