The archaeomagnetic field recorded in ancient kiln walls in Si Satchanalai, Sukhothai

R Supakulopas*

Division of Physical Science, Faculty of Science, Prince of Songkla University, Hat Yai, Songkhla, 90110, Thailand

*Corresponding author's email address: radchagrit.s@psu.ac.th

Abstract. Archaeological dating is crucial in archaeology as it is a key to understand human history. However, traditional dating methods used by archaeologists such as potassium-argon dating and luminescence dating can provide ambiguous age results, e.g., argon loss during the dating returns young apparent ages. Therefore, I plan to establish an archaeomagnetic secular variation (ASV) curve to resolve this problem and use the ASV curve as an alternative tool to date archaeological artefacts. However, archaeomagnetic data in Thailand are absent from literature. Therefore, the ASV curve cannot be constructed from the archaeomagnetic data for this locality. To provide archaeomagnetic data to construct the ASV curve, the directions of the Earth's magnetic field recorded in kiln walls from Ban Ko Noi (KN123, age 1,370 ± 100 A.D.), Si Satchanalai were measured. The mean declination and inclination of 49.6° and 32.6° with 95% confidence limit of 5.4° were determined from 10 samples from kiln KN123. Mean directions from this study were also compared with the directions of the Earth's magnetic field in Thailand during 1,370 A.D. from the global archaeomagnetic field model ARCH3k.1. Declination and inclination from this study show significant departure from the field predicted by the ARCH3k.1 model.

1. Introduction

Archaeological dating methods used by archaeologists in Thailand include radiometric dating [1, 2] and luminescence dating [3, 4]. Despite their robustness, these methods still have some limitations. For example, a large amount of historically materials is used in the radiocarbon dating process [5]. The direct determination of ages cannot be made directly from artefacts such as baked clay or ceramic, but instead peat buried in the same soil layer with the artifacts. Moreover, as we are in a carbon-rich environment, archaeological artefacts can be contaminated by current-day carbon. This leads to a significant error of the samples' ages. With regards to the luminescence dating, the advantage of this method is that the determination of ages can be measure directly from archaeological artefacts. However, this method is considerably time consuming due to sample preparation processes. Furthermore, the data can be disturbed by noises during the dating procedure [3].

Archaeomagnetic dating is considered as an alternative dating of historical artefacts. There are two types of archaeomagnetic dating methods: secular variation (SV) dating [6] and magnetic reversal dating [7]. The first method relies on the directional and intensity changes of the Earth's magnetic field over time. The directional and intensity dating are the local pattern-matching method with the accuracy of ±25 years. This method is suitable for dating of 10-ka samples or younger. The magnetic reversal dating, known as magnetostratigraphy, is based on the global pattern matching of the normal and reverse polarity of the Earth's magnetic field. As the polarity of the magnetic field reverses every ~0.25 Ma, and the current Matuyama reversal chron is ~0.78-2.6 Ma [8, 9], therefore, this method is used to date samples older than 0.78 Ma with the accuracy of ±0.01 Ma [7].

In this proposed research, I focus on the archaeomagnetic secular variation (ASV) dating, which can be considered as a derivative dating method [10]. The technique relies on the Earth's magnetic field trapped in archaeological samples during the first firing [11]. As the geomagnetic field is a vector, both the direction and the intensity of the field are recorded in the artefacts and can be measured directly from the samples [12]. The variations of the direction and intensity, hereafter palaeodirection and palaeointensity, that change over time recorded in the artefacts can be used to construct and calibrate archaeomagnetic secular variation (ASV) curves [6]. The archaeological dating using the ASV curves is a suitable method for dating artefacts such as baked clay, slag, kilns and potteries [13-16]. This method reduces the age error gaps and considerably less time consuming, e.g., measurements of palaeodirection of two samples can be done in 40 minutes. However, no ASV curve in Southeast Asia has been calibrated and constructed, rendering the technique not applicable to date archaeological artefacts in the region. Therefore, the aim of this research is to collect palaeomagnetic data to construct the ASV curve, beginning from the 13th – 17th century samples in Si Satchanalai and Sukhothai, Thailand.

2. Fieldwork in Si Satchanalai, sample preparation and palaeomagnetic measurement

The fieldwork campaign to collect pottery and kiln wall samples was held in October 2020 at Ban Ko Noi and Ban Pa Yang in Si Satchanalai (17.476284°N, 99.755171°E), and Sukhothai historical park in Mueang Sukhothai (17.0326621°N, 99.697276°E). Samples were drilled using a portable electric drilling machine equipped with a diamond drill bit and a water cool system. Samples were orientated and measured azimuths and dips using an orientator before taking the cores out of the drilled holes. Approximately 1-cm diameter cores were drilled from the kiln walls. In case the kiln walls are fragile, brick samples were taken by an axe and a hammer. Before taking brick samples, samples were orientated using a Brunton compass. The Sun compass was not measured in this study as all sites are under the roofs. A total of 33 cores and 18 bricks were collected covering the time spanning ~13th-17th centuries. Then, samples were shipped to the palaeomagnetic laboratory, Prince of Songkla University for preparations and palaeomagnetic measurements. In sample preparation processes, brick samples were cut into 2-cubic centimeter cube using a hand saw, yielding ~6-10 specimen per brick. The natural remanent magnetisation (NRM) directions including declination and inclination were measured using an AGICO JR6 spinner magnetometer. Note that the standard demagnetisations: alternating field (AF) and thermal demagnetisations were not performed here.

3. Results and discussions

The palaeomagnetic directional data obtained from a kiln (KN123, age 1,370 ± 100 A.D. [17]) in Ban Ko Noi, Si Satchanalai are presented here. Declination and inclination data from 10 specimens from kiln KN123 were plotted on an equal area projection (figure 1(a)). The sample mean directions were calculated using the Fisher statistics [18], yielding the mean declination and inclination of 49.6° and 32.6° with the 95% confidence limit (α_{95}) of 5.4°. Overall, the data are tightly cluster on the sphere.

The mean directions were compared with the global archaeomagnetic field model during the past 3 ka, ARCH3k.1 [19]. The ARCH3k.1 predicts the inclination of ~18° with the confidence limit of 3.4° for the site locality during 1,370 A.D. (figure 1(b)). The inclination data deviate from the ARCH3k.1 model with no overlap between the confidence error. With regards to the declination data, the declination data show higher deviation from the ARCH3k.1 model during 1,370 (dec = -1.9° with the confidence error of 3.2°) than the inclination data do (figure 1(a)).

As the mean directions are tightly cluster with the precision parameter $k \geq 50$, and were calculated from 10 specimen per site (the number of specimen per site $N = 10$), it is clear that the data meet the modern site selection criteria of the palaeomagnetic community ($k \geq 50$ and $N \geq 5$) [20]. High departure of the data from the model may be from these reasons. (1) The ARCH3k.1 model was constructed using the palaeomagnetic data during the past 3 ka. Most of the data are from Europe. Minor data are from North America, South America and East Asia. Therefore, the model may have the bias toward Europe. (2) The samples may acquire secondary overprint such as isothermal remanent magnetisation (IRM) induced by lightning strike which occurs commonly in tropical region. Therefore, samples may be partially remagnetised or fully demagnetised by the IRM and the secondary overprint deviates the NRM directions that samples acquired during the time of the kiln production.

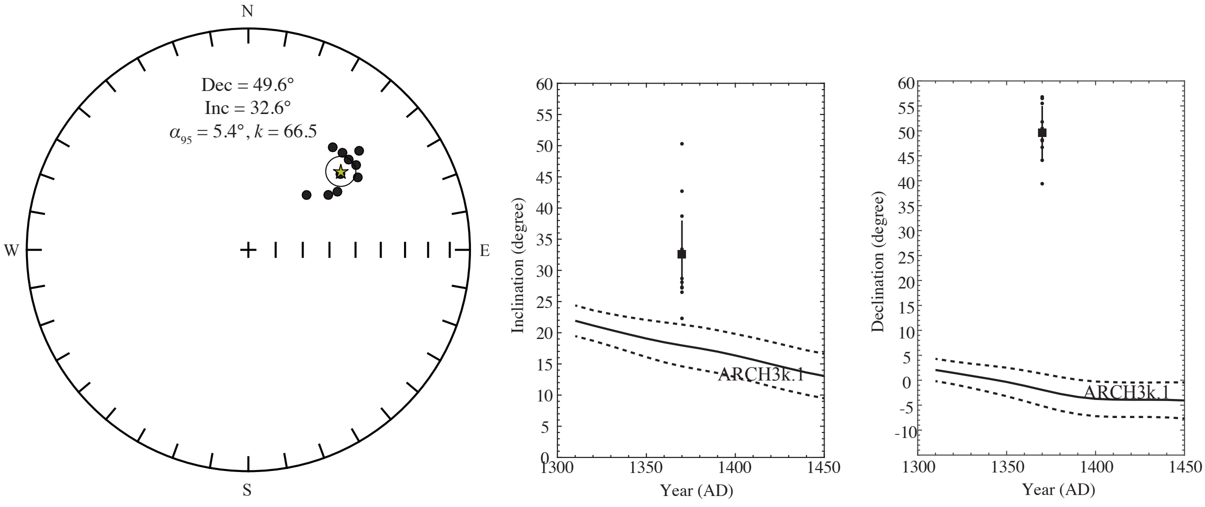

Figure 1. (a) Equal area projection of the NRM directions (black circles) with the site mean direction (yellow star) and 95% confidence cone (circle). (b) and (c) represent the plots of mean inclination and declination (big squares) with the 95% confidence boundaries against the ARCH3k.1 model (black line) with the upper and lower boundaries (dash lines). Black circles show directions from individual specimen.

4. Conclusion

The palaeomagnetic directions from the kiln KN123 show large deviations from the archaeomagnetic field model ARCH3k.1. To examine whether samples acquire secondary overprint after the production time, samples should be fully demagnetised using the standard demagnetisation protocols including stepwise AF and thermal demagnetisations to isolate the characteristic remanent magnetisation (ChRM) acquired during the kiln production time. Rock magnetic properties including hysteresis loops, backfield curves and thermomagnetic curves should also be measured to understand magnetic domain grains, types of magnetic minerals and its Curie temperature. The domain grain information provides coercivity data of magnetic minerals in kilns and confirms whether samples easily acquire secondary overprint. Besides, the palaeomagnetic intensity measurements will be performed to understand the behaviour of the palaeomagnetic field during the 13^{th} – 17^{th} in Southeast Asia.

Acknowledgement

Radchagrit Supakulopas would like to express appreciation to the Faculty of Science, Prince of Songkla University for funding this research under the project grant number SCI6304004S, and archaeologists and staff at Si Satchanalai historical park and Sukhothai historical park for fieldwork support.

References

[1] Sako T 2019 *Ancient Maritime Cross-culture Exchanges: Archaeological Research in Thailand* (Bangkok: Rung Silp Printing Co. Ltd.) pp 167–91

[2] Thongaram B 2019 *Ancient Maritime Cross-culture Exchanges: Archaeological Research in Thailand* (Bangkok: Rung Silp Printing Co. Ltd.) pp 193–207

[3] Puttagan T, Chawchai S, Surakiatchai P, Chalorsantisakul S and Preusser F 2019 *Archaeol. Anthropol. Sci.* **11**(10) 5393–403

[4] Pailoplee S, Won-in K, Chaisuwan B and Charusiri P 2016 *Songklanakarin J. Sci. Technol.* **38**(6) 699–705

[5] Cersoy S, Zazzo A, Rofes J, Tresset A, Zirah S, Gauthier C, Kaltnecker E, Thil F and Tisnerat-Laborde N 2017 *Sci. Rep.* **7**(1) 7141

[6] Sternberg R S 1997 *Chronometric Dating in Archaeology* (Boston: Springer) pp 323–56

[7] Barr S M, Macdonald A S, Haile N S and Raynolds P H 1976 *J. Geol. Soc. Thailand* **2**(1) 1–10

[8] Ogg J G 2012 *The Geologic Time Scale* (Boston: Elsevier) pp 85–113

[9] Haneda Y, Okada M, Suganuma Y and Kitamura T 2020 *Prog. Earth. Planet. Sci.* **7** 1–22

[10] Aitken M J 1990 *Science-Based Dating in Archaeology* (London: Longman)

[11] Cai S, Jin G, Tauxe L, Deng C, Qin H, Pan Y and Zhu R 2017 *Proc. Natl. Acad. Sci. U.S.A.* **114**(1) 39–44

[12] Tauxe L, Butler R F, Van der Voo R and Banerjee S K 2010 *Essentials of Paleomagnetism* (Berkeley: University of California Press)

[13] Donadini F, Motschi A, Rösch C and Hajdas I 2012 *J. Archaeol. Sci.* **39**(7) 2153–66

[14] Ech-Chakrouni S, Hus J and Marchal J P 2015 *Studia Geophysica et Geodaetica* **59**(4) 578–93

[15] Shin S, Park Y H, Cheong D and Shin S C 2018 *Geosciences Journal* **22**(1) 1–9

[16] Stillinger M D, Hardin J W, Feinberg J M and Blakely J A 2016 *Near Eastern Archaeology* **79**(2) 90–106

[17] Barbetti M and Hein D 1989 *World Archaeololgy* **21**(1) 51–70

[18] Fisher R 1953 *Proceedings of the Royal Society of London Series* A **217**(1130) 295–305

[19] Korte M, Donadini F and Constable C G 2009 *Geochem. Geophys. Geosyst.* **10**(6) Q06008

[20] Johnson C L *et al.* 2008 *Geochem. Geophys. Geosyst.* **9**(4) Q04032