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Large geomagnetic field anomalies revealed in Bronze to Iron Age archeomagnetic data from Tel Megiddo and Tel Hazor, Israel

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ABSTRACT

Geomagnetic field measurements from the past few centuries show heightened secular variation activity in the southern hemisphere associated with the south Atlantic anomaly (SAA). It is uncertain whether geomagnetic anomalies at a similar scale have existed in the past owing to limited coverage and uncertainties in the paleomagnetic database. Here we provide new evidence from archaeological sources in the Levant suggesting a large positive northern hemisphere anomaly, similar in magnitude to the SAA during the 9th–8th centuries BCE, called "Levantine Iron Age anomaly". We also report an additional geomagnetic spike in the 8th century. The new dataset comprises 73 high precision paleointensity estimates from ca. 3000 BCE to 732 BCE, and five directional measurements between the 14th and the 9th centuries BCE. Well-dated pottery and cooking ovens were collected from twenty archaeological strata in two large contemporaneous stratigraphical mounds (tells) in Israel: Tel Megiddo and Tel Hazor. The new data are combined with previously published data and interpreted automatically using the PmagPy Thellier GUI program. The Tel Megiddo and Tel Hazor data sets demonstrate excellent internal consistency and remarkable agreement with published data from Mesopotamia (Syria). The data illustrate the evolution of an extreme geomagnetic high that culminated in at least two spikes between the 11th and the 8th centuries BCE (Iron Age in the Levant). The paleomagnetic directional data of the 9th century BCE show positive inclination anomalies, and deviations of up to 22° from the averaged geocentric axial dipole (GAD) direction. From comparison of the Levantine archaeomagnetic data with IGRF model for 2015 we infer the "Levantine Iron Age anomaly" between the 10th and the 8th centuries BCE is a local positive anomaly. The eastward extent of the anomaly is currently unknown.

1. Introduction

The geomagnetic field has changed constantly throughout Earth's history, from large-scale global events such as reversals and excursions to short temporal and spatial scale changes known as secular variation (SV). SV is among the least well constrained of the geomagnetic phenomena. Yet, it is of key interest for a number of research fields: In geophysical research SV is used to study geodynamo processes, outer core properties, and lower mantle heterogeneities (Jackson et al., 2000; Jackson and Finlay, 2007; Korte and Holme, 2010); in climatic and environmental research SV is used to decipher the role that geomagnetism may play in controlling climate (Gallet et al., 2005, 2006; Courtillot et al., 2007; Wanner et al., 2008; Knudsen and Riisager, 2009; Ertepinar et al., 2012); in geochronology, SV helps constrain chronologies for archaeological dating (Ben-Yosef et al., 2008b; Lodge and Holme, 2009; Ben-Yosef et al., 2010; Pavon-Carrasco et al., 2011).

Recent SV data from the first two millennia BCE from Euro-Asian archaeological sources have revealed intriguing anomalies. Ben-Yosef et al. (2009) and Shaar et al. (2011) reported high field intensity fluctuations in the southern Levant (Israel and Jordan) during the 10th and the 9th century BCE that they referred to as "geomagnetic spikes". The "spikes" are the extreme climax of a high field maximum (>160 ZAm^2) in the Levant that appears in close approximation to other unusually high paleointensity values seen in Turkey (Ertepinar et al., 2012) and Georgia (Shaar et

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al., 2013), and to other local maxima with lower values seen, for example, in France (Herve et al., 2013), and SE Asia (Hong et al., 2013). Thus, at least at a continental scale, the high-field episode is likely associated with a complicated field structure (Genevey et al., 2008; Kovacheva et al., 2009; Korte and Constable, 2011; Tema and Kondopoulou, 2011; Tema et al., 2012; Kovacheva et al., 2014), suggesting a complex global deviation from a simple dipole configuration (de Groot et al., 2013, 2015) that calls for further investigation.

After establishing the observation of a high field maximum in the Levant during the 10th to 9th centuries, it is now paramount to investigate its evolution through time. Also, it is of particular interest to investigate whether the Levant high field episode is a local anomaly (e.g. de Groot et al., 2015) or a global dipole feature (e.g. Hong et al., 2013). Addressing these issues is the main target of this research.

To accomplish the abovementioned objectives we investigate two key archaeological mounds (tells) in Israel: Tel Megiddo (also known as Armageddon of Revelations) and Tel Hazor. These two contemporaneous sites were of the most important settlements during the Bronze and Iron Age in the Levant, well known in biblical, Egyptian, and Mesopotamian texts. Owing to intense archaeological explorations of the sites over the past decades their chronologies are precisely dated, and hence, the sites provide invaluable well-dated archaeological material for high-resolution archaeomagnetic investigation.

The rationale for this work is as follows. First, we explore and test the robustness of our absolute paleointensity methodology by: a) deploying a recently published automatic interpretation technique (Shaar an Tauxe, 2013; Shaar et al., 2015), and b) cross-checking the two independent contemporaneous archaeomagnetic datasets. Second, we aim to deliver a comprehensive, and the most complete to date, description of paleointensity variations during the Bronze and Iron Age in the Levant by combining the overall published data. Finally, we compare the anomalies observed in the archaeomagnetic data with today's IGRF field in order to seek similar patterns between the SAA and the local Levantine high.

2. Methods

2.1. Archaeological sites

Both sites of this study hosted central cities during the Bronze and Iron Age, and were two of the most important Bronze and Iron Age settlements in the Levant. The sites controlled the international traffic route leading from Egypt to Mesopotamia and Anatolia, and witnessed the development of urbanization, religion, and technology. Both sites were continuously settled through major parts of the Bronze Age and the Iron Age until their destruction in 732 BCE in the military campaign of Tiglath Pileser III, the Asyrian ruler.

2.1.1. Tel Megiddo

Tel Megiddo (32.585N, 35.184E, Fig. 1; Armageddon of Revelations) was excavated in the beginning of the 20th century by a German team and again by the Oriental Institute of the University of Chicago. In the 1960s the Late Yigael Yadin from the Hebrew University of Jerusalem conducted further excavations. Since 1994 an extensive excavation campaign has been carried out at the site by Israel Finkelstein and David Ussishkin from Tel Aviv University, Israel.

The site was inhabited almost continuously, with no substantial occupational gaps, and succeeding settlements were built one top of the other, creating a typical multi-layered mound (tell). The absolute chronology of Tel Megiddo is well established by ceramic typology, dozens of radiocarbon samples, and historical

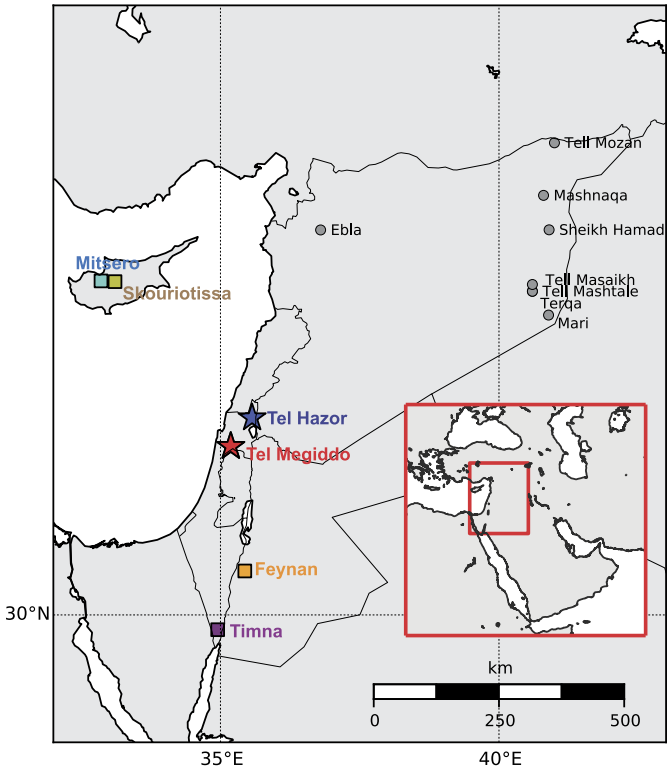

Fig. 1. Location map. Tel Megiddo and Tel-Hazor (this study) are marked with stars. Sites with measurement data uploaded to the MagIC database (colored symbols in Fig. 5) are shown in colored squares. Other sites from Syria are shown in gray circles (open squares in Fig. 5). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

records (Finkelstein and Piasetzky, 2010; Regev et al., 2014; Toffolo et al., 2014). Most significant are several destruction layers, dated by a large number of radiocarbon ages, which make the backbone of the Megiddo chronology (Finkelstein and Piasetzky, 2009; Regev et al., 2014). At least one destruction layer is also securely dated historically – the one caused by the Assyrian king Tiglath-Pileser III in 732 BCE. The Early Bronze Age settlement was exceptionally large and monumental in the beginning of the 3rd millennium BCE, but experienced a decline until ca. 2000 BCE when the city started to flourish again. The Middle Bronze to Iron Age Megiddo was an important regional center – first as a Canaanite city–state and later as an administrative center of the Northern Kingdom of Israel. It is represented by a complete sequence of occupation until its destruction in 732 BCE.

For this study we collected pottery material from ten well-dated strata in four different Areas of the Tel Aviv Expedition, labeled *J*, *F*, *K*, and *H*. In addition, we sampled five *in situ* cooking ovens (tabuns) during the 2010–2011 excavation seasons from Areas *K*, *Q*, and *H*. Complete information on the areas, strata, and samples (listed in the Supplementary Material) can be found in the published excavation reports (available online from megiddo.ittau.ac.il/).

2.1.2. Tel Hazor

Tel Hazor (33.017N, 35.568E, Fig. 1) was first excavated in the 1950s and 1960s under the direction of Late Yigael Yadin from the Hebrew University of Jerusalem. Excavations were re-initiated in 1990 under the direction of Amnon Ben-Tor from the Hebrew University, and continue annually to the present.

The extensive excavations revealed over 20 superimposed stages in two distinct sections: the upper city that includes an acropolis, and a lower city with a fortified enclosure. The