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Late Triassic freshwater conchostracan, ostracods, and stromatolites from Huai Hin Lat Formation, northeastern Thailand.

Anisong Chitnarin[a*], Stephen Kershaw[b], Anucha Promduang[a], Prachya Tepnarong[a]

[a] *Geological Engineering Program, School of Geotechnology, Institute of Engineering, Suranaree University of Technology, 111 University Avenue, Suranaree subdistrict, Mueang, Nakhon Ratchasima 30000, Thailand*
[b] *Department of Life Sciences, Brunel University London, UB8 3PH, UK; and Earth Sciences Department, The Natural History Museum, Cromwell Road, London, SW7 5BD, UK*
**Corresponding author, email: anisong@sut.ac.th*
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Abstract

Although ostracods are well-known in marine environments, their study in non-marine facies is less understood. In the Khorat Plateau region of northeast Thailand, a well-exposed example of fluvial-lacustrine facies in the Dat Fa Member of the Huai Hin Lat Formation (Norian, Late Triassic), contains abundant ostracods that in the oldest known non-marine sedimentary sequence in Thailand. *Euestheria buravasi*, the Late Triassic index fossil is recovered for the first time at the studied section. Associated with the ostracods is a restricted non-marine stromatolite, together with non-marine clastic sediments. A combined study of ostracod faunas and sedimentary characters herein provides more detail of the nature of the environments of the Huai Hin Lat Formation. The ostracods are from the superfamily Darwinulidae, thus are a low diversity assemblage of exclusively non-marine forms that confirms the freshwater nature of the beds. The stromatolite layer consists of some stromatolite domes of hybrid construction combining laminae with filamentous structure (suspected to be cyanobacteria) together with probable inorganic layers of fine-grained carbonate. The stromatolite represents an episode of carbonate-rich waters available in these freshwater facies to create a hybrid stromatolite deposit in this non-marine setting. The sum of facies study in this investigation makes an interpretation of the setting as being very shallow water, in contrast to other studies that proposed the lacustrine setting was deeper.

Keywords: Huai Hin Lat Formation, Khorat Plateau, Late Triassic, Ostracods, stromatolite

1. Introduction

Ostracods are crustaceans with small size (average 1 mm in length) living in (semi) aquatic environments, from lakes, springs, lagoons, shallow shelves to deep oceans. They were entirely marine during the Early Paleozoic (e.g., Salas et al. 2007; Ghobadi Pour et al. 2011), then invaded non-marine environments during the Carboniferous (e.g., Bennett, 2008; Iglikowska, 2014; Williams et al. 2006; Bennett et al. 2012). Marine ostracods were inten-sively affected by the end-Permian mass extinction (i.e., Crasquin & Forel, 2015), yet opportunely, some ostracods survived in a specific condition related to microbialites (i.e., Kershaw et al. 2007; 2012; Forel, 2012; 2015; 2018). In contrast, non-marine ostracods survived and radiated during the Mesozoic and through the Cenozoic (Horne & Marten, 1998; Horne, 2003). In Thailand, marine Permian and Triassic ostracods have been reported from northern, central and northeastern regions (Chitnarin et al. 2008; 2012; 2017; Burrett et al. 2014; Ketmuang-moon et al. 2018). However, the study of fossil non-marine ostracods is uncommon. This study focuses on the occurrence of the oldest known non-marine ostracods in Thailand, as well as a conchostracan found in the same level as the ostracods, and associated sedimentary facies that include a stromatolite deposit (also the oldest non-marine stromatolite in Thailand) found in the Dat Fa Member of the Huai Hin Lat Formation. The aim is to record the occurrence of these fossil arthropods, enhance understanding of their associated facies, and their applications in analysis of the depositional environment of the Huai Hin Lat Formation using a key study section.

2. Geological setting and locality

The Huai Hin Lat Formation is part of the oldest non-marine Mesozoic Erathem on the Khorat Plateau in northeastern Thailand (Fig. 1) which accumulated in half-graben basins as a result of the Indosinian I Orogeny (Bunopas & Kositanon, 2008; Booth & Sattayarak, 2011). Although there is evidence that natural gas in northeastern Thailand reservoirs has a lacustrine source signature (Chinoroje & Cole, 1995; Sattayarak et al. 1989), knowledge of the depositional setting of the Huai Hin Lat Formation is not completely developed (Asairai et al. 2014; 2016; Phujaranchaiwon et al. 2021). Facies of the Huai Hin Lat Formation consist of mainly clastic sedimentary rocks deposited in fluvial-lacustrine environments during the Late Triassic (Chonglakmani & Sattayarak, 1978; Chonglakmani, 2011) and is exposed extensively at the western and rim of the Khorat Plateau (Wongprayoon & Saengsrichan, 2004.; Treerotchananon, 2012; Phujaranchaiwon et al. 2021). Various fossils including vertebrates (Ingavat & Janvier 1981; Buffetaut et al. 1993, Laojumpon et al. 2012; 2013), invertebrates (Hayami, 1968; Kobayashi, 1973; 1975), and floral groups (Endo & Fujiyama, 1966; Kon'no & Asama 1973; Haile, 1973) have been reported. A Late Triassic age is assigned due to presence of Norian plants and palynomorphs (Kon'no & Asama 1973; Haile, 1973) and conchostracans (Kobayashi, 1973; 1975). The equivalent rock formation of the Huai Hin Lat Formation is in the subsurface under the Khorat Plateau, and is recognized as one of petroleum source rocks in northeastern Thailand (Booth, 1998; Racey, 2011). The formation is overlain unconformably by a thick succession of the younger Upper Triassic to Jurassic Nam Phong Formation and the Jurassic-Cretaceous 'Red Beds' of the Khorat Group (Ward & Bunnag, 1964; Sattayarak, 1983; Meesook, 2001; Racey, 2011) (Fig. 2A). The maximum thickness of the Khorat Group as recognized from seismic profiles is approximately 6,000 meters in the center of the Khorat Plateau. Hydrocarbon production is achieved from reservoirs below these rocks (Booth & Sattayarak, 2011; Racey, 2011).

Terrestrial Triassic sedimentary rocks named as Huai Hin Lat formation were primarily recognized by Iwai and Asama (1964) for the lowest succession of the Khorat Group which lies unconformably on the Permian limestone and is overlain by sandstones of the Nam Phong Formation in Loei and the Khon Kaen areas. Later on, Bunopas (1971) erected the Nam Pha Formation for sequences of conglomerate, sandstone and shale in Chiyaphum area further to the south. Lithology and relative age of both formations are similar, thus Chonglakmani & Sattayarak (1978) correlated and compiled these two formations and formally proposed the Huai Hin Lat Formation with details of five members, from bottom to top (Fig. 2).

- The Pho Hai Member: consisting mainly of volcanic rocks including tuff, agglomerate, rhyolite and andesite with intercalations of sandstone and conglomerate (210 meters thick).

- The Sam Khaen Member: consisting mainly of basal conglomerates intercalated with red siltstone, shale, and local limestone beds (100 meters thick).

- The Dat Fa Member: comprised of a thick sequence of gray to black, carbon-rich, calcareous, well bedded shale and numerous argillaceous limestone beds (390 meters thick).

- The Phu Hi Member: consisting of gray sandstone, shale and argillaceous limestone with some conglomerate beds (650-850 meters thick).

- The I Mo Member: consisting of diorite and volcanic clastic rocks intercalated with well-bedded gray shale, sandstone and limestone (300 meters thick), locally exposed.

Among these units, the Dat Fa Member, the lacustrine facies, is emphasized in this study. The Dat Fa Member is characterized by a thick sequence of shale with intercalations of fine--grained sandstone in the lower part and with argillaceous limestone in the upper part (Chonglakmani & Sattayarak, 1978; Wongproyoon & Saengsrichan, 2004.; Treerotchana-non, 2012). The outcrops vary from place to place: the thick sequence of carbonaceous shale is interpreted as

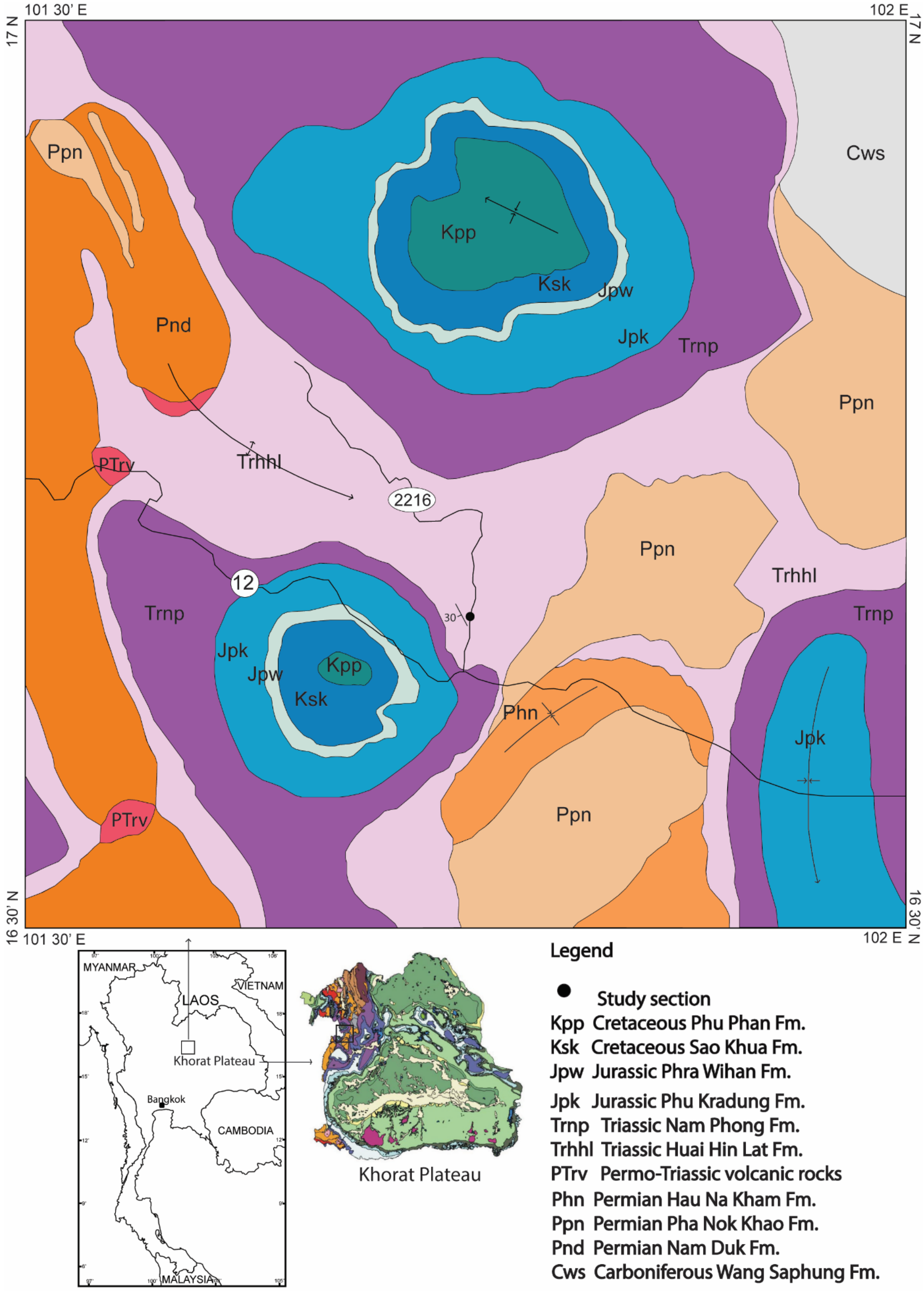

Fig. 1: Geologic map and location of the study section (modified after Chonglakmani & Sattayarak, 1979)

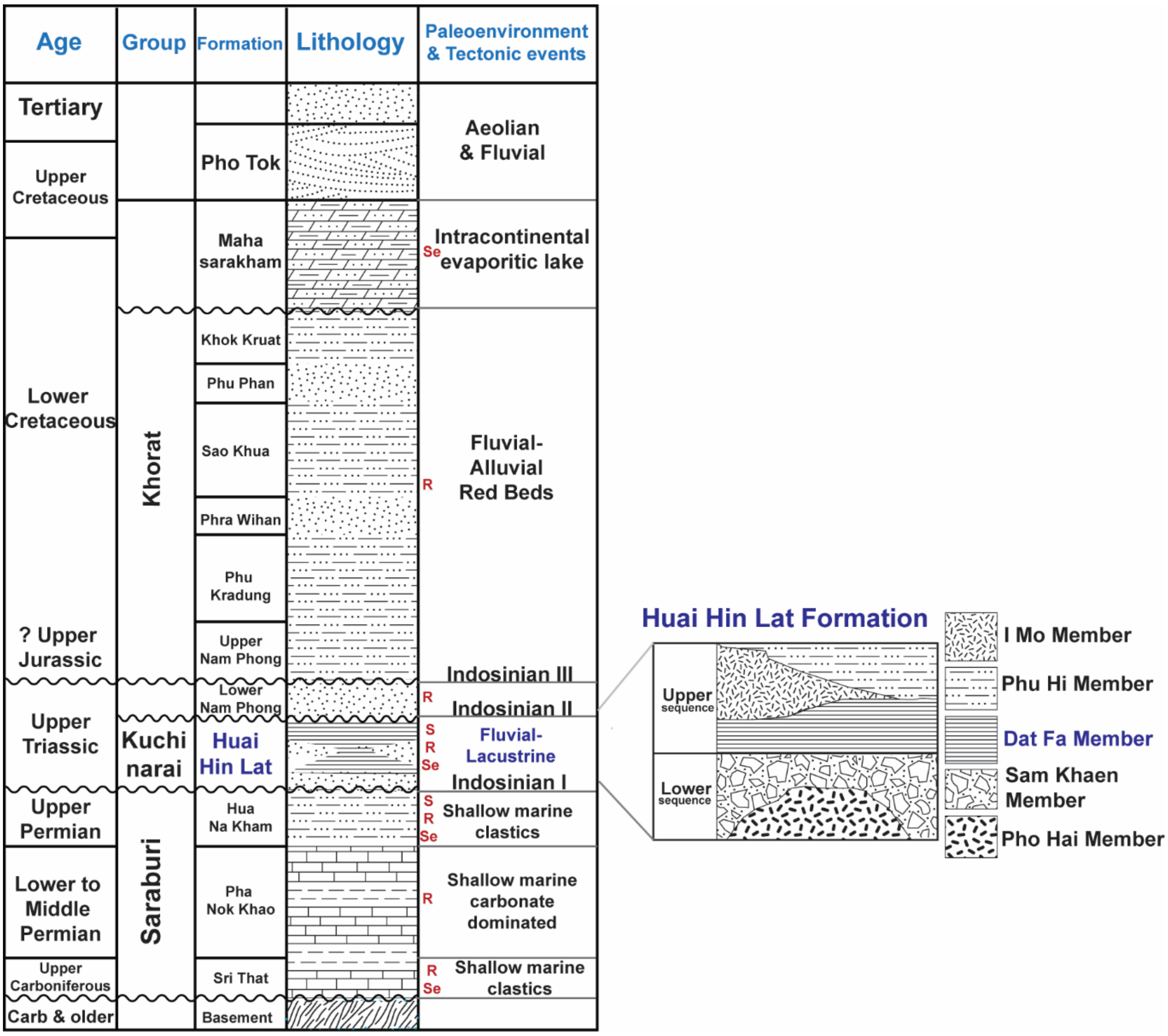

Fig. 2: General lithostratigraphy of northeastern Thailand, modified after Chonglakmani and Sattayarak (1978) and Racey (2011). Letters in red represent the petroleum play: S-source rock; R-reservoir; Se-seal. See text for description.

the middle part of the lake (Phujaranchaiwon et al. 2021), the calcareous siltstone and limestone beds are in the shallower zone; sandstones, siltstones and coals are uncommonly exposed (Asairai et al. 2012; 2016).

The study section is located at 101˚44'30.4"E, 16˚40'59.3"N, at km 2 on highway No.2216, in Nam Noa Subdistrict, Phetchabun Province and belongs to the Dat Fa Member (Figs. 1, 2). The section is approximately 40 meters thick, exposed on both sides of the road, but partly covered by asphaltic pavement. It is composed of well bedded calcareous mudstone in the lower part, intercalations of calcareous mudstone and shale in the middle part, and silty sandstone with coal-bearing strata in the upper part (Fig. 3). The bedding attitude is 30°/240 (dip/dip direction). Fig. 4A shows outcrops of the upper part of the section, Fig. 4B shows the middle part. The lower part of the section exposed on the east side of the road consists of medium-, to thick-bedded, dark grey to black, calcareous mudstone containing abundant ostracods which can be seen on rock surfaces (Fig. 5), and rare stromatolites. During field mapping in 1976-1977, approximately ten stromatolite mounds were found in an argillaceous limestone bed (exposed length of the bed was 2 meters) at this location (Nares Sattayarak, 2020, PTTEP, pers com). They are possibly the oldest freshwater stromatolites known in Thailand, and of the observed stromatolite mounds, samples from two are available. One mound is exhibited at Sirindhorn Museum in

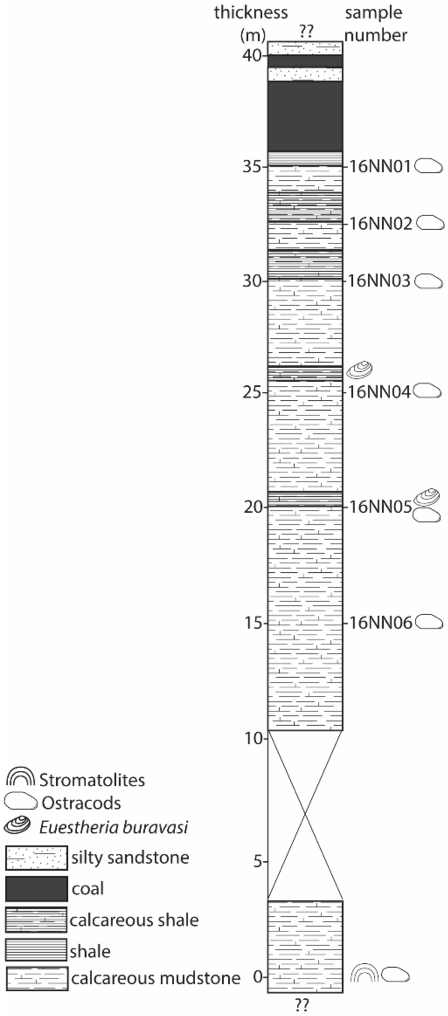

Fig. 3: Lithologic log of the study section, Dat Fa Member, Huai Hin Lat Formation.

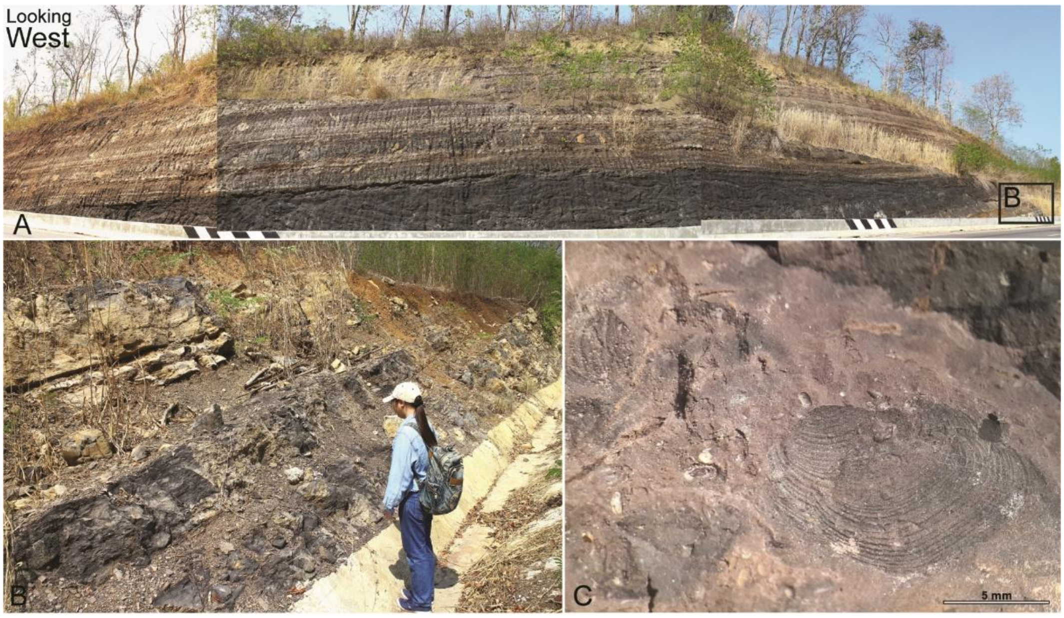

Fig. 4: Field photographs of the study section: A, sandstone and coal beds in the upper part; B, calcareous mudstone and shale in the middle part; C, *Euestheria buravasi* found on calcareous mudstone surface in the middle part (sample No. 16NN04).

Kalasin Province (Fig. 6A), and another is in the collection of Suranaree University of Technology in Nakhon Ratchasima Province (Figs. 6B - C).

3. Methods

Field logging was used to collect samples for sedimentological study, including the microbialite, and palaeontological assessment of the ostracods and the conchostracan. Six calcareous mudstone samples were collected and labelled as NN01-NN06 (Fig. 3); thin sections of sediment and microbial structures are used for analysis. For ostracods, the calcareous mudstone samples were processed by hot acetolysis (Lethiers & Crasquin-Soleau, 1988; Crasquin-Soleau et al. 2005). Few specimens could be freed from the rock matrix due to their low calcareous content. The preservation and density of the ostracods can be seen on these mudstone surfaces as shown in Fig. 5. In general, the ostracod carapaces are well preserved and embedded tightly within the matrix. They are more obvious on the naturally broken or weathered surfaces than on the parting surfaces broken by hammer. There are many ostracods but it is not possible to estimate their abundance. The carapaces are thin,

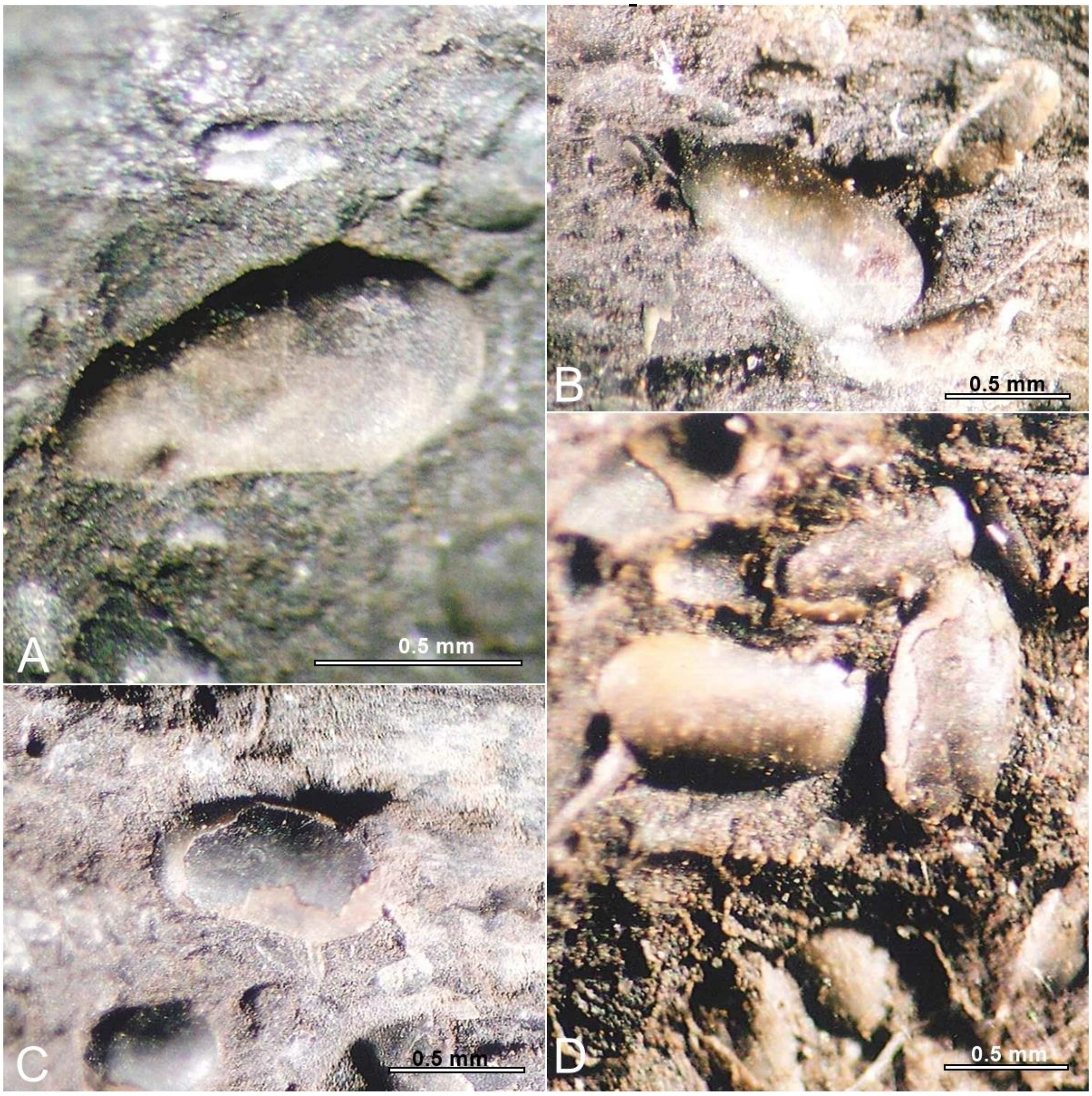

Fig. 5: Steromicrographs of ostracods found in calcareous mudstone in the lower part of the section with associated to stromatolite deposit: A, *Suchonellina* sp.4; B, *Suchonellina* sp.1; C, *Suchonellina* sp.5; C, D, showing rosette pattern of central muscle scars.

delicate and closed, muscle scars are preserved on internal casts (Fig 5 C, D). Ostracod identification is in section 4.3. On the other hand, the conchostracan is rare, occurs as incomplete cast and mold (Fig 4C). Characteristics of the valves are used for identification (section 4.2.1).

4. Methods

4.1 Age of strata

Few specimens of the conchostracan are found in samples NN04 and NN05 (Fig. 3). The fossils are embedded in the calcareous mudstones, they can be observed on naturally weathered surfaces or surfaces parallel to bedding planes (and 4C). The specimens are cast and mold, only the species *Euestheria buravasi* Kobayashi, 1975 can be identified and confirmed (Fig. 4C). *Euestheria buravasi* is important because it demonstrates the freshwater nature of the facies.

In 1973 Kobayashi identified *Euestheria mansuyi* from the basal part of Nam Pha formation at Nam Prom Dam (renamed as Chulabhorn Dam), located about 12 km to the Southwest of the studied section. The *E. mansuyi*-bearing strata were assigned to the Upper Triassic because they are correlated to the

Fig. 6: A stromatolites form the study section: A, stromatolite mound exhibited at Sirindhorn Museum in Kalasin Province; B, unpolished section of the stromatolite mound scrutinized in this study; C, polished section of the studied mound.

lower part of the contemporaneous Huai Hin Lat formation (exposed to the north), and plants collected from the middle part of the Huai Hin Lat formation were dated to Norian age (Kon'no & Asama, 1973). Later in 1975, Kobayashi identified six more species and one new genus (also called the mansuyi faunule by Kobayashi) from the rocks collected at the same locality including *Euestheria thailandica* Kobayashi, 1975; *E. buravasi*, Kobayashi, 1975; *Khoratestheria macroumbo* Kobayashi, 1975; *Cyclestherioides bunopasi* Kobayashi, 1975; *Metahabdosticha*? sp. and *Asmussia symmetrica* Kobayashi, 1975. He also classified these materials as belonging to the Dido Conchostracan Group whose members were dispersed in Japan, Vietnam and Yunnan and confined to the Norian. In 1978, Chonglakmani & Sattayarak compiled the geological map in this area and merged the Nam Pha and the Huai Hin Lat formations to the newly established Huai Hin Lat Formation, thus, the mansuyi faunule can be used as index fossils for the Huai Hin Lat Formation. Since then, fossil conchostracans have been mentioned in reports of geological investigations especially for the Huai Hin Lat Formation, but without taxonomic details.

Kozur & Weems (2010) reviewed the occurrences of the conchostracans in the northern hemisphere including Europe, Asia and America, and established a conchostracan zonation for Late Permian to Early Jurassic time (including 34 biozones in the Triassic). They recorded that *E. buravasi* was found in the United States of America (North Carolina), Germany (Thuringia) and Thailand (Chaiyaphum Province). Kozur & Weems (2010) placed *Euestheria buravasi* – *Euestheria* n. sp. zone at Middle Lacian Substage (Lower Norian). Weems & Lucas (2015) investigated new localities of the Upper Triassic Systems in North America, then revised and simplified the Upper Triassic conchostracan zonation. The *Shipingia weemsi* – *Euestheria buravasi* zone was place at the base of the Norian to indicate the whole Lacian Substage in North America. According to the biostratigraphic zonation of conchostracans as mentioned above, the *E. buravasi* and the mansuyi faunule is confined in the Lower Norian (Lacian Substage). The presence of *E. buravasi* in the studied section suggests the Early Norian age and indicates that the section is the base of the Huai Hin Lat Formation (correlated with the formal Nam Pha formation at the Chulabhorn Dam - Kobayashi, 1973).

4.2 Systematic Paleontology

4.2.1 Conchostracan

We follow the systematic classification of Astrop & Hegna (2015) for the higher levels. Method of conchostracan classification of Scholze and Schneider (2015) is followed as much as possible. The description of *Euestheria buravasi* by Kobayashi (1975) is adopted.

Class Branchiopoda Latreille, 1817

Order Spinicaudata Linder, 1945

Superfamily Eosestherioidea Zhang and Chen in Zhang et al., 1976 *sensu* Chen and Shen, 1985

Family Euestheriidae Defretin-Lefranc, 1965

Genus *Euestheria* Depéret & Mazeran, 1912

Type species. *Posidonia minuta* von Zieten, 1833

Euestheria buravasi Kobayashi, 1975
Fig. 4 C

Materials: one incomplete carapace and one incomplete cast.

Remarks: The specimens are incomplete; the carapace is partly embedded in rock matrix and is overlain by another cast. However, carapace shape and concentric ribs are observed. They are identified to *Euestheria buravasi* due to diagonally elongated carapace with submedial umbo. The growth lines and concentric ribs are coarse in the medial region and narrower on the umbonal side. Sizes of both specimens are very large; length of the carapace is approximately 12.5 mm.; length of the cast is approximately 13.3 mm. *E. buravasi* can be differentiated from *E. mansuyi* by having coarser growth lines and concentric ribs, and from *E. thailandica* by more diagonal carapace which causes the diagonal curvature of the growth line and ribs at medial region. Weems

& Lucus (2015) constructed a sketch of complete *E. buravasi* (fig. 3, p. 305) showing the finer growth lines bounded along the carapace rim, though; this feature cannot be observed in our specimens.

4.2.2 Ostracods

The circular outline and pattern of the muscle scars imprinted on internal molds of the ostracods recovered indicate that they belong to Superfamily Darwinulidae (Figs. 5 and 7). The characters observable here are external features of the carapace (shape, size). The shell characters such as marginal inner teeth and keels which are normally used to identify extant materials (Rossetti and Martens, 1998) are not observed. In this study, we classify fossil darwinulocopines following Antonietto et al. (2017; 2018), Liebau (2005) for above family level and Molostovskaya (2000) for lower ranks. The distinct characters of most studied specimens are ovate to sub-rectangular shape with rounded posterior margin which led us to the attribution of the materials to genus *Suchonellina* Spizharsky, 1937 (Antonietto et al. 2017). Thus, five species are recognized: *Suchonellina* sp.1, *Suchonellina* sp.2, *Suchonellina* sp.3, *Suchonellina* sp.4, and *Suchonellina* sp.5 (Fig. 8, A-L). The systematic attributions are discussed as follows.

Abbreviations used in this study: LV, left valve; RV, right valve; DB, dorsal border; ADB, antero-dorsal border; AB, anterior border; AVB, anteroventral border; VB, ventral border; PVB, postero-ventral border; PB, posterior border; PDB, postero-dorsal border; H, height; L, length. The length of specimen is indicated as very small (0.40-0.50 mm), medium (0.51-0.70 mm), large (0.71-0.90 mm) and very large (> 0.90 mm).

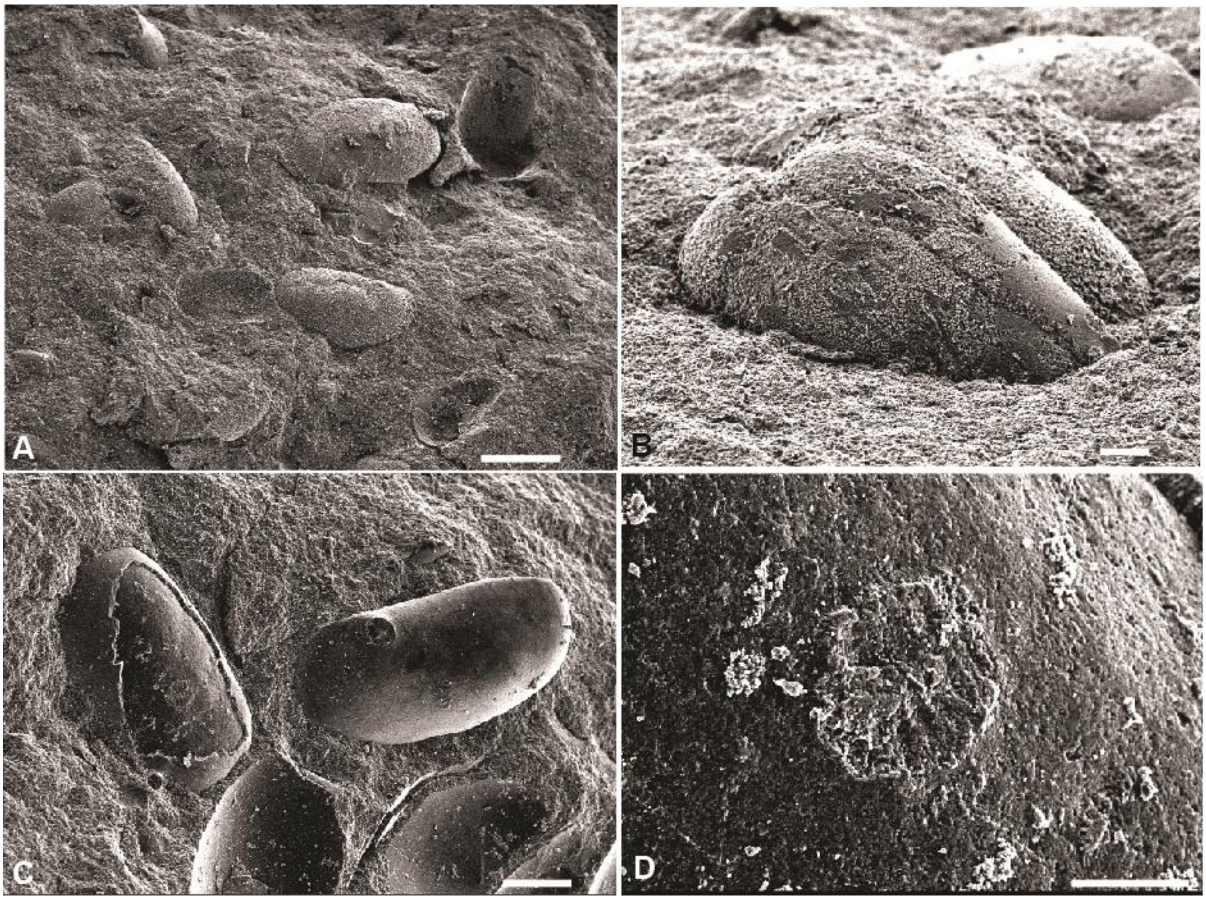

Fig. 7: Pictures from scanning electron microscope showing ostracods embedded in calcareous mudstone in the lower part of the section with associated to stromatolite deposit: A, carapaces and valves partly exposed from the matrix, scale bar = 0.5 mm.; B, carapace partly exposed from the matrix, scale bar = 0.1 mm.; C, carapaces, casts and mold with imprinted central muscle scar, scale bar = 0.2 mm.; D, central muscle scar, scale bar = 0.1 mm.

Class Ostracoda Latreille, 1802

Superorder Podocopomorpha Kozur, 1972

Order Podocopida Sars, 1866

Suborder Darwinulocopina Sohn, 1988

Superfamily Darwinuloidea Brady and Norman, 1889

Family Suchonellinidae Kukhtinov, 1985

Genus *Suchonellina* Spizharsky, 1937

Type species. *Suchonellina inornata* Molostovskaya, 1980

***Suchonellina* sp.1**

Fig. 8, A-D

Materials: more than 12 incomplete carapaces.

Measurement: (figured specimens) H = 0.433-0.727 mm; L = 0.811-1.309 mm; H/L = 0.52-0.57.

Remarks: This species is characterized by its long and sub-rectangular carapace in lateral view. DB is short (25% of L) and straight to slightly convex, ADB is straight and incline at 30°. AB of both valves is rounded with small radius of curvature and maximum convexity is located at 30% of H. VB is long (70% of L) and straight. PVB and PDB are rounded. PB is rounded with large radius of curvature and maximum convexity is located at 50% of H.

Maximum H is located at 50% of L, maximum L is located at 30% of H. Carapace is flattened laterally. The carapace size ranges from large to very large. Surface is smooth. The lateral outline of the carapace looks similar to *Darwinula accuminata* Belousova, 1961 which was described from Wayaobu Formation (Upper Triassic) of Tongchun, Shaanxi (Plate 2, fig. 12 in Xu, 1988).

***Suchonellina* sp.2**

Fig. 8, E-F

Materials: more than 5 incomplete carapaces.

Measurement: (figured specimens) H = 0.400-0.600 mm; L = 0.833-1.183 mm; H/L = 0.48-0.50.

Remarks: This species is characterized by elongated carapace and a rounded PB which maximum of convexity is located above mid of H. DB is longer than 50% of L and straight. ADB is straight and slightly inclined at 30°. AB of both valves is rounded with medium radius of curvature; maximum convexity is located just below 50% of H. VB is long (80% of L) and straight. PVB is slightly convex. PB is rounded with medium size of curvature and maximum convexity is located above 50% of H. PDB is very short. Carapace is flattened laterally. The carapace size ranges from medium to very large. Surface is smooth. *Suchonellina* sp. 2 can be differentiated from *S.* sp. 1 by the longer carapace, position of maximum convexity of PB, and the less H/L ratio.

***Suchonellina* sp.3**

Fig. 8, G-I

Materials: more than 5 incomplete carapaces.

Measurement: (figured specimens) H = 0.228-0.550 mm; L = 0.521-1.183 mm; H/L = 0.43-0.46.

Remarks: *Suchonellina* sp. 3 can be differentiated from *S.* sp. 2 by the longer carapace, position of maximum convexity of PB which located below 50% of H, and the less H/L ratio. Shape of the carapace resemble genus *Praesuchonellina* which has been found from Upper Paleozoic rocks of Russia (Molostovskaya et al. 2000).

***Suchonellina* sp.4**

Figs. 5, A; 8, J

Materials: more than 6 incomplete carapaces.

Measurement: (figured specimen) H = 0.600 mm; L = 1.183 mm; H/L = 0.52.

Remarks: This species is characterized by having a distinct antero-ventral knob on LV as shown in Figs. 5A and 8J. DB is long and straight, and sloped at 20° to anterior. ADB is short, AB is rounded with small radius of curvature, maximum convexity is located at 25% of H. AVB is short, VB is long and straight,

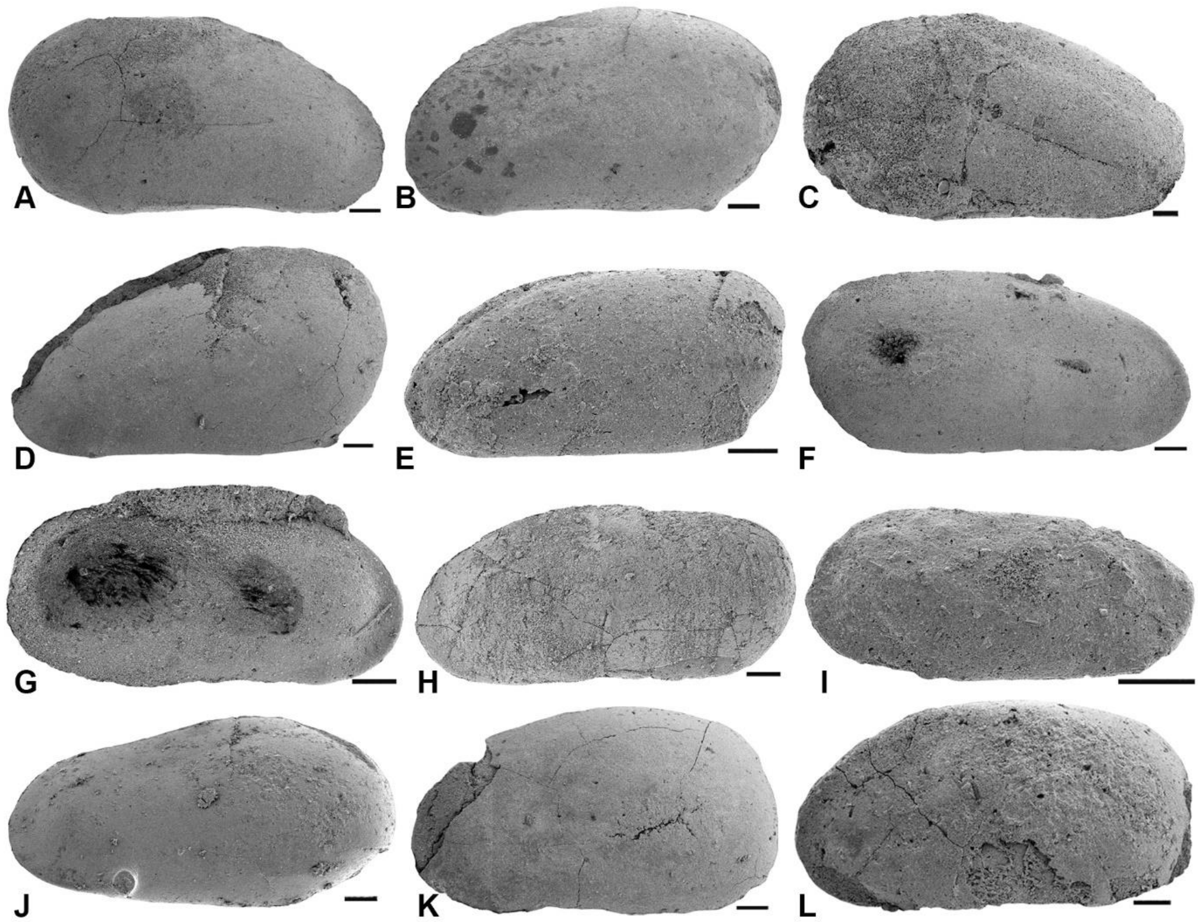

Fig. 8: Late Triassic ostracods from Dat Fa Member, Huai Hin Lat Formation, Phetchabun Province, northeastern Thailand: A-D, *Suchonellina* sp.1, A, right lateral view of complete carapace, sample No. 16NN02, SUT-16-001; B, left lateral view of complete carapace, sample No. 16NN03, SUT-16-002; C, right lateral view of complete carapace, sample No. 16NN03, SUT-16-003; D, left lateral view of complete carapace (partly embedded), sample No. 16NN05, SUT-16-004; E-F, *Suchonellina* sp.2, E, left lateral view of complete carapace, sample No. 16NN03, SUT-16-019; F, right lateral view of complete carapace, sample No. 16NN04, SUT-16-017;G-I, *Suchonellina* sp.3, G, left lateral view of complete carapace, sample No16NN04, SUT-16-023; H, left lateral view of complete carapace, sample No. 16NN04, SUT-16-021; I, right lateral view of complete carapace, sample No. 16NN05, SUT-16-020; J *Suchonellina* sp.4, left lateral view of complete carapace, sample No. 16NN06, SUT-16-016; K-L, *Suchonellina* sp.5, K, left lateral view of complete carapace, sample No. 16NN06, SUT-16-005; L, left lateral view of complete carapace, sample No. 16NN05, SUT-16-006. Scale bars = 0.1 mm.

PVB is long. PB is rounded with medium radius of curvature, maximum convexity is located above 50% of H. Carapace is flattened laterally. The size is very large. Surface is smooth. This species cannot be compared to any known species.

***Suchonellina* sp. 5**

Fig. 8, K-L

Materials: more than 4 incomplete carapaces.

Measurement: (figured specimens) H = 0.58-0.66 mm; L = 1.166-1.183 mm; H/L = 0.50-0.55.

Remarks: This species is characterized by its short and sub-rounded carapace. DB is slightly convex, ADB is sloped at 25°. AB is rounded with medium radius of curvature and located at 30% of H. AVB is short and slightly convex. VB is slightly concave in middle part, PVB is short and convex. PB is rounded with large radius of curvature, maximum convexity is located at 30% of H. PDB is convex. Carapace is flattened laterally. The size is very large. Surface is smooth. Shape of the carapace resemble genus *Wjatkellina* which has been found from Upper Paleozoic rocks of Russia (Molostovskaya et al. 2018). Unfortunately, more precise identification cannot be made because the ostracods were tightly embedded in rock matrix.

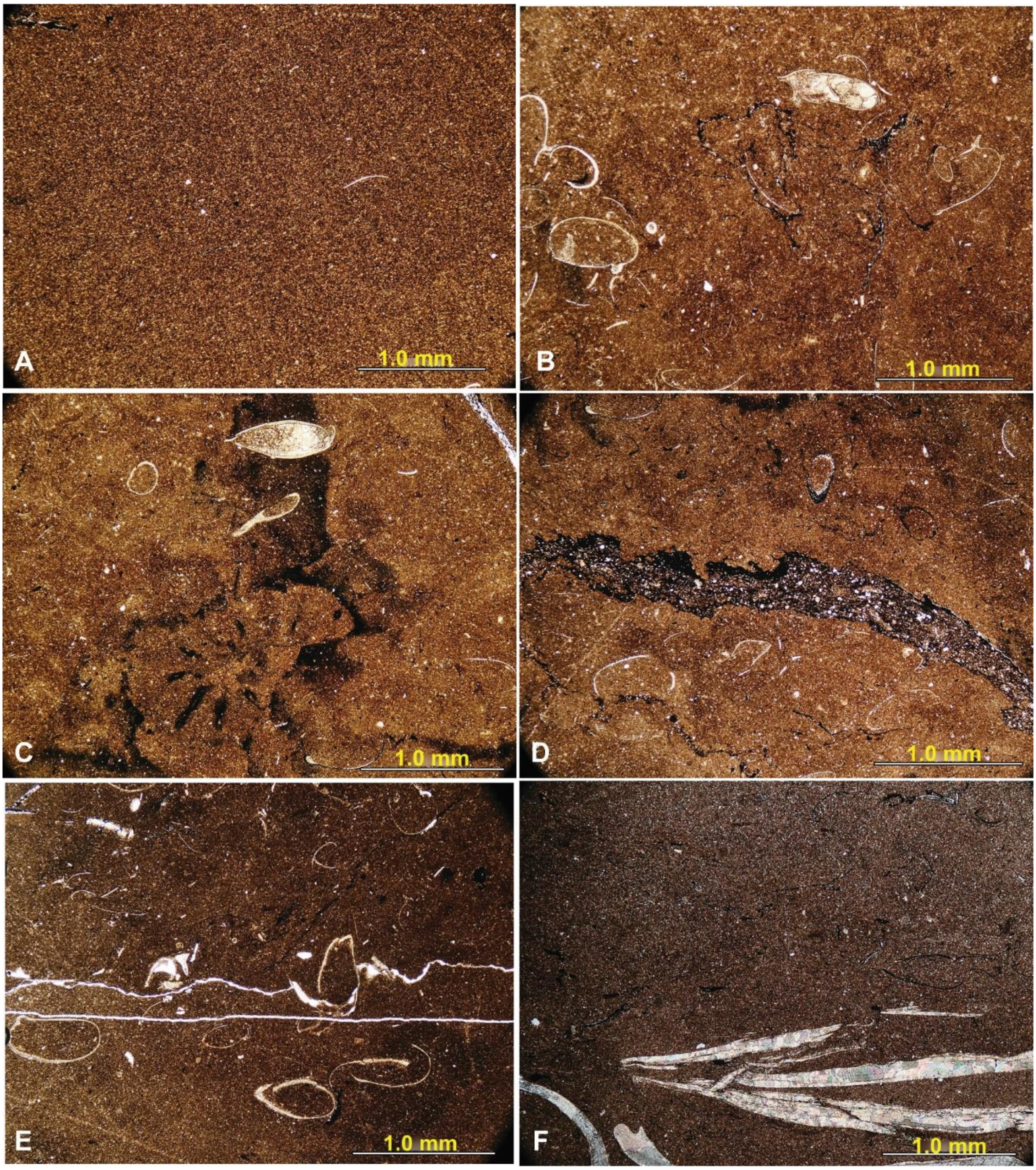

Fig. 9: Photomicrographs of massive carbonates facies from the Dat Fa Member, Huai Hin Lat Formation: A, sample No. 16NN01, massive carbonate mudstone (regular light); B-D, sample No.16NN02, massive carbonate wackestone with bioclasts (regular light); E, sample No.16NN03, massive carbonate wackestone with bioclasts and stylolite (regular light); F, sample No. 16NN04, massive carbonate wackestone with bivalve shell fragments (polarized light).

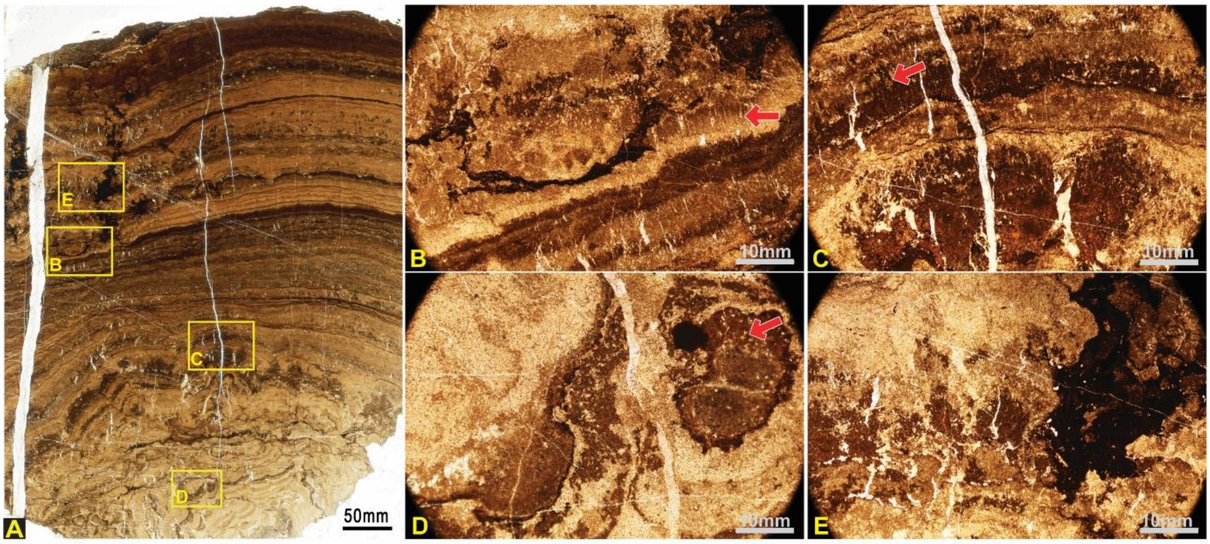

Fig. 10: Photomicrographs of vertical sections of stromatolite from microbial carbonates facies from the Dat Fa Member, Huai Hin Lat Formation: A, laminated structure of stromatolite clearly demonstrated; B-E, enlargements of the yellow boxes in A. In B and C, the filamentous structure is shown (arrows). In D, part of the stromatolite is shown in transverse section due to curvature of the laminations; the filamentous structure is arrowed. E, the stromatolite is broken and partially infilled with carbonate matrix.

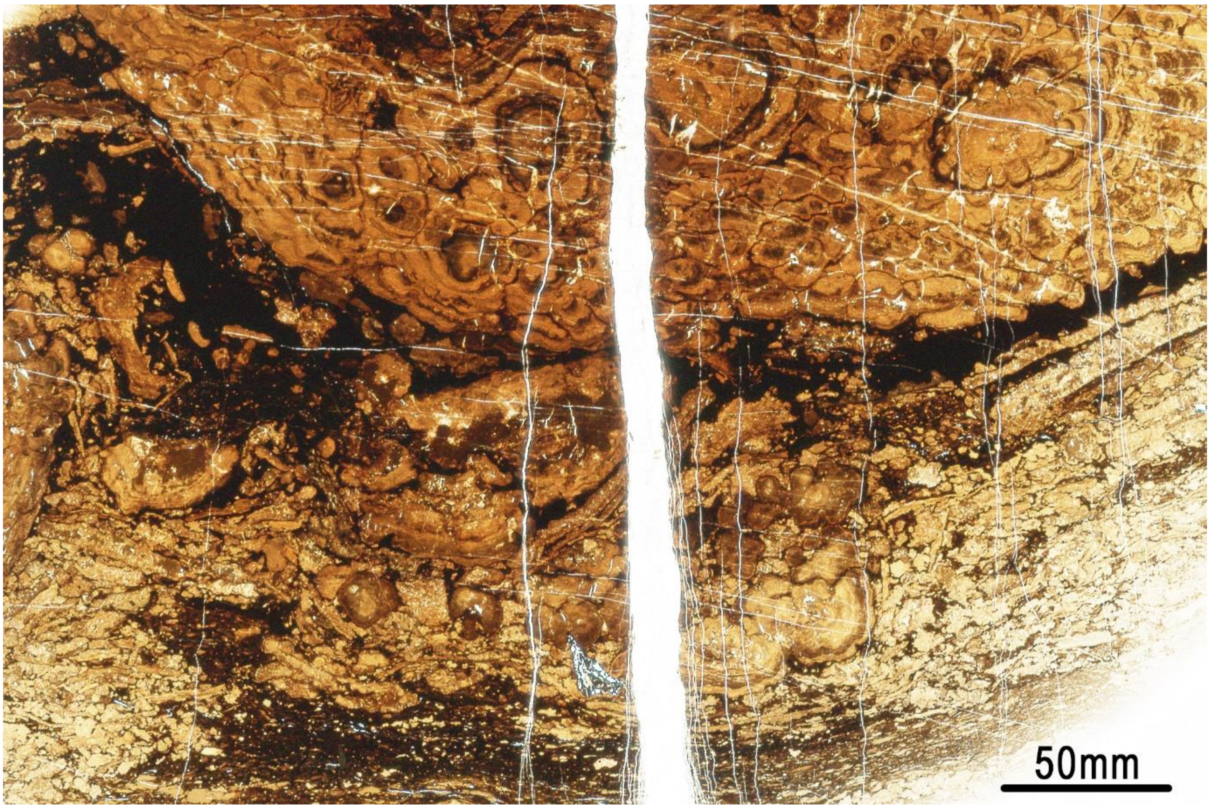

Fig. 11: Photomicrograph of stromatolite from microbial carbonates facies from the Dat Fa Member, Huai Hin Lat Formation. This photograph shows the complex laminated structure in transverse section in the upper two thirds of the picture; in the lower part are abundant fragments, probably formed due to high energy events affecting the surface environments.

4.3 Sedimentary facies from log and thin sections

The studied section is composed of well bedded calcareous mudstone (with stromatolite mounds) in the lower part, intercalations of calcareous mudstone and shale in the middle part, and coal-bearing strata in the upper part (Fig.3). The succession is dominated by fine--grained, grading to coarser grained, clastic rocks and terminated by the coal seams and silty sandstone; altogether this assemblage indicates a fluvial-lacustrine facies association (Renaut & Gierlowski-Kordesch, 2010). The stromatolite can be classified to microbial carbonates facies and described in section 4.4. All thin sections of the calcareous mudstone from the middle part (16NN01-16NN06) are identical and can be classified as massive carbonates facies by lacking sedimentary structure except some bioturbation (Fig. 9). Fossils such as ostracods and bivalve fragments are found.

4.4 Stromatolite and associated sediments

Rock slabs and thin sections were prepared from the stromatolite mound (Figs.10-11). The stromatolite (Figs. 6, 10, 11) at the base of the section indicates higher levels of carbonate input than other parts of the study site. Fig. 6 shows vertical sections of the two stromatolite samples available, and Figs. 10 and 11 show representative thin section views of the stromatolite fabric. Fig. 10 demonstrates the stromatolite has variable structure but a key component is layers containing a vertical fabric of filaments likely to be of cyanobacterial composition. Between filament layers are fine-grained calcium carbonate layers of possible bacterially-mediated, or perhaps inorganic, origin. Some of the stromatolite was fragmented (Fig. 11) indicating episodic events of higher energy, possibly storms, that affected the region and damaged the stromatolite.

5. Discussion

5.1 Taxonomy of conchostracan and ostracod from the Dat Fa Member, Huai Hin Lat Formation

Conchostracans and ostracods are groups of arthropods which belonged to Subphylum Crustacea, and Class Branchiopoda and Class Ostracoda, respectively (Ahyong et al. 2011). They are different from each other by biology and evolution (Negera et al. 1999; Yamaguchi & Endo, 2003; Newman, 2005). Both are known as fossils and living animals, but detailed studies are rare in Thailand.

Conchostracan is a common name of animals in Superorder Conchostraca Sars, 1867, they are also called spinicaudatan which means the animals in Order Spinicaudata Linder, 1945 (Negrea et al. 1999). The name conchostracan however is more familiar to paleontologists (Scholze & Schneider, 2015). A phylogenetic study between living and fossil spinicaudatan was carried out by Astrop & Hegna (2015) and their classification is adopted in this study. The Late Triassic conchostracan genus *Euestheria* identified by Kobayashi (1973 and 1975) is therefore moved from Family Lioestheriidae Kobayashi, 1954 to Family Euestheriidae under Superfamily Eosestherioidea. It should be noted that a common name estheriid which is assigned for animals in Family Estheriellidae (Superfamily Estherielloidea), is not the same as the taxa identified by Kobayashi (1973, 1975). According to him, genus *Estheria* was not described from the Huai Hin Lat Formation. The Rhaetian *Estheria* sp. found in the Nam Pha Formation by Bunopas 1971 (cited in Sattayarak, 1983, p. 132) should thus be reviewed. So far, Thai conchostracans have been recorded from the Upper Triassic, Huai Hin Lat Formation in Chaiyaphum Province (Kobayashi, 1973; 1975), Phetchabun Province (this study) and the ?Middle Jurassic, ? Phra Wihan Formation in the Nan-Phrae area (Heggeman et al. 1990).

The ostracods recovered from the Huai Hin Lat Formation belong to the Superfamily Darwinulidae, which can be recognized by their smooth carapaces and rosette-pattern muscle scar with circular outline. Though the Darwinulid ancestors were marine in origin since the Paleozoic, the extant animals are entirely non-marine, benthic organisms (Horne and Martens, 1998; Martens and Horne, 2009; Karanovic, 2012). During the Mesozoic, members of the Superfamily Darwinulidae were known to be wholly non-marine inhabitants and the maximum number of species was recorded in Late Triassic rocks (Horne and Marten, 1998). Their abundance declined in the Jurassic due to evolution of other freshwater ostracod groups (Cypridoidea and Cythe-roidea), so that less than ten species have been recorded from the Middle Jurassic to the Cretaceous (Horne and Martens, 1998).

Late Paleozoic Darwinulid ostracods were recorded and well studied from the Russian Plate, three Superfamilies including Darwinuloidea, Suchonelloidea, Darwinuloidoidea and nine genera were classified (Molostovskaya, 2000). The Darwinulid ostracods were also recovered from the Permian-Triassic boundary beds of several sections of the East European platform (Kukhitnov et al. 2008). According to them, the Triassic sediments at the studied sections were marked by species of the Early Triassic *Gerdalia* (Gerdaliidae) and the Late Permian and Early Triassic assemblages might share some taxa in common. On the contrary, the complete stratigraphic record during Late Permian to Middle Triassic is unknown in Northeastern Thailand. The ostracods scrutinized in this study are from the Huai Hin Lat Formation which was deposited after the Indosinian I Orogeny. There is a big gap between the upper Middle Permian marine sediments and the Upper Triassic terrestrial sediments that conceals the evolution of the ostracods from marine to freshwater realms. Most of the studied materials are embedded in the rock matrix, identification to the genus *Suchonellina* is based on the observable features of the carapaces. More research is needed especially if there were suitable sedimentary facies or well-preserved materials.

5.2. Paleoenvironmental reconstruction

Chonglakmani et al. (2006) preliminarily reported occurrence of freshwater stromatolites associated with the ostracods from the same locality of this study and concluded that the microbial and micro-invertebrate communities thrived in a shallow lake during the time of deposition. Co-occurrence of the Darwinulids and conchostracan supports the interpretation of a freshwater lake or pond environment. For example, an assemblage described from lacustrine Late Carnian claystone at Krasiejów in southwestern Poland (Olemska, 2004) was interpreted to be deposited in shallow, still water pools. The conchostracans are non-marine, aquatic biotopes, but occasionally they occur in more saline environments (i.e., large playa lakes, coastal salt flats) where they usually die when water salinity reaches about 5‰ (Olemska, 2004). A well-known Darwinulid ostracod genus *Darwinula* is known as a non-swimming, infaunal ostracod which inhabits muddy substrates in fresh to slightly brackish water (Carbonel et al. 1988; Van Doninck et al., 2003). Members of the Darwinuloidea preferred lakes with terrigenous sediments with minor bicarbonate (Molostovskaya, 2000). Freshwater stromatolites can be found in fluvial-lacustrine deposits, and indicate water chemistry, generally carbonate and salinity, of the environments (Renaut and Gierlowski-Kordesch, 2010). The stromatolites are found in lacustrine environments (Gierlowski-Kordesch, 2010) and can be formed in fluvial deposits (Arenas-Abad et al. 2010). Our study reveals that sedimentary facies of the middle part of the study section contains massive carbonate facies (structureless with bioturbation) that corresponds with the lacustrine carbonates (Gierlowski-Kordesch, 2010), but lack oncoidal facies or alignment of bioclastic materials representing directional current, thus do not resemble fluvial carbonates (Arenas-Abad et al. 2010). The lake was shallowing upward as shown by presence of the coarser-grained clastic rocks and coal seams in the upper part. This facies corresponds with shoreline deposits including the proximal deltaic sediments and coals of the overfilled lake type (Renaut and Gierlowski-Kordesch, 2010). The sedimentary facies in the study section is different from the deeper facies of the Dat Fa Member previously studied (Asairai et al. 2016; Phujaranchaiwon et al. 2021).

6. Conclusions

We present an analysis of sedimentary facies of the study section, a part of the Dat Fa Member (Huai Hin Lat Formation) in Nam Nao area, Phetchabun Province, including dark grey to black calcareous mudstone (in the lower part), calcareous mudstone interbedded with calcareous shale in the middle part, and silty sandstone with coal seams in the upper part. The calcareous mudstone in the lower part contains stromatolite mounds with ostracods. We report the occurrence of *Euestheria buravasi* (conchostracan) which indicates the Late Triassic (Early Norian age) in the middle part of the section. The stromatolite is constructed of layers of carbonate containing filamentous structure, and shows contemporaneous fragmentation, probably caused by episodes of higher energy affecting the surface environments. Abundant ostracods are found in the lower to middle parts, five ostracod species are identified, all belong to the family Suchonellinidae. The microbial carbonate facies and massive carbonate facies are determined for the lower and middle parts of the section, respectively. The facies and associated microfossils suggest a shallow lacustrine environment. The silty sandstone and coal seams in upper part of the section correspond to proximal deltaic sediments in the shoreline area of an overfilled lake.

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