Improving dating of three sites from Catalonia (NE Spain) via Archaeomagnetism.

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ABSTRACT

Archaeomagnetic dating for four archaeological structures has been attempted 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 dating results have been used to add to the dating discussion for the three archaeological sites, which are from three very different periods: Roman, Medieval and modern.

Besides, some considerations on the usefulness of the three reference curves and the corresponding geomagnetic models have been done. The last firing of a Roman limekiln near Tarragona occurred during the 1st century BC according to the Iberian SVC and during the 1st century AD according to the archaeomagnetic models, i. e. closer to the chronology of the kiln infillings (2nd-3rd centuries AD). All three reference curves date successfully two structures from an archaeological site north to Barcelona within the 10th-11th century AD. The obtained ages match with the determined radiocarbon ages. Dating a modern limekiln near Girona, with a presumed age of more than 200 years produced an inconsistent age when using the Iberian SVC but plausible ages within the 17th-18th centuries AD using the archaeomagnetic models. This suggests that the Iberian SVC has been superseded by the regional SCHA.DIF.3k and the global SHA.DIF.14k model which exhibit excellent dating capability. Older archaeological sites, including prehistoric sites, should be investigated to fully exploit and check the possibilities of the new SHA.DIF.14k archaeomagnetic model.

Key words: Archaeomagnetic dating, Pottery, Geomagnetic field modelling, Spain

1 INTRODUCTION

Archaeomagnetic dating is an archaeometric technique that uses the Earth's magnetic field variations to estimate the age of materials from an archaeological site that were subjected to high temperatures (baked clays, kiln walls, burn pits, etc.). In this technique the same principles and equipment as in palaeomagnetic studies are used. A natural thermomagnetic remanence (NRM) is adquired by materials containing magnetic particles as these cool down below their critical temperature. The direction of the NRM coincides with the local direction of the Earth's magnetic field prevailing at the time of cooling. Archaeomagnetic dating is achieved by comparing the measured mean archaeomagnetic data from a sampled structure with a reference curve that describes the known local evolution of the Earth's magnetic field. These reference curves were firstly developed as regional secular variation curves (SVC) defined at a reference location (usually a main or a central city); later, regional models were also developed at a country level in such a way that through the model a SVC can be computed for any location within the region; finally global models were also developed, these formally cover all the Earth's surface although their non-uniform distribution of archaeomagnetic data results in a variable reliability of their magnetic field predictions.

Europe is one of the areas were archaeomagnetic SVC and geomagnetic models are quite well developed. France was one of the first countries to build its own SVC (Thellier, 1981) and this has been regularly updated (Bucur, 1994; Gallet et al. 2002; Genevey et al., 2009 and 2013). Archaeomagnetic dating in Spain could only be attempted using the French SVC (Parés et al., 1992) before the publication by Gómez-Paccard et al. (2006) of the first SVC for the Iberian Peninsula which was based on 143 archaeomagnetic directions with ages ranging from 775 BC to AD 1959. Since then, various archaeomagnetic studies have produced new data (e. g. Catanzariti et al., 2012; Gómez-Paccard et al., 2013) and the existing SVC has been used as a dating tool (e. g. Catanzariti et al., 2007; Gómez-Paccard and Beamud, 2008; Prevosti et al., 2013; Casas et al., 2014a). Additionally, for a relatively high-density area of archaeomagnetic data such as Europe, it has been possible to develop a regional model based on spherical cap harmonic analysis (Pavón-Carrasco et al., 2009). This model have also been successfully applied to determine the age of archaeological sites in Spain (e.g. Prevosti et al., 2013; Casas et al., 2014a; Casas et al., 2014b). Recently, a new global geomagnetic field model based on archaeomagnetic and volcanic data has been published (Pavón-Carrasco et al., 2014). This model describes the geomagnetic field variations for the last 14000 years and was built using the updated GEOMAGIA50v2 database (Korhonen et al., 2008) containing new data from Spain. Other existing global models based partially on lake sediments records result in strongly smoothed SVC with a limited use for archaeomagnetic dating.

In the present paper we intend to use the main available assets to build reference curves to undertake archaeomagnetic dating in Spain (this assets are the Iberian SVC, the regional SCHA.DIF.3k and the global SHA.DIF.14k models). These have been used to infer the age of the last heating in four archaeological structures from three sites in Catalonia (NE Spain), see Fig. 1. The sampled structures have archaeological/historical context and are associated to a more or less constrained ages (Roman, Medieval and modern). The archaeomagnetic dating should constraint further their age.

2 ARCHAEOLOGICAL BACKGROUND OF THE SITES AND SAMPLED STRUCTURES

2.1 Forn Teuler (Nulles, Tarragona)

Forn Teuler is a Roman villa at Nulles (15 km north from Tarragona). The villa lies around 1.5 km to the south-west of the modern village and its existence was not been reported previously because it was discovered in 2010. Significant amounts of potsherds are scattered on a surface of about 2 ha and reused sherds can be found in modern dry stone walls that delimit outcrops. In situ walls of the villa have been integrated into a small country house, including 3-meter high *opus caementicium* walls. The abundant potsherds and tiles indicate a chronology spreading from the 2nd-1st centuries BC up to the 4th century AD.

In 2013 archaeological prospection works were performed in the area and a cylindrical structure corresponding to a limekiln was reported. The structure is cut by an unpaved lane whose level was decreased recently (Fig. 2a). The estimated diameter of the kiln is around 3 meters. The kiln has not been excavated but 35 visible pottery fragments from its interior were recovered and some of them were used to reconstruct partially their corresponding vessels. Among the reconstructed vessels there were three Hayes 200 forms of African red slip ware (Fig. 3) which indicate a chronology between mid-2nd century AD and mid-3rd century AD (Hayes, 1972) when the kiln was already abandoned.

The in-situ visible parts of the kiln walls below a dry stone wall were intensively drilled (Fig. 2a, bottom). From one side of the kiln nine oriented samples were retrieved and seventeen from the other, a total amount of twenty-six oriented samples were retrieved to perform archaeodirection analyses.

2.2 Cal Ticó (Barcelona)

This archaeological site is located on a hill delimited by a meander of the small Argençola stream, within the municipality of Castellnou de Bages (~40 km north-west from Barcelona). The name of the site refers to a country house that lies 390 meters south-west to the hill. The presence of potsherds in the area motivated prospection works performed in 2006 and excavation works in a small rectangular area (250 m^2) during 2008-2009. These revealed the presence of a small pottery workshop as indicated by structures very eroded which only preserve their bottom parts, excavated in the natural ground. The identified structures comprise two circular kilns (both with a diameter of around one meter), an oval working area and several clay extraction points (Folch and Gibert, 2011). Since 2011 the excavated area was progressively extended up to 575 m^2. One end of the rectangular area, where lies the oval working area, was excavated further to the south-east and hints of a hut were revealed, including a small rectangular area originally interpreted as a hearth though perhaps it is an oxidized kiln floor.

Folch and Gibert (2011) reported the radiocarbon dating results on the older infillings of the oval working area, indicating an age between Cal AD 880 and 1020 at a 95% confidence level (2σ). This age would presumably be also the *terminus post quem* age of the associated dwelling space. On the other hand, Cantoni et al. (2012) published an updated report of the excavation works including an additional radiocarbon dating of one of the kilns (labelled 1 in Folch and Gibert (2011)) indicating a later age, comprising three time intervals: Cal AD 1050-1090, 1120-1140 and 1150-1220 (2σ). This, as well as the repetition of similar structures at slightly different topographical levels suggests the existence of different archaeological phases.

Two structures were sampled for archaeomagnetic purposes (Fig. 2b). On one hand, some burnt stones that formed the walls of the mentioned kiln were drilled and yielded and we get ten oriented samples. On the other hand, a flat stone from the small rectangular area was also sampled. This stone exhibited an oxidized reddish surface due to the high temperature and it was firmly attached to the ground and surrounded by oxidized clay. Twelve oriented samples were obtained from the small rectangular area (see Fig. 2b). It is unclear whether this area was really a hearth or part of a kiln. For simplicity and to help the reader to distinguish it from the other sampled structure we will refer to it as a hearth throughout the text.

2.3 Camps de Mas Vidal (Girona)

From 2010 to 2013, coinciding with roadworks in the municipality of Vilademuls (~20 km north from Girona) three archaeological sites (Aguelo et al., 2014) were identified and excavated, among them 'Camps de Mas Vidal'. The site lies close to the track of the Roman Via Augusta and connected with this period two concentrations of silos were found. Only the inferior part of these structures was preserved, and the potsherds from their infillings indicated an age within the 2nd century BC.

In the same site, but in a different area, an isolated limekiln was found. This limekiln is very close to the country house which gives to the site its name (Mas Vidal). The kiln was cut in the ground taking advantage of the natural gradient of the land; its lateral opening was visible and it was situated at the same level that an internal shelf that supported the chalk blocks (Fig. 2c). The preserved interior of the kiln has a depth higher than 4 meters and the structure continued above the cut ground as stone blocks of its walls were found among the infilling material. No pottery or any other datable artifact was recovered from the kiln though typologically the kiln could be medieval or more likely modern. On the other hand the nearby country house, which construction was possibly connected with the production of lime in the kiln, is more than 200 years old (Camps, 2013).

The limekiln was sampled all around its perimeter; the hard lime waste and slag that covered the shelf was particularly drilled but some samples were also obtained from the burnt sandstone that forms the lintel of the opening side. A total number of twenty-eight holes were drilled to produce oriented samples.

3 EXPERIMENTAL MEASUREMENTS AND RESULTS

3.1 Sampling and experimental methods

There exist basically two different archaeomagnetic data than can be retrieved from heated structures and used to assign ages to them; the archaeomagnetic direction and the intensity. The first requires *in situ* structures whereas the latter can also be applied to displaced objects. At first sight it would seem obvious that the use of both direction and intensity should even be better than the use of only one of them. However, we have discarded the use of intensity. On one hand, there are harder requirements to retrieve reliable intensity estimates (in terms of particle size and magnetic mineralogy). On the other hand the inherent dating uncertainties of the archaeomagnetic methods indicates, within the area and presumed time intervals under study, that intensity would not constraint further the time intervals obtained using directions (Fig. 4). This is basically due to the high uncertainty of the intensity values given by the dating curves and the low rates of change of these intensity values over time.

A portable electrical drill with a water-cooled diamond bit was used to sample the archaeological structures following the standard palaeomagnetic procedure. The *in situ* azimuth and dip of the cores were measured using a compass coupled to a core orienting fixture with clinometer. The obtained cores were cut to get standard palaeomagnetic specimens (~2.5 cm diameter and length); some samples produced a single specimen, others produced two, and occasionally spare bits of the cores were also obtained.

The magnetic mineralogy of the sampled materials was investigated using magnetic susceptibility equipment from Bartington, available at the Geology Department in the Universitat Autònoma, in Barcelona (UAB): a MS3 magnetic susceptibility meter and two kinds of sensors (MS2B dual frequency and MS2W water jacketed). The susceptibility of all the cores was measured at two different frequencies (0.465 and 4.65 kHz) before and after application of the archaeodirection measuring protocol. The available spare bits of cores were crushed to fill the ceramic crucible that fits into the MS2WF furnace to obtain thermomagnetic susceptibility curves; the maximum heating temperature was 540ºC.

Archaeodirections were obtained for each specimen following a standard laboratory protocol that comprised stepwise thermal demagnetization and measurement of the remnant magnetization after each temperature step. The equipment used was a 755R SRM superconducting rock magnetometer (2G Enterprises) and a MMTD-80 oven (Magnetic Measurements) available at the Paleomagnetism Laboratory (CCiTUB-CSIC) of the Institute of Earth Sciences Jaume Almera (Barcelona, Spain). Ten steps, from 150ºC to 570ºC, were applied. For each specimen the characteristic remnant magnetization (ChRM) direction was calculated by principal component analyses (Kirschvink, 1980) on Zijderveld diagrams using the Plotcore software developed at the University of Liverpool. The corresponding maximum angular deviation (MAD) was also calculated. Specimens with MAD values higher than five were disregarded to compute the mean direction of each sampled structure (Hervé et al., 2011). Mean directions were calculated following Fisher (1953) statistics; concentration parameter k and confidence factor α95 were also computed.

3.2 Magnetic susceptibility results

All the samples from Forn Teuler (Nulles, Tarragona) are very similar, whitish and compact with a mass susceptibility (χ_{LF}) between 2 and $10 \cdot 10^{-6}$ m^3/kg. Their values of frequency dependent susceptibility (χ_{FD}) are around 8% and rarely exceed 10%. This would indicate the presence of a significant amount of superparamagnetic (SP) grains (Dearing et al., 1996). After the measurement of the archaeomagnetic directions, the susceptibility of the samples decreases slightly and the values of χ_{FD} become more erratic. This can be interpreted as an enhancement of antiferromagnetic compensation of magnetic moments and the creation of new extremely fine SP grains. Thermomagnetic curves also support the presence of an antiferromagnetic phase as susceptibility increases with the temperature within the range 40ºC to 240ºC.

All the samples from Cal Ticó (Barcelona) are made of local reddish (rubefacted) sandstone, samples from the kiln exhibited χ_{LF} values from 2 to $9 \cdot 10^{-6}$ m^3/kg, whereas samples from the hearth showed much lower χ_{LF} values, around $5 \cdot 10^{-8}$ m^3/kg (except one bearing a rust crust with a χ_{LF} value of $4 \cdot 10^{-6}$ m^3/kg). χ_{FD} is around 4% for samples from the kiln and even lower for samples from the hearth. After having heated repeatedly the samples to retrieve their archaeomagnetic directions, the susceptibility of the samples from the kiln decreases slightly and remains unchanged for samples from the hearth. This would imply that in both cases the susceptibility signal is dominated by coarse-grain multidomain (MD) ferromagnetic or, more likely, ferrimagnetic minerals though their presence is very diluted within the sandstone.

There are three types of samples from Camps de Mas Vidal (Girona), slag, sandstone and baked clay. Slag and sandstone samples show low susceptibility values ($\sim 2 \cdot 10^{-7}$ m^3/kg), whereas samples of baked clay exhibit higher values ($\sim 7 \cdot 10^{-6}$ m^3/kg). χ_{FD} are below 4% for all kinds of samples indicating again that the susceptibility signal is dominated by coarse-grain MD particles.

There is a good reversibility of the thermomagnetic curves for the samples from the three sites, the cooling curves showing only a slight decrease for samples from Forn Teuler. Despite the different magnetic phases and domain state that could be deduced from the susceptibility values, the distribution of the Koenigsberger ratios (Q_{NRM}) for all the samples from the three sites, except those from the sampled hearth in Cal Ticó, showed Q_{NRM} values above 1 (Fig. 5) indicating stable remnant magnetizations not influenced by the current field. In contrast, all samples from the hearth (but one) show Q_{NRM} values below 1 and therefore they could be dominated by an induced magnetization due to the present geomagnetic field; this has to be taken into account to analyze the corresponding archaeodirection results.

3.3 Archaeodirection results

Representative Zijderveld diagrams of specimens from each sampled structure are shown in Fig. 6 along with the Lambert equal-area projections of all the individual ChRM directions that contribute to the computations of the mean archaeomagnetic direction of each structure. All twenty-six samples from Nulles produced a single specimen and only three were rejected, one due to a MAD>5º and two due to broken cores that were wrongly replaced in their original position to retrieve their orientation.

From the ten samples from kiln 1 in Can Ticó, two outliers were rejected (with an anomalously high declination value, around 40º), only one sample produced two specimens and the corresponding direction datum was computed as the mean value between both measurements before computing the mean archaeodirection using the eight accepted values. From the twelve samples from the hearth, sampled in the same site, only one sample was rejected again due to a very high declination value. Two samples produced two specimens instead of one; in this case, only one was used to compute the corresponding direction data because for both samples one of the specimens exhibited a MAD value higher than 5º. Finally, from the twenty-eight samples collected in Mas Vidal, six were rejected, four due to MAD>5º, and two due to broken cores wrongly replaced in the original position.

A Fisher's test using fishqq.py from the PmagPy software package (Tauxe, 2010) proved that all data ensembles used to compute mean archaeodirections are Fisher distributed and therefore Fisher statistics can be used to calculate the corresponding mean direction. Table 1 summarizes the obtained archaeomagnetic directional results.

4 ARCHAEOMAGNETIC DATING

The obtained mean directions were compared with three available reference curves: i) the SVC for the Iberian Peninsula (Gómez-Paccard et al., 2006) that describes the evolution of the geomagnetic field at Madrid during the period of time between 815 BC to 1900 AD (Fig. 7a). ii) a curve computed using the regional archaeomagnetic model SCHA.DIF.3k (Pavón-Carrasco et al., 2009) that allows the computation of reference curves for the interval between 1000 BC and 1900 AD in Europe and neighboring areas (Fig. 7b). And iii) a curve computed using the global archaeomagnetic model SHA.DIF.14k (Pavón-Carrasco et al., 2014) that extends the computation of the geomagnetic field back to 12000 BC (although the model is not well constrained before 6000 BC) and to any location on the Earth. Comparison was performed using a Matlab dating tool developed by Pavón-Carrasco et al., (2011), for model SHA.DIF.14k only the time interval 2000 BC to 1900 AD was used (Fig. 7c).

5 DISCUSSION

In general, comparison with the reference curves produces similar time intervals that roughly agree with the presumed archaeological age or with available radiocarbon data. However, the Iberian SVC fails to get a plausible age for the limekiln at Camps de Mas Vidal. This is due to the higher level of smoothing for this curve compared with those produced by the curves obtained using the archaeomagnetic models. In particular, the unsuccessful dating is possibly due to the fact that the Iberian SVC does not define a sharp inclination peak that occurs around the presumed age of the limekiln. Additionally, SVC are defined at a reference point (in this case Madrid) and their use involves the relocation of the archaeomagnetic data assuming a purely dipolar field which is, as indicated by Casas and Incoronato (2007) a possible source of error.

For the kiln sampled at Nulles (Forn Teuler) the dating solutions consist of several rather wide time intervals. The available contextual data (Hayes 200 forms within the the infillings of the kiln) indicates that in the 2nd-3rd centuries AD the kiln was already abandoned. Both the regional SCHA.DIF.3k and the SHA.DIF.14k solutions indicate at a 95% confidence level that the kiln could have been used for the last time in the mid-1st century AD (see Fig. 8a). In contrast, the Iberian SVC places the last use quite earlier, in the 1st century BC. It does not seem very reasonable to admit that much more than 100 years passed after the last use of the kiln and its filling but it is not impossible. Besides that, the dating solution obtained using the Iberian SVC also includes a time interval that points to a modern use (or remagnetization) of the kiln. This remagnetization is quite unlikely as the kiln was not exposed until very recently. The fact that the other two tested dating assets do not produce this modern age interval points to think that this is an artifact produced by the Iberian SVC.

The comparison between the experimental results from the two structures sampled at Cal Ticó (the kiln and the hearth) and the reference curves produced probability distributions always consisting of a single and very narrow time interval. It is worth to mention that the two structures produced basically the same time intervals. This concurrence is particularly noticeable using the archaeomagnetic models to date the structures instead of the Iberian SVC. Moreover, Koenigsberger ratios (Q_{NRM}) from the hearth suggested that the remanence from these samples could be influenced by the present values of the geomagnetic field. Consistently, both mean declination and inclination values from the hearth are slightly closer to the present field values (Fig. 7), and paradoxically the slight difference in the mean direction provokes that the dating solution for the hearth is always a time interval that begins slightly earlier than that of the kiln. The available radiocarbon ages have been compared with the archaeomagnetic results (Fig 8e). Considering the 2-σ radiocarbon ages (which directly compare to the 95% confidence level archaeomagnetic ages) the agreement between the radiocarbon and archaeomagnetic ages of the kiln is quite good. The archaeomagnetic age of the kiln appears to be just statistically a bit older than the radiocarbon one. This fact makes the results fit even better if we consider that the archaeomagnetic age dates the last heating of the kiln and the radiocarbon age dates its infillings. In contrast, the age of the working oval area and the hearth do not overlap. This poorer agreement is not surprising as the link between the oval area and the hearth is only suggested by their proximity and also, because the Q_{NRM} values from the hearth samples suggest that their magnetic remanence could have been perturbed by the current geomagnetic field.

Coming back to the Camps de Mas Vidal site, besides the discordant results obtained using the Iberian SVC, the other reference curves produce very similar and very narrow time intervals. This is what one should expect for modern structures because the uncertainty bars of the archaeomagnetic models decrease drastically when they approach the present time. For modern structures, the precision of archaeomagnetic dating is at its highest point and the dating discussion can go to the yearly scale (Casas et al., 2014b). Unfortunately, no written documentation on the construction date of Mas Vidal country house has been found. Besides that, the link between the country house and the limekiln is merely a hypothesis. In any case the hypothesis is now supported by archaeomagnetic dating as the presumed age of the country house (>200 years) and the archaeomagnetic age of the limekiln (mid 17th-early 18th century) show a good agreement.

6 CONCLUSIONS

The ages of last heating of four structures from three archaeological sites from Catalonia (NE Spain) have been constrained. The kiln sampled at Nulles (Forn Teuler) was used during the mid-1st century AD. Both structures sampled at Cal Ticó are almost concurrent and were used during the 11th century AD. The limekiln from Camps de Mas Vidal was used during the second half of the 17th century or early 18th century AD.

The comparison between the contextual archaeological data, radiocarbon ages and the obtained archaeomagnetic ages, as well as the dating discussion, indicate that in general archaeomagnetic direction dating is reliable. However, the Iberian SVC does not describe rapid changes of the Earth's magnetic field and could be too smooth to obtain precise archaeomagnetic ages. This has been shown in the case of the limekiln at Camps de Mas Vidal where the SVC can even fail to produce a reasonable archaeomagnetic age. The Iberian SVC was the first archaeomagnetic dating asset specifically designed for application on sites from Spain and Portugal, but it has been superseded by the regional SCHA.DIF.3k model. For the time span and area investigated, the new SHA.DIF.14k global model appears to be basically identical to the regional model.

One of the advantages of archaeomagnetic dating is that this technique dates a very well defined moment, i.e. the last thermal event that occurred on the measured material. This thermal event in the case of undisturbed kilns corresponds to the last firing. Therefore, decontextualization issues can only hardly arise using this technique. This has to be taken into account when it comes to putting together all the data from an archaeological site with different overlapped parts and chronological phases. The 'Cal Ticó' site can be a good example of site with such a complexity.

The results corroborate that archaeomagnetic dating of structures of unknown age (due to the lack of contextual data) can already be successfully undertaken in north-eastern Spain in a very wide time window. This was already pointed out in previous publications for model SCHA.DIF.3k (e.g. Casas et al., 2014a) and it also applies to the new SHA.DIF.14k model. The precision of dating decrease as we go back in time as it has been shown for the limekiln at Forn Teuler (Nulles). The expected precision of archaeomagnetic dating for Roman sites is around the century. Fortunately, in the

Mediterranean area, there are many Roman sites bearing typologically datable artifacts that can be used to progressively increase the available data to improve the archaeomagnetic models; this is an ongoing collective task. Besides that, in future work, older archaeological sites, including prehistoric sites, should be investigated to fully exploit and check the possibilities of the new SHA.DIF.14k archaeomagnetic model.

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Figure Captions

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

Fig. 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 excavated area at Cal Ticó, the sampled structures (kiln 1 and rectangular area) are identified on it and depicted in photographs; (c) photograph of the sampled limekiln at Camps de Mas Vidal (Vilademuls). Sampling focused on the shelf and the sandstone lintel.

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

Fig. 4. Inherent age uncertainty of SCHA.DIF.3K model for three time intervals around the presumed archaeological ages of the three studied structures. In yellow the inherent uncertainty using directional data and in blue that using intensity. It is apparent that intensity could hardly constrain ages determined using only declination and inclination. A similar situation is found using the global SHA.DIF.14k model.

Fig. 5. Intensity of natural remanent magnetization (NRM) versus the induced magnetization in the current geomagnetic field (calculated from bulk susceptibility). Black lines indicate constant Koenigsberger ratios (Q_{NRM}).

Fig. 6. To the left, a representative Zijderveld plot for a specimen from each sampled structure depicting the orthogonal projection of the remnant magnetization vectors during progressive demagnetization; lines indicate the ChRM directions. To the right, stereographic projection of the archaeomagnetic directions calculated for each sample from (a) Forn Teuler (Nulles), (b) Cal Ticó 1, kiln, (c) Cal Ticó 2, rectangular area (d) Camps de Mas Vidal (Vilademuls); the squares are the obtained mean directions with concentric α_{95} error circles.

Fig. 7. Evolution of the geomagnetic field declination (left) and inclination (right) values with indication of the uncertainties as predicted by (a) the Iberian SVC (defined at 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 values obtained for the four sampled structures are also shown.

Fig. 8. Probability-of-age density functions obtained with the Matlab tool from Pavón-Carrasco et al. (2011) resulting from comparison between the archaeodirection values obtained for (a) Forn Teuler (Nulles), (b) Cal Ticó 1, kiln, (c) Cal Ticó 2, rectangular area (d) Camps de Mas Vidal (Vilademuls) and the three tested dating assets (Iberian SVC, and models SCHA.DIF.3k and SHA.DIF.14k). In (e) the distributions obtained at Cal Ticó are depicted in more detail and compared with the radiocarbon ages (1σ and 2σ) for the oval area and the kiln.