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First directional archaeomagnetic results from Syria: evidence from Tell Mishrifeh/Qatna

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SUMMARY

We report on the first archaeomagnetic directional data obtained from Syria. Reliable palaeomagnetic directions were collected from four pyrotechnological archaeological structures dated by type of pottery and radiocarbon from the 19th to 8th century BC (Middle Bronze to Iron Age) in Tell Mishrifeh/Qatna, Syria. Fairly constant northward declination values (within confidence limits) were obtained, whereas inclination values increased from 42.3° to 73.0° from the Middle Bronze to Iron Age. At first approximation, these new data are consistent with coeval archaeomagnetic directions from Western Europe and Bulgaria. The high inclination (73.0° ± 2.8°) documented for the Iron Age (translating to a VGP latitude of 65.9°N) suggests that very strong secular variation was occurring during the 8th century BC.

Key words: archaeomagnetism, geomagnetic secular variation, Syria.

1 INTRODUCTION

During the last few years, considerable efforts have been made to compile reliable archaeomagnetic data sets for recent millennia (e.g. Gallet *et al.* 2002). Once an accurate, reliable directional archaeomagnetic curve is available for a given region, it may serve as a valuable dating tool for *in situ* fired archaeological structures which cannot be dated by other conventional methods. It has also been demonstrated that archaeomagnetic curves are fundamental in unravelling the ages of recent eruptive products emplaced by active volcanoes, for example, Vulcano (Lanza & Zanella 2003), Etna (Tanguy *et al.* 2003), and Stromboli (Speranza *et al.* 2004).

The Middle East should be ideal for expanding archaeomagnetic curves back in time, because it hosts a wealth of archaeological settlements that were inhabited by the oldest human civilizations. Here, directional data (extending over the last 4000 yr) were gathered in Iraq (Hammo-Yassi 1983), and some inclination-only values (for the last 3500 yr) in Egypt (Hussain 1983, 1987). In Syria, only field intensity variations during the last 8000 yr have been documented (Genevey *et al.* 2003).

Large reliable archaeomagnetic directional data sets are available for several parts of Europe, extending over the last 2000 yr (Batt 1997; Márton 2003; Schnepp *et al.* 2004), the past 3000 yr (Gallet *et al.* 2002) and the last 8000 yr (Kovacheva *et al.* 1998), respectively.

2 HISTORICAL BACKGROUND

Tell Mishrifeh (central–western Syria) is the site of the ancient city of Qatna, a large urban settlement (110 ha) going back to the second millennium BC, located in the middle Orontes Valley (Fig. 1). Due to its strategically crucial position, it became one of the main regional powers in the geo-political scene of the entire Levant during the Middle and Late Bronze Ages (*ca*. 2000–1200 BC), as testified by a monumental second-millennium royal palace in Areas H and G (Novák & Pfälzner 2002; Barro 2003, Fig. 2) and two Late Bronze Age palaces in Areas K (Luciani 2003) and C (Al-Maqdissi 2003). On the central mound of the acropolis (Area J) a well-dated stratigraphic sequence of architecture, pottery and artefacts has been established (Morandi Bonacossi 2003), in which several kilns reveal the existence of large-scale pottery production in the period ranging from Middle to Late Bronze Age (2000–1200 BC). Well-preserved Late Bronze and Iron Age kilns have also been found in Areas C and D, respectively (Al-Maqdissi 2003).

3 PALAEOMAGNETIC SAMPLING

In 2003 September, 74 oriented palaeomagnetic cores were collected from six different baked (or burnt) archaeological structures located within the ancient city of Qatna (Fig. 2 and Table 1): three pottery kilns (GX from Area D, CE-VII from Area C, 1576 from Area J), a 'tannur' (small bread oven) (2411 from Area K),

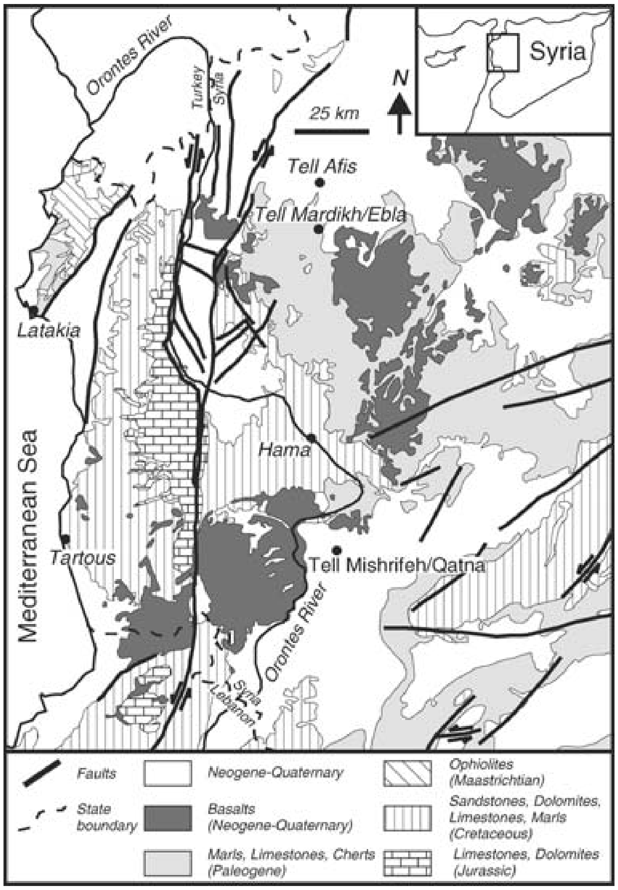

Figure 1. Geological sketch of central-western Syria (modified after Brew *et al.* 2001) and location of Tell Mishrifeh/Qatna.

limestone pebbles from the fired wall of a large granary (3215 from Area H), and blocks of basalt from the corridor of the royal palace (AQ from Area G), which underwent a tremendous fire dated to the reign of the Hittite king Shuppiluliuma I (*ca.* 1350–1318 BC) (Klengel 2000; Novák & Pfälzner 2003; Richter 2003). For each of these archaeological structures, 11–14 standard palaeomagnetic cores, 2.5 cm in diameter, were drilled by a petrol-powered water-cooled drill, and *in situ* oriented with both sun and magnetic compasses. Unfortunately, only ceramic material from kilns GX, CE-VII, tannur 2411, and limestone blocks from kiln 1576 provided reliable results (Table 1). The ages of kilns and of granary were inferred by the type of pottery (GX, CE-VII, 2411, 3215; Al-Maqdissi *et al.* 2002), and by radiocarbon dating (kiln 1576; Morandi Bonacossi 2003). The present-day magnetic declination values evaluated from core orientations (i.e. the difference between magnetic and sun compass reading) are generally slightly negative, and range between 0.0° and −12.5°. These large values likely arise from the influence of the baked structures on the magnetic compass readings. In fact, our palaeomagnetic measurements have shown that the remanence of the kilns specimens is very high (in the order of some A m^{-1}, Fig. 3).

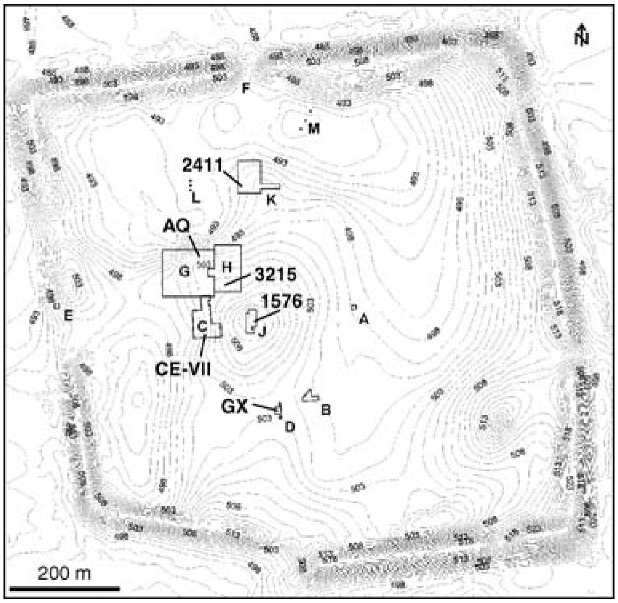

Figure 2. Topographic map of the archaeological site of Tell Mishrifeh/Qatna. Arrows indicate the location of the sampled structures within the excavated areas. DTM (digital topographic model) derived from Kriging interpretation of 2117 digital GPS points (kindly provided by A. Beinat and A. Marchesini, University of Udine).

4 MEASUREMENTS AND RESULTS

All cores were cut into standard cylindrical specimens and measured in the palaeomagnetic laboratory of the Istituto Nazionale di Geofisica e Vulcanologia (INGV) in Rome (Italy). All specimens were

Table 1. Palaeomagnetic directions from the pyrotechnological structures and fired walls from Tell Mishrifeh/Qatna.

Structure	Age	Me	n/N	$D(°)$	$I(°)$	k	$\alpha_{95}(°)$
3215	8th century BC	Pottery	4/13		scattered		
AQ	1337 ± 1 BC	Documental	11/13		scattered		
GX	Mid-eighth century BC	Pottery	10/12	353.9	73.0	294	2.8
CE-VII	13th century BC	Pottery	9/11	1.2	57.4	159	4.1
2411	15th century BC	Pottery	5/11	358.6	49.3	141	6.5
1576	1950–1750 BC (1σ)	^{14}C	10/14	348.9	42.3	26	9.7

Structures (see Fig. 2): 3215, fired wall of a granary, area H; AQ, blocks of basalt from the corridor of the royal palace fired by the Hittite king Shuppiluliuma (Klengel 2000, the given age is relative to firing), area G; GX, kiln from Area D; CE-VII, kiln from Area C; 2411, 'tannur' from Area K, Building 6, room C; 1576, kiln from Area J, Phase J17. Me, dating method. n/N, number of cores yielding LT or characteristic palaeomagnetic directions/total number of cores drilled at a site. D and I: *in situ* mean palaeomagnetic declination and inclination. k and α_{95} = statistical parameters. Coordinates of Tell Mishrifeh/Qatna: 34°50′N; 36°53′E. Error on ages based on pottery is about ±100 yr. Radiocarbon dating was carried out by Geochron Laboratories, Krueger Enterprises, Cambridge, Massachusetts. ^{14}C dates were calibrated using OxCal 3.5 (Bronk Ramsey 1995, available at http://www.rlaha.ox.ac.uk). The conventional radiocarbon age is 3540 ± 70 yr BP.

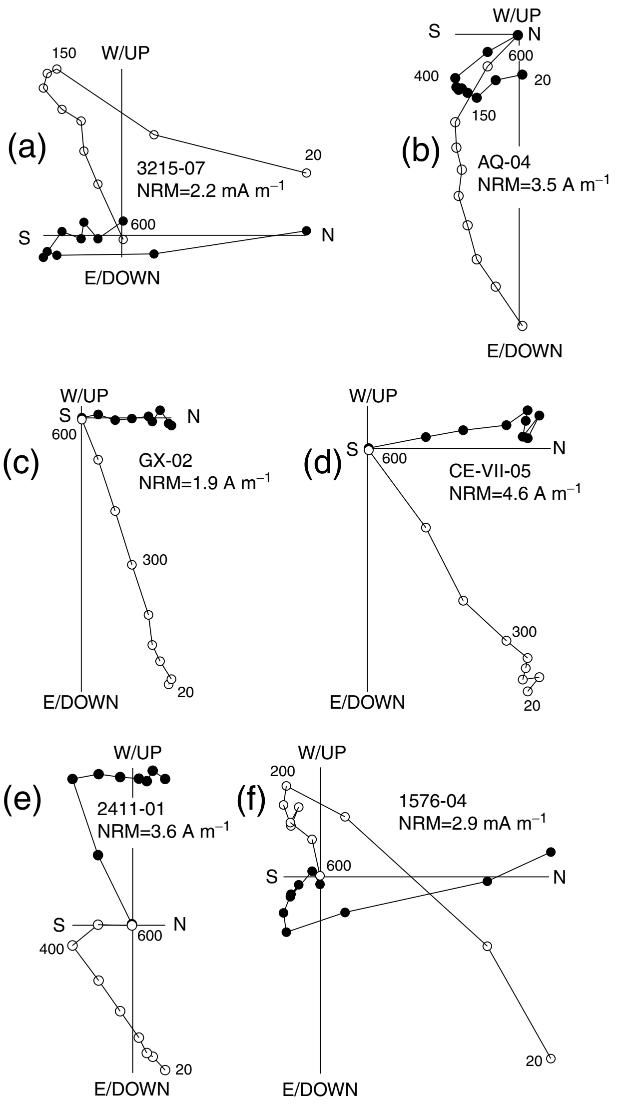

Figure 3. Thermal demagnetization data projected in orthogonal vector diagrams (*in situ* coordinates) for one representative specimen for each of the considered structures: (a) 3215; (b) AQ; (c) GX; (d) CE-VII; (e) 2411 and (f) 1576. Open and solid circles: projections on vertical and horizontal planes, respectively. Demagnetization step values expressed in °C.

thermally demagnetized in 9–10 steps, and their remanent magnetization was measured after each step in a 2G cryogenic magnetometer with DC-SQUIDS in a shielded room. Low-temperature (LT) magnetization components (isolated by principal component analysis, Kirschvink 1980) from the burned granary (Fig. 3a) and the corridor wall (Fig. 3b) were scattered (Fig. 4), indicating that these specimens were not significantly heated or that peak temperature lasted for too short to significantly reset magnetization. These specimens were consequently discarded from further analyses. In kilns GX and CE-VII (Table 1), a well-defined characteristic remanent magnetization component (ChRM) was isolated between 250 and 600°C (Fig. 3c, d). In 'tannur' 2411, LT and high-temperature (HT) components were observed, respectively below and above 400°C (Fig. 3e). Similarly, in the limestone blocks from kiln 1576, LT and HT components, respectively below and above 200°C (Fig. 3f) were isolated and measured. In both these structures, only the LT components were examined, and interpreted as thermo-remanent magnetizations (TRM) acquired during the last firing. Seven (up to 400°C) and four (up to 200°C) temperature steps were used to calculate the LT components from the 2411 and 1576 kilns, respectively.

The scattered HT components from kilns 2411 and 1576 probably represent TRM acquired during pottery making in the case of 'tannur' 2411, and original depositional remanent magnetization in the case of limestone blocks from the wall of kiln 1576. All specimens were completely demagnetized between 500 and 600°C (Figs 3a–f), implying that they contain a magnetite near mineral as magnetic carrier.

The mean direction for three out of the six sampled structures is well defined, with α_{95} values between 2.8° and 6.5°, while kiln 1576 yields an α_{95} value of 9.7°, and LT components from 3215 and AQ fired walls are scattered (Fig. 4, Table 1). The relatively large α_{95} value at kiln 1576 may be explained with the presence of an unresolved viscous magnetization determining a bias to the LT component, isolated at very LTs (up to 200°C, Fig. 3f).

All sites show mean declination values which are statistically indistinguishable from the geographic north, whereas the inclination values increase from the Middle Bronze (42.3°) to the Iron (73.0°) Age.

This evolution in archaeomagnetic directional data in Syria from the 19th to the 8th centuries BC indicates that such data might be useful tools constraining age determinations of loosely dated *in situ* kilns and ovens from excavation sites in the Middle East, although further data are needed to strengthen the definition of the reference curve and hence perform satisfactory dating. Moreover, the palaeointensity data of Genevey *et al.* (2003) show that the field intensity in Syria underwent continuous increase from $\sim$43 to $\sim$71 μT from the 18th to the 8th century BC. Therefore, a combination of directional and palaeointensity data would probably allow high-precision dating of Bronze to Iron Age archaeological sites in the Middle East.

5 COMPARISON WITH COEVAL RELOCATED DATA FROM EUROPE AND MIDDLE EAST: EVIDENCE FOR STRONG SECULAR VARIATION IN THE 8TH CENTURY BC

Our new archaeomagnetic data from Syria are compared here with approximately coeval European and Middle East data from both archaeological structures and lake sediments, after data relocation to Qatna (latitude: 34.8°N; longitude: 36.9°E) by the virtual geomagnetic pole (VGP) method (Noel & Batt 1990). Fig. 5 shows the relocated archaeomagnetic data from Western Europe (Gallet *et al.* 2002), Bulgaria (Kovacheva *et al.* 1998), Iraq (Hammo-Yassi 1983), Egypt (Hussain 1983), as well as the relocated British record from lake sediments (Turner & Thompson 1982). The three 1400–1525 BC inclination-only values from Egypt were relocated at Qatna by assuming systematic 0° declination values. The Bulgarian, Iraqi, and British data roughly cover the same time-span as our Syrian data, whereas the Western Europe data are not older than the first millennium BC, and Egyptian data are limited to the 1400–1525 BC time interval.

The Syrian declination values are roughly consistent with those from Bulgaria and Iraq, except for that of the 19th century BC from Bulgaria, whereas the Western European and British declination values are generally positive, between 10° and 20°. This slight inconsistency may be due to the fact that archaeomagnetic curves are

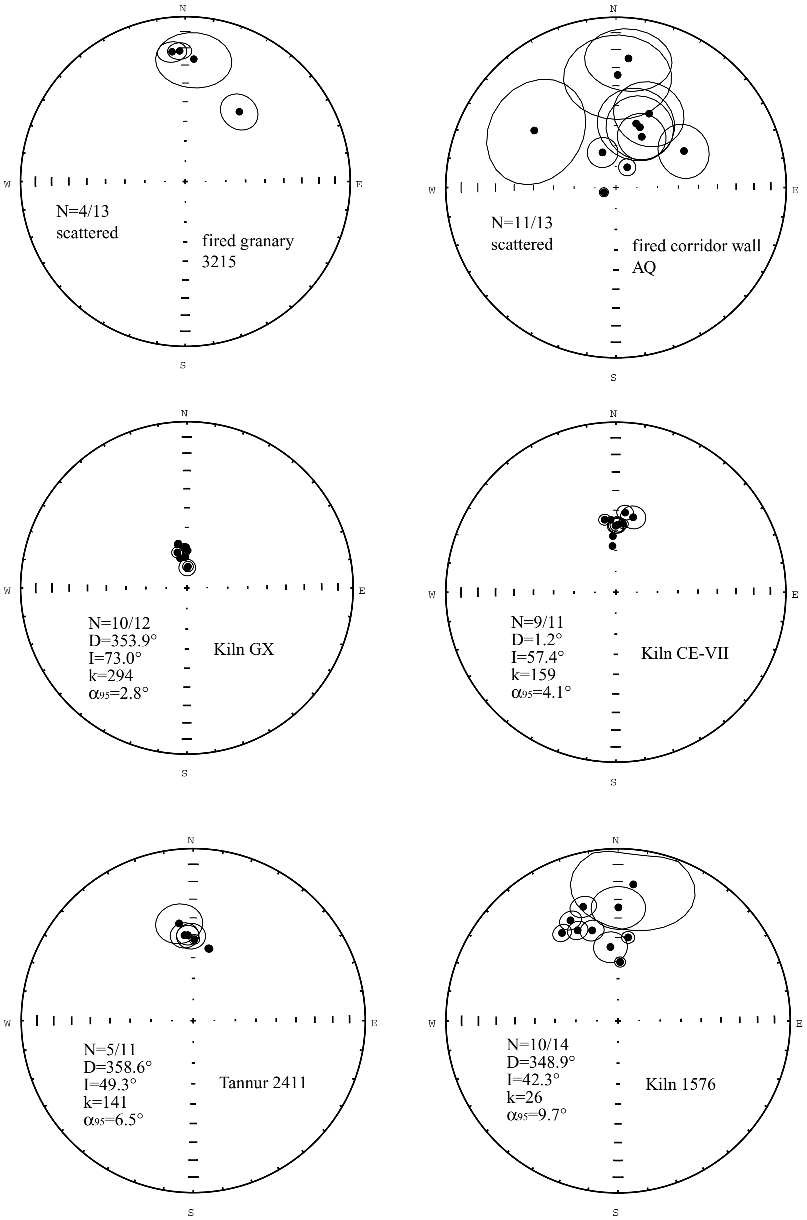

Figure 4. Lower hemisphere equal-area projection of the LT (structures 3215, AQ, 2411, and 1576) and characteristic (structures GX and CE-VII) remanent magnetization components from the specimens sampled at Tell Mishrifeh/Qatna, evaluated by principal component analysis (e.g. Kirschvink 1980). Open ellipses are the projections of the maximum angular dispersion values relative to the mean directions.

considered to have regional significance, so that data from distant areas (such as Syria, with respect to Northern and Western Europe) may display some differences due to non-dipole influences.

Inclination variation versus age of all these data are reported in Fig. 6. The British and Egyptian values are systematically greater by 5°–20° than coeval data from all the other curves, with the exception of Syrian one referred to the 8th century BC. The British discrepancy may arise either from erroneous age calibration of the curve (Gallet *et al.* 2002) and/or from errors in reconstructing the azimuthal orientation of the core (translating into incorrect VGP coordinates). Syrian and Bulgarian data substantially agree, both showing increasing values from the 19th to the 10th century BC, but are not consistent for the 8th century BC. Data from Iraq also show an inclination increase from the 19th–17th to the 7th century BC, and a very shallow inclination for the 10th century BC, which may arise from a poorly constrained age assignment (see Hammo-Yassi 1983). Due to systematic difference with respect to the coeval Syrian, Iraqi, and Bulgarian data, we suspect that inclination-only data from Egypt (Hussain 1983) may be too high by some 20°.

In the 8th century BC (Iron Age), the inclination value in Syria (73.0°) was 7° and 14° greater than relocated Western Europe and Bulgarian values, respectively (Fig. 6). The VGP coordinates calculated for the Iron Age direction are latitude 65.9°N, longitude 29.1°E, implying a deviation of 24.1° from the geographic North Pole. This evidence adds further support to the recent hypothesis of a brief geomagnetic excursion of the field during the 8th

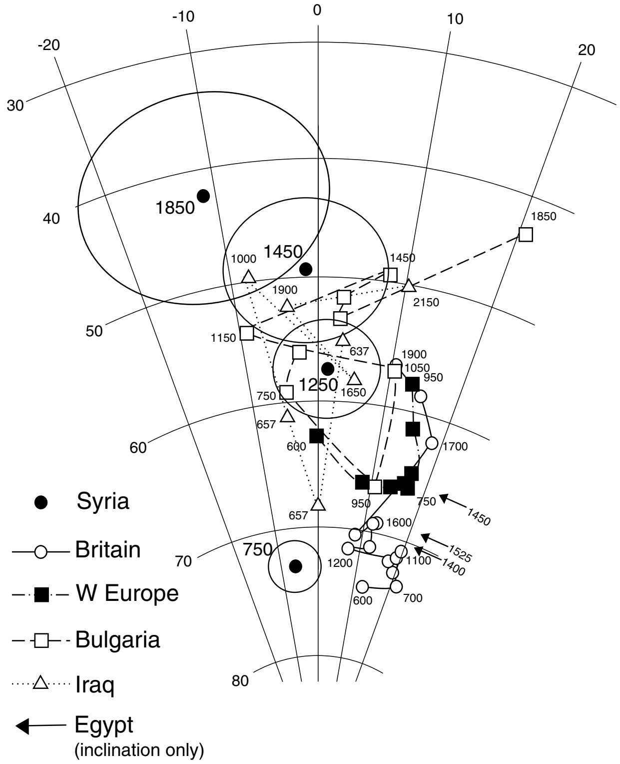

Figure 5. Lower hemisphere equal-area projection of mean palaeomagnetic directions for structures in Tell Mishrifeh/Qatna, and other coeval palaeosecular variation reference data derived from archaeomagnetic data and lake sediments from Britain, Western Europe, Bulgaria, Iraq, and Egypt, relocated to Qatna coordinates (lat. 34.8°N; long. 36.9°E) by VGP method (Noel & Batt 1990). Inclination-only values from Egypt were relocated by assuming 0° declination values. Numbers adjacent to data are ages BC. Open ellipses: projections of α_{95} cones of individual mean palaeomagnetic directions from Qatna. Data from Iraq and from Egypt were extracted from the global data compilation from Korte *et al.* (2005) at http://earthref.org/cgi-bin/er.cgi?s=erda.cgi?n=331.

century BC, as inferred by a directional cusp observed in the archaeomagnetic curve of Western Europe (Gallet *et al.* 2003; see also Fig. 5) and by several lacustrine and marine sedimentary data from the northern hemisphere, indicating an abrupt departure from dipolar directions (Raspopov *et al.* 2003; Snowball & Sandgren 2004). This event also corresponds to a relative maximum in the palaeointensity curve obtained from Syrian potsherds and brick fragments (Genevey *et al.* 2003). This Iron Age rapid variation of the geomagnetic field may have been smoothed out from the (relocated) Western Europe archaeomagnetic curve, which shows rather constant relative inclination maxima from 800 to 650 BC (Fig. 6).

Also the relocated directional data set from Bulgaria and Iraq shown in Fig. 6 display a relative inclination maximum in the 10th–6th century BC interval, though it is centred at 950 (66.4°) and 657 (68.9°) BC, respectively (Fig. 6).

6 CONCLUSIONS

Archaeomagnetic directional data from Tell Mishrifeh/Qatna (Syria) show that the geomagnetic field in the Middle East was characterized by almost zero declination values, and suggest an increase in inclination values from 42.3° to 73.0°, going from the 19th to the 8th centuries BC (i.e. from the Middle Bronze to Iron Ages). The high inclination value documented for the 8th century BC (Iron Age), corresponding to a VGP latitude of 65.9°, does not show an excursional behaviour of the geomagnetic field in Syria. However, it shows strong secular variation which is not in contradiction and seems to strengthen the recent hypothesis, based on palaeomagnetic measurements from several localities in the northern hemisphere, of a brief geomagnetic excursion of the field during the 8th century BC. Therefore more data for this time interval are needed for a better characterization of the geomagnetic field in Syria and Middle East.

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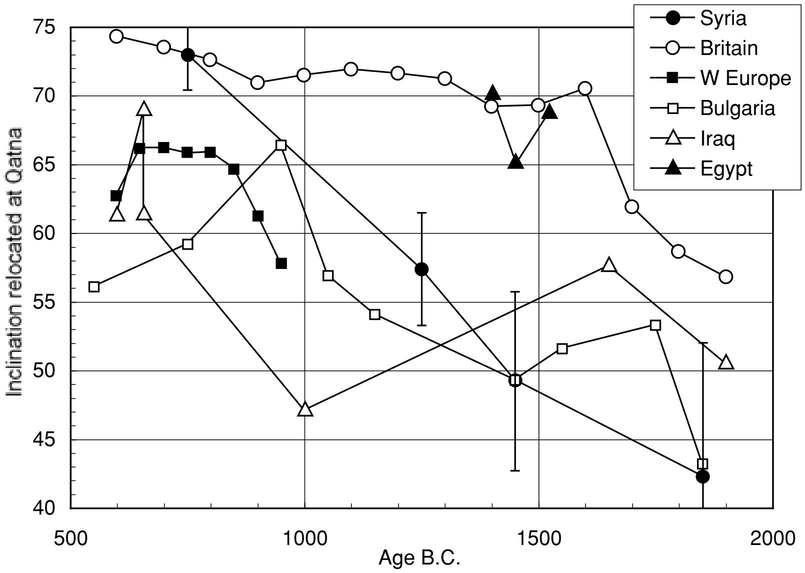

Figure 6. Palaeomagnetic inclination versus age BC for data from Tell Mishrifeh/Qatna, and comparison with coeval data from Britain, Western Europe, Bulgaria, Iraq and Egypt (relocated to Qatna by VGP method, Noel & Batt 1990). Inclination-only data from Egypt were relocated assuming 0° declination values. Error bars of Syrian data are the site-mean α_{95} values. Data from Iraq and Egypt were extracted from the global data compilation from Korte *et al.* (2005) at http://earthref.org/cgi-bin/er.cgi?s=erda.cgi?n=331.

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