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Does Earth's magnetic field secular variation control centennial climate change?

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Abstract

We obtained new archeointensity data from French faience potsherds dated from the 17th to 19th century. These results further document the occurrence of sharp changes in geomagnetic field secular variation in Western Europe over the past three millennia. The intensity variation curve shows several maxima whose rising parts appear to coincide in time with the occurrence of cooling events documented in this region from natural and historical data. This coincidence suggests a causal link between enhanced secular variation of the geomagnetic field and climate change over centennial time scales, challenging the role of solar forcing as the sole factor provoking these climatic variations. We propose that the archeomagnetic jerks described by Gallet et al. [1] [Y. Gallet, A. Genevey, V. Courtillot, On the possible occurrence of archeomagnetic jerks in the geomagnetic field over the past three millennia, Earth Planet. Sci. Lett. 214 (2003) 237–242.] may engage the mechanism for centennial climate change.

Keywords: archeomagnetism; geomagnetic secular variation; centennial climate change; archeomagnetic jerks; Western Europe

1. Introduction

Cyclic variations in Earth's orbit around the Sun govern the long-term (10 to 1000 kyr) climatic changes on Earth, leading to alternate glacial and interglacial periods. However, climatic variations also exist over much shorter, decadal to centennial, time scales which cannot be simply related to orbital (Milankovic) forcing. During the past millennium, these variations include the Little Ice Age (~AD 1550 to 1850) and the Medieval Warm Period (~AD 900 to ~1300) climatic events (e.g. [2–4]). Such anomalies, which likely have left worldwide imprints, are generally interpreted as reflecting long-term variations in solar activity, in particular solar irradiance (e.g. [5]). These latter fluctuations, inferred from the

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Table 1
New archeointensity results obtained from French faience potsherds

Potsherd	Sample	n	$T_{min}-T_{max}$	f	g	q	$H_{non\ corrected}$	SE	$H_{anisotropy\ corrected}$	H_{mean} value per potsherd corrected for the cooling rate effect $\pm\sigma H$	$H_{mean}\pm\sigma H$	H_{mean} in Paris	VADM $\times 10^{22}$ (A m^2)
MON03 : Montpellier (E 3.9°, N 43.6°) — [1600–1620]													
MON03-01	T575	14	225–550	0.53	0.92	19.48	61.6	1.5	58.8	56.1 ± 1.0			
	T576	15	200–550	0.59	0.92	26.74	60.4	1.2	56.8				
MON03-02	T579	17	150–575	0.80	0.92	60.35	60.0	0.7	59.1	55.0 ± 0.0	55.0 ± 1.1	58.1	9.1
	T580	17	150–575	0.81	0.92	57.15	59.7	0.8	59.1				
MON03-06	T596	16	150–550	0.81	0.92	45.13	59.3	1.0	59.3	55.2 ± 0.1			
	T597	16	150–550	0.77	0.92	39.40	57.8	1.0	59.5				
MON03-07	T600	16	150–550	0.80	0.93	42.90	57.6	1.0	58.4	53.5 ± 0.4			
	T602	16	150–550	0.80	0.93	44.28	58.2	1.0	59.1				
MON01 : Montpellier (E 3.9°, N 43.6°) — [1620–1650]													
MON01-05	T692	10	150–400	0.40	0.88	9.19	45.4	1.7	55.4	52.0 ± 0.7			
	T693	10	150–400	0.42	0.88	14.49	39.8	1.0	54.1				
MON01-06	T695	14	150–500	0.60	0.91	21.48	38.8	1.0	63.1	57.2 ± 1.6	53.2 ± 3.6	56.2	8.8
	T696	17	150–575	0.64	0.93	35.56	40.4	0.7	60.0				
MON01-08	T704	16	225–600	0.81	0.92	50.27	38.8	0.6	52.8	50.4 ± 0.3			
	T705	16	225–600	0.82	0.92	43.50	37.1	0.6	53.4				
NE02 : Nevers (E 3.2°, N 47.0°N) — [1660–1680]													
NE02-05	T042	12	150–475	0.73	0.90	63.05	50.2	0.5	51.4	48.5 ± 0.2			
	T043	13	150–475	0.74	0.91	91.98	49.8	0.4	51.8				
NE02-06	T046	12	200–475	0.62	0.89	54.07	48.2	0.5	47.9	45.4 ± 0.1	48.8 ± 2.8	49.7	7.8
	T047	12	200–475	0.62	0.89	40.50	47.4	0.7	47.7				
NE02-09	T419	10	150–400	0.69	0.88	30.90	54.3	1.1	54.3	52.3 ± 1.3			
	T420	9	200–400	0.56	0.87	19.10	56.0	1.4	56.9				
NE02-11	T427	11	150–425	0.73	0.89	22.23	52.8	1.5	52.8	48.9 ± 0.8			
	T429	11	150–425	0.73	0.89	22.22	51.8	1.5	51.3				
NE04 : Nevers (E 3.2°, N 47.0°N) — [1720–1735]													
NE04-02	T077	13	150–475	0.61	0.88	36.55	53.2	0.8	55.6	51.2 ± 0.6			
	T078	13	150–475	0.62	0.88	40.51	52.8	0.7	54.4				
NE04-03	T081	13	150–475	0.61	0.90	28.28	49.8	1.0	50.8	48.0 ± 0.3	48.5 ± 1.9	49.4	7.8
	T082	13	150–475	0.61	0.90	19.65	50.3	1.4	51.3				
NE04-04	T085	12	200–475	0.45	0.90	20.23	44.5	0.9	49.4	48.1 ± 0.2			
	T086	12	200–475	0.46	0.90	24.59	46.3	0.8	49.8				
NE04-11	T488	10	150–400	0.65	0.88	23.17	47.9	1.2	49.3	46.6 ± 0.3			
	T489	10	150–400	0.65	0.88	21.24	48.9	1.3	49.9				
NE05 : Nevers (E 3.2°, N 47.0°N) — [1760–1780]													
NE05-02	T101	18	150–600	0.75	0.93	40.56	45.8	0.8	46.7	45.8 ± 0.1			
	T102	16	150–550	0.70	0.93	47.28	45.6	0.6	46.8				
NE05-04	T110	10	150–400	0.57	0.87	20.80	46.8	1.1	47.7	44.0 ± 0.4	42.6 ± 2.8	43.4	6.8
	T112	10	150–400	0.56	0.87	17.74	45.7	1.3	46.9				
NE05-07	T372	10	150–400	0.52	0.86	17.36	44.3	1.2	43.0	41.3 ± 0.5			
	T373	10	150–400	0.52	0.86	17.74	44.2	1.1	44.0				
NE05-11	T501	18	100–575	0.93	0.94	67.98	40.3	0.5	43.9	43.4 ± 0.8			
	T502	18	100–575	0.92	0.94	70.50	41.4	0.5	45.5				
NE05-13	T508	10	150–400	0.54	0.87	11.99	40.2	1.6	40.6	38.6 ± 0.5			
	T509	10	150–400	0.54	0.87	12.77	41.3	1.5	41.6				

Table 1 *(continued)*

Potsherd	Sample	n	$T_{min}-T_{max}$	f	g	q	$H_{non\ corrected}$	SE	$H_{anisotropy\ corrected}$	H_{mean} value per potsherd corrected for the cooling rate effect $\pm\sigma H$	$H_{mean}\pm\sigma H$	H_{mean} in Paris	VADM × 10^{22} (A m^2)
NE06 : Nevers (E 3.2°, N 47.0°N)— [1820–1830]													
NE06-02	T126	16	200–575	0.72	0.93	43.24	42.8	0.7	44.5	43.2 ± 0.0			
	T127	16	200–575	0.72	0.93	41.50	42.8	0.7	44.5				
NE06-03	T130	17	150–575	0.86	0.93	61.25	39.8	0.5	46.3	43.3 ± 0.3	43.7 ± 0.6	44.5	7.0
	T132	17	150–575	0.85	0.93	59.47	39.3	0.5	45.8				
NE06-04	T133	17	150–575	0.88	0.93	86.00	41.3	0.4	46.9	44.4 ± 0.2			
	T134	17	150–575	0.87	0.93	75.35	42.3	0.5	46.5				
NE06-07	T523	17	150–575	0.86	0.93	61.82	39.8	0.5	46.3	43.8 ± 0.2			
	T524	17	150–575	0.86	0.93	55.27	39.6	0.6	45.9				
NE07 : Dijon (E 5.0°, N 47.3°)— [1845–1855]													
NE07-02	T150	17	150–575	0.79	0.93	44.86	46.8	0.8	50.1	42.7 ± 0.4			
	T151	17	150–575	0.79	0.93	43.34	44.8	0.8	49.3				
NE07-03	T155	18	150–600	0.91	0.92	90.01	39.2	0.4	47.8	43.3 ± 0.4	45.5 ± 3.0	46.2	7.3
	T156	18	150–600	0.92	0.92	83.21	39.4	0.4	48.5				
NE07-04	T159	18	150–600	0.83	0.92	73.23	42.5	0.4	48.6	47.4 ± 0.3			
	T160	18	150–600	0.82	0.92	65.96	42.5	0.5	49.1				
NE07-06	T161	13	200–500	0.65	0.91	23.60	44.7	1.1	50.5	48.7 ± 0.3			
	T163	14	150–500	0.77	0.91	33.59	43.8	0.9	50.0				

n, number of heating steps used to determine intensity; $T_{min}-T_{max}$, temperature interval (in °C) of intensity determination; f, fraction factor; g, gap factor; q, quality factor (see in ref. [14]); $H_{non\ corrected}$, archeointensity before TRM anisotropy and cooling rate corrections in μT; SE, standard error in μT of the slope determination; $H_{anisotropy\ corrected}$, archeointensity after TRM anisotropy correction in μT; σH, standard deviation of the mean determined at the fragment level in μT; $H_{mean}\pm\sigma H$, mean intensity at dated-site level and standard deviation in μT, $H_{mean\ in\ Paris}$, mean intensity reduced to the latitude of Paris (48.9°N) in μT; VADM, virtual axial dipole moment. Note that all intensity experiments were carried out using a laboratory field of 50 μT.

time-varying production of cosmogenic nuclides in the upper atmosphere after removing the long-term influence of the geomagnetic dipole moment, are traced back to the number of vortices of plasma formed at the surface of the Sun (the sunspots) and to the number of aurorae. It is usually thought that the Earth's climate was colder during periods of lessened sunspot and auroral activity and warmer during periods of frequent sunspot and auroral occurrence (e.g. [6]). This connection however remains debatable as the coldest period of the Little Ice Age, at the end of the 16th century and beginning of the 17th century, preceded the Maunder minimum (~AD 1645–1715) and did not coincide with low solar activity [7].

Up to now, the influence of forcing factors internal to the Earth, such as rapid dipolar and/or non-dipolar geomagnetic field variations has been only rarely taken into account to explain climate change (e.g. [8–10]). Holocene paleointensity records derived from the St-Lawrence Estuary (Canada) sediments recently led St-Onge et al. [9] to propose that the geomagnetic field may control the millennial- and perhaps some centennial-scale fluctuations in the production of cosmogenic isotopes. These authors further envisaged a connection between the geomagnetic field and climate change over these time scales. New archeomagnetic results obtained from France allow one to make a more detailed comparison between geomagnetic field behaviour and centennial climatic variations in Western Europe over the past three thousand years. This comparison shows evidence for a closer relationship between these two phenomena than previously thought. Mechanisms that could involve the geomagnetic field as a cause of centennial climate change should therefore be sought.

2. Geomagnetic field secular variation in Western Europe over the past 3000 years

Over the past three millennia, geomagnetic secular variation in France, and more generally in West-

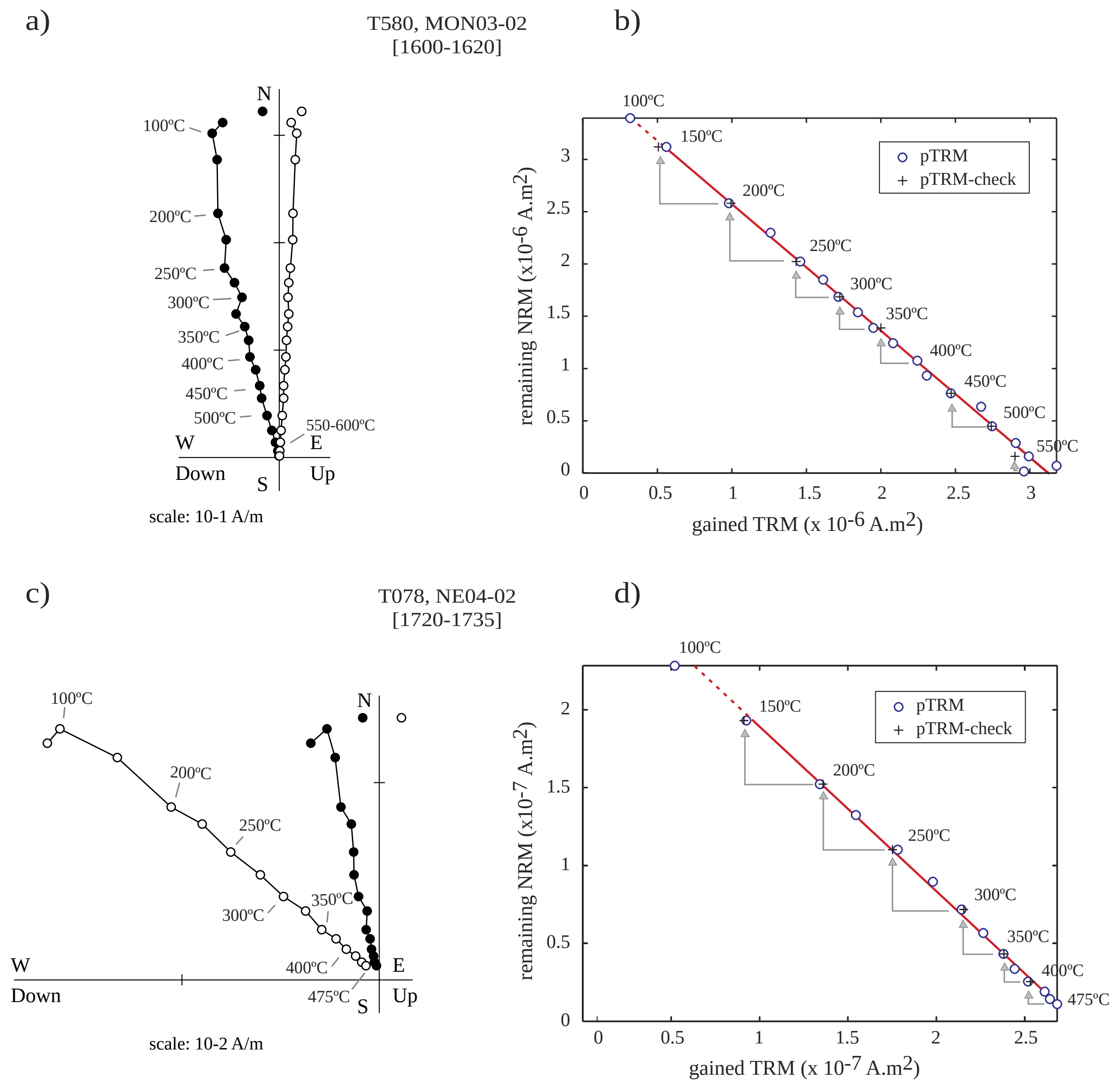


Fig. 1. Thermal demagnetisation curves (Fig. 1a,c) obtained from two specimens and their respective NRM-remaining versus TRM-gained diagrams (Fig. 1b,d). In the demagnetisation diagrams, the open (closed) symbols refer to the inclinations (declinations). During intensity experiments, pTRM-checks were performed every 2 thermal steps (crosses in Fig. 1b,d). The linear segments considered for slope computations are indicated by a continuous line.

ern Europe, has been characterized by large changes in direction, with amplitudes reaching ~50° in declination and ~15–20° in inclination [11,12], while intensity variations show an overall decrease with several peaks in intensity [13,14]. This evolution can be roughly described as a succession of segments of smooth secular variation separated by sharp changes both in direction and intensity during short periods of less than one century. The latter geomagnetic features, called “archeomagnetic jerks” [1], are marked by sporadic intensity maxima together with cusps in geomagnetic field directions (see also [15]). Four such archeomagnetic jerks have been detected so far, at ~800 BC, ~AD 200, 750 and 1400 [1,14].

Here we report new archeointensity results from several groups of faience shards found in Montpellier, Nevers and Dijon (France). These potsherds were dated from the 17th to the 19th century using the combination of historical and archeological constraints [16,17]. For the two sites from Montpellier, archeomagnetic directional dating constraints were also used [16,22]. The paleointensities were acquired using the Thellier and Thellier [18] method revised by Coe [19] and corrected both for anisotropy of thermoremanent magnetization (TRM) (e.g. [20]) and for the cooling rate dependence of TRM acquisition (e.g. [21]) (see [14] for a description of the experimental procedure and of the selection criteria). Seven groups of faience shards provided reliable archeointensity results (Table 1, Fig. 1). The mean intensity values show a sharp increase in intensity between ~AD 1550 and 1600, followed by a decrease until ~AD 1750 when the intensity started to increase again (Fig. 2a,b). The possibility that the intensity maximum at ~AD 1600 is associated with a special feature in directional variation is not yet well established [22], although the rare archeomagnetic data available from France and Great Britain seem to favour the hypothesis of an additional archeomagnetic jerk during the second half of the 16th century. Two other archeomagnetic jerks may be missing from the archeomagnetic record as intensity maxima are observed around 350 BC and ~AD 600 in Bulgaria [23], but presently not yet identified in Western Europe, which in both cases would coincide in time with significant directional variations [1,14].

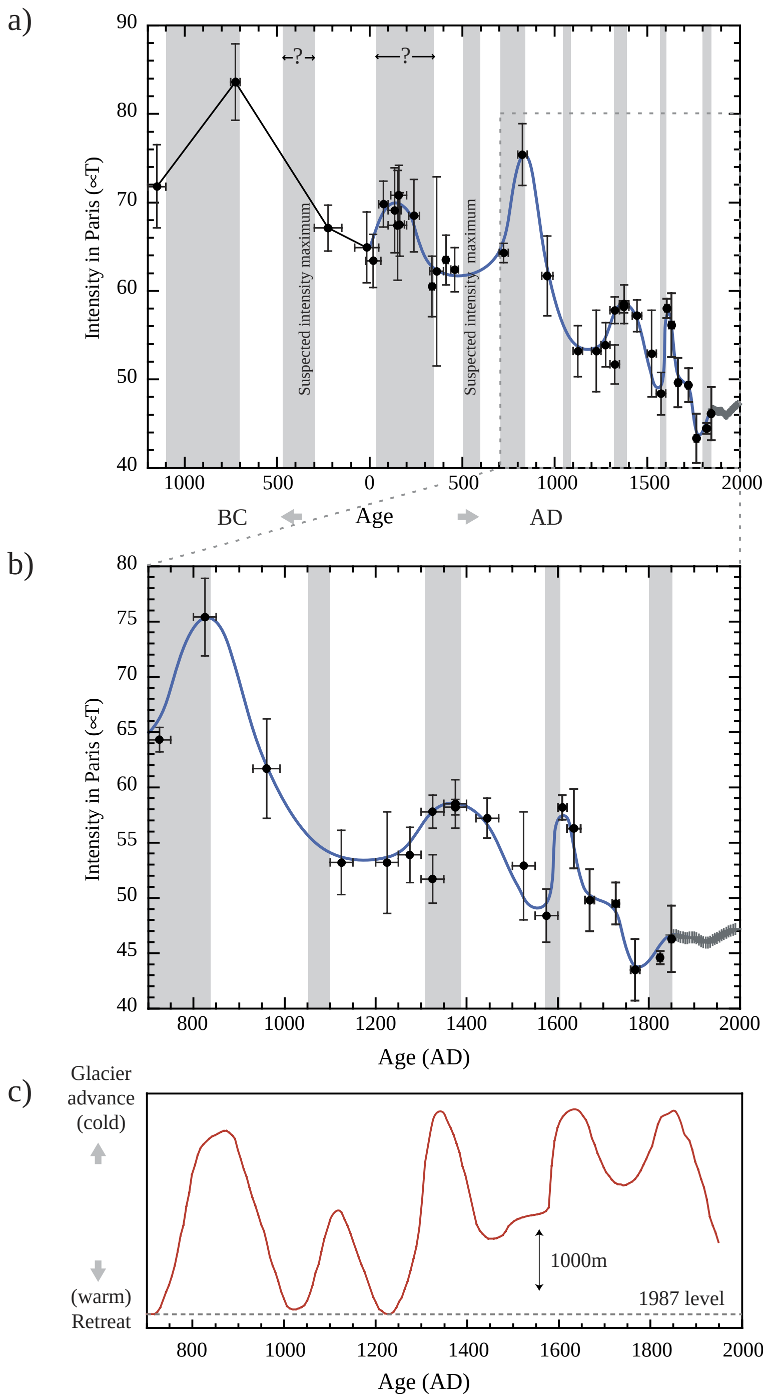
3. Comparison between geomagnetic field behaviour and centennial climate change

Evidence for recent and important climatic variations during the past millennia come from many different sources such as fossils, continental and marine sediments, stalagmites, tree rings, pollen, ice, glacier fluctuations and texts. Among these archives, the successive advances (i.e. colder periods) and retreats (warmer periods) of Alpine glaciers have provided very useful information on overall temperature variations in Western Europe (e.g. [3,24]), which have had a strong impact on human civilisation [4]. Several cold and warm periods have been identified during the past millennium (Fig. 2c; see [4] for a synthesis): a warm period between ~AD 900 and ~1300 corresponding to the Medieval Warm Period, possibly interrupted by a short colder period during the 11th century, a cooling period during the 14th century, the occurrence of a warmer period between AD 1500 and 1560 followed by the beginning of a very cold period between AD 1560 and 1600 continuing during the 17th century, and again a warmer and a cold period between ~AD 1710 and 1750 and ~AD 1810 and 1850, respectively. Note that the well-known Little Ice Age climatic event, which may have started as early as the 14th century (e.g. [4]), is in fact the concatenation of several cold periods interrupted by warmer periods.

Prior to the past millennium, data constraining climatic variations in Western Europe become less precise. However, the Dark Middle Age (second half of the first millennium AD) was overall a cold period marked by the first advance of Alpine glaciers during the 6th century and a second advance during the 8th century which just preceded the beginning of the Medieval Warm Period [24]. Using paleoecological and geological data, Van Geel et al. [25] also documented another severe cold epoch in northwest Europe at the beginning of the first millennium BC up to ~700 BC (called the "Netherlands cooling event" in Bond et al. [26]). Two other cold periods, but less well constrained from Alpine glaciers, occurred during the second half of the first millennium BC and during Imperial Roman times (~first half of the first millennium AD) [24].

When comparing the archeointensity and climatic records described above, there appears to be a very good coincidence in time between the rising part of intensity maxima and the cooling periods summarized above (shaded bands in Fig. 2a,b). The concordance is particularly telling for the past millennium. Only the minor cold period around AD 1050–1100 is presently not associated with an intensity increase: this may be due to the poor resolution of the archeointensity curve during this time interval. A good concordance also exists for the Dark Middle Age and for the beginning of the first millennium BC.

The pre-to post Roman period appears less well resolved: the intensity maximum observed during the second century AD (one of the detected archeomagnetic jerks [1]) and the two possible ones around 350 BC and ~AD 600 could be all associated with a cold period, but this requires confirmation by



the continued acquisition of well-dated archeointensity and climatic data.

4. Discussion

Should the temporal concordance underlined above not be fortuitous, we may propose a connection between the geomagnetic field and climate change over centennial time scales. The apparent relationship between rapid intensity increases and the occurrence of cooling periods, while the subsequent decreases in intensity might correspond to the return toward warmer conditions, suggests that enhanced secular variation of the geomagnetic field may have had a significant influence on the climatic variations observed in Western Europe during the past millennia. The main problem is to identify a plausible mechanism which could efficiently link geomagnetic field and climate. This also raises the question of the origin of archeomagnetic jerks. Do they correspond to periods of rapid dipolar field variations? Could the axial dipole field contribute less to geomagnetic field during these periods? Genevey et al. [27] and Gallet et al. [1] noticed that geomagnetic field intensity variations were largely consistent over a large geographical area, at least from Western and Northern Europe to Central Asia [15], during the past millennia. This suggests that the intensity variation curve is strongly dominated by the lower-degree (dipolar?) geomagnetic terms. Several sedimentary and archeomagnetic records also show strong and sudden departures from axial dipolar directions around the 8th century BC, called the "Sterno-Etrussia" geomagnetic excursion by Raspopov et al. [29] (see also [30]), at the time of our older detected archeomagnetic jerk [1]. The fact that the same magnetic signature is observed for all archeomagnetic jerks detected so far in Western Europe pleads in favour of a common cause. If archeomagnetic jerks are global features, they may correspond to short periods of strong equatorial dipole field moment (i.e. of strongly inclined dipole) that would have been repeatedly directed, at least during the past three millennia, toward the Western Eurasian hemisphere. If not global, they may be caused by a sporadic (high-field) non-dipole structure located in the core below the Western European region.

The axial dipolar nature of the geomagnetic field likely contributes to a persistent global geometry of magnetospheric and ionospheric currents produced by the interactions between solar activity, galactic cosmic ray flux and the geomagnetic field which protects Earth from charged particles. The flux of these particles breaking through the magnetic shield and penetrating the atmosphere may play an important role in the Earth's atmospheric dynamics, such as variations in cloud and aerosol production and cloudiness radiative properties which control the Earth's radiation budget, and consequently on climate (e.g. [9,10,31–33]). A first hypothesis would be that the smaller the geomagnetic dipole moment, the larger the flux of particles penetrating the atmosphere and the cloud production, resulting in cooler conditions. Dergachev et al. [10] have proposed to associate in this way the Netherlands cooling event with a significant decrease in geomagnetic field intensity. However archeomagnetic data fail to reveal an intensity minimum during the first three to four centuries of the first millennium BC; in contrast, this period probably exhibited the largest geomagnetic field intensity of the entire Holocene [27]. Another hypothesis is to assume that the incoming charged particles are deflected toward the poles, where the overall low-humidity level due to cold temperatures limits cloud formation. If archeomagnetic jerks indeed correspond to periods of strongly inclined dipole, then the charged particles would interact with more humid air from lower-latitude environments, leading to significantly larger cloud

Fig. 2. Geomagnetic field intensity variations in Western Europe during the past three millennia determined from archeomagnetic analyses [1,13,14] (Fig. 2a). The data for the first millennium BC come from Syria [27]. The incorporation of new archeointensity data obtained from French faience potsherds (this study) allows to better define the intensity variations between the 17th and 19th centuries (Fig. 2b). Vertical and horizontal error bars correspond to standard deviations of intensity means and age brackets of the dated sites, respectively. The geomagnetic field intensity variations in Paris deduced from geomagnetic field models [28] from 1850 onwards are indicated by small crosses. Climatic variations during the past millennium deduced from retreats and advances of the Alpine glaciers (i.e. from the Grosser Aletsch and Groner glaciers [24]) are shown in Fig. 2c. Cooling periods are indicated in Fig. 2a and b by shaded bands (see text for further explanation; note that we consider for the past millennium the cooling period extents discussed in ref. [4]). Question marks in Fig. 2a indicate that the age and duration of the concerned cooling periods are presently poorly constrained.

production and cooling [10]. Although tentative, this mechanism might be more efficient than the one induced by the variations of the axial dipole moment, which otherwise may contribute to longer-term (millennial-scale) climatic variations [9]; the data from Fig. 2 do not support a simple relationship between geomagnetic field strength (again assuming that the archeointensity record from Western Europe does reflect global, dipolar variations) and centennial climate change. Note that if archeomagnetic jerks are due to sporadic strong non-dipole anomalies, their climatic impact might be more regional.

Additional well-dated archeomagnetic data are clearly needed to substantiate whether most centennial climate variations observed during the past millennia have been driven by the secular variation of the geomagnetic field. It would be particularly fascinating to imagine that the history of human civilisations, which strongly depended on climatic fluctuations, could have been influenced by the geomagnetic field generated in the deep Earth. We therefore think that the following hypotheses merit further consideration and testing:

i) Centennial climatic changes could be triggered by enhanced secular variation, in particular by archeomagnetic jerks. As a consequence, the role of solar forcing in explaining these climatic variations should be reconsidered;
ii) The geomagnetic field could have a smaller axial dipole component during archeomagnetic jerks, which could be responsible for centennial climate change.

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References

[1] Y. Gallet, A. Genevey, V. Courtillot, On the possible occurrence of archeomagnetic jerks in the geomagnetic field over the past three millennia, Earth Planet. Sci. Lett. 214 (2003) 237–242.
[2] H.H. Lamb, The early medieval warm epoch and its sequel, Palaeogeogr. Palaeoclim. Palaeoecol. 1 (1965) 13–37.
[3] J.M. Grove, R. Switsur, Glacial evidence for the medieval warm period, Clim. Change 26 (1994) 143–169.
[4] E. Le Roy Ladurie, Histoire humaine et comparée du climat. Canicules et glaciers XIIIe–XVIIIe siècles, Fayard ed. (2004).
[5] J. Haigh, The impact of solar variability on climate, Science 272 (1996) 981–984.
[6] J. Eddy, The Maunder minimum, Science 192 (1976) 1189–1202.
[7] J.-P. Legrand, M. Le Goff, C. Mazaudier, On the climatic changes and the sunspot activity during the XVIIth century, Ann. Geophys. 8 (1990) 637–644.
[8] V. Courtillot, J.-L. Le Mouël, J. Ducruix, A. Cazenave, Geomagnetic secular variation as a precursor of climatic change, Nature 297 (1982) 386–387.
[9] G. St-Onge, J. Stoner, C. Hillaire-Marcel, Holocene paleomagnetic records from the St. Lawrence Estuary, eastern Canada: centennial- to millennial-scale geomagnetic modulation of cosmogenic isotopes, Earth Planet. Sci. Lett. 209 (2003) 113–130.
[10] V. Dergachev, O. Raspopov, B. van Geel, G. Zaitseva, The 'Sterno-Etrussia' geomagnetic excursion around 2700 BP and changes of solar activity, cosmic rays, and climate, Radiocarbon 46 (2004) 661–681.
[11] I. Bucur, The direction of the terrestrial magnetic field in France, during the last 21 centuries, Phys. Earth Planet. Inter. 87 (1994) 95–109.
[12] Y. Gallet, A. Genevey, M. Le Goff, Three millennia of directional variation of the Earth's magnetic field in Western Europe as revealed by archaeological artefacts, Phys. Earth Planet. Inter. 131 (2002) 81–89.
[13] A. Chauvin, Y. Garcia, P. Lanos, F. Laubenheimer, Palaeointensity of the geomagnetic field recovered on archaeomagnetic sites from France, Phys. Earth Planet. Inter. 120 (2000) 111–136.
[14] A. Genevey, Y. Gallet, Intensity of the geomagnetic field in Western Europe over the past 2000 years: new data from French ancient pottery, J. Geophys. Res. 107 (2002) 2285.
[15] I. Snowball, P. Sandgren, Geomagnetic field intensity changes in Sweden between 9000 and 450 cal BP: extending the record of "archeomagnetic jerks" by means of lake sediments and the pseudo-Thellier technique, Earth Planet. Sci. Lett. 227 (2004) 361–375.

[16] O. Ginouvez, L. Fabre, V. Forest, D. Foy, E. Henry, M. Leenhardt, J. Thiriot, L. Vallauri, J.-L. Vaysettes, Montpellier (34) Tramway: Pôle-d'Echange-Corum: Fenêtre sur le Faubourg-du-Pila-Saint Gély (XIVe–XXe siècles), Faïencerie Favier (XVIIe siècle), DFS de fouille préventive (13–24 décembre 1999/13 mars–30 avril 2000), Association pour les Fouilles Archéologiques Nationales, Laboratoire d'Archéologie Médiévale Méditerranéenne, 2001, 258 pp.

[17] J. Rosen, in La faïence française, du XIIIe au XVII siècle, Doss. Art 70 (2000) (73 pp.).

[18] E. Thellier, O. Thellier, Sur l'intensité du champ magnétique terrestre dans le passé historique et géologique, Ann. Géophys. 15 (1959) 285–376.

[19] R. Coe, The determination of palaeointensities of the Earth's magnetic field with emphasis on mechanisms which could cause non-ideal behavior in Thellier's method, J. Geomagn. Geoelectr. 19 (1967) 157–179.

[20] J. Rogers, J. Fox, M. Aitken, Magnetic anisotropy in ancient pottery, Nature 277 (1979) 644–646.

[21] J. Fox, M. Aitken, Cooling-rate dependence of thermoremanent magnetisation, Nature 283 (1980) 462–463.

[22] M. Le Goff, Y. Gallet, A. Genevey, N. Warmé, On archaeomagnetic secular variation curves and archaeomagnetic dating, Phys. Earth Planet. Inter. 134 (2002) 203–211.

[23] M. Kovacheva, Archaeomagnetic database from Bulgaria, Phys. Earth Planet. Inter. 102 (1997) 145–151.

[24] H. Holzhauser, Fluctuations of the Grosser Aletsch Glacier and the Groner Glacier during the last 3200 years, in: B. Frenzel, G. Boulton, B. Glser, U. Huckriede (Eds.), Glacier fluctuations during the Holocene, Akademie der Wissenschaften und der Literatur, 1997, pp. 35–58.

[25] B. van Geel, J. Buurman, H. Waterbolk, Archaeological and palaeoecological indications of an abrupt climate change in the Netherlands, and evidence for climatological teleconnections around 2650 B.P., J. Quat. Sci. 11 (1996) 451–460.

[26] G. Bond, B. Kromer, J. Beer, R. Muscheler, M. Evans, W. Showers, S. Hoffmann, R. Lotti-Bond, I. Hajdas, G. Bonani, Persistent solar influence on North Atlantic climate during the Holocene, Science 294 (2001) 2130–2136.

[27] A. Genevey, Y. Gallet, J. Margueron, Eight thousand years of geomagnetic field intensity variations in the Eastern Mediterranean, J. Geophys. Res. 108 (2003) 2228.

[28] A. Jackson, A. Jonkers, M. Walker, Four centuries of geomagnetic secular variation from historical record, Philos. Trans. R. Soc. Lond. Ser. A 358 (2000) 957–990.

[29] O. Raspopov, V. Dergachev, E. Goos'kova, Ezekiel's vision: visual evidence of Sterno-Etrussia geomagnetic excursion? EOS 84 (2003) 77.

[30] K. Burakov, I. Nachasova, Anomalous behaviour of the geomagnetic field in the first millennium BC, Geomagnetic field in Quaternary, Postdam, 1990, pp. 135–138.

[31] B. Tinsley, F. Yu, Atmospheric ionization and clouds as link between solar activity and climate, Geophys. Monogr. 141 (2004) 321–339.

[32] H. Svensmar, E. Friss-Christensen, Variation in cosmic ray flux and global cloud coverage —a missing link in solar–climate relationship? J. Atmos. Sol.-Terr. Phys. 59 (1997) 1225–1232.

[33] J.-L. Le Mouël, V. Kossobokov, V. Courtillot, On long-term variations of simple geomagnetic indices and slow changes in magnetospheric currents; the emergence of anthropogenic global warming after 1990? Earth Planet. Sci. Lett. 232 (2005) 273–286.