Geomagnetism and the Orientation of Temples in Thailand

Toshihiko Iyemori, Michio Hashizume, Akinori Saito, Masahito Nose, Nithiwatthn Choosakul, Toshitaka Tsuda and Yoko Odagi

ABSTRACT—Traditionally a Buddha image should face eastward. Consequently, temples should be oriented in that same direction. Yet in China and elsewhere, the actual orientation has been shown to vary according to the time of construction. Orientations of ancient large temples and their associated structures in Thailand were measured and found to have similar variations. If the orientation of those temples was determined using a magnetic compass, the variation should reflect the Earth's magnetic field drifting over time. The resulting estimates of the geomagnetic field show a westward drift at about 0.2° per year.

The Earth's geomagnetism

Seismological investigation shows that the chemical components of the Earth's core are iron (ca. 90 percent), nickel (ca. 5 percent), and minor elements. The inner core is solid and the outer core is liquid. The Earth's geomagnetic field is generated by an electromagnetic reaction induced by hydrodynamic movements within the outer core known as the dynamo. Simulation of the dynamo would require a computer capable of solving non-linear differential equations in three dimensions using realistic parameters of the properties of materials and appropriate boundary conditions between the outer and inner core, as well as between the outer core and mantle. Such a computer would need a capacity three orders more powerful than the current generation of supercomputers. Simplified computational modeling has demonstrated that hydrodynamic convection in the outer core can generate the magnetic dipole of the Earth (Kageyama and Sato 1997). The dipole is aligned north–south although it is not exactly symmetrical. Through numerical simulation of the movement of the outer core, Glatzmaier and Roberts (1996) predicted that the magnetic field drifts westward if the inner core rotates faster than the outer core, as seismological analysis suggests (Woodhouse et al. 1986; Morelli et al. 1986).

While the external origin of Earth's magnetic field lies in outer space and the internal origin within the Earth itself, the present investigation concerns only the internal origin from the dynamo. The geomagnetic field varies secularly, over long periods of time. Investigation of secular variation may provide for constraints in modeling of the dynamo. The strength of the geomagnetic dipole moment has varied over the last ten thousand years, as detected through use of various kinds of

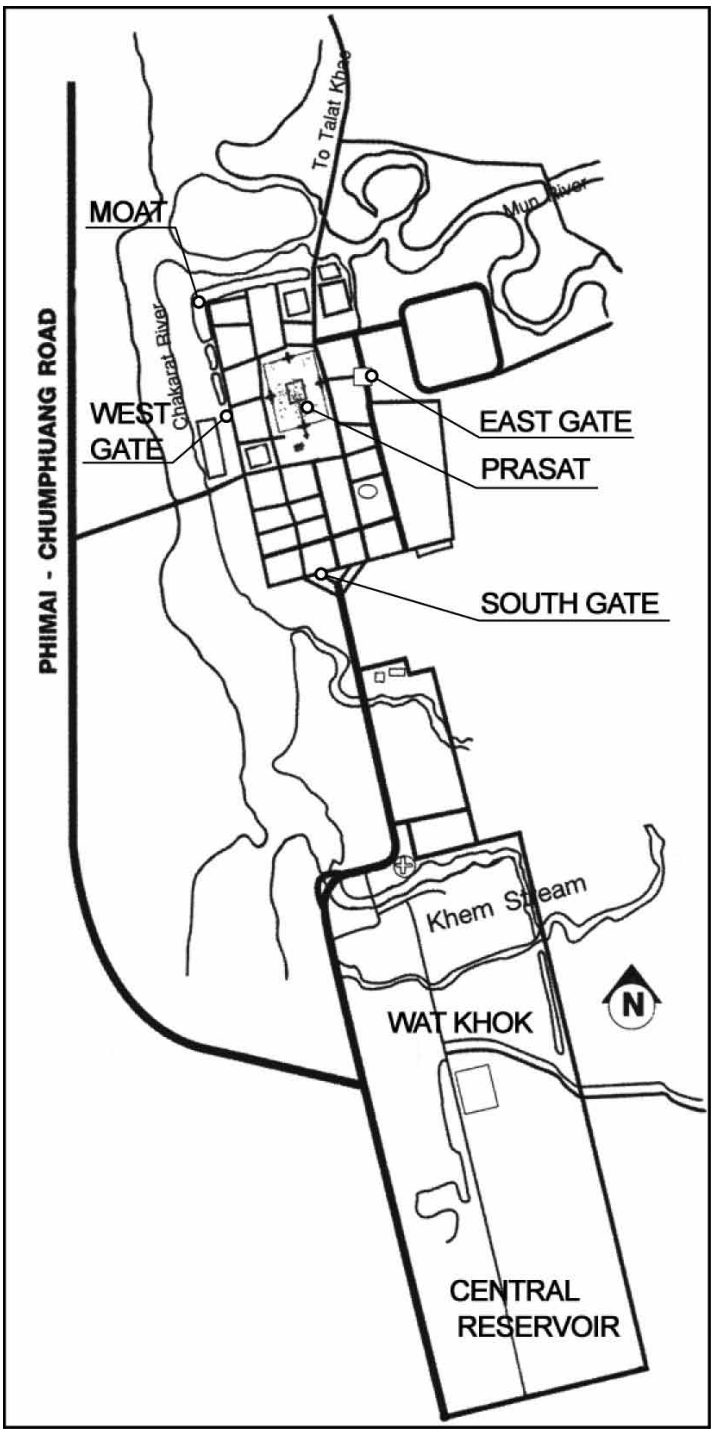

Figure 1. Plan of a Khmer-type temple site at Phimai Historical Park

NOTE: The orientation of the structure significantly deviates from orthogonal direction system of north. (See also PHI in the table.)

SOURCE: Department of Fine Arts, Government of Thailand.

palaeomagnetic data (Openshaw et al. 1997; Yang et al. 2000; Valet 2003; Korte and Constable 2005). The strength has varied by as much as 50 percent or more. The dynamo even reverses its direction, but the sequence and the transitions need further study. Crucial evidence for plate tectonics comes from tracing geomagnetic reversals recorded in the ocean floor.

Secular variation of geomagnetic declination

The angle between astronomical north and geomagnetic north is called the declination. Some evidence exists that the declination had been already noticed in China by 1088 (Needham, 1962). In Europe, Columbus is thought to have discovered it in 1492.

At any particular site, the declination changes a few tens of degrees over several hundred years. Several attempts have been made to plot that movement through study of historical states of the geomagnetic field that are preserved in natural or anthropological sites such as sedimentary layers, volcanoes, speleothems, ancient buildings and kilns (Barmore 1985; Barbetti and Hien 1989; Openshaw et al. 1997; Jackson et al. 2000). Generally, it is recognized that the declination changes at a rate of around 0.15° per year. Unfortunately, in tropical areas such data are scanty because so little documentation has survived and geological evidence has been highly eroded. Nonetheless, the orientation of architectural structures may record the historical state of the declination. In short, if temples have been oriented eastward through use of a magnetic compass, that orientation should be a historical record of the declination at the time the temple was constructed.

Measurement of geomagnetic declination at ancient temples in Thailand

In Japan there is some evidence that the magnetic compass was used in determining the orientation of ancient structural foundations (Hirooka 1971). In Thailand the magnetic compass was most likely introduced from China[1] through relations with the Khmer, who used it primarily in geomancy and divination. When and how magnetic compasses were introduced to the Khmer is unclear.

The plan of Khmer temples was based on Hindu cosmology. Crowned images of the Buddha were enshrined in the sanctuary. In figure 1, a Khmer-type temple at Phimai in northeastern Thailand exhibits an orientation that deviates significantly from the cardinal direction of north.

[1] The magnetic compass was invented in China, before or by the sixth century. Until the tenth century a spoon-type compass was used but was not very accurate because of friction. A floating compass was invented in 1027 and pivotal suspension in 1135. It was not until 1110 that the magnetic compass was used in navigation (Needham 1962). Compasses were taken to Europe around 1190 but were not widely used there until the fourteenth century (Yamamoto 2003).

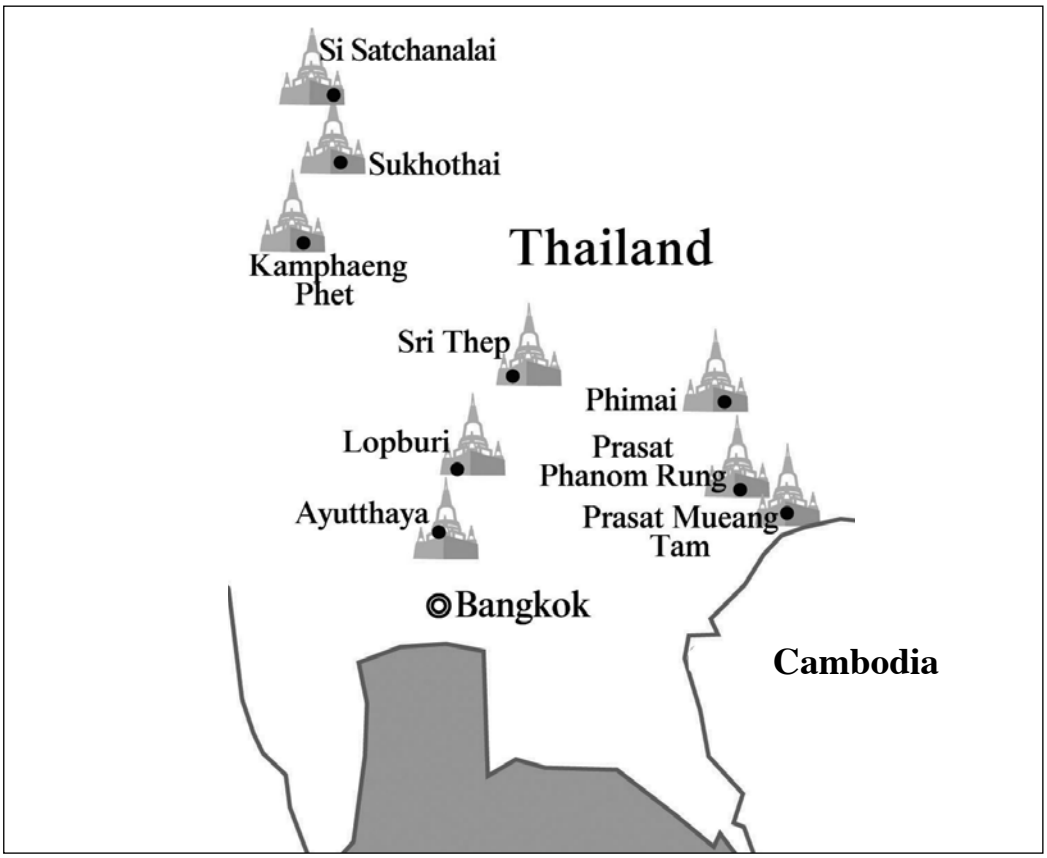

Figure 2. Schematic map of ancient temple sites in Thailand investigated in the present study

NOTE: The temples were selected from among the archeological sites compiled by Phayao *et al*. (1966).

SOURCE: Department of Fine Arts, Government of Thailand.

For this preliminary study, fifteen temples were selected from among well-documented archeological sites on a map published by the Department of Fine Arts (Phayao et al. 1966). Figure 2 shows the site locations while details of the temples are listed in the accompanying table. Dating of those structures depends on historical evidence because dating by radioactive elements is difficult with masonry structures.

The present authors measured the orientation of the foundations of the principal temple structures with a magnetic compass and the naked eye. In difficult cases, we used the global positioning system (GPS). As those structures are usually large, regular and rectangular (e. g., figure 1), the accuracy of measurements falls within 1 degree. In some cases small variations exist between the orientations of parallel or perpendicular sides. These variations are given using an error bar. The results are listed in the table with a few observational and editorial remarks. Where the dating is uncertain, it is expressed as an error bar.

Table of geomagnetic declinations measured at ancient temples in Thailand

SITE NAME (ABBREVIATION)	LOCATION	FOUNDED	ORIENTATION
Kao Klang Nai, Sri Thep (KKN)	15.464N; 101.162E; 70m	9th C	9.5°E (+/- 2°)
The compound was established in the Dvaravati period (7–11th centuries) and is preserved in the Sri Thep Historical Park. The large rectangular structure with steps on the east side was perhaps a warehouse for weapons, or a treasury. The style of the stucco figures suggests a date of the 9th century.			
Prasat Phanom Rung (PPR)	14.530N; 102.940; 383m	10 –11th C	5.5° W
The temple was built as a Hindu monastery and not a royal residence. An inscription found on site describes it as a major place of worship even before initiation of construction in the latter part of the 10th century. It was completed in the 13th century. The temple is located on an isolated monogenetic volcano and astronomical observation should have been easier.			
Prasat Hin Phimai (PHI)	15.218N; 102.497E; 155m	11th C	20°W
Phimai is the most complete example of Khmer religious architecture in Thailand. Its oldest inscription is dated to the 11th century.			
Prasat Mueang Tam (PMT)	14.497N; 102.983E; 202m	11–12th C	10°W
This temple was constructed as a residence for the Governor.			
Pond near Prasat Mueang Tam (PMT)	14.533N; 102.964E; 190m	11–12th C	10°W
A rectangular pond 600 x 200m to the North for irrigation near Prasat Mueang Tam.			
Prang Song Phi Nong, Sri Thep (SPN)	15.465N; 101.161E; 70m	11–12th C	2.5°E (2 - 7°E)
The compound is located in the same Sri Thep Historical Park as Kao Klan Nai. Dating was based on the recovered lintel (a block of stone depicting Buddhist history).			
Wat Phra Sri Rattana Mahathat, Lopburi (RML)	14.799N; 100.615E; 43m	12th C	1°W (2°W - 0°)
Khmer-style laterite *prang* (reliquary tower). The temple was modified in later periods.			
Wat Pra Sri Mahathat, Sukhothai (SUK)	17.018N; 99.703W; 63m	Mid-13th C	8°W
Wat Pra Sri Mahathat is one of the temples in Sukhothai Historical Park. Sukhothai was the capital of a powerful empire from mid-13th century to mid-15th century.			
Si Satchanalai	17.43N; 99.79E; 70m	13–15th C	NA
There are more than 40 ruined sites in this historic park. Orientations of temples widely vary from 45°W to 14°W.			
Mueang Kamphaeng Phet	16.48N; 99.52E; 79m	14–15th C	NA
Orientation varies widely from 23°E (Wat Phra Kaew) to 8°W (Wat Pra Si Ariyabat). Mueang Kamphaeng Phet was a major outpost of the Sukhothai Kingdom.			
Wat Phra Mahathat, Ayutthaya (AY1)	14.356N; 100.568E; 4m	1388	5.3°W (+/- 2°)
Founded by the King Ramesuan			
Wat Phra Ram, Ayutthaya (AY2)	14.354N; 100.561E; 4m	Late 14th C	4.3°W (+/- 1°)
Founded by the successor of the King Ramesuan			
Wat Ratburana. Ayutthaya (AY3)	14.359N; 100.568E; 4m	1424	5°W
Founded by the King Boromraja II			
Wat Phra Si Sanphet, Ayutthaya (AY4)	14.359N; 100.558E; 4m	1448	4.5°W
Founded by the King Boromatrailokanat			

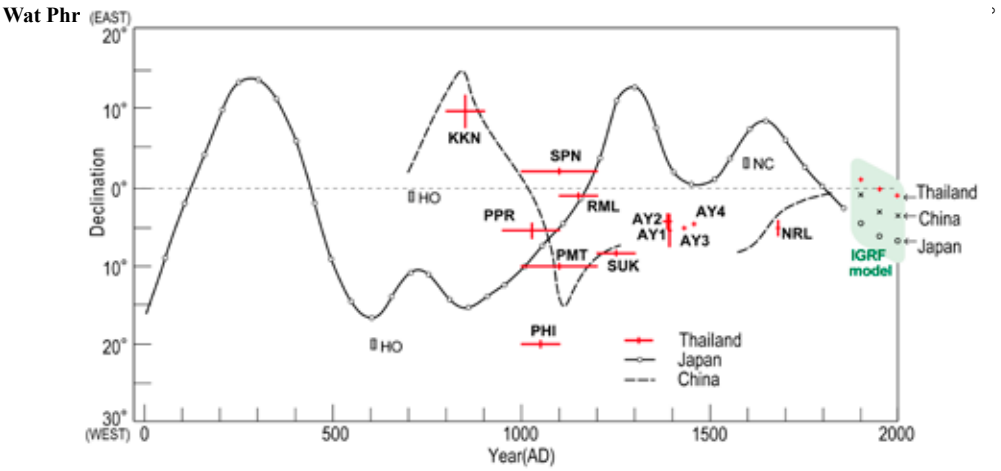

Figure 3. Geomagnetic declinations in Thailand, China and Japan

NOTES: Geomagnetic declinations for Thai temples are taken from the accompanying table. Secular variation curves of geomagnetic declination for China are from Merrill and McElhinny (1983) and for western Japan are from Hirooka (1971), respectively. Three points in Japan—Horyu-ji at the time of construction and reconstruction (HO) and Nijo Castle (NC)—are plotted together.

In figure 3, the orientations are plotted against time. This chart also shows the secular variation estimated for China (Merrill and McElhinny 1983, as drawn after Needham 1962 and Smith and Needham 1967) and for Japan (Hirooka 1971). The geomagnetic declination differs depending on relative location from the magnetic pole. Chinese data came predominantly from the central part of ancient China at latitudes of around 35°N. The Thai data are on similar longitudes but at latitudes of around 15°N. The Thai data appear to follow the same trend as the Chinese data.

Traditionally, a Buddha image should face eastward. Hence the main building of a Buddhist temple should be oriented in that direction. However, the orientation of some temples appears to follow other criteria, such as local topography or astronomical determinations. The orientations of temples in Si Satchanalai Historical Park and Mueang Kamphaeng Phet are extremely varied (see accompanying table of geomagnetic declinations). Hirooka (1976) also found similar confusing data in Japan, and consequently grouped his data into those determined by (a) astronomical methods, (b) geomagnetic methods and (c) topographical considerations. For example, Horyuu-ji in Nara was constructed in 607 AD and reconstructed about a century later after a fire. Excavation of the original foundations showed that they had been oriented 20° westward from north, while the reconstruction is only a few degrees westward (Uehara 1987). The original orientation may have been determined with a magnetic compass and the later one through astronomical observation with a small deflection from true north possibly because of observational error.

Let us assume that the global pattern of geomagnetic declination has not changed in the past and has simply drifted at a constant rate. Using declination *Y* given in the table at a certain time *T,* the longitude *X* can be converted into a virtual geographic longitude *VX* with the formula:

$$VX = (X - T * r),$$

where

r: rate of geomagnetic drift.

Declinations *Y* can thus be plotted against the virtual geographic longitudes *VX* converted from the longitudes *Y* in the accompanying table of geomagnetic declinations. Adjusting to the International Geomagnetic Reference Field (IGRF 2000) for Thailand (about 15°N), the best fitted rate *r* of geomagnetic drift of 0.2° per year was obtained (figure 4). IGRF 2000 of (western) Japan (about 35°N) is also shown in figure 4. Since differences of IGRF in terms of latitude are not large, only consideration of longitude is sufficient for this study. A rapid change of geomagnetic declination in figure 3, of about the 300 AD to 600 AD in Japan (the period of construction of Horyu-ji in Japan), corresponds to the data of our investigation of about 800 AD to 1100 AD in Thailand. The rate of 0.2° per year, although slightly higher than in most of the previous investigations, may confirm the so-called "westward drift" of the geomagnetic field.

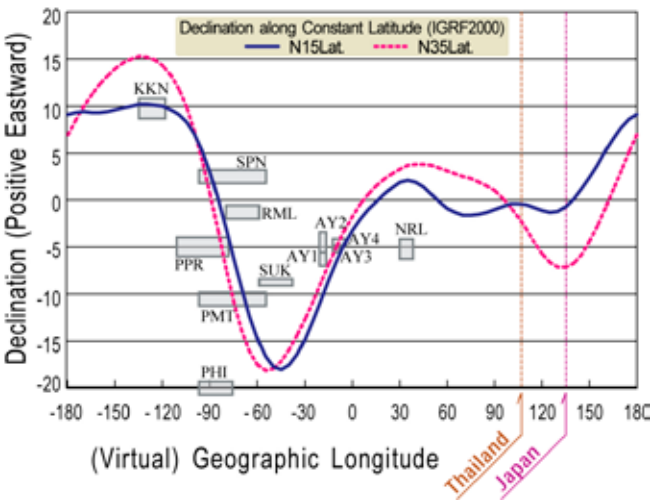

Figure 4. Comparison of Thai declinations at 12 temple sites

NOTES: The declinations given in the accompanying table are plotted here at a virtual geographic longitude with the assumption that the global pattern of geomagnetic declination did not change in the past and has drifted westward at the rate of 0.2° per year. Longitudinal variation of declination at constant latitudes for western Japan (N15Lat.) and central Thailand (N35Lat.) are calculated with the International Geomagnetic Reference Field (IGRF) for 2000 and shown together.

Discussion

We have addressed issues arising from our investigation by posing and answering the following questions.

1. When and how was the magnetic compass introduced into Thailand?

It is not clear when and how the magnetic compass was introduced to the Khmer culture. The oldest compass in Southeast Asia, which most probably was used for navigation, arrived early in the 14th century (Miksic 2004). Our result suggests that the compass was introduced earlier, not via a sea route in association with the Buddhist Holy Text but via land in association with the migration of the Tai tribe from Southern China in the mid-8th to 9th centuries.

2. How was orientation determined: by astronomical observation or compass?

In early times, the difference between astronomical north and magnetic north was probably unknown. Orientation of Thai temples may not be feasibly determined by astronomical methods owing to the low latitude and humid climate. The magnetic compass had already been used in China for ritual purposes, namely determining the so-called Cosmo Center, and may have found its way to Cambodia for use in determining the orientation of buildings. Astronomy may have developed later, and if the method had been widely used, the orientation should be precisely east after that period. We conclude that deviation from the east is rather systematic and consistent with the use of a magnetic compass.

3. What were the effects of renovation and remodeling of temples?

Many of the temples we measured had been remodeled at various times over their long history. They should have been constructed under the strong influence of Hinduism but may have been remodeled or renovated under a consolidated Buddhism. Their original orientation may thus remain unknown.

4. Is the assumption valid that a temple should face the east?

In order to examine this assumption, we visited a set of temples in Samut Songkhram province, about 70 km south of Bangkok. They are located in a tidal area developed with excavation of irrigation canals no earlier than 200 years ago. The statistics of orientations of these temples are given in figure 5. Our results suggest that the assumption that temples always face eastward is not valid. A high-ranking priest told us that nowadays topographical criteria determine the direction of a temple. In confirmation of his observation, we have collected data on a random distribution of temple orientations in this region with a median value near east.

Originally, the magnetic compass was introduced with ritual practice. Construction of a temple is certainly a most important ritual event. Orientations of temples at Ayutthaya seem to have been determined by magnetic compass as they

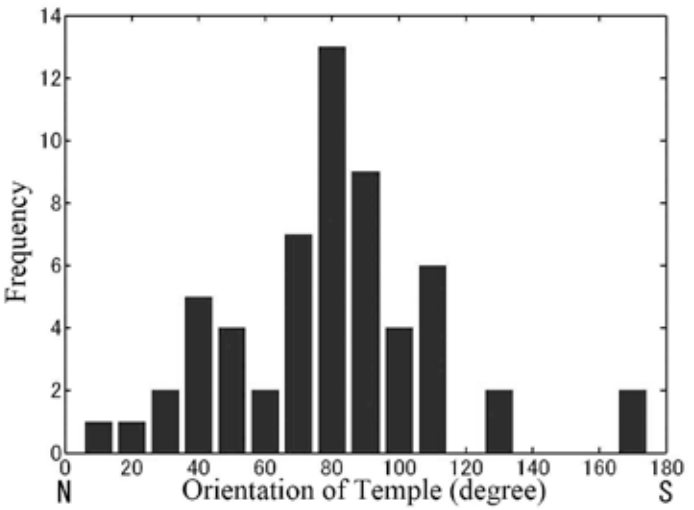

Figure 5. Orientation of Buddhist temples in Samut Songkhram province

NOTE: All temples were constructed no earlier than 200 years ago in this area, which is about 70 km south of Bangkok.

orientation lie on the IGRF line (figure 4). Therefore the practice might have been consistent until quite recent times, as declination was known among the holy orders or Sangha. Modern ritual practice can be investigated in documents preserved in large temples. Excavation of magnetic compasses may be an interesting subject for archeology that could lead to traces of the early migrations of Thai people and ritual practices inside holy places, as the origin of Thai people is still shrouded in mystery. Our results provide some hints in tracing the pathways by which they arrived. If the orientation of Khmer temple structures is known, we could estimate the foundation time by doing the reverse operation of the procedure given above.

Since the magnetic compass was not popular in Europe before the fourteenth century, Asia may be able to provide a longer perspective on magnetic declination. In Thailand and surrounding countries there are still many temples that could be fruitfully studied to supplement this study. Barmore (1985) conducted a similar study of mosques in Turkey. Other approaches can be used such as measuring remnant magnetism at kilns of well-preserved ancient pottery sites in Si Satchanalai (Barbetti and Hien 1989). We are presently developing an instrument for in-situ, non-destructive measurement of remnant magnetism (Weerapong et al. 2007). Measuring magnetic declination at speleothem can yield data over a longer period but they are easily rounded to 500 years (Openshaw et al. 1997).

ACKNOWLEGEMENTS

The authors are grateful to Dr. Somchai Nakapadungrat and Ms. Boossarasri Thana of the Department of Geology, Chulalongkorn University, for their support in conducting this investigation. The colloquium "Earth Magnetic Field and Archeology", held on 18 October 2006 and jointly organized with the National Museum of Phimai, was extremely instructive. Heartfelt thanks go to Mr. Vijak Pangsapa for his logistical arrangements. This research was partly supported by Kyoto University Active Geosphere Investigations for the 21st Century Program and a grant from Heiwa Nakajima Foundation.

REFERENCES

Barbetti, M. and D. Hien. 1989. Palaeomagnetism and high resolution dating of ceramic kilns in Thailand: A progress report. *World Archeology*, 21–1, Ceramic Technology (June).

Barmore, F. 1985. Turkish mosque orientation and the secular variation of the magnetic declination. *Journal of Near Eastern Studies*, 44.2, 81–97.

Glatzmaier, G. A. and P. H. Roberts. 1996. Rotation and magnetism of Earth's inner core. *Science*, 274. 1887–1891.

Hirooka, K. 1971. Archeomagnetic study for the past 2,000 years in southwest Japan. Memoirs Faculty Sci., Kyoto Univ., Ser. Geolog. & Mineral. 38-2, 167–207.

Hirooka. K. 1976. Kojigaran Chuujikusen Houi to Koko Chijiki. *Kokogaku Zasshi*. 62.1, 49–63.

Jackson, A., A. R. T. Jonckers and M. R. Walker. 2000. Four centuries of geomagnetic secular variation from historical records. *Phil. Trans. R. Soc., Lond.* A. 358, 957–990.

Kageyama, A. and T. Sato. 1997. Generation mechanism of dipole field by a magnetohydrodynamic-dynamo. *Phys. Rev.*, E55, 4617–4626.

Korte, M. and C. G. Constable. 2005. The geomagnetic dipole moment over the last 7000 years—New results from a global model. *Earth Planet. Sci. Let.*, 236, 348–358.

Merrill, R. T. and M. McElhinny. 1983. The Earth's magnetic field: Its history and planetary perspective. International Geophysical Series 32.

Miksic, J. N. 2004. Fourteenth-century Singapore: A port of trade. Singapore History Museum, Early Singapore 1300s–1819. 41–54.

Morelli, A., A. M. Dzievonski and J. H. Woodhouse 1986. Anosotropy of the inner core inferred from PKIKP travel times. *Geophys. Res. Lett.*, 13, 1545–1548.

Needham, J. 1962. Science and civilization in China. *Physics and Physical Technology*. Part I: *Physics*. Cambridge Univ. Press. 229–335.

Openshaw, S., A. Latham and J. Shaw. 1997. Speleothem Palaeosecular Variation Records from China: Their Contribution to the Coverage of Holocene Palaeosecular Variation Data in East Asia. 49-4, 485–505.

Phayao Khemnak, Praphid Choosiri and Somsuda Rutnin. 1966. The archeological sites by the Archeological Site Survey Project. Research Section, Division of Archeology, Department of Fine Arts, Thailand.

Smith, P. J. and J. Needham. 1967. Magnetic declination in mediaeval China. *Nature*, 214**,** 1213–1967.

Uehara, K. 1987. *Shotokutaisi*. Kodansha-Gakujyutu-Bunko, 25.

Valet, J-P. 2003. Time variations in geomagnetic intensity, *Rev. Geophys*., 41, 1, 1-43.

Weerapong Kamuduang, T. Iyemori, M. Hashizume, Y. Odagi, A. Saito, M. Nose and T. Tsuda. 2007. Measurement of vector magnetic anomaly around kilns of Khmer era. Asia Oceania Geosciences Society 2007 Meeting Proceedings, IWG06.

Woodhouse, J. H., D. Giargini and X-D. Li. 1986. Evidence of inner core anisotropy from free oscillation. 13, 1549–1552.

Yamamoto, Y. 2003. *Jiryoku to Jyuuryoku no Hakkenn I*. Misuzu-Shobo.

Yang, S., H. Odah and J. Show. 2000. Variations in geomagnetic dipole moment over the last 12,000 years. *Geophys., J. Int*. 140, 158-162.