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Archaeomagnetic dating of a limestone kiln at Nijmegen (The Netherlands)

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Abstract

A kiln used for the burning of limestone was found in the town centre of Nijmegen (The Netherlands) and was sampled for archaeomagnetic dating purposes, since at the time of excavation archaeological dating materials were still absent.

Samples taken from the kiln wall generally yield consistent characteristic remanent magnetizations. The mean direction is compared with the archaeomagnetic calibration curve for Britain. The result shows that the kiln is of Roman age rather than belonging to the Middle Ages. Combined with the few archaeological data found later, an age in the 4th century AD is most probable.

Introduction

During extensive excavations in the town centre of Nijmegen (The Netherlands), a kiln was found which was used for the burning of limestone. Detailed investigations of the structure showed that it most probably consisted of two phases which reflects two different periods of lime production (Kisters, in prep.).

The kiln structure of the younger phase is dish-shaped, with a diameter of nearly 4 metres. This structure is mainly built up of baked loam and is situated directly on top of the horse-shoe-shaped older kiln. A draught channel belonging to the younger phase was found, filled with remains comprising lime and charcoal.

One of the major questions arising during an early stage of the investigation of the dish-shaped kiln was its function. The presence of several blocks of unaltered limestone together with patches of amorphous lime at the inside of the kiln did suggest that limestone was burned in this Nijmegen area, where otherwise natural occurrences of limestone are absent. Additional evidence for the burning of limestone was presented by the röntgen diffractometry of some samples of the lime patches which contained occasional traces of portlandite (Wevers, 1988 pers. comm.).

The horse-shoe-shaped structure belonging to the oldest phase is built up of rectangular blocks of volcanic tuff, with some occasional tiles of Roman age (ca. 12 BC–400 AD) in between. The outer diameter ranges from 2.85 to 3.00 metres. The tuff is recognized as a trachytic lithic crystal tuff and certainly is imported from the Eifel region in West Germany (Kars 1982); the tiles are assumed to be of local origin (Kisters, in prep.). Kilns of a closely related type have been described, for instance, for the Iversheim site in West Germany (Sölter 1970) and Weekley in Great Britain (Jackson et al. 1973), whereas the process of lime production and the use of lime is described by Dix (1982).

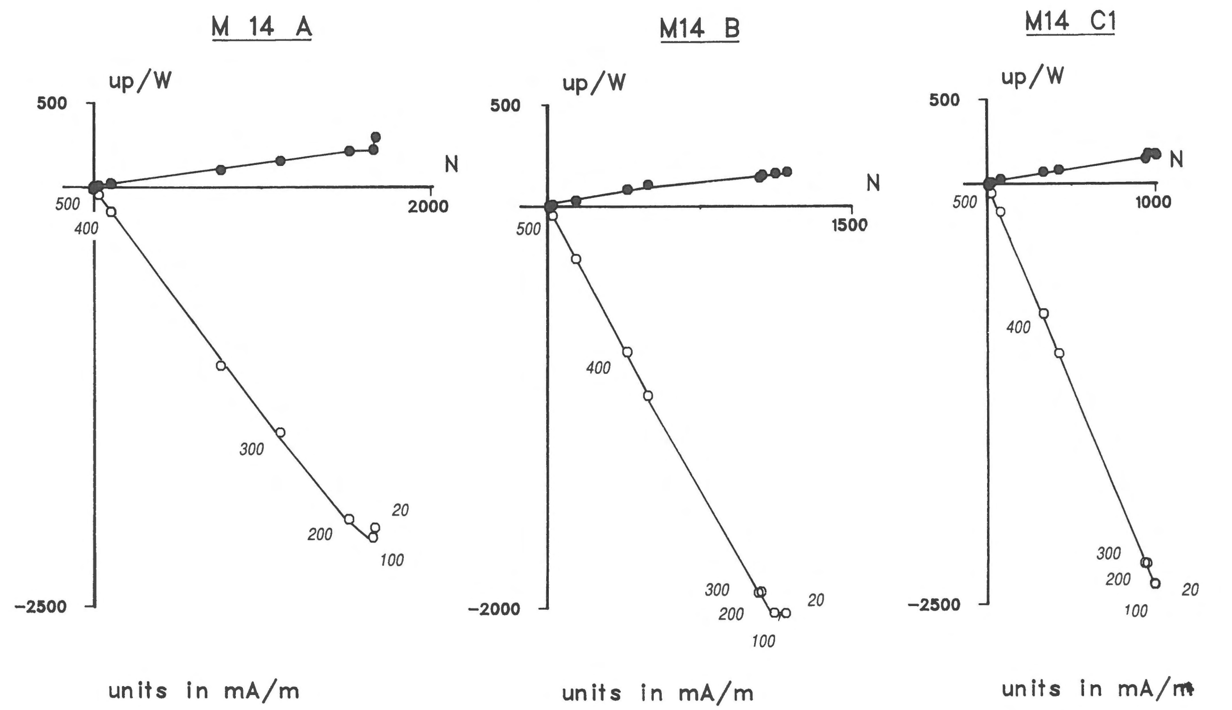

Fig. 1. Orthogonal projection diagrams (Zijderveld 1967) of thermal demagnetizations of three specimens from a tuff block, showing very consistent directions within the block. Closed (open) symbols denote projection on the horizontal (vertical) plane; numbers refer to temperature steps.

An important question were the dates of the two successive phases of the kiln. Were they of Roman age or should one or even both phases be dated to the Middle Ages? And, if they were Roman, should they then be dated to the late Roman period or earlier? When the younger phase of the kiln was excavated and archaeological dating materials at that moment were still nearly absent, it was decided to sample the altered wall of the remaining, older structure for archeomagnetic dating purposes.

From the lower part of the older kiln, only a tile of baked clay was sampled (L-series, sample 15), in the middle part samples were taken from a vertically placed clay tile as well as from 4 tuff blocks (M-series) and in the upper part from another 4 tuff blocks (H-series). One block from the upper part (H 17) was noticed to be clearly displaced with respect to the other blocks. Orientated cores were either drilled in situ using a water-cooled electric drill and a generator as power supply or from the orientated handsamples (entire blocks from the kiln wall) in the laboratory. From the cores one or two specimens were cut.

Laboratory treatment and results

Measurements of the natural remanent magnetization (NRM) were done using a modified Jelinek spinner magnetometer; the NRM intensities typically range 100–200 mA/m. All specimens have been demagnetized thermally, generally using temperature increments of 100° C (up to 300° C), of 50° C (up to 500° C) and of 30° C or even smaller (up to the maximum temperature of 690° C).

In all specimens from the volcanic tuff, a very small and often negligible, randomly directed magnetization component is removed at 100° C. At temperatures above 100 or 200° C up to the maximum blocking temperature, only one single component is removed (Fig. 1). The direction of this component is consistent within and characteristic

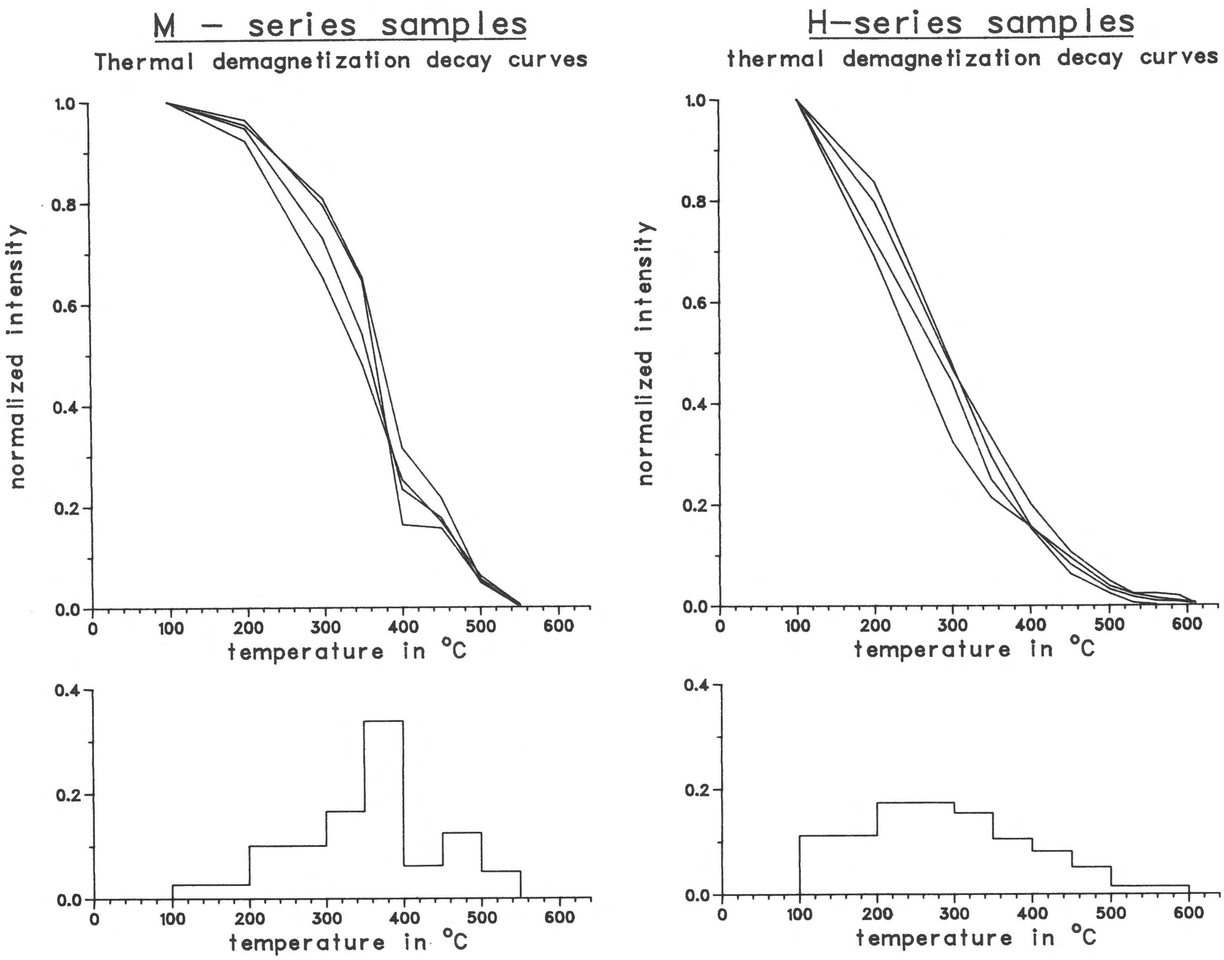

Fig. 2. Thermal demagnetization ChRM decay curves for some representative samples from the middle part (M) and the higher part (H) of the kiln wall, showing a consistent difference between the two series. The blocking temperature spectra are derived by taking the average decay from all curves at 50° C intervals.

for each block of volcanic tuff: it is a characteristic remanent magnetization (ChRM).

The maximum blocking temperatures and hence the Curie temperatures of this characteristic remanent magnetization (ChRM) are approximately 530–550° C for the M-series and somewhat above 600° C for the H-series (Fig. 2). There is a consistent difference, not only in the maximum blocking temperatures, but particularly in the blocking temperature spectra between the samples from the M- and H-series as can be seen from some representative decay curves: there seems to be a general shift towards lower blocking temperatures for the H-series, although the *maximum* blocking temperatures are somewhat higher (Fig. 2). This difference must be related to the fact that temperatures during burning of the limestone have been progressively higher towards the top of the kiln. Evidence for this is found by the appearance of the tuff: in the lower part of the kiln the rock surface is nearly unaltered, whereas in the middle and especially in the higher part, the rock is completely altered, showing a sintered to glassy surface.

The maximum blocking temperatures point to titanomagnetite or titanomaghemite as the carrier of the remanence. Titanomagnetite is a magnetic mineral often found in volcanic tuffs; titanomaghemites are essentially produced by oxidation of titanomagnetites (O'Reilly 1984), a process which is very likely to have occurred in the limestone kiln. The original titanomagnetite in the tuff (before heating) probably had lower Curie temperatures than the ones observed here and increased deuteric (high temperature) oxidation of titanomagnetite (Nishitani & Kono 1983, O'Reilly 1984) may have caused it to be oxidized and to alter it into titanomaghemite and/or higher oxides (e.g. hematite). This could well agree with the observed blocking temperature spectra: the M-series displays two maxima, possibly due to titanomaghemite (350–400° C) and to titanomagnetite (450–500° C), whereas in the H-series the latter maximum has altogether disappeared.

It must finally be noted that there is no consistent or significant difference in direction of the ChRM between M- and H-series (Table 1). All directions obtained from individual specimens are shown in Fig. 4.

Thermal demagnetization of the clay tiles shows entirely different results (Fig. 3). Apart from a small viscous component removed at 100° C, subsequent demagnetization shows that the NRM consists of two magnetization components. First, a low temperature (LT) component is removed between 100° C and 300–350° C. Considering the good agreement between (the directions of) the LT component and the ChRM component in the tuffs (Fig. 4), this LT component is probably a partial thermoremanent magnetization (partial TRM) induced by the heating of the kiln. It would indicate that the temperature in the lower part of the kiln has not been higher than approximately 350° C. Indeed, this was already indicated by the unaltered appearance of the tuffs in this part of the kiln. The inclinations of the LT component are somewhat steeper than those of the volcanic tuff (Fig. 4). This may be due to the fact that there are few demagnetization steps in this temperature interval so that the direction can be less accurately determined. The directions of the LT component have not been included in the calculation of the kiln mean direction.

Demagnetization at higher temperatures reveals that a high temperature (HT) component is removed with a maximum blocking temperature of 690° C, indicating that the magnetization is carried by hematite. The direction of the HT component is entirely different from the ChRM directions of the volcanic tuff blocks (Fig. 4) and very likely represents the direction of the ambient geomagnetic field during manufacturing of the clay tile. The date and original orientation of manufacturing is, of course, unknown and not relevant in the dating of the kiln.

In general, there is a good grouping of the ChRM directions of the volcanic tuff blocks (Fig. 4); also the LT component directions from one of the clay tiles (L 15) agree well with these ChRM directions. Two blocks of volcanic tuff yield entirely different directions. From one block (H 17) it was already noted that it was displaced with respect to the other blocks which is in agreement with the observed, deviating directions. From another block (H 15) no displacement was apparent at the time of sampling.

Table 1. Mean directions per tuff block or clay tile. The mean direction of the kiln is based on the results of six tuff blocks and is corrected for the deviation from North in Nijmegen at the time of sampling; the results of the tiles (L15 and M16) have not been used, nor those of two tuff blocks from the upper part of the kiln (H15 and H17). The mean direction of the kiln has been corrected for the deviation from north at the time of sampling (Rietman 1988). The mean declination (dec) and inclination (inc) of N samples is given, k is Fisher's (1953) precision parameter, α_{95} is the cone of confidence at the 95% level

	N	dec	inc	k	α_{95}
L 15 (HT)	2	141.2	0.1		
L 15 (LT)	2	354.0	70.6		
M 10	2	339.4	66.8		
M 11	4	345.3	65.5	265	5.7
M 14	3	349.9	60.8	170	9.5
M 16 (HT)	1	273.6	69.8		
M 16 (LT)	1	4.7	82.2		
M 18	2	15.4	61.1		
H 15	3	144.6	− 24.9	291	7.2
H 16	3	350.2	67.0	402	6.2
H 17	4	221.8	68.1	122	8.3
H 18	2	351.6	60.3		
kiln	6	352.5	64.0	162	5.3
deviation from North		− 2.2			
kiln, corrected	6	350.3	64.0	162	5.3

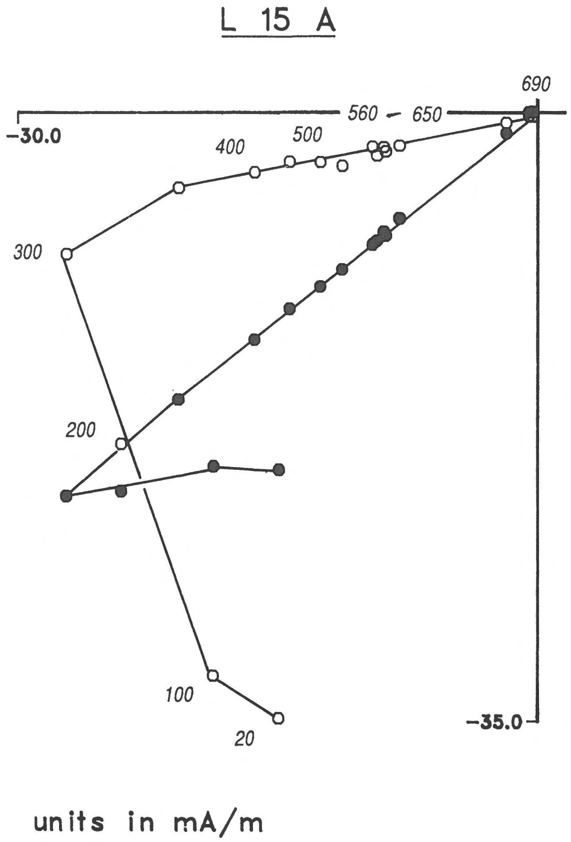

Fig. 3. Thermal demagnetization of a baked clay tile from the lower part of the kiln wall. The high temperature component shows a direction entirely different from the ChRM directions of the tuff blocks, whereas the low temperature component (100–300° C) is quite close to these directions. This suggests that this component is a partial TRM due to heating to a maximum temperature of some 300–350° C.

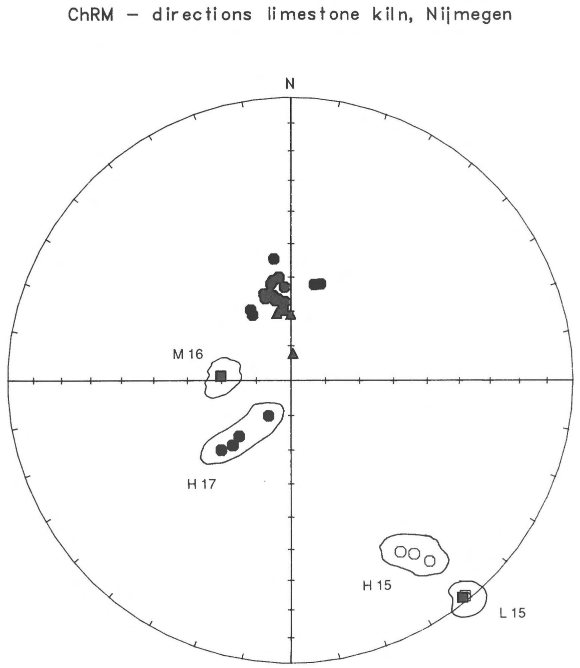

Fig. 4. Equal area projection of all ChRM directions of the tuff blocks (circles). The general ChRM direction is approximately 10° W, except in the case of two tuff blocks, H15 and H17. The latter was noticed to be clearly displaced in the kiln wall. The high temperature component of two tiles of baked clay (L15 and M16, squares) are also entirely different, whereas the low temperature component of these tiles (triangles) are quite close to the general ChRM direction.

Possibly, this block has been displaced as well after all; the result has not been used for computation of the mean direction. The deviating directions from these two blocks indicate that the ChRM directions from the volcanic tuff are not a present day field direction due to recent (secondary) remagnetization, but represent a stable TRM due to the heating of the kiln.

Secular variation in the Netherlands

It is essential for archaeomagnetic dating that a secular variation calibration curve is available for the region being studied. In the Netherlands, regular measurements of the geomagnetic field started only in 1862, in Utrecht, and were continued from 1899 to 1938 in De Bilt (5 km from Utrecht) and from 1938 onwards in Witteveen, in the northeast of the country. Generally, these secular variation data compare quite well with data from the London observatory (Malin & Bullard 1981; Fig. 5), showing a maximum difference of approximately 3° in declination during the 1860–1980 time span; (the difference in inclination is always less than 0.5°).

Older data are rare, and consist mainly of declination measurements. From 1652 to 1701 declination measurements were done in Akersloot, some 25 km northwest of Amsterdam, by Slikker (1703; referenced by Van Bemmelen 1899) and only in 1686 and 1688 he measured the inclination, which was 74.5°, only 0.5° higher than the London in-

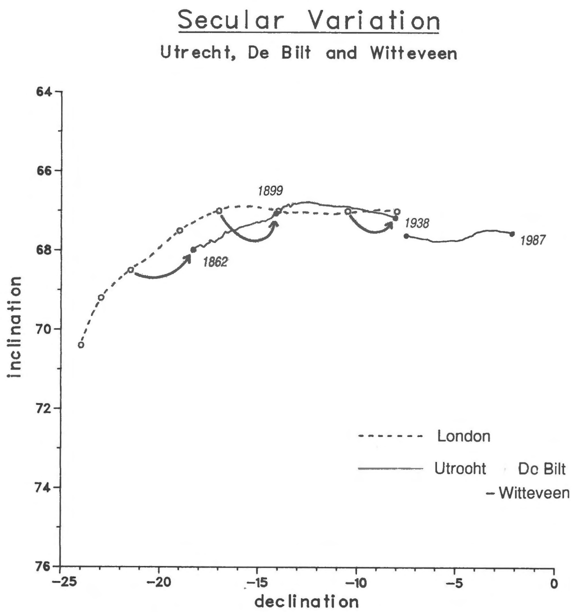

Fig. 5. Secular variation data from Dutch observatories since 1862 (Utrecht), 1899 (De Bilt) and 1938 (Witteveen). The dashed line represents the London observational data (1820–1960; after Malin & Bullard 1981), arrows connect corresponding years, showing a maximum (easterly) difference of some 3.0° in declination and less than 0.5° in inclination.

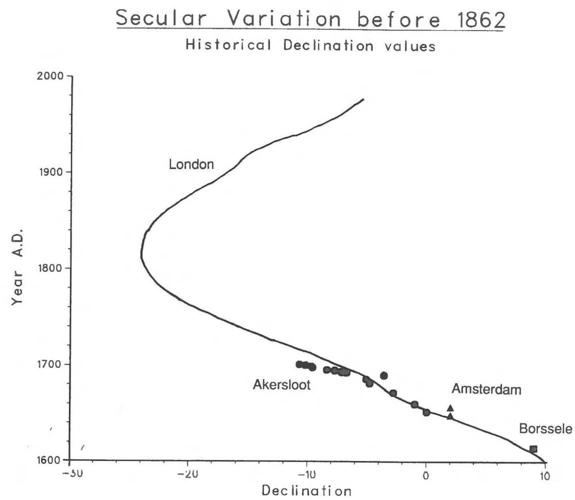

Fig. 6. Declination data from London since 1600. Dutch secular variation data older than 1862 are only known from Akersloot (circles), Amsterdam (triangles) and, very recently, from Borssele (square). The available data agree very well with the London data, showing a maximum (westerly) difference of some 3.0° in declination.

clination at the time. The declination data from Akersloot are close to the London data (Fig. 6). Two more declination values are known for Amsterdam in 1649 and 1657 (Van Bemmelen 1899), which agree well with the Akersloot data.

One more declination value in the Netherlands has been discovered recently (De Vries 1988 pers. comm.) by some coincidence. In ca. 1615 the small village of Borssele in the province of Zeeland was founded in a newly formed mud flat area, where the usual landmarks such as church-steeples were entirely missing. In staking out the layout of the village, most probably a compass was used, at the time directed according to the local geomagnetic field and not corrected for any variation. It can be seen in Fig. 7 that the rectangular layout of the village has an orientation of 9° E with respect to true north. This value agrees very well with the London observations (Fig. 6).

The fact that the secular variation data known for the Netherlands (i.e., since 1615) generally agree very well with the London data, showing a maximum angular difference of 3.0–3.5°, has given us confidence in using British archaeomagnetic data for dating purposes in the Netherlands. In addition, almost any location in the Netherlands is within a radius of 350 to 450 km from London, i.e., still less than the maximum distance within the London calibration curve can still be safely used (Clark et al. 1988).

Discussion

The ChRM directions for each block have been averaged using Fisher (1953) statistics (Table 1), and the mean directions of six blocks have been used to compute the mean direction of the limestone kiln. The results of the LT components of the clay tiles have not been used because of too few datapoints, nor the results of the two blocks from the upper row which have probably been displaced.

It is clear that the final result is close to the British archaeomagnetic directions of 50 BC to 400 AD (Clark et al. 1988; Fig. 8). The mean direction is not corrected for magnetic refraction (Aitken & Hawley 1971): in order to compare our results with

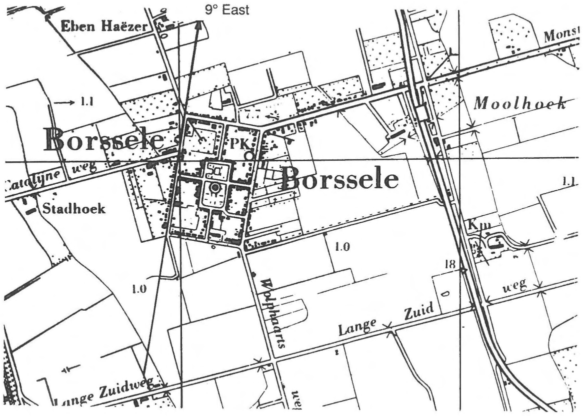

Fig. 7. Layout of the village of Borssele (province of Zeeland, the Netherlands), which was founded in 1615 on a mud flat area where no orientation mark was present. The orientation of the town layout was taken along magnetic north and shows a 9° East declination.

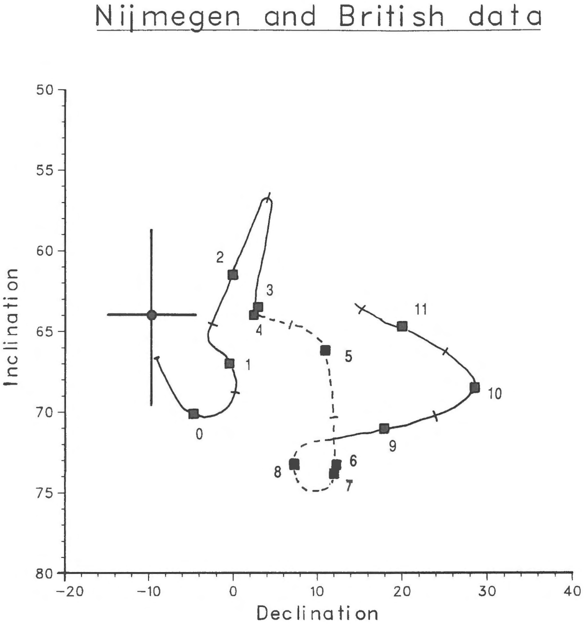

Fig. 8. Mean direction of the Nijmegen kiln, including the 95% cone of confidence (bars), with respect to British data (Clark et al. 1988) for 50 BC–1150 AD; numbers denote centuries AD. Considering the maximum difference of some 3.0–3.5° in the Dutch and British secular variation data, it is concluded that the kiln is Roman in age, not from the Middle Ages.

the results from Clark et al. (1988) the inclination should be steeper by 2.4° than is indicated in Fig. 8.

It is also clear, on the other hand, that the British directions for 900–1100 AD differ some 30° to 40° from our result. We have shown that there may be a slight difference between Dutch and British secular variation data – with probably a maximum of some 3.5°. A difference of more than 30° seems therefore highly unlikely. It may thus be concluded that the Nijmegen limestone kiln was not fired in the Middle Ages, but that it is of Roman age. This means a date between 12 BC and the beginning of the 5th century AD; see also Willems (1986) for the archaeological setting of Nijmegen.

On the basis of the present result, however, it would seem very tentative to determine whether the older phase of the Nijmegen kiln should be attributed to the late Roman period or that it should be dated earlier. The kiln mean direction including its cone of confidence is closest to the 50 BC direction; should we assume a maximum declination difference of 3.5° and a maximum inclination difference of 1.0° between Dutch and British secular variation, then our result would also encompass 0 AD and part of the British curve between 100 and 200 AD (Fig. 8). The relatively small differences in declination of the British directions between 0 and 200 AD makes any small and unknown difference in secular variation crucial in distinguishing the age more precisely. However, recently compiled archaeomagnetic data (Tarling 1989, pers. comm.) strongly suggest that the average declination values for the 3rd and 4th century AD are in fact more westerly than in the compilation of Clark et al. (1988). This would imply that our result most closely matches an age of 300–400 AD.

The few datable sherds found in the filling of the younger kiln phase suggest a *terminus ante quem* of 400 AD. Datable finds from the older phase were not found. Surrounding traces and stray finds refer to a date in the first or second century AD (Kisters, in prep.), a date which would quite well agree with the archaeomagnetic result from the Nijmegen kiln. However, from an archaeological point of view such an early date is not very likely. In the first place because of the fact that the kiln was constructed against a wall of volcanic tuff, which for archaeological reasons cannot have been built before 70 AD and – much more likely – has not been built before 200 AD (Willems 1986, Willems & Sarfatij 1988, pers. comm.). In the second place because of the absence of raw limestone material at Nijmegen at that time. In an area lacking natural occurrences of consolidated rocks the reuse of imported rock material is quite common. After 300 AD, during the increasing threat of the Frankish invaders, civilian monuments and buildings, constructed of limestone imported from several quarries in northeastern France (Kars & Broekman 1981), were demolished to obtain raw material for the production of lime for fortress building. Fragments of these limestones have been found scattered around the kiln. From a combination of the archaeomagnetic results and the very few archaeological data it can therefore be concluded that an age somewhere between 300 and 400 AD for the limestone kiln is most likely.

Acknowledgements

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