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Detailed Jaramillo field reversals recorded in lake sediments from Armenia – Lower mantle influence on the magnetic field revisited

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ABSTRACT

While it is well established that the Earth's magnetic field is generated by a self sustaining dynamo that reversed its polarity at irregular intervals in the geological past, the very mechanisms causing field reversals remain obscure. Paleomagnetic reconstructions of polarity transitions have been essential for physically constraining the underlying mechanisms in terms of time scale, but thus far remain ambiguous with regard to the transitional field geometry. Here we present new paleomagnetic records from a rapidly deposited lacustrine sediment sequence with extraordinarily stable paleomagnetic signals, which has captured in unprecedented detail the bottom (reverse to normal: R–N) and top (normal to reverse: N–R) transitions of the Jaramillo subchron (at 1.072 Ma and at 0.988 Ma). The obtained virtual geomagnetic pole (VGP) path indicates an oscillatory transitional field behavior with four abrupt transequatorial precursory jumps across the Pacific.

The distribution of VGP positions indicates regions of preferred occurrence. Our results are in agreement with previously proposed bands of transitional VGP occurrence over the Americas and Australia/northwest Pacific. Additionally, our VGP positions seem to avoid large low shear velocity provinces (LLSVPs) above the core mantle boundary (CMB). Thus, our data supports the idea that the transitional field geometry is controlled by heat flux heterogeneities at the CMB linked to LLSVPs.

1. Introduction

More than 100 geomagnetic polarity flips are documented in the magnetostratigraphic record, but details about the actual reversal process remain subject to controversy (see review by Valet and Fournier, 2016). The standard approach to represent magnetic field reversals on the basis of paleomagnetic data is to calculate virtual geomagnetic poles (VGP) for all transitional directions (e.g., Channell and Lehman, 1997; Mazaud et al., 2009), thereby assuming a dipolar field throughout the transition. For a persisting dipole, the transitional VGP paths from different sites would practically coincide, but paleointensity studies suggest that the dipole strength declines during a reversal (Yamazaki and Oda, 2005), implying a violation of the dipole hypothesis. Nonetheless, transitional VGP paths for different geographic sites often are found to lie within two preferred longitudinal bands of transitional VGPs, one over the Americas and one over the westernmost Pacific and Australia (e.g., Laj et al., 1991; Herrero-Bervera and Runcorn, 1997; Love, 2000). This non-uniform distribution of transitional data has been related repeatedly to lower mantle heterogeneities (Laj et al., 1991; Runcorn, 1992), which was discussed controversially (Langereis, 1992; Valet et al., 1992; Valet and Meynadier, 1993; Leonhardt and Fabian, 2007). A shortcoming in all models linking field behavior to LLSVPs was the missing mechanism underlying the relation of preferred transitional VGP paths with lower mantle structures. First explanations in terms of a shielding effect by a high-conductivity layer at the CMB (Runcorn, 1992) were found to be rather unlikely (Brito et al., 1999). However, more recently the phenomenon was related to heat flux variations through the CMB (e.g., Glatzmaier et al., 1999; Bloxham, 2000). This concept was supported by dynamo simulations which show that heterogeneities in the CMB heat flux can produce a longitudinal confinement of transitional VGPs (Kutzner and Christensen, 2004).

Despite these new theoretical insights and numerous reversal records published in the last decades, this debate has not been settled yet (Kissel et al., 2014; Valet and Fournier, 2016). Espe-

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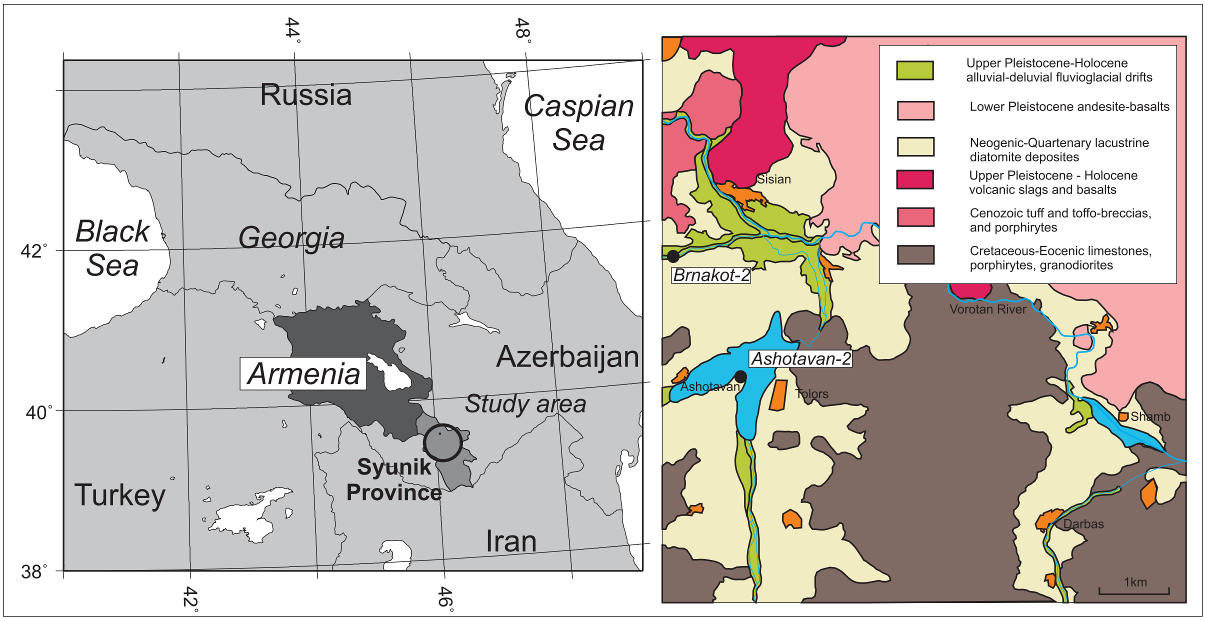

Fig. 1. Left: Geographic map of the Caucasus region centered on Armenia. Study region within the Syunik Province is marked with a black circle. Right: Enlargement of study area showing main geological features. In orange villages are shown. Black dots mark the two studied sections of Ashotavan-2 and Brnakot-2. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

cially with regards to the geometry of the transitional field, no consensus has emerged. Alternative transitional VGP distributions have been presented persistently. Among these are random distributions, extremely rapid reversals, VGP clusters and a confined distribution surrounding the sampling site (e.g., Langereis, 1992; Channell and Lehman, 1997; Valet et al., 1992; Mazaud et al., 2009; Sagnotti et al., 2014). Reasons for the persisting discrepancy in reversal geometries are most probably related to the type of recording material: VGP records obtained from volcanic sequences typically cluster (Coe et al., 2014), whereas those from marine sediments form smooth paths, often preceded by loops (Channell and Lehman, 1997; Mazaud et al., 2009). Therefore it has been argued that more high quality reversal records are needed, especially from continuously recorded sediments with high sedimentation rates and low degree of post-depositional reworking (e.g., Valet and Fournier, 2016).

Most paleomagnetic studies focus on the most recent polarity transition (the Brunhes–Matuyama boundary, Hoffman, 2000), but the observed longitudinal confinement of the transitional VGPs seems to be present in older reversals as well (Herrero-Bervera and Theyer, 1986; Clement et al., 1998). To address this debate, we tackle the second and third youngest polarity transitions of the Jaramillo subchron (top and bottom transition of chron C1r.1n, Hilgen et al., 2012). The top and especially the bottom Jaramillo reversals are by far less well studied compared to the Brunhes–Matuyama transition. However, recently some high quality records have been published for these specific reversals based on volcanic rocks (Chauvin et al., 1990; Kissel et al., 2014). Here, we provide new paleomagnetic single-sample data from two rapidly deposited lacustrine sediment sequences in Armenia, which have recorded the two R–N and N–R transitions of the Jaramillo subchron (Kirscher et al., 2014).

2. Sampling material and methods

Here we present VGP reversal data of four different outcrops from one lacustrine sequence. Since the quality of the demagnetization data of two sections is much higher, the majority of detailed experiments are shown only for these two sections. Only the VGP pattern is shown for the remaining two sections for comparison.

The studied sections are located in southern Armenia, Lesser Caucasus. Volcanic and tectonic activities in this area are related to the still ongoing collision of the Arabian peninsula with Eurasia. The stress of the collision zone is taken up by lateral extrusions, resulting in strike slip faults (Philip et al., 2001) and active volcanism (Adamia et al., 1984, 2011; Karapetian et al., 2001).

Resulting lava flows are thought to be responsible for the formation of large paleolakes by blocking major drainage systems like the diatomitic lake sediment succession close to the city of Sisian (Joannin et al., 2010; Kirscher et al., 2014, Fig. 1).

In four of the studied sections of Kirscher et al. (2014), namely Uyts-2, Darbas-2, Ashotavan-2 and Brnakot-2, a polarity transition is present. In two sections (Ashotavan-2 and Brnakot-2), Kirscher et al. (2014) already observed transitional directions with low inclinations during the 2007 sampling. They state a lower limit for the sedimentation rate of $\sim 35\ \frac{\text{cm}}{\text{kyrs}}$, based on the presence of ~ 30 m of sediment, which show a normal magnetic polarity and was correlated based on seven $^{40}Ar/^{39}Ar$ ages (Kirscher et al., 2014) to the Jaramillo subchron. This sedimentation rate is therefore sufficient to resolve details of a present transitional record with high temporal resolution (Roberts and Winklhofer, 2004). The primary character of the paleomagnetic results is confirmed by a positive reversal test (classified B after McFadden and McElhinny, 1990).

The rock-magnetic parameters are characterized by the presence of a high coercivity mineral with a low Curie temperature ($T_C \approx 150\,^\circ$C, goethite) and a low coercivity mineral with a high Curie temperature ($T_C \approx 600\,^\circ$C, magnetite, see also Kirscher et al., 2014, for details). A slightly elevated Curie temperature of up to 620 °C might be attributed to a partial low temperature oxidation of magnetite to maghemite (e.g., Gehring et al., 2009).

We resampled two sections in 2008, where the transitions and the material were most promising with an increased sample resolution. The resampled intervals are composed of very homogeneous silty-sandy diatomite without any visible lithological changes during the reversals (Supplementary Figs. 1 + 2). A total of 60 and 37 samples from Ashotavan-2 and Brnakot-2, respectively, were collected with sampling resolutions of less than