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Middle Miocene Molluscan Assemblages in Mae Moh Basin, Lampang Province, Northern Thailand

Wickanet Songtham[a], Hiroaki Ugai[b], Suvapak Imsamut[a], Somkiat Maranate[b], Wattana Tansathien[a], Assanee Meesook[a] and Wirote Saengsrichan[a]

[a] Bureau of Geological Survey, Department of Mineral Resources, Bangkok, Thailand
[b] Goshoura Cretaceous Museum, Goshoura-cho, Kumamoto Prefecture, Japan

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ABSTRACT: Molluscan beds in the Mae Moh basin have been observed and studied. Each individual molluscan bed has its own unique assemblage and occurs in a stratigraphic succession which allows for close stratigraphic correlations to be made within the Middle Miocene Mae Moh Group. Each molluscan species occurs in a particular facies showing close relationship between each taxon and its habitat. ?*Paludina* occurs in claystone and ligneous claystone indicating that its habitat was a lake with no vegetation or only sparse vegetation growing around it. Specimens of the Family Planorbidae must have preferred living in swamp containing dense vegetation since they occur in coal beds and ligneous claystone. *Melanoides* sp. cf. *M. tuberculata* occurs in claystone, suggesting that their habitats were in lake with little or no vegetation growing in it, similar to the living *Melanoides tuberculata*, which is a burrower into the lake sediments. The specimens of the Genus *Bellamya* have probably lived in the same conditions as *Melanoides* sp. cf. *M. tuberculata* did but not burrow. The twelve metre-thick *Bellamya* Bed was formed by a dynamic sedimentary process rather than by snail dying and being deposited *in situ*. The snails were regarded as being somehow transported for a short distance. This thick shell bed has been probably interpreted as the result of water level changes in the Mae Moh Lake under a desiccation regime. Viviparous snails such as *Margarya* occurred in a restricted local swamp of a fluvial system at a time when the Huai Luang Formation was deposited. Faunal changes in the molluscan assemblages have been occurred in direct response to the changes of their depositional environment.

INTRODUCTION

A nearly twelve metre-thick shell bed was discovered in the southwest margin of the coal pit in 2003 by a mine staff of the Mae Moh coal mine. The staffs of the Department of Mineral Resources (DMR) were strongly encouraged by this discovery to investigate the shell bed to get a detailed record for pictures and its significance. The shell bed was dominated by freshwater mud snails, *Bellamya*, and rare occurrences of tiny spire snails, *Bithynia*. This is, however, not the first discovery of a shell bed in the Mae Moh basin. Previously, the shell beds have been found in many localities and at many stratigraphic levels in the area of coal mine. The *Bellamya* Beds were found frequently during mine activities, but they were just thin layers with no interest to miners. The present shell bed is newly discovered and is now regarded as the thickest shell bed in Thailand, and is probably thickest freshwater shell bed in the world. The DMR hopes to conserve this fossil site as a national heritage site and to develop the site to become a geopark.

This paper discusses not only the thick *Bellamya* bed but also other shell beds in those horizons that provide a picture of the development of molluscan assemblages during the Middle Miocene time. These include molluscan assemblages of *Bellamya*, *Bithynia*, Planorbidae, Viviparidae, *Melanoides* sp. cf. *M. tuberculata* and *Margarya*. A gastropod taxon, previously identified as *Paludina*,[1] is herein considered as unidentifiable, because the shells are always fragile and incomplete to identify. However, we will refer to this taxon as ?*Paludina*, with a question mark, until further study by good fossil material becomes possible.

This paper reports on molluscan fossils from the Mae Moh Basin including these additional well preserved specimens as well as those at the opening of this coal mine. However, the significance has never been formally discussed in publications. We also present information on the geology and palaeontology, with particular respect to their biostratigraphic significance.

GEOLOGY

The Mae Moh basin is situated in the Mae Moh District of Lampang Province, which is about 26 kilometres east of Lampang City (Fig 1). It is distributed in the area of about 135 square kilometres, 7 kilometres in east-west and 16 kilometres in north-south. The basin floor is about 320-340 metres above mean sea level. The basin is an intermontane fault bound basin of a graben type containing Tertiary and Quaternary sediments underlain by basement rocks, including the Hong Hoi formation of the Triassic Lampang Group.[2] There are a series of Pleistocene basalt flows covering the southern part of the basin [3] (Fig 2). A set of north-south trending faults divides the basin into two sub-basins, western sub-basin and eastern sub-basin, recognised by an exposed central ridge of the Hong Hoi formation. The eastern sub-basin contains some coal measure formations and is so far exploited for a power plant operated by the Electricity Generating Authority of Thailand.

The Tertiary sediments have been named as the Mae Moh Group. The group consists of three formations, namely the Huai King, Na Khaem, and Huai Luang formations, in ascending order. The total thickness is nearly 1,000 metres in ascending order (Fig 3). The Huai King formation unconformably overlies the basement rock, Lampang Group. It consists of a sequence of upward grading conglomerate, sandstone and pebbly sandstone, siltstone and finally fining upwards into interbedded red and gray claystone. The uppermost part of the formation is marked by a thin layer of coal named the S coal zone.

The Na Khaem formation is a coal measure

Fig 1. Map of northern Thailand showing location of the Mae Moh basin with respect to locations of some provincial cities.

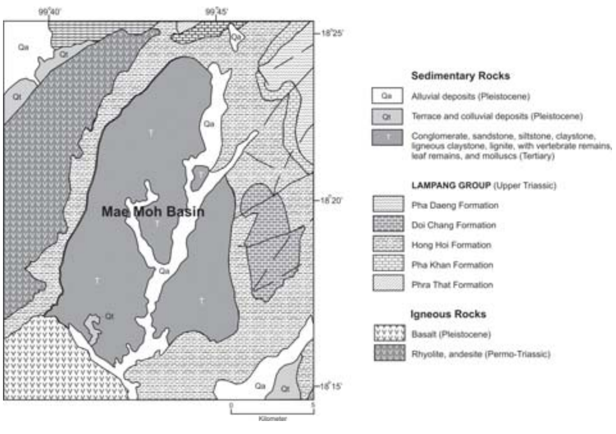

Fig 2. Geological map of Cenozoic Mae Moh basin showing the area of Cenozoic exposure and geology in the surrounding areas.[4]

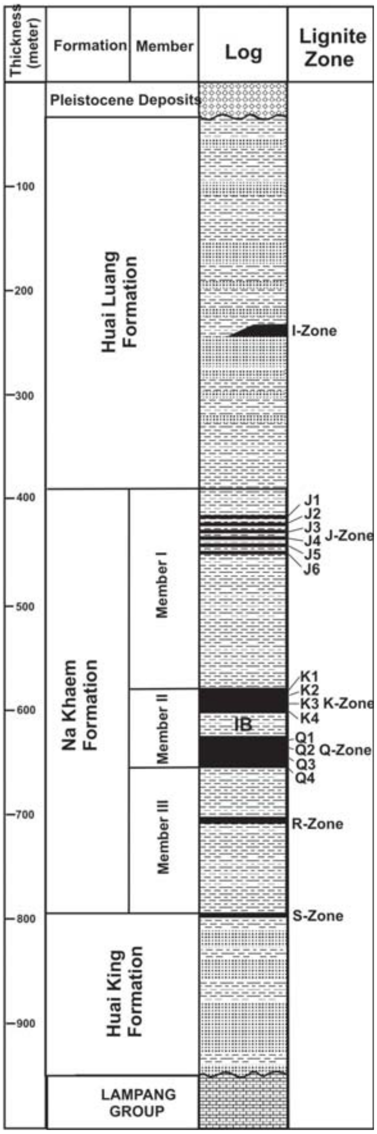

Fig 3. Schematic lithostratigraphic units of the Mae Moh Group.

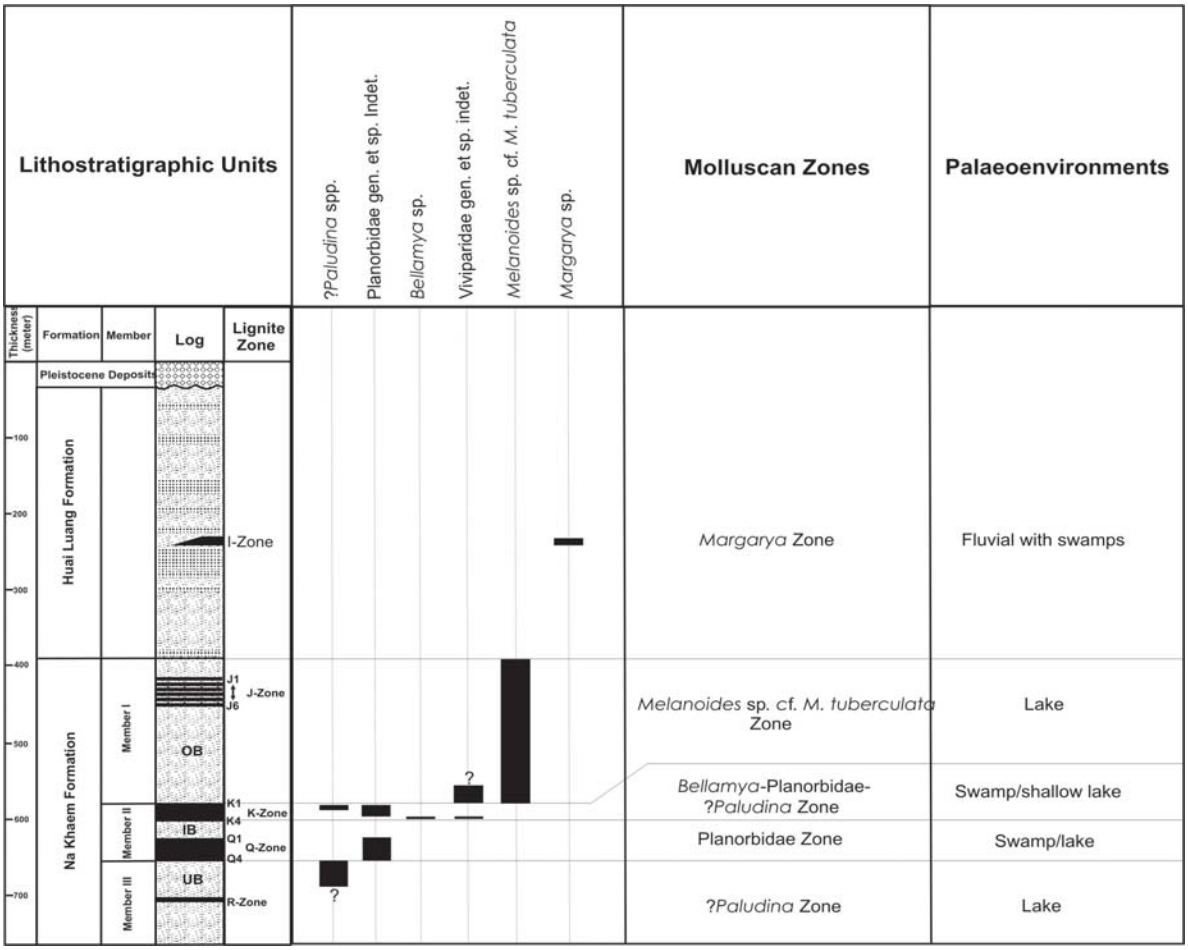

Fig 4. Molluscan zones of the Mae Moh Group with their palaeoenvironments.

comprising three main coal zones, Q, K, and J assigned to Middle Miocene age.[5] This formation has been divided into three members as Member III, Member II, and Member I, in ascending order. The Member III , or the so-called underburden, is a greenish gray to gray claystone with a thin layer of coal, named the R coal zone. The Member II is composed of two main coal zones, which are the Q coal zone in the lowermost part and the K coal zone in the uppermost part, and are intercalated by an interburden of claystone. There are some reports on mammalian fossils of mastodon *Stegolophodon*,[6,7] otter *Siamogale thailandica* and rhinoceros cf. *Gaindatherium* from the lignite K.[7] From our investigations, we also discovered skeletons of mastodon with tusk and molars which are now being studied. The Member I is a thick overburden consisting of claystone with a series of coal layers named the J coal zone. The J coal zone is an intercalation between claystone and six main coal layers. Well preserved specimens of fish and turtle plates were also discovered during our works at this member. The Member II and Member I are enriched with various kinds of molluscan fossils.

The Huai Luang formation is composed of claystone and siltstone with some sandstone and conglomerate lenses. A red to brownish red colour is the general characteristic of this formation with some gray layers interbedded in some horizons. A form of gypsum, selenite, is abundant in this formation. There is a coal zone, named I coal zone, in the middle portion, intercalated between a series of gray claystone with a thin *Margarya* gastropod-bearing layer.

Molluscan zones

During the present field investigations, we could only observe the shell beds and their related stratigraphic levels in the coal pit where the Na Khaem and Huai Luang formations were exposed. The Huai King formation was exposed in the north of the pit with a thin, well cemented viviparous shell bed, since identification of viviparous specimens was uncertain.

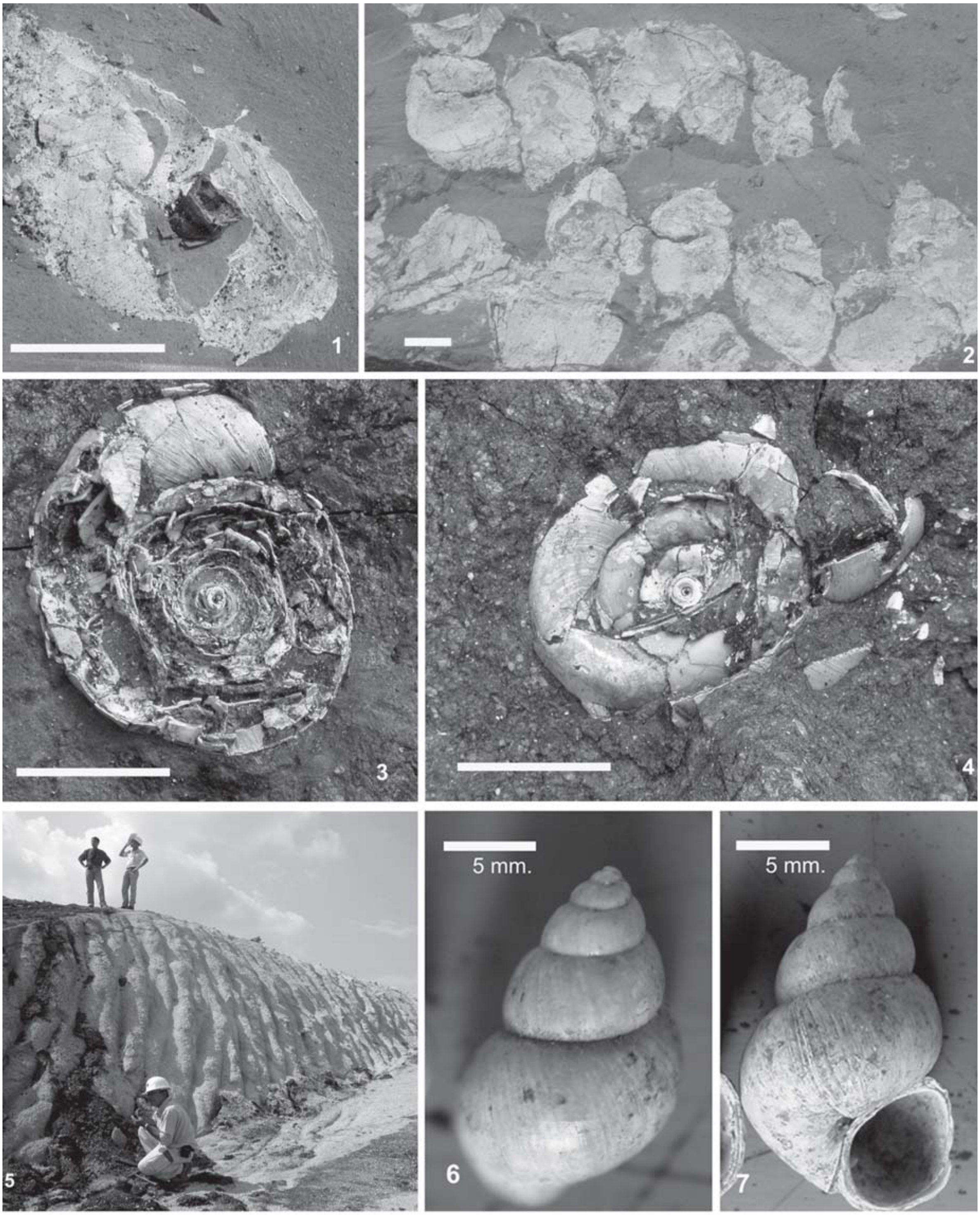

Plate 1. fig. 1: ?*Paludina* sp.; 2: ?*Paludina* sp.; figs. 3-4: Planorbidae gen. et sp. indet.; fig. 5: A corner of *Bellamya* bed exposed in the southwest margin of the coal pit; figs. 6-7: *Bellamya* sp. All scale bars are 1 centimetre except where otherwise stated.

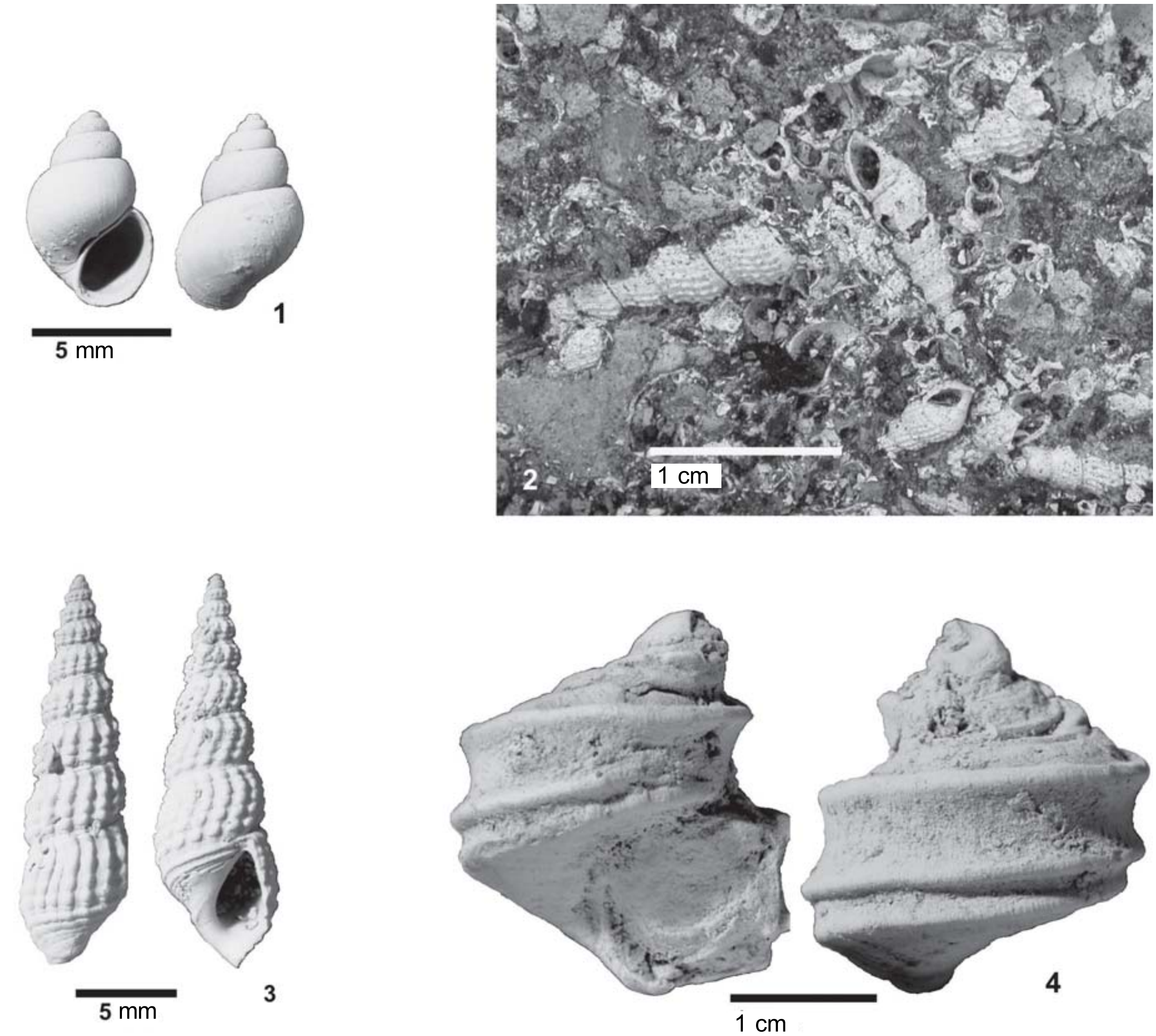

Plate 2. fig. 1: *Bithynia* sp.; figs. 2-3: Occurrence of *Melanoides* cf. *tuberculata* and its specimens; fig. 4: *Margarya* sp. All scale bars are 1 centimetre except where otherwise stated.

Therefore, the shell beds in this study only come from the uppermost part of Member III (Na Khaem formation) up to the I zone (middle part of the Huai Luang formation). The stratigraphic range of each taxon is plotted on a stratigraphic column showing the first and last appearances of each taxon (Fig 4). During the Middle Miocene, the Mae Moh basin was certainly a large lake and swamp where living organisms such as fish, turtle, crocodile, and various species of aquatic molluscs lived. The molluscs might have appeared and disappeared through time depending on environmental changes that altered the composition of the molluscan assemblages in each successive time slice in the Middle Miocene. These molluscan assemblages changed from horizon to horizon, allowing for a division into five molluscan zones (Fig 4). Each zone is defined by markers of some first and last appearances among the taxa. Where the taxon ranges are incomplete, an interpolation is made.

?*Paludina* Molluscan Zone (Lake)

This zone is at the underburden/lignite Q boundary downward, but the lower regime is unknown. It is confined to the upper part of the Member III of the Na Khaem formation. The upper boundary of the zone is defined by the first occurrence of the Planorbidae snails. The zone is composed by lacustrine claystone and abundant ?*Paludina* shells occur in the upper portion. The shells are not packed closely together. They are enveloped by claystone and are sometimes broken and flatten into formless shapes with about 2-3 centimetres long, are difficult to be described and positively identified (Plate 1, figs 1-2). Each shell body is separated from other closest shell bodies by about 2-3 centimetres. Mae Moh lake was occupied by these viviparous snails, ?*Paludina*, along a shallow shore in quiet conditions without any vegetation growing nearby at this space and time.

Planorbidae Molluscan Zone (Swamp/Lake)

The Planorbidae zone is located between the underburden/lignite Q boundary and the K-4/K-3 boundary. Even though there is no report on fossil molluscs from the interburden and K-4 sub-zone, we regarded these portions as a part of the Planorbidae zone. We use the family name Planorbidae (wheel snail) rather than the genus name *Planorbis* used by the previous study [1], because no good fossil specimens as *Planorbis* have been found (Plate 1, figs 3-4). The shell Planorbidae are the largest family of freshwater, pulmonate, and lung breathing gastropods. Living species of Australian Planorbidae are found wherever there are habitable waterbodies ranging from seasonal rain pools to large lakes.

The Planorbidae are common in some places in the lignite Q seam. This indicates that the fossil species of Planorbidae were living in a swamp environment containing sparse to densely distributed vegetation. The interburden indicates that the basin was in a lake cycle without any vegetation.

Bellamya-Planorbidae-?*Paludina* Molluscan Zone (Swamp/Shallow Lake)

This molluscan zone is confined within the K-3, K-2, and K-1 sub-zones, but the shell beds between the K-4 and K-3 sub-zones can also be regarded as a part of this zone. The end of the previous molluscan zone is defined by the very thin lignite layer, K-4, which is an indicative of a swamp deposit. The overlying thick *Bellamya* (Plate 1, fig 5) and Viviparidae Beds are designated as the lowest occurrence of this molluscan zone. The Viviparidae bed (*Bellamya* belongs to Viviparidae) is widely distributed over the most of the basin, but the *Bellamya* bed is the thickest layer, in the southwest margin of the coal pit. The uppermost part of the interburden is in places overlain by the K-4 sub-zone and in the southwest margin of the coal pit, overlain by the *Bellamya* shell bed. The K-4 sub-zone is a thin coal layer that thins out in places. However, the contact between either the interburden and *Bellamya* bed or the lignite K-4 and the *Bellamya* bed is sharp. No fossil molluscs were discovered from the interburden and the K-4 sub-zone. At the lower boundary, the greenish gray interburden claystone gradually changes onward with more organic material contents like a peat formation and then the lignite K-4 on top. The *Bellamya* shell bed with sharp contact between the shell bed and the underlying the lignite K-4 and interburden claystone resembles an erosional surface (Fig 5). At the upper boundary in contrast, the *Bellamya* shell bed gradually changes towards the lignite K-3. *Bellamya* snails densely occur in the lowermost portion of the lignite K-3 and begin to gradually disappear upward (Fig 6).

This widespread viviparous shell bed,

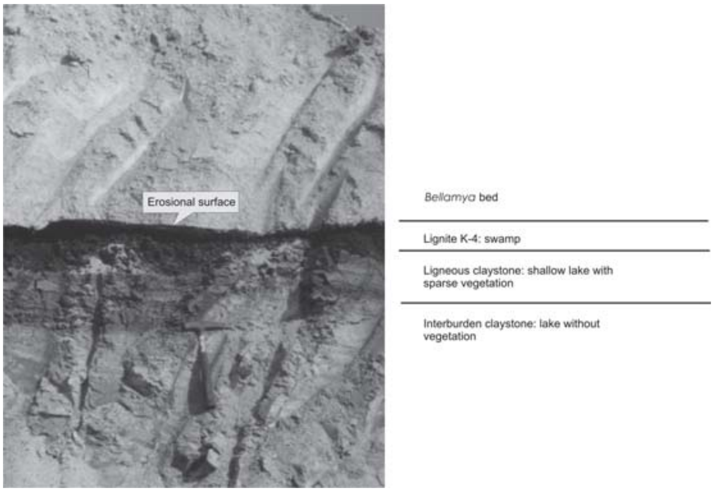

Fig 5. Lower boundary of the *Bellamya* shell bed showing environmental changes from lake, shallow lake, swamp, and then the one that formed the *Bellamya* bed on top with a sharp contact.

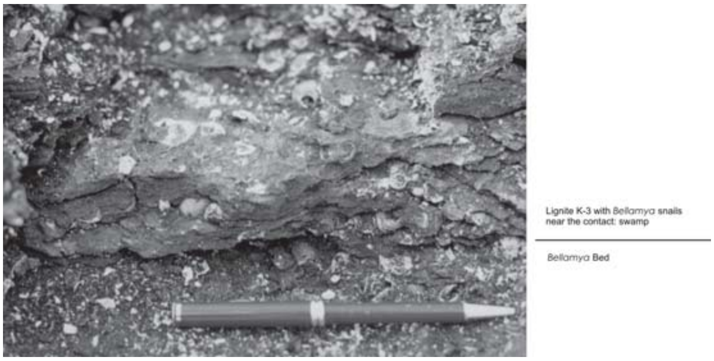

Fig 6. Upper boundary of the *Bellamya* shell bed showing environmental changes from the *Bellamya* bed to swamp.

with thickness ranging from 20-30 centimetres to nearly 12 metres, occurs between the lignite bed K-4 and K-3. The shells of the Family Viviparidae, not identified in the genus, generally occur in this horizon. The characteristics of these shells are compared well with the forms that occur from the Huai King formation exposed in the north of the pit. In the southwest margin of the coal pit, the twelve metre-thick *Bellamya* bed, covering an area of at least 70,000 square metres, is exposed. This freshwater mud snail, *Bellamya* (Plate 1, figs 6-7), dominates in dense aggregations almost without sediments as matrix, while in other places, they are loosely cemented. They are accumulated under the conditions that formed alternations between layers of entire snail shells and layers of densely fragmented snail shells. This clearly observable layering has a dip direction of about 130° and dip angle of about 20°. An isopach map (not shown in this paper) shows that the thickness variation of the shell bed looks like that of a lens body, but actually the shell bed is bound by a set of faults. These *Bellamya* snails range in size from small juveniles of about 1 millimetre to adult of about 3 centimetres. Many juveniles and their associated opercula occur in inside of some female snail shells. However, a different taxon of tiny snails was also found in the *Bellamya* Assemblage, namely a spire snail, *Bithynia* (Bithyniidae) (Plate II, fig 1). Since *Bithynia* is relatively small, about 5-7 millimetres, when compared with *Bellamya*, *Bithynia* seems to be very rare in occurrence.

Molluscan assemblages between the K-4 and K-3 sub-zones are dominated by freshwater viviparous snails, including *Bellamya*, in the southwest, and by indeterminate viviparous snails in other places. The tiny spire snail, *Bithynia* (Bithyniidae), which confirms the freshwater swamp depositional environ-ment, occurs at the same time. Remarkably, the *Bellamya* bed occurs separated from the enclosing lignites, K-4 and K-3, whereas the Planorbidae occurs in the lignite K-3 and K-2 and ligneous claystone K-2 in some places. All taxa are missing from the ligneous claystone K-1. To clarify this, from the sub-zones K-4 to K-1, the environment changed from a swamp to a shallow lake and then to a deeper lake in the overburden claystone. These environmental changes had been probably controlled by the presence and absence of the molluscs, which each had a different environmental preference.

The specimens of the Family Planorbidae in this zone occurred widely from both lignite and ligneous claystone of the K-2 sub-zone. Whereas, ?*Paludina* occurs just from the ligneous claystone of the K-2 sub-zone in association with Planorbidae snails. This indicates that the specimens of Planorbidae preferred to inhabit in swamp with dense vegetation rather than in lake with sparse vegetation but ?*Paludina* preferred to live in the lake with sparse vegetation. The ?*Paludina* also preferred to live in a lake without vegetation as found in the ?*Paludina* Zone.

Melanoides sp. cf. *M. tuberculata* Molluscan Zone (Lake)

The boundary of the K-1 sub-zone and the overburden claystone is where these Malaysian Trumpet snails, *Melanoides* sp. cf. *M. tuberculata* (Plate 2, figs 2-3), first appeared. This zone is a good lower boundary of this acme zone. This zone covers the claystone overburden and the lignite J. The lower boundary of the zone is defined by the first appearance of *Melanoides* sp. cf. *M. tuberculata* in association with abundant indeterminate viviparous snails, while the upper boundary is at the disappearance of *Melanoides* sp. cf. *M. tuberculata*. This molluscan zone is defined by lacustrine claystone indicating that the previous swamp was flooded, turning into a lake. Living *Melanoides tuberculata* is known to burrow through lake substrates by day and come out to feed at night. It is a carnivorous snail living in freshwater environments near bank, avoiding stronger currents. This is why there is a high likelihood of finding these snails in claystone rather than coal. At the same time, the indeterminate viviparous snails had to survive in the same conditions without being able to burrow. This is a key to understanding how the viviparous bed between the K-4 and K-3, including *Bellamya* bed, was preserved. It is highly likely that sedimentation rates were low to allow this situation to occur.

Margarya Molluscan Zone (Local Swamp-Shallow Lake)

A layer of the pond snail *Margarya* (Plate 2, fig 4) was discovered in the I zone of the Huai Luang formation. This layer is not uniform in lateral distribution and thickness forming a lensoid shape. The molluscs aggregated densely with a thickness about 50 centimetres in some places, whereas in other places, they occur sparingly in dark gray sandy claystone with a thickness ranging from 1 to 2 metres. There is well-crystalline selenite, scattering in the red bed of sandy claystone. The lignite I clearly indicates that this zone is a local deposit as it is found in a lensoid shape.

Interpretation, Discussion and Conclusion

The appearance range charts of molluscan taxa plotted against the lithostratigraphic unit clearly indicate that paleoenvironmental changes led to corresponding changes in rock type and their associated molluscan assemblages. Freshwater shells attributed to ?*Paludina* inhabited lakes beyond the shallow shore but not the swamps. Shells of the Family Planorbidae preferred to inhabit swamp and shallow lake, whereas

Melanoides sp. cf. *M. tuberculata* inhabited areas beyond the shallow shore on the lake substrate where there was a lack of vegetation or only sparse vegetation growing.

Coexistence of the burrowing mollusc *Melanoides* sp. cf. *M. tuberculata* and non-burrowing indeterminate viviparous snails in the *Melanoides* sp. cf. *M. tuberculata* molluscan Zone suggests that the depositional environment of *Bellamya* bed is the same condition as *Melanoides* sp. cf. *M. tuberculata*. The alternation between layers of entire snail shell bed and fragmented snail shell bed indicates that the *Bellamya* bed was formed by a dynamic sedimentary process rather than snails dying and being deposited *in situ*. The snail shells may have been transported from just a short distance to the site of deposition. The presence of brown stain on the shell regarded as original colour and well-preserved growth lines on the outside of shell surface is a good indication for the short distance transportation. The aggregation of complete shells without any sediment matrix indicates that either there was some water current action to carry away the fine muddy sediments from the *Bellamya* shell deposit or that little or no sedimentation occurred at all at that time. The alternation of complete and fragmentary shell layer can probably also be interpreted as the result of water level changes in the Mae Moh lake under a desiccation regime. The possible erosional surface between the *Bellamya* bed and the underlying sedimentary layer is a good evidence in term of sedimentary process. It suggests that prior to deposition of the shell bed, the underlying lignite K-4 was partially wiped out by some water current producing the erosional surface. After that *Bellamya* snails were transported from somewhere to continuously accumulate on the surface of erosion in succession forming the alternations between the entire snail shell layers and the fragmented snail shell layers. Each cycle of the alternations of complete and fragmentary shell layers may have occurred in the same episode of time but the complete and fragmentary shells were separated by different rate of deposition.

Margarya in the ligneous I zone is confined within a small local swamp in the red bed of the Huai Luang formation suggesting that *Margarya* occurred in a small swamp probably in a flood plain environment. The selenite-bearing red bed sandy claystone is considered as secondary deposit sometimes after the Huai Luang formation was deposited. It is considered that the environment during the secondary deposit was arid condition. The hydrous calcium sulfate crystals, $CaSO_4.2H_2O$, are said to be resulting from solution cavities through precipitation of calcium sulfate-bearing groundwater that was saturated under an arid condition. The presence of selenite is in contrast to the massive gypsum that is more frequently associated with evaporite deposits in playa in the arid environment which formed beds parallel to nearby sedimentary strata. But the selenite crystals from the Huai Luang formation are randomly scattered like nodules in red bed of sandy claystone without forming beds. The gypsum crystals, selenite, and red bed were secondarily formed by some proposed chemical reactions such as the ones below:

$$CaCO_3 \longrightarrow CaO + CO_2 \quad (1)$$

$$4FeS_2 + 11O_2 \longrightarrow 2Fe_2O_3 + 8SO_2 \quad (2)$$

$$CaO + SO_3 + 2H_2O \longrightarrow CaSO_4.2H_2O \quad (3)$$

Source of calcium came from limestone ($CaCO_3$) of the Lampang Group that decayed to become lime (CaO). The lime reacted with sulfur trioxide (SO_3) (derived from SO_2) and water forming selenite crystals ($CaSO_4.2H_2O$) in saturated groundwater under an arid environment. The pyrite (FeS_2) was oxidised, producing iron oxide (Fe_2O_3) partially changing the colour of original flood plain sediments into the red bed formation containing the selenite crystals. This is why the red bed formation still retains some original colour of greenish gray sandy claystone occurring in some places. The ligneous I zone with *Margarya* bed is still, however, preserved in the original colour of greenish gray claystone lens, as this lens was under groundwater table with low transmissibility, and thus oxidation and selenisation were not taken place.

All successions of the molluscan assemblages throughout the Mae Moh Group clearly indicate that sedimentation in the Mae Moh Basin occurred in freshwater environments as the lake or swamp alternations and ended up with a fluvial environment. Palynological assemblages indicate that there was a major climatic change from a warm temperate climate to a tropical climate condition with evidence of exclusive freshwater microscopic algae including *Closterium* and *Pediastrum* as well as *Cyperus*, a taxon of sedge, growing well in freshwater swamps. The Huai King formation was possibly formed under a warm temperate climate. The Member III of the Na Khaem formation was developed under a transition between the warm temperate and tropical climates. The rest of the Na Khaem formation onward (Member II and Member I) was deposited under a real tropical climate.[8,9] The Huai Luang formation was formed under fluvial deposits. The red colour of the Huai Luang formation is regarded as secondary alteration under an arid climate producing the red bed formation containing abundant gypsumand selenite.

Molluscan assemblage successions in the Mae Moh basin form good stratigraphic markers. We can use each taxon and its overlapping ranges to define stratigraphic levels within the Mae Moh basin. Correlation of these molluscan assemblages with other basins in the region of northern Thailand and elsewhere needs further investigation.

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