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Full vector archaeomagnetic records from Anatolia between 2400 and 1350 BCE: Implications for geomagnetic field models and the dating of fires in antiquity

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ABSTRACT

Anatolia, as one of the busiest crossroads of ancient civilizations, provides an ideal platform for archaeomagnetic studies. Previous results from the Middle East have suggested the occurrence of a strong peak in geomagnetic intensity at ∼1000 BCE associated with dramatic field strength variations that could require a radical rethinking of geodynamo theory. The behavior of the field in the centuries preceding this peak remains poorly constrained, however. Here we present the results of full-vector archaeomagnetic experiments performed on 18 sets of samples from three archaeological sites belonging to Assyrian Trade Colony and Hittite periods. Associated rock magnetic analyses showed that the major magnetic carrier is magnetite chemically stable up to 700 °C and the magnetic mineral assemblage is composed mostly of non-interacting PSD grains.

The directional results are compared with existing data and with the most recent global geomagnetic field models pfm9k.1b and SHA.DIF.14k. The directions are in remarkably good agreement with SHA.DIF.14k which is based on archaeomagnetic and lava flow data. Together with our earlier results from Anatolia, we triple the existing database of directions for the 700 year long period 2200–1500 BCE, over a large region from Greece to Azerbaijan, and from Moldavia/Ukraine to Egypt.

Three archaeointensity methods: thermal IZZI-Thellier, microwave Thellier and the multi-specimen protocol (MSP) produced virtual axial dipole moment estimates (9.0–10.9 × 10^{22} Am^2) that are somewhat higher than contemporaneous (regional and global) data and model predictions suggesting that the field was already substantially stronger than today more than 800 years prior to the reported peak. In addition to constraining geomagnetic variability, our data also allow us to assign relative dates to inferred fire events in the Assyrian Trade Colony Period sites. This allows us to conclude that the fire events at the largest site, Kültepe, were not all contemporaneous with one another and with the abandonment of the site as has been previously hypothesized.

1. Introduction

Over the past decade, evidence for a short-lived period of very high geomagnetic intensities in the Levant rapidly accumulated (Ben-Yosef et al., 2009; 2008b; Gallet and al-Maqdissi, 2010; Gallet and Butterlin, 2015; Gallet et al., 2014, 2006, 2008; Gallet and Le Goff, 2006; Genevey et al., 2003; Shaar et al., 2011; Stillinger et al., 2015). At least three studies present reliable paleointensities that exceed twice the current field strength in this region ∼1050–850 BCE. The occurrence of extreme geomagnetic field intensity variations during a few decades at most, referred to as *'geomagnetic spike'* (Ben-Yosef et al., 2009) sparked considerable debate: such geomagnetic features are not captured by even the most recent geomagnetic models describing changes in the field (Nilsson et al., 2014; Pavón-Carrasco et al., 2014). Moreover, it was recently shown that current geodynamo theory cannot sustain the existence of this phenomenon (Livermore et al., 2014).

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Most of the available data for this region is derived from archaeological artefacts, such as sherds, copper slag or fired mudbricks. Their rock magnetic properties are generally favourable, but such samples are often found un-oriented, so they do not provide constraints on directional variations. Only in-situ materials like kilns or burnt mud-brick walls provide the opportunity to obtain reliable palaeodirections; studies reporting these or full vector descriptions of the field are scarce (e.g.: Bucha and Mellaart, 1967; Sarıbudak and Tarling, 1993; Ertepinar et al., 2012). Therefore, directional records for the Levant are supported by less data than the palaeointensity curve for the past millennia – only 30% of the data in GEOMAGIA50 includes directions. Directional data is particularly scarce ∼2200–1500 BCE, part of the Assyrian and Hittite periods in the Levant.

To further constrain the occurrence of the high palaeointensities – and to possibly elucidate their driving force – a full vector record of the geomagnetic field in this area for the past 5 millennia is indispensible. Here, we look at Anatolia as one of the busiest crossroads of ancient civilizations, an ideal platform for archaeomagnetic studies. Here, we present new data from two Assyrian (Kültepe and Kalehöyük) and one Hittite (Şapinuva) Period site. The Assyrian sites and their excavation levels are older, of Middle Bronze Age (2000–1750 BCE). Only one level in Kültepe (KT12) is Early Bronze Age (∼2400 BCE) (Table 1). The Hittite site Şapinuva is of Late Bronze Age, ∼1350 BCE. Our new data triples the available directional information for this particular time interval. Our palaeointensities are obtained by three different and independent methods: thermal IZZI-Thellier experiments, the Microwave Thellier technique, and the Multi-specimen protocol. The credibility of our findings is greatly enhanced if the results of (at least two of) these methods agree. We compare our results to the latest compilations and models of the field, pfm9k.1b (Nilsson et al., 2014) based on both sediment and igneous/archaeomagnetic data, and SHA.DIF.14k (Pavón-Carrasco et al., 2014) based on archaeomagnetic and lava flow data alone.

2. The Bronze Age in Anatolia

In the early second millennium BCE, Anatolia was in the form of city-states where Assyrian merchants came to trade textiles and metals. These merchants sometimes resided in Anatolia which gave the era its name: Assyrian Trade Colony Period. After the trading relations had started, a number of trading centers called *Karum* were established in the major cities of the time. This is also contemporaneous with the earliest writing to appear – inscribed on clay cuneiform tablets. There are more than 20.000 tablets found in Kültepe, 'the trade capital of the period', dating between 1950–1700 BCE. The richness of cultural findings and extensive dendrochronology studies allowed the archaeologists to have a well defined age constraint on the site. This unique combination made Kültepe the reference site for dating the other archaeological sites. The Assyrian Trade Colony Period ended at ∼1685 BCE with the emergence of Hittites in Anatolia (Fig. 1).

Around 1700 BCE, people of unknown origin migrated to Anatolia and united the city states under one central authority, laying the foundations of the Hittite empire centered at Hattusa, which is now a UNESCO World Heritage site. The domination of the Hittites lasted for almost a thousand years and the empire reached its height in the 14th century BCE controlling a large part of Anatolia, the northern Levant and Upper Mesopotamia. The reign started as a kingdom (Old Kingdom, ca. 1650–1500 BCE), then became an Empire between 1400–1200 BCE. After 1180 BCE, the empire disintegrated into several independent city states called Neo-Hittites and completely vanished by the 8th century BCE. The historical documentations of Hittites show a remarkable political and military power as well as a very rich and long lasting culture (Sagona and Zimansky, 2009).

A detailed description per site can be found in the supplementary information (Appendix), here we report the main characteristics and archaeological background of the sites.

Kültepe (KT)

Kültepe, ancient Kaneš, is one of the primary sites of the Assyrian Trade Colony Period, and has served as the point of contact between Assyria and the rest of central Anatolia. It produced the most textual (in cuneiform script) and archaeological evidence. The settlement is composed of two parts; an upper town (the mound) where the palace and the temple were located, and a lower town which contained a large merchant quarter (Kârum). The Kârum of Middle Bronze Age is composed of four levels (I–IV), the youngest having two phases (Ia–Ib). We have sampled 12 sites from levels 1b and II; 2 from the mound and 10 from the Kârum. The levels are well dated by means of dendrochronology (of juniper wood) and tablets (Table 1). One site (KT12) is of Early Bronze age and dated by archaeological findings. It consists of intensely burnt (vitrified) mud-brick. The chronology chart of Assyrian Trade Colony Period sites is given in the appendix (Fig. A1).

From the mound we took 3 sets, from the Kârum part we took 10 sets (Table 1). Oriented cores were drilled from mud-bricks which are usually well heated during the fires, but we also took samples from the foundation stones, here typically ignimbrites from a nearby stratovolcano (Erciyes, near Kayseri) (Fig. A2, Table 1). One of the main puzzles for the archaeologists is the timing and character of the demise of this settlement. By comparing our archaeomagnetic results from different parts of the settlement, we hope to (partly) solve these puzzles. We will argue that this settlement was destroyed (burned) in various stages.

Kalehöyük (KA)

The site Kalehöyük is a medium-sized mound of which the levels have been correlated to the Kültepe-Kârum chronology (Fig. A1). This correlation can be tested by our archaeomagnetic results, and we will argue that may require modification. Archaeomagnetic samples were taken from four structures allegedly belonging to levels Ib (KA1, KA4) and II (KA2) and one older level (KA3) (Fig. A3, Table 1). Here, the foundation stones are granite rather than ignimbrite.

Şapinuva (SPN)

Şapinuva (or Sapinuwa) is a Late Bronze Hittite city (∼1300 BCE) and was one of the major religious and administrative centres and occasional residence of Hittite Kings. Only one site (SPN1) could be sampled; samples were taken from fallen mud-brick blocks of a public building ('Building-A') which is believed to have fallen during the fire that were lying on the sandstone and limestone foundation stones (Fig. A4, Table 1). It is therefore assumed that the mudbricks are *in-situ*.

3. Rock magnetic analyses and results

Room temperature bulk magnetic susceptibilities and thermomagnetic curves were determined for the identification of the magnetic carriers and thermal stability. Based on the preliminary results from these experiments and the quality of the directional results, 9 sites appeared to be suitable for archaeointensity measurements. For these, we additionally performed hysteresis loop, Isothermal Remanent Magnetization (IRM) acquisition and First Order Reversal Curve (FORC) diagram experiments (Roberts et al., 2000).

Low field bulk magnetic susceptibility. Samples were measured with a Kappabridge KLY-2. The results are homogeneous among