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Possible impact of the Earth's magnetic field on the history of ancient civilizations

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Abstract

We report new archeointensity results from Iranian and Syrian archeological excavations dated from the second millennium BC. These high-temperature magnetization data were obtained using a laboratory-built triaxial vibrating sample magnetometer. Together with our previously published archeointensity results from Mesopotamia, we constructed a rather detailed geomagnetic field intensity variation curve for this region from 3000 BC to 0 BC. Four potential geomagnetic events ("archeomagnetic jerks"), marked by strong intensity increases, are observed and appear to be synchronous with cooling episodes in the North Atlantic. This temporal coincidence strengthens the recent suggestion that the geomagnetic field influences climate change over multi-decadal time scales, possibly through the modulation of cosmic ray flux interacting with the atmosphere. Moreover, the cooling periods in the North Atlantic coincide with episodes of enhanced aridity in the Middle East, when abrupt societal changes occurred in the eastern Mediterranean and Mesopotamia. Although the coincidences discussed in this paper must be considered with caution, they lead to the possibility that the geomagnetic field impacted the history of ancient civilizations through climatically driven environmental changes, triggering economic, social and political instability.

Keywords: Archeomagnetism; climate change; environmental impact; ancient civilizations; Eastern Mediterranean; Mesopotamia

1. Introduction

Boasting a long and rich cultural past, Mesopotamia offers the opportunity to recover the detailed geomagnetic field intensity variations over the past ~8 millennia. Relatively numerous archeointensity data were already obtained from this region which permit to know those variations with a quite good time resolution, revealing large and sporadic rapid changes [1–3]. The detection of rapid geomagnetic field intensity fluctuations is of particular interest because Gallet et al. [4] reported a good temporal coincidence, at least over the past three millennia, between the occurrence of intensity maxima in Western Europe and multi-decadal-scale

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cooling events, for instance, during the Little Ice Age [5–8]. Such a coincidence suggests a link between both phenomena. St-Onge et al. [9] put forward a similar inference by studying the paleointensity of Holocene sediments from the St. Laurence estuary (Canada). They proposed that geomagnetic variation may control the millennial and perhaps some centennial-scale fluctuations in the production of cosmogenic isotopes. Up to now, the latter fluctuations were thought to be caused by long-term solar variability, and in fact, they were used as a proxy for characterizing this variability and deriving the Holocene climatic changes (e.g., [10,11]). On the other hand, the geomagnetic dipole moment was assumed to have varied smoothly during the Holocene (e.g., [12]), which is contradicted by recent paleomagnetic and archeomagnetic data and field modeling [2,9,13–15]. Altogether, these results support the idea that geomagnetic field secular variation may trigger dynamical processes in the atmosphere, such as the rate of cosmogenic nuclide production and climatic fluctuations, over centennial time scales. We presently know little about the mechanism that could link the geomagnetic field of internal origin to climate change. An appealing, but not yet demonstrated scenario is that variations in field morphology (sporadic dipole axis motion toward lower latitudes or non-dipole features) could modulate the cosmic ray flux interacting with the atmosphere, altering cloud nucleation, and thus the Earth's radiation budget [4,9,16,17].

If confirmed, the above relationship would give the possibility that the geomagnetic field, because of its impact on climate, influenced the trajectory of ancient civilizations. Cultural responses to Holocene climatic variations have been the subject of several studies, leading for instance to the claim that the collapse of the Akkadian empire at ~2150 BC was provoked by a drought, evidence for which was found in Oman Gulf sediments [18,19], or that the Bronze Age/Iron Age transition in Europe was triggered by a climatic degradation detected in raised-bog deposits from The Netherlands [20]. Other examples of societal collapses caused by climatically induced environmental changes were also suggested in Mesoamerica, in particular for explaining the end of the Classic Maya empire around the end of the first millennium AD [21].

Our attention was originally attracted by a special geomagnetic feature characterized by a strong intensity maximum synchronous with abrupt directional changes observed at ~800 BC, at the time of the Bronze Age/Iron Age transition [4,13,17,22,23]. Other similar geomagnetic features, called "archeomagnetic jerks" by Gallet et al. [13], were detected over the past three millennia that were correlated with climatic cooling events documented in Western Europe from natural and historical data [4,6–8]. Taking advantage of previously reported archeointensity data from Mesopotamia (Syria) [2,3], together with new results from Iranian and Syrian archeological excavations presented in this paper, we explore whether additional archeomagnetic jerks potentially occurred during the third and the second millennia BC that would be coincident with both climatic variations and cultural changes in the eastern Mediterranean and Mesopotamia.

2. Acquisition of new archeointensity results from Iran and Syria

We analyzed 13 groups of baked brick fragments collected from three Iranian and two Syrian archeological sites. The Iranian excavations (Haft Tepe, Chogha Zanbil and Susa), well described in Potts [24], are located in the Mesopotamian alluvial plain in southwestern Iran (Khuzistan province; Fig. 1). Four archeomagnetic sites were collected from the tomb-temple complex at Haft Tepe. Fragments were taken from two pavements (IR04, IR07) and two tombs (IR05 and IR06) dated from the Middle Elamite I period (~1500–1400 BC according to the Middle Chronology framework; e.g., [25]). Five archeomagnetic sites were collected from Chogha Zanbil, particularly remarkable for its impressive and well preserved ziggurat. Groups of fragments were taken from the ziggurat itself (IR02, IR03), from two vaulted tombs located in the palace hypogeum (IR01, IR09) and from a water reservoir (IR08). As discussed in Potts [24], all the structures were built by King Untash-Napirisha during the Middle Elamite II period (~1350–1300 BC). Two other archeomagnetic sites were collected from Susa, where we sampled two pavements dated from the Achemenid period, one at the Darius royal residence (522–486 BC; IR10) and the other at the Shaur palace built under King Artaxerxes II (404–358 BC; IR11).

Two additional archeomagnetic sites were collected from the old cities of Mari and Terqa located along the middle course of the Euphrates river in eastern Syria (Fig. 1). Lot25 from Mari consists of fragments from a water conduit found in a building constructed inside the Great Royal Palace (City 3 of Mari) during the reign of Shamsi Adad I, shortly before the destruction of the city by the Babylonian troops of King Hammurabi (~1750 BC in the middle chronology) [26]. Note that this archeomagnetic site is slightly younger than the two sites MR11 and MR08, also dated from the Amorite Dynasty (end of City 3 of Mari), which were previously

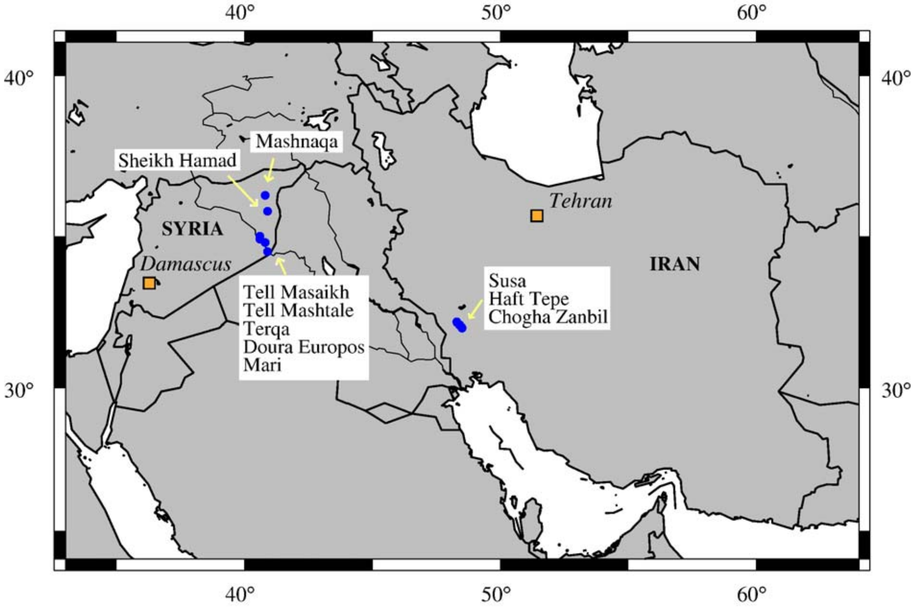

Fig. 1. Location map of the different archeological excavations in Iran and Syria where the groups of baked brick fragments analyzed in this paper have been collected.

analyzed by Genevey et al. [2] and Gallet and Le Goff [3]. Finally, in Terqa, we sampled several fragments from a water conduit dated from the Khana period (~1750–1500 BC; Lot26) [27].

Archeointensity determinations were derived using the experimental procedure described in Le Goff and Gallet [28] (and references herein), which involves continuous high-temperature and in-field magnetization measurements carried out using the three-axis vibrating sample magnetometer “Triaxe” (see also [3]). With this technique, each 0.75-cm^3 sample yields a rather large number of archeointensity results (one every ~5 °C) over a single but large temperature interval, generally between 150 °C (T_1) and 450 °C (T_2). Based on previous analyzes detailed in the aforementioned publications, these results are obtained from the ratio $R'(T_i)$ between the natural remanent magnetization (NRM) and the laboratory thermoremanent magnetization (TRM) fractions unblocked between T_1 and any temperature T_i intermediate between T_1 and T_2. An archeointensity value, which is both corrected for TRM anisotropy (as the laboratory TRM is acquired in the direction of the NRM) and for cooling rate dependence of TRM acquisition [28], is then determined for each sample by averaging the $R'(T_i)$ data through the temperature interval of analysis. In our study, only the most reliable results were retained using the same selection criteria as those described in Gallet and Le Goff [3]. We briefly recall here these criteria which were deduced from the analysis of thermally stabilized samples possessing varying pseudo-ancient NRM acquired in known laboratory-field and temperature conditions:

i) The magnetization must be univectorial through the entire temperature interval considered for intensity determination.
ii) The magnetization fraction between T_1 and T_2 must represent at least 50% of the magnetization fraction with unblocking temperatures $>T_1$.
iii) The values of the ratio $R(T_i)$ between the NRM and the laboratory TRM fractions unblocked between T_i and T_1 must be continuously increasing or approximately constant from T_1 to T_2.
iv) The $R'(T_i)$ data must be nearly straight and approximately constant through the T_1-T_2 temperature interval. A slope is computed which must be less than 15%.
v) One sample is analyzed per fragment and a mean archeointensity value is computed at the site level when at least 3 fragments provide reliable results. This mean intensity value is rejected if its standard deviation is >5 µT or >10% of the mean value.

Using these criteria, Gallet and Le Goff [3] compared Mesopotamian archeointensity results derived respectively from the Triaxe and from the classical Thellier and Thellier [29] method revised by Coe [30]; these results differ mostly within ±5% at the fragment and site levels.

The new fragments have magnetic signatures dominated by titano-magnetite in the pseudo single domain range, very similar to that previously observed by Genevey et al. [2] and Gallet and Le Goff [3]. Excluding 14 samples too weakly magnetized to allow measurements with the Triaxe, the archeointensity results from 75 samples fulfilled our selection criteria (Table 1). This gives a success rate of 84%, comparable to the one obtained by Gallet and le Goff [3] using the same experimental procedure, again confirming the overall good suitability of Mesopotamian baked clay materials for archeointensity studies [2,3]. The $R'(T_i)$ data obtained from six archeomagnetic sites are shown in Fig. 2. Among the 13 studied sites, two sites from Chogha Zanbil (IR01 and IR03) were eliminated because most fragments from IR01 are too weakly magnetized, while a high data dispersion prevents the determination of a well constrained site mean intensity value for site IR03 (standard deviation >5 μT and >10% of the site mean intensity value; Table 1). The baked brick fragments that constitute site IR03 were collected from the ziggurat built of millions of sun-dried bricks protected from erosion by baked bricks. Our results for this site may either indicate late renovation phases for this "skin" of protection or the reemployment of old baked bricks when the ziggurat was elevated.

Table 1
New archeointensity results obtained from Iranian and Syrian baked brick fragments using the Triaxe method

Archeological excavation	Site	Age (BC)	Mean intensity (μT)	nb fragments
Haft Tepe	IR 04	1500–1400	50.8±2.3	8
Haft Tepe	IR 05	1500–1400	52.6±4.0	6
Haft Tepe	IR 06	1500–1400	52.0±3.1	4
Haft Tepe	IR 07	1500–1400	50.9±2.5	6
Chogha Zanbil	IR 01	1350–1300	–	2
Chogha Zanbil	IR 02	1350–1300	53.7±0.9	6
Chogha Zanbil	IR 03	1350–1300	(53.8±5.6)	5
Chogha Zanbil	IR 08	1350–1300	56.4±3.3	6
Chogha Zanbil	IR 09	1350–1300	52.2±1.9	4
Susa	IR 10	522–486	65.3±2.2	7
Susa	IR 11	404–358	58.5±2.5	8
Mari	Lot 25	1800–1750	38.1±2.3	7
Terqa	Lot 26	1750–1500	40.8±1.0	6

Mean intensity μT, mean Triaxe intensity value in μT obtained at the site level and its standard deviation; nb fragments, number of data used for the computation of the site-mean intensity value. For complete table, see Electronic Supplement.

3. Geomagnetic field intensity variations in Mesopotamia from 3000 BC to 0 BC

We now have a data set of 31 site mean intensity values from Mesopotamia covering the last three millennia BC obtained using the Thellier and Thellier [29] method revised by Coe [30] and the Triaxe procedure [28] (Table 2). When both types of data are available from the same fragments, we simply average them at the fragment level before computing a site mean intensity value. The latter values therefore update the site mean intensity results given by Genevey et al. [2] and Gallet and Le Goff [3]. All data are reported in Fig. 3 after being transferred to the latitude of Mari (34.5°N); we also incorporated few results dated from the fourth millennium BC. Altogether these data show several interesting features, particularly the occurrence of strong geomagnetic field intensity variations. The two older ones, already discussed by Gallet and Le Goff [3], are dated at ~2800–2600 BC and ~2100–1900 BC. In these two cases, significantly different archeointensity values are observed although the corresponding sites are dated from the same age based on archeological constraints. The new result from Terqa provides evidence for yet another occurrence between ~1750 and 1500 BC. The mean intensity value obtained from the water conduit (Lot26) is indeed much lower than the one derived from a group of potsherds collected from the same archeological site (Lot09) [2]. According to the overall field intensity variations during the second millennium BC, the water conduit would then be older than the potsherds, which seems quite reasonable. The period of ~1000 years between the fall of Mari (~1750 BC) and the beginning of the first millennium BC, up to ~750 BC, is characterized by an increase in geomagnetic field intensity by a factor of two [1–3]. The new Iranian data from Haft Tepe and Chogha Zanbil may indicate that this increase was not regular, with first a strong increase between ~1750 and 1500 BC, then a moderate increase between ~1500 and 1200–1100 BC and finally another strong increase up to ~750 BC. In contrast, the two results from Susa indicate a strong intensity decrease between ~700 and 200 BC.

Data from Fig. 3 therefore point toward four potential geomagnetic events characterized by strong intensity increases during the last three millennia BC (red lines in Fig. 3). These events require further confirmation and it is of interest to compare them to the geomagnetic features found by Snowball and Sandgren [23] from two lacustrine long cores from Sweden. They identified four distinct directional cusps dated by radiocarbon at ~4500, 3900, 3700 and 2900 cal BP

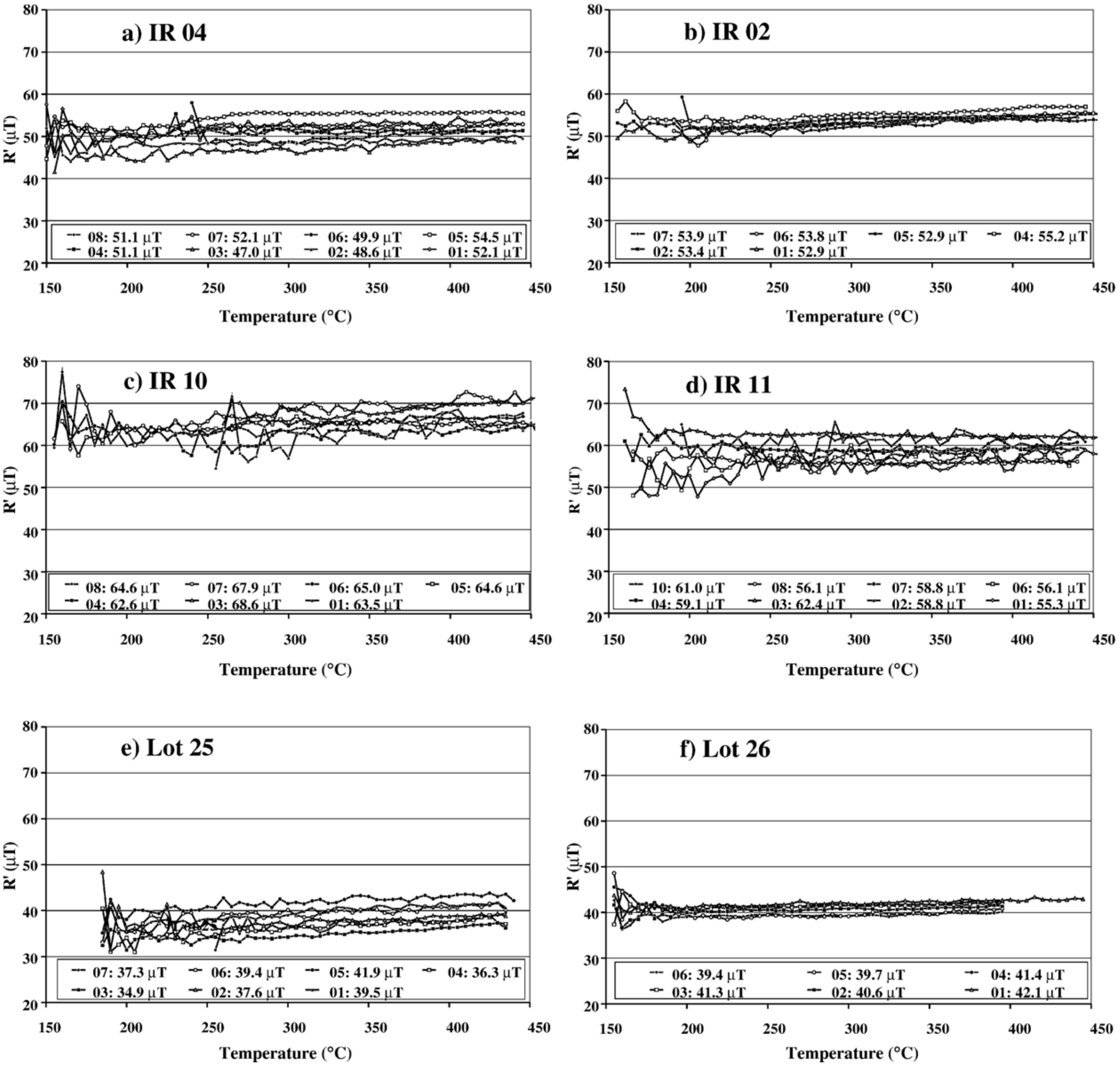

Fig. 2. $R'(T_i)$ data obtained from six archeomagnetic sites: four from Iran (2a: Haft Tepe; 2b: Chogha Zanbil; 2c,d: Susa) and two from Syria (2e: Mari; 2f:Terqa). One sample was analyzed per fragment providing each individual $R'(T_i)$ curve.

that appear in two cases (the second and the fourth) to be coincident with a maximum in intensity derived from relative paleointensity estimates. We also note that the two Swedish geomagnetic field intensity records show a moderate intensity peak around the middle of the second millennium BC, also found in Spain by Burakov et al. [31] from archeomagnetic data, that might be correlated to our geomagnetic event proposed between ~1750 and 1500 BC. The agreement between our findings and the Snowball and Sandgren [23] data is not fully satisfactory, which is most probably linked to the different nature of the data and of the dating process. However, available results provide some support for interpreting the geomagnetic events we have uncovered as being the signatures of four archeomagnetic jerks [13,23].

4. Discussion

4.1. Comparison between geomagnetic field intensity variations and climate change in the North Atlantic

A continuous climatic record of the Middle and Late Holocene is not yet available for Mesopotamia.

Table 2
Synthesis of all our archeointensity data obtained in Syria and Iran dated from the past four millennia BC (this study and [2,3])

Archeological excavation	Site	Location (λ°*N*,*Φ*°E)	Age (BC)	Intensity (site) (μT)	Intensity (Mari) (μT)	nb fragments	Method
Mashnaqa	Lot 17	36.3°, 40.8°	3900±100	31.9±2.3	31.2±2.3	7	TTC+Triaxe
Mashnaqa	Lot 16	”	3700±100	33.6±0.3	32.9±0.3	3	TTC
Mashnaqa	Lot 15	”	3500±100	33.9±0.6	33.2±0.6	3	TTC
Mashnaqa	Lot 03	”	3400±100	41.5±2.1	40.6±2.1	5	TTC+Triaxe
Mari	Lot 24	34.5°, 40.9°	2900±100	37.2±1.1	37.2±1.1	8	Triaxe
Mashnaqa	Mas 02	36.3°, 40.8°	2700±100	40.9±3.4	40.0±3.4	4	Triaxe
Mari	Lot 12	34.5°, 40.9°	2700±100	46.4±1.8	46.4±1.8	5	TTC
Mari	MR 05	”	2550±100	51.4±2.2	51.4±2.2	5	TTC+Triaxe
Mari	MR 14	”	2550±100	51.9±0.4	51.9±0.4	5	Triaxe
Mari	Lot 14	”	2300±100	48.2±1.7	48.2±1.7	6	TTC+Triaxe
Mari	MR 15	”	2000±100	45.9±1.5	45.9±1.5	6	Triaxe
Mari	MR 02	”	2000±100	46.8±2.3	46.8±2.3	5	TTC+Triaxe
Mari	MR 03	”	2000±100	37.4±1.4	37.4±1.4	6	Triaxe
Mari	MR 04	”	2000±100	40.8±2.7	40.8±2.7	6	Triaxe
Mari	MR 11	”	1825±75	42.7±1.2	42.7±1.2	4	TTC+Triaxe
Mari	MR 08	”	1825±75	43.4±0.9	43.4±0.9	4	Triaxe
Mari	Lot 25	”	1775±25	38.1±2.3	38.1±2.3	7	Triaxe
Terqa	Lot 09	34.9°, 40.6°	1625±125	51.0±3.9	50.8±3.9	3	TTC
Terqa	Lot 26	”	1625±125	40.8±1.0	40.6±1.0	6	Triaxe
Haft Tepe	IR 04	32.1°, 48.4°	1450±50	50.8±2.3	52.4±2.3	8	Triaxe
Haft Tepe	IR 05	”	1450±50	52.6±4.0	54.2±4.0	6	Triaxe
Haft Tepe	IR 06	”	1450±50	52.0±3.1	53.6±3.1	4	Triaxe
Haft Tepe	IR 07	”	1450±50	50.9±2.5	52.5±2.5	6	Triaxe
Chogha Zanbil	IR 02	32.0°, 48.5°	1325±25	53.7±0.9	55.4±0.9	6	Triaxe
Chogha Zanbil	IR 08	”	1325±25	56.4±3.3	58.2±3.3	6	Triaxe
Chogha Zanbil	IR 09	”	1325±25	52.2±1.9	53.9±1.9	4	Triaxe
Sheikh Hamad	Lot 27	35.8°, 40.9°	1250±50	57.1±3.6	56.2±3.6	4	Triaxe
Tell Mashtale	Lot 05	34.9°, 40.6°	1150±50	59.2±3.6	58.9±3.6	7	TTC+Triaxe
Tell Masaikh	TM 01	35.0°, 40.6°	725±25	71.5±2.9	71.1±2.9	6	TTC+Triaxe
Tell Masaikh	Lot 28	”	725±25	73.4±2.5	73.0±2.5	8	Triaxe
Tell Masaikh	Lot 29	”	650±50	74.7±1.9	74.2±1.9	4	Triaxe
Sheikh Hamad	Lot 31	35.8°, 40.9°	575±25	70.1±0.9	69.0±0.9	7	Triaxe
Susa	IR 10	32.2°, 48.3°	504±18	65.3±2.2	67.2±2.2	7	Triaxe
Susa	IR 11	”	381±23	58.5±2.5	60.2±2.5	8	Triaxe
Doura Europos	Lot 19	34.8°, 40.8°	225±75	57.4±2.6	57.2±2.6	3	TTC

These results were obtained using the Thellier and Thellier [29] method revised by Coe [30] (TTC) and the Triaxe procedure [28]. When both types of data were available from the same fragments, we averaged them before computing a site-mean intensity value. For complete table, see Electronic Supplement.

However, the good consistency observed in geomagnetic field intensity fluctuations over a wide part of Eurasia (at least from Central Asia to Western Europe) during the past millennia likely indicates that these variations reflect the evolution of low-degree geomagnetic terms [2,13,23]. We therefore compare the occurrence of the newly detected archeomagnetic jerks to the main climatic features obtained by Bond et al. [32] in the North Atlantic. The latter climatic fluctuations were determined through the entire Holocene from petrologic tracers of drift ice in deep-sea sediment cores ("drift ice indices"; Fig. 4) that closely match the changes in production rates of cosmogenic nuclides, showing in particular a good correlation with the Medieval Climate Optimum and the Little Ice Age and providing further evidence for the occurrence of a cooling period at the beginning of the first millennium BC [20]. Four cooling periods are observed over the last three millennia BC (shaded bands in Fig. 4), whose ages appear either coincident with or relatively close to the ages of the archeomagnetic jerks (Fig. 4a, b). The main problem concerns the geomagnetic event detected around 2000 BC from different archeomagnetic sites collected in Mari that are all dated at the beginning-middle of City 3 [26]. A better coincidence with the cooling period found by Bond et al. [32] at the end of third millennium BC would imply that the two archeomagnetic sites showing the lower archeointensity

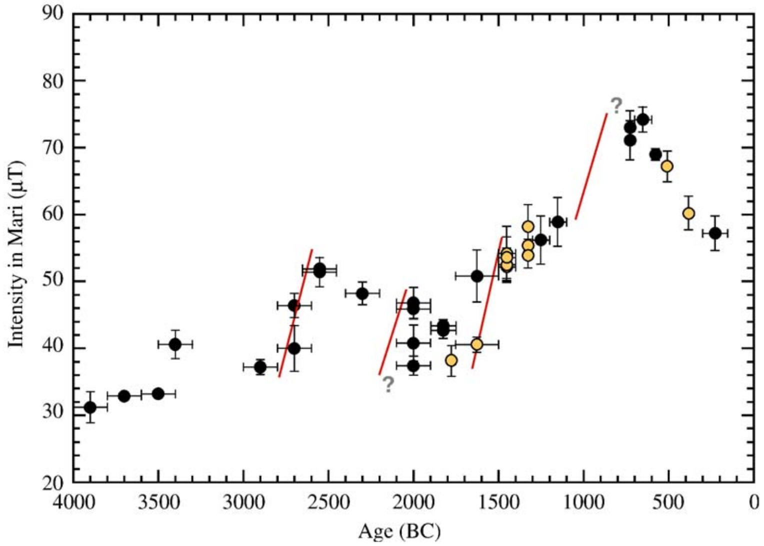

Fig. 3. Variations of the Earth's magnetic field intensity from Mesopotamia during the past four millennia BC. The archeointensity results reported here are from Genevey et al. [2], Gallet and Le Goff [3] (black dots) and this study (yellow dots). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

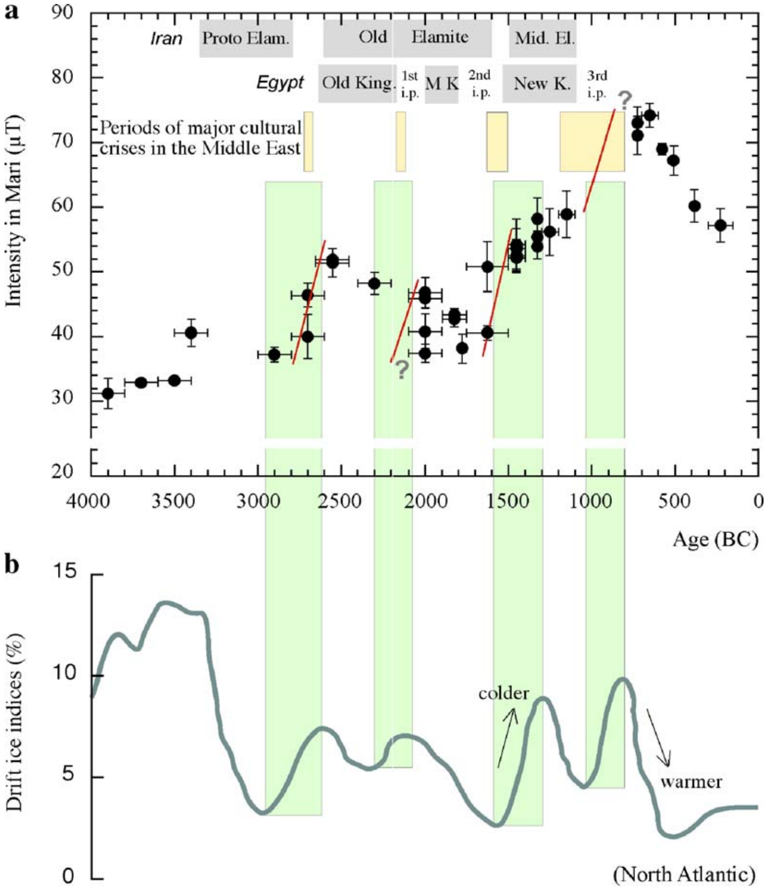

Fig. 4. Comparison between geomagnetic field intensity variations from Mesopotamia (a), climate change in the North Atlantic (b after Bond et al. [32]) and the main cultural changes in the eastern Mediterranean and in Mesopotamina (a). 1st i.p., 2nd i.p. and 3rd i.p. indicate the three intermediate periods that occurred during the dynastic Egyptian history.

values actually be one or two centuries older (Fig. 4a). Although possible (since City 3 emerged at ~2200–2100 BC), the chronological constraints presently available on the history of Mari do not permit to ascertain this modification. The continued acquisition of archeointensity data during the Late Akkadian period should bring new constraints on this particular question.

4.2. Outline of the main cultural changes in the eastern Mediterranean and Mesopotamia, and coincidence with climatic and geomagnetic features

The history of cultural changes in Egypt and in Mesopotamia has been the subject of many textbooks. In this study, we only focus on well-accepted changes (Fig. 4a), such as the transition between the Old and Middle Kingdoms, the transition between the Middle and New Kingdoms and the end of the New Kingdom in Egypt. These successive transitions were marked by three "intermediate" periods dated at ~2150–2000 BC, ~1800–1550 BC and ~1100–650 BC respectively (e.g., [33]). In Mesopotamia, the situation is more complex as the regional context involved several cultural groups which had intermittent political and/or economical relationships. We summarize below the three best documented crises (from younger to older times):

i) Collapse of most Eastern Mediterranean societies in a few decades around 1200 BC (e.g., [34]). The Late Bronze civilization regressed almost everywhere from Iran to the Aegean area and fell into eclipse during several centuries. The whole period between ~1200 and ~800 BC is often described as the "Ancient Dark Ages".

ii) Between ~1700 and ~1500 BC: suspension of most economic relationships between cultures from the Indus valley to those from Mesopotamia and Central Asia (e.g., [35]), and disappearance of several major societies such as the 1st Dynasty of Babylon (~1600–1500 BC) in South Mesopotamia, the fragmentation of the Harappan (Indus valley) civilization or the demise of the Minoan palatial civilization in the Aegean.

iii) Collapse of the North Mesopotamian (Akkadian) civilization around 2150 BC [18].

Huot [35] finally mentioned the abrupt disappearance of the proto-Elamite civilization in the Fars region (Iran) around 2700 BC, in particular with the abandonment of the main city of Tal-e Malyan (roughly synchronous with the other unexplained abandonment of City 1 of Mari at ~2600 BC [26]), that might indicate a fourth regional cultural crisis.

Uncertainties still exist on the precise dating of the societal events discussed above (e.g., [36]). However, Fig. 4a, b shows a good temporal coincidence between the occurrence of strong geomagnetic field intensity increases, cooling periods in the North Atlantic and the main societal crises in the eastern Mediterranean and Mesopotamian areas during the third and second millennia BC. For the case at ~2150 BC, available climatic data obtained both in the North Atlantic and in Mesopotamia allow us to correlate a cooling period observed to the west with a severe drought in Mesopotamia that ultimately caused the political disintegration of a highly organized (Akkadian) empire. More generally, a number of investigations have concluded that the Holocene cooling episodes detected in the North Atlantic, accompanied by changes in atmospheric moisture availability and both in oceanic and atmospheric circulation, were synchronous with Asian monsoon weakening and enhanced aridity at northern hemisphere low-mid latitudes such as in Mesopotamia (e.g., [37,38] and references herein). A prolonged drought was also proposed by Weiss [34] to explain the end of the Late Bronze civilization. This major crisis was previously attributed to the sole irruption of new peoples (the "Peoples of the Sea") in the eastern Mediterranean area, but this population movement itself could have been triggered by the inferred climate change. Up to now, no clear interpretation has been proposed to explain cultural changes around the middle of the second millennium BC. However, the coincidence seen in Fig. 4 and the large geographical distribution of the concerned cultures may indicate a similar cause.

Brooks [38] recently discussed the role of climatic and environmental stress in the emergence of complex societies, with a particular interest for the rise of the dynastic civilization in Egypt. The beginning of the third millennium BC was marked by increasing aridity in this region which would have provoked population clustering and permanent settlement in the Nile valley, offering the social and political conditions for the emergence of the Old Kingdom (~2700 BC). Fig. 4 shows that an archeomagnetic jerk occurred at this time. Brooks [38] further emphasized the different cultural "trajectory" of Mesopotamia during this period (regional differentiation instead of unity) with the collapse of the Uruk culture and the emergence of new competing city states. The courses of the Euphrates and Tigris were more variable, in response to climatic change, than that of the Nile, and shifts in their courses could have had a dramatic impact on the cities that grew near them. This might for instance explain the temporary abandonment of City 1 of Mari whose existence relied on the commercial exchanges between the Taurus mountains and Southern Mesopotamia and was totally depending on the Euphrates river [26].

5. Concluding remarks

The data reported in Fig. 4 are compatible with our previous suggestion that there is a connection between geomagnetic secular variation, in particular the occurrence of archeomagnetic jerks, and climate change over multi-decadal (centennial) time scales [4]. Considering that these climatic changes owe their origin to internal geomagnetic field fluctuations, it is then possible that geomagnetic field had some influence on the history of ancient civilizations. Climatically driven environmental change, such as a modification of regional water budget, would have drastically altered the economic and social situations leading to political instability and major political reorganization over various time scales, with possible societal disintegration and/or the emergence of new societies. This paper attempts to show a potential correlation between geomagnetic field and climatic variations on one hand, and between climatic (environmental) and human events on the other. By extension, one should wonder whether a link exists between geomagnetic field variation and the course of human history. Our study presents evidence that is sufficiently intriguing to merit further investigation.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.palaeo.2004.10.001.

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