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The 13 million year Cenozoic pulse of the Earth

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ABSTRACT

The geomagnetic polarity reversal rate changes radically from very low to extremely high. Such process indicates fundamental changes in the Earth's core reorganization and core–mantle boundary heat flow fluctuations. However, we still do not know how critical such changes are to surface geology and climate processes. Our analysis of the geomagnetic reversal frequency, oxygen isotope record, and tectonic plate subduction rate, which are indicators of the changes in the heat flux at the core mantle boundary, climate and plate tectonic activity, shows that all these changes indicate similar rhythms on million years' timescale in the Cenozoic Era occurring with the common fundamental periodicity of ∼13 Myr during most of the time. The periodicity is disrupted only during the last 20 Myr. Such periodic behavior suggests that large scale climate and tectonic changes at the Earth's surface are closely connected with the million year timescale cyclical reorganization of the Earth's interior.

1. Introduction

Earth's magnetic field has flipped from a normal to a reverse polarity many times in the Cenozoic Era. The polarity is recorded during sea floor formation in the spreading zones when magma cools and becomes magnetized by the geomagnetic field. Magnetic stripes with alternating normal and reverse polarities are produced parallel to the ridge axis (Vine and Matthews, 1963). Based on the assumption that spreading rates in the South Atlantic were smoothly varying, Cande and Kent (1995) calibrated ages of the magnetic stripes and established the CK95 geomagnetic polarity time scale (GPTS). Studies suggest that the geomagnetic polarity reversal rate is an indicator of the Earth's core–mantle boundary (CMB) heat flow fluctuations that exert an impact on global scale climate change by mantle plume related volcanism (Courtillot and Olson, 2007; Sobolev et al., 2011; Biggin et al., 2012; Rampino and Prokoph, 2013). These phenomena suggest a virtual connection between deep Earth behavior and long-term climate change on a million year scale; however, it is not known how these processes are associated in the Cenozoic Era.

Previous studies have suggested that geomagnetic reversal frequency show primary 15 Myr cycles over the last 100 Ma (Mazaud et al., 1983; Mazaud and Laj, 1991) and ∼33 Myr cycles over the last 300 Ma (Rampino and Strothers, 1984; Pal and Creer, 1986). As for climate change, there has been no identification of any significant long-term periodicities in the Cenozoic marine $\delta^{18}O$ data from earlier research (Rampino and Stothers, 1987). The climate changes over the Cenozoic Era have now been well reconstructed using $\delta^{18}O$ (Zachos et al., 2001). Cenozoic marine $\delta^{13}C$ data, which are an indicator of carbon cycle changes, show that the 9 Myr cyclicity (Boulila et al., 2012) could possibly be linked to the long-term orbital eccentricity modulation. Our study aims to explore if there is any common global rhythm imprinted in the geomagnetic and the climatic records that can be indicative of the existence of such virtual connection.

2. Methods and results

To compare geomagnetic reversal frequency and climate variation cyclicity in the Cenozoic Era, we calculated the reversal frequency with a moving window for the last 73 Ma using the GPTS revised by Gee and Kent in 2007 (Gee and Kent, 2007). The window width is 2 Myrs and the time step interval is 0.1 Myr. The red line in Fig. 1a is the variation in reversal frequency over the last 73 Ma. The minimum and maximum reversal frequency values between 73 and 30 Ma are 0.5 Myr^{-1} and 3.5 Myr^{-1}, respectively. From 30 Ma to the present day, the minimum values increase almost linearly from 0.5 Myr^{-1} at 31.8 Ma to 3 Myr^{-1} at 6 Ma, the maximum values increase from 4 Myr^{-1} at 29.3 Ma to 6.5 Myr^{-1} at 23 Ma, and further rise to 9.5 Myr^{-1} at 12 Ma. The net difference between the minimum values for both intervals is

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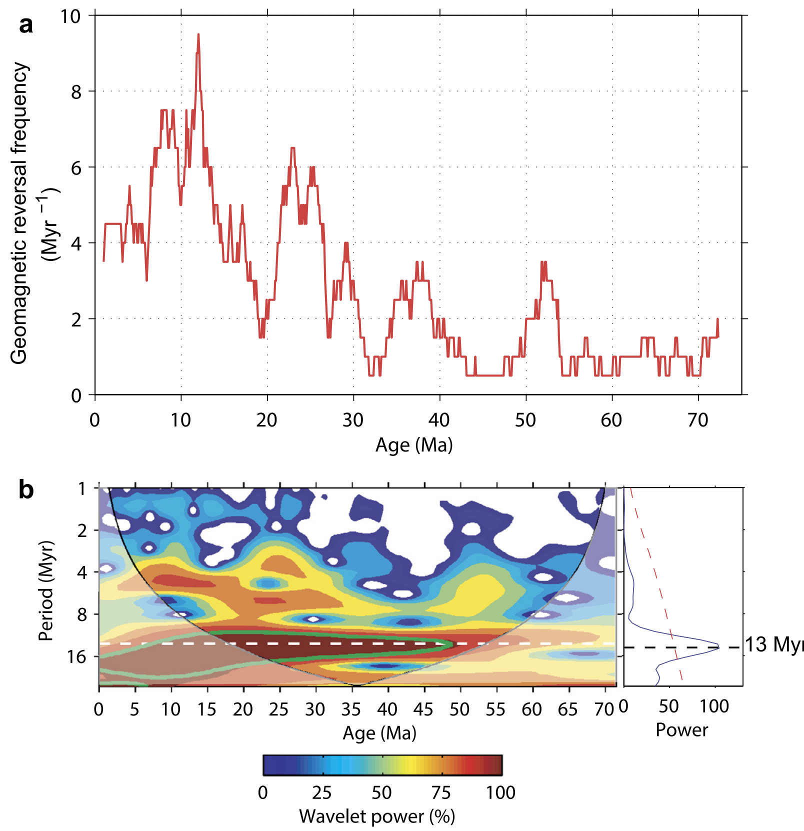

Fig. 1. Variations of geomagnetic polarity reversal frequency. (a) Geomagnetic reversal frequency (red line). (b) Wavelet analysis for reversal frequency. Black solid line corresponds to cone of influence, shadowed are is outside of the cone. Horizontal white dot line in wavelet power spectrum (left) denotes 13 Myr periodicity and green line is 95% significance contour. Black and red dashed lines in global wavelet spectrum (right) denote 13 Myr periodicity and 95% confidence level. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

$\sim$3.5 Myr^{-1}. The reversal frequency shows peaks at 52 Ma, 39 Ma, 26–23 Ma and 12 Ma. The difference between these peaks, i.e. periodicity of the high reversal frequency intervals is $\sim$13 Myr.

To evaluate subtle changes through time we performed wavelet analyses on the reversal frequency curve using the method of Torrence and Compo (1998) (Fig. 1b). The Matlab code is from http://paos.colorado.edu/research/wavelets/. Mother wavelet is Morlet, the sampling interval is 0.1 Myr, and the lag-1 autocorrelation for the red noise background is 0.72. The wavelet power spectrum demonstrates the prevailing periodicity of 13 Myr between 50 and 10 Ma with a confidence level of 95% (Fig. 1b). A 15 Myr periodicity registered in the geomagnetic polarity record was already proposed in 80s and 90s (Mazaud et al., 1983; Mazaud and Laj, 1991; Marzocchi and Mulargia, 1992). However, the previous result is based on outdated reversal record, our analysis suggests that very similar 13 Myr cycle dominates the geomagnetic reversal frequency record for the last 73 Myr. The periodicity seems to be disrupted during last 10 Myrs, but this interval cannot provide exact estimation as it is outside of the confidence cone.

Furthermore, we searched for any very large scale rhythms registered in the climate global record because a few substantial climate changes have occurred in the Cenozoic Era. Climate changes over the last 67 Myr have been reconstructed by the δ^{18}O isotope record of oceanic foraminifera shells (Zachos et al., 2001). The δ^{18}O record is sensitive to deep-sea temperature and ice volume changes; a high δ^{18}O value corresponds to low temperature and high ice volume. Fig. 2a illustrates the variations of δ^{18}O between 67 Ma and the present (Zachos et al., 2001). The δ^{18}O record (shown as a blue line) is characterized by a continuously rising long-term trend since 50 Ma (shown as a magenta line) with two large scale temporary decreases. The Cenozoic cooling trend has been attributed to the drawdown of atmospheric CO_2 due to the increasing continental weathering as a result of the Tibetan Plateau uplift (Garzione, 2008), or attributed to the slow CO_2 input related to the slow spreading rate as the BLAG hypothesis suggested (Berner et al., 1983). Here we explore the rhythms of the Cenozoic climate change. The long-term trend of δ^{18}O is constructed by smoothing the dataset. The trend is nonlinear, therefore we use the nonlinear locally weighted polynomial regression (LOWESS method) where the smoothing parameter is 0.5 which means 50% of the data are used in each fit. Further, we subtract the trend from the original δ^{18}O record to evaluate the second order features and their possible cyclicity (green line in Fig. 2a).

Fig. 2b is the output of the wavelet analysis for the detrended δ^{18}O record. The wavelet power spectrum shows a primary 13 Myr periodicity between 67 and 17 Ma, and an 8–10 Myr periodicity for 23–0 Ma interval, which is similar to the 9 Myr cycle in the marine δ^{13}C record (Boulila et al., 2012). The 13 Myr cycle between 67 and 17 Ma are 65–52, 52–39, 39–26 Ma (red dashed line in Fig. 2a). The periodicity is shorter for the last $\sim$20 Ma, but three peaks can still be accounted. However, the most recent and oldest time intervals are outside the 95% confidence level cone.

It has been suggested that the geomagnetic reversal rate could be closely associated with sea-floor creation and subduction rate (Gaffin, 1987). To explore any million year scale periodicity we used known rates of tectonic plate subduction (Rowley, 2002) shown in Fig. 3a since the data is compiled for the entirety of the world and can represent global tectonic processes. The wavelet power spectrum of the subduction rate (Fig. 3b) also shows a primary $\sim$13 Myr cycle between 70 and 17 Ma, which coincides with the cyclicity of the geomagnetic reversal rate and δ^{18}O records. The subduction rate is somewhat better reconstructed than the