Mediterranean Archaeology and Archaeometry, Vol. 13, No 2, pp. 221-229

ARCHAEOMAGNETIC INTENSITY OF CERAMIC SHERDS FROM TWO RHODIAN BYZANTINE CHURCHES: A PRELIMINARY INITIATIVE

W.S. Downey[1] and I. Liritzis[2]

[1]*University Brunei Darussalam, Geoscience Dept. Tungku Link, Gadong, BE 1410. Brunei Darussalam*
[2]*University of the Aegean, Lab. of Archaeometry, Dept. of Mediterranean Studies, 1 Demokratias Str., Rhodes 85100, Greece*

Received: 11/05/2013
Accepted: 28/08/2013
Corresponding author: billdowney49@yahoo.com

ABSTRACT

Archaeointensity results were obtained from ceramic sherds incorporated in the 'mortar' of two Rhodian Byzantine churches. Samples were analysed using a modified Thellier method with samples orientated so that the Natural Remanent Magnetization is at right angles to the applied laboratory field. Only a few samples showed high magnetic stability and an archaeointensity result was obtained from ceramic sherds (tilebrick) from the lower interior walls of the church (Afandou Katholiki). Comparison with the Geomagnetic Field Variation plot indicated the probability density of possible dates between ~1000 to ~1500 AD. a date, broadly consistent with historical records.

KEYWORDS: Rhodian Byzantine Churches, Archaeointensity, Ceramic sherds, Modified Thellier method, Dating

INTRODUCTION

Archaeomagetic studies have allowed for the determination of the palaeomagnetic secular variation (PSV) record of the past geomagnetic field and have been used as a means to establish absolute or relative dates for suitable archaeological materials including pottery sherds (Kovacheva *et al.,* 1998). When pottery is removed from a kiln, generally, only the archaeomagnetic intensity can be determined, as the orientation of the firing position is lost and the directional parameters (declination and inclination) cannot be determined. It is the small magnetic minerals within clay-based materials used for the manufacture of ceramics which record the strength and direction of the ambient magnetic field after they have cooled in-situ. Palaeo Secular Variation (PSV) curves for ancient magnetic field intensity, declination and inclination, have been established regionally from such archaeological and other natural materials, such as lavas and indicate the past behavior of the geomagnetic field. If the archaeointensity of suitable materials, such as pottery sherds from a particular archaeological context, is known, then, it is possible to compare such archaeointensity results with the established PSV curves and thus obtain a date. A preliminary study was made on thirteen samples of pottery sherds, taken from two Rhodian Byzantine churches: St. Nicolas Foundoukli, and Afandou Katholiki, both of uncertain age spanning between 10^{th} to 17^{th} c AD. Archaeointensity determinations were made on the sherds which had been incorporated in the wall mortar, using the Modified Thellier method, Kono and Ueno (1977), which uses single heating during treatments, however, some modifications were made to the sample preparation. As a prerequisite criterion for determination of ancient magnetic field strength, only samples which exhibited a very high magnetic stability to progressive thermal demagnetization (PTD) were used. PTD results used with principal component analyses showed that a single component of remanent magnetization remained up to ~500-550^{0}C and Viscous Remanent Magnetization (VRM) was removed after the ~100^{0}C treatment. Previous investigations initiated on Byzantine Churches by one of us (IL) include Liritzis and Kovacheva (1992), Aitken *et al.*, (1989), and Liritzis (1989).

SAMPLES AND SAMPLING

Two Rhodian Byzantine churches were sampled: St. Nicolas Foundoukli, East wall (5 sherds, code NFE) and South wall (3 sherds, code NFS) of ~15^{th} c AD (Achimastou-Potamianou, 2004) and Afandou Katholiki, (Orlandos, 1948, Sifopoulos 2004) Lower interior wall (3 sherds, code AKL) and Upper interior wall (2 sherds, code AKU).

For the church at Afandou Katholiki (Sifopoulos, 2004) according to tradition construction started ~10^{th} c AD there was a temple dedicated to Demeter, built at that location in the 3^{rd}. century BC. This was destroyed but in the 5^{th}- 6^{th} century AD, another building, a triparted palaeochristian Basilica was erected, possibly using some of the materials from the previously destroyed site. This in turn was destroyed by unknown causes in the 8^{th} century AD. A new church was built upon the ruins of the palaeochristian church ~10^{th} c. AD with well constructed Gothic arches but occupied only the mid-aisle area of the earlier construction. It bears wall paintings believed to be from the 14^{th}. to 16^{th} centuries AD or later 17^{th} c AD. (Orlandos 1948) (Photos 1A, B).

METHODS

Treatment and Sample Preparation

Measurements were made using the MMTD (Magnetic Measurements Thermal Demagnetizer) and Molspin fluxgate magnetometer, (Molyneux, 1971). The essential principles of the single heating modified Thellier method (Kono and Ueno, 1977) are applied in this study with an additional step which allows a laboratory field Thermoremanent Magnetization (TRM) to be directed, exactly perpendicular to the stable Natural Remanent Magnetization (NRM), 'cleaned' of any VRM components. Kono and Ueno (1977) routinely removed VRM components using a 100 ^{0}C step in thermal demagnetization treatments. It is however, indeed preferable to experiment with samples of the same type as those to be used for archaeointensity determinations, to establish the exact temperature level, required to remove these soft secondary components before proceeding with ancient field intensity determinations.

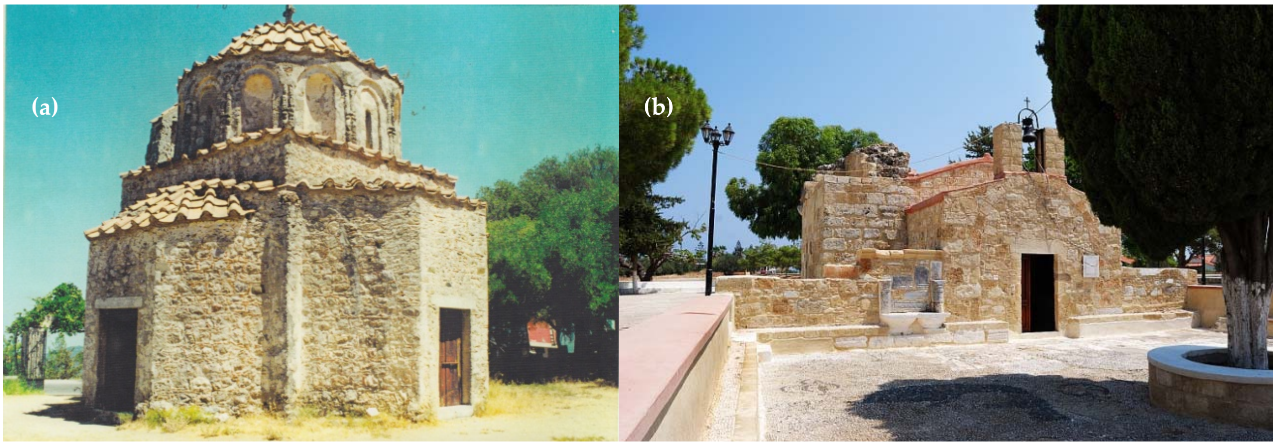

Photo 1. View of present status of the two churches: (a) Aghios Nikolaos Foundoukli, (b) Afandou Katholiki

Technical note on sample preparation

'Directional' methods have been applied in Thellier-type treatments to obtain archaeo and palaeo-intensity results with a laboratory field applied in the same direction as the NRM with success in the use of ceramics obtained from Peru, China and Egypt (Shaw *et al*., 1996, 1999) and lavas from Italy (Hill and Shaw, 2000).

This is carried out using the controlling program for microwave heating to allow the field coils around the microwave cavity to be programmed so that the laboratory field is applied in such a manner. In this study, a conventional modified Thellier method is used and the sample itself can be physically oriented, so that a laboratory can be applied (TRM) at 90^0 to the 'cleaned' NRM direction.

After the direction of the NRM vector of the sample is established, it can be oriented so that it is confined to the plane of the circular end plane of a standard one inch (2.54 cm.) 'palaeomagnetic' sample, in this case, a perspex or quartz open-ended cylinder.

Archaeological samples of burnt mud brick or pottery sherds are not drill cored and may be fairly irregular, so the sample is firstly cut to an approximate 1cm side cube. This regular shape may also have benefits in reducing magnetic anisotropy effects especially those related to shape anisotropy (O'Reilly, 1984).

This size of sample can fit into and be rotated within the standard cylinder. On a small mound of magnetically clean plasticine placed on a bench, the cylinder is pushed on to it vertically and then carefully withdrawn, retaining the flat-surface plasticine onto which an arbitrary fiducial mark can be drawn. The 'cubed' pottery sample is then pushed gently into the plasticine in random orientation, making sure that it is well secured and at the approximate centre of the cylinder. The magnetic remanence is then measured and a note made of the inclination value.

The sample is then re-orientated by a small amount in any direction by accessing it from the open end of the cylinder before a second remanence measurement is made. The inclination value is checked to see if it has increased or decreased. This process is repeated until the inclination value becomes zero at which point, the NRM vector lies in the plane of the end face of the cylinder. This is necessary, so that when the cylinder is lying elongate in the furnace tray, a laboratory TRM (applied along the axis of the furnace) is directed at right angles to the NRM direction.

Next, the open end of the cylinder is filled with non-magnetic "Plaster of Paris" (gypsum) making sure no air bubbles remain and the filled end is smoothed off. The sample is allowed to dry after which the plasticine originally retaining the sample but now retained by the hardened plaster of paris, can be removed. Complete removal of the plasticine is essential so that there is no burning of any residual plasticine during the subsequent elevated temperature treatments. The open end is then filled with plaster of paris and smoothed off, so that the sample is completely contained within the cylinder. When dry, an arbitrary fiducial mark can be made on the cylinder-end surface. The monitoring of the arbitrary declination direction (fiducial mark), after each heating step is important as it indicates any departure from the NRM - TRM plane.

As an additional check (pTRM; partial TRM), on the arbitrary declination value (which would indicated a departure of the measured vector from the NRM - TRM plane), a field free space (FFS) heating/cooling step can be made between 400^{0}C to 550^{0}C (before remanenence is completely lost) depending on the magnetic constituents type and Curie temperature (Tc) of the sample. Maximum furnace temperatures up to 650^{0}C or above 700^{0}C can be used were cylinders are pyrex or quartz glass respectively (ie) for a sample containing hematite.

For ancient field strength determinations, a choice of laboratory TRM value, close to the ancient archaeomagetic field intensity should be used so that the condition $F_{Ancient} / F_{lab.} = 1$ is satisfied (Aitken, 1981).

Experimental laboratory TRM fields of 31, 37, 49 and 57 μT were applied to different samples (Table 1). Only two samples AKL2 and 3 fulfilled the criterion $F_{Ancient}/F_{lab.} = 1$.

TABLE 1. Magnetic results from PTD and Modified Thellier archaeointensity determinations. NFE and NFS are codes for samples from St. Nicolas Foundoukli (East and South) exterior walls, respectively. AKU and AKL are codes for samples from Afandou Katholiki (Upper and Lower) interior walls, respectively.

Sample No.	No. vector end pts. used in regression	Magnetic Stability	Gradient	(F^L) Lab Field (μT.)	(F^A) Uncorrected Ancient Field (μT.)
NFS 1	4	Fair	1.4481	49	70.8
NFS 2	4	Good	1.4962	49	71.1
NFS 3	4	Good	1.4129	49	69.2
NFE 1	11	Good	1.5001	31	46.5
NFE 2	4	Poor	2.0214	31	62.7
NFE 3	8	Poor	2.4355	31	75.5
NFE 4	7	Poor	0.7362	49	36.1
NFE 5	10	Poor	0.8803	49	43.1
AKU 1	11	Fair	1.9628	37	72.6
AKU 2	11	Very good	1.6389	37	60.6
AKL 1	8	Fair	0.8301	57	47.3
AKL 2	12	Very good	0.9727	57	55.4
AKL 3	12	Very good	0.9382	57	53.5

	Corrected 9% ± 3%	(F^A/F^D) -1
AKL 2	(F^A) Mean	
AKL 3	(μT)	
	49.6 ± 1.6	0.12 ± .03

Demagnetization and modified Thellier method

Progressive thermal demagnetization (PTD) was carried out on test samples from each sherd at 50⁰C intervals (Fig.1) and the low field susceptibility measured after each heating cooling step to monitor for any thermally induced irreversible mineralogical changes. No significant changes were observed. The laboratory cooling period was 'forced' and generally about 2 hours down to room temperature. The shape of the demagnetizations curves together with principal component analyses indicates the stabilities of the NRM (Table 1, Fig. 1). VRM components were removed after the 100⁰C PTD step. Magnetic remanences appears to diminish to less than 10% at approximately 500 – 550⁰C possibly indicating that the magnetic carrier is magnetite or low titanium titanomagnetite (Fig.1).

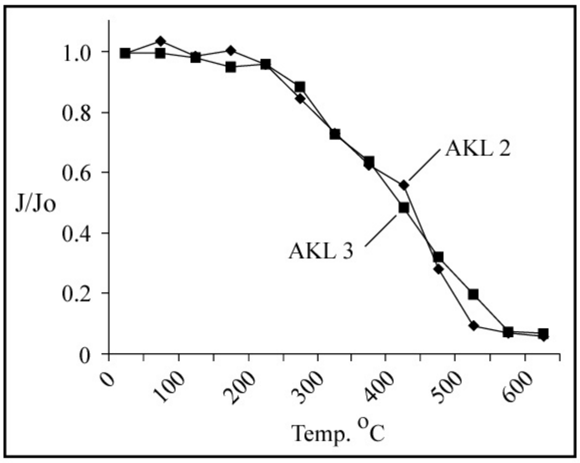

Figure 1. Progressive Thermal Demagnetization curves. Normalized decay of NRM with incremental increase in temperature for two sherd samples from Afandou Katholiki.

Other samples (intended for archaeomagnetic intensity determinations) were routinely thermally demagnetized at 100⁰C before sample preparation. For the determination of ancient magnetic intensity, single heating steps were made at steps of 25⁰C up to a maximum of 400⁰C with forced cooling. Low field susceptibility was monitored after each heating/cooling step and a non-magnetic field, heating/cooling step applied at higher temperature in order to check for consistency in the arbitrary declination of the sample. This is necessary to confirm that the magnetization has remained in the TRM-NRM plane. A deviation of more than 2 degrees in the arbitrary declination value (ie) out of the plane is regarded as unacceptable.

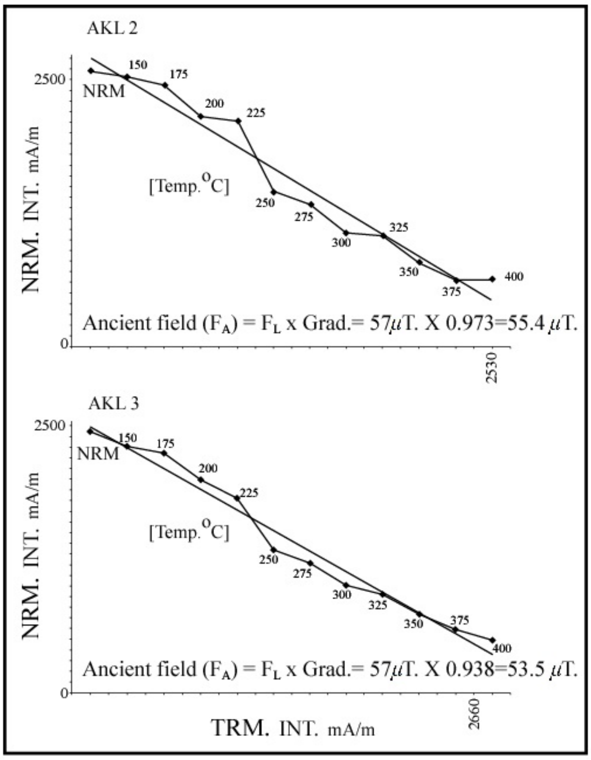

Figure 2. Archaeointensity values obtained from linear regression analyses (gradients), using the Modified Thellier method with samples' NRM oriented at 90⁰ to the laboratory field (TRM).

RESULTS AND DISCUSSION

Only two samples, AKL 2 and 3 after receiving a laboratory field of 57 μT came close to satisfying the condition $F_{ancient}/F_{lab.}$ =1. The gradients obtained from the 'best fit' linear regressions are 0.97 and 0.94 respectively with calculated 'raw' archaeointensities of 55.4 and 53.5 μT. (mean ≈ 54.45 ± 0.93) (Table1, Fig.2).

Concerning the determination of archaeintensities and notwithstanding, any apparent mineralogical changes, Barbetti *et al*, (1977) noticed that Thellier-type measurements of ancient field intensity on specimens of clay and sediments which were apparently well-baked and oxidized in ancient times, often fail to give consistent results over part or even most of the blocking temperature spectrum. They suggest, that post-baking chemical alteration or "weathering" (when not preserved in a dry environment) leads to the presence of hydrated iron minerals which are major cause of the non-ideal behavior in such materials. The behavior of hypothetical specimens containing either goethite or lepidocrocite can be predicted using simple models. The presence of such hydrated minerals may not be readily detected by methods other than Thellier type techniques and would result in estimates of ancient geomagnetic field strength that are systematically too low. A forced cooling rate at 30^0C per minute using the MMTD caused samples to cool to room temperature in the laboratory over a short period (approximately 2 hours) as opposed to the presumed cooling period after a conflagration (or cooling kiln) which is more likely to be over a period of a few days or even longer. Furthermore, archaeointensity results may be affected by the rate at which the sample is cooling while the TRM is being acquired during the Thellier type experiment (Walton, 1982). This was predicted by Dodson and McClelland-Brown (1980) and shown experimentally by Fox and Aitken (1980) to be 6% to 12% too high. According to Chauvin *et al*, (2000), for baked clays which contain single domain grains, as is the case in the burnt mud brick samples (Downey, 2011) and probably the magnetic carrier in the sherds in this study, the TRM acquisition after natural slow cooling can be higher by 5% to 12% than that acquired (after rapid laboratory cooling), producing an overestimate of the archaeointensity value.

However, the cooling rate effect is considered significant only if it is higher than the 'alteration factor' otherwise it is impossible to estimate whether the TRM acquisition capacity has changed because of the cooling rate effect or because of mineralogical changes (De Marco *et al*, 2008). This alteration factor given as a percentage relates to changes in TRM acquired before and after heating in order to investigate if any there had been mineralogical alterations during the slow cooling rate stage. In this study, monitoring of low field susceptibility after each successive heating and cooling step indicated that there were no thermally induced mineralogical changes.

Dodson and McClelland-Brown (1980) showed that for a given group of grains, the effective blocking temperature is lower in the case of slow cooling and therefore the fractional alignment that is blocked-in, is higher, both because of the reduced thermal agitation at the lower temperature and because of the intrinsic increase of activation energy. According to Fox and Aitken (1980) it would be desirable to use a laboratory cooling time of the same order as the presumed archaeological cooling time.

Anisotropy of magnetic susceptibility (AMS) is a reliable petro-fabric indicator as numerous studies have shown for laboratory and natural materials and there are many factors which control it. De Marco *et al* (2008) report that the degree of magnetic anisotropy K_{max}/K_{min} may vary greatly from 6.5% to 58% but there is no correspondence of the anisotropy degree with the type of structure or the way it was constructed. It appears to depend on the type of material. For 'baked' clays (burnt mud brick) or pottery sherds as in this study, the anisotropy degree is generally lower than 12% but in some cases, correction factors of only 1.5% need be applied. Morales *et al* (2006) report that in some TRM acquisitions, no anisotropy corrections are applied since the AMS is less than 1%.

In view of the varied arguments presented above and in the absence of specific cooling rate correction factor or anisotropy measurements for the samples used in this study, a reduction of the archaeointensity value obtained, between 6% and 12% as suggested by Fox and Aitken (1980) (ie) 9% ± 3% , has been applied. This reduces the archaeointensity value to 49.6 μT ± 1.6 μT. (Table 1).

This mean value for F^A is used in the formula and compared to the 'Geomagnetic Field Variation' plot, (Xanthakis and Liritzis, 1991) showing (F^A/F^D -1) against Age (years), {$F^D = 0.309 (4 - 3Cos^2L)^{1/2}$ }, F^A is the ancient geomagnetic field, F^D is the axial dipole field and L is the latitude of the site. The F^D value is calculated to be 0.443 Oe. (44.3 μT) for the sites Rhodes and (F^A/F^D -1) = 0.12 ± 0.03. (Table 1, Fig. 3). The intersection of this value on the Geomagnetic Field Variation plot, shows the probability density of possible dates between ~1000 to ~1500 AD. (which includes the High and Late Middle Ages).

Another, but entirely unlikely possible date (intersection) occurs between ~ 1700 to ~ 1500 BC and a much younger date at ~1750 AD. (Fig. 3). During the Medieval period, the geomagnetic field intensity change with time was within narrow limits, thus making it difficult to determine an exact date (Liritzis, 1989; Aitken *et al*., 1989).

The archaeointensity (49.6 μT) result is also compared directly to the SCHA.DI-00 palaeosecular variation curve obtained for Sofia (Bulgaria) (Pavon-Carrasco *et al* 2008), which is ~ 6 degrees latitude north of Rhodes, where the archaeomagnetic intensity value is considered to be of similar value and gives an age ranging from ~1420 – 1480 AD.

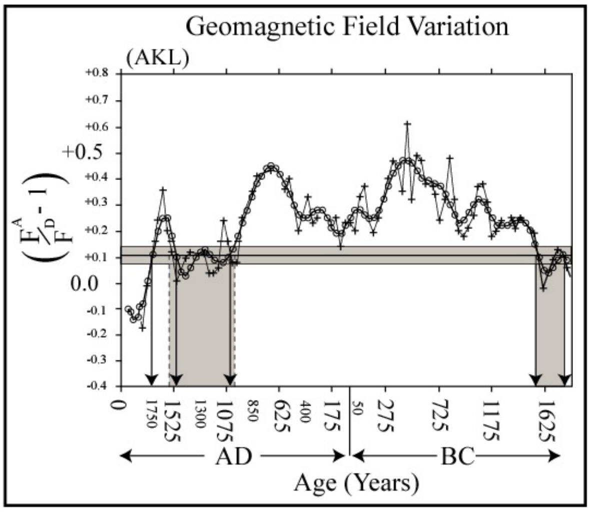

Figure 3. Geomagnetic Field Variation (after Xanthakis and Liritzis,1991, modified). Where F^A is Geomagnetic Field and F^D is Axial Dipole Field, calculated from:- $F^D = 0.309\ (4 – 3\ Cos^2\ L)^{½}$: where L is site Latitude (36.4°N). F^D = 0.443. Intersection of reference curve shows probability density of possible dates with errors (grey shading).

The SCHA.DI.00 model was developed using the Spherical Cap Harmonic Analysis (SCHA) technique applied to five of the Bayesian Palaeosecular Variation Curves (Gallet et al., 2002; Schnepp and Lanos, 2005; Marton and Ferencz, 2006; Gomez-Paccard *et al.,* 2006 and Zananeri *et al.,* 2007). The date is also consistent with the archaeointensity secular variation curve record obtained for Bulgaria by Kovacheva *et al.,* (1998), while it concords with the evidence of intensity variations demonstrated earlier from Greek and Bulgarian churches during same period of interest (Liritzis and Kovacheva, 1992). The date is also consistent (~ 1500 AD.) with the most recent archaeomagnetic Bayesian SV curves for Greece (calculated at Athens), De Marco *et al*., (2008).

CONCLUSION

The single heating modified Thellier method with an orthogonal sample preparation approach, which also reduces shape anisotropy effects, shows that, meaningful archaeointensity results can be obtained. The age range presented here ~1000 to ~1500 AD, from a limited number of pottery sherds, present in the mortar of the Rhodian Byzantine church walls, appears to be consistent with the incorporation of contemporary pottery (Middle Ages) (ie) during the most recent building phase.

However, older pot- sherds, re-used from previous destruction rubble, may also be present or may even have been imported from another region entirely. Pottery derived from further afield is a possibility but would have to come from some distance where the geomagnetic field intensity was significantly different.

Only preliminary results are presented here and a more comprehensive sampling programme, under progress, may reveal the presence of more ancient pot- sherds, as well as, better defining the ages of the Medieval sherds.

ACKNOWLEDGEMENTS

We would like to thank the Rhodes Archaeological authority who permitted the sampling of the Churches and the University of Botswana who funded the research visit (WSD). We would also like to extend our thanks to the referee on this paper for the comments and constructive criticisms and to Phua Eng Siong, (University Brunei Darussalam) for his technical assistance.

REFERENCES

Achimastou-Potamianou, M. (2004). Thorakion, Dedication to the memory of P.Lazarides. The wallpaintings of Bardanis family at Aghios Nikolaos in Foundoukli of Rhodes, Athens, 247-260 (with English summary 261-262).

Aitken, M. J. (1981). Archaeomagnetic determination of the past geomagnetic intensity using ancient ceramics: allowances for anisotropy. *Archaeometry* 23, 53-64.

Aitken, M.J., Allsop, A.L., Bussell, G.D., Liritzis, Y. and Winter, M.B., (1989). Geomagnetic intensity measurements using bricks from Greek churches of first and second millenia *AD. Archaeometry*, 31, 1, 77-87.

Barbetti, M. F., McElhinny, M. W., Edwards, D. J. and Schmidt, P. W. (1977). Weathering processes in baked sediments and their effects on archaeomagnetic field-intensity measurement. *Physics of the Earth and Planetary Interiors* Vol. 13. Issue 4, 346-354.

Bowles, J., Gee, J., Hildebrand, J. and Tauxe, L. (2002). Archaeomagnetic intensity results from California and Ecuador: evaluation of regional data. *Earth and Planetary Science Letters.* Vol. 203, Issues 3-4, 967-981.

De Marco, E., Spatharas, V., Gomez-Paccard, M., Chauvin, A and Kondopoulou, D. (2008). New archaeointensity results from archaeological sites and variation of the geomagnetic intensity for the last 7 millenia in Greece. *Physics and Chemistry of the Earth.* 33, 578-595.

Dodson, M. H. and McClelland-Brown, E. (1980). Magnetic blocking temperatures of single-domain grains during slow cooling. *Journal of Geophysical Research: Solid Earth* (1978 – 2012). Vol. 85, Issue B5, 2625 – 2637.

Downey, W. S. (2011). Archaeomagnetic Directional Determinations on Various Archaeological Materials from the Late Minoan Destruction Site at Malia, Crete. *Mediterranean Archaeology and Archaeometry.* Vol.11, No. 1, 21-31.

Fox, J. M. W. and Aitken, M. J. (1980). Cooling-rate dependenceof thermoremanent magnetization. *Nature,* Vol. 283, 462-463

Gallet, Y., Genevey, A. and Le Goff, M. (2002). Three Millennia of Directional Variations of the Earth's Magnetic Field in Western Europe as revealed by Archaeological Artefacts, *Phys. Earth. Inter*, 131, 81 – 89.

Gomez-Paccard, M., Lanos, Ph., Chauvin, A., McInstoch, G., Osete. M. L., Gatanzariti, G., Ruiz-Martinez, V.C. and Nunez, J. I. (2006). The First Archaeomagnetic Secular Variation Curve for the Iberian Peninsula. Comparison with other Data from Western Europe and with Global Geomagnetic Field Models, *Geochemi., Geophys., Geosyst*, 7, Q12001, doi; 10.1029/2006GC001476.

Hill, M. and Shaw, J. (2000). Magnetic Field Intensity for Historic Lavas from Mt. Etna using Microwave Demagnetization/Remagnetization in a Modified Thellier-type Experiment. *G. J. Int.*, 139, 583 – 590.

Marton, P. and Ferencz, E. (2006). Hierarchical verses Stratification Statistical Analysis of Archaeomagnetic Directions : The Secular Variation Curve for Hungary, *Geophys. J. Int.* 164, 484 – 489.

Molyneux, L. (1971). A complete result magnetometer for measuring the remanent magnetization of rocks, *Geophys.J.R. Astr. Soc*. 24, 429-434

Morales, J., Goguitchaichvili, A and Urrutia-Fucugauchi, J. (2006). Cooling rate effects on the magnetization of volcanic rocks: Some implications for palaeointensity determination. *Geofisica Internacional*. Vol. 45, No. 2.

Orlandos, K (1948) Archives of Byzantine monuments of Greece. Magazine Vol VI, Estia Press, Athens, 24-28.

O'Reilly, W., (1984). Rock and Mineral Magnetism. Blackie, Glasgow, London.

Pavon-Carrasco, Fco. J., Osete, M.L., Torta, J.M and Gaya-Pique, L.R. (2008). A Regional Archaeomagnetic Model for the Palaeointensity in Europe for the last 2000 Years and its Implications for Climate Change. *Pure and Applied Geophysics*. 165, 1209 – 1225.

Sifopoulos T.E (2004) From Brigindarion municipality to Afandou, Rhodes (in Greek) Kono, M. and Ueno, N. (1977). Palaeointensity determination by a modified Thellier method. *Phys. E. P. Int.* 13, 355-359.

Kovacheva, M., Jordanova, N. and Karloukovski, V. (1998). Geomagnetic Field Variations as Determined from Bulgarian Archaeomagnetic Data. Part II: The Last 8000 Years. *Surveys in Geophysics*, 19, 431 – 460.

Liritzis Y. and Kovachena M. (1992). Evidence for sharp changes in the archaeomagnetic intensity variation during the last 2000 years. *Physics of the Earth and Planetary Interiors* 70, 85-89

Liritzis Y., (1989) Greek archaeomagnetic intensities; Some aspects of reliability and geophysical implications. *Earth, Moon and Planets*, 47, 1-13.

Schnepp, E. and Lanos, Ph. (2005). Archaeomagnetic Secular Variation in Germany during the past 2500 Years, *Geophys. J. Int*. 163, 479 – 490.

Shaw, J., Yang, S., Rolph, T.C. and Sun, F. (1999). A Comparison of Archaeointensity Results from Chinese Ceramics using Microwave and Conventional Thellier's and Shaw's Methods. *Geophys. J. Int*., 136, 714 – 718.

Shaw, J., Walton, D., Yang, S., Rolph, T.C. and Shan, J.A. (1996). Microwave Archaeo-intensities for Pervian Ceramics, *Geophys. J. Int*., 124, 241 – 244.

Xanthakis, J. and Liritzis, I. (1991). Geomagnetic Field Variation as Inferred from Archaeomagnetism in Greece and Palaeomagnetism in British Lake Sediments since 7000BC. *Academy of Athens Publications,* Vol. 53. Athens.

Zananiri, I., Batt, C.M., Lanos, Ph., Tarling, D.H., and Linford, P. (2007). Archaeomagnetic Secular Variation in the UK during the past 4000 Years and its application to Archaeomagnetic Dating, *Phys. Earth Planet. Inter*. 160, 2, 97 – 107.