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First Record of the Belemnite Genus *Hibolithes* from Late Jurassic–Early Cretaceous Turbidites from Malaysia

Muhammad MURTAZA[1, 2, *], Abdul Hadi Abd RAHMAN[2], Joerg MUTTERLOSE[3], Najiatun NAJLA[2], and Mazshurraiezal Bin NASIR[2]

[1] *Department of Earth and Environmental Sciences, Hazara University, Mansehra, Khyber Pakhtunkhwa 21120, Pakistan.*
[2] *Department of Geosciences, Universiti Teknologi PETRONAS. Bandar Seri Iskandar, Tronoh, Perak 31750, Malaysia.*
[3] *Department of Geology, Mineralogy and Geophysics, Ruhr-Universität Bochum, Universitätsstrasse 150, Bochum 44801, Germany*

Abstract: Discovery of the remains of belemnites referred to the *Hibolithes* sp. from the Jurassic–Cretaceous Pedawan Formation in Sarawak, on the island of Borneo (Malaysia) comprises four fragments of belemnite rostra. The specimens are characterized by multiple fractures and vein filling. Two fragments measuring about 130 mm are relatively intact, with only part of the alveolar region missing; a third piece represents the middle part of a rostrum, and the fourth specimen is too fragmentary to be assigned to any specific part of the rostrum. Based on specimen characteristics, a Tithonian–Hauterivian age is plausible. The sedimentary succession that yielded the belemnite material comprises thick shale that reflects the Te division of Bouma sequence. The occurrence of a *Hibolithes* taxon in the uppermost Jurassic to lowermost Cretaceous Pedawan Formation sediments in Borneo reflects a near to global palaeobiogeographic distribution of this genus.

Key words: invertebrate paleontology, Belemnitida, *Hibolithes*, turbidites, Pedawan Formation, Tithonian–Hauterivian, Sarawak, Borneo

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1 Introduction

The belemnites (Belemnitida) belong to an extinct order of squid-like cephalopods that existed from the Late Triassic to Late Cretaceous; they originated in eastern Tethys and western Paleo-Pacific in the Late Triassic (Iba et al., 2012) and spread worldwide during the Late Mesozoic (Doyle et al., 1994). The biogeographic distribution and diversity patterns of belemnites in the Jurassic and Cretaceous have been well documented (Stevens, 1963, 1973; Challinor, 1979, 1989, 1990, 1991; Challinor and Skwarko, 1982; Doyle, 1987; Doyle and Kelly, 1988; Christensen, 1990, 2002; Mutterlose, 1992; Doyle and Benton, 1993; Doyle and Shakides, 2004; Challinor et al., 2005; Iba et al., 2011, 2015). Belemnites have frequently been found and studied in the southernmost and eastern parts of Southeast Asia (Indonesia) and in the southwestern Pacific. The oldest Triassic belemnites were found in the Bihati area of Timor (Wanner, 1911; von Bülow, 1915; Gheyselinck, 1934). Late to Middle Jurassic and Early Cretaceous belemnites are common in the Papua New Guinea area and easternmost Indonesia (Kruizinga, 1921; Challinor and Skwarko, 1982; Challinor, 1990, 1991). Early Cretaceous belemnites were found in West Papua (Challinor, 1990), northwestern Australia and Southeast Asia (Mutterlose, 1992). No belemnites have previously been recorded from Mesozoic successions of Peninsular Malaysia and the Borneo region. In Borneo, Mesozoic successions are widespread in the provinces of Kalimantan, Sabah and Sarawak.

During the Mesozoic, the study area in Sarawak, Malaysia was characterized by the deposition of deep marine sediments (Pedawan Fm.) and shallow marine carbonates (Bau Limestone) (Fig. 1a). These deposits are confined to the Kuching and Sibu Zones of Sarawak (Fig. 1b), and the Bau Limestone Formation (Fm.) and the Pedawan Fm. occur in close vicinity (Fig. 1c). The Bau Limestone had been dated as Late Jurassic to Early Cretaceous using algae (Wilford Kho, 1965), foraminifera (Bayliss, 1966), brachiopods (Yanagida and Lau, 1978), and corals (Beauvais and Fontaine, 1990). The age of the Pedawan Fm. ranges from Late Jurassic to Late Cretaceous, an assignment based on ammonites (Wilford, 1955; Sarkar, 1973; Ishibashi, 1982), foraminifera (Hashimoto and Matsumaru, 1977; Abdullah and Abang, 1987), palynology (Muller, 1968), and radiolaria (Jasin and Said, 1999; Jasin, 2000).

This study reports on specimens referred to the belemnite genus *Hibolithes* from the Pedawan Fm., exposed in the western Sarawak, Malaysia. The identified belemnite rostra are taxonomically characterized while the enclosing clastic sediments are evaluated in terms of facies characteristics and depositional setting. The objectives of this article are:

1) to report on the occurrence of belemnites in Sarawak,

* Corresponding author. E-mail: mmurtaza.u@gmail.com

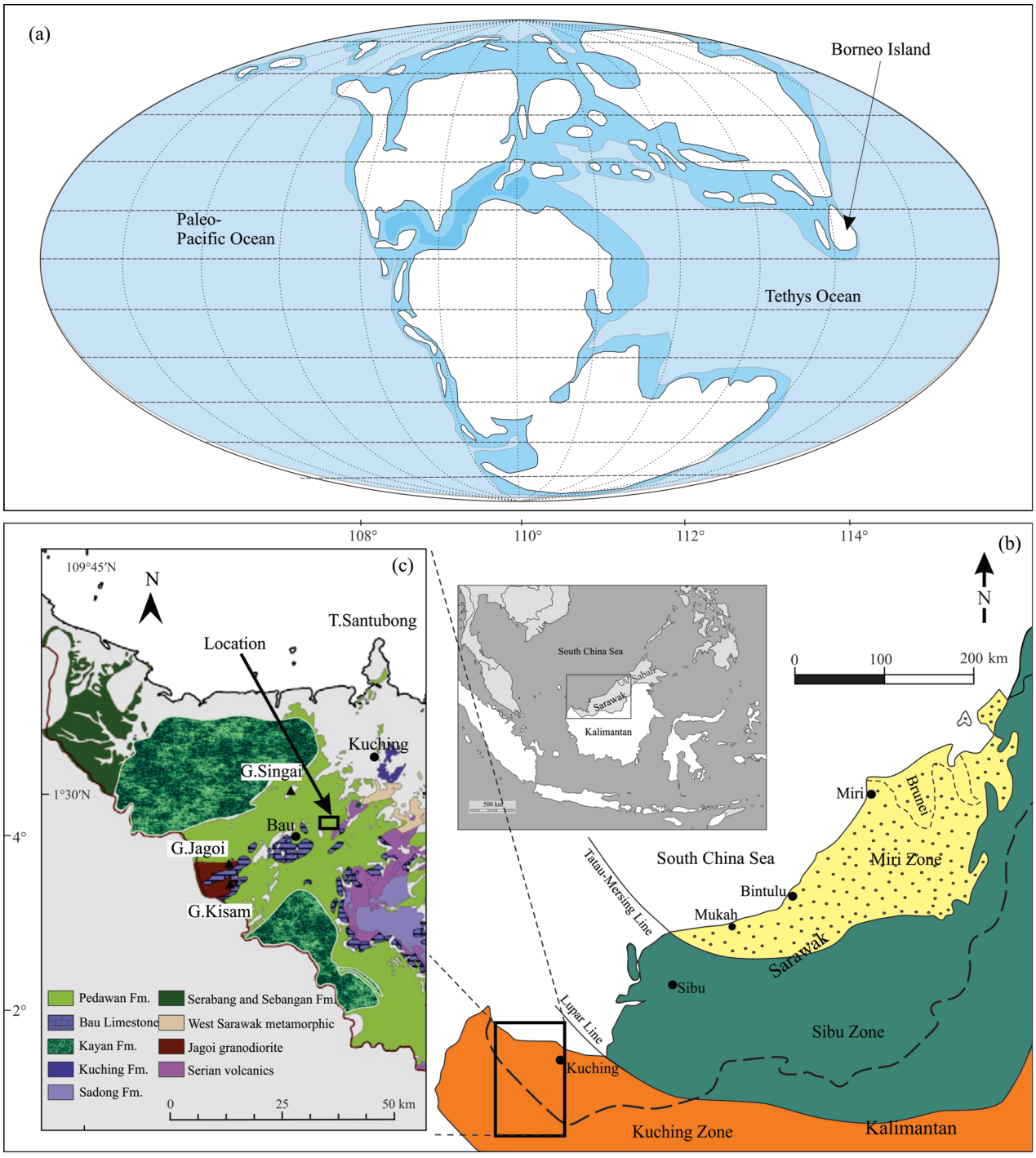

Fig. 1. (a) Location of the deposition of the Pedawan and Bau Limestone formations related to Late Jurassic paleogeography (Leinfelder et al., 2002; Kakizaki et al., 2013). Outline of Borneo is based on Metcalfe (2011); (b) tectono-stratigraphic map illustrating the onshore structural sub-division of Sarawak (based on Haile, 1974; Madon, 1999); (c) geological map of the Kuching and Bau districts indicating the distribution of different formations (after Wilford, 1955, 1965; Wilford Kho, 1965, modified by Breitfeld et al., 2018).

eastern Malaysia;

2) to evaluate the sedimentary succession in which the belemnites occur, in terms of depositional setting;

3) to discuss the paleobiogeographic implications of these findings.

2 Geological Setting

Geologically, the Sarawak state has been divided into three tectonostratigraphic zones: the Kuching, Sibu and Miri Zones (Fig. 1b) (Haile, 1974; Madon, 1999). The

Kuching Zone represents the northward extension of the West Borneo Basement with the Lupar Line that separates it from the younger Sibu Zone interpreted as a NW-trending tectonic mélange or fault zone, which formed during the Eocene (Haile, 1968; Tan, 1982; Haile et al., 1994). The Sibu Zone is characterized by the Rajang Group, Cretaceous to Eocene turbiditic successions of metamorphosed and ophiolitic rocks (Haile, 1968). The Sibu and Miri zones are separated by the Tatau–Mersing unconformity. The Miri Zone comprises relatively younger, gently dipping strata (Amir Hassan et al., 2013, 2016; Murtaza et al., 2015, 2017, 2018) than other zones without much structural ambiguity (Hutchison, 1989).

The described belemnite specimens were recovered from the Pedawan Fm. near the town of Bau, along the Bau–Kuching road in the Kuching Zone (Fig. 1c). The lithology of the Pedawan Fm. indicates a transition from a calcareous shallow marine environment (Bau Limestone) to a clastic-dominated deeper marine depositional environment (Wilford, 1965; Wilford Kho, 1965; Wolfenden, 1965; Tan, 1986, 1993). In earlier studies the Pedawan Fm. and Bau Limestone were assigned a Cretaceous age (Zeylmans van Emmichoven, 1939; Krekeler, 1955; Krol, 1955). On the basis of ammonites, a Late Jurassic (Tithonian) age was assigned to the lower part (Wilford Kho, 1965) of the Pedawan Fm. (Ishibashi, 1982), whereas a Late Tithonian to Early Valanginian age is suggested by other fragmentary ammonites (Sarkar, 1973). The middle part of the formation was assigned a Barremian or Aptian to Cenomanian age, based on the age -diagnostic foraminiferan *Orbitolina lenticularis* (Hashimoto and Matsumaru, 1977) and palynomorphs (Muller, 1968). A Maastrichtian age was assumed for the upper part of the Pedawan Fm., based on foraminifera (Wilford Kho, 1965). This age was revised to Late Santonian (Abdullah and Abang, 1987), supported by palynological findings (Muller, 1968). The most recent study concluded a Late Tithonian (Late Jurassic) to Berriasian (Early Cretaceous) age, which was based on radiolarian species (Jasin and Said, 1999; Jasin, 2000) found in the Pang Bau area, Sarawak (Kuching Zone). (Supplementary Data 1).

3 Materials and Methods

The four belemnite fragments (PD-B1 to PD-B4) were found in a newly exposed section of the Pedawan Fm., which is located two kilometers northeast of Bau town (Fig. 1). The basal part of the succession is marked by a 6-meter thick sequence of shale containing fossiliferous limestone boulders (Fig. 2a). The middle part is a sandstone-dominated chaotic unit that displays slump beds (Fig. 2b). The upper part contains sheet-like sandstones and interbedded mudstones (Fig. 2c). The entire section has a total thickness of 23 meters. The belemnite specimens were recovered from the lower, 6-m thick unit and consist of two rostra, one broken fragment probably from the apical and stem part, and an unidentifiable fragment (Fig. 3).

The specimens, PD-B1 to PD-B4, are housed in Universiti Teknologi Petronas, Malaysia.

4 Taxonomy

The Belemnitida subdivision includes the Belemnopseina and Belemnitina: belemnites that possess alveolar grooves belong to the suborder Belemnopseina; those with apical grooves belong to suborder the Belemnitina. The characteristics of both Belemnopseina and Belemnitina correlate remarkably well with the Tethyan Realm and the Boreal Realm, respectively (Stevens, 1963, 1973; Doyle, 1987; Doyle and Howlett, 1989; Challinor et al., 2005; Iba et al., 2011).

The genus *Hibolithes* (Belemnopseina) includes a wide range of morphological forms ranging from elongate-cylindrical to stout, and strongly hastate in shape (Mutterlose, 1986; Mutterlose and Wiedenroth, 2008). The length of the central groove also varies. The belemnite guards described here belongs to genus *Hibolithes* owing to their elongate guard, hastate shape and ventral groove, which is confined to the alveolar region. The morphology, terminology of the belemnite rostra and the taxonomic concept of this study follows Stevens (1965) and Jeletzky (1966).

Systematic paleontology

Order Belemnitida (Zittel, 1895)

Suborder Belemnopseina (Jeletzky, 1966)

Family Belemnopseidae (Naef, 1922)

Genus *Hibolithes* (Denys de Montfort, 1808)

Hibolithes sp. (Figs. 3a-f)

Material: Four fragments (Fig. 3: PD-B1 to PD-B4).

Description: The most complete specimen no. PD-B1 has a large symmetrical, slightly hastate rostrum. Its length is 134 mm, with a maximum diameter of 12.5 mm. The widest diameter is located midway, slightly towards the apex. The apex is moderately acute. The ventral side has a shallow alveolar groove, which is narrow, short and ~26 mm long. It terminates well before the midpoint. There are two faint, closely spaced lateral lines, which disappear near the apex.

The specimen PD-B2 is characterized by medium asymmetrical, hastate rostrum. The length of the guard is 99.7 mm and maximum diameter is 11.3 mm. The widest point is also midway, but slightly towards apex. The surface is smooth having no alveolar and apical groove. Apex seams slightly mucronate (Fig. 3f).

The specimen PD-B3 is broken middle part of the rostrum solidum. Specimen PD-B4 is an undiagnosed fragment.

Remarks: No data on any other parts of the belemnite taxon, i.e., protoconch, phragmocone or alveolus, is available.

Comparison: The guards of the specimens belonging to taxa of the genus *Mesohibolites* are relatively more stout and conical in shape, with a long median ventral groove. In the case of *Neohibolites* spp., the guards are relatively less elongated with a short groove (Mutterlose, 1986).

5 Enclosing Clastics

The studied interval of the Pedawan Fm. can be classified into five types of facies (F1–F5; Figs. 2, 4). These are: F1, Massive-graded sandstone; F2, Parallel

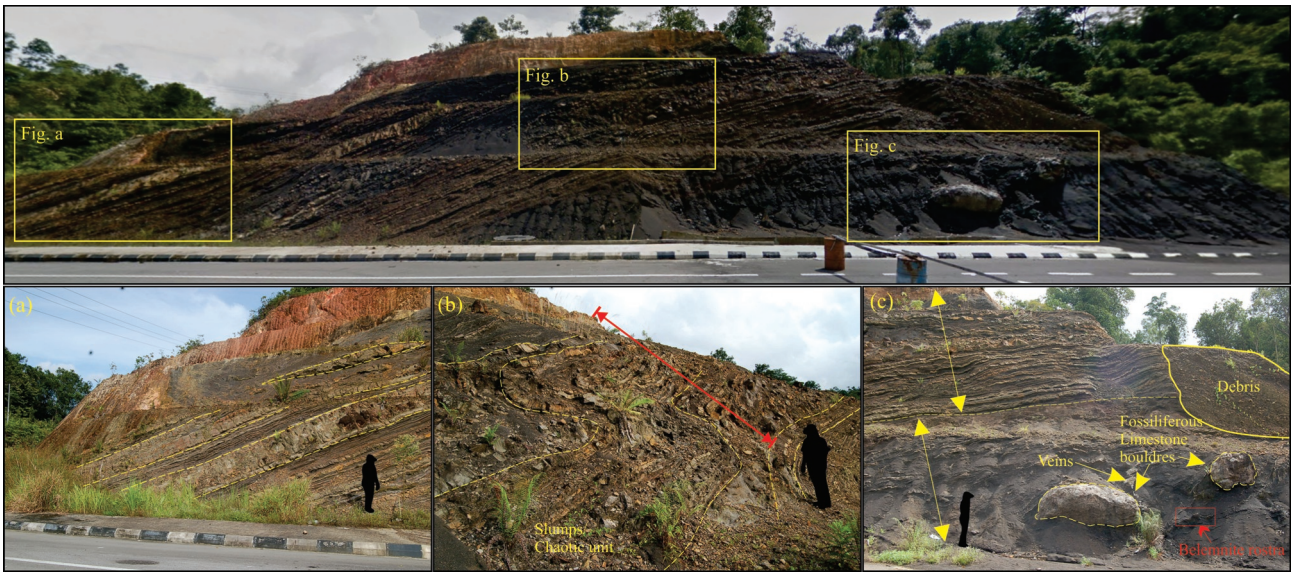

Fig. 2. Photographs of the logged study outcrop located near Bau Town (1°25'16.9"N; 110°10'22.5"E), Sarawak. (a) Lower shale dominated strata with large limestone boulders (Facies F5) and location of the belemnite rostra; (b) middle chaotic unit (Facies F1–F5); (c) upper sheet-like sandstone and mudstone interbeds (Facies F4 and F5).

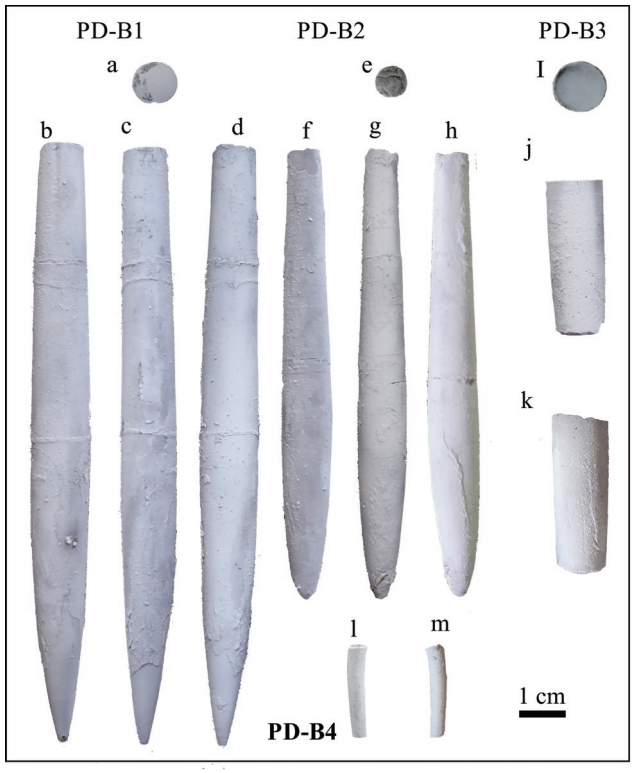

Fig. 3. Photographs of the belemnite rostra without alveolar region; PD-B1 (a-sectional view, b-ventral view, c-dorsal view, d-lateral view) and PD-B2 (e-sectional view, f-ventral view, g-dorsal view, h-lateral view), fragments PD-B3 (i-k) and PD-B4 (l-m) found from the newly exposed outcrop belonging to Pedawan Fm. to the northeast of Bau.

laminated sandstone; F3, Ripple-wavy sandstone; F4, Heterolithic sandstone and shale; and F5-Shale (Fig. 4). Details of the sedimentary facies are given in Supplementary Data 2.

The Pedawan Fm. originated from deep marine turbidity currents and mass flow processes. Incomplete Bouma sequences (Bouma, 1962) were observed at various intervals (Fig. 5a–d). Facies F1 has an eroded base, is poorly sorted and shows graded, massive beds as well as inverse graded beds. It displays characteristics of the Ta deposits of Bouma sequences. These deposits are products of turbidity currents and plastic debris flow processes. The term ‘debrite’ has been used for inverse graded beds (Pluenneke, 1976; Stow, 1984), which reflects debris flow while the dominant massive-graded bedded sandstones reflect turbidity currents. The debrite and turbiditic products suggest a possible genetic association, referred to as ‘linked debrite’ (Haughton et al., 2003), also observed in the deep marine-deposited Belaga Fm. (Bakar et al., 2007). Facies F2 is dominated by parallel-laminated, well-sorted sandstone, which resembles the Tb division of the Bouma sequence and the B2 facies association of Mutti and Lucchi (Bouma, 1962; Mutti and Ricci Lucchi, 1978; Pickering et al., 1986). Facies F3 is a sandstone-dominated facies displaying the Tc division of the Bouma sequence overlain by the Td division (Bouma, 1962). The thin bedding of facies F4 above rippled sandstone can be referred to Td. The shales reflect the Te division representing the hemipelagic/pelagic background sedimentation (Bouma, 1962). A typical turbidite succession comprises thin and sharply bedded massive/graded sandstone, overlain by parallel-laminated and climbing ripple-laminated sandstone, capped by a shale horizon. Settling of finer sediment during the final waning -flow stage formed the uppermost shale horizon. Overall,

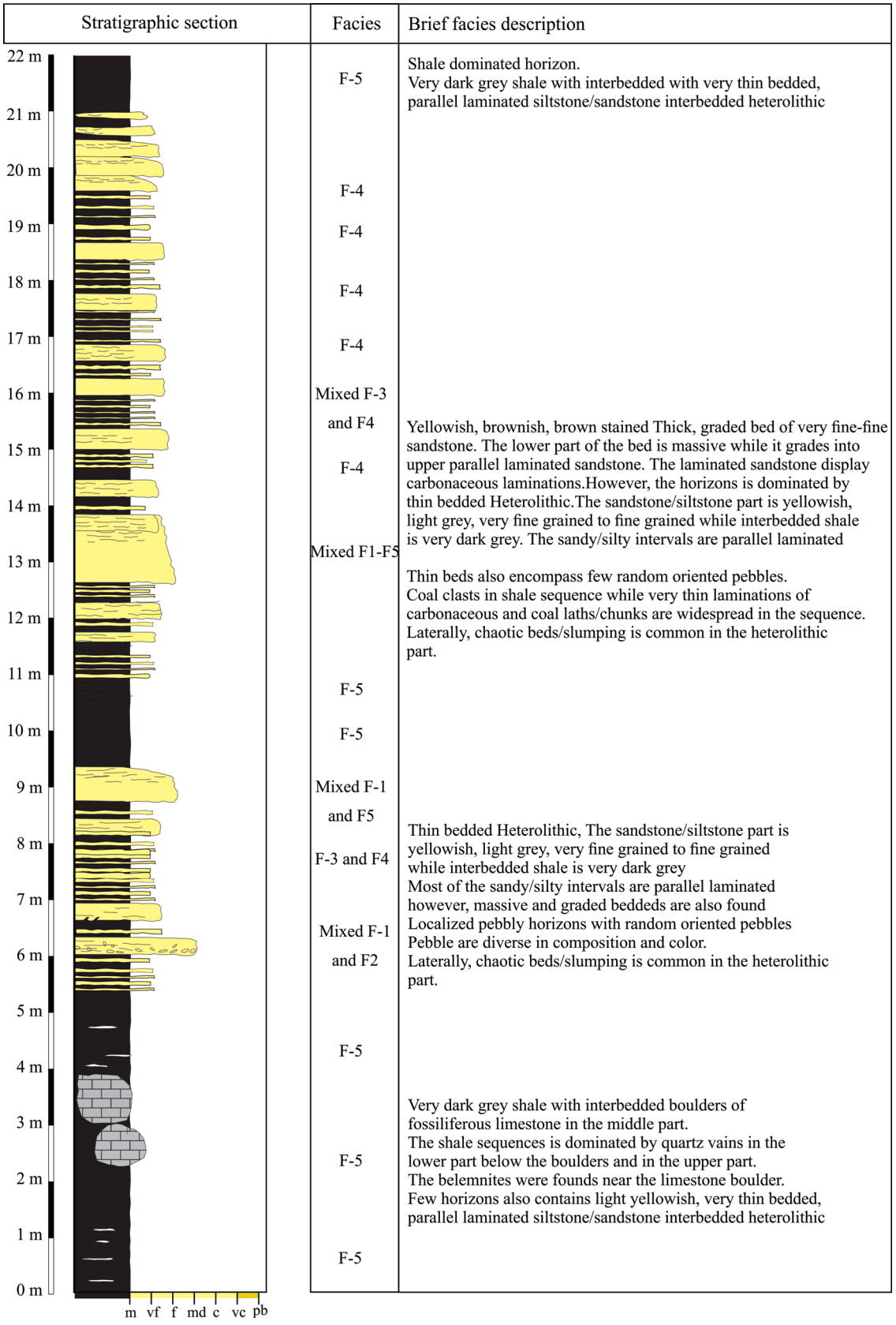

Fig. 4. Sketch of the logged outcrop showing the distribution of different deep marine turbiditic facies (F1–F5) and their characteristics.

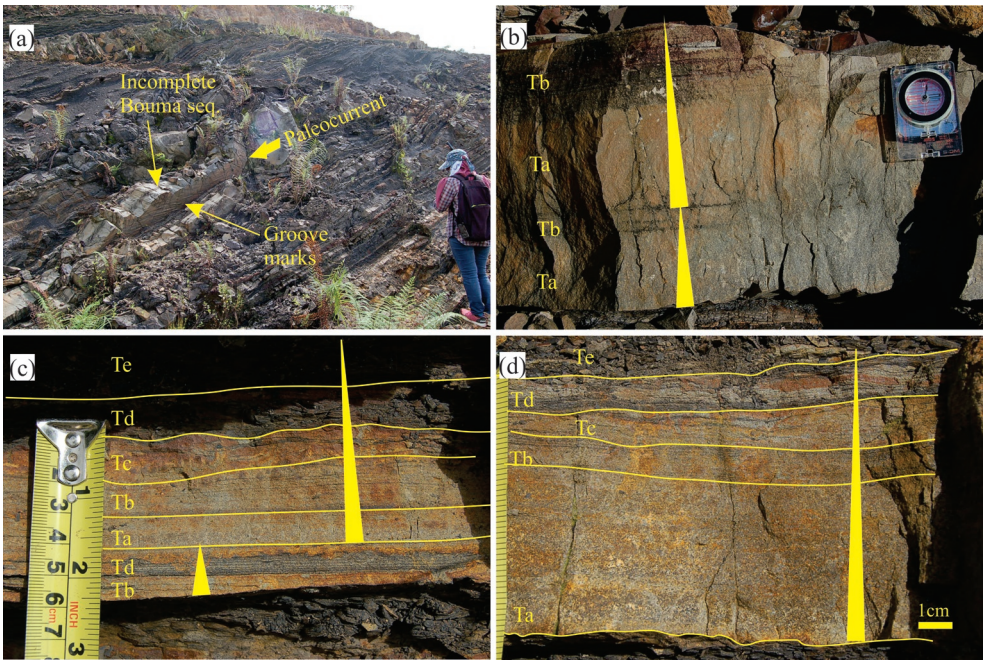

Fig. 5. Photographs of the exposed strata from the Pedawan Fm. (a) chaotic unit with a bed of incomplete Bouma sequence. Groove marks are noticeable; (b) Ta and Tb divisions of Bouma sequence (Bouma, 1962); (c) a complete Bouma sequence with irregular contact between Tb, Tc and Td; (d) complete Bouma sequence having thicker Ta division than the rest of the units.

the facies has the lens and sheet-like geometry with thin mud interbeds, characteristic of submarine fan lobes (e.g. (Mutti and Ricci Lucchi, 1978; Fig. 6).

The limestone boulders in the basal part of the outcrop suggest proximity to shallow marine limestone deposits. The Bau Limestone Fm. is the only limestone in the vicinity. It is widely distributed around Bau Town in western Sarawak, Malaysia. The Bau limestone contains some age-diagnostic fauna, such as Late Jurassic foraminifera (Bayliss, 1966) and Oxfordian to Early Kimmeridgian brachiopods (Yanagida and Lau, 1978). The present data set suggests that these boulders were broken down from the parent rock by a catastrophic event and rolled down into the deeper marine setting (Fig. 6).

6 Stratigraphic Position and Age of Belemnites

During the Early Jurassic, belemnites were fairly cosmopolitan and their remains are found abundantly worldwide within Late Mesozoic deposits (Stolley, 1929; Stevens, 1963; Challinor, 1989, 1990, 1991; Mutterlose, 1992; Challinor et al., 2005; Iba et al., 2015). They were very common in Jurassic–Cretaceous marine environments (Challinor et al., 2005; Iba et al., 2015). The Middle Jurassic was dominated by Tethyan and Boreal belemnite realms (Doyle and Pirrie, 1999). During the Middle to Late Jurassic, the Tethyan Realm, which extended southwards circum to Gondwana, was inhabited largely by species of the genus *Hibolithes* (Belemnopseina) (Doyle, 1992). *Hibolithes* (Middle Jurassic–Lower Aptian) has wide geographical distribution: Middle and Late Jurassic of Europe (central and southern) and New Zealand; Late Jurassic of Madagascar, South America, India and Indonesia; Early Cretaceous of Europe (northern, central and southern), North America, Madagascar, Australia and Indonesia (Mutterlose, 1986; Challinor, 1989, 1990; Challinor et al., 2005). The belemnite specimen from the Mesozoic succession of the Borneo region reiterates that this genus (*Hibolithes*) has a wider paleo-biogeographic range.

The guard morphology and characteristics of the belemnite rostra suggests a Tithonian–Hauterivian age. There are numerous exposed sections of the Pedawan Fm. in western Sarawak. Different sections yielded different age-diagnostic fossils, hence their upper and lower age limit vary within the area. However, the closest exposed section has a chert sequence at the base of the Pedawan Fm., which yielded Late Tithonian–Berriasian radiolarians in the Bau area (Jasin and Said, 1999). Belemnites with a similar morphology have been found in the Early Cretaceous (Valanginian–Hauterivian) of western Morocco (Mutterlose and Wiedenroth, 2008), West Papua (Challinor, 1990), northwest Australia and Southeast Asia (Mutterlose, 1992). However, other methods (absolute dating/micropaleontology) would be useful to determine a more precise and accurate age of the enclosing strata.

Belemnites were common in neritic settings as both predators and prey (e.g., Doyle and MacDonald, 1993; Rexfort and Mutterlose, 2006). They were an abundant and important part of the food chain and fed on mollusks and crustaceans. They were generally nearshore dwellers and are hardly known from pelagic environments (Mutterlose and Wiedenroth, 2008). Limestone boulders found in the lower part of the exposed strata indicate the

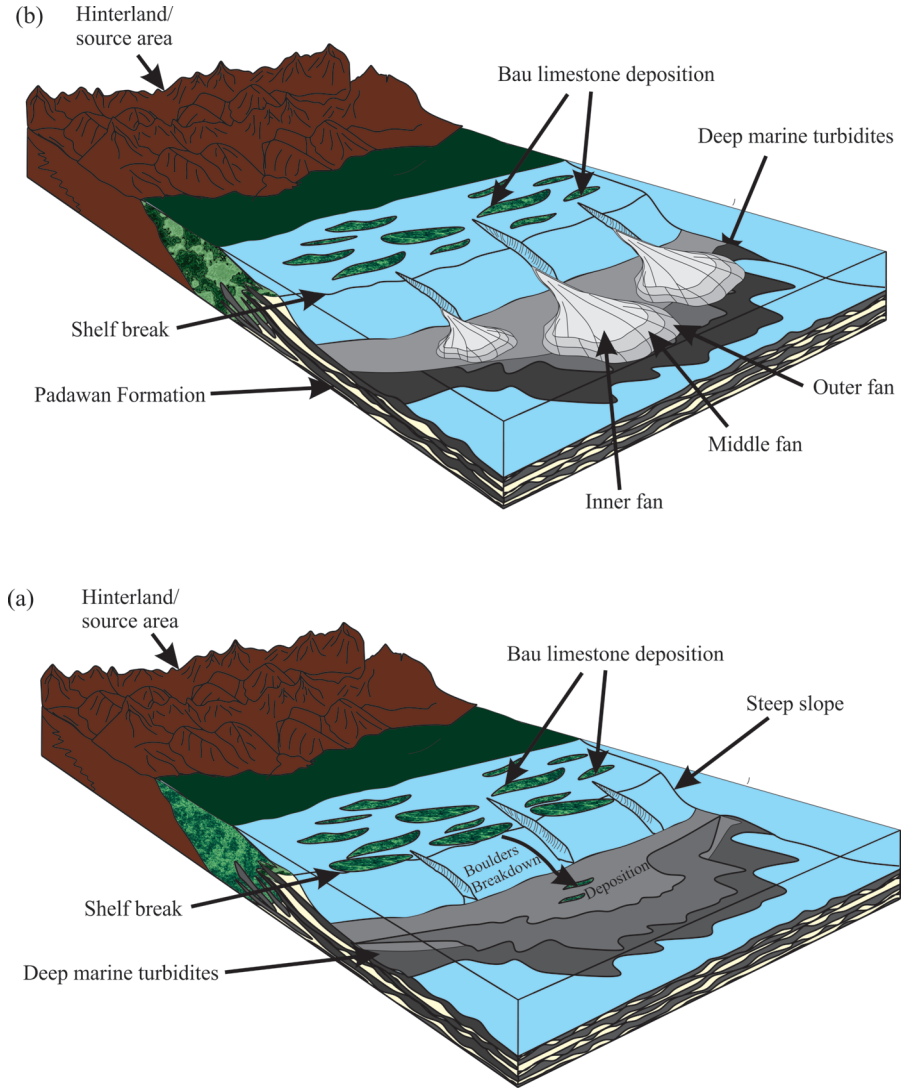

Fig. 6. A diagrammatic depiction of the depositional environment of the Pedawan Fm. (a) disintegration of limestone boulders from the Bau Limestone Formation and re-deposition in the deeper setting; (b) deposition of the deep marine turbiditic heterolithic strata.

proximity of neritic setting in the vicinity. In the suggested scenario, it is most probable that the Pedawan Fm. belemnites died in the shallow reaches of the water column and their body parts were transported and/or settled in the deeper depositional setting.

7 Conclusions

Studies of the Pedawan Fm. have revealed the following information from a newly exposed section in northwest Borneo, Malaysia:

(1) Specimens referred to *Hibolithes* represent the first ever belemnite found in the Pedawan Fm. in Malaysia as well as in the whole eastern Southeast Asia (Borneo, East Malaysia, etc.).

(2) The genus is associated with the Pedawan Fm., which is the product of deep marine turbidity currents and mass flow processes.

(3) The specimens have a presumed Late Jurassic (Tithonian)–Earliest Cretaceous (Hauterivian) age.

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About the first and corresponding author

Muhammad MURTAZA (Ph.D.) is an Assistant Professor at the Department of Earth and Environmental Sciences, Hazara University, Mansehra, Khyber Pakhtoonkhwa Pakistan. He graduated with a PhD degree in Petroleum Geosciences from Universiti Teknologi PETRONAS, Malaysia. He has done extensive field and core-based studies on fluvial, shallow marine and deep marine depositional systems. He has worked on different geological and geophysics-related projects from the Universiti Teknologi PETRONAS in collaboration with Petroliam Nasional Berhad (PETRONAS). Email: mmurtaza.u@gmail.com