Magnetism and Time—The Scientific Dating of Archaeological Burnt Features

A Perspective for the Archaeomagnetic Dating Method in Romania*

Felix Marcu
Călin Şuteu

Introduction

Modern archaeology makes good use of several methods of scientific dating available nowadays, including the method known as archaeomagnetic dating. The importance of this method for archaeologists lies in the fact that the material required for samples (baked clay) is not organic and therefore not as perishable as the organic materials needed for the well-known and established methods of radiocarbon and dendrochronology. Another argument is that the baked clays that retain magnetic information are often found in archaeological contexts, in features such as hearths, ovens, kilns and even in the most common artefact, pottery. Archaeomagnetism allows for the dating of such contexts by comparing the magnetic information within collected samples with the records of past variations of the magnetic field of the Earth. The method was developed by geologists with the aim of establishing the movements (and sometimes reversals) of the geomagnetic North Pole throughout geological times and was later introduced to the field of archaeology by Robert Dubois in the 1960's.

This scientific dating method and the subsequent analysis of magnetic mineralogy for baked clay is carried out by various dedicated laboratories in Europe[1] and all over the world with the aim of creating a large database of directional and intensity data, travelling back in time as much as possible, a database that can be used to generate regional secular variation curves that take into account the spatial differences that occur in the Earth's magnetic field.

* The present paper represents a step in the development of research project no. 884 (2504), financed by The Ministry of Education, Research, Youth and Sports, through UEFISCSU, named *The reference curve for archaeomagnetic dating in archaeology. The Carpathians area*.

The uses of these secular variation curves are varied, from dating new archaeological features to complex studies of the Earth's magnetic field. Geomagnetic investigations on archaeological features have long been proven to be the best method available for revealing field variations during the historical past. These variations can be used, for example, to define models of climatic change, but also to date archaeological features, a very important issue for archaeologists.

Reviews on the current status of archaeomagnetic data available for the Balkans were given by Mary Kovacheva[2] and more recently by E. Tema and D. Kondopoulou.[3] For Romania, the only available data comes from scattered studies carried out in the 1960's by M.J. Aitken[4] and I. Bucur,[5] a review of methodology in 1988 by M. Mantu[6] and the more recent study published by us,[7] a study that also provides new directional data.

By analysing the conclusions of these articles we can see that for the territory of Romania there are only a few points of data with relevant accuracy and this comes in contrast with the relatively high number of archaeological excavations being carried out each year, on sites ranging from the Early Neolithic to the Late Medieval. It is therefore understood that the newly founded archaeomagnetic laboratory in Alba Iulia aims at closing this gap and at providing a good dataset for constructing a regional secular calibration curve for Romania.

The method

The processes involved in the mechanism of this dating method are briefly defined onwards; for a more detailed approach see English Heritage's new guidelines on the method.[8] Natural, unfired clays usually carry a weak, randomly oriented natural magnetization. These clays, when used in the manufacturing of kilns and hearths, are most often subjected to high temperatures, often over 700ş C. As they cool down, the magnetization becomes much stronger as it is aligned to the (then) present geomagnetic field. As the direction and intensity of the geomagnetic field change in time, this acquired thermoremanence (TRM) is "fossilized" for the time and place of this firing event and can be recovered from samples nowadays. It is important to know that the TRM resets at every firing that has reached these high temperatures, the dated event being always the last intense (over 700ş C) firing. By analysing the oriented samples taken from these features, directional and intensity parameters that describe the ancient geomagnetic field at this last firing event can be recovered in the laboratory, following a complex set of procedures. These values can be used against a pre-existing calibration curve that shows the variation of the geomagnetic field through time for that area in order to derive accurate dates for the features investigated.

There are various features associated to human habitation that require combustion and very often rather high temperatures to accomplish their designated functions. Most of these are highly suitable for archaeomagnetic sampling if they are reasonably well preserved. The list includes fireplaces and domestic hearths, temporary campfires and accidental (intense) firing of the soil, intense heat in situ incineration burials and burnt clay houses. For more recent times, suitable features include: any combustion structures like the hypocaust burning chamber or various industrial use kilns (for the production of pottery, glass, bricks and tiles, lime etc), metal smelting furnaces, baking ovens and burnt pits for the storage of cereals and various other structures. It is very important to remember that not all fired features are suitable for this analysis. There are numerous factors, natural or human, that can render the magnetic information retained in the fired clay unusable.[9]

Archaeomagnetic dating of the Roman kiln complex in Alba Iulia—*Dealul Furcilor*

In October 2006 rescue excavations were performed by the National Union Museum of Alba Iulia in an area outside the Municipium Septimium Apulense, on the site known to specialists as *Dealul Furcilor*.[10] The excavation revealed a rather intense Medieval habitation, but also the presence of Roman features that are proof of the existence, at the outskirts of the Municipium, of a pottery *officinae,* with a battery of at least two pottery kilns and the complementary annexes. In the infill of one of the kilns, two Roman denars were recovered, dating from the reign of Emperor Septimius Severus, between 193 and 217 AD, and bearing the effigy of his wife Julia Domna.

Samples were taken from the two kilns using the methods devised by A. J. Clark,[11] using disks for consolidated materials and tubes for burnt (soft) soil. The method provided a direct and minimally destructive way of sampling burnt clays as well as in situ burnt sediments from archaeological sites. The kilns were oversampled (in usual circumstances a number of 12 samples would suffice) as 41 samples were collected for ADF2 and 29 for ADF3; this allowed for several tests to be performed in order to establish if any relations between sample position and the quality of its magnetic information exist i.e. if evidence of magnetic refraction could be seen. The two kilns and the disposition of the samples can be seen in Figure 1. Several areas of the kiln were sampled and analysed separately, where available, namely the outer wall and dome of the kiln (A), the inner wall of the pottery chamber (A'), the floor of the pottery chamber (B) and the pillar (D) supporting the floor in between the two chambers.

The laboratory measurements, all performed at the Alba Iulia facility, included natural remanent magnetization measurements (NRM) using a Molspin Spinner magnetometer, 12 steps detailed alternating field demagnetization (AFD) using a Molspin AFD, IRM acquisition and backfield experiments on selected representative samples using the Magnetic Measurements pulse magnetizer MMPM10. All the data was statistically treated and relocations were performed so that the final data could be compared to the two existing regional curves of Bulgaria and Hungary. The special RenDATE© software was used to compute the probabilities of the date intervals.

The initial NRM measurements displayed a very good clustering, kiln ADF2 having the statistical parameters[12] of *alpha95* of 1.4 and $k = 249$, out of all the 41 samples taken while kiln ADF3 displayed an *alpha95* of 1.29 and $k = 461.4$ out of all the 29 samples collected. The characteristic remanent magnetization was estimated by principal component analysis, as proposed by Kirschvink,[13] including the origin of the coordinate system. Step-wise demagnetization only slightly improved these good statistics, the final values being, for ADF2 of *alpha95* = 1.47 and $k = 230.1$ while ADF3 had the statistical indicators of ChRM *alpha95* = 1.43 and $k = 347.9$. A stereo plot showing both ChRM for the two kilns and a representative demagnetization (magnetic cleaning) Zjiderveld plot[14] for sample ADF301 (wall) can be seen in Figure 2. It can be noticed that viscous remanence (VRM) was present in the first stages, but the vector was cleaned by demagnetizing the sample further on. The median demagnetizing field (MDF) was achieved in fields of around 20 mT for hard samples (discs) and much sooner for soft soil samples (tubes), around 8 mT; a difference in the magnetization percentage retained at 100mT demagnetizing field is also noticeable between the two types of samples.

The final directions for the datasets are: for ADF2 the mean declination $D_{site} = -8.12$ and the mean inclination $I_{site} = 59.1$, samples used $N = 41$, *alpha95* = 1.47 and for ADF3 $D_{site} = -11.24$ and the mean inclination $I_{site} = 58.83$, samples used $N = 29$, *alpha95* = 1.43. The site's magnetic variation according to IGRF was determined to be of 4.11 degrees to the east.

Taking into account the ChRM for the two kilns we plotted the values obtained for each sample relative to its location on the kiln in order to see if any particular pattern of refraction can be noticed, as seen in Figure 3a. Also, a separate treatment on each type of location that provided the samples (wall, kiln floor, pillar) was attempted, a stereo plot of results being shown in Figure 3b. Even though early studies of kiln structures suggested that magnetic refraction could be a major source of error in archaeomagnetic studies of large, strongly magnetized structures, we did not experience any issues in this particular case the noticeable variations being most likely related to sampling and measurements errors.[15]

Using recent secular variation data (moving window averaged, 100 year, 50 years apart, with fractional and overlap weightings) published for Hungary by Peter Marton[16] and the specialized probabilistic dating software RenDate©, developed for archaeomagnetic dating by Lanos and Dufresne,[17] a dating procedure was attempted to verify the given archaeological date estimate as seen in Figure 4. The mean directions for the two kilns were relocated to Budapest for better agreement with this data set, now being, for ADF2 $D_{BP} = -2.09$ and $I_{BP} = 64.33$ and for ADF3

D_{BP} = -8.28 and I_{BP} = 63.42. The combined probabilities of declination and inclination suggest, at a 95% confidence level, for kiln ADF2 a date interval ending at 184 AD, and for kiln ADF3 a date interval ending at 189 AD. By correlating with the archaeological evidence at the site and the coins found in the infill of kiln ADF3 (Julia Domna denars) we can infer that the last probable firing over 700ş C that took place in this kiln complex – the event dated by this method – was just prior to Septimius Severus's rule. The coins arrived later to this context as the kilns probably became refuse dumps. It is known that archaeomagnetic dating can only date the last firing event of the feature and not its associated context or artefacts, probably of later deposition in this case.

In order to establish the reliability of the data presented in this study, the available regional secular variation data from Bulgaria, Hungary and Ukraine[18] was compiled and relocated to the central point in Romania, along with the data recovered from the two kilns in Alba Iulia – *Dealul Furcilor* (Figure 5). There is a general good agreement, taking into account the time errors associated with archaeological estimates. This broader perspective on the existent regional data also emphasises the need for more data at specific time intervals, as well as an improvement of the associated error envelopes in order to allow precise dating of archaeological events.

Future developments

The newly established facilities in Alba Iulia will be used to address the current issues of regional dataset by recovering as much archaeomagnetic data as possible from archaeological sites all over Romania. Recently, thanks to the latest grants, a considerable number of archaeomagnetic samples were collected from various sites all over Romania and are currently undergoing processing at the Alba Iulia laboratory. It is also expected that the construction of highways in Romania should lead to the discovery of archaeomagnetic samples, as it was proven by our recent visit at the Şoimuş – *Teleghi* site on the Transylvania Highway project in the proximity of Deva; in this single location, about eight feasible features were identified, with ages ranging from prehistoric to Medieval, two of which were consequently sampled. A second visit to the site has already been scheduled.

For the current state of research and in order to create a good database for the Romanian secular variation curve it is imperative that most of the features that provided viable archaeomagnetic data be previously dated as accurately as possible by other methods. This existing data (archaeometric or archaeological) is absolutely necessary in the process of building the calibration curve for future dating purposes. A secular variation curve contains such well-dated magnetic references until the whole data set acquired allows for an appropriate estimation of the evolution of the geomagnetic field through time, with as little error as possible. It is also essential that this type of magnetic data, already dated by other means, to cover as much as possible all periods in time and to be spread as evenly as possible, avoiding gap periods. Improvements are also to be made in creating awareness and recognition in the archaeological community of this dating method, essential for ensuring future access to materials and features.[19]

❑

Notes

1. See the AARCH European Research Training Network project for European laboratories and recent activity in the field of archaeomagnetic dating; also at http://dourbes.meteo.be/aarch.net/index.html, accessed October 29, 2011.
2. M. Kovacheva, "The Balkan Peninsula and archaeomagnetism – A brief review," *Journal of the Balkan Geophysical Society* 6 (3) (2003): 173–178.
3. E. Tema, D. Kondopoulou, "Secular variation of the Earth magnetic field in the Balkan region during the last eight millennia based on archaeomagnetic data," *Geophysical Journal International* 186 (2011): 603–614.
4. M. J. Aitken, H.N. Hawley, "Archaeomagnetic dating in Britain," *Archaeometry* 3 (1966): 129–135.
5. I. Bucur, "La variation de l'Inclinaison magnétique du XIVe au XVIIe siècle, établie pour deux regions de la Roumanie," *Revue Roumaine de Géologie, Géophysique et Géographie—Série de Géophysique*, 11(2), (1967): 105–111.
6. C.M. Mantu, "Metoda arheomagnetică şi datarea siturilor arheologice," *Arheologia Moldovei*, 12 (1988): 281–302.
7. C.A. Şuteu, C.M. Batt, I. Zananiri, "New developments in archaeomagnetic dating for Romania – A progress report on recent directional studies," *Physics and Chemistry of the Earth* 33 (2008): 557–565.
8. P. Linford, *Archaeomagnetic dating. Guidelines on producing and interpreting archaeomagnetic dates*, (English Heritage Publishing Swindon, UK, 2006) available online at http://www.english-heritage.org.uk/upload/pdf/Archaeomagnetic_Dating.pdf accessed October 29, 2011.
9. C.A. Şuteu, "A review on the current sampling requirements for the archaeomagnetic dating method – a guide for the archaeologist," *Annales Universitatis Apulensis. Series Historica,* 13 (2009): 89-95.
10. See the archaeological brief report in *Cronica cercetărilor arheologice, campania 2006* (Bucharest, 2007), available on the web at http://www.cimec.ro/Arheologie/cronicaCA2007/cd/index.htm accessed October 29, 2011.
11. A.J. Clark, D.H. Tarling, and M. Noel, "Developments in Archaeomagnetic dating in Britain," *Journal of Archaeological Sciences*, 15 (1988): 645–667.
12. R.A., Fisher, "Dispersion on a sphere," *Proceedings of the Royal Society*, (London, 1953), 295–305.
13. J. Kirschvink, "The least-squares line and plane and the analysis of palaeomagnetic data," *Geophysics Journal of Royal Astronomical Society*, 62 (1980): 699–718.
14. J. Zijderveld, "AC demagnetization of rocks: analysis of results," in D. Collinson, K. Creer, S. Runcorn, eds., *Methods in Paleomagnetism* (New York: Elsevier, 1967), 245–256.

15. D. H. Tarling, N. B. Hammo, W. S. Downey, "The scatter of magnetic directions in archaeomagnetic studies," *Geophysics* 51 (1986): 634.
16. P. Marton, "Archaeomagnetic directions: the Hungarian calibration Curve," in Morris, A., Tarling, D.H., eds., *Palaeomagnetism and Tectonics of the Mediterranean Region. Geological Society Special Publications*, 105, 1996, 85-399; more recently in P. Marton, "Recent achievements in archaeomagnetism in Hungary," *Geophysical Journal International* 153 (3) (2003): 675–690.
17. P. Lanos, "Bayesian inference of calibration curves: application to Archaeomagnetism," in C.E. Buck, A.R. Millard, eds., *Tools for Constructing Chronologies Crossing Disciplinary Boundaries*, vol. 177, *series: Lecture Notes in Statistics* (London: Springer-Verlag), 43–82.
18. O.M. Rushakov, G.F. Zagniy, "Archaeomagnetic secular variation study in the Ukraine and Moldavia," *Archaeometry* 15 (1973): 153–157.
19. I.G. Hedley, "New directions in archaeomagnetism," *Journal of Radioanalytical and Nuclear Chemistry* 247 (3) (2001): 663–672.

Abstract

Magnetism and Time—The Scientific Dating of Archaeological Burnt Features: A Perspective for the Archaeomagnetic Dating Method in Romania

Archaeomagnetic dating is a chronometric method that relates the shifts and movements of the Earth's magnetic field in time, represented as a secular variation curve, with the phenomenon of magnetic thermoremanence that allows for the characteristics of direction and intensity of that field to be recorded within the matrix of burnt clay features from archaeological sites. If throughout Europe and the rest of the world the method has seen several decades of data gathering and refinement of the procedure, for Romania there are just a few data points, despite the opportunities of sampling feasible features in numerous excavated archaeological sites each year. Recently, advances have been made due to the set up of a modern laboratory dedicated to archaeomagnetic dating at Alba Iulia and the publishing of a progress report on recent directional studies from the area. The current article aims to give an overview on the current status of research for Romania and the methodology used to recover directional magnetic data from an archaeological feature using the example of the Alba Iulia – *Dealul Furcilor* Roman kiln complex.

Keywords
archaeomagnetic dating, kiln, Roman, secular variation curve, direction, dating, Romania

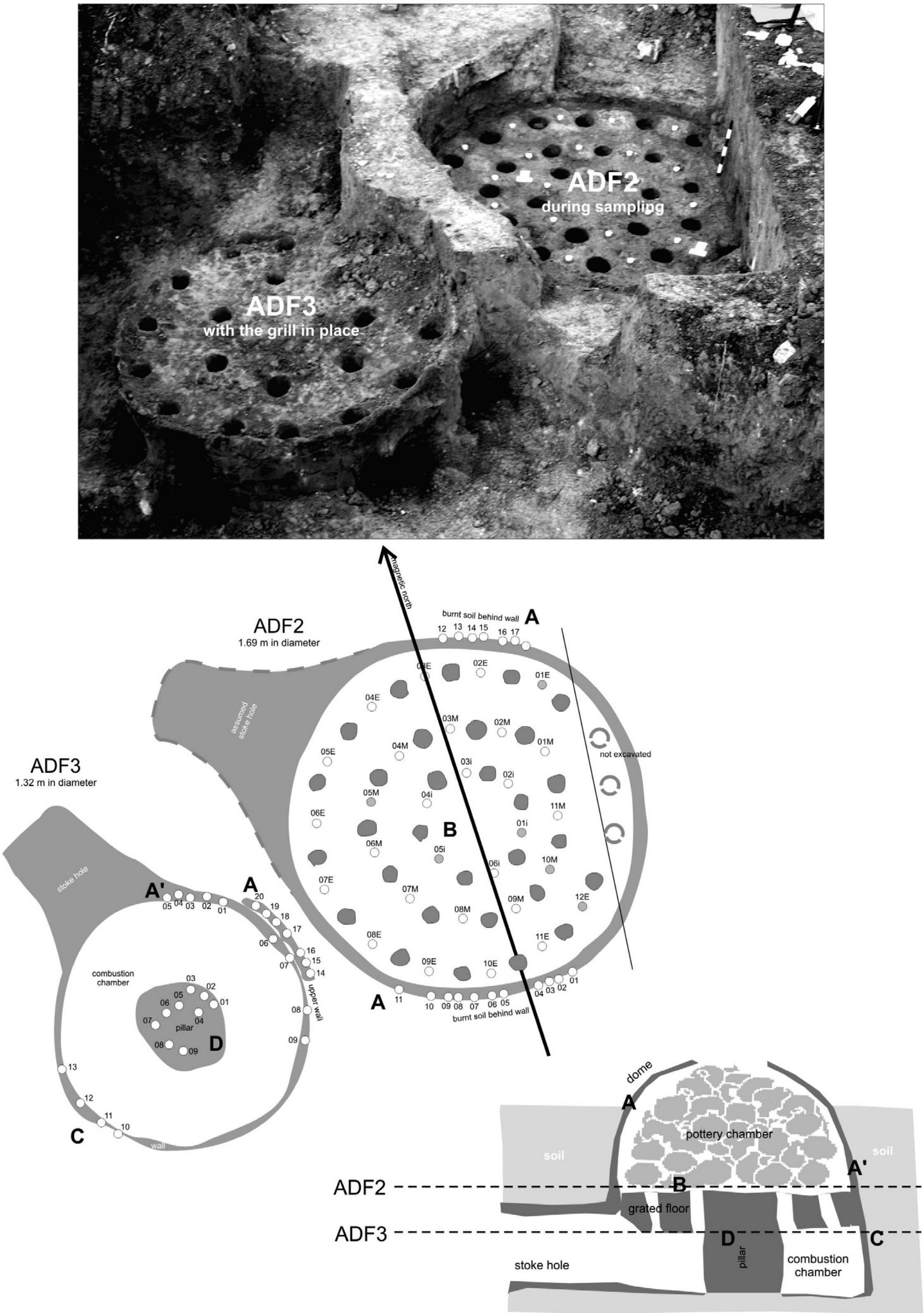
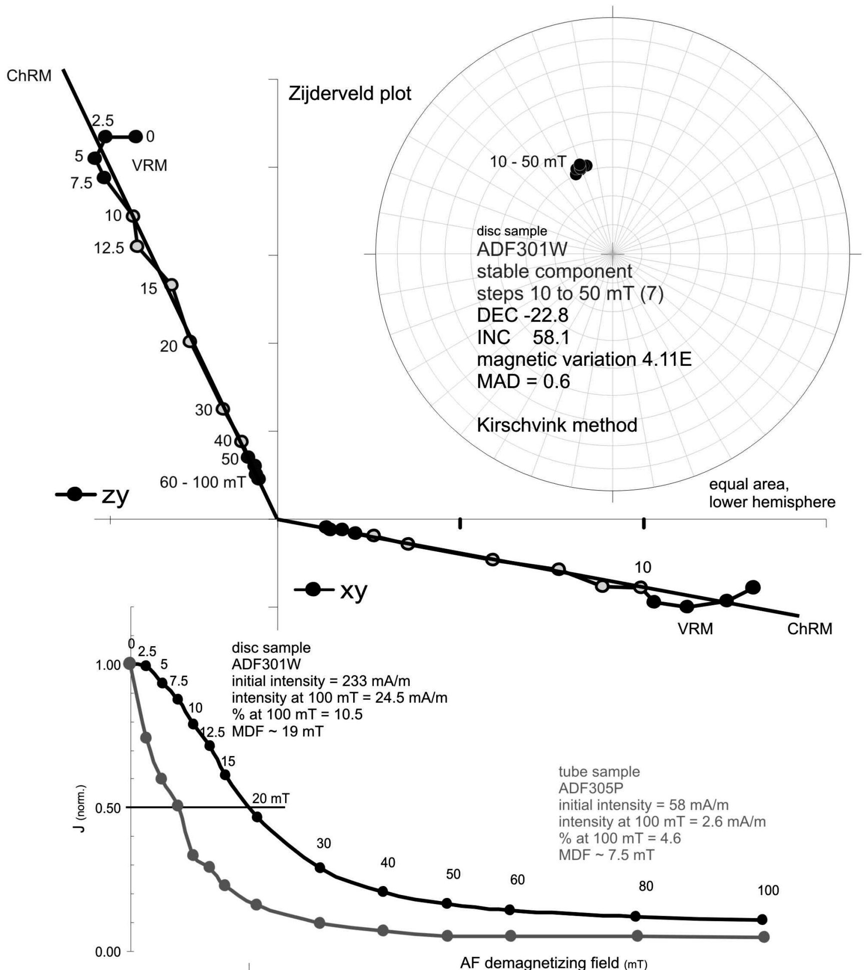


Figure 1. The two Roman kilns found at Alba Iulia - *Dealul Furcilor*, after being excavated and the location of samples on the two features.



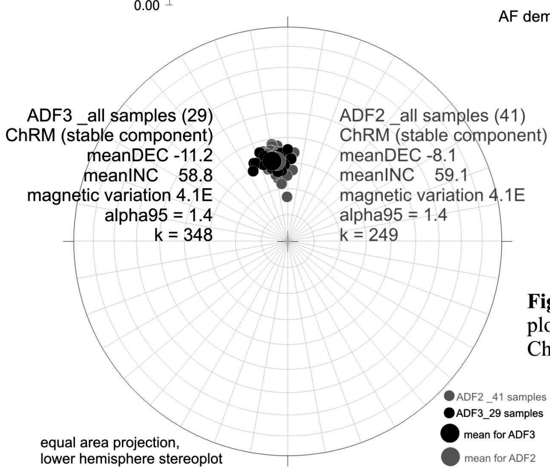


Figure 2. Alternating frequency demagnetization plot (Zjiderveld) of an ADF3 sample and final result ChRM (stable component) stereoplot for the two kilns.

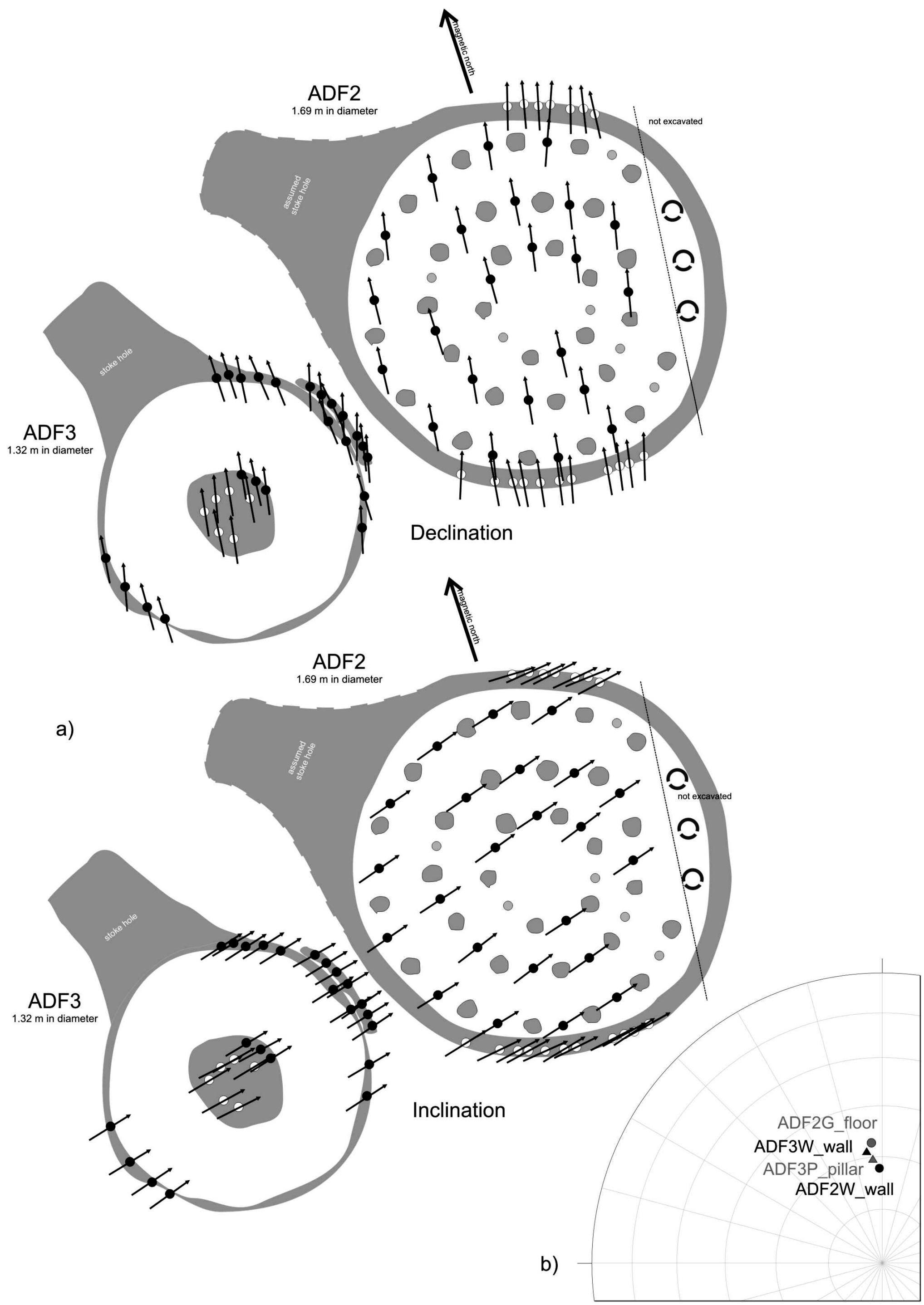


Figure 3. Testing the samples taken for evidence of magnetic refraction. The data used was the stable component of the characterstic remanence (ChRM).

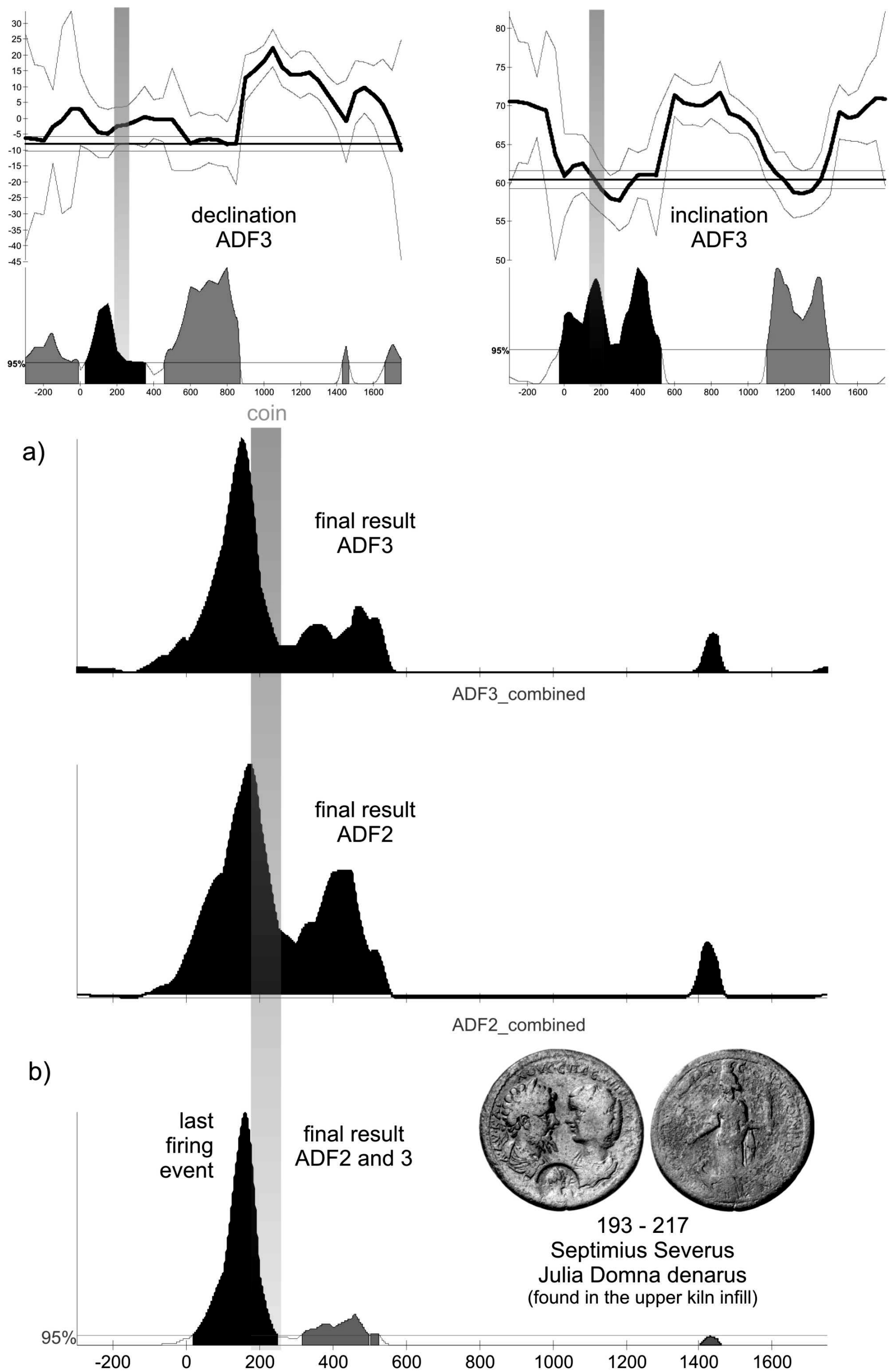
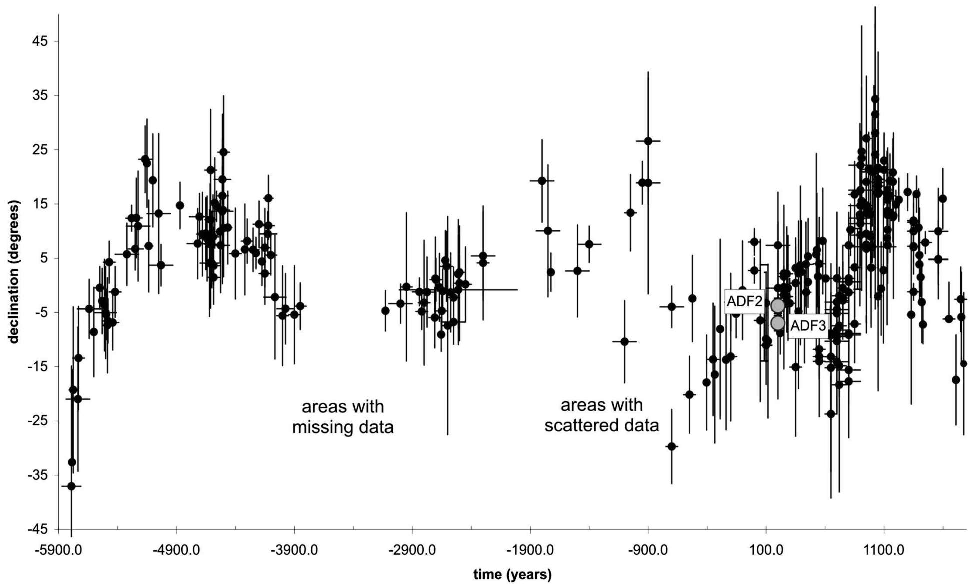


Figure 4. Dating the two kilns based on archaeological evidence (coins) and the data published for Hungary by Marton 2003 using the REN-DATE© software: a) dating the AFD3 kiln, declination and inclination plot and final probability plot; b) dating the entire kiln complex based on the final probabilities of both features.



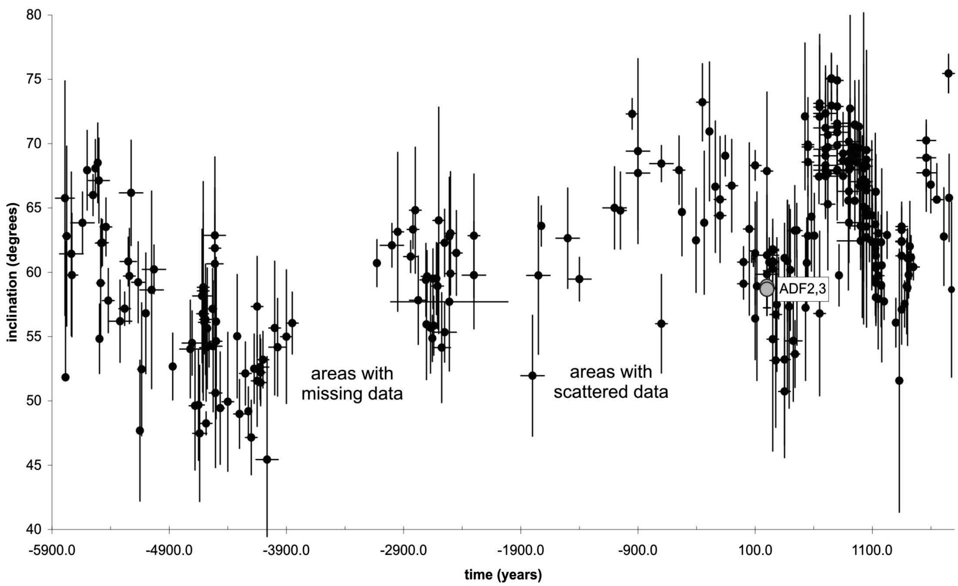


Figure 4. The agreement of the ADF 2 and ADF 3 final results with the entire set of available reference points from both Bulgaria and Hungary, all relocated to Dealu Frumos, Agnita, Romania.