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A high-resolution paleointensity stack of the past 14 to 68 ka from Black Sea sediments

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ABSTRACT

Detailed paleo- and mineral magnetic analyses of a sediment composite record from the southeastern Black Sea yielded a high-resolution, well-dated paleointensity record. Though hampered by some larger hiatuses in some cores, and contaminated by diagenetically formed greigite, the paleomagnetic composite record obtained from the preserved primary detrital magnetite phase reflects a highly dynamic geomagnetic field during the last glacial period. Relative variations of paleointensity inferred from the sediments' magnetisations were converted into a record of the virtual axial dipole moment (VADM). Lowest VADM values are linked with the Laschamp (0.50×10^{22} A m^2 at 41.0 ka), the Norwegian–Greenland-Sea (1.5×10^{22} A m^2 at 64.5 ka), and the Mono Lake (3.0×10^{22} A m^2 at 34.5 ka) geomagnetic excursions. The fully reversed field during the Laschamp excursion exhibits a VADM of 2.0×10^{22} A m^2 which is more than 25% of the present day axial dipole moment (7.628×10^{22} A m^2). Rates of change calculated from the Black Sea VADM record also give some information on how to assess the global decay of the present-day geomagnetic field, which is significantly enhanced in the area of the South Atlantic Anomaly. Comparison with provided Δ^{14}C and ^{10}Be records confirm, partly in the very detail, the non-linear anti-correlation of geomagnetic field intensity and the production of cosmogenic radionuclides in the Earth's upper atmosphere. However, discrepancies in the timing of lows and highs in the compiled records points out that the combination of different data sets from different archives remains a challenge.

1. Introduction

Since ∼60 yr sediments are being investigated as recorders of geomagnetic field intensity (e.g., Constable and Tauxe, 1987; Harrison and Somayajulu, 1966; Kent and Opdyke, 1977; Levi and Banerjee, 1976; Meynadier et al., 1992; Tauxe, 1993; Tric et al., 1992; Valet, 2003). However, only relative changes can be reconstructed. The basic assumption is that the intensity of the sedimentary magnetisation is proportional to the ambient field during deposition, at least in the range of the modern geomagnetic field strength ($\leqslant 70$ μT). This has been proven by (re-)deposition experiments (e.g., Barton et al., 1980; Johnson et al., 1948; Spassov and Valet, 2012; Tucker, 1980). Since the magnetisation intensity of sediments is also proportional to the concentration of magnetic particles, the natural remanent magnetisation (NRM) of sediments has to be normalised by an appropriate concentration-related parameter. Commonly, the low-field magnetic volume susceptibility κ_{LF}, the anhysteretic remanent magnetisation (ARM), and the saturated isothermal remanent magnetisation (SIRM) are used. According to Tauxe (1993), it is required that investigated sediments are characterised by fine grained magnetite particles (1–15 μm), that carry (mostly) a single component magnetisation, and that vary in concentration not more than an order of magnitude. Further, the sediments' magnetisation should be of detrital origin and should have faithfully recorded directional variations. Finally, all normalisation methods should yield consistent results, showing no correlation to variations in magnetic concentration and/or grain size, and different records from a certain region should agree to each other, once plotted on a common time scale.

Additional criteria should be considered since magnetic particles are prone to further, post-depositional processes (e.g. Roberts and Winklhofer, 2004). Especially, lakes or marine basins that (repeatedly) turn anoxic involve the danger of dissolution of the primary detrital iron oxides (e.g. Canfield and Berner, 1987; Channell and Hawthorne, 1990; Karlin and Levi, 1983; Karlin et al., 1987; Karlin, 1990a, 1990b; Larrasaoña et al., 2003; Leslie et al., 1990a, 1990b; Nowaczyk et al., 2002, 2007; Nowaczyk, 2011; Rowan et al., 2009). This is often accompanied by the precipitation of secondary magnetic iron sulphides in the anoxic phase, or iron oxides in cases when the associated water body turns oxic again. Both is the case in marine sediments from the Eastern Mediterranean Sea,

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comprising a succession of sapropels, indicating anoxic events. Peaks in the NRM/ARM ratio on top of the sapropels do not indicate phases of high geomagnetic field intensity but mark the precipitation of iron oxides (Dekkers et al., 1994). Thus the observed NRM/ARM peaks mark the formation of a chemical remanent magnetisation (CRM), which is much more effective than a detrital remanent magnetisation (DRM).

Since $\sim$20 yr, sedimentary records of relative paleointensity are being compiled into composite records, such as the Sint-200 (Guyodo and Valet, 1996), Sint-800 (Guyodo and Valet, 1999), PISO-1500 (Channell et al., 2009), Sint-2000 (Valet et al., 2005), or EPAPIS-3000 (Yamazaki and Oda, 2005) stacks, with numbers indicating the lengths of the records in ka, and the PADM2M field model for the past 2 Ma (Ziegler et al., 2011). These stacks are mostly of intermediate temporal resolution (1 ka). Higher temporal resolutions, but for shorter time series are provided in NAPIS-75 (0.1 ka resolution; Laj et al., 2000), SAPIS (Stoner et al., 2002), and GLOPIS-75 (0.2 ka resolution; Laj et al., 2004). Here we present a well-dated, high-resolution paleointensity record obtained from a total of six sediment cores recovered from three sites in the southeastern Black Sea. Obtained paleomagnetic results yielded a high-resolution record of the Laschamp excursion (Bonhommet and Babkine, 1967; Gillot et al., 1979; Guillou et al., 2004; Plenier et al., 2007), perfectly repeated in four parallel cores, showing a complete field reversal lasting about 440 yr (Nowaczyk et al., 2012). A younger excursion found in Black Sea sediments is referred to as the Mono Lake excursion (Denham and Cox, 1971; Liddicoat and Coe, 1979; Lund et al., 1988). According to Vazquez and Lidzbarski (2012), dating of a tephra (Ash 15), intersecting the geomagnetic excursion documented in the Wilson Creek Formation at Mono Lake, yielded an age of 40.8 ± 1.9 ka. Thus, leading Vazquez and Lidzbarski (2012) to conclude that actually the Laschamp excursion has been recorded at Mono Lake. This was already postulated by Kent et al. (2002), or Zimmerman et al. (2006). However, there is clear evidence for a post-Laschamp excursion (e.g., Laj and Channell, 2007; Kissel et al., 2011).

2. Geological setting

The recent Black Sea with a modern maximum water depth of 2212 m is currently connected to the world's ocean system through the Bosphorus (modern minimum water depth 36 m), the Sea of Marmara, the Mediterranean Sea, and the Strait of Gibraltar (modern minimum water depth $\sim$300 m). It is the Earth's largest anoxic basin. However, during glacial times, when the global sea level was lower by 110 to 120 m (e.g. Lembeck et al., 2002), the basin was regularly isolated from the world's oceans (e.g. Badertscher et al., 2011; Ross and Degens, 1974; Winguth et al., 2000) and its water body developed into a well-oxygenated freshwater lake (e.g. Deuser, 1972). At the ends of glacial maxima, e.g., at 14.6–16.6 ka and 129.8–133.2 ka, a connection between the Caspian Sea and the Black Sea basin existed (Badertscher et al., 2011). This was due to an overflow of the Caspian Sea caused by massive meltwater pulses during the deglaciations. The last reconnection of the Black Sea to the world's ocean system occurred fairly rapidly (Ballard et al., 2000; Ryan et al., 1997) at around 9.3 ka B.P. (Bahr et al., 2008). Today, only the upper about 100 to 150 m are oxygenated, whereas the complete lower water body is anoxic.

Sediments at the Archangelsky Ridge in the southeastern Black Sea (Fig. 1) are provided by rivers draining wide areas of Mesozoic and Cenozoic igneous (acidic to mafic) rocks exposed in the Pontides of central and northeastern Turkey (e.g., Okay and Şahintürk, 1997). Thus, the hinterland has a high potential in providing sufficient magnetic minerals into the southeastern Black Sea.

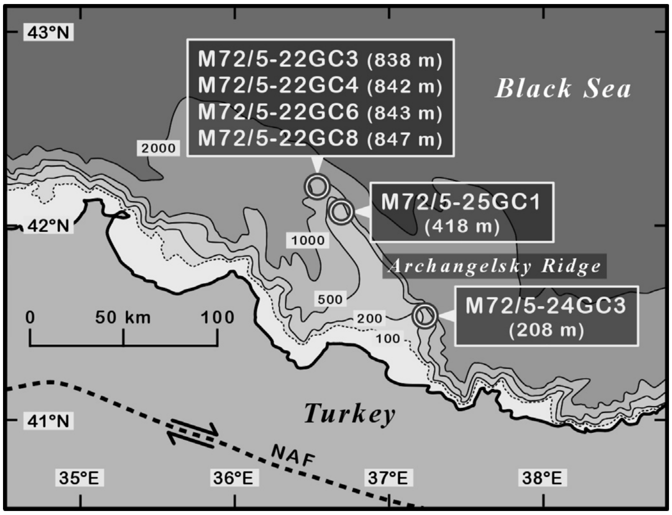

Fig. 1. Locations of the three sites in the southeastern Black Sea offshore of Turkey. Core numbers are indicated together with corresponding water depth in brackets. NAF – North Anatolian Fault.

3. Material and methods

3.1. Core sampling and sedimentology

Six gravity cores with an internal diameter of 12 cm were recovered from three different water depths along the Archangelsky Ridge in the southeastern Black Sea (Fig. 1) during cruise M72/5 of the German *RV Meteor*. After recovery, the 8.0 to 9.1 m long cores were cut on board into 1 m segments. Splitting of the core segments into working and archive halves was performed onshore at the GFZ Potsdam, Germany.

According to Major et al. (2006) and Kwiecien et al. (2008) the recovered sediments represent a basin-wide succession of late glacial to early Holocene lacustrine clayey muds (Unit III), a finely laminated Holocene marine sapropel (Unit II), and coccolith oozes (Unit I). The investigated glacial limnic sediments consist of fine grained siliciclastic material with calcium carbonate contents between 15 and 40% (Nowaczyk et al., 2012). Authigenic, partly magnetic iron sulphides (greigite, Fe_3S_4) were quite frequently observed, leading to either layers or non-stratiform patches of deep black sediment colours. However, after opening the black colour frequently faded away within days to weeks, with the sediments' colours turning into light greyish or brownish hues.

3.2. Age models

Initial tie points for the age models (Fig. 2) were provided by 16 accelerator mass spectrometry (AMS) ^{14}C dates from core M72/5-24-GC3 (juvenile shells of the bivalve species of *Dreissenia rostriformis*). Calendar ages were determined by applying the INTCAL09 (Reimer et al., 2009) calibration curve. Identification of tephra material related to the Campanian Ignimbrite (C.I.) eruption at 39.3 ka (De Vivo et al., 2001; Pyle et al., 2006) in cores M72/5-24-GC3 and M72/5-25-GC1 yielded further tie points for the age models. Further on, variations of Ca counts from X-ray fluorescence (XRF) scanning, carbonate content, and normalised counts of ice-rafted detritus (IRD) were tuned to the NGRIP oxygen isotope record (Andersen et al., 2006; NGRIP members, 2004) on basis of the GICC05 age model (Svensson et al., 2006, 2008) using a multi-parameter correlation software. The morphologies of mentioned parameters clearly resemble the succession of the so-called Dansgaard–Oeschger (DO) events (Dansgaard et al., 1993). More details of sedimentologic investigations and development of the age models are given by Nowaczyk et al. (2012). Since the