PRELIMINARY REPORT ON COPROLITES FROM THE LATE TRIASSIC OF THAILAND

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Abstract—169 coprolites were found at Huai Nam Aun in Chaiyaphum province (Huai Hin Lat Formation, Upper Triassic) and are sub-divided into seven different morphotypes. Four groups of spiral coprolites are interpreted as being produced by fish-eating sharks and lungfish, whereas non-spiral coprolites containing numerous bone fragments and fish scales were probably produced by other carnivorous vertebrates. *Liassocopros hawkinsi* and *Saurocopros bucklandi* are recognized in this study for the first time in Southeast Asia; this discovery supports palynological studies suggesting a Carnian-Norian age for the Huai Hin Lat Formation.

INTRODUCTION

Research on Mesozoic vertebrate fossils in Thailand by Thai-French palaeontological teams began in 1980 (Buffetaut et al., 2009). Many vertebrate fossils have been found in the last 30 years in the terrestrial deposits known as the Khorat Group, an Upper Triassic to Lower Cretaceous unit (Buffetaut et al., 2005) and in the underlying Huai Hin Lat Formation, an Upper Triassic marine unit. Although dozens of thousands of vertebrate remains have been found (including freshwater sharks, actinopterygian fishes, lungfish, temnospondyl amphibians, turtles, crocodilians, dinosaurs and pterosaurs: cf. Lauprasert et al., 2009), coprolites were identified by one of us (P.S.) from only one locality of the Lower Cretaceous Sao Khua Formation. In November 2010, a team of the Palaeontological Research and Education Centre (PRC) , Mahasarakham University found a large number of coprolites housed at Wat Tum Wiman Nakin, Nong Yakong village (Khon San District, Chaiyaphum Province). "Wat" means temple in Thai and the presence of a large collection of coprolites at a Buddhist temple is not so surprising, as locally those coprolites are used to make amulets to provide good luck to their owners and to protect them from ghosts (Fig. 1). Fossils are often kept in Buddhist temples (see for example Cavin et al., 2003) where local people usually bring intriguing objects found in the countryside. We heard that the spiral coprolites are especially sought out because they have the shape of butterflies' pupae, and we learned that villagers used to excavate them in the vicinity. We undertook excavations in December 2010 at a locality called Huai Nam Aun (Fig. 2), near the village. Abundant coprolites and a lot of bony remains including a *Hybodus* tooth, bony fish scales and temnospondyl vertebrae were found at this locality.

GEOLOGICAL SETTING

All the coprolites were embedded in the upper part of the outcrop (see Fig. 3). The lowest layer of the outcrop consists of dark limestone with chert nodules; above are dark calcareous mudstones with fossil algae (Fig. 4A). Finally, the upper part of the outcrop contains thinly (0.5-2 cm) laminated beds of calcareous mudstone. In these beds, we found small shells and fish scales besides coprolites (Figs. 4B-C). These lithologies suggest deposition in brackish water near a calcium carbonate source (e.g., pond near coastline) with more or less anoxic conditions during the deposition of the basal layers.

This locality belongs to the Huai Hin Lat Formation, dated as Late Triassic (Carnian to Norian: see Chonglakmani and Sattayarak, 1978) by palynomorphs (Racey et al., 1996; Racey and Goodall, 2009), and vertebrate assemblages (Buffetaut and Suteethorn, 1998).

Scientific reports concerning Triassic fossil vertebrates in Thailand are still uncommon, most of them dating from 1981-1985. Triassic vertebrates from the Huai Hin Lat Formation include a shark denticle (Cuny et al., 2007) a tooth of *Ferganoceratodus szechanensis* (Martin and Ingavat, 1982; Martin et al., 1997; Cavin et al., 2007) the turtle *Proganochelys ruchae* (Broin, 1984), the amphibians *Cyclotosaurus* cf. *C. posthumus* and a plagiosauroid (Ingavat and Janvier, 1981), and phytosaurs (Buffetaut and Ingavat, 1982). All of them were found at an outcrop near Chulaborn Dam in Chaiyaphum Province. The latest reported fossils from the Huai Hin Lat Formation are archosaur trackways found at Tad Huai Nam Yai, near Nam Nao in Phetchabun Province (Le Loeuff et al., 2009).

MATERIALS AND METHODS

The 169 coprolites (PRC-CY-HN 21-204) used in this study were collected from the locality of Huai Nam Aun and they are housed at the Palaeontological Research and Education Centre (PRC), Mahasarakham University. Each specimen was measured, with the description and classification being based on shape, surface texture and inclusions.

TERMINOLOGY

The coprolites were identified directly on the basis of their external morphology (Hunt et al., 1994). Amphipolar coprolites as defined by Neumayer in 1904 display an even distribution of coils in overall length (Fig. 5A), whereas heteropolar specimens have multiple spirals that do not extent the whole length. In case of heteropolar spiral coprolites, we followed Hunt et al. (2007), who introduced the new terms "microspiral" for specimens in which the spiral portion constitutes less than 50% of the overall length (Fig.5B) and "macrospiral" when the tightly spiral portion constitutes 50% or more of the total length (Fig. 5C).

SYSTEMATIC ICHNOLOGY

Ichnotaxon Group 1 (Fig. 6 A-B)

Material: 45 mainly complete specimens (PRC-CY-HN 21-26, PRC-CY-HN 48-90).

Description: Two non-spiral morphotypes can be recognized in the material at hand. The first one is 1-2 cm in width and 2-5 cm in length. Overall shape varies from almost spherical to elongate ellipsoidal with acute tips (PRC-CY-HN21; Fig. 6A1- A2). The surface texture is rather rough and covered by undulating lines running from one end to the other. Flattened shape and rough texture in some specimens of morphotype 1 may result from taphonomic processes.

FIGURE 1. Amulet made of coprolites from Huai Nam Aun.

The second morphotype is smaller than morphotype 1. The most complete specimen is approximately 0.7 cm wide and 2.5 cm long (PRC-CY-HN26; Figs. 6.B1- B2). This morphotype is rod-like with numerous undulating, branching and striating lines on its surface, with many inclusions of fish scales visible on lateral surfaces.

Discussion: Rod-like and more or less cylindrical is a are common shape in coprolites (Hunt et al., 1994; Eriksson et al., 2011). It is difficult to decide whether the two morphotypes belong to one or two groups, although the second morphotype is smaller than the first one.

Ichnotaxon Group 2 (Fig. 6C)

Material: 5 incomplete specimens (PRC-CY-HN38, PRC-CY-HN 91-94).

Description: This group is lacking a complete specimen. The most complete specimen (PRC-CY-HN38; Fig6.C1 and C2) is 2.5 cm in width and 5.0 cm in length, oblong in shape, and slightly arcuate in lateral view. Surface texture is irregular. Several fish scales are visible in some areas.

Discussion: Specimens from group 2 differ from group 1 in being larger, shorter and somewhat arcuate in lateral view.

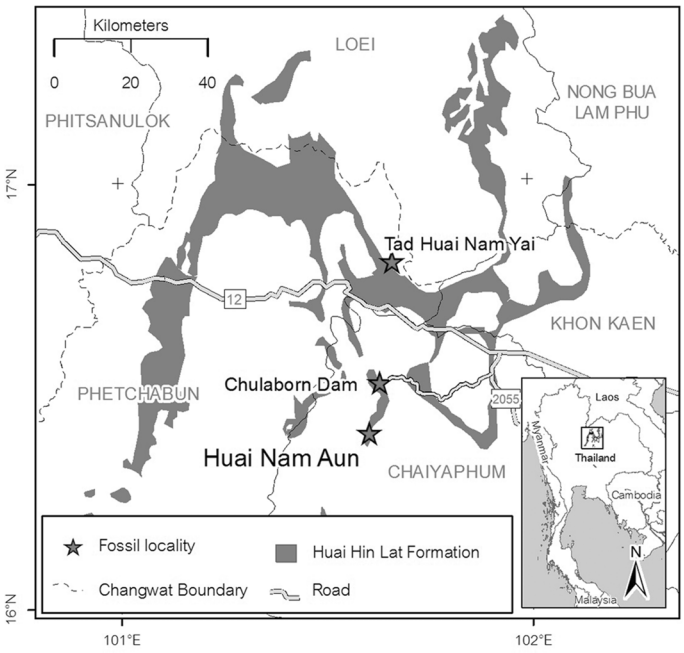

FIGURE 2. Vertebrate fossil localities in the Triassic Huai Hin Lat Formation of Thailand.

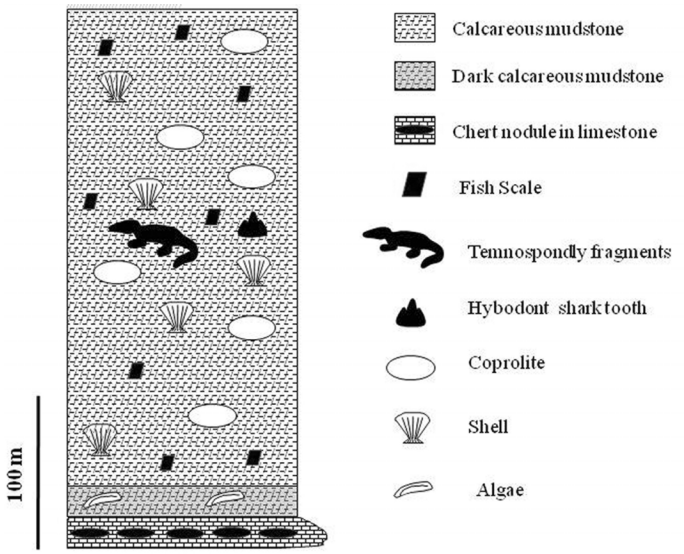

FIGURE 3. Stratigraphic column of Huai Nam Aun locality.

Ichnotaxon Group 3 (Fig. 6D)

Material: 9 incomplete specimens (PRC-CY-HN40, PRC-CY-HN 95-102)

Description: The material is fragmentary, lacking a complete specimen. The largest and most complete specimen (PRC- CY-HN40; Fig 6. D1 and D2) is 1 cm in width and 24 cm in length. The coprolites of this group are very elongate, rod-like, narrow and quite arcuate in lateral view, rounded in cross section. Surface texture is rather smooth, and no inclusions are visible.

Discussion: Specimens in this group differ from other non-spiral coprolites described here in being narrow and elongate. In addition, the absence of inclusions on their surface suggests that they were not produced by fish-eating organisms.

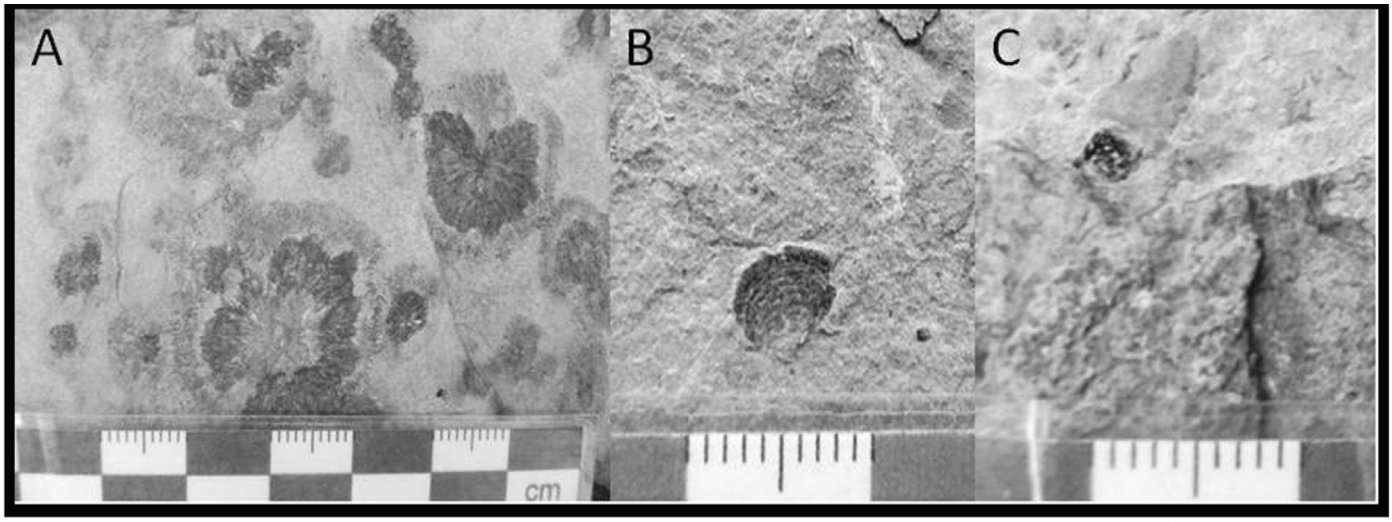

FIGURE 4. Fossils in Huai Nam Aun sediment. **A**, Algae? in dark calcareous mudstone bed. **B-C**, Fossils in calcareous mudstone bed, **B**, algae? and **C**, fish scales.

Ichnotaxon Group 4 (Fig. 7A-B)

Material: 52 complete specimens (PRC-CY-HN41-42, PRC-CY-HN 103-152).

Description: Coprolites in this group are very well preserved, showing various shapes such as almost spherical, rod-like, oval (PRC-CY-HN41;Figs. 7.A1- A2) and oblong (PRC- CY-HN42; Figs. 7.B1-B2). Overall size varies from 1-5 cm in length. In lateral view, only one large spiral is visible, the width of which is more than half of total length. Surface texture shows a lot of undulating lines, originating from one end to the other. Several inclusions of fish scales are visible on the lateral surface of specimens.

Discussion: As only one spiral constitutes more than 50% of the total length it is not easy to refer these specimens to heteropolar or amphipolar categories. However, the coil is evenly distributed. Thus, we consider this group as amphipolar. A single spiral is the typical character of this group, which could be a new taxon of spiral coprolites.

Ichnotaxon Group 5 (Fig. 7C-D)

***Saurocopros bucklandi* Hunt et al., 2007**

Material: 20 complete specimens (PRC-CY-HN43-44, PRC-CY-HN 153-170).

Description: These specimens are very well preserved. In Huai Num Aun two groups can be referred to this ichnotaxon; the first one is oval in shape (PRC-CY-HN43; Figs. 7, C1- C2), measuring approximately 4-6 cm in length, whereas the second one is cylindrical in shape (PRC-CY-HN44; Figs. 7D1- D2) with approximately 1-2 cm in length. The largest specimen is 1.7 cm in width and 6 cm in length (PRC-CY-HN43; Figs. 7 C1- C2). The general shape of these coprolites is oblong and oval. The lateral surface consists of 3-4 small spirals. Each of these spirals is 0.1-1 cm in width. The surface of all specimens is rather rough and ornamented by numerous small longitudinal ridges running between each spiral. No bone or fish scale fragments are visible on the coprolites' surfaces.

Discussion: The shape and spiral characters of this microspiral heteropolar group are very similar to those of *Saurocopros bucklandi* Hunt et al., 2007, to which we refer these specimens. This taxon is distributed from the Late Triassic to the Late Cretaceous of Europe and North America (Hunt et. al., 2007).

Ichnotaxon Group 6 (Figs. 7E-F)

***Liassocopros hawkinsi* Hunt et al., 2007**

Material: 34 complete specimens (PRC-CY-HN43-44, PRC-CY-HN 171-202).

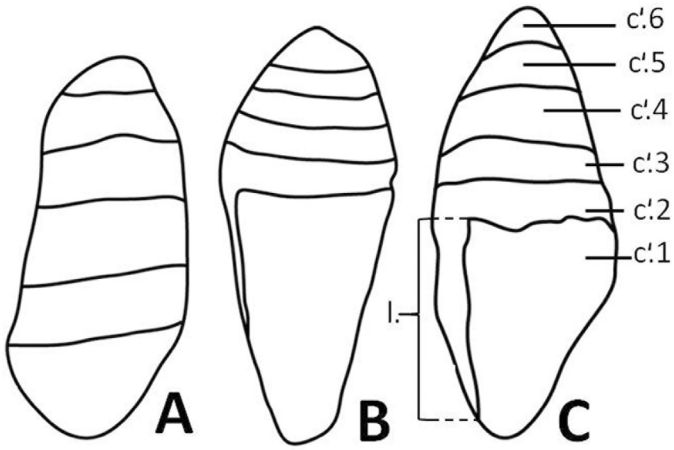

FIGURE 5. Terminology of coprolite morphotypes. **A**, Amphipolar. **B**, Microspiral heteropolar. **C**, Macrospiral heteropolar. **Abbreviations: c.**, coil; **l.**, lip of the coil (modified from Jain, 1983 and Hunt et al., 2007).

Description: All specimens are well preserved, showing various sizes ranging from 1.5 to 2.5 cm in width and 1 to 6.8 cm in length. The general shapes of this group are ellipsoidal, ovoid (PRC-CY-HN45; Figs. 7, E1- E2) and cylindrical (PRC-CY-HN46; Figs. 7, F1-F2), with numerous spirals. The number of coils varies from five to eleven; width of each coils is approximately 0.1 to 4 cm. A distinct lip depression is also present. The surface displays many perpendicular branching folds running between each spiral. Inclusions of ganoid fish scales are visible on the external surfaces of some specimens.

Discussion: These specimens are macrospiral heteropolar as are most coprolites found in the Huai Nam Aun locality. Hunt et al. (2007) indicated that numerous coils, which constitute more than 50% of total length, are the typical characters of *Liassocopros hawkinsi*. Moveover, they suggest that *L. hawkini* consists of 2 types, one with an acute tip (trochospiral) and rounded end. *L. hawkini* is distributed from the Late Triassic to the Late Cretaceous of Europe, India and North America. In Huai Num Aun most specimens belong to the trochospiral type and are very similar to specimens from the Lower Lias of Lyme Regis in England (Hunt et al., 2007, fig. 7A-C).

Ichnotaxon Group 7 (Fig. 7G)

Material: 4 incomplete specimens (PRC-CY-HN47, PRC-CY-

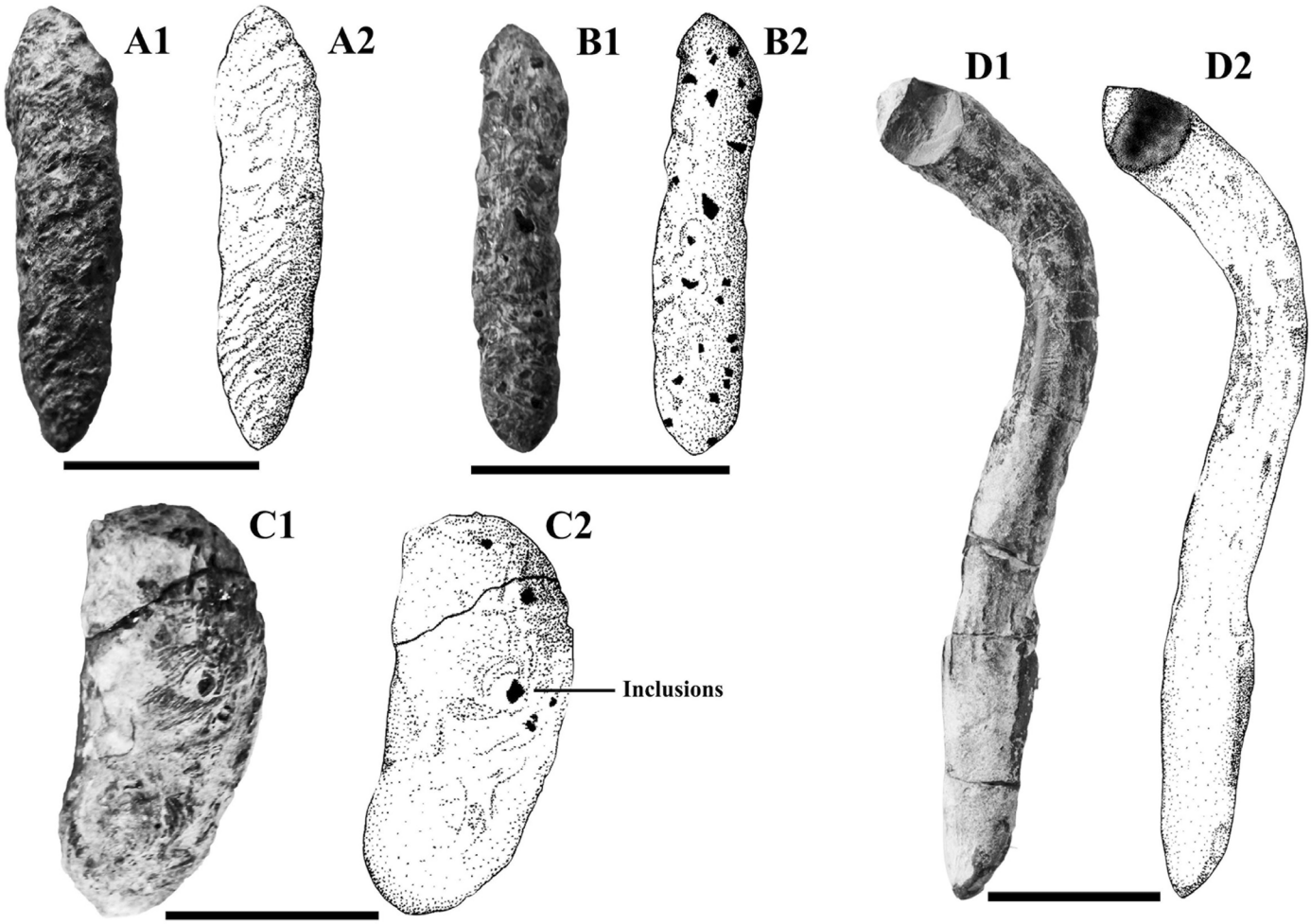

FIGURE 6. Coprolites of ichnotaxa groups 1-3. **A**, Ichnotaxon group 1, type 1 (CY-HN21), lateral view. **B**, Ichnotaxon group 1, type2 (CY-HN26), lateral view. **C**, Ichnotaxon group 2 (CY-HN38), lateral view. **D**, Ichnotaxon group 3 (CY-HN40), lateral view. Scale bars are 2 cm.

HN 203-205).

Description: The largest specimen (PRC-CY-HN47; Fig. 7 G1-G2) lacks its upper part. It measures 4 cm in width and 6 cm in length and is ellipsoidal in shape. The specimen consists of four spirals, each coil being separated by approximately 1 to 2 cm. Surface texture is quite rough. Bone fragments have been observed at the surface of specimens.

Discussion: This group contains the largest of the spiral coprolites in Huai Nam Aun. A lot of bones or fish scales inclusions are embedded in coprolite surfaces, implying that they have been produced by vertebrate-eating animals. Both their size and their characters differ from *Hyroconopros* sp., which is less than 2 cm in length and lacks inclusions (Hunt et al., 2005b), but the absence of a complete specimen recovered prevents a more precise determination for the time being.

DISCUSSION

An important issue in coprolite studies is the identification of coprolite producers in terms of size and taxonomic group (Thulborn 1991; Hunt et al. 1994; Eriksson et al., 2011). The seven coprolite ichnotaxa recognized at Huai Nam Aun are quite varied in shape and size, suggesting a relatively high biodiversity. Coprolites can vary significantly in size, ranging from invertebrate fecal pellets, less than a millimeter in length, to several decimeters for some dinosaurs (Hunt et al., 1998). Invertebrates produce coprolites that are less than a few millimeters in length (Eriksson et al., 2011), thus all specimens described here were produced by vertebrates. Although coprolites at Huai Nam Aun are very different in size (e.g. ichnotaxa group 1 and group 7), it cannot be ascertained that they were produced by animals of different sizes because many large animals can produce small feces (Hunt et al., 1994). Thus, the shape and the inclusions of a coprolite are more useful than its size to try to identify its producer.

Several studies have shown that feces of living organisms show a rather high variation. One organism can produce different feces shapes while unrelated organisms can produce similar feces (Hunt et al., 1994; Hunt and Lucas, 2010; Mancuso et al., 2004). Thus, it can prove difficult to identify the producer of coprolites. Several palaeontological and experimental studies indicate that spiral coprolites were produced by fishes with a spiral valve (Williams, 1972; Jain, 1983; Hunt et al., 1993; Hunt and Lucas, 2005; Duffin, 2009). Normally sharks, having more complex intestinal valves, produce heteropolar coprolites, whereas amphipolar coprolites are generally produced by bony fishes (Williams, 1972; Jain, 1983, Eriksson et al. 2011). A tooth of the fish-eating shark *Hybodus* was found at Huai Nam Aun, thus ichnotaxa groups 5 and 6 (heteropolar spiral coprolites which contain fish scales on their surface) may have been produced by hybodonts. However, the variability in size and gross morphology between groups 5 and 6 strongly suggest that they were produced by different taxa. Groups 4 and 7 comprises the only amphipolar coprolites found in this study, which may have been produced by lungfishes as Martin and Ingavat (1982) have recorded a single tooth plate of the lungfish *Ferganoceratodus szechuanensis* from the Huai Hin Lat Formation (Martin et al., 1997; Cavin et al., 2007).

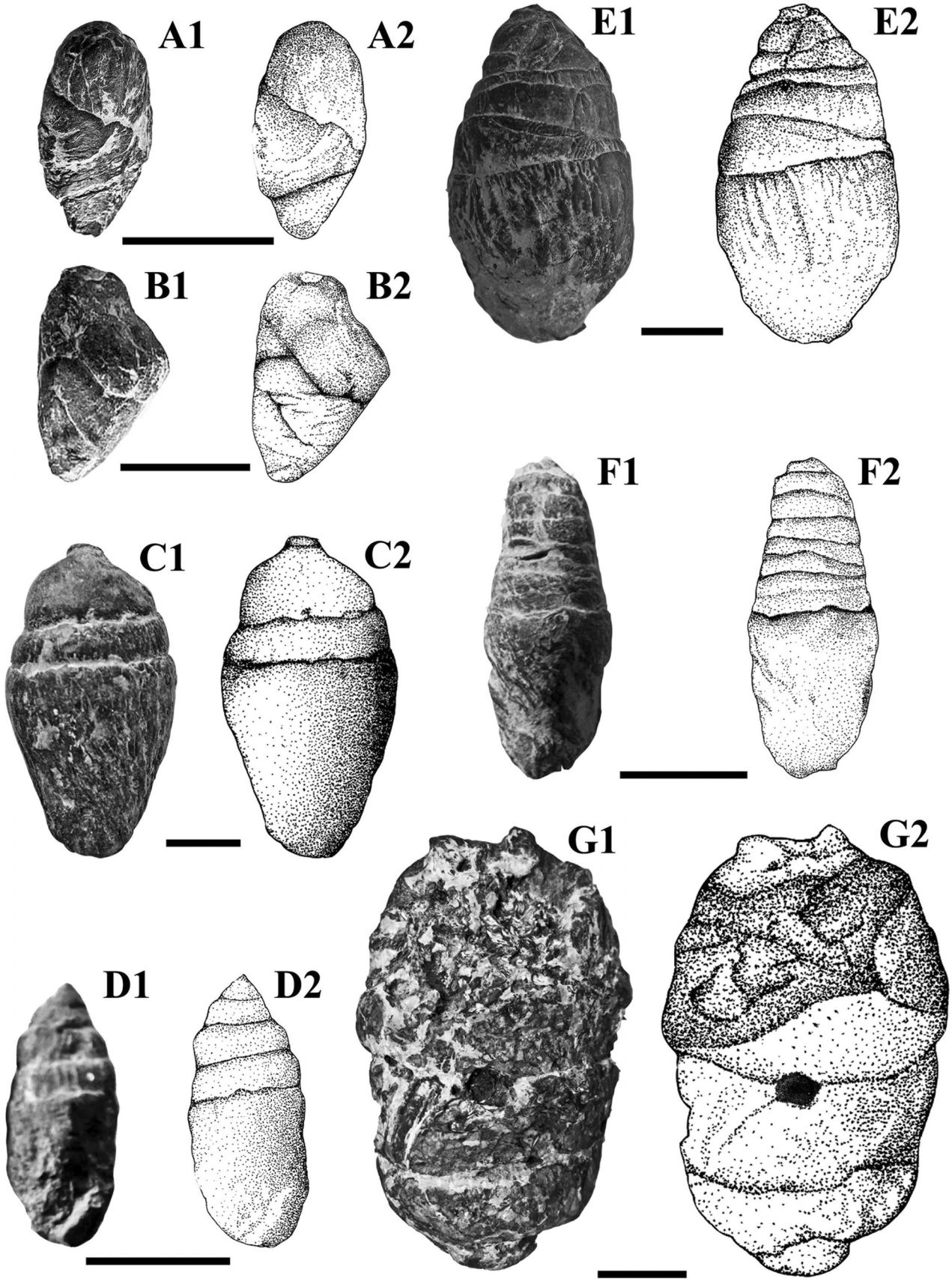

FIGURE 7. Coprolites of ichnotaxa groups 4-7. **A**, Ichnotaxon group 4 (CY-HN41), lateral view. **B**, Ichnotaxon group 4 (CY-HN42), lateral view. **C**, Ichnotaxon group 5 (CY-HN43), lateral view. **D**, Ichnotaxon group 5 (CY-HN44), lateral view. **E**, ichnotaxon group 6 (CY-HN45), lateral view. **F**, Ichnotaxon group 6 (CY-HN46), lateral view. **G**, Ichnotaxon group 7 (CY-HN47), lateral view. Scale bars are 2 cm.

Concerning non-spiraled coprolites, Mancuso et al. (2004) suggested that the shape of coprolites can change because of transportation processes. Jain (1983) indicated that spirals of fecal material in modern lungfishes are somewhat loosened after dropping in water for several hours. Thus, it is difficult to identify the producers of ichnotaxa groups 1-3 from their external morphology, although inclusions in coprolites can provide information about the diet of the producer. The presence of many bony fish scales and bone fragments implies that ichnotaxa groups 1 and 2 have been produced by a carnivorous vertebrate whereas ichnotaxa group 3 was probably produced by herbivorous or insectivorous animals.

Hunt (1992) suggested that coprolites, especially invertebrate coprolites, can be useful in palaeoecology. Moreover, Hunt et al. (2007) indicated that coprolites ichnocoenoses can be distinguished with a relatively limited distribution in space and time. In Huai Nam Aun many ovoid coprolites and *Liassocopros hawkinsi* can help to recognize the palaeoenvironment as Hunt et al. (2007) remark that *Liassocopros hawkinsi* usually occurs in shallow marine strata, whereas ovoid structure coprolites (e.g. groups 2, 4, 5,6 and 7) come from carbonaceous ponds. This is in accordance with preliminary sedimentological studies of the outcrop suggesting that these deposits may have formed in an anoxic lagoon or carbonaceous pond close to the sea.

The utility of coprolites in terms of biochronology is rather limited as they generally represent higher level taxonomic groups (Hunt et al., 1998; Lucas, 2007). However some localities yield only coprolites, thus there is a potential to utilize them in terms of bichronology (Hunt et al., 2007). Coprolites were used in several papers in terms of biostratigraphy and biochronology (e.g.. Hunt et al.. 1992, 1998, 2005a, b).

Some specimens from Huai Nam Aun are referred to *Liassocopros hawkinsi* and *Saurocopros bucklandi*. Hunt et al. (2007) remarked that *Liassocopros hawkinsi* and *Saurocopros bucklandi* are quite abundant in the Late Triassic (Carnian-Norian) and the Early Jurassic. This is in good agreement with the palynological results of Racey et al. (1996) and Racey and Goodall (2009), suggesting a Carnian-Norian age for the Huai Hin Lat Formation.

CONCLUSIONS

The varying size and shape of the coprolites found in Chaiyaphum province suggests that they were made by different producers. Spiral coprolites were probably produced by lungfishes and fish-eating sharks (possibly hybodonts) whereas non-spiral coprolites with visible fish scales and bone fragment inclusions represent another fish-eating producer. *Liassocopros hawkinsi* and *Saurocopros bucklandi* are recognized for the first time in Southeast Asia. Their presence confirms the Late Triassic age for the Huai Nam Aun locality. However, the seven morphotypes of coprolites that we present in this study represent only a part of the coprolites found at Huai Nam Aun. It is an extremely interesting locality for the study of coprolites, and further work is planned at this site in the future. Ichnotaxon group 4, which shows a large spiral on the lateral view with a width about half of total length, may be a new ichnotaxon and will be the subject of further study.

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