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^{10}Be signature of the Matuyama-Brunhes transition from the Heqing paleolake basin

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ABSTRACT

We present a new ^{10}Be record spanning the Matuyama-Brunhes (M-B) reversal from the Heqing paleolake basin in southern China. It provides a robust proxy for past geomagnetic variations that can be compared with paleomagnetic records. The M-B transition is identified as a pronounced maximum of authigenic ^{10}Be/^{9}Be ratio between 768.6 and 778.5 ka, that is consistent with all other available ^{10}Be-proxy records from marine, ice and loess archives. However, it is offset by approximately 0–60 cm depth from the magnetic signature of the polarity transition recorded in the same sediments. We attribute this offset to the lock-in effect of the remanence acquisition process, which is similar to the phenomenon that exists in marine sediments. We suggest that after eliminating the climatic-hydrological signal, the Heqing sediments may be used as an archive for atmospheric ^{10}Be production rate changes. The combination of magnetic remanence measurements and the cosmogenic ^{10}Be allows for a more precise geochronology of geomagnetic polarity reversals.

1. Introduction

Geomagnetic polarity reversals are generally considered to occur synchronously around the world and have served as important time markers to correlate climatic events between different sediment archives (Mankinen and Dalrymple, 1979; Zhou and Shackleton, 1999). The Matuyama-Brunhes (M-B) transition is the most recent geomagnetic field reversal and is an important time marker for the Quaternary period, since it corresponds to the official global boundary stratotype section and point (GSSP) for the Middle Pleistocene (Head and Gibbard, 2015). During the past few decades, this reversal has been investigated in many geological archives, including basalts, ice core, marine and lacustrine sediments, as well as Chinese loess (e.g., Love and Mazaud, 1997; Zhou and Shackleton, 1999; Singer et al., 2005; Raisbeck et al., 2006). The M-B reversal is generally recorded within the interglacial marine isotope stage (MIS) 19 in marine sediments (Tauxe et al., 1996; Suganuma et al., 2010, 2011; Valet et al., 2014), while it has been usually reported in glacial loess unit L_8, corresponding to MIS 20 (Heller and Liu, 1986; Sun et al., 1993; Zhu et al., 1994; Zhou and Shackleton, 1999). This timing discrepancy has introduced uncertainties in the stratigraphic correlation between loess and marine sequences.

Geomagnetic polarity reversals are usually detected by measuring remanent magnetization in sediments (e.g., Zhu et al., 1994; Guyodo and Valet, 1999; Carcaillet et al., 2003, 2004b; Yamazaki and Kanamatsu, 2007; Valet and Fournier, 2016; Channell et al., 2010, Channell, 2017; Sagnotti et al., 2016; Evans and Muxworthy, 2018). It is generally accepted that Earth's magnetic field strength drops to low levels and the field direction progresses through a 180° change during polarity reversals (Merrill and McFadden, 1999). Remanent magnetization measurements are

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well established, but the acquisition of detrital remanent magnetization depends on several factors that can alter the reliability of the pristine paleointensity information (Tauxe, 1993). Transitional directions can be affected by viscous and chemical remagnetization resulting in controversial interpretations (Valet et al., 1988; Larson and Patterson, 1993; Evans and Muxworthy, 2018). Therefore, geomagnetic polarity reversals should be estimated from a combination of directional information and relative intensity information, if the latter is available (Merrill and McFadden, 1999).

As an alternative, changes in cosmogenic ^{10}Be production rate provide, in principle, a closely related estimate of temporal geomagnetic intensity changes. This is due to the fact that globally averaged ^{10}Be atmospheric production rate is inversely proportional to the geomagnetic dipole moment (GDM) (Lal and Peters, 1967; Masarik and Beer, 1999). Geomagnetic reversals or excursions are characterized by GDM collapses, so these geomagnetic events can be reconstructed by the ^{10}Be overproduction they trigger, independently of paleomagnetic measurements (e.g., Raisbeck et al., 1985, 2006; Robinson et al., 1995; Frank et al., 1997; Wagner et al., 2000; Christl et al., 2003, 2007; Carcaillet et al., 2004a; b; Mchargue et al., 1995; Muscheler et al., 2005; Zhou et al., 2007, 2010; 2014; Ménabréaz et al., 2012; Simon et al., 2016, 2017; 2018a; b). Zhou et al. (2014) used ^{10}Be to determine the precise M-B boundary in two Chinese loess sections and found that it occurred in paleosol S_7, which corresponds to MIS 19. This result showed that the timing of the M-B boundary in Chinese loess was synchronous with that in marine records and highlighted the benefit of using cosmogenic ^{10}Be to trace geomagnetic polarity events in loess.

In addition to marine sediments and loess sequences, lacustrine sediments are also useful archives of solar activity, and in paleoclimatic and paleogeomagnetic studies (e.g., Belmaker et al., 2008, 2014; Nilsson et al., 2011; Czymzik et al., 2016), especially when the sediments are continuously and rapidly deposited (Ojala and Saarinen, 2002). Belmaker et al. (2008) analyzed different components of ^{10}Be from laminated sediments obtained from Lake Lisan and identified a^{10}Be peak at ~41 ka, which coincides with the Laschamp geomagnetic excursion. Their study also suggested that “detrending” the climate-hydrological signal from the ^{10}Be data is crucial to obtain a reliable reconstruction of atmospheric ^{10}Be production rates associated with geomagnetic variations. Nilsson et al. (2011) have produced one of the first convincing coupled paleomagnetic and cosmogenic radionuclide records of the Laschamp excursion from the Southern Hemisphere. Their study highlights the value of a multiproxy approach not only for accurate dating but also for precise reconstruction of geomagnetic dynamics.

The Heqing lake sediment record is a well-established paleoenvironmental archive that persists throughout the Quaternary (An et al., 2011). Several geomagnetic excursion/reversal events, including the M-B and Matuyama-Gauss (M-G) boundaries have been identified by magnetostratigraphy of this lacustrine sequence (An et al., 2011). However, a reliable paleointensity record cannot be obtained due to inhomogeneous concentration and grain size of the magnetic minerals. In order to satisfy this sole missing criterion and provide a comparable position of the M-B boundary in the Heqing, we present new high-resolution ^{10}Be and ^{10}Be/^{9}Be records across the M-B transition interval. The aim of this study is the identification of the GDM collapse associated with the M-B transition using ^{10}Be from lacustrine sediments for the first time. The comparison between the paleomagnetic direction and ^{10}Be records will assist in more precise estimates of the geomagnetic polarity reversals. Furthermore, the study can help understand temporal discrepancies in geomagnetic events recorded in different depositional environments.

2. Materials and methods

2.1. Sediment sources

The Heqing Basin (26°27′-26°46′N, 100°8′-100°17′E) is located in Yunnan Province, near the northeastern part of the Yunnan-Guizhou Plateau (Fig. 1). In 2002, a 666-m sediment core (26°33′43″N, 100°10′14″E, 2190 m above sea level) was retrieved from the central part of the Heqing paleolake basin with 97% recovery (Xu et al., 2010). The sediments consist mainly of horizontally laminated grayish-green calcareous clay and silty clay with thin-bedded silt and fine sand layers, except for 37 m of riverbed deposits at the bottom (Xu et al., 2010; An et al., 2011). We selected samples between 145 and 158 m that cover the M-B transition time interval according to the magnetostratigraphy established by An et al. (2011). A total of 166 samples were obtained at 8-cm sampling intervals.

2.2. Chronology

An et al. (2011) employed an orbital tuning strategy to construct a timescale for the Heqing core. First, they developed a two-point age model (the M-B and termination II (T2) boundaries) for the last 800 ka in order to verify a good match between high Tsuga percentage and ice minima. Then, an orbital tuning approach that involved simultaneously tuning the filtered 41- and 21-ka components of the Tsuga content to lagged obliquity and precession curves, respectively. Including the sources of error discussed by Imbrie et al. (1984), the uncertainty in our chronology is about ±5 ka. This timescale yielded an average sedimentation rate of 24.7 cm/ka. The 8-cm sampling interval therefore represents an average temporal resolution of ~0.3 ka.

2.3. Chemical procedures

Approximately 1 g of sample was leached in 6 ml HCl (6 mol/L) along with 3 ml H_2O_2 (30%) for 24 h (Zhou et al., 2007). This procedure coextracted ^{10}Be and its stable isotope ^{9}Be from the authigenic phase of the sediments. The supernatant was dried and then dissolved with 1 mol/L HCl. After removal of 2-ml aliquots for ^{9}Be, Al and Ti measurements, the remaining leachate was spiked with 0.5 mg of ^{9}Be carrier. The Be-purification included two stages. The solution was adjusted to pH 8–9 by adding NH_4OH, and then to 14 by adding NaOH. The precipitate was separated by centrifugation and then dissolved in HCl. The supernatant liquor was transferred to a Teflon beaker. This stage removed calcium (Ca), magnesium (Mg), and iron (Fe). After these two precipitation processes, Be oxy-hydroxides were precipitated at pH 8–9 from the supernatant liquor by adding NH_4OH. The precipitate was separated by centrifugation, dissolved in HCl and then processed onto a column loaded with 15 ml of pretreated cation resins. The second purification stage was to separate boron (B) and aluminum (Al). After the two separation stages, the final Be oxy-hydroxides were precipitated at pH 8–9 from the eluted solution by adding NH_4OH. The precipitate was rinsed by MilliQ® water and centrifuged twice. The purified Be oxy-hydroxides were gently evaporated to dryness in a quartz crucible at 100 °C and finally oxidized to BeO by heating at approximately 900 °C in an oven for 2 h. The BeO was then mixed with niobium powder into a holder for AMS measurements. The experimental principle of this method is similar with the chemical procedure used for marine sediments (e.g. Simon et al., 2016). We used inductively coupled plasma atomic emission spectrometry (ICP-AES) for the chemical composition measurements and accelerator mass spectrometry (AMS) for ^{10}Be concentration measurements at the Xi'an AMS Center, where the background value for ^{10}Be