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Magnetostratigraphy of the Miocene Chiang Muan Formation, northern Thailand: Implication for revised chronology of the earliest Miocene hominoid in Southeast Asia

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Abstract

A paleomagnetic study has been conducted on the Miocene Chiang Muan Formation in northern Thailand, in order to provide a chronology for the earliest large-bodied Miocene hominoid in Southeast Asia. The Chiang Muan Formation is mainly composed of clay, silt and sand beds, indicating lacustrine and fluvial environments. Paleomagnetic samples were collected from 124 horizons along an approximately 150 m thick section from the Chiang Muan Formation at the opencast Chiang Muan Mine. Rock magnetic experiments and stepwise thermal demagnetizations revealed that the main carrier of the magnetization of the sediments is magnetite and the samples have stable magnetization. Exceptionally, stable magnetization is also carried by hematite, which is represented by red colored sediments. Characteristic remanent magnetization (ChRM) directions, calculated by the principal component analysis, revealed normal or reversed polarities of magnetization, which allow the application of the reversal test of McFadden and McElhinny [McFadden, P.L., McElhinny, M.W., 1990. Classification of the reverse test in paleomagnetism. Geophys. Int. 103, 725–729]. The mean paleomagnetic directions of the normal and reversed polarities passed the reversal test with a classification C, indicating that the Chiang Muan Formation preserved the primary magnetization. In total, five normal and four-reversed polarity zones are recognized from the studied section. Based on paleontological age constraints, this magnetostratigraphic column of the Chiang Muan Formation correlates best with Chron C5AAn-C5n of the geomagnetic polarity time scale (GPTS) from the geological time scale (GTS2004) developed by Gradstein et al. [Gradstein, F., Ogg, J., Smith, A. (Eds.) 2004. A Geological Time Scale 2004. Cambridge Univ. Press, Cambridge, UK, p. 589]. This correlation revealed that sedimentation of the Chiang Muan Formation began approximately at 13 Ma and continued until 9.8 Ma with a mean sedimentation rate of approximately 4.2 cm/ky. The age of the earliest Southeast Asian hominoid is between 12.4 and 13.0 Ma.

Keywords: Magnetostratigraphy; Mae Moh Group; Miocene; Hominoid; Thailand

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1. Introduction

In northern Thailand, there are numerous basins, which are generally trending NNE–SSW and filled with sequences of Tertiary non-marine sediments. A general tectonic model of the evolution of these basins is that approximately E–W extension related with the Himalayan orogeny developed fault-graben or half-graben structures during the Oligocene to Early Miocene (e.g., McCabe et al., 1988; Morley et al., 2001). Gilbert and Ratanasthien (1980) provided regional geological descriptions of the sediments that filled the basin and grouped them into a single stratigraphic unit named the "Mae Moh Group". The Mae Moh Group is mainly composed of clay, silt and sand beds, indicating lacustrine and fluvial environments. The Mae Moh Group frequently contains petroleum and lignite layers, which has led to industrial and economical interest. The age of the Mae Moh Group has been discussed based mainly on palynology (e.g., Watanasak, 1989, 1990) and sometimes on vertebrate fossils (Ginsburg et al., 1988), but remains unresolved. Morley et al. (2001) provided new results of a palynological analysis and used these to correlate the basin fills of northern Thailand. Recently, a paleomagnetic investigation by Benammi et al. (2002) provided a significant contribution to determinate the age of the Mae Moh Group in the Mae Moh basin based on comparison between a high resolution magnetostratigraphy of sediments and the geomagnetic polarity time scale (GPTS).

The Chiang Muan Formation (named in this article) in the Chiang Muan Basin is one of the best exposed sequences of the Mae Moh Group, which has benefited from opencast mining by the Chiang Muan Mine Co., Ltd. The Chiang Muan Formation is important because it contains the earliest large-bodied Miocene hominoid in Southeast Asia (Kunimatsu et al., 2000, 2003a,b, 2004, 2005b), associated with a large number of mammalian fossils (e.g., Nakaya et al., 2002a; Pickford et al., 2004). Additional finds of hominoids from the Chiang Muan Formation have been reported (e.g., Chaimanee et al., 2003; Kunimatsu et al., 2005a). Because no hominoid fossil had been described from the Neogene in Southeast Asia before these discoveries, these findings provide significant information for the evolutionary history of Miocene hominoids in eastern Eurasia. However, the lack of detailed chronology of the Mae Moh Group in the Chiang Muan Mine prevents correlation of these hominoid specimens with other Miocene hominoids in Eurasia.

In order to provide age control for the Chiang Muan Formation, paleomagnetic investigations were conducted by Suganuma et al. (2002) and Benammi et al. (2004). The same normal–reversed–normal of paleomagnetic-polarity sequence was obtained from the Chiang Muan Formation in both studies. Suganuma et al. (2002) interpreted this polarity sequence to correspond with chrons C5An to C5n of GPTS, whereas Benammi et al. (2004) reported a different correlation. They correlated the upper normal polarity to chron C5ABn, which is several million years older than the correlation proposed by Suganuma et al. (2002). The inconsistency is probably caused by a low resolution and a short stratigraphic section for paleomagnetic sampling. To provide a reliable magnetostratigraphy and correlation with GPTS a high resolution sampling from an expanded stratigraphic section is required.

The purpose of this study is to establish a high-resolution magnetostratigraphy of the Chiang Muan Formation, northern Thailand. A large number of horizons were chosen from a well-exposed 150 m thick section of the Chiang Muan Mine for this paleomagnetic study. The correlation between the magnetostratigraphy and the GPTS provides an age control for the Chiang Muan Formation and a revised chronology for the earliest hominoid in Southeast Asia.

2. Geological setting

The Chiang Muan Basin is located in the northern part of Thailand, approximately 150 km east of Chiang Mai City (Fig. 1). This basin trends almost N–S and is trough-shape, being approximately 22.5 km long and 7.5 km wide. Our paleomagnetic study was conducted at the Chiang Muan Mine, approximately 1 km long and 300 m wide, located at the western margin of the Chiang Muan Basin. The Chiang Muan Basin is mainly filled by the Mae Moh Group, which is named as the Chiang Muan Formation in this article. The Chiang Muan Formation, comprising mud to silt stones, unconformably overlies the Triassic–Jurassic red sandstone and underlies Quaternary fluvial deposits that are ~20 m thick. The thickness of the Chiang Muan Formation is ~200 m. The strike is N–S in the southern part and NE–SW in the northern part, with simple tilting to the east by 10–20°. Minor faults with strikes from N–S to ENE–WSW are recorded in the mine.

The lithostratigraphy of the Chiang Muan Formation was divided into five units (Nagaoka and Suganuma, 2002) (Fig. 2). These are the Under Burden, Lower Lignite, Inter Burden, Upper Lignite and Over Burden in ascending order. The Under Burden is composed mainly of mud beds and a few intercalated fine-grained sand beds. The sedimentary environment of the Under Burden

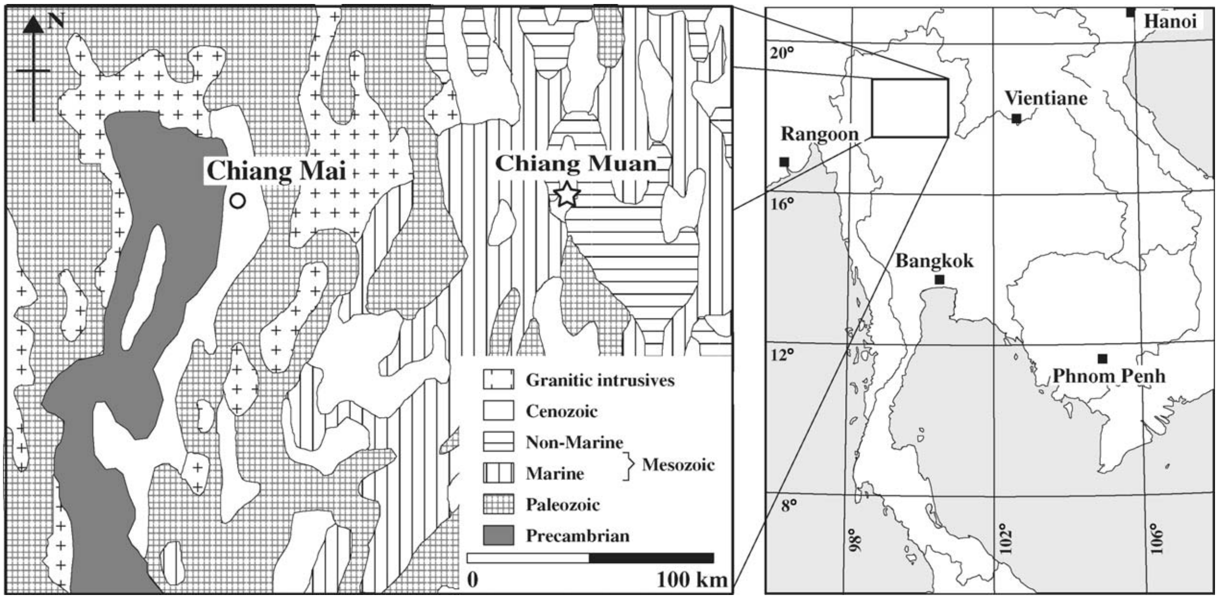

Fig. 1. Simplified geological map of northern Thailand after Workman (1997). The study area is shown by a star.

is interpreted to be a floodplain. The Lower Lignite and the lower part of the Inter Burden show a generally upward coarsening from mud to sand beds with minor gravel layers. This sequence corresponds to a sedimentary environmental change from floodplain to channel environment. The sediments from the upper part of the Inter Burden to the Upper Lignite are mainly composed of mud beds with several intercalated lignite layers. This is interpreted as a lacustrine or floodplain environment. The Over Burden consists of mud and sand beds, which were likely deposited in channel and flood plain environments.

A large number of mammalian fossils have been found in the Chiang Muan Mine, including the earliest known hominoid from the Miocene of Southeast Asia. These mammals are proboscideans, rhinocerotids, tayasuids, suids, tragulids and bovids (Pickford et al., 2004; Nakaya et al., 2001, 2002a,b,c, 2003). The horizons of the major finds of mammalian fossils within the Chiang Muan Formation are shown in Fig. 2. The earliest hominoid specimen was discovered in the Lower Lignite (Kunimatsu et al., 2000, 2004) and additional hominoid fossils were found in the Upper Lignite (Chaimanee et al., 2003; Kunimatsu et al., 2002, 2005a).

3. Methodology

3.1. Sampling

As mentioned above, previous paleomagnetic samplings were carried out by Suganuma et al. (2002) and Benammi et al. (2004) for the Chiang Muan Formation. Because of the low resolution and the short stratigraphic section of the paleomagnetic samplings, a sufficient magnetostratigraphic sequence was not obtained. In order to establish a high-resolution magnetostratigraphy, we carried out a paleomagnetic sampling from an expanded stratigraphic section of the Chiang Muan Formation.

In total, paleomagnetic samples were collected from 124 horizons along an approximately 150 m long section. The sampling section of this study has been expanded by 15 m (11 sampling horizons) downwards from the lowest level of the Benammi et al. (2004) and by several dozen meters upwards from the highest level of both studies. The paleomagnetic samples were not taken from lignite layers, because no reliable paleomagnetic results were obtained by previous studies due to the effect of sulfide minerals (e.g., Benammi et al., 2002, 2004).

Outcrops in the Chiang Muan Mine have suffered from heavy weathering and dense vegetation cover, so that their surfaces were unsuitable for paleomagnetic sampling. We therefore obtained flesh exposures by cutting a 2–3 m deep trench using an earthmover owned the Chiang Muan Mine Co., Ltd. Paleomagnetic samples were taken using a portable battery-powered drill and oriented by a magnetic compass.

3.2. Measurements

In the laboratory, samples were cut into standard blocks, 25 mm in diameter, using a water-cooled

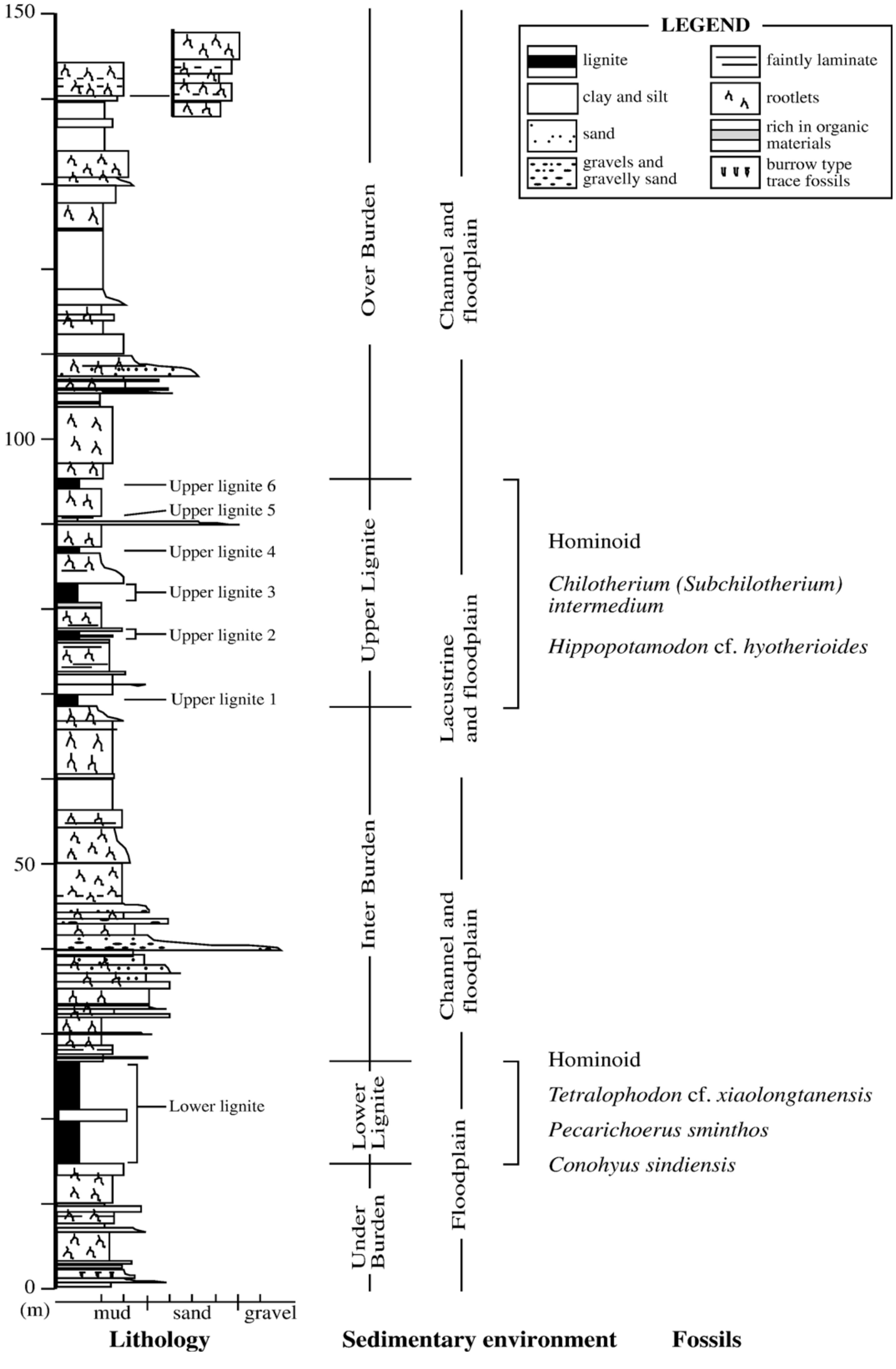

Fig. 2. Stratigraphy of the Chiang Muan Formation in the Chiang Muan Mine, showing generalized lithologies. The horizons with fossils are shown in the right hand side of the column.

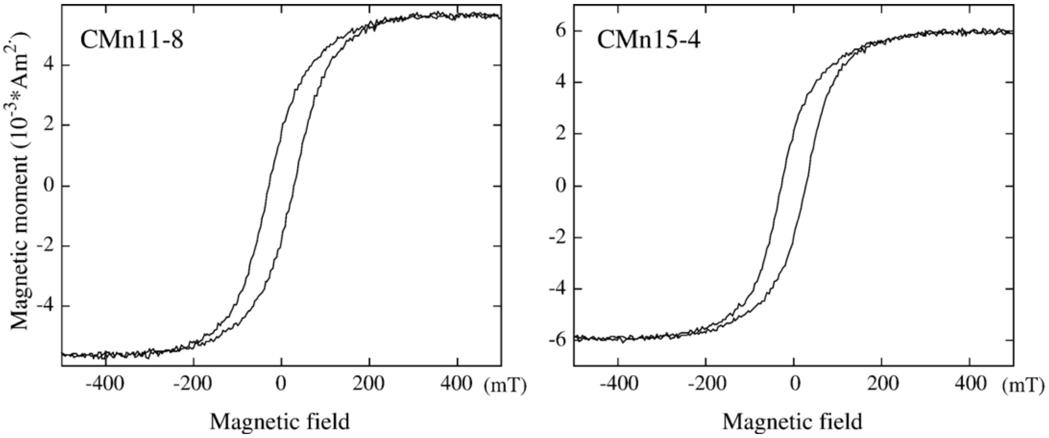

Fig. 3. Examples of hysteresis loops for selected specimens after paramagnetic slope correction.

nonmagnetic diamond. The trimmed ends of the samples were used for rock magnetic experiments.

In order to identify the magnetic minerals, hysteresis and thermomagnetic experiments were performed using a Vibrating Sample Magnetometer (VSM) (MicroMag 3900; Princeton Measurements Corporation) at the Department of Earth and Planetary Sciences, University of Tokyo. Hysteresis loops were measured in the fields up to 400 mT. Specimens were heated in helium gas from 100 to 700 °C in a field of 500 mT.

All paleomagnetic samples were subjected to the progressive thermal demagnetizations (ThD) from 100 to 580 °C at 25–50 °C intervals. If specimens were not fully demagnetized by 580 °C, additional thermal demagnetization was carried out up to 690 °C. Magnetic susceptibility was measured after each thermal demagnetization step in order to detect formation of new magnetic minerals or other changes in magnetic characteristics. These paleomagnetic analyses were conducted in the magnetically shielded paleomagnetic laboratory at the Department of Earth Sciences, Ibaraki University. Natural remanent magnetization (NRM) was measured with a 2G 750R cryogenic magnetometer. Magnetic susceptibility was measured using a Bartington MS2 sensor. Characteristic remanent magnetization (ChRM) directions were calculated by the principal component analysis (Kinschvink, 1980).

4. Results

4.1. Rock magnetism

Hysteresis loops were measured for selected specimens extracted from several horizons of the Chiang Muan Formation. Typical magnetic hysteresis loops are shown in Fig. 3. The hysteresis loops display a rapid increase of magnetic intensity during low magnetic field. Standard hysteresis parameters of Mrs/Ms and Hcr/Hc (Mrs: saturation remanent magnetization, Ms: saturation magnetization, Hcr: remanent coercive forces, Hc: coercivity) for all measured specimens are plotted on the Day plot (Day et al., 1976, 1977) (Fig. 4). This result shows that most specimens vary from the pseudo-single-domain (PSD) to the multi-domain (MD) area of the diagram. This result suggests that the main magnetic mineral of the sediments of the Chiang Muan Formation is magnetite. The grain size of magnetite varies from PSD to MD.

The thermomagnetic behaviors were classified into three types (Fig. 5). The thermomagnetic curves of types A and B show a clear single Curie temperature at approximately 580 °C without alteration during

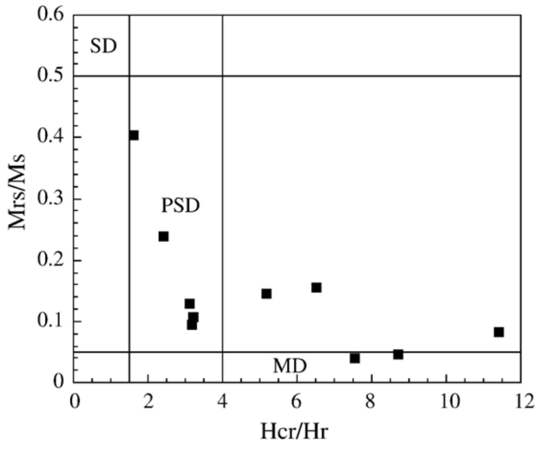

Fig. 4. Day plot of hysteresis parameter for selected specimens. SD: single domain, PSD: pseudo-single domain, MD: multi-domain.

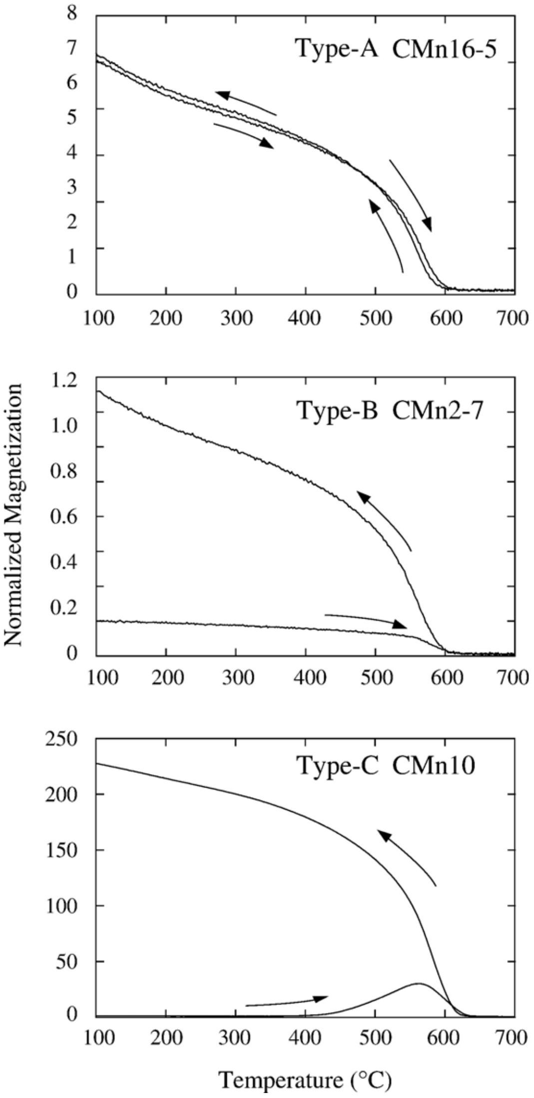

Fig. 5. Examples of thermomagnetic analysis for selected specimens from 100 to 700 °C. Arrows represent heating and cooling.

heating. Type A shows no significant difference in magnetization between heating and cooling. This indicates that this group was not altered by heating. Type B shows an increase in magnetization by cooling with a single Curie temperature at 590 °C. This suggests that alteration occurred substantially, but only above the Curie temperature. Type C shows a single Curie temperature at 580–610 °C with a pronounced increase between 450 and 570 °C, indicating the creation of a ferrimagnetic mineral phase. On cooling below the Curie temperature, magnetization significantly and continuously increases to room temperature. This indicates that magnetite was created through the thermal treatment.

4.2. Paleomagnetism

Typical examples of the stepwise thermal demagnetization (ThD) are shown in Fig. 6 with the Zijderveld diagram (Zijderveld, 1967). Through ThD treatments, 59% (73/124) of analyzed samples displayed coherent demagnetization trajectories. The coherent demagnetization trajectories were obtained from the types A and B of the thermomagnetic experiments (Fig. 6A–D). The type C of the experiments demonstrated unstable behaviors at higher than 400–450 °C (Fig. 6E).

The stepwise ThD revealed that the most samples had a low temperature component, which was especially apparent on the samples of reversed polarity. This low temperature component was removed in a temperature range before 300 °C. Because the paleomagnetic directions of the low temperature component are clustered near the present Earth's magnetic field direction of the study area, this component is probably viscous remanent magnetization. In a temperature range between 300 °C and 580 °C, the majority of the samples showed the presence of a characteristic component, decaying towards the origin. This blocking temperature indicates that the main carrier of the magnetization of these samples is magnetite (titanomagnetite), which is consistent with the result of the thermomagnetic analysis. Some samples exhibit coherent demagnetization behaviors with unblocking temperatures extending to 680 °C. This high unblocking temperature component is probably carried by hematite, which is not recognized by the rock magnetic analysis. Because the hematite has saturation remanence in only about 2% of the magnetite, identification of hematite was difficult by the rock magnetic analysis when it coexists with magnetite. This type of samples occurs in the lower part of the Inter Burden and the Upper Burden, and has a distinctive reddish tint. Thus, the difference of the carrier of magnetization is caused by the difference of the lithology of the samples, which is probably related with a sedimentary environment change during deposition of the Chiang Muan Formation.

After bedding correction, the ChRM directions oriented either north down or south up were interpreted as the normal and reversed ChRM, respectively. The mean directions of the both ChRM groups were calculated using the Fisher statistics (Fisher, 1953) and shown as an equal-area projection in Fig. 7. The mean directions of the both ChRM groups are $D=2.7°$, $I=25.7°$ and $D=177.8°$, $I=-19.4°$, respectively. In order to evaluate our results, a reversal test was carried out using McFadden and McElhinny (1990). The angle between the mean directions of the normal and reversed polarities was 7.8°, which was smaller than the critical

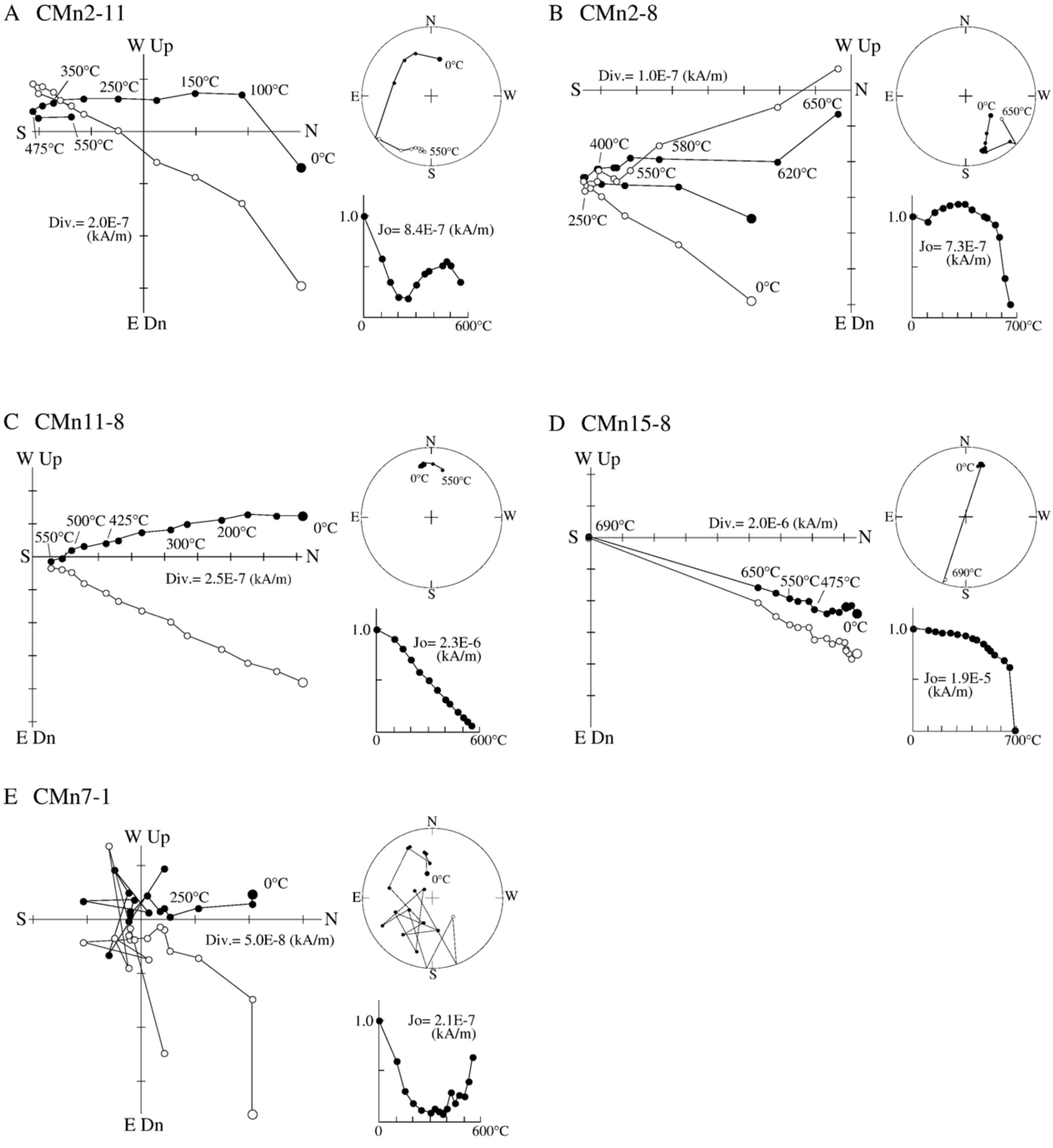

Fig. 6. Examples of progressive thermal demagnetization for selected specimens. Left: an orthogonal vector plot with solid (open) symbols for data projected onto the horizontal (vertical) plane (Zijderveld, 1967). Upper right: equal-area projection. Lower right: a normalized plot of the intensity of magnetization versus demagnetization temperature. (A and B) Samples of fine-grained sand beds from the Inter Burden. (C and E) Samples of mud beds from the Upper Lignite. (D) Sample of mud beds from the Over Burden.

angle of 16.0°. Thus, mean paleomagnetic directions of the normal and reversed polarities passed the reversal test (quality classification C). This positive result of the reversal test indicates that the Chiang Muan Formation preserves reliable primary magnetization.

4.3. Magnetostratigraphy

Virtual geomagnetic pole (VGP) positions calculated from the ChRM direction of each sample yield a magnetic polarity sequence of the studied section (Fig.

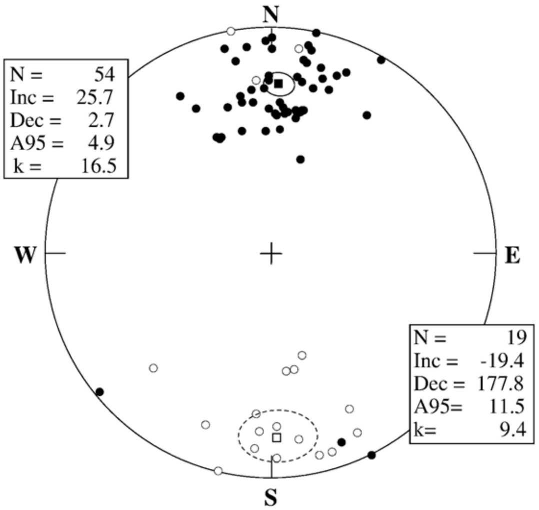

Fig. 7. Equal-area projection of paleomagnetic directions after bedding correction. Open and solid symbols indicate negative and positive inclinations, respectively.

8). The normal and reversed polarities of the magnetostratigraphic column were determined from VGP latitudes approaching +90° and −90°, respectively. In total, five normal and four-reversed polarity zones are recognized from the studied section, and numbered from CMn1 to CMn5. Polarity zones CMn1 and CMr1 are defined from the Lower Burden to the lower part of the Inter Burden. The CMr1 is dominated by a reverse polarity zone with a few short normal polarity intervals. Because two of the short normal polarity intervals are defined by only a single sample, the reliability of them is relatively low. The interval from the upper part of the Inter Burden to the lower part of the Upper Lignite is characterized by a N–R–N–R polarity sequence, which is assigned to CMn2 to CMr3. The normal polarity zones of CMn4 and CMn5 dominate from the Upper Lignite to the Upper Burden with a short reverse polarity zone of CMr4, defined by samples at two horizons. These normal polarity zones occupy approximately 60 m of the stratigraphic section.

5. Discussion

Suganuma et al. (2002) and Benammi et al. (2004) obtained a normal–reversed–normal polarity sequence from the Chiang Muan Formation. Based on stratigraphic correlation between these studies and the present study, CMn4 and CMn5 correspond to the upper normal polarity zone in these previous papers. The lower normal polarities of Suganuma et al. (2002) and Benammi et al. (2004) correspond to CMn1 and CMn2 or a short normal polarity zone within CMr1, respectively. The reversed polarity zone of Suganuma et al. (2002) and Benammi et al. (2004) is likely to be CMr2 or CMr1. This result indicates that the sampling resolution of these studies was not sufficient to provide a reliable magnetostratigraphy for the Chiang Muan Formation.

Age constraints of the Chiang Muan Formation were provided by paleontological analysis, but the resolution was not high. Previously, the age of the Chiang Muan Formation was thought to be late Early Miocene to Middle Miocene. The mammal faunas from other Tertiary basins in northern Thailand (e.g., Ducrocq et al., 1994) gave the same correlation. Recently, Morley et al. (2001) reported a new age estimation based on palynological analysis. Their results suggest that the lower section in the Chiang Muan Formation is of upper Early Miocene age, while the section in the mine is of Middle Miocene age.

However, recent work by the Thai–Japanese Paleontological Expedition Team (TJPET) proposed relatively younger ages for the Chiang Muan Formation based on the newly discovered mammalian fauna (Kunimatsu et al., 2004, 2005a,b; Nakaya et al., 2001, 2002a,b,c; Pickford et al., 2004). The mammalian fossils from the Chiang Muan Formation include primates, gomphotheriids, rhinocerotids, tayasuids, suids, tragulids and bovids.

A tayassuid *Pecarichoerus sminthos*, a suid *Conohyus sindiensis* and a gomphotheriid *Tetralophodon* cf. *xiaolontanensis* were discovered only from the Lower Lignite. A suid *Hippopotamodon* cf. *hyotherioides* was found mainly from the Upper Lignite horizon and a rhinocerotid *Chilotherium* (*Subchilotherium*) *intermedium* from the Upper Lignite horizon only. Hominoid fossils were collected from both the Upper and Lower Lignite horizons (Kunimatsu et al., 2004, 2005a,b). In the Chiang Muan Mine, some fossils were collected by TJPET, but others were rescued during lignite excavation, so that their precise stratigraphic provenience is sometimes uncertain. The latter sample includes another suid *Parachleuastochoerus sinensis*.

Among the suoid taxa from Chiang Muan, a suid *C. sindiensis* and a tayassuid *P. sminthos* from the Lower Lignite are also known from the Middle Miocene of the Siwaliks (Colbert, 1933; Pickford, 1987, 1988). The other two suids (*H.* cf. *hyotherioides* and *P. sinensis*) and a gomphotheriid *T.* cf. *xiaolongtanensis* from the Chiang Muan Formation are known from the lignite mine of Xiaolongtan (Kaiyuan District, Yunnan Province, southwestern China) (Tobien et al., 1988). The age of Xiaolongtan is estimated as ca. 10 Ma by Pickford and

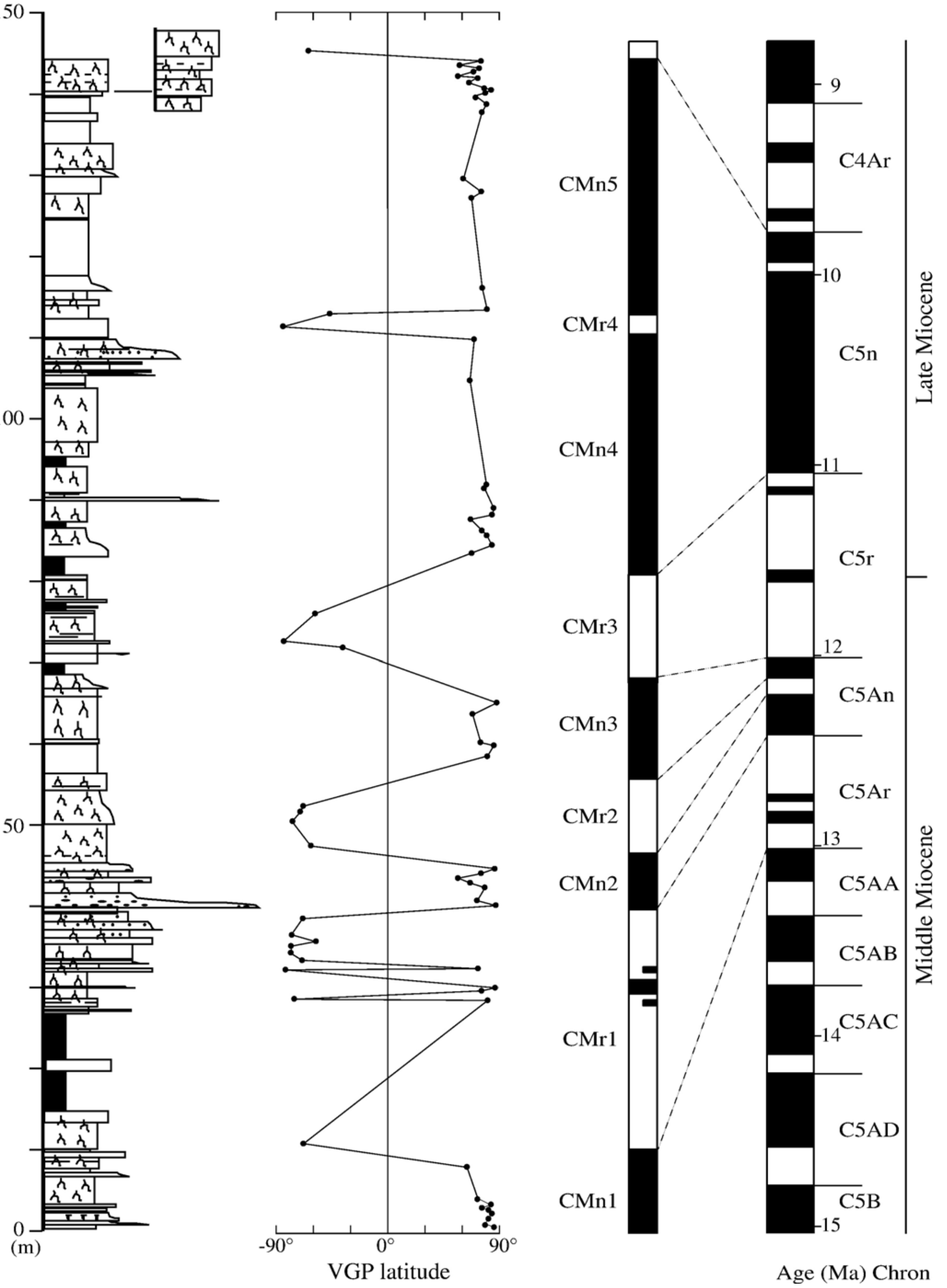

Fig. 8. Correlation of the magnetostratigraphy of the Chiang Muan Formation to the geomagnetic polarity time scale (GPTS) of the geological time scale 2004 (GTS2004) (Gradstein et al., 2004). Magnetic polarity zones are shown by black (white) bars for normal (reversed) polarity; polarity zones represented by a single sample are shown by half bars. VGP: virtual geomagnetic pole.

Liu (2001), but it could be slightly older (Pickford et al., 2004). The presence of *T.* cf. *xiaolongtanensis* in the Lower Lignite suggests that this unit is unlikely to date back to the early part of the Middle Miocene. The range of *C.* (*Subchilotherium*) *intermedium* from the Siwaliks is from the Lower Chinji to Upper Dhok Pathan (MN7 to MN11) (Heissig, 1972). *Hipparion* has not been recovered from the Chiang Muan Formation or Xiaolongtan. The absence of *Hipparion* might indicate that these two fossil sites are older than the hipparion datum (ca. 11 Ma), though it could also be due to palaeoecological factors, rather than chronological differences.

These new mammalian faunal data suggest that the age of the Chiang Muan Formation probably ranges from the Late Middle to early Late Miocene.

Based on the paleontological constraints, we consider a correlation of our new magnetostratigraphic column to the geomagnetic polarity time scale (GPTS) of the geological time scale 2004, which is newly established by Gradstein et al. (2004) (Fig. 8). The longest interval in the GPTS from late Middle to upper Late Miocene is chron C5n. Thus, the thick normal polarity zones from CMn5 to CMn4 are most probably correlated with chron C5n. According to this correlation, the polarity sequence from CMr3 to CMn1 is likely to be correlated to chrons C5r to C5AAn. In this case, deposition of the Chiang Muan Formation began approximately at 13 Ma and continued until 9.8 Ma. Based on this correlation, sedimentation rates of the Chiang Muan Formation were calculated (Fig. 9). The sedimentation rates vary from 1.1 to 8.5 cm/ky with a mean rate of 4.2 cm/ky. The lowest sedimentation rate corresponds to the polarity zone CMr3. The polarity zone CMr3 is observed in the lower part of the Upper Lignite, which corresponds to lacustrine to floodplain environments. Such low-energy sedimentary environments tend to have low sedimentation rates. In contrast, the polarity zones from CMn2 to CMn3, observed in the Inter Burden, show a high sedimentation rate. This interval corresponds to channel and floodplain environments, which generally have high sedimentation rates. Thus, the variation in the sedimentation rates calculated from this correlation of our magnetostratigraphic polarity zones to the GPTS is generally consistent with the paleoenvironmental interpretation based on lithology.

Alternatively, the polarity sequence from CMr3 to CMn1 of the magnetostratigraphic column is possibly correlated to chrons C5r to C5An.1n. Except for a few short normal polarity intervals in CMr1, the match of our magnetostratigraphic column to the GPTS also appears straightforward. However, the sedimentation rates calculated from this correlation vary from 2.4 to 40.0 cm/ky. The variation is significantly lager, compared to the result deduced from the prior correlation. In addition, these sedimentation rates are lass consistent with the paleoenvironmental interpretation based on the lithology. We have concluded, therefore, that this alternative correlation is not reliable and that the prior magnetostratigraphic correlation is preferable for the following discussion.

This magnetostratigraphic correlation provides a new chronology for the earliest hominoid in Southeast Asia (Kunimatsu et al., 2000, 2004). The hominoid was found from the Lower Lignite, which corresponds to

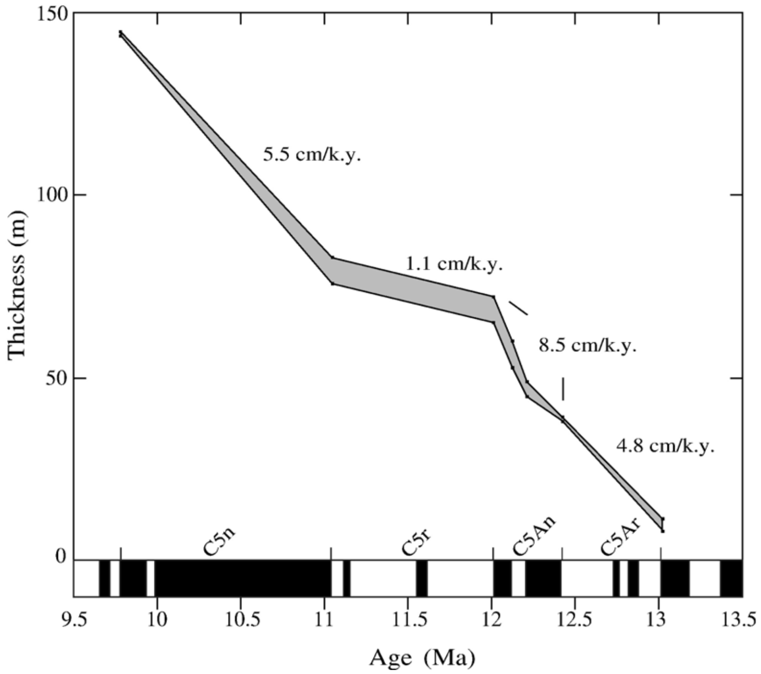

Fig. 9. Sedimentation rates of the Chiang Muan Formation based the correlation of our magnetostratigraphic polarity zones to the GPTS of the GTS2004. Numbers of side of the line are average sedimentation rates. Gray zones represent errors of sedimentation rates, caused by ambiguities of magnetic polarity boundaries on the stratigraphic column.

chron C5A. This indicates that the age of this hominoid is between 12.4 and 13.0 Ma. This is almost the same age as the oldest *Sivapithecus* specimens from the Siwaliks (12.5 Ma: Kappelman et al., 1991). Our results, therefore, suggest that once large-bodied hominoids reached eastern Eurasia, they spread rapidly and widely from the northwestern corner of the Indian subcontinent to Indochina. The age of the other hominoid specimens from the Upper Lignite (Chaimanee et al., 2003; Kunimatsu et al., 2002, 2005a,b) can also be estimated from the magnetostratigraphic correlation to be 10.5 Ma to 12.1 Ma, which is younger than the estimation published by Chaimanee et al. (2003).

6. Conclusions

A paleomagnetic study was conducted on the Chiang Muan Formation in northern Thailand to provide a detailed chronology for the earliest large-bodied Miocene hominoid in Southeast Asia. We carried out a high-resolution paleomagnetic sampling from a 150 m thick section of the Chiang Muan Formation in the Chiang Muan Mine. Rock magnetic experiments and stepwise thermal demagnetization revealed that a main carrier of the magnetization of the sediments is magnetite and that the samples have a stable magnetization. Characteristic remanent magnetization (ChRM) directions, calculated by the principal component analysis, are antipodal. The positive result of the reversal test indicates that the Chiang Muan Formation preserves reliable primary magnetization. In total, five normal and four reversed polarity zones are recognized from the studied section. Based on the mammalian fauna correlation and this polarity pattern, the magnetostratigraphic column of the Chiang Muan Formation can be correlated from chron C5AAn to C5n of the GPTS from GTS2004 (Gradstein et al., 2004). This result suggests that the Chiang Muan Formation was deposited from 13 Ma to 9.8 Ma, with a mean sedimentation rate of 4.2 cm/ky. This indicates that the age of the earliest hominoid is between 12.4 and 13.0 Ma. The age of the other hominoid specimens reported by Chaimanee et al. (2003) and Kunimatsu et al. (2002, 2005a) is probably 10.5 Ma to 12.1 Ma.

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