Stratigraphy and Palaeoichnology of "Black Shale" Facies: Chert Unit of the Semanggol Formation, Perak

Farahana Azwa Drahman and José Antonio Gámez Vintaned

Abstract The exposed area of Bukit Putus, one of the Semanggol abandoned quarries in Bukit Merah (NNW of Taiping, Perak, Peninsular Malaysia) has allowed us to start a detailed study of the "black shales" of the chert unit of the Semanggol Formation. Presently, no integrated palaeoichnological-stratigraphical studies have ever been performed in the Semanggol Formation. The chert unit in particular is claimed to have been deposited in a deep oceanic basin under the influence of different regimes of transportation (Basir Jasin and Zaiton Harun [2]). The analysis conducted herein aims to reconstruct the palaeoenvironmental evolution, contrasting with previous interpretations. Description of sedimentary facies and facies associations was done at the main outcrop. Samples collected have been studied through thin sections, total organic content (TOC) analysis, scanning electron microscope (SEM)–EDX, and photography and image enhancement. As a result, palaeontological and sedimentological data indicate that as far as the "black shale" facies is concerned, the basin evolved from mid-distal continental shelf settings into shallower sublittoral conditions. The general evolution is compatible with the dynamics of a deltaic apparatus prograding seawards (prodelta facies evolving into lower delta front ones). At the outcrop of the Bukit Putus quarry, several levels bearing abundant specimens of *Claraia* sp.—an Early Triassic pectinid bivalve—have been found. Questionable brachiopods of the order Lingulida also seem to be present. In short, results from the integration of stratigraphical and paleoichnological data support the palaeoenvironmental conclusions obtained in this study.

Keywords Semanggol Formation · Permo-Triassic · Trace fossils · *Cruziana* ichnofacies · Bivalvia · Brachiopoda

F.A. Drahman (✉) · J.A.G. Vintaned
Petroleum Geoscience Department, Universiti Teknologi PETRONAS,
Seri Iskandar, Malaysia
e-mail: farahanaazwa.drahma@petronas.com.my

M. Awang et al. (eds.), *ICIPEG 2016*,
DOI 10.1007/978-981-10-3650-7_53

1 Introduction

A few geological studies have been conducted on the Semanggol Formation which is widely exposed in north Perak, as well as in south and north Kedah (Peninsular Malaysia). Burton (1973) [3] divided the formation—from the bottom to the top—into three informal members, namely the chert member, the rhythmite member and the conglomerate member; they were later called “units” by [7]. The age of the Semanggol Formation was previously assigned to the Triassic based on the bivalves found [3]. Nevertheless, the age is now recognized as Early Permian to mid-Triassic as proposed by [1] based on the radiolarian present in the chert unit in Kedah. Most of the studies were conducted in the Kedah area as compared to Perak. Hence, an outcrop has been herewith selected at Bukit Merah (Perak) to further study the Semanggol Formation.

The present study of the Semanggol Formation at Bukit Merah focuses on the stratigraphy and palaeoichnology of the “black shale” facies of the chert member. The application of Palaeoichnology in sedimentary geology is consolidated and being recognized today as a capable apparatus to reconstruct the palaeoenvironment, to perform facies interpretation and to identify discontinuities, among other topics, and has accumulated a vast knowledge used for prospection and exploration of hydrocarbon resources. This is mostly because trace fossils are not susceptible to post-mortem displacement; they are virtually always found in situ [4]. Trace fossils are good facies indicators, as they record the behaviour of the producers, typically as a response to subtle changes in environmental parameters such as salinity, oxygen and food supply [6].

The siliciclastic succession of Bukit Merah has been described by Hutchison and Tan in 2009 [5], who interpreted the succession as mainly deposited in deepwater environments across the Semanggol Basin. The presence of radiolarians supports this vision. However, until now no integrated ichnological and stratigraphical studies have ever been performed. More precise interpretations can be done on the Semanggol Formation by using the trace fossil evidence which is present in the rock. In particular the ichnological analysis may prove valuable in detailing the environmental evolution of the basin.

2 Geological Setting

The Semanggol Formation is widely exposed at three separate locations, namely Padang Terap (north Kedah), Kulim-Baling (south Kedah) and Gunung Semanggol (north Perak). As previously mentioned in Chap. 1, the stratigraphy of the

Semanggol Formation at Gunung Semanggol consists of three units: the chert unit, rhythmite unit and conglomerate unit. The outcrops exposed at the Padang Terap area show all of the units, and they are conformably overlying the Permian Kubang Pasu Formation. Meanwhile, in the south of Kedah, at Kulim-Baling only two units are identified, namely the chert and the rhythmite units. As for the area of interest, Gunung Semanggol, three units are represented: the chert unit, the rhythmite unit and the conglomerate unit. All of them were later intruded by a Late Triassic granitic intrusion [2].

3 Methodology

3.1 Field Techniques

1. Stratigraphic Logging and Sampling—A log of ca. 50 m has been made, with multipurpose sampling at regular intervals.

3.2 Laboratory Techniques

1. Polished (macroscopic) sections and thin (microscopic) sections—these techniques, combined with others of staining and/or impregnation, are essential to enhance the visibility of trace fossils in bioturbated fabrics, apart from allowing the study of ichnological systematics on the samples.
2. Scanning electron microscopy (SEM) with EDX—selected, sample is studied at the SEM, and analysed where necessary with EDX. This allows the study of the ethological structures in detail.
3. Photography and image enhancement—an important method to enhance the visibility of biogenic structures after sectioning and polishing the rock samples.
4. Total organic content (TOC)—the colour of the “black shale facies” ranges from dark to light grey, depending on weathering. TOC analyses determine the carbon content of a rock attributable to the organic matter preserved on it.
5. Whitening of samples for photography—most samples of body fossils and bioturbation structures benefit from being “whitened” with ammonium chloride in order to improve the visibility of the 3D morphology by increasing the contrast.

4 Results

Palaeontological evidences found at the stratigraphic section BM1 are compatible with the sedimentological ones, both indicating a shallowing-upward trend, from mid-sublittoral shelfal environments—located above the storm wave base—to shallower sublittoral conditions. The basin was probably receiving muddy sediments from a deltaic apparatus.

4.1 Data from Body Fossils

Abundant specimens of the pectinid genus *Claraia* (Fig. 1a)—an Early Triassic bivalve—and also scarce questionable brachiopods of the order Lingulida (Fig. 1b) are found at several levels, indicating the presence of epifaunal (*Claraia*) and shallow infaunal (lingulids) suspension-feeder invertebrates. The complete array of sizes found among the valves of *Claraia*—although disarticulated—talks in favour of a short-distance transportation of these shell assemblages, if any transportation existed at all.

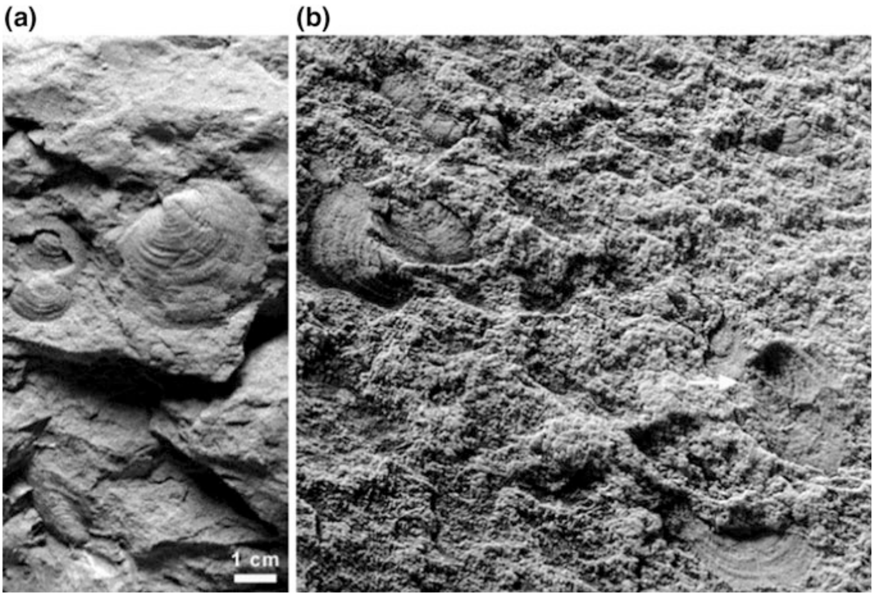

Fig. 1 **a** Different-sized specimens (*inner moulds*) of the bivalve *Claraia* sp. **b** Probable outer mould of a brachiopod of the order Lingulida, showing the migration line of the pedicle (*arrowed*). Level BM1/16

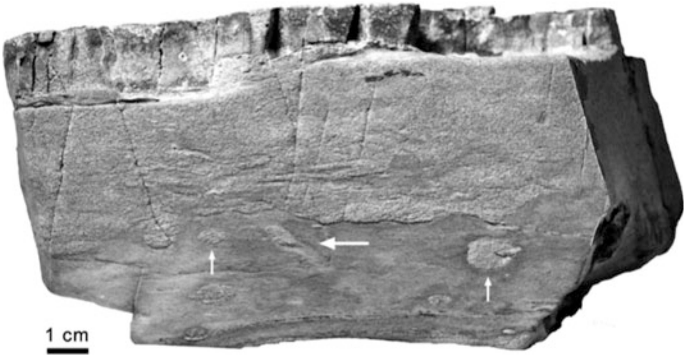

Fig. 2 Longitudinal section of oblique Skolithos (*big arrow*) and transverse sections of Palaeophycus (*smaller*). Level BM1/16

4.2 Data from Ethological Structures

The benthic fossil communities identified were composed not only of shelly, suspension-feeder invertebrates but also of soft-bodied invertebrates which left bioturbation structures (ethological structures, in which action can be semiquantitatively measured by means of the bioturbation ichnofabric index), as well as bioarrangement structures (another kind of ethological structures) left by microbial mats. From the present study of the ethological structures, we may perform a more complete study of the benthic living communities populating the sea bottom.

The identified bioturbation ichnogenera are a total of nine: *Cochlichnus*, *Cylindrichnus*, *Diplocraterion*, *Palaeophycus* (Fig. 2), *Planolites*, *Scolicia*, *Skolithos* (Fig. 2), *Torrowangea* and *Psammichnites*. They all indicate the presence of a diversified benthic fauna populating the sea bottom. Most of the ichnological contents represent the *Cruziana* ichnofacies, although suites dominated by dwelling, oblique burrows may indicate the *Skolithos* ichnofacies developed at deeper conditions than normal, below the fair-weather wave base. The *Cruziana* ichnofacies is indicative of mid-distal continental shelf settings, slightly below the normal wave base and exposed to the action of storms (i.e. above the storm wave base).

At a lesser scale of the producer's body size, the phenomenon of cryptobioturbation has been identified under microscope observations in thin sections of parallel laminated mudstone and silty mudstone at levels BM1/3 and BM1/4. Cryptobioturbation may eventually produce intense mixing of the sediment, with deep alteration or destruction of the sedimentary fabric. Nevertheless, in such cases, the bioturbation ichnofabric index is not of common use at all.

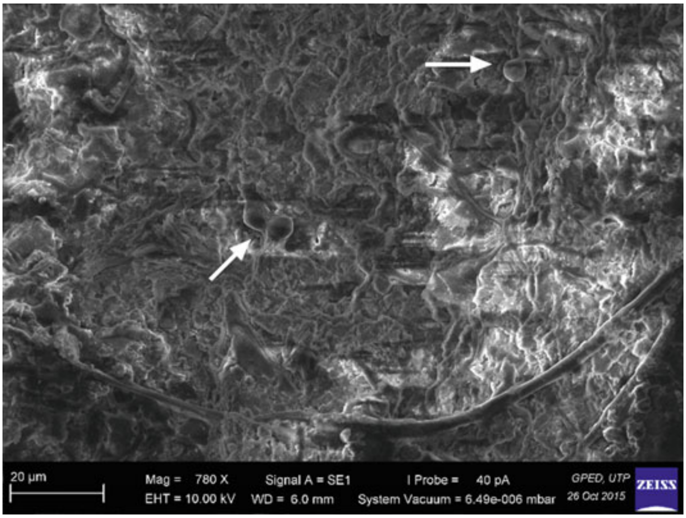

Fig. 3 Three 5-µm-wide coccoids (*arrows*) and filaments (*below*) spotted in a microbial mat sample, level BM1/7

At several levels of the section, thin microlaminated intervals are interpreted as fossil microbial mats (bioarrangement structures), most probably of cyanobacterial origin. Under the SEM, they show minute coccoids and filaments of either cyanobacterial or fungal origin (in the latter case, fungi would be interpreted as eating on the mat) (Fig. 3).

4.3 *Data from TOC (Total Organic Content)*

In terms of palaeoxygenation of the benthos (i.e. the seafloor bed), a preliminary analysis has been carried out based on the TOC. The analysis has been conducted on shale samples from levels 5 and 16 (Fig. 4), indicating TOC values of 0.342 and 0.497%, respectively, which are very low, most probably due to modern weathering.

The presence of organic carbon talks in favour of early diagenetic conditions which have favoured its preservation, which ultimately entails a deficit of oxygen during burial so that some of the organic carbon—despite the low values measured—is eventually preserved from oxygenation.

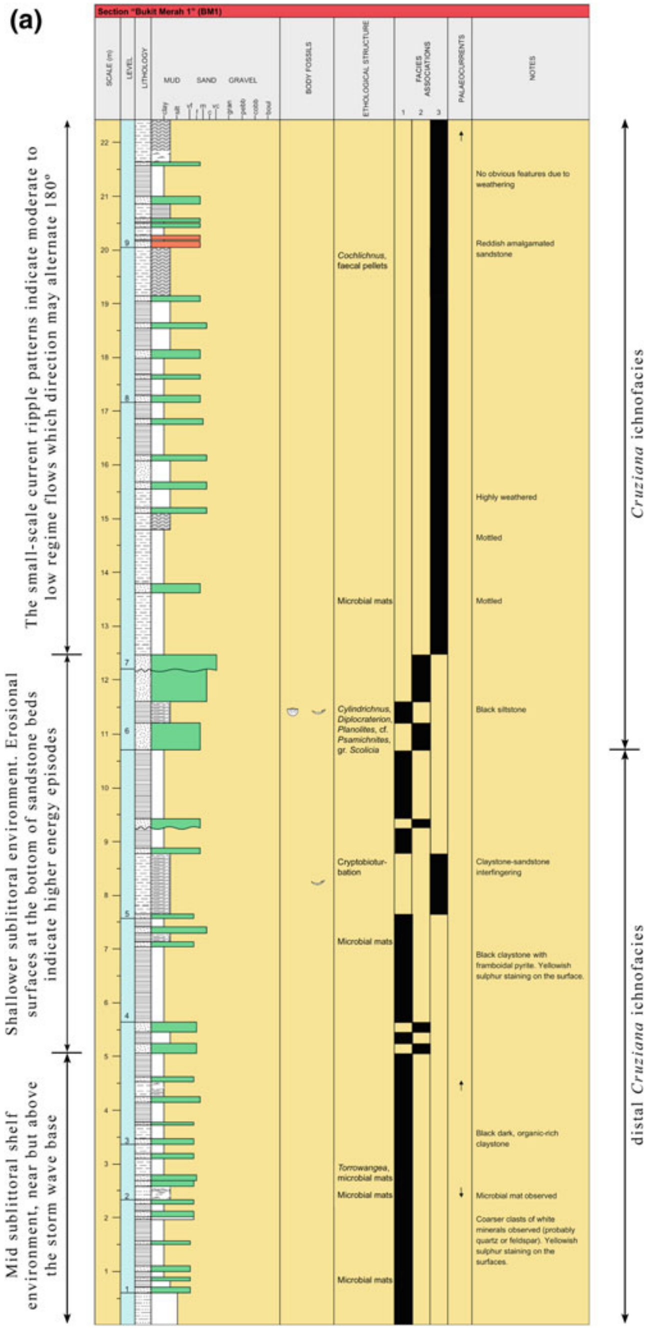

Fig. 4 (*opposite page*) Integrated stratigraphical and palaeoichnological log at section BM1 (*lower part*). Legend, in **b**. Key for facies associations: *1*, *dark grey* mudstone with few centimetric, very fine-grained sandstone; *2*, decimetric, erosive, medium-grained sandstone; *3*, *dark grey* mudstone with centimetric, len-ticular, fine-grained sandstone. **b** (*opposite page*) Integrated stratigraphical and palaeoichnological log at section BM1 (*upper part*). Facies associations, as in **a**.

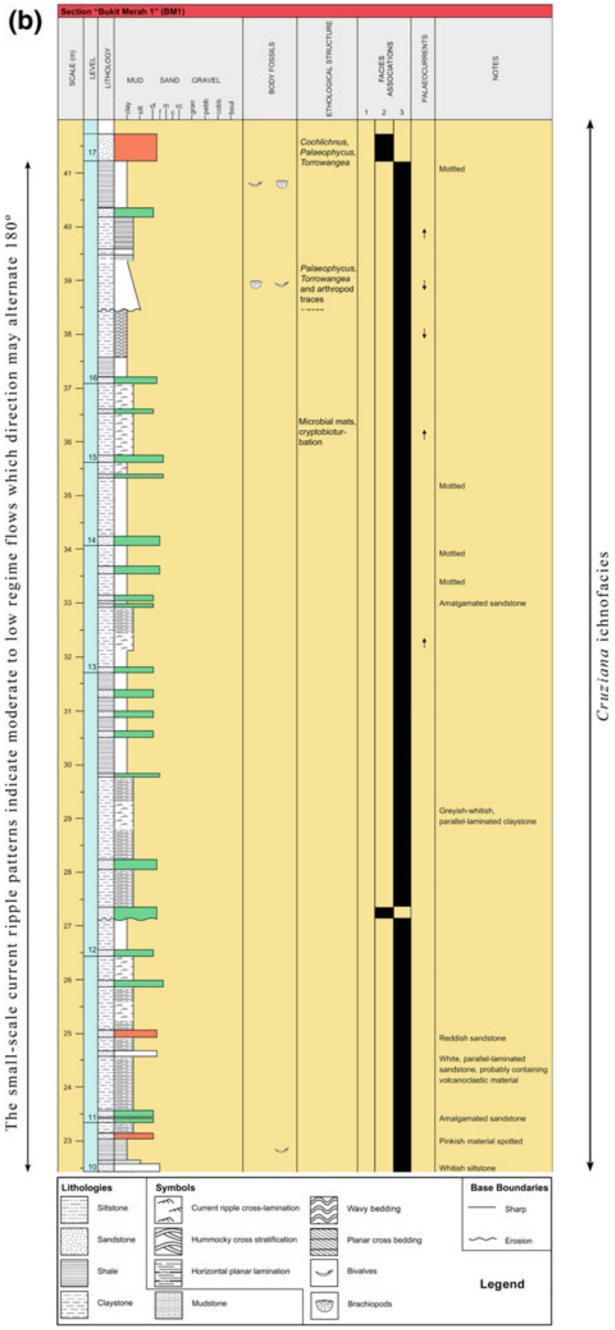

Fig. 4 (continued)

5 Conclusions

An integrated study of the palaeoichnology and the stratigraphy of the Semanggol Formation, focused on the Bukit Merah area, has shown its potential to certainly improve our understanding of the facies distribution and interpretation, environmental evolution and palaeoecological reconstruction of the basin.

Evidence of benthic fauna traces—mostly of the *Cruziana* ichnofacies—populating the sea bottom indicate that the basin evolved—during the time of deposition of the “black shale” facies—from a distal-mid continental shelf setting into a more proximal one with shallower sublittoral conditions, above the storm wave base but always below the action of the fair weather wave base. Lithostratigraphic and sedimentological evidences also indicate a shallowing-upward trend: from mid-sublittoral shelfal conditions—above the storm wave base—to shallower sublittoral conditions. Thus, trace and body fossil data are in agreement with the sedimentological ones throughout the 41.8-m-thick stratigraphic log obtained. The general sedimentary evolution is compatible with the dynamics of a deltaic apparatus prograding seawards, as indicated in the integrated stratigraphy given herein (Fig. 4).

The “black shale” facies are only in a few cases reflecting true anoxic conditions during deposition (i.e., those intervals lacking completely benthic life or their palaeoichnological evidences). Most of the dark grey facies visible at the studied section reached anoxia in phases after burial, during diagenesis, since they showed moderate-to-high contents of palaeontological remains indicative of benthic life.

All these observations and concluding remarks will contribute to the palaeogeographical knowledge of the Semanggol Basin and its geotectonic setting.

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