RECENT ARCHEOMAGNETIC INVESTIGATIONS IN GREECE AND THEIR GEOPHYSICAL SIGNIFICANCE

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A B S T R A C T

Remanent magnetization vectors recorded in certain archeological structures fired in antiquity provide important geophysical data for the elucidation of the behaviour of the geomagnetic field and hence for the understanding of core dynamics. This paper summarizes the preliminary results so far available for Crete and the Greek mainland. Broadly speaking, these can be interpreted in terms of westward drifting magnetic sources in the uppermost outer core similar to those often invoked to explain the historically recorded secular variation at London and Paris.

ΠΡΟΣΦΑΤΕΣ ΑΡΧΑΙΟΜΑΓΝΗΤΙΚΕΣ ΕΡΕΥΝΕΣ ΣΤΗΝ ΕΛΛΑΔΑ ΚΑΙ Η ΓΕΩΦΥΣΙΚΗ ΤΟΥΣ ΣΗΜΑΣΙΑ

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Π Ε Ρ Ι Λ Η Ψ Η

Αρχαιολογικές δομές που εκτέθηκαν σε φωτιά κατά την αρχαιότητα αποτυπώνουν την παραμένουσα μαγνήτιση και παρέχουν σημαντικά γεωφυσικά δεδομένα για την διελεύκανση της συμπεριφοράς του γεωμαγνητικού πεδίου και την κατανόηση της δυναμικής του πυρήνα. Αυτή η εργασία συνοψίζει τα προκαταρκτικά αποτελέσματα που διαθέτουμε για την Κρήτη και την Ηπειρωτική Ελλάδα. Αυτά μπορούν να ερμηνευθούν με μιά προς Δυσμάς μετακίνηση των μαγνητικών πηγών στον εξωτερικό πυρήνα παρόμοια με εκείνη που συχνά χρησιμοποιείται για να ερμηνεύσει την αιώνια μεταβολή από ιστορικά δεδομένα στο Λονδίνο και το Παρίσι.

INTRODUCTION

Archeomagnetic investigations at several sites in Greece are beginnning to establish a worthwhile interface between geophysics and archeology. In a nation with such a rich heritage this is a welcome development, long overdue. Geophysically, the new data are of interest as a source of knowledge about the past behaviour of the geomagnetic field, in particular the determination of secular variation (SV) patterns and their interpretation in terms of fluid motions in the outer core. Archeologically, the interest lies in the possibility of magnetic dating, once a reference SV curve is established.

Field procedure consisted of collecting several small (~10 gram) samples from in situ fired structures, usually kilns, but

including wall and floor material of buildings destroyed by fire. Each sample (usually about 10 per structure) was carefully orientated by means of a solar compass and bubble inclinometer. In the laboratory they were set in plaster and drilled into a convenient cylindrical shape (25 mm diameter, 25 mm length). Remanent magnetization vectors were determined by means of standard commercial spinner magnetometers (Schonsted and Molspin) and magnetic stability was tested by progressive alternating field (AF) demagnetization. Some samples were thermally demagnetized in an oven located in a magnetically shielded room in which the field is less than 50 nT. Details of all experimental procedures can be found in Evans (1986, 1991) and Evans & Mareschal (1988, 1989). A useful introduction to the subject in general is provided by Creer et al. (1983).

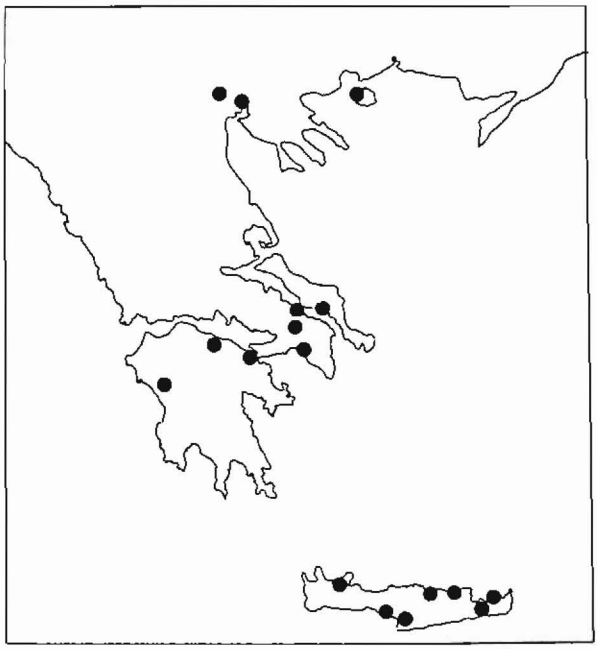

Fig.1. Sketch map showing the sample collection sites. From west to east these are:- Pella, Thessaloniki, Thassos (Macedonia), Olympia, Aegira, Corinth (Peloponese), Penakton, Avlis, Athens, Eretria (Aticca), Hania, Kommos, Agia Triada, Cnossos, Gouves, Vassiliki, Kavousi (Crete).

Sites at which samples have been collected are indicated in Fig.1; at some of them more than one structure has been studied. At the present time, about thirty Greek structures have been investigated. Previous work by the University of Alberta Paleomagnetism Laboratory provides data from a similar number of structures in southern Italy which will eventually facilitate the development of a broad regional interpretation.

RESULTS

For the purposes of discussion it is convenient to divide the various sites into two chronological groups. Archeologically, these are usually referred to as Minoan and Classical; they represent periods of a few centuries centred on dates of ~ 1500 BC and ~ 300 BC, respectively.

A. Classical Sites: Remanence vectors from 5 kilns are summarized in Fig.2. First note that the relative ages of kilns CR and CO (both at Corinth) are known; CR is older. It is also known that kiln CM (at Cnossos) is early to middle 4th Century BC, whereas kiln CO is most likely late 4th Century. These archeologically constrained ages enable us to indicate the direction in which the local geomagnetic field vector was

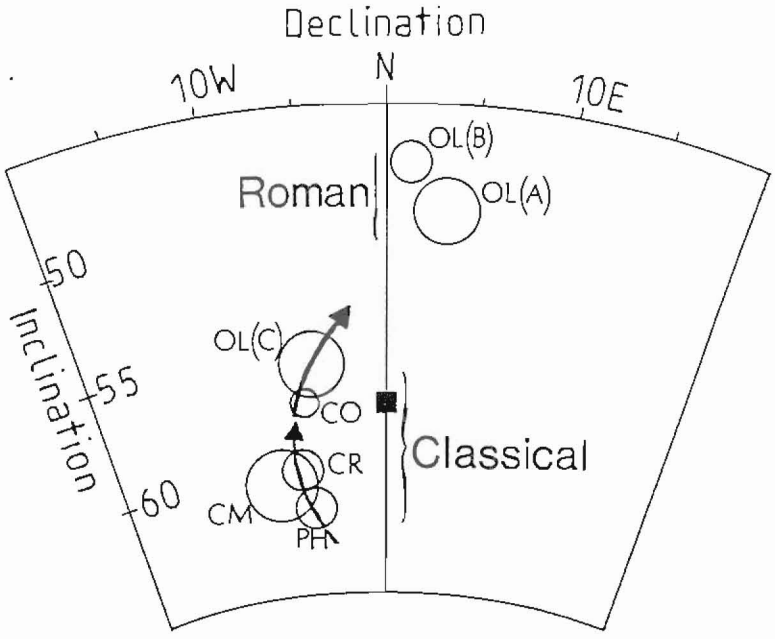

Fig.2. Archeomagnetic vectors for sites Phari (PH, Thassos), Cnossos (CM), Corinth (CR, CO), and Olympia (OL; A, B and C). Circles represent circular standard deviations, large square represents the field direction corresponding to a geocentric axial dipole.

evolving. Declinations were westerly and inclinations were shallowing. This trend is confirmed by the three kilns at Olympia. One of these (C) is Classical but the other two are Roman (i.e. several centuries younger). It would not be prudent to anticipate the actual form of the SV pattern between Classical and Roman times, but the trend to shallower inclinations obviously continues and it appears that westerly declinations give way to easterly ones.

B. Minoan Sites. The relevant data are summarized in Fig.3. Although the structures involved are more than a millennium older than the Classical sites discussed above, the magnetic vectors define a very similar pattern in which the SV again consists of a clockwise open loop. The sequence of directions has implications for the history of destruction of the celebrated palace sites in Minoan Crete, and has been discussed at length by several authors (Downey & Tarling, 1984; Sparks, 1985; Liritzis, 1985, Evans & Mareschal, 1988). It appears that the sites in central Crete were destroyed at a significantly earlier date than those in the east, which argues against the much-discussed suggestion that geological hazards, namely the eruption of Santorini and associated seismic activity, caused the downfall of Minoan civilization.

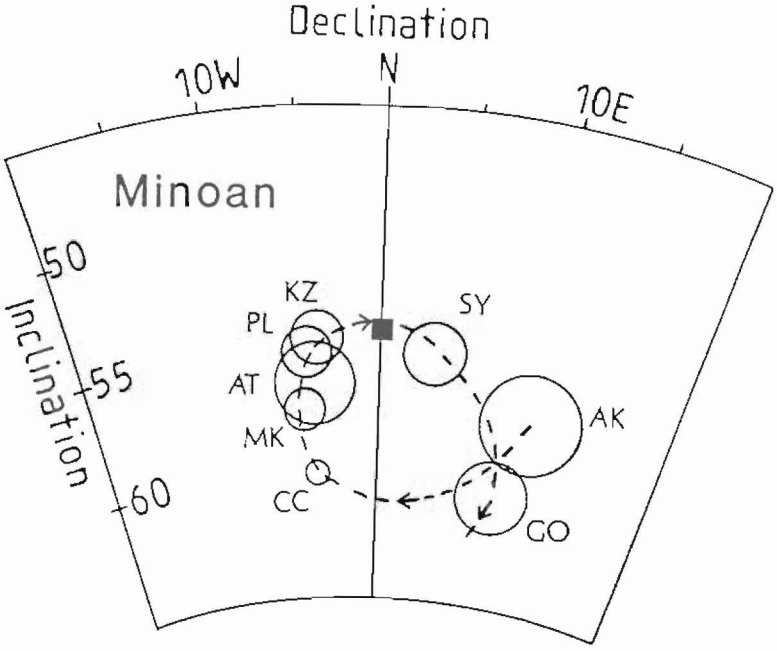

Fig.3. Archeomagnetic vectors for Minoan sites in Crete and Thera. Akrotiri (AK), Central Cretan Palaces (CC, 7 sites combined), Makrygialos (MK), Agia Triada (AT), Palaikastro (PL), Kato Zakro (KZ), Stylos (SY) and Gouves (GO). Circles and square as in Fig.2.

DISCUSSION

Both sets of data described here provide evidence for secular variation (SV) in the form of clockwise open loops of a few degrees diameter. This type of feature is familiar to geomagnetists since the most complete historical record available (the one for London) exhibits the same general morphology (Fig.4). It is generally interpreted as the signature of a magnetic source just below the core-mantle boundary (CMB) undergoing zonal retrograde drift (Malin & Bullard, 1981). In recent years it has proved possible to downward continue the geomagnetic field observed at the surface, and at satellite altitudes, to the CMB (Bloxham & Gubbins, 1985). This important advance has verified the existence of such sources (in this context often referred to as flux bundles) and their drift to the west essentially along lines of latitude. For the archeological and geological past there is a great need for more extensive data, and global coverage is far from complete. Indeed, it is unlikely that the robust type of analysis possible with satellite data will ever be possible for ancient times. Nevertheless, certain broad features can be discerned and these have the enormous advantage of extending the temporal coverage even if the spatial limitations are severe.

Malin & Bullard (1981) demonstrate that the observatory SV record for London (Fig.4) can be attributed to a small magnetic dipole situated just below the CMB and drifting westwards along the line of latitude of London at a rate of 0.17 degrees/year.

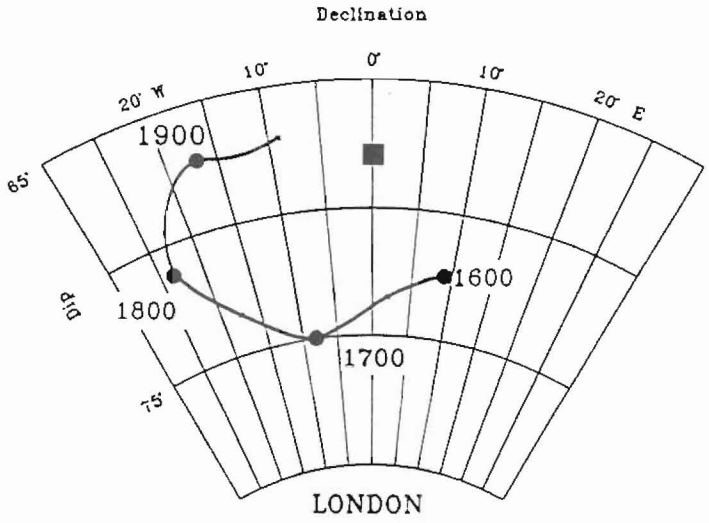

Fig.4. Historical SV observatory record for London (1600-1950 AD). Redrawn from Malin & Bullard (1981). Square represents the field direction due to geocentric axial dipole.

Such a source need only have a magnetic moment of 3% of the main geocentric dipole to adequately explain the historical observations. A similar model can be readily adapted to the archeomagnetic data reported here, as shown in Fig.5. The trajectories shown illustrate the result of allowing a small eccentric dipole to drift along a line of latitude under Greece. If drift is to the west, these paths are traced out in a clockwise direction, and vice-versa, in accordance with Runcorn's rule (Runcorn, 1959). No claim is made for the actual reality of this simple model, the trajectories in Fig.5 are merely provided to show that the main features of the archeomagnetic data can be reproduced by a quite acceptable flux source just below the CMB. A secondary dipole of moment only a few percent of that of the main geocentric dipole suffices to increase inclinations by 5 degrees or so and to deflect the field vector 10 degrees or so to the west, as observed in the archeomagnetic results. If the secondary dipole drifts at a rate of 0.2 degrees/year, then the tic marks indicated in Fig.5 (for clarity, shown only on the 10% curve) represent 50 year intervals. The bulk of the clockwise loops thus cover intervals of a few centuries, which is again consistent with the archeological information.

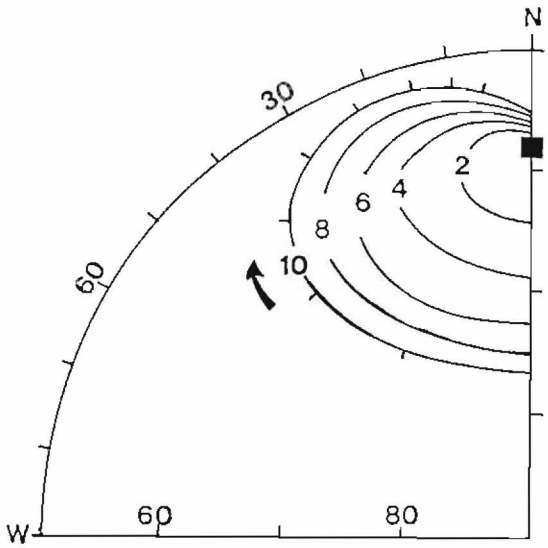

Fig.5. SV trajectories corresponding to the westward drift of a small radial dipole along the 38 N latitude line. The numbers give the strength of the dipole as a percentage of the main central dipole, the direction of which is indicated by the square. (Note that only inclinations greater than 50 degrees are represented).

The historical and archeological data combine to produce an SV pattern in which a clockwise loop spanning a few centuries is traced out three times. Is a repetitive phenomenon involved? The two intervals between the three passages are about 1200 and 2100 years respectively (taking the westerly extrema on Figs. 2,3, and 4 as reference points). This is of the right order to allow complete passage of a single source around the globe (1800 years at 0.2 degrees/year), but this cannot be regarded as demonstrated by the data currently available. It is equally likely that a separate source is responsible for each of the three cases. These can be pictured in the mind's eye like vortices in a river, successively being created, drifting downstream (westward) and gradually dying out. Gubbins (1987) argues that such a flux patch broke from an undulation in the geomagnetic equator beneath Indonesia in the late eighteenth century and drifted westward at an average rate of 0.3 degrees/year. Archeointensity data for the period 500 to 1800 AD (summarized by Evans, 1987) suggest that two similar features, about 700 years apart, have passed between Japan and Bulgaria at an average rate of 0.3 degrees/year giving rise to field enhancements of 50% or more as they passed underneath the observation sites.

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