ΠΡΑΚΤΙΚΑ ΤΗΣ ΑΚΑΔΗΜΙΑΣ ΑΘΗΝΩΝ

ΣΥΝΕΔΡΙΑ ΤΗΣ 10ΗΣ ΙΟΥΝΙΟΥ 1982

ΠΡΟΕΔΡΙΑ ΠΕΡΙΚΛΗ ΘΕΟΧΑΡΗ

ΑΣΤΡΟΝΟΜΙΑ.— **200-yrs cycling of the earths archaeomagnetic field intensity and in related solar-terrestrial phenomena,** *by Yiannis Liritzis**. Ἀνεκοινώθη ὑπὸ τοῦ Ἀκαδημαϊκοῦ κ. Ι. Ξανθάκη.

ABSTRACT

The 200 - yrs quasiperiodicity observed in some solar-terrestrial phenomena, (for example : the C - 14 atoms variations in the atmosphere ; auroral and sunspot records, and released volcanic and seismic activity), has led me to make an initial preliminary study to see if such a periodicity is reflected in the earth's magnetic field intensity variations detected through archaeological pottery and kiln samples.

In the same study, recorded paleointensity changes are related with the variable parameters of solar activity, tree - ring width fluctuations, glacial and seismic activity.

INTRODUCTION

For the period 1800 - 1960 a strong correlation has been found between solar activity (expressed by the numbers of sunspots e.g., by the relative number of Zurich R_z) and certain terrestrial phenomena.

These phenomena include: Geomagnetic indices (aa) (Simon, 1979); Precipitation index (Xanthakis 1975); Annual released seismic energy

* ΓΙΑΝΝΗ ΛΥΡΙΤΖΗ, **Περίοδοι 200 ἐτῶν στὴν ἔνταση τοῦ Ἀρχαιομαγνητικοῦ Πεδίου τῆς Γῆς καὶ σὲ συναφῆ Γήινα καὶ Ἡλιακὰ Φαινόμενα.** Research Center for Astronomy and Applied Mathematics, Academy of Athens.

(Xanthakis 1982); Auroral activity (Simon 1979, Schove 1980), and C-14 variations (Suess 1980). It is the aim of the present investigation to examine if these correlations and periodicities can be found in the paleo-intensity variations of the earth's magnetic field, as revealed by archaeological materials of the past 4.500 yrs.

ASPECTS ON PALEOINTENSITY MEASUREMENTS (ARCHAEOMAGNETIC CURVE)

Over the past two decades, scholarship on paleointensity and the subsequently derived archaeomagnetic curve has resulted in quite a broad geographical coverage, ranging from Japan (Kawai **et al**, 1965, 1972; Asami **et al**, 1972; Hirooka, 1971, and Nagata **et al**, 1963), America (Nagata **at al**, 1964; Du Bois, 1967), Europe (Aitken **et al**, 1964, 1966, 1967; Cook **et al**, 1958; Kovacheva 1976; Bucha, 1970, Barbetti 1977, Thellier 1966, Thellier **et al**, 1959; Brynjolfsson 1957; Abrahamsen 1973; Liritzis **et al**, 1980, and Walton 1979), Russia, (Burlatskaya **et al**, 1970; Rusakov **et al**, 1973), and the East, (Smith **et al**, 1967, and Kawai **et al**, 1972). However, the bias of areal coverage is concentrated in Europe, and in particular in Greece, due to the fact that Greece has an inheritance of wide and varied archaeological material most of which can be dated absolutely or relatively.

Archaeomagnetism depends on archaeological materials having been magnetized at a specific time, so that the present direction and intensity (paleointensity) of their magnetization provides an exact record of the original earth's magnetic field in that location.

Most archaeological materials e. g. pottery, kilns, fired clays, contain some ferromagnetic minerals, such as magnetite (Fe_3O_4) or haematite (Fe_2O_3) and are therefore capable of carrying a permanent magnetization.

These minerals are often highly concentrated in archaeological materials, that is to say they constitute some 5% of the clays from which pottery is made, also occuring as impurities in most archaeological materials.

At high temperatures, above 575 - 675^{0}C, these minerals are non - magnetic, but at lower temperatures, they can be magnetized by any external magnetic field, such as that of the earth, by any of the three main processes-by further cooling, by deposition and by chemical changes affecting their size.

A magnetic field will always try to align the orbits of spinning electrons in a ferromagnetic mineral so that the mineral itself has a magnetisation parallel to that of the external field.

Heat, however, makes the electrons vibrate so that they are more difficult to aling at high temperatures, but can retain their alignment for much longer times at lower temperatures.

This means that, as a clay pot or kiln wall, for example, is cooled, its ferromagnetic minerals only become magnetized when the thermal agitation becomes small enough for the internal magnetic forces to maintain the alignment.

On cooling further, it would first take a few minutes before another magnetic field could change their alignment and by the time the pottery has reached room temperature then it would take a magnetic field of the strength of that of the earth for some thousands, millions or even billions of years to change the magnetic orientation already acquired by ferromagnetic particles some 10^{-5} to 10^{-3} cm in diameter.

This means that when the magnetization of these particles is measured very much later, the strength of their magnetization will be directly related to the strength of that original field (thermoremanent magnetism, trm).

Some factors contributing to errors are the viscous magnetization (building-up of natural term by time), chemical magnetization, strong external fields, mineral changes on heating, magnetic instability of small or most large ferromagnetic grains and magnetic anisotropy.

For paleointensity determinations on Cretan kilns, Shaw's method was used (Shaw 1974). This method involves the comparison of the alternating field (a.f.), demagnetization curves of an n.r.m (natural remanent magnetism, acquired in the kiln sample during its last firing), and of a partial t.r.m (partial thermoremanent acquired during colling down from the laboratory field) given in a known field in the laboratory.

The Ancient Field strength / Field in Laboratory, is calculated as the gradient of the best fit line of the nrm-trm plots.

Kono's and Coe's correction and modified versions, respectively, were applied to the samples (Kono, 1978, Coe, 1967); while certain other test were carried out to increase the reliability of the measurements.

Thus, the strength of the geomagnetic field in Greece has been determined for Crete during Minoan and Roman times the dates being provided by the thermoluminescence dating method by myself (Liritzis 1979, Liritzis and Thomas 1980, Liritzis and Galloway 1981).

The material used was Kiln wall samples from three Minoan palaces, of Phaistos, Hagia Triada, Kato Zakro, from the Minoan Village at Stylos Hania and a Roman kiln at Kalo Horio Mirambelo (Liritzis and Thomas 1980, Thomas 1981) and for the other sites pottery samples, repeated by Aitken for Crete 1982, (pers. comm.) and on pottery by Walton, (1979), Kovacheva (1976), Rusakov **et al**, (1973), and Bucha (1970).

DISCUSSION ON THE APPROX. 200 - YRS CYCLES OF PALEOINTENSITY CURVE

Fig. 1. shows the basic archaeomagnetic curve from Greece which is supplemented here, by certain points derived from the Bulgarian and Checkoslovakian curves.

The varied nature of the data on paleointensity, (i. e. Hypothetical Modelling of Dipole Axis movements, Westward effect, see APPENDIX I), requires the inter-comparison of curves composed from data derived by various models.

When the Greek composite curve is compared with a curve from Mexico and another from India, a broad similarity is seen to exist though the later two are lacking in short term variations and they have a time lag of 600 yrs. This is probably due to Westward Drift at around 120^0/600 yrs (Bullard **et al**, 1950, see APPENDIX I). For China, this time lag is around 1100 yrs and for Japan around 600 yrs from the Greek composite curve.

Arrows in the abssisca indicate the great earhquakes historically reported, while certain periods are called after particular archaeological or historical phases. The following comments can be made :

From Fig. I., there is an approx. 200 yrs cycling of minima (or maxima).

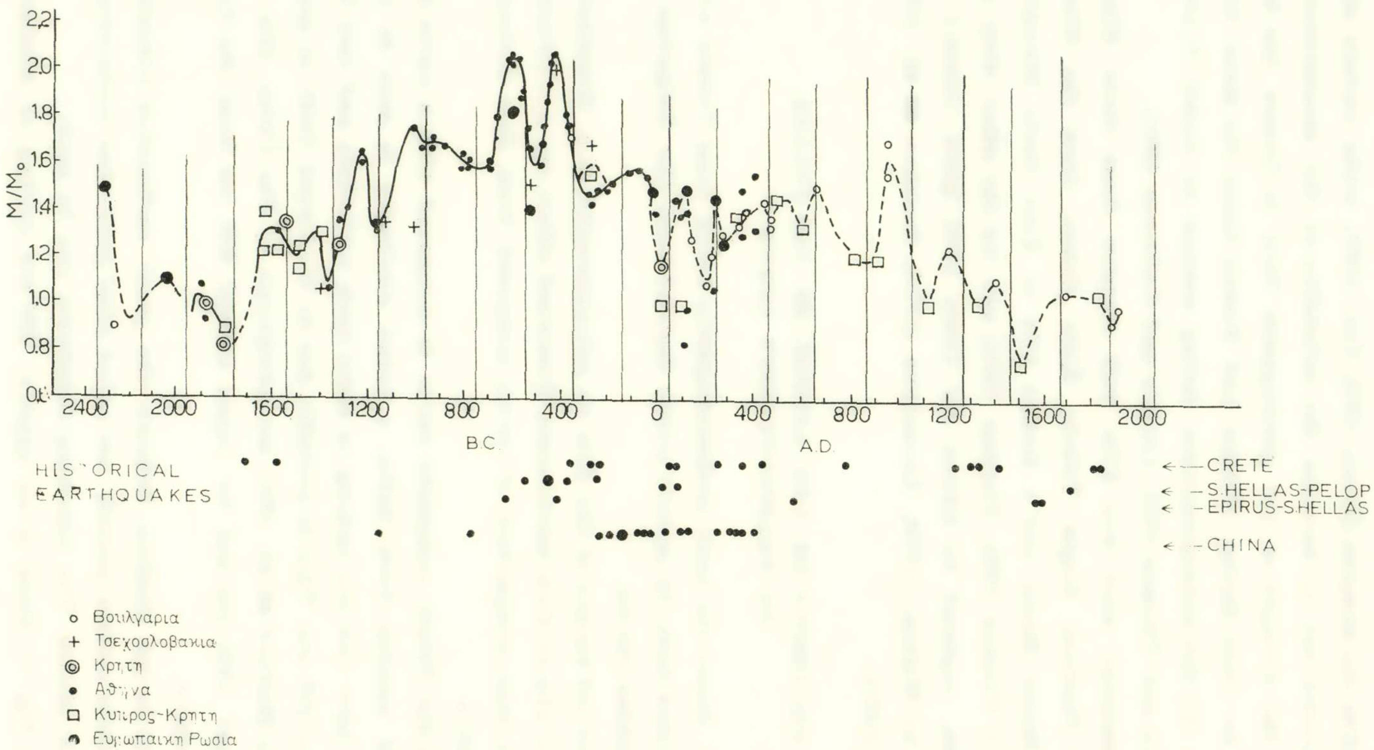

Fig. 1. Archaeomagnetic curve. Each entry corresponds to a 200 yrs length. Beyont 2500 yrs b. C. the dating errors involved are of the order of 300 yrs and thus it is not expected the 200 yrs periodicity to be seen; while any longer period can be defined. (o Bulgaria, + Tsechoslovakia, ⊙ Crete, ● Athens, □ Cyprus - Crete, ● European part of U.S.S.R).

Especially around the christian era, we observe short term fluctuations, (Shaw and Barbetti, also report such erratic changes on samples from Glozel, Barbetti, 1976).

The suggested curve of the 200 yrs paleointensity peak beyond 1500 yrs BC is probably due to the lack of more data, and large errors involved in both dating and paleointensity measurements (that is why the same work is planned for on well dated and documented materials covering the last 2000 yrs). It is worth noticing that in some 200 yrs entries, there is not a certain peak, eg. 460 - 660 AD., 660 - 860 AD., 1260 - 1460 AD., 1460 - 1660 AD.

More data are of course needed ; while provisionally we could expect to see the missing paleointensity peaks in these periods, as well as beyond 2000 yrs B.C. A symmetry around 400 - 800 B.C. is seen, and another periodic term, longer than the 200 yrs appears, with the 200 yrs cycles superimposed on to this longer period. Some points (mostly Bucha's) do not fit the basic curve. Instead, such points would rather spoil the general trend of the 200 yrs cycling, and are not accounted for (reservations are however expressed for Bucha's data, Creer, Aitken, pers. comm.). Aitken's tentative data (squares), though in some cases smoothes-out the general trend, in other cases, especially between 950 - 1500 AD give lower intensities. Here it should be mentioned that those measurements have accounted for the magnetic anisotropy, while on the other hand the average of many samples inheres large probable dating error limits (Walton, 1979, 1982, Rogers **et al**, 1979).

This observation for the existence of a quasiperiodic term of 200 yrs in the earth's magnetic field has led me to plan a more complete mathematical analysis of the available magnetic data in order to obtain a more reliable representation of the existent periodic terms.

The paleointensity peaks are of varied magnitude, a quasiperiodicity of approx - 200 yrs cycles probably superimposed on a longer periodic terms.

The reason for fluctuation of the magnetic moment and subsequently paleointensity values, should be found in the sources of she earth's magnetic field i.e. hydromagnetodynamic processes in the core's motion and in the core and mantle electromagnetic coupling. (Hide, 1966, Yukutake 1973, Rochester **et al**, 1975).

However, provisional theoretical calculations based on the free-oscillations of the fluid core give the 200 yrs periodicity under certain conditions.

From historical sources the occurance of earthquake activity (in Greece and China) with reported catastrophic effects seem to be in anti-correlation with maxima of the paleointensity curve (fig. 1) (for reported data see, Galanopoulos 1955, Lee, **et al** 1979). A general observation is that many consecutive earthquakes result in erratic and short-term changes of the magnetic field intensity. (It has been documented that earthquakes occur at around $2^{1}/_{2}$ yrs in advance of Volcanic eruptions, Thorarinson, 1978).

OTHER APPROX. 200 YRS PERIODICITIES IN SOLAR TERRESTRIAL PHENOMENA

The cycle of approx. 200 yrs has been found in other solar-terrestrial phenomena; while there are indications of the relationship of geomagnetic intensity variations with such phenomena.

These periodic phenomena include:

1) In a recent paper by Xanthakis (1982), possible periodicities of 180 yrs of the annual released planetary seismic energy ($M \geqslant 7.8$) during the period 1898 - 1977 has been found, as Kalinin **et al**, (1978) suggested some years ago. Xanthakis (1975, 1982) has also found a correlation between seismic activity and the precipitation index with Rz but for 11-yrs cycle of solar activity;

2) The period of 150 and 200 yrs has been found in a Fourier spectrum analysis of C-14 variations by Neftel (pers. comm. to Suess, 1980) from data of the La Jola radiocarbon laboratory.

3) Schove (1980) has also found periodicities of 200 - 205 yrs in Auroral and sunspot records mainly since AD 200, that were collected as part of the spectrum of Time Project, (from data by Keimatsu, 1976).

4) A solar cycle of 180 - 200 yrs was also postulated by Schove (1955) on the basis of multivarious reports from China and Europe (Lamb 1972, vol. 1, p. 22).

5) The sunspot number, expressed by Rz correlate with C-14 variations in atmosphere and Auroral activity (Lamb, 1972). In fact Vailev

and Kandaurova (1970) have postulated the existence of a cycle of 170 yrs almost period and its frequency spectrum for solar activity.

6) There is some evidence of quasiperiodic componets of volcanic activity variation, including one of about 200 yrs length. (Lamb, 1977, vol. 2, p. 694).

7) Climatic fluctuations of about 200 yrs in length have been indicated in a considerable diversity of climatic data (Lamb, vol. 1, ch. 6) and in the isotope measurements in the Greenland ice sheet stratigraphy, as well as in the fossil evidence of the quantity of radioactive carbon (C-14) in the atmosphere, (Suess 1970). Provisionally, all these fluctuations are taken to be of solar origin, (similarly fluctuations of around 80 and 100 yrs).

8) Also it is known that the indices of Geomagnetic activity (a.a) (for 1870 - 1980) follow the curve of solar cycle R_z with a time lag of 1 year for the minima, (Simon, 1979).

Overall, the correlations and periodicities between solar-terrestrial phenomena as well as the approx. 200 yrs cycle found here, in the earth's magnetic field intensity, are important considerations for the studies on the investigations of possible links and the related mechanisms between Solar-Terrestrial phenomena.

Acknowledgments. I wish to express my sincere gratitudes to Prof. Xanthakis and Dr. Petropoulos for initiating and stimulating discussions, and to both Prof. Creer for his valuable comments, and Dr. Aitken for supplying me with his unpublished data which ought to be considered as provisional.

APPENDIX I

The earth's magnetic field has several components each of which vary irregularly.

The secular or long-term variation is thought to be compounded of (i) the main Dipole field of the earth, which has its North Pole to the north of Hudson Bay and is static over long periods, and, ii) of several regional distrurbances-non-Dipole field-which is distributed erratically and have ranges of up to 1000 miles.

These regional disturbances have a limited period of growth and decay and move westwards at a rate of about 1^0 in 5 years.

For this reason the direction and intensity of the earth's magnetic field at one place does not necessarily have a completely systematic relation to its direction and intesity at another place some hundrends of miles away.

The westward drift of the non-dipole fields relative to mantle has long been considered the cause of the variation in the secular field even without changing the intensity and the direction of the dipole field.

However, Kawai and Hirooka support that their hypothetical wobbling dipole field is a more important cue to the secular variation. (Kawai and Hirrooka, 1967).

Bullard **et, al** (1950) have investigated the westward drift of the non-dipole part of the earth's magnetic field and of its secular variation for the period 1907 - 45. It was found that a real drift exists, having an angular velocity which is independent of latitude. For the non-dipole field the rate of drift is 0.18 ± 0.015^0/yr, that for the secular variation is 0.32 ± 0.067^0/yr.

The drift is explained as a consequence of the dynamo theory of the origin of the earth's field.

This theory requires the outer part of the core to rotate less rapidly than the inner part. As a result of electromagnetic forces the solid mantle of the earth is coupled to the core as a whole, and the outer part of the core therefore travels westwards relative to the mantle, carrying the minor features of the field with it.

ΠΕΡΙΛΗΨΗ

Χρησιμοποιήσαμε μετρήσεις τῆς ἔντασης τοῦ ἀρχαιομαγνητικοῦ πεδίου πού ἐκάμαμε στὰ ἀγγεῖα καὶ κλιβάνους τῆς Κρήτης (κατὰ τὴ Ρωμαϊκή, καὶ Μινωϊκὴ ἐποχή), ὅπως ἐπίσης τοῦ ἀρχαιομαγνητικοῦ πεδίου τῆς γῆς στὸν Ἑλλαδικὸ χῶρο ἄλλων ἐρευνητῶν γιὰ τὴ χρονικὴ περίοδο 2400 π. Χ. - 1800 μ. Χ. Ἀπὸ τὴ μελέτη τῆς καμπύλης μεταβολῆς τῆς Ἀρχαιοέντασης προέκυψε, ὅτι ἡ μεταβολὴ τοῦ ἀρχαιομαγνητικοῦ πεδίου τῆς γῆς παρουσιάζει περιοδικότητες 200 περίπου ἐτῶν ὅπως καὶ ὁ ἀριθμὸς τῶν ἡλιακῶν κηλίδων, ἡ συγκέντρωση τοῦ C^{14} στὴν ἀτμόσφαιρα, ἐπίσης ἡ σεισμικὴ καὶ ἡ ἡφαιστιακὴ δραστηριότητα σὲ πλανητικὴ κλίμακα, καὶ ἡ συχνότητα τῶν σελάων.

BIBLIOGRAPHY

N. Abrahamsen, J. Geomagn. Geoel. 25, 105-111, 1973.

M. Aitken et al., Nature 201, 4920, 659-660, 1964.

———, Archaeometry, 9, 187-197, 1966.

———, Archaeometry, 10, 129-135, 1967.

E. Asami et al., Japan Memoirs of the Faculty of Literature and Science, Schimaue Univ., Natural Science 5, Matsue, Japan, 1972.

M. Barbetti, Archaeomagnetic Analysis of Six Glozelian Ceramic Interfaces, Archaeomagnetism and Glozel, ed. Delaporte, Paris, 1977.

V. Bucha, Phil. Trans. Roy. Soc. London A 269, 47-55, 1970.

Bullard et al., Phil. Trans. Roy. Soc, London A 243, 67, 1950.

S. P. Burlatskaya et al., Archaeometry 12, 78-88, 1970.

A. Brynjolfsson, Adv. Phys. 6, 247-254, 1957.

R. S. Coe, J. Geoph. Res. 72, 3247-3269, 1967.

R. M. Cook - J. C. Belche, Archaeomagnetism: A preliminary Report of Britain. Antiquity XXXII, 167, 1958.

R. L. Du Bois, Some Features of the secular variation of the geomagnetic field. Space magnetic exploration and technology symposium, Reno, Univ. of Nevada, 1967.

A. G. Galanopoulos, Annal. Géol. des pays Hellén. **6**, 83-121, 1955.

K. Hirooka, Archaeomagnetic study for the past 2 000 yrs in South West Japan, Mem. Fac. Sci., Kyoto Univ Series of Geol. and Mineral vol. XXXVIII No 2, 167-207, 1971.

R. Hide, Royal Society philos. Trans. 259 A, 615-647, 1966.

M. Kaimatsu, Ann. Sci Zanazawa Univ. 13, (1), 1-33, 1976.

Yu. Kalinin - V. M. Kisselev, Int. Solar Terrestrial predictions, Proceed. vol. 2, E. R. Donnely, Publ. U. S. Dept. of Commerce, 1980.

N. Kawai et al., Archaeomagnetic studies in Southern Japan. Annales de Geophys. vol. 21, No 4, 1965.

M. Kono, Geophys. J. R. Astr. Soc. 54, 241-261, 1978.

N. Kawai et al., Nature 236, 1972.

M. Kovacheva, Archaeometry 18, 1, 99-106, 1976.

B. M. Lamb, Climate: present, past and future, vol. 2, edit. Methuen, Barnes and Noble N. York, 17, 1972, 1977.

W. H. Lee - D. R. Brillinger, On Chinese earthquake history. An attempt to Model an incomplete data set by point process Analysis. Geophys. vol. 117, 1229-1231, Birkhanser Verlag, Basel, 1979.

Y. Liritzis - R. Galloway, PACT Journal, in press, 1981.

———, Ph. D. Thesis University of Edinburgh, England, 1979.

———, R. Thomas, Nature **283**, 5742, 54-55, 1980.

T. Nagata et al., Scient. Rapp. No 3, Univ. Pittsburg NSFGF - 75, 1964.

———, J. Geoph. Res. **68**, 18, 5277, 1963.

Cr. M. Rochester - A. J. Jacobs - E. D. Smylie and F. K. Chong, Geoph. J. R. astr., Soc., 43, 661 - 678, 1975.

O. M. Rusakov - G. F. Zaguiy, Archaeometry **15**, 275, 1973.

J. Rogers - W., H. J. Fox - M. Aitken, Nature, 277, 644 - 646, 1979.

J. Shaw, Geoph. J. R. Astr. Soc. 48, 263, 1974.

D. J. Schove, J. Geophys. Res. **60**, 127 - 146, 1955.

———, Auroral, Sunspots and Weather mainly since A. D. 12C0, NATO conference, 1980.

A. Simon, Sol. Phys. **63**, 399, 1979.

P. J. Smith - J. Needham, Nature **214**, 5094, 1213, 1967.

H. E. Suess, in Radiocarbon Variations and absolute Chronology Proc. 12th Nobel Symp., Upsala 1969 ed. I. Wolsson N. York (Wiley) and Stockholm (Almavist & Wiksell), 1970.

———, Sun and Climate, Int. Conf. Toulouse Ed. CNES p. 307, 1980.

F. Thellier, Nucleus **7**, 1 - 35, 1966.

E. Thellier - O. Thellier, Annales Géophys. 15, 285, 1959.

R. Thomas, Ph D Thesis, Edinburgh University, 1981

Thorarinson, Thera and the Aegean World, Acta I, ed. C. Doumas, Bishopsgate, London, 1978.

Vailev and Kondaurova, Solts. Dannye No 1, p. 92, No 2, p. 106, 1970.

D. Walton, Nature 277, 643 - 644, 1979.

———, Nature, 295, 512 - 515, 1982.

J. Xanthakis, Proceedings of the first European Astronomical Meeting Athens, September 4 - 9, 1972. Volume 1, 1975.

J. Xanthakis, Tectonophysics **81**, 17, 714, 1982.

T. Yukutake, J. Geomag. Geoelectr. 25, 195 - 212, 1973.