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Using archaeomagnetism to improve the dating of three sites in Catalonia (NE Spain)

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Summary

Archaeomagnetic dating was performed on four archaeological structures in Catalonia (NE Spain) using magnetic inclination and declination values from three reference curves: the Iberian SVC and two curves computed using the regional SCHA.DIF.3k model and the global SHA.DIF.14k. The results provide new data for discussions regarding the dating of three archaeological sites from three very different periods: Roman, Medieval and Modern. In addition, some considerations were made regarding the usefulness ofthe three reference curves and the corresponding geomagnetic models. The Iberian SVC suggests that a Roman limekiln near Tarragona was last fired during the 1st century BC, but the archaeomagnetic modelssuggest it was last fired during the 1st century AD, i.e. closer to the date of the kiln infillings (2nd–3rdcenturies AD). All three-reference curves date two structures from an archaeological site to the north of Barcelona to the 10th or 11th century AD. These ages match those determined using radiocarbonages. Dating a modern limekiln near Girona with a presumed age of more than 200 years produced aninconsistent age when using the Iberian SVC, but plausible ages in the 17th or 18th centuries AD using the archaeomagnetic models. This suggests that the Iberian SVC has been superseded by the regional SCHA.DIF.3k model and the global SHA.DIF.14k model, both of which exhibit excellent dating capabilities. Older archaeological sites, including prehistoric sites, should be investigated to fully exploit and verifythe potential of the new SHA.DIF.14k archaeomagnetic model.

Keywords

Archaeomagnetic dating, Pottery, Geomagnetic field modelling, Spain

Introduction

Archaeomagnetic dating is an archaeometric technique that uses variations in the Earth's magnetic field (EMF) to estimate theage of materials from an archaeological site that were subjected to high temperatures (baked clays, kiln walls, burnt pits, etc.). Thetechnique works using the same principles and equipment as in palaeomagnetic studies. A characteristic thermomagnetic remanence (usually labelled ChRM) is acquired by materials containing magnetic particles as they cool down below their critical temperature. The direction of the ChRM is the same as the local direction ofthe EMF at the time of cooling and the intensity of the ChRM is proportional to that of the EMF. Archaeomagnetic dating is achieved by comparing the mean archaeomagnetic data from asampled structure with a reference curve that describes the knownlocal changes in the EMF. The reference curves are computed using compilations of archaeomagnetic data [1,2]. These curves were first developed as secular variation curves (SVCs) defined at a reference location (usually a major city or central city within the SVC area) with a limited area where they could be used for dating purposes (usually about 1000 km around the reference location). Dating associated with experimental data requires these data to be relocated to the reference location. These relocations bring about errors that increase as the relocation distance increases [3]. Regional archaeomagnetic models were also developed as an alternative. They have a wider scope than the SVCs (e.g. [4,5]) and allow personalized SVCs to be computed at the coordinates of the site to be dated. Finally, global models were developed that formally cover the Earth's entire surface, but their non-uniform distribution of archaeomagneticdata makes the magnetic field predictions unreliable in many areas.

Europe is one of the areas where archaeomagnetic SVC and geomagnetic models are quite well developed. Updates of SVCs areregularly published (Schnepp and Lanos, 2005) [6–8] and their timeranges are extended [9–11]. France was one of the first countriesto build its own SVC [12], which has also been updated regularly[13–16]. Until Gómez-Paccard et al. [17] published the first SVCfor the Iberian Peninsula based on 143 archaeomagnetic directionswith ages ranging from 775 BC to AD 1959, archaeomagnetic datingin Spain could only be attempted using the French SVC [18]. Sincethen, various archaeomagnetic studies have produced new data[19,20] and the existing SVC has been used as a dating tool [21–24]. Additionally, for areas like Europe that have a relatively high density of archaeomagnetic data, it has been possible to develop aregional model based on spherical cap harmonic analysis [25]. Thismodel has also been successfully applied to determine the age ofarchaeological sites in Spain (e.g. [23,24,26]). Recently, a new globalgeomagnetic field model has been published based on archaeomagnetic and volcanic data [27]. This model describes the geomagneticfield variations over the last 14,000 years and was built using theupdated GEOMAGIA50v2 database [1], which contained new datafrom Spain. Other existing global models based partially on lakesediment records result in a very smooth SVC that is of limited usefor archaeomagnetic dating.

The present paper uses the main available instruments to build reference curves for archaeomagnetic dating in Spain. Thethree have been used to infer the age of the last heating of fourarchaeological structures from three sites in Catalonia (Fig. 1). Thesampled structures have archaeological/historical context and arefrom more or less fixed periods (Roman, Medieval and Modern). Archaeomagnetic dating should help to further pinpoint their date.

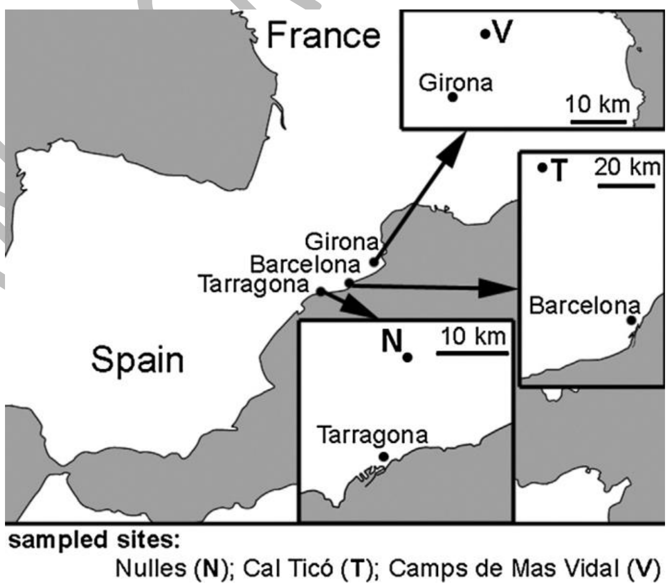


Figure 1. Location of the sampled archaeological sites in Catalonia.

2. The archaeological background of the sites and sampledstructures

2.1. Forn Teuler (Nulles, Tarragona)

Forn Teuler is a Roman villa discovered in 2010 in Nulles (15 kmnorth of Tarragona). The villa lies around 1.5 km to the southwestof the modern village. Significant amounts of potsherds are scattered across an area covering around 2 ha and reused sherds canbe found in the modern dry stonewalls that delimit the cultivated cultivatedfields. In situ walls from the villa have been used to build a smallcountry house, including 3-metre-high opus caementicium walls. The abundant potsherds and tiles indicate a period stretching fromeither the 2nd or 1st century BC until the 4th century AD.

In 2013, archaeological prospection works were performed inthe area and a cylindrical structure from a limekiln was reported. Situated under an unpaved lane, the kiln was recently broken whenthe lane was dug up and made lower (Fig. 2a). The kiln (labelled Nin Fig. 2) has an estimated diameter of around 3 metres. The kilnhas not been excavated, but during the construction work that wasdone on the lane, 35 pottery fragments were recovered from insidethe kiln and some were used to partially reconstruct its corresponding vessels. Among the reconstructed vessels were three Hayes 200 forms of African red slipware (Fig. 3), indicating that it comesfrom some time between the mid-2nd century AD and the mid–3rdcentury AD [28], when the kiln had already been abandoned.

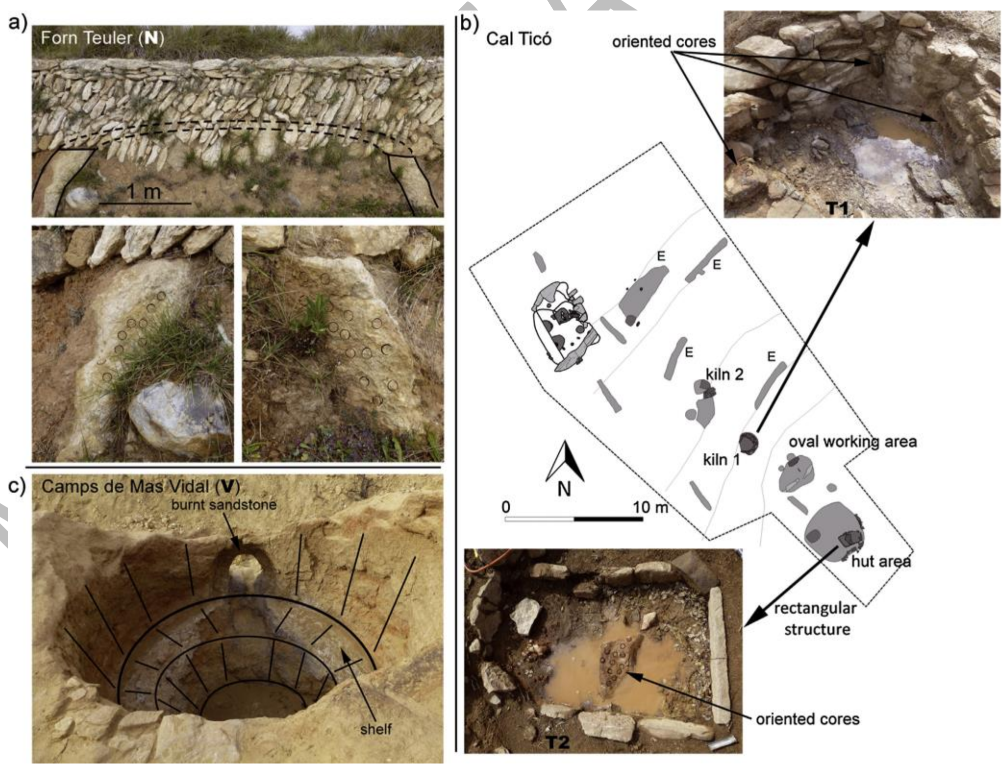


Figure 2. The sampled structures: a: Forn Teuler (Nulles). View of the kiln below a dry stone wall (top) and detailed view of the drilled walls (bottom); b: plan of the excavatedarea at Cal Ticó, with the sampled structures (kiln 1 and rectangular area) identified on it and depicted in photographs; c: photograph of the sampled limekiln at Camps deMas Vidal (Vilademuls). Sampling focused on the shelf and the sandstone lintel.

Figure 3. Hayes 200 forms retrieved from the limekiln interior at Forn Teuler (Nulles), dated between the mid–2nd century and the mid–3rd century AD.

The in situ visible parts of the kiln walls below a dry stonewallwere intensively drilled (Fig. 2a, bottom). Nine oriented sampleswere retrieved from one side of the kiln and seventeen from theother, creating a total of twenty-six oriented samples on whicharchaeodirection analysis could be performed.

2.2. Cal Ticó (Barcelona)

Located in the municipality of Castellnou de Bages (~40 km north-west of Barcelona), this archaeological site is located on a hilldelimited by a meander in a small stream (Argenc¸ ola). The nameof the site refers to a country house that lies 390 metres south-west of the hill. Because of the presence of potsherds, prospectionworks were performed in 2006, then excavation works were performed in a small rectangular section (250 m2) in 2008 and 2009. The excavations revealed the presence of a small pottery workshop,as indicated by highly eroded structures in which only the bottomparts were preserved. The structures identified were two circularkilns (both with a diameter of around one metre) (see Fig. 2b), anoval working area and several clay extraction points (labelled E inFig. 2b), [29]. Starting in 2011, the excavated section was gradually increased to 575 m2. One end of the excavated section, wherethe oval working area lies, was excavated further to the south-east,which revealed indications of a hut, including a small rectangularstructure originally interpreted to be a hearth, but which is perhapsan oxidized kiln floor (T2 in Fig. 2c).

Folch and Gibert [29] reported the radiocarbon dating resultson the older infillings of the oval working area, indicating an agebetween Cal AD 880 and 1020 at a 95% confidence level (2σ). Thisage is based on a single measurement on charred material (charcoal). The age would presumably also be the terminus post quemage of the associated dwelling space. Cantoni Gómez et al. [30],meanwhile, published an updated report of the excavation works,including additional radiocarbon dating of one of the kilns (labelled1 in Folch and Gibert [29] and in Fig. 2b), which indicated a laterage with three time intervals: Cal AD 1050–1090, 1120–1140 and1150–1220 (2). The age is also based on a single measurementobtained from charred material. The different age and the repetition of similar structures at slightly different topographical levelssuggest the existence of different archaeological phases.

Two structures were sampled for archaeomagnetic purposes(Fig. 2b). Firstly, some burnt stones that formed the walls of oneof the kilns (kiln 1 and T1 in Fig. 2b) were drilled and yielded tenoriented samples. Secondly, a flat stone from the small rectangularstructure within the hut area was also sampled (T2 in Fig. 2). Thelatter exhibited an oxidized reddish surface due to the high temperature and it was firmly attached to the ground and surroundedby oxidized clay. Twelve oriented samples were obtained from thesmall rectangular structure (see Fig. 2b). It is unclear whether thisarea was really a hearth or it was part of a kiln. For simplicity, and to help the reader to distinguish it from the other sampled structure,it is referred to as a hearth throughout this paper.

2.3. Camps de Mas Vidal (Girona)

From 2010 to 2013, when roadworks took place in the municipality of Vilademuls (~20 km north of Girona), three archaeologicalsites [31] were identified and excavated, one of which was Campsde Mas Vidal. The site lies close to the track of the Roman ViaAugusta and two concentrations of silos were found from theRoman period. Only the bottom parts of these structures were preserved, and the potsherds from their infillings indicated an age fromthe 2nd century BC. An isolated limekiln was found at a different part of the samesite, close to the Mas Vidal country house that gives its name to thesite itself. The kiln was dug into the ground, taking advantage of thenatural gradient of the land. The side opening was visible and wassituated at the same height as an internal shelf that supported thechalk blocks (Fig. 2c). The preserved interior of the kiln (labelled Vin Fig. 2) had a depth of more than 4 metres and the structure continued above the cut ground as stone blocks of its walls were foundamong the infilling material. No pottery or any other datable artefact was recovered from the kiln. However, the kiln, typologically,could be medieval or, more likely, modern, whereas the nearbycountry house, perhaps built because of the production of lime inthe kiln, is little more than 200 years old [32]. The entire perimeter of the limekiln was sampled. Most of thedrilling was on the hard lime waste and slag that covered the shelf,but some samples were also obtained from the burnt sandstone thatforms the lintel of the opening side (Fig. 2c). In total, twenty-eight holes were drilled to obtain oriented samples.

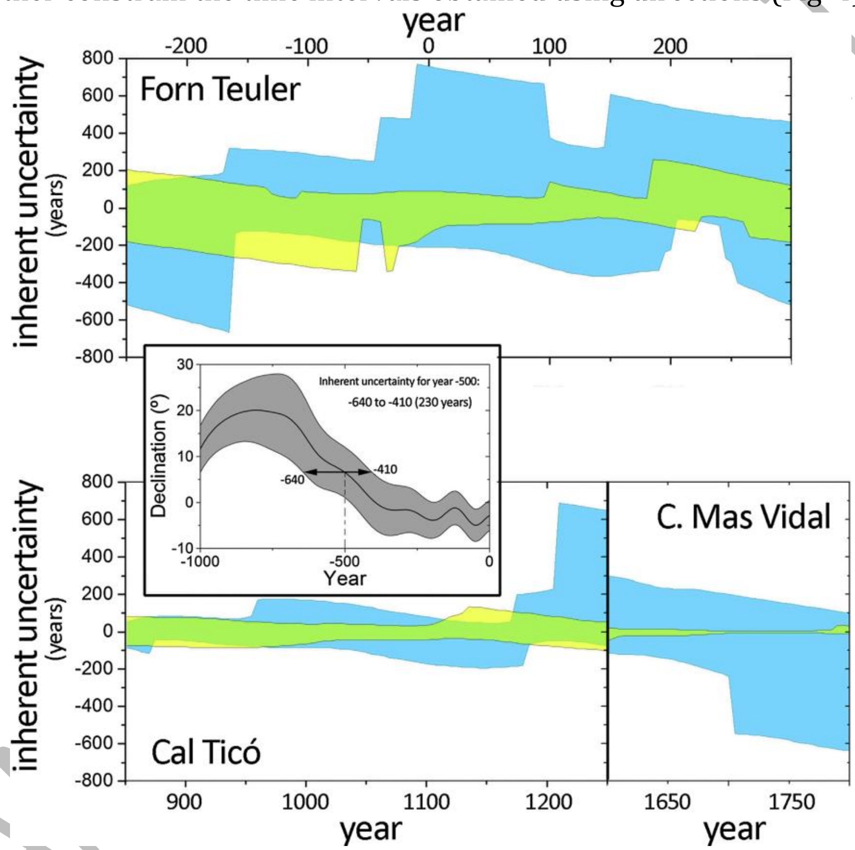
3 Experimental measurements and results

3.1. Sampling and experimental methods

There are basically two different types of archaeomagnetic datathan can be retrieved from heated structures and used to assignages to them: the archaeomagnetic direction and intensity. Thedirection is usually indicated by the declination (deviation of thecompass from the geographical north) and the inclination (deviation from the horizontal) angles. Typical in situ features that canrecord the archaeomagnetic direction are kiln walls, hearths andburned floors and pits, usually made of baked clay or stone. Thearchaeomagnetic intensity is the strength of the field and can beretrieved by comparing the strength of the magnetization carriedby the analysed feature with that gained in a known field in the laboratory. The intensity can also be determined in displaced objects(typically potsherds and collapsed kilns).

Although the most accurate way to determine age is by combining both the direction and the intensity, we decided to use only thearchaeomagnetic direction for two reasons:

- the conditions required (in terms of particle size and magneticmineralogy) to retrieve reliable intensity estimates are muchharder to find;
- the inherent dating uncertainties of the archaeomagnetic methods indicate, within the area and presumed time intervals understudy, that intensity would not further constrain the time intervals obtained using directions (Fig. 4).



- **Figure 4. Inherent age uncertainty using directional data (yellow) and using intensity (blue) with the SCHA.DIF.3k model for three time intervals around the presumedarchaeological ages of the three structures studied. It is apparent that intensity can rarely constrain ages determined using only declination and inclination. The situation issimilar using the global SHA.DIF.14k model.**

Inherent uncertainties were calculated taking into account theconfidence limits given in the analysed geomagnetic field models (SCHA.DIF.3k and SHA.DIF.14k). For every year in the model, we measured the period of time with the same values as the thecorresponding component of the EMF (declination, inclination andintensity) within the confidence limits (see the central inset inFig. 4). The inherently high uncertainty of intensity-based dating isbasically due to the high uncertainty of the intensity values givenby the models and the low rates of change of those intensity valuesover time.

A portable electrical drill with a water-cooled diamond bit wasused to sample the archaeological structures following the standardpalaeomagnetic procedure. The in situ azimuth and dip of the coreswere measured using a compass coupled to a core-orienting fixturewith a clinometer. The obtained cores were cut to obtain standardpalaeomagnetic specimens (~2.5 cm diameter and length); most ofthe samples produced a single specimen, a few produced two, andoccasionally, spare bits of the cores were also obtained.

Archaeodirections were obtained for each specimen followinga standard laboratory protocol that comprised stepwise thermaldemagnetization and measurement of the remanent magnetization after each temperature step. The equipment used was a 755RSRM superconducting rock magnetometer (2G Enterprises) and anMMTD-80 oven (magnetic measurements) available at the Paleomagnetism Laboratory (CCiTUB-CSIC) of the Institute of EarthSciences Jaume Almera (Barcelona, Spain). Ten steps, from 150◦C to570◦C, were applied. For each specimen, the characteristic remanent magnetization (ChRM) direction was calculated by principalcomponent analyses [33] on Zijderveld diagrams using the Plotcoresoftware developed at the University of Liverpool. The corresponding maximum angular deviation (MAD) was also calculated. Specimens with MAD values higher than five were disregarded tocompute the mean direction of each sampled structure [5]. Meandirections were computed following Fisher [34] statistics; concentration parameter k and confidence factor $\alpha 95$ were also computed.

3.2. Archaeodirection results

Representative Zijderveld diagrams of specimens from eachsampled structure are shown in Fig. 5 along with the Lambert equal-area projections of all the individual ChRM directions thatcontribute to the computations of the mean archaeomagneticdirection of each structure. All twenty-six samples from Nulles produced a single specimen. Only three specimens were rejected, onedue to a MAD > 5◦and two due to broken cores that were wronglyreplaced in their original position to retrieve their orientation.

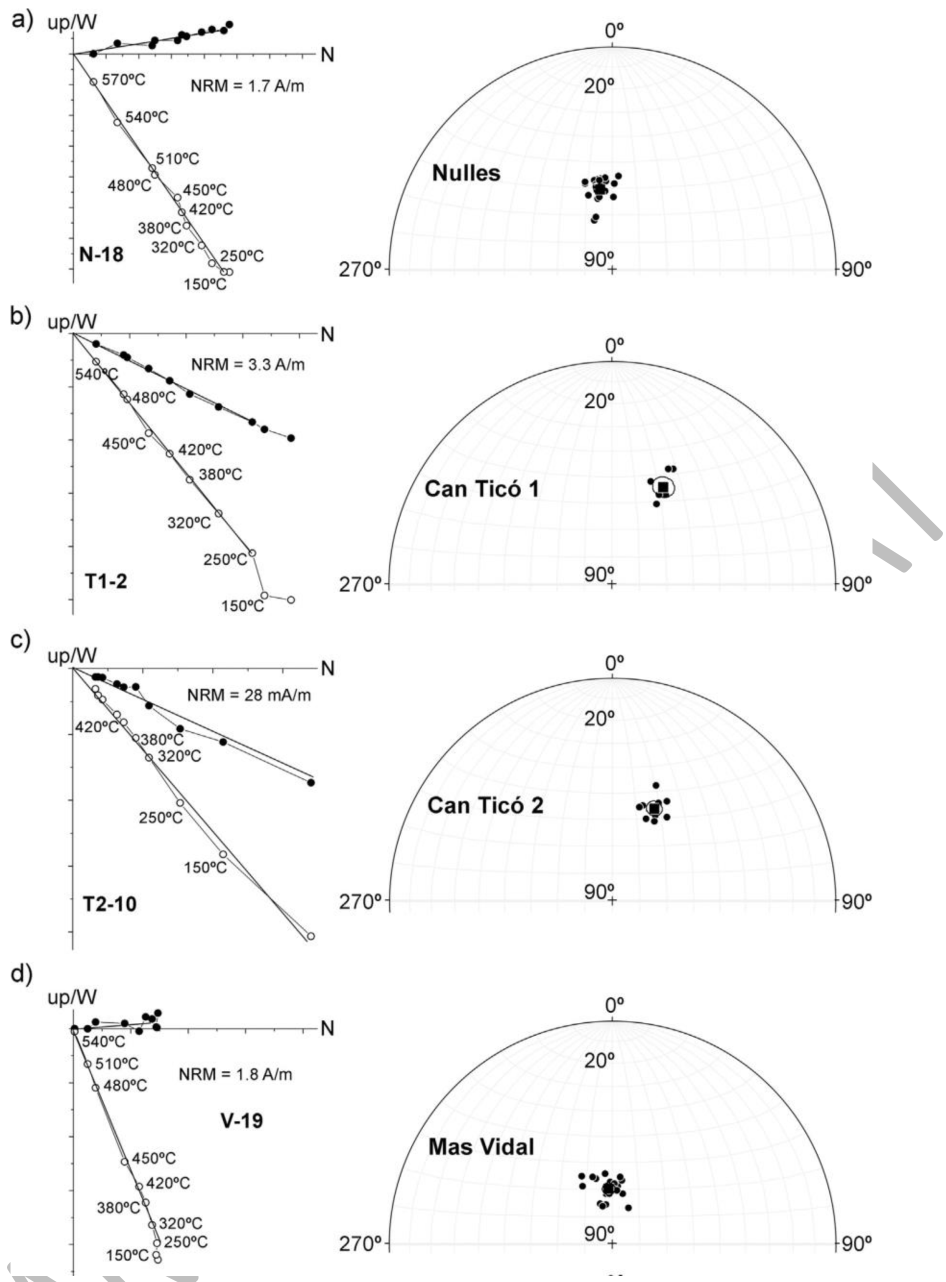


Figure 5. A typical Zijderveld plot (left) for a specimen from each sampled structure depicting the orthogonal projection of the remanent magnetization vectors duringprogressive demagnetization, with lines indicating the ChRM directions. A stereographic projection of the archaeomagnetic directions (right) calculated for each samplefrom (a) Forn Teuler (Nulles), (b) Cal Ticó 1, kiln, (c) Cal Ticó 2, rectangular area, and (d) Camps de Mas Vidal (Vilademuls). The squares are the mean directions obtained withconcentric α95error circles.

For the ten samples from kiln 1 in Can Ticó, two were rejectedas outliers (due to an anomalously high declination value of around40◦) and one sample produced two specimens, with the directionfor that sample computed as the mean value between the twospecimens. The mean archaeodirection was computed using theremaining eight accepted values.

For the twelve samples from the hearth, sampled at the samesite, only one sample was rejected, again due to a very high declination value. Two samples produced two specimens instead of one;in those cases, only one specimen was used to compute the corresponding direction data, because in both cases one of the specimensexhibited a MAD value higher than 5◦.

Finally, for the twenty-eight samples collected in Mas Vidal, sixwere rejected, of which four due to MAD > 5◦and two due to brokencores wrongly replaced in the original position.

A Fisher's test using fishqq.py from the PmagPy software package [35] showed that all data ensembles used to compute meanarchaeodirections are Fisher distributed, so Fisher statistics canbe used to calculate the corresponding mean direction. Table 1 summarizes the archaeomagnetic direction results obtained, single specimen results (declination and inclination) can be consultedin the Supplementary Table.

Structure	Lat. (◦N)	Long. (◦E)	Label	n/N	nu	D (◦)	I (◦)	k	α95 (◦)
Kiln at Nulles (N)	41.24	1.28	N	26/26	23	351.3	59.9	235.9	2.0
Kiln at Can Ticó (T1)	41.86	1.79	T1	11/10	9	27.9	49.1	208.1	3.8
Hearth at Can Ticó (T2)	41.86	1.79	T2	14/12	11	24.4	52.3	276.9	2.8
Kiln at Mas Vidal (V)	42.08	2.89	V	28/28	22	356.4	69.7	196.4	2.2

Taula 1. Coordinates of the sampled sites.

(Lat., latitude and Long., longitude), sample labels and number of collected samples; n: number of standard specimens obtained from the N collected samples; nu: numberof specimens used to compute the archaeomagnetic direction; D: archaeomagnetic declination; I: archaeomagnetic inclination; k and α95: precision parameter and 95% confidence limit of the characteristic remanent magnetization, from Fisher statistics.

4. Archaeomagnetic dating

The mean directions obtained were compared with three available reference curves:

•the SVC for the Iberian Peninsula [17], which describes the evolution of the geomagnetic field in Madrid during the period between815 BC to AD 1900 (Fig. 6a);

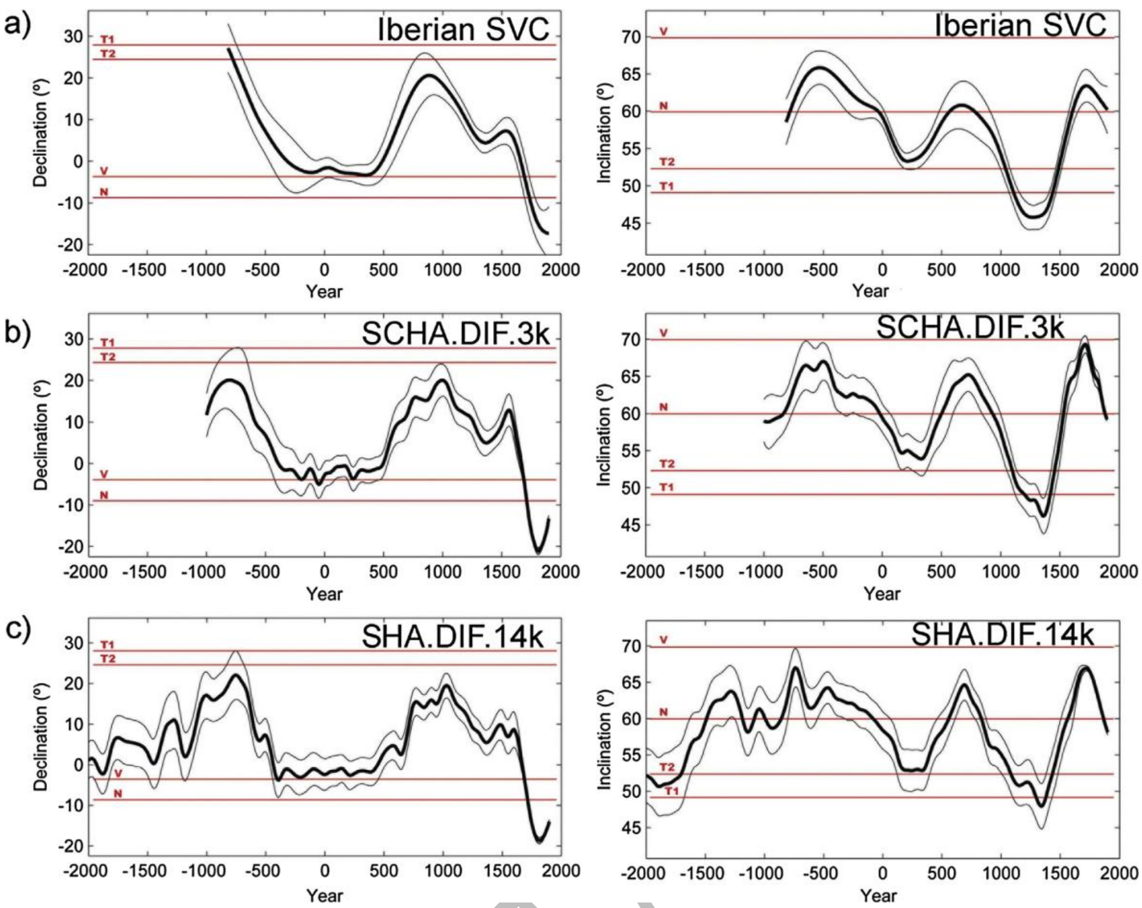


Figure 6. Evolution of the geomagnetic field declination (left) and inclination (right) values, with uncertainties indicated as predicted by (a) the Iberian SVC (defined in Madrid),(b) the regional SCHA.DIF.3k model, and (c) the global SHA.DIF. 14k model (both models computed at the Nulles coordinates). The experimental archaeodirectional valuesobtained for the four sampled structures are also shown.

•a curve computed using the regional archaeomagnetic modelSCHA.DIF.3k [25], which allows the computation of referencecurves for the period between 1000 BC and AD 1900 in Europeand neighbouring areas (Fig. 6b);

•a curve computed using the global archaeomagnetic modelSHA.DIF.14k [27], which extends the computation of thegeomagnetic field back to 12,000 BC (although the model is notwell constrained for periods before 6000 BC) for any location inthe world.

Comparison was performed using a Matlab dating tool developed by Pavón-Carrasco et al. [36] for model SHA.DIF.14k. Only thetime interval from 2000 BC to AD 1900 was used (Fig. 6c).

5. Discussion

In general, comparison with the reference curves produces similar time intervals (Fig. 7 and Table 2) that roughly agree with thepresumed archaeological age or with available radiocarbon data.However, the Iberian SVC fails to obtain a plausible age for the limekiln at Camps de Mas Vidal (Fig. 7d). This is due to the higherlevel of smoothing for this curve than for the curves obtained usingthe archaeomagnetic models. In particular, the unsuccessful datingis possibly due to the fact that the Iberian SVC does not define asharp inclination peak that occurs around the presumed age of thelimekiln. Additionally, SVCs are defined at a reference point (in thiscase Madrid) and their use involves the relocation of the archaeomagnetic data assuming a purely dipolar field, which, as indicatedby Casas and Incoronato [3], is a possible source of error.

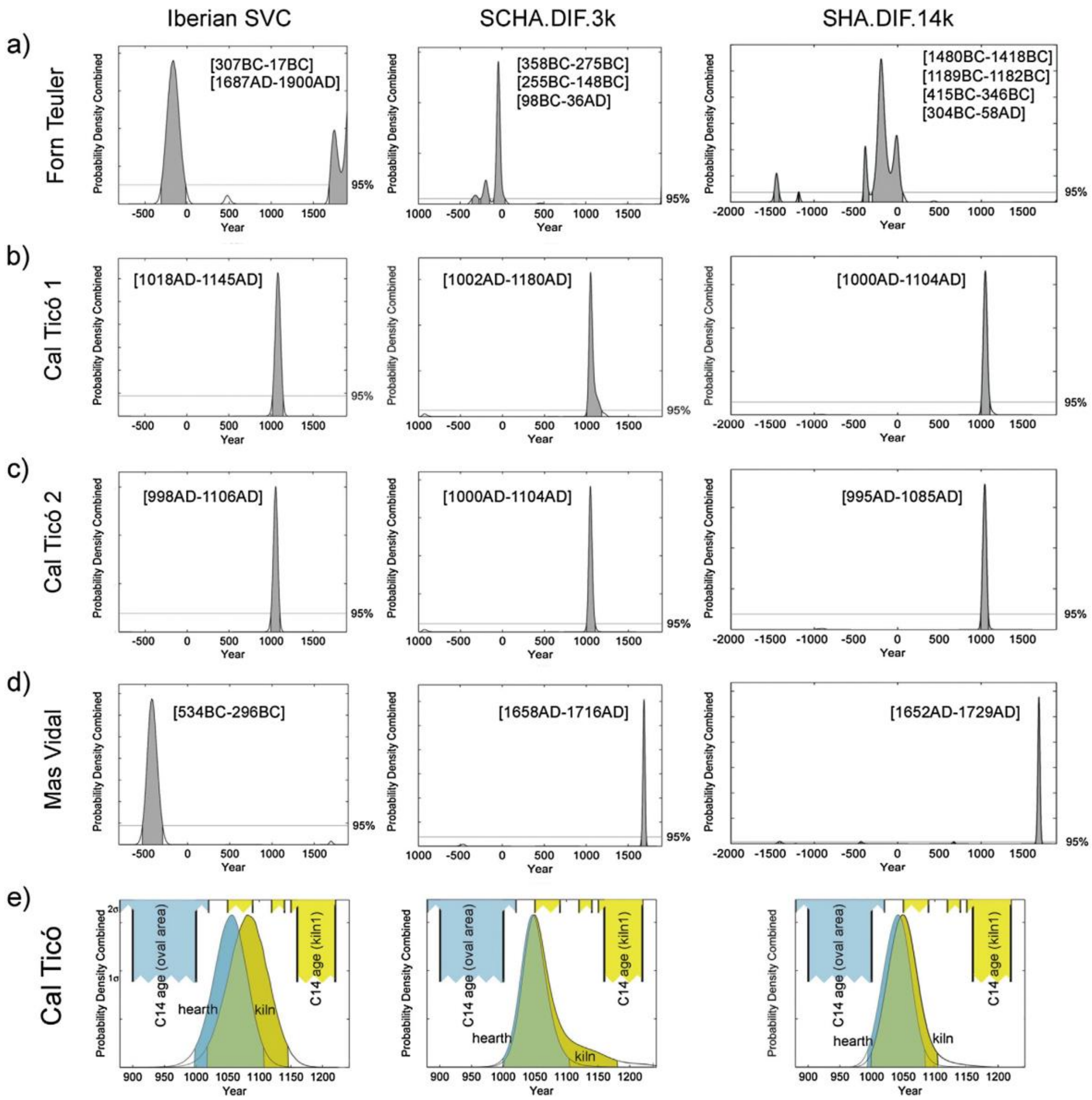


Figure 7. Evolution of the geomagnetic field declination (left) and inclination (right) values, with uncertainties indicated as predicted by (a) the Iberian SVC (defined in Madrid),(b) the regional SCHA.DIF.3k model, and (c) the global SHA.DIF.14k model (both models computed at the Nulles coordinates). The experimental archaeodirectional valuesobtained for the four sampled structures are also shown.

Structure	Reference curve	Main solutions at 95% confidence level (in bold letters the solution	Archaeological/historical context/radiocarbon dates

		that matches the context)	
N	Iberian SVC SCHA.DIF.3k SHA.DIF.11k	BC 307–17; AD 1687–1900 BC 358–275; BC 255–148; BC 98–AD 36 BC 1480–1418; BC 1189–1182; BC 415–346; BC 304–AD 58	≤ 2nd–3rd centuries AD
T1	Iberian SVC SCHA.DIF.3k SHA.DIF.11k	AD 1018–1145 AD 1002–1180 AD 1000–1104	2-σ Cal AD 1050–1090; AD 1120–1140; AD 1150–1220
T2	Iberian SVC SCHA.DIF.3k SHA.DIF.11k	AD 998–1106 AD 1000–1104 AD 995–1085	2-σ Cal AD 880–1020
V	Iberian SVC SCHA.DIF.3k SHA.DIF.11k	BC 534–296 AD 1658–1716 AD 1652–1729	≤18th century AD

Taula 2. Archaeomagnetic ages comparing the archaeomagnetic directions from the sampled structures with the three tested reference curves. The ages of the structures inferred by archaeological/historical context or determined by radiocarbon dating are also indicated.

For the kiln sampled at Nulles (Forn Teuler), the dating solutions consist of several rather wide time intervals. The availablecontextual data (Hayes 200 forms within the infillings of the kiln)indicate that in the 2nd–3rd centuries AD the kiln had already beenabandoned. Both the regional SCHA.DIF.3k and the SHA.DIF.14ksolutions indicate, at the 95% confidence level, that the kiln may have been used for the last time in the mid-1st century AD (seeFig. 7a). In contrast, the Iberian SVC suggests that the last use wasquite a bit earlier, in the 1st century BC. It may seem unlikely thatmore than 100 years passed between the last use of the kiln andits filling, but it is not impossible. Furthermore, the dating solution obtained using the Iberian SVC also includes a time intervalthat points to a modern remagnetization of the kiln. This remagnetization is quite unlikely as the kiln was not exposed until veryrecently. The fact that the other two tested dating instruments donot produce this modern age interval suggests that this is an artefactproduced by the Iberian SVC.

The comparison between the experimental results from the twostructures sampled at Cal Ticó (the kiln and the hearth) and the reference curves produced probability distributions always consistingof a single, very narrow time interval (Fig. 7b and c). It is worth mentioning that the two structures produced basically the same timeintervals. This concurrence is particularly noticeable when usingthe archaeomagnetic models, rather than the Iberian SVC, to datethe structures. The available radiocarbon ages have been comparedwith the archaeomagnetic results (Fig. 7e). For the 2σ radiocarbon ages (which are directly comparable with the 95% confidencelevel archaeomagnetic ages), the radiocarbon and archaeomagneticages of the kiln are quite similar. The archaeomagnetic age is statistically slightly older than the radiocarbon one, but that meansthe results are even more consistent, given that the archaeomagnetic age refers to the last heating of the kiln but the radiocarbonage refers to the infillings. In contrast, the ages of the working ovalarea and the hearth do not overlap, which is not surprising, as thelink between the oval area and the hearth is suggested only bytheir proximity to each other. Additionally another possibility couldalso explain the discrepancy; the charcoal used for dating the ovalarea could belong to an older tree that was cut off much earlier incomparison to its burning.

Regarding the Camps de Mas Vidal site, apart from the discordant results obtained using the Iberian SVC, the other referencecurves produce very similar and very narrow time intervals (Fig. 7d). This is what one would expect for modern structures,because the error bars of the archaeomagnetic models becomedrastically smaller as the period approaches the present time. Archaeomagnetic dating is therefore most precise for modernstructures, for which dating can be done to the nearest year [26]. Unfortunately, no written documents have been found showingthe construction date of Mas Vidal country house. Besides, the linkbetween the country house and the limekiln is merely a hypothesis, albeit one that is now supported by archaeomagnetic dating,since the presumed age of the country house (> 200 years) and thearchaeomagnetic age of the limekiln (mid 17th–early 18th century)are very similar.

6. Conclusions

The ages of the last heating of four structures from three archaeological sites in Catalonia have been constrained. The kiln sampledat Nulles (Forn Teuler) was used during the mid–1st century AD. Both structures sampled at Cal Ticó are archaeomagnetically indistinguishable, with both appearing to have been used during the11th century AD. The Camps de Mas Vidal limekiln was probablyused during the second half of the 17th century or the early 18thcentury AD.

The comparison between the contextual archaeological data, theradiocarbon ages and the archaeomagnetic ages, as well as the dating discussion, indicate that archaeomagnetic direction dating isgenerally reliable. However, the Iberian SVC does not describe rapidchanges in the Earth's magnetic field and seems to be too smoothto obtain precise archaeomagnetic ages. This has been shown inthe case of the limekiln at Camps de Mas Vidal, where the SVC caneven fail to produce a reasonable archaeomagnetic age. The Iberian SVC was the first archaeomagnetic-dating instrument specificallydesigned for sites in Spain and Portugal, but it has been supersededby the regional SCHA.DIF.3k model. For the time and area investigated, the new SHA.DIF.14k global model appears to be basicallyidentical to the regional model.

One of the advantages of archaeomagnetic dating is that thistechnique dates a precise moment, i.e. the last thermal event thatoccurred on the material being measured. This thermal event is usually the last firing of the kiln, as late incidental burning of exposedkilns is quite unlikely. Decontextualization issues are therefore rarewhen this technique is used. This has to be taken into account whenputting together all the data from an archaeological site with different overlapping parts and chronological phases, such as the Cal Ticó site.

The results suggest that archaeomagnetic dating can already be performed on structures of unknown age (due to a lack ofcontextual data) in northeastern Spain for a very wide time window (at least the last 2000 years). Previous publications for modelSCHA.DIF.3k [24] reached the same conclusion and the same is truefor the new SHA.DIF.14k model. The precision of dating decreasesfor older periods, as shown for the limekiln at Forn Teuler (Nulles).For Roman sites, archaeomagnetic dating is expected to provideresults that are accurate to the nearest century.

Thanks to the abundance of Roman sites in the Mediterraneanarea, many Roman sites hold typologically datable artefacts that canprovide new data to improve the archaeomagnetic models. This isan ongoing, collective task.

To fully exploit and explore the possibilities of the new SHA.DIF.14k archaeomagnetic model, future studies should look atolder archaeological sites, including prehistoric sites.

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Appendix A.

Supplementary dataSupplementary data associated with this article can be found,in the online version, at http://www.sciencedirect.com and https://doi.org/10.1016/j.culher.2017.11.004.

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