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Cracking the code of Earth's magnetic mysteries: ancient secrets unveiled by Byzantine bricks reconfirmed by Mesopotamian ceramics

Ioannis Liritzis

Dean of Class IV, Natural Sciences, Alma Mater Europaea ECM University, Maribor, Slovenia

ABSTRACT

The study of the magnetization of artifacts discovered at archaeological sites, such as ceramics or hearth remnants, is known as archaeomagnetism. This technique is based on the idea that some materials get magnetized in the direction and intensity of the Earth's magnetic field at the time when heated or exposed to extreme heat. Development in the field has been made to improve magnetometer devices and sample size, as well as measuring techniques of thermal remanent magnetization. It helped to study the variation of the complex Earth's magnetic field or geomagnetic field (GMF) for both geophysical and archaeological dating benefits. The rapid change in GMF within a few hundred or decades, as being of genuine origin or methodological and sample unsuitability has been a matter of debate. Data from about 40 years ago derived from well-dated Byzantine churches that first confirmed such geomagnetic spikes is discussed along with recent archaeomagnetic data from Mesopotamian inscribed bricks and Levantine slags.

The archeomagnetism of byzantine churches and dating

Construction ceramic tiles and bricks date the Byzantine period based on epigraphic (inscription) evidence in Greek Orthodox Byzantine churches and Monasteries from Mount Athos, and throughout Greece (Figure 1). These religious temples are spread over Greece and the Balkans and beyond in the southern arc of Southeastern Mediterranean-Balkan-Anatolia-Circum Caucasian -Near and Middle East.

Back in 1980s to 90s with my team we utilized ceramic build materials to gain insight into Earth's magnetic field variations last 1500 years. This archaeomagnetic approach was a unique concept that provided a precise method for dating ancient buildings and ceramic fabric artifacts and for understanding the historical geomagnetic field fluctuations.

These old ceramics were built material for Byzantine Churches and have provided important clues into mysterious anomalies in Earth's magnetic field in the past. It was thought the field varies smoothly as a secular variation, and spikes were smoothed out thought was due to technical issues of measurement and/or problematic materials.

The early research that I led (Liritzis, 1989; Aitken *et al*., 1989; Liritzis and Kovacheva, 1992; Kovacheva *et al*., 2007), described how changes in the geomagnetic field preserved on iron oxide grains found in old clay bricks, and how the inscribed texts on the Church concerning their construction allowed scientists to piece together these alterations. Around 70 samples were collected from Greek churches of known age, between 215 AD to 1927 AD (Figure 2). The majority of these samples were taken from bricks forming part of the internal structure of the church and some were from external walls.

The study of Earth's magnetic field through rocks, sediments (geological materials) and ceramics (archaeological materials, hence, archaeomagnetic field) is achieved from measurements of the field's direction (inclination and declination) and intensity.

The archaeomagnetic dating has been used occasionally as a chronological tool. The early investigations using this "archaeomagnetism," looked for signatures of the Earth's magnetic field in archaeological objects. It was anticipated to improve the history of Earth's magnetic field and help better date ceramic artifacts with accuracy that the previously archaeological typology and luminescence dating did not give high accuracy in the order of some years.

Correspondence: Ioannis Liritzis.
E-mail: ioannis.liritzis@euro-acad.eu

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The measurements

Heated minerals that are magnetic field-sensitive have a unique signature of the Earth's magnetic field's gradual weakening and strengthening. The measurements in the Byzantine project were performed with a SQUID cryogenic magnetometer at Oxford (Research lab of Archaeology and History of Art, in collaboration with late Prof Martin Aitken "father" of archaeometry) on carefully chipped tiny fragments from broken faces of the tiles, and bricks.

Iron oxide grains within fired objects contain magnetic strength that can be measured and compared to Earth's known magnetic field strengths throughout history. This technique can be used to date Byzantine Churches and reigns of kings with greater precision than radiocarbon dating, which only provides an approximate date for organic artifacts within a range of a few hundred years. This method is particularly useful for dating objects that do not have inscriptions and have been around for hundreds of years.

Recent data from Mesopotamian and Levantine

Recent work on Mesopotamian bricks and Levantine slags has reconfirmed the earlier obtained short-term variation, and within a lifetime of a king (e.g., ca. 40 years period), a relatively short period the Earth's magnetic field seemed to change dramatically adding evidence to the earlier results from Greece. That is no longer a hypothesis that rapid spikes in intensity are possible, but a confirmation of such a phenomenon. The recent measurements allowed them to construct a broad overview of the Earth's magnetic field behavior over approximately 2,000 years, spanning from the 3rd to the 1st millennia BCE (Howland *et al*., 2023) (Figure 3). In addition, another observation from slag data of the Near East called the Levantine Iron Age Geomagnetic anomaly, a period when Earth's magnetic field was powerful around modern Iraq between about 1050 to 550 BCE for unclear reasons, is another reconfirmation of earlier data.

Evidence of this "anomaly" has been detected in Greece and the Balkans, and as far away as China and the Azores, but data from within the southern part of the Middle East itself had been sparse (Xanthakis and Liritzis, 1991; Shaar *et al*., 2017, 2022; Ben-Yosef *et al*., 2009).

Further research is needed to establish if this is a steady westward shifted Global Iron Age Magnetic Anomaly. Studies on the evolutionary temporal variation of drift rates between comparable GM non-dipole peaks of two distant regions in the World indicate rates between 0.04-0.37° longitude/year. The westward (or eastward) drifting of non-dipole magnetic disturbances is certainly compelling, and the two simultaneous non-dipole peaks cannot be ruled out (Liritzis and Lagios, 1993). Indeed, the so-called Levantine Archaeomagnetic Curve has contributed to the construction of the archaeomagnetic secular variation reconfirming earlier data from Greece and elsewhere. Whereas more than 30 years ago it has been shown the World regional studies on archaeomagnetic and limnomagnetic intensity variation over the past 10,000 years exhibit a periodic variation analyzed by time series methods and smoothing of 100 years even spacing (cubic splines, maximum entropy, Fourier transform with smoothing and cutoff periods between 100-1000 years). Prominent and stationary ones, ca. 1000 years, 4000±500 years, and intermediate periods of 1300-1800 years, and 330-700 years have been obtained. The earlier results were obtained from archaeomagnetic corroborated by limnomagnetic data analysis (from lake sediments), for ancient intensity data F^A presented, cautiously as normalization, as ratios over the dipole field intensity F^D, eq. 1 (assuming axial geometric symmetry at the site's latitude L; M is the publication day magnetic moment

Figure 1. Holy Monastery of Koutloumous at Athos northern Greece, 12th century, a unique monastic state. Sampling was made for the Byzantine project. Credit: https:// koutloumous.com/en/holy-monastery-2/

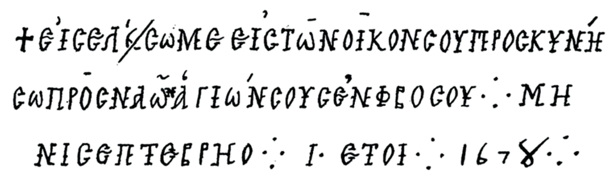

Figure 2. Main Church at Great Lavra Monastery, Athos Mount, inscription on tiles. Credit: https://www.jstor.org/stable/4629222

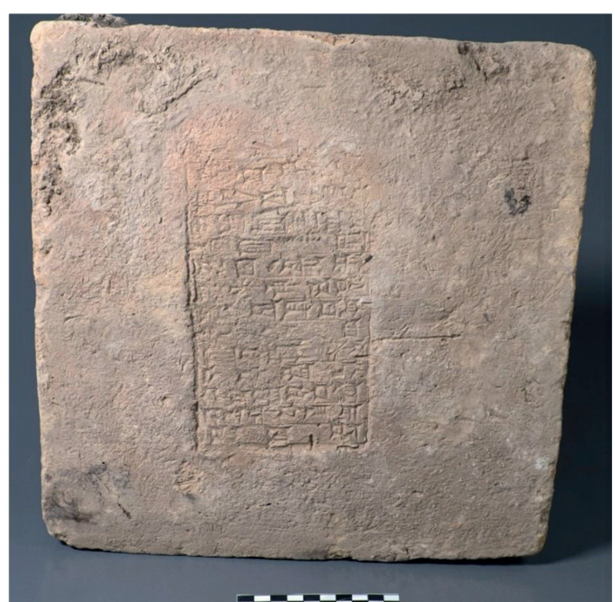

Figure 3. Brick inscribed with the name of King Nebuchadnezzar II, Babylon, c. 604-561 BC (clay) from Slemani Museum. Image credit: Howland *et al*., doi: 10.1073/pnas.2313361120).

$= 8*10^{22}$ Am^2, R the Earth's radius at L ($=M/R^3 \sim 0.309$) (Xanthakis and Liritzis, 1991) (see Figure 4):

$$F^D = \frac{M}{R^3}\sqrt{4-3\cos^2 L} \quad \text{(eq. 1)}$$

The recent publication for Mesopotamia and the Levant together with the earlier first announced Greek data currently contribute to the establishment of a crucial dating baseline so that others might profit from precise dating based on archaeomagnetism. Provided the context -the relation of the artifact or masonry wall to the accurately dated material- is securely controlled. In addition, they shed new light on the complex GMF variation over the Holocene.

Implications and clues on the geomagnetic field

In these earlier Byzantine results important clues were drawn, such as: a) an overall oscillating character in the geomagnetic variation was evident for four latitudinal zones from 35-44^{o}N; b) sharp changes appeared to occur in consecutive 200-300 year intervals and are commensurate with the non-dipole part of the recent (last 400 years) geomagnetic field; c) during the period 900-1400 AD peaked at ca 1300 AD the overall trend between Bulgarian and Greek data is similar for the denoted latitudinal zone; while at around 1000 AD the ~44^{o}N archaeointensities are higher than those at 35^{o}N, and geomagnetic intensity changes within ca. 30 years period by about 32%, and about 27% over 3.7^{o}N latitude; d) rapid changes are observed in other time intervals (100-200 AD, ca.1600 AD, 1000 AD); e) the observed shifts in regional geomagnetic peaks from an area implied a latitudinal drift of an oscillating and drifting source, which grows and decays periodically (Liritzis and Kovacheva, 2002; Liritzis, 1989).

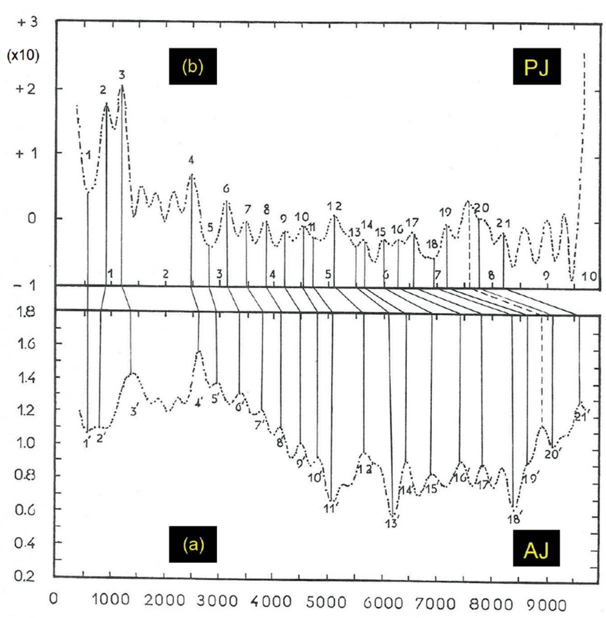

Figure 4. Palaeomagnetic intensity (PJ) from British lake sediments and archaeomagnetic (AJ) intensity, transformation of PJ to AJ time scale. The data are Fourier smoothed with cutoff periods of 300 years. Points 1-21 correspond to 1' - 21'. The AJ values are F^A/ F^D ratios and the PJ values are as (PJ-av.PJ) but Fourier smoothed (after Xanthakis and Liritzis, 1991; Figure 6.1).

In fact, the AD c.1300 coincides with a seemingly anticlockwise to clockwise motion of the magnetic direction and this may imply the development of localized disturbances at the core-mantle boundary, and that it should be recalled that interferences between the growth and decay patterns of two or more standing sources may contribute to rotation of the geomagnetic vector. Thus, two or more geomagnetic sources that grow and then decay as, for example, drift west, would perhaps yield virtual geomagnetic pole paths that exhibit counterclockwise loops, if the influence of the changing variations in their intensity were to outweigh the influence due to that of the movement. Such a short nondipole source may last less than a century (Liritzis, 1989; Skilles, 1970). Various eminent scholars in the past have tackled this issue (Yukutake, Vestine, Runkorn, Creer, Nagata, Kawai, Burlatskaya, Bullard, Bucha) to mention major ones.

One should be very cautious about the spatial dependence of non-dipole field, as well as rapid spikes observed for some areas, as any attempt to smooth out the data may cause a loss of important information.

From the archaeomagnetic data, the dating of ceramic fabric may be possible as these do not contain any organic residue for radiocarbon dating. Especially dating artifacts within a period of smooth monotone variation or a period containing a rapidly changed magnetic field.

Any time bricks and tiles were made in a kiln to use for the construction and decoration of a Church an inscription was written inside at the entrance upper lintel of the Church. This date corresponds within one to two years to the foundation and construction while another inscription refers to its hagiography (mural painting).

The magnetic field is very complicated to interpret with great accuracy, hence regional studies of the field can only contribute to the elucidation of the associated problems. The Greek Monasteries much like other inscribed or indirectly well-dated ceramic material, offer a means to decipher the complex geomagnetic dipole pole wander and non-dipole sources when they grow, faint, and shift. This way a holistic interpretation of the geomagnetic field aided by archaeomagnetic studies enriches our knowledge of Earth's dynamo, and correlation with other solar and terrestrial phenomena, and offers a reliable chronological tool. I urge young scientists to revisit Orthodox Churches/ Monasteries and with the aid of learned priests and architects / archaeologists apply sampling of tiles and bricks, with care which part of a wall to sample; most Monasteries actually include several consecutive chronological constructional phases either from inscription of written documents.

From the rapid geomagnetic changes within a few decades confirmed thanks to the accurately dated Greek Byzantine Churches, but also archaeological ceramics and kilns and recently reconfirmed on well-dated samples, has become clear that it will be necessary to revisit and thoroughly re-examine the cause of those geomagnetic intensity deviations which are of a magnitude greater than those associated with experimental errors. This really ought to have been done long ago as I have maintained in 1989. Instead of only being restricted to more accumulated data alone, the smoothing models, once formulated, are tenaciously adhered to and can yield misleading rather than simply incomplete conclusions. That more archaeomagnetic data should be collected from many more Byzantine tiles and bricks of buildings bearing secure inscriptions corresponding

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to the date of construction, as well as inscribed tiles from other civilizations, is a wishful plea. At present it holds the earlier finding that during the Holocene GMF varies in a sinusoidal-like manner upon which overlap shorter-term quasi-periodic non-dipole GM components.

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