Earth and Planetary Science Letters 383 (2013) 142–152

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

Globally strong geomagnetic field intensity circa 3000 years ago

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A R T I C L E I N F O

Article history:
Received 5 March 2013
Received in revised form 25 September 2013
Accepted 26 September 2013
Available online 18 October 2013
Editor: J. Lynch-Stieglitz

Keywords:
strong geomagnetic field intensity
archeomagnetism
paleointensity
secular variation
dipolar field
non-dipolar field

A B S T R A C T

High-fidelity geomagnetic field intensity determination was carried out using 191 baked fragments collected from 20 kilns or hearths with ages ranging between ∼1200 BC and ∼AD 1725 in South Korea. Geomagnetic field intensity variation displayed three narrow minima at ∼800–700 BC, ∼AD 700, and ∼AD 1600 and two maxima at ∼1200–1100 BC and ∼AD 1000–1100. In most time intervals, virtual axial dipole moment (VADM) variation is confined within 20% of the present VADM. However, geomagnetic field intensity circa 3000 yr ago is nearly 40% larger than the present value. Such high VADMs circa 3000 yr ago are in phase with those in other longitudinal bands in northern hemisphere centered at 5E (France), 30E (the Middle East) and 200E (Hawaii). Although strong geomagnetic field intensity circa 3000 yr ago is globally synchronous, the highest VADM occurs at slightly different time intervals in different locations. Hence it is possible that the globally strong geomagnetic field intensity circa 3000 yr ago reflects the migration of persistent hemispheric flux in northern hemisphere or an episode of geomagnetic field hemispheric asymmetry.

1. Introduction

The Earth's magnetic field is composed of a dominant dipolar component and a weak non-dipolar fraction. In practice, the non-dipolar field reflects a difference between the actual Earth's field and the estimated best-fitting dipole. In contrast to the dipolar component, the non-dipolar field is smaller and has a regional significance with much shorter temporal variation.

Changes of direction and intensity of the geomagnetic field have substantially improved our understanding of past geodynamic evolution. In particular, paleosecular variation (PSV) explores the spatial and temporal evolution of the geomagnetic field in relatively short time scales less than a million years. Recent compilation of a vast global dataset (e.g., Donadini et al., 2006, 2009) includes archeomagnetic data as well as PSV records observed from sedimentary and volcanic material. In addition, optimization of computation technique contributed to the development of continuous spherical harmonic global geomagnetic field models. These comprehensive models include ARCH3k.1/CALS3k.3/CALS3k.4 for the past three millennia (Korte and Constable, 2003, 2011; Donadini et al., 2009; Korte et al., 2009), CALS7k.2 for the past seven millennia (Korte and Constable, 2005a, 2005b; Korte et al., 2005), and CALS10k.1 for the past ten millennia (Korte et al., 2011). Despite such progress, regional geomagnetic characterization is still challenging because the global geomagnetic field models are strongly influenced by the reliability of individual data sets and by the uneven distribution of PSV records in time and space. In fact, evaluating the significance of non-dipole contribution is possible only when the dipole contribution is quantifiable from the compilation of regional PSV records (e.g., Genevey et al., 2008; Valet et al., 2008). Unlike Europe where high resolution PSV records are available in individual country level, only a limited number of modern PSV investigations have been performed over entire East Asia.

One interesting feature resolved in most global geomagnetic field models is the Asian flux lobe, a persistent non-axial dipole contribution to radial magnetic field at the core-mantle boundary (CMB) (e.g., Constable et al., 2000). Recent advances in numerical field models also indicate the evidence of persistent and dynamic northern hemispheric flux patches (Korte and Holme, 2010). Then, it is interesting to see whether such a persistent flux lobe at the CMB influences the intensity variation of surficial magnetic field in East Asia. At present, more than three hundred individual absolute paleointensity estimates are available for Holocene in East Asia (Nagata et al., 1963; Sasajima, 1965; Kinoshita, 1970; Kitazawa, 1970; Domen, 1977; Kono, 1978; Tanaka, 1980, 1982; Wei et al., 1982, 1986, 1987; Sakai and Hirooka, 1986; Tang

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http://dx.doi.org/10.1016/j.epsl.2013.09.043

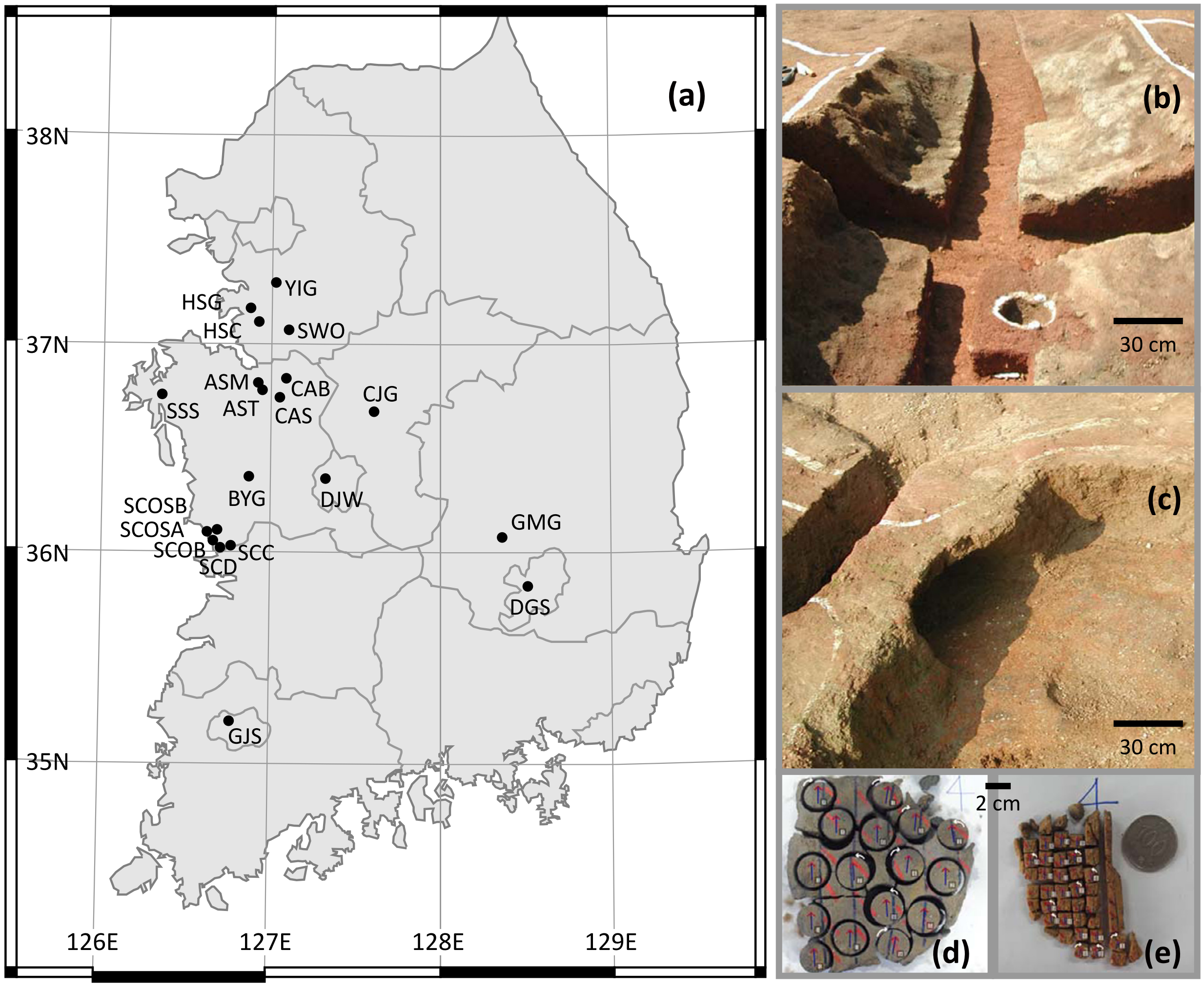

Fig. 1. (a) Schematic map showing the archeological sites sampled in this study. Field photographs of (b) YIG kiln and (c) SWO hearth. (d) One-inch oriented drill coring from extremely well-consolidated hearth fractions. (e) Sliced cubic fragments of kiln blocks.

et al., 1991; Yang et al., 1993a, 1993b; Tsunakawa and Shaw, 1994; Shaw et al., 1995, 1999; Nachasova and Burakov, 1997; Huang et al., 1999; Burakov et al., 2000; Yoshihara et al., 2003; Yamamoto and Hoshi, 2008; Yu, 2012). However, only 36 individual results are of use when stringent criteria are applied including systematic alteration checks and age uncertainty less than 200 yr (see Yu, 2012 for details). Such rarity of modern reliable paleointensity data in East Asian countries needs to be improved by employing more systematic archeomagnetic investigations. Extracting faithful geomagnetic field intensity information is possible when numerous baked relics (and/or erupted volcanic material) that contain exclusively fine-grained magnetic minerals are easily accessible. To this end, East Asian countries are ideal inventories for archeomagnetic investigations as the long pottery-producing civilizations in China and Korea are well-known (e.g., Yu et al., 2010).

To date, no attempt to determine paleointensity has been made from the Korean peninsula. The present study was aimed to provide high quality paleointensity estimates from baked archeological materials in the Korean peninsula for the first time. Providing high-fidelity field intensity variation in Korea may extend our knowledge of regional PSV records.

2. Samples

Recent archeological excavation in South Korea from thirteen cities revealed twenty independent pottery kilns and baked hearths, with hundreds to thousands of ceramic and lithic fragments (Fig. 1a, Table 1). Location and ages of the studied hearths/kilns are summarized in Table 1. It is typical that kilns are a few meters in length and 1–2 m in width (Fig. 1b) and hearths are 1–2 m in length and a few ten centimeters in width (Fig. 1c). Whenever possible, the ^{14}C dates are displayed in compliance with historical age determination. Relative ages were established on the basis of historical context, quartz optically stimulated luminescence (OSL) dates, or the pottery typology, decoration pattern, jewels and/or coins. The ^{14}C dates were determined from accelerator mass spectrometry on charcoal or residues from each excavated hearths/kilns. We adopt typical data entries in modern archeological articles as Cal BP records the calibrated radiocarbon date in BP time scale with the standard deviation of calibrated dates in years as provided with every date and as ^{14}C min and ^{14}C max represent the minimum and maximum calendar date range to two standard deviations, as calibrated from the most recent calibration curve (Ramsey, 2009) using Oxcal 4.2 (http://c14.arch.ox.ac.uk/).

Nine sites in late Bronze age were excavated including Buyeo Gajoong (BYG, 1380–990 BC), Seosan Sinsong (SSS, 1220–1130 BC), Cheonan Baekseok (CAB, 1320–1000 BC), Asan Myeongam (ASM, 1290–1010 BC), Seocheon Okbuk (SCOB, 860–630 BC), Seocheon Dosam (SCD, 770–520 BC), Seocheon Osuk-A (SCOSA, 630–470 BC), Gwangju Soomoon (GJS, 600–440 BC), and Seocheon Osuk-B (SCOSB, 520–340 BC). In addition to ^{14}C dates, presence or ab-