LITHOSTRATIGRAPHY AND PALAEONTOLOGY OF THE 'BLACK SHALE' FACIES OF THE SEMANGGOL FORMATION (CHERT UNIT) AT BUKIT MERAH (PERAK, PENINSULAR MALAYSIA)

Joannemarie Estelle Liew, José Antonio Gámez Vintaned

Department of Geosciences, Faculty of Geosciences & Petroleum Engineering, Universiti Teknologi PETRONAS

Email: jmariex94@gmail.com

ABSTRACT

In the Semanggol formation cropping out in Northern Perak, a 'black shale' facies was identified at the lowermost level of the chert unit at Bukit Merah, containing trace and body fossils. Despite some recent contributions made in Northern Perak outcrops, some questions about the origin of the 'black shale' facies remain open, particularly its depositional palaeoenvironment, palaeo-oxygenation history and biochronological age. Moreover, the presence of trace and body fossils in the facies contradicts 'classical' views of the 'black shales' of the Semanggol formation. Therefore, this study aims to describe the lithostratigraphic and palaeontological contents of the facies, as well as to apply sedimentological, palaeoichnological, petrographical and geochemical analyses for ascertaining the origin of it. The results revealed a shallow marine, sublittoral setting based on the identification of the Cruziana ichnofacies. The coarsening- and the thickening-upward trend observed in the studied stratigraphic section is compatible with a prograding, distal deltaic sequence. Two sources of additional oxygen are identifying as the episodic storm events and the presence of microbial mats, which frequently replenished the oxygen levels at the seafloor. Hence, the deposition occurred under relatively well-oxygenated conditions. Finally, the age of the succession is Early Triassic based on the presence of the bivalve genus Claraia.

Keywords: *Cruziana ichnofacies, palaeo-oxygenation, body fossils, sedimentological, petrographical, microbial mats*

INTRODUCTION

The Semanggol formation was introduced initially by Alexander [1] for the sedimentary rocks that were found exposed in the Semanggol Range [1]. The formation crops were found out later in Northern Kedah, Southern Kedah and Northern Perak [2]. In the latter area, a 'black shale' facies was recently identified at the lowermost level of the chert unit in Bukit Merah, containing trace and body fossils [3]. Given the significant extension of the outcrops of the Semanggol formation in Peninsular Malaysia and their palaeogeographical significance – it seems to be linked with the closure of the Palaeozoic/Mesozoic ocean in the region –, a deeper understanding of the geology of this unit is highly desirable.

The majority of the studies on the Semanggol formation have concentrated on the outcrops of Northern and Southern Kedah, and only some recent contributions have been made in the Northern Perak outcrops by Drahman & Gámez Vintaned [3] and Mansor & Sokiman [4]. Hence, numerous questions starting with the lithostratigraphy of the Semanggol formation – especially in Northern Perak – are still open. Notably, the 'black shale' facies are yet to unstated regarding its detailed facies, its sedimentology, palaeontology, depositional palaeoenvironment, palaeo-oxygenation history and biochronology. As an example, the establishment of a view of the 'black shales' of the Semanggol formation as fossiliferous stratigraphic units associated with anoxia [5]. Nevertheless, the presence of trace and body fossils in succession contradicts this 'classical' view of anoxia at the moment of deposition [3]; hence it will also be a matter of discussion in this work.

The objectives of this study are to describe and analyze the facies associations, lithostratigraphy and palaeontological contents of the 'black shale' facies located at the lowermost stratigraphic level of the chert unit of the Semanggol formation at Bukit Merah, as well as to analyze its sedimentology, palaeoichnology, petrography and total organic carbon in order to ascertain its origin.

GEOGRAPHICAL AND GEOLOGICAL SETTING

The Semanggol Range is located about 13 km northwest of Taiping (Perak) and comprises a narrow range of hills trending North-South. The location area of study is in the central sector of the Semanggol Range, at the locality known as Bukit Putus where one active and one abandoned quarry are found. Section BM1 situated at the lower level of the abandoned quarried hill, bounded by the latitude 04° 57′ 54.9″ N and longitude 100° 39′ 36.3″ E.

From a geological point of view, the Semanggaol Range comprised of the Western Belt. The formation consists of three informal "units" [6, 7] (Figure 1), the oldest unit being the chert unit which was given the initial description comprising of alternations of black, carbonaceous mudstone with chert, siltstone and greywacke [8]. Later, the unit was separated

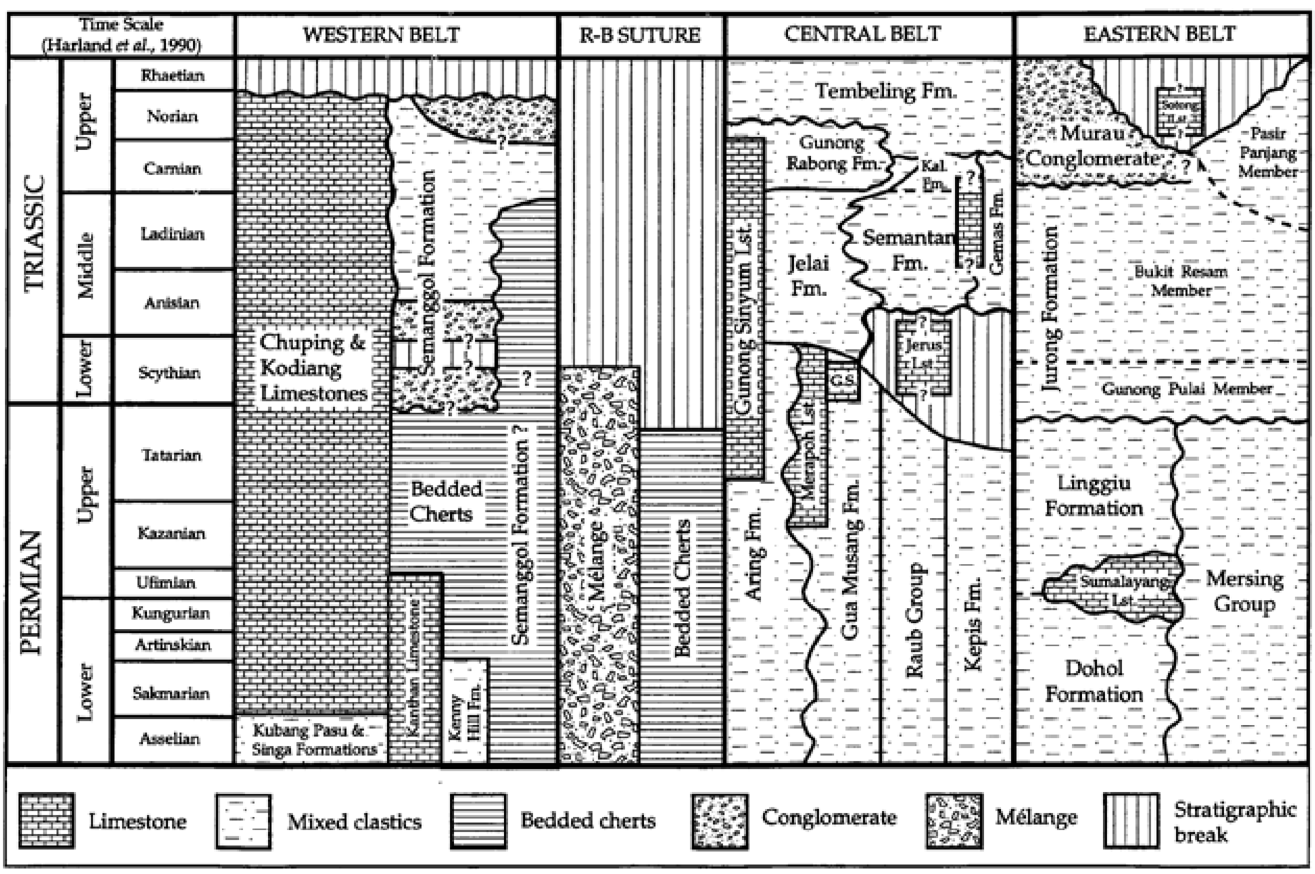

Figure 1 Stratigraphic correlation chart for the Permian and Triassic of Peninsular Malaysia (after [7]). The synthetic stratigraphy of the Semanggol formation is shown. (Units shown are not to scale. Kal. Fm. = Kaling Formation; G.S. = Gua ~ Sei Limestones).

into 7 different lithofacies, among which the 'black laminated mudstones' occupied the lowermost succession [5]. The age of the chert unit was assigned to the early Permian – Middle Triassic based on studies on radiolarian microfossils in Bukit Larek and Pokok Pauh, Northern Kedah [2].

OUTCROP DESCRIPTION

The access to section BM1 is made by a 15 minutes walk from the roadside, through a dirt road heading towards the North (Figure 2). The outcrop is located at almost the lowest level of the quarried hill, close to

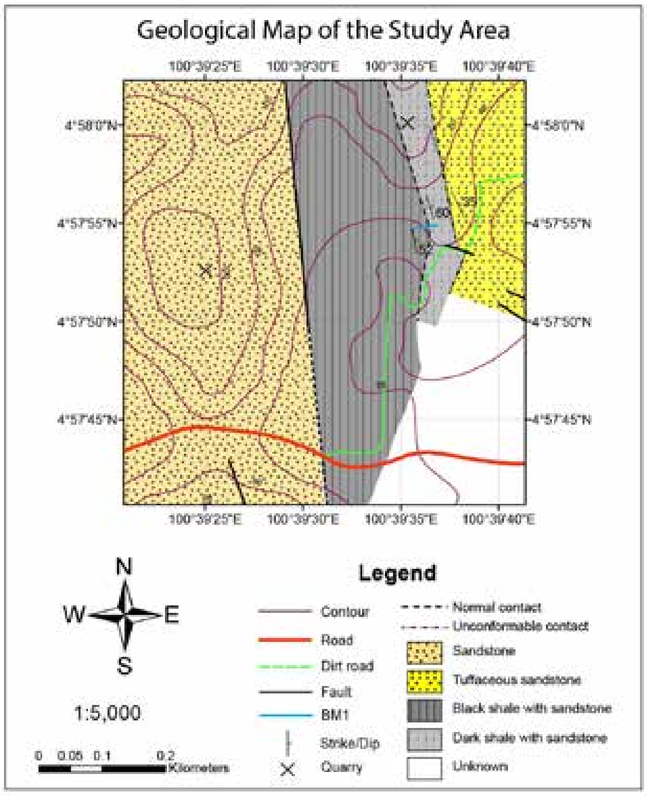

Figure 2 Geological map of the area of the study area

Figure 3 The 'black shale' facies as exposed at the section Bukit Merah-1 (BM1). The section is divided into 17 stratigraphic levels for study and sampling purposes. A human figure on the right side (arrowed) is used as a graphic scale.

a small pond that is hardly distinguishable due to the dense vegetation surrounding. The bottom part of the section is partially covered in thick vegetation while the top of the article is well exposed. Several parts of the section have also undergone small landslides as a result of weathering.

At a glance, the outcrop comprises predominantly dark mudstones and sandstones in which the beds are increasingly dipping towards the East (Figure 3). The mudstones vary between light- to dark grey and are often separated by millimetric to decimetric sandstones. At least three types of sandstones were identified, namely the red sandstones, greyish sandstones and whitish sandstones, and they appear to be thicker and more frequent towards the younger strata at the top. The strike and dip of the section from the lower and upper part vary from 011°/51° E to 015°/69° E.

specimens containing the trace and body fossils for describing the ichnotaxonomy, identifying and characterising the ichnofacies and establishing the biostratigraphy. Besides, the bioturbation ichnofabric index (BII) of the beds is evaluated based on Miller & Smail [9]. Subsequently, four samples comprising of mudstones and sandstones are prepared into thin sections for identifying the rock type and presence of cryptobioturbation. Mudstones from each stratigraphic level and a few sandstones are also sampled for performing analyses of the Total Organic Carbon (TOC). Finally, all the information is presented in a stratigraphic column, as shown in Figure 5.

RESULTS AND DISCUSSION

Stratigraphy and Facies Associations

The stratigraphic succession of BM1 has been logged

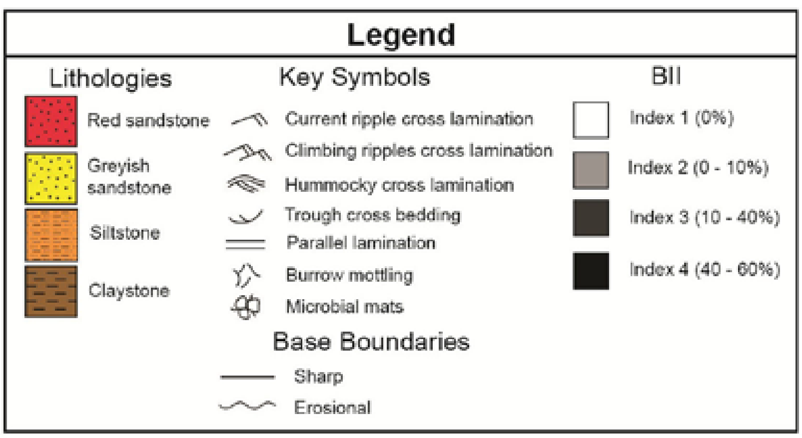

Figure 4 Legend for the stratigraphic column

METHODOLOGY

A detailed study on one outcrop at the Bukit Putus locality has been conducted by using various geological methods including lithostratigraphic, palaeontological, petrographical and geochemical analyses. Firstly, the thickness of the succession is measured by using Jacob's staff and information regarding the lithology, sedimentological features, facies change and bioturbation index of every bed is recorded for establishing the facies associations. Secondly, detailed observations are made on the

and produced at a scale of 1:100 (Figures 5 & 6). The thickness of the section is about 37 m. In general, a high mud to sand ratio is observed. The sandstone intervals are thickening progressively and becoming more frequent towards the top of the section, indicating a slight coarsening- and thickening-upward upward trend. Some notable primary sedimentary structures observed in the section include hummocky cross laminations, current ripple and climbing ripple cross lamination, parallel lamination and trough cross-bedding.

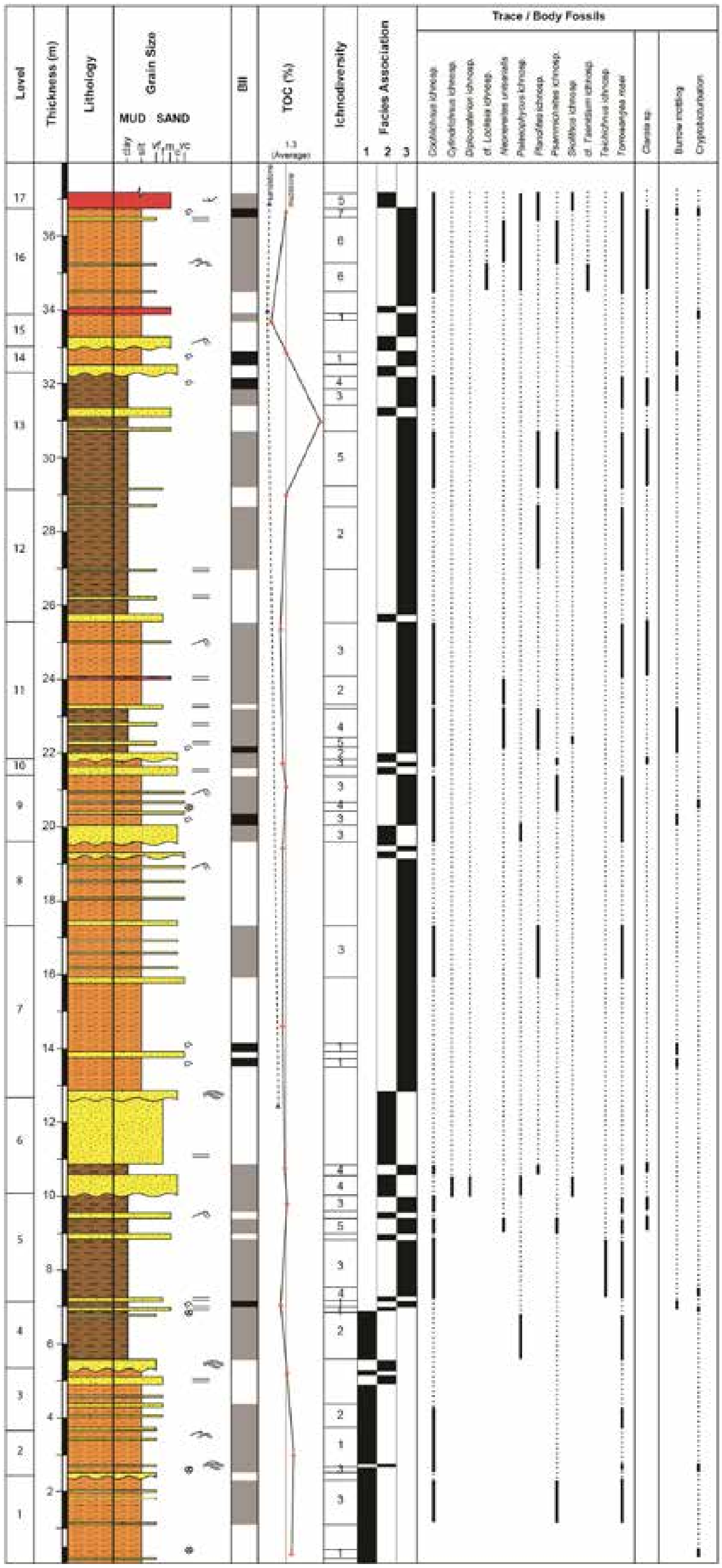

Figure 5 Stratigraphic column of section BM1

Three types of facies associations have been established in section BM1: interlaminated sandstone and mudstone (FA 1), tabular and amalgamated sandstone (FA 2) and interbedded sandstone and mudstone (FA 3). Detailed description and interpretation of each facies associations are included below.

Facies association 1: Interlaminated sandstone and mudstone

FA 1 consists of an interlamination of millimetric to centimetric, very fine- to fine-grained sandstone within a predominantly clayey and/or silty mudstone interval. The sandstones show climbing ripple cross lamination. The bioturbation ichnofabric index is 1 to 2, and the maximum ichnodiversity observed is 3.

FA 1 is interpreted to represent more distal deposits since it comprises thin layers of very fine- to fine-grained sandstones within thick mud intervals. The sedimentary structure observed in the sandstones of FA 1 indicates a relatively high sedimentation rate but, because the sandstone layers are limited to a thickness of few centimetres, the period of high sedimentation rate was rather short.

Facies association 2: Tabular and amalgamated sandstone

FA 2 comprises centimetric to decimetric, very fine- to coarse-grained sandstones that are sometimes the result of the amalgamation of several sandstone bodies. The sandstones appear to be almost tabular with distinct erosional bases and are often found isolated. The primary sedimentary structures observed include parallel lamination, hummocky cross lamination (Figure 6) and trough cross-bedding. The bioturbation ichnofabric index is 1 to 2 and ichnodiversity is a maximum of 5.

FA 2 is interpreted to represent episodic storm events, and the sandstones here would represent storm deposits, i.e. tempestites. The amalgamated sandstones are indicative of multiple flow surges occurring at a particular level. The sedimentary structures observed here are typical of storm events which generally have higher energy levels. In the stratigraphic column, the isolated sandstones of FA 2 seem to be frequent throughout the section, indicating that perhaps the storm energy was relatively low.

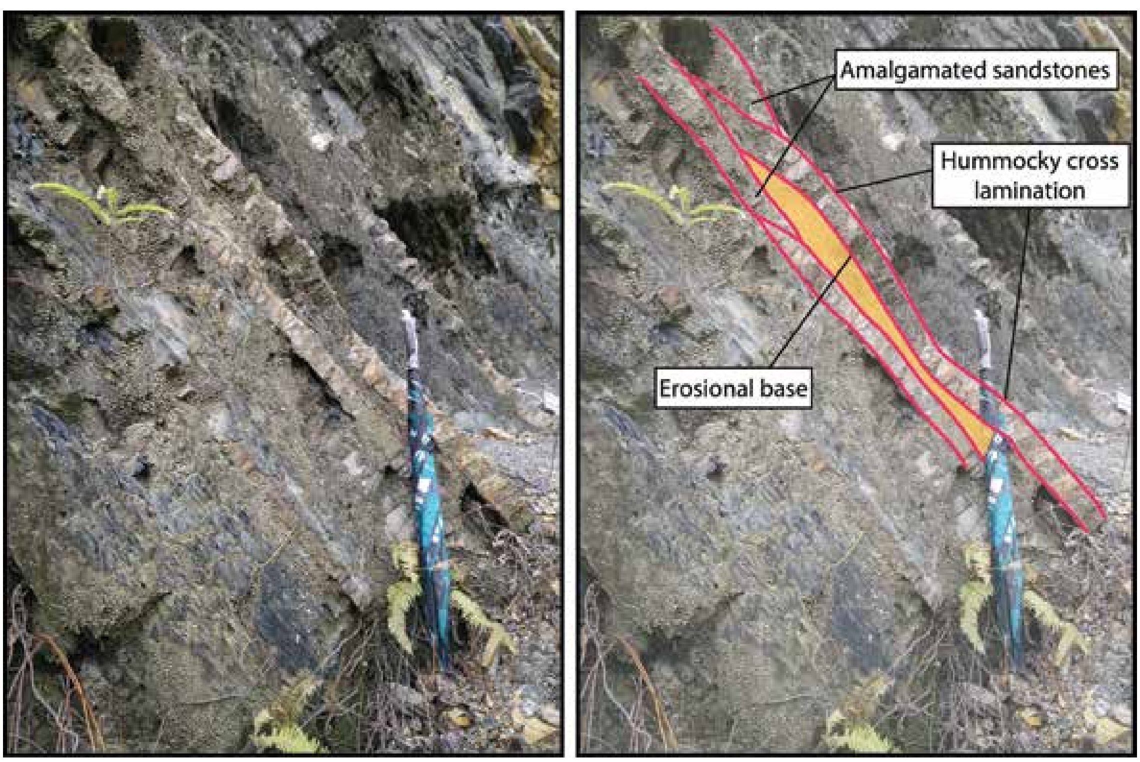

Figure 6 Hummocky cross lamination in very fine-grained sandstone with erosional basal surface observed at level 4. Shreds of evidence of minor amalgamation are found in both the top and the underlying beds.

Facies association 3: Interbedded sandstone and mudstone

FA 3 contains centimetric, fine- to coarse-grained sandstone interbedded with predominantly clayey and/or silty mudstone intervals. The primary sedimentary structures observed in the sandstones include current ripple and climbing ripple cross lamination, and parallel lamination. The bioturbation ichnofabric index is 1 to 4, and the maximum ichnodiversity observed is 7.

The sandstones in FA 3 are generally thicker, coarser and occurring more frequently as compared to the sandstones in FA 1. Therefore, the sandstones here are believed to represent more proximal deposits. The sedimentary structures comprise structures which are formed either under high or low flow regime. Climbing ripple cross lamination and parallel lamination developed under higher flow regime whereas current ripple cross lamination is produced under a lower flow regime.

PALAEONTOLOGICAL FINDINGS

Body Fossils

Numerous specimens of the bivalve *Claraia* sp. – preserved as body fossils and their corresponding moulds – have been found (Figure 7), showing a biostratigraphic distribution from level 5 up to level 16 of the section. The specimens were often found to be articulated and show a continuous size distribution, suggesting that they were residing *in situ* and have not been transported. Besides, the bivalves show a reduced thickness in their shells (only a few microns), making the thin growth lines of the shells to be preserved in both the inner and outer moulds. Concerning the facies associations, bivalves are found in the FA 3.

Ethological Structures

Among the ethological structures, both bioturbation structures and arrangement structures have been found. As for the former ones, a total of 12 ichnogenera have been identified, consisting of dwelling structures or domichnia (*Cylindrichnus* ichnosp., *Diplocraterion* ichnosp., *Palaeophycus* ichnosp. and *Skolithos* ichnosp.), grazing traces or pascichnia (*Neonereites uniserialis*, *Psammichnites* ichnosp. and *Torrowangea rosei*), feeding burrows or fodinichnia (*Planolites* ichnosp., *Taenidium* ichnosp., cf. *Teichichnus* ichnosp.) and locomotion traces or repichnia (*Cochlichnus* ichnosp. and cf. *Lockeia* ichnosp.). Some of them are depicted in Figure 8. Regarding the ethological bioarrangement structures, microbial mats were identified at specific intervals.

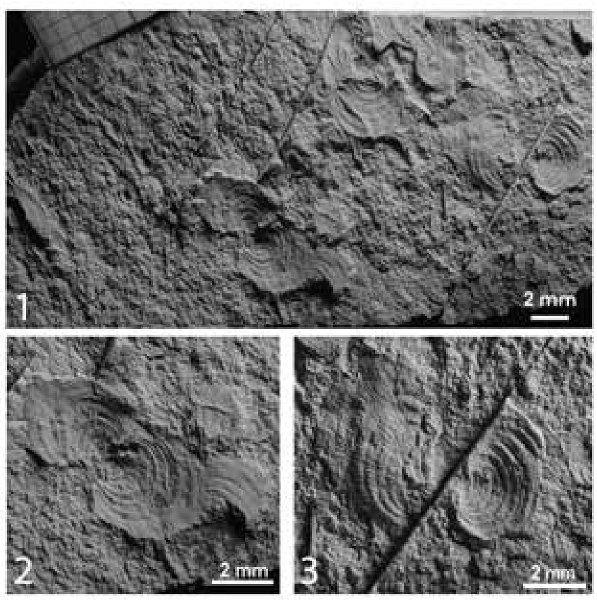

Figure 7 (1) Some articulated specimens of the bivalve *Claraia* sp. from the level 5 of the studied section (sample BM1/5/7); (2), (3) close-ups of examples in (1).

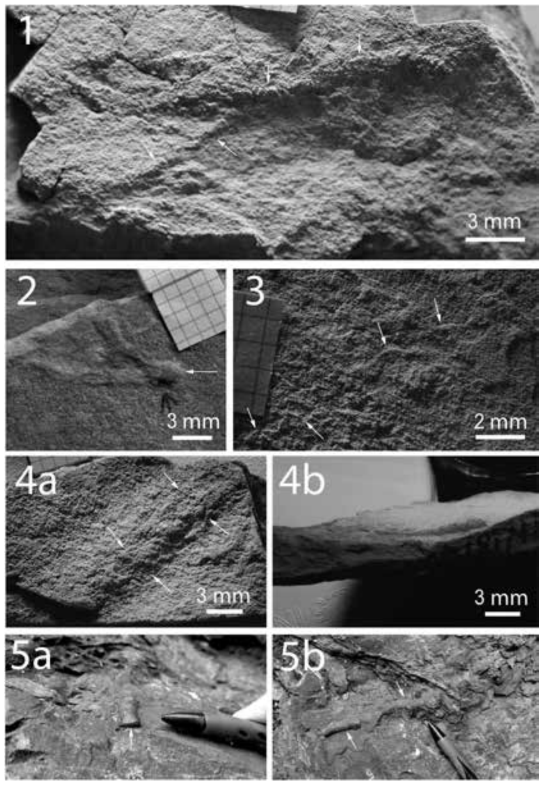

Figure 8 Some specimens of trace fossils; (1) *Torrowangea rosei*; (2) cf. *Lockeia* ichnosp.; (3) *Cochlichnus* ichnosp.; (4a) *Psammichnites* ichnosp.; (4b) cross-sectional view of *Psammichnites* ichnosp.; (5a), (5b) oblique view is showing cross-section and a plane view of *Teichicnus* ichnosp. (length of the darker pencil tip is 1.8 cm).

Interpretation of the fossils found

In the studied section, the assemblages of *Claraia* sp. show a consistently continuous biometric distribution. Among a single collection, specimen sizes range from those corresponding to young ones up to adults. Moreover, it is common to find articulated specimens, which is relevant to the taphonomy of the assemblages. Generally, *Claraia* had a weak hinge which must have often resulted in easy post-mortem disarticulation even under moderate environmental energy. Thus, from a taphonomic point of view, the *Claraia* fossil assemblages can be considered as *in situ*, i.e. true palaeopopulations. Therefore, their use in any further geological analysis is valid.

After a comprehensive palaeontological analysis, two types of palaeocommunities can be recorded in the strata of the studied section: a background palaeocommunity and an event palaeocommunity. The background palaeocommunity is dominated by horizontal burrows and trails assigned to the ethological categories pascichnia, fodinichnia and repichnia; *Claraia* is often found as a member of this palaeocommunity. The background palaeocommunity representing throughout the section, in strata deposited under the "normal palaeoenvironmental conditions".

These particular ichnoassemblages are interpreted to belong to the *Cruziana* ichnofacies, typically found in sublittoral, marine settings [10]. This interpretation correlates well with the conclusions obtained after the overall stratigraphic study, which suggest that deposition took place in a shallow marine environment. The lack of natural and complex burrow systems, as well as of trace fossils of the ethological category agrichnia in the background palaeocommunity ruled out the possibility of a deep marine (abyssal) setting. On the other hand, the dominance of pascichnia is also an indication of organic-rich sediments deposited under a low sedimentation rate. The reason is that the producers of this kind of traces feed on organic detritus, i.e. the layer of fresh organic matter deposited on top of the sediment surface, a process which generally requires some time to work through the slab.

As for the event palaeocommunity, it was dominated by vertical burrows attributed to the ethological category domichnia. The occurrence of the event palaeocommunity is very isolated, as it only conquers the section at some particular, brief intervals, deposited during episodic sedimentary events, and its existence must have generally been quite short-lived. The ichnoassemblages observed here belong to the *Skolithos* ichnofacies, typically found in high-energy, littoral settings [10]. In the case of section BM1, this ichnofacies is developed when opportunistic organisms colonised the physical space of a perturbated background palaeoecosystem for a short interval after a high-energy event such as a storm. The resulting event palaeocommunity is an important indication of a sudden peak in the environmental energy, which resulted in a higher amount of oxygen supplied to the surface of the seafloor.

SYNTHETIC PALAEOENVIRONMENTAL INTERPRETATION

The identification of the *Cruziana* ichnofacies points towards a sublittoral, shallow marine environment, located between the low-tide level and the storm wave base [10]. Furthermore, the preservation of hummocky cross laminations in sandstones of FA 2 suggests that deposition took place between the fair weather- and the storm wave base, as those laminations were well preserved and not destroyed by normal wave processes occurred above the fair-weather wave base.

As for the upward trend of the sedimentary succession, the slight coarsening- and thickening-upward trends seem to be continued beyond section BM1. Based on field observations, the series above the level BM1/17 (i.e., section BM2) shows a much lower mud to sand ratio and the sandstone intervals are distinctively thicker – up to metric beds – as compared to the ones below. An unpublished report by Ar Alhan [11] concluded that the coarsening- and thickening-upward trends were observed at section BM2. Hence, when comparing the stratigraphic data from sections BM1 and BM2, the coarsening- and thickening-upward patterns found in both sections seem to be reflecting an overall shallowing-upward succession, seemingly compatible with a prograding, distal deltaic succession. More likely, the sequence below was a more distal part of the deltaic setting while the one above was approaching a more proximal environment.

Regarding the matter of depositional energy regime, the section shows the influences of storms and fluctuating energy levels. In the stratigraphic column, the background palaeocommunity can, in general, occur throughout FA 1 to FA 3, whereas the event palaeocommunity delimited to FA 2 only. The event palaeocommunity (technically comparable to the *Skolithos* ichnofacies) is an essential indication of a sudden peak in the depositional energy which resulted in a higher amount of oxygen supplied to the surface of the seafloor. The increase in the oxygen level allowed the event palaeocommunity to colonise the palaeoecosystem briefly until the conditions returned to normal and wiped out the opportunistic animals.

PALAEO-OXYGENATION HISTORY

Based on the evidence gathered, the palaeo-oxygenation history at the seafloor was, in fact, much more complicated than earlier presumed. Some evidence also indicates the sedimentation rate in the section. The evidence and its palaeo-oxygenation meanings will be discussed in further detail.

The colour variation observed in the mudstones throughout the section is visual evidence of the differences in the preservation of the organic matter in the original sediments. The results from TOC analysis – which shows fluctuating values of total organic carbon preserved in the mudstones and sandstones – are directly linked to that preservation. Preservation is related to both the oxygen levels at the surface of the seafloor during the time of deposition, and also more importantly, underneath the sediment surface. If the oxygen level were low, it would create favourable conditions for the preservation of the organic matter. Therefore the TOC yielded will be higher, as the amount of free oxygen would be limited and hence insufficient for oxidising all the organic matter deposited. Thus, the oxygen levels on the seafloor recorded in section BM1 were not at a constant low level or in dysaerobic conditions because there were time intervals where the oxygen level at the surface was higher.

The different types of sandstones – i.e. amalgamated sandstones, thinly-laminated sandstone and tabular sandstones – as well as the sedimentary structures – hummocky cross lamination, parallel lamination, trough cross-bedding, current ripple and climbing ripple cross lamination – are all compatible with oxygen being supplied to the water bottom through episodic sedimentary processes of various energy levels, including storm events. These processes introduced significant amounts of oxygen to the surface of the seafloor before and during the deposition; therefore, the conditions at the surface could not be dysaerobic. Besides, it can be observed clearly in the stratigraphic column that the occurrences of storm events (represented by FA 2) are more frequent in the intervals of FA 3 as compared to FA 1. Probably this explains the slight decrease in the TOC percentage in FA 3, as oxygen was replenished regularly by the storms.

The density of occupation of the substrate by members of the *Cruziana* ichnofacies observed in the section is low, but not low enough as to suggest dysaerobic conditions. Moreover, the presence of *Palaeophycus* ichnosp., which is a type of domichnion made by a carnivore, also disagrees with dysaerobic conditions. Carnivores generally have a high metabolic rate, which means they require more oxygen to survive. *Psammichnites* ichnosp. Could, in some cases, be produced in dysaerobic conditions present below the sediment-water interface, provided that they were connected to aerobic conditions at the surface of the sea bottom. The animal producers of this trace had a morphological adaptation to obtain oxygen from the seafloor through a snorkel while it excavates for food within the sediment.

The predominance of pascichnia in the stratigraphic succession is not only an indication of an organic-rich sediment surface but also gives information about the sedimentation rate. The preservation of the pascichnia traces depends on whether the animals have had sufficient time to scavenge for detritus accumulated on top of the sediment layer before the next layer is deposited above the existing one. If the sedimentation rate was high, the time window for the animals to graze was shorter, hence either the animal would not have the opportunity to graze through the sediment layer at all or a lesser amount of pascichnia traces are preserved. In the case of section BM1, many pascichnia traces are observed, implying that there was sufficient time for the animals to graze for food. In other words, the sedimentation rate must have been relatively low.

The presence of the bivalve *Claraia* sp. also implies that anoxia did not exist since they are benthic. Hence, relatively well-oxygenated conditions must have prevailed close to the seafloor so that they were able to live. However, it is unclear whether this species' characteristic of fragile shells could be a morphological adaptation to low-oxygen or dysaerobic conditions.

The presence of burrow mottling in the mudstones – typically sandwiched between two sandstones – is also a sign of high oxygen content in the water of the seafloor, as well as an interruption in the sedimentation (Figure 9). Burrow mottling is produced when animals penetrate deeper into the sediments and introduce oxygen into the older sediments – or historical layer –, thus resulting in the oxidation of the organic matter previously stored in the historical layers. In order to develop the mottled levels, a higher oxygen level is required for such intense oxidation to occur and, as observed in the stratigraphic column, the mudstone levels where burrow mottling is present generally have TOC values less than the average TOC of 1.3 %, proving that the oxidation process was more significant as compared to levels without burrow mottling. Besides, the process of producing intense burrows and deep penetrations within the sediment is also time-dependent. Therefore, there must be an interruption in the sedimentation, necessary for providing more time for the animals to produce their burrows.

Microbial mats are thin sheets of microorganisms stacked in multi-layers usually growing on the sediment surface. They can produce oxygen through photosynthesis even under low light conditions. The occurrence of these mats points towards another source of oxygen in addition to the episodic storm events. Therefore, the conditions at the surface of the water bottom could not be dysaerobic at the levels where microbial mats are present since the mats are providing a steady supply of oxygen to the surface. Besides, the mats are also indicative of a relatively low sedimentation rate. As they grow, they migrate upwards to keep on top of the sediment surface. If sedimentation were too rapid, then the upward migration of the mats would not have been possible.

As a summary, the pieces of evidence ultimately imply that it is unlikely for the water of the seafloor to be dysaerobic because two sources of oxygen existed, namely the episodic storm events and the microbial mats. Oxygen is continuously being replenished or supplied to the surface of the seafloor, hence allowing animals, including predatory kinds, to colonise it and also the top layer of the sediment. The predominance of pascichnia also tells that the deposits were generally very rich in organic matter, probably associated with the pelagic rain and occasional planktonic blooms. In terms of sedimentation rate, occurrences of microbial mats and burrow mottling, as well as the predominance of pascichnia, suggest that it was relatively low and there were periods when sedimentation was interrupted.

Figure 9 Mudstone intervals with burrow mottling. The diameter of the coin is 2 cm.

BIOCHRONOLOGICAL AGE

The ichnotaxa found throughout the section are not age-diagnostic, but the presence of the bivalve genus *Claraia*, which is a pectinoid genus most probably belonging to the family Pterinopectinidae, has a value as a biochronological indicator. Moreover, the taphonomic analysis indicates that *Claraia*-bearing assemblages were preserved *in situ*, without any significant transport. In consequence, they can be trusted as authentic sources of both palaeoecological and biochronological information.

The genus *Claraia* sp. appeared during the latest Permian (the Changhsingian Age) and reached its acme during the earliest and mid-Early Triassic (Induan Age and Early Olenekian Age) [12]. Therefore, the presence of *Claraia* sp. in the study area can be interpreted as indicative of, most probably, the Early Triassic Epoch. At section BM1, the lowest stratigraphic occurrence of the *Claraia* sp. is at level 5, hence the age of the rocks from the level 5 upwards is assumed to be Early Triassic. Below level 5, the age of the stones is unknown due to the lack of age-diagnostic palaeontological data.

CONCLUSION

The primary purpose of the study is to define the possible origin of the 'black shale' facies in terms of depositional palaeoenvironment, palaeo-oxygenation history and biochronological age, through lithostratigraphic, palaeontological, petrographical and geochemical analyses. Based on the results and discussion, some conclusions can be made regarding the 'black shale' facies at the lowermost level of the chert unit of the Semanggol formation cropping out in Bukit Merah:

The general stratigraphy can be described as a succession of predominantly dark mudstones with sandstones containing trace and body fossils. The rocks are interpreted to reflect a shallow marine, shallowing-upward sequence deposited in a deltaic environment. The succession comprises more distal deposits at the bottom which are overlain by more proximal deposits towards the top. The succession also shows signs of influence by storm events and fluctuating energy levels.

A total of 12 ichnogenera of bioturbation trace fossils and one genus of body fossil were identified in the 'black shale' facies. The ichnoassemblages are interpreted to represent soft ground marine palaeoecological conditions compatible with the *Cruziana* ichnofacies, but with a notably lower ichnodiversity. This ichnofacies is known to occur in sublittoral, shallow marine settings (continental platform).

In terms of the palaeo-oxygenation history, the conditions of the sea bottom were unlikely to be dysaerobic since two sources of oxygen existed, namely the episodic storm events and the photosynthetic metabolism of the microbial mats. They have regularly replenished the oxygen levels at the water of the seafloor surface. However, intervals which lack palaeontological remains may likely reflect anoxia at the seafloor.

The biochronological dating of the studied section is made after the bivalve genus *Claraia* which is known to have its acme during the earliest and mid-Early Triassic. The appearance of these bivalves in the division is at level 5, continuing upwards until level 16, hence the age of the rocks is most probably Early Triassic. Below level 5, the age of the rocks there is yet to be known.

For future studies, it is possible to conduct a more in-depth analysis on the bivalve genus *Claraia*, especially in terms of its taxonomy, palaeobiology and palaeoecology, to better understand their morphology and elucidate whether they were adaptable to dysaerobic conditions. On the other hand, it is also possible to carry out detailed geochemical analyses such as Rock-Eval Pyrolysis and vitrinite reflectance analysis on the shale beds for the purpose of identifying the kerogen type. The information could be useful for evaluating the source of the organic matter, i.e. whether it mainly derived from marine or continental settings.

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