Bulletin of the Geological Society of Malaysia, Volume 71, May 2021, pp. 57 - 69
DOI: https://doi.org/10.7186/bgsm71202105

The Devonian-Carboniferous boundary at Guar Sanai, Kampung Guar Jentik, Perlis: An updated map and stratigraphic section

Meor Hakif Amir Hassan

Department of Geology, University of Malaya, 50603 Kuala Lumpur, Malaysia
Author email address: meorhakif@um.edu.my

Abstract: The Sanai Hill B outcrop, exposed at Kampung Guar Jentik, Beseri district, Perlis, exposes one of the best-preserved Devonian-Carboniferous boundary successions in Malaysia. A new geologic map for the locality is presented, which is based on better exposure of the outcrop due to active quarrying, and was constructed using a combination of aerial drone imagery, three-dimensional photogrammetry, Google Earth satellite imagery and traditional field methods. The sedimentary strata include the Silurian Mempelam Limestone, the Lower Devonian Timah Tasoh Formation, the Upper Devonian Sanai Limestone, the Lower Carboniferous Telaga Jatoh Formation and the Lower Carboniferous Chepor Member of the Kubang Pasu Formation. The Devonian-Carboniferous boundary is marked by the contact between the Sanai Limestone and the Telaga Jatoh Formation. It shows an abrupt change from carbonate to siliceous (chert) deposition, with the contact represented by a paraconformity. This unconformity can be correlated to the Devonian-Carboniferous unconformity in the Kanthan Limestone of Perak. It can also be identified in many sections throughout the Western Belt, including in southern Thailand, Langkawi, Kedah, Perak and the Selangor-Kuala Lumpur area. The unconformity can be linked to a eustatic sea level fall at the end of the Devonian. N-S trending imbricate reverse faults and repeated sections have been interpreted as evidence for collisional tectonics associated with the Late Triassic Indosinian Orogeny. E-W trending normal faults mark a Tertiary extensional phase.

Keywords: Malaysia, Devonian-Carboniferous boundary, Perlis

INTRODUCTION

A relatively complete Palaeozoic sedimentary succession is preserved in Perlis and Langkawi, northwest Peninsular Malaysia. Several un-deformed sections cross the boundary between strata of different geologic periods. This includes the Cambrian-Ordovician boundary in the Machinchang Formation on the west coast of Langkawi island (Lee, 1983), the Ordovician-Silurian boundary in the Tanjong Dendang Formation on Pulau Langgun (Jones, 1981; Cocks *et al*., 2005), the Silurian-Devonian boundary in the transition between the Mempelam Limestone and Timah Tasoh Formation, also on Pulau Langgun (Jones, 1981; Cocks *et al*., 2005), and the Devonian-Carboniferous boundary at Sanai Hill B, Kampung Guar Jentik, Perlis (Hassan & Lee, 2002, 2003, 2005; Hassan *et al*., 2014). Such boundary sections are important sites for studying geologic events of global significance that commonly are associated with geologic boundaries, e.g. extinction events, climatic changes and tectonic upheavals (e.g. Kaiser *et al*., 2016). This paper focuses on the Devonian-Carboniferous boundary section at Sanai Hill B, in Perlis, and has the following objectives: (1) to present an updated geological map of the Sanai Hill B site based on data from new excavations and drone-based aerial imagery; (2) to present updated sedimentary logs for the Sanai Hill B section, and (3) to summarize and review our current understanding of the Devonian-Carboniferous stratigraphy in Perlis and Malaysia.

GEOLOGICAL SETTING

The area encompassing Perlis, Kedah and northwest Perak has been termed the NW Domain, which is part of the Gondwana-derived Western Belt, but with a slightly different structural grain (NNW-SSE for the whole Western Belt, but N-S for the NW Domain) (Lee, 2009; Mustaffa, 2009). The geology is dominated by sedimentary rocks, which are part of a N-S trending, broad fold-belt with wide synclines (Figure 1). The sedimentary succession is thick (estimated to be around 7,000 m thick) and ranges in age from the Cambrian to Early Triassic (Figure 1B). The overall stratigraphy is well-established (Jones, 1981), but a progressive increase of data from new exposures and continuing excavation of known outcrops in Perlis and north Kedah over the last 18 years has led to many discussions, disagreements and revisions to the higher resolution stratigraphy (see Cocks *et al*., 2005; Hassan & Lee, 2005; Lee, 2009; Hassan *et al*., 2014; 2015 for a more extensive review of the history of the stratigraphic nomenclature). Here, we follow Lee (2009), our most recent revisions to the Silurian-Permian stratigraphy of Perlis (Hassan *et al*., 2014; 2015), insights from the regional mapping study by the Malaysian-Thai Working Group (2009) as well as revised biostratigraphic ages in Metcalfe (2017) and Metcalfe & Crowley (2020) (Figure 2). The Palaeozoic stratigraphy of Perlis is divided into several main units: (1) the Ordovician-Devonian Setul Group, comprising the Kaki Bukit Limestone (Ordovician),

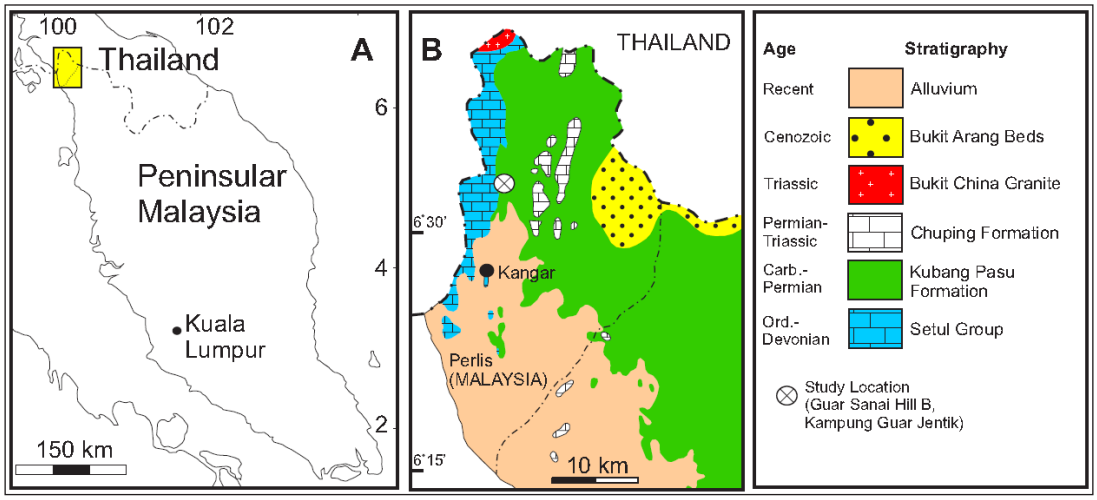

Figure 1: Location maps of the study area. (A) Map of Peninsular Malaysia, with area shown in Figure 1B marked as a yellow box. (B) Geological map of Perlis, showing the location of Sanai Hill B outcrop.

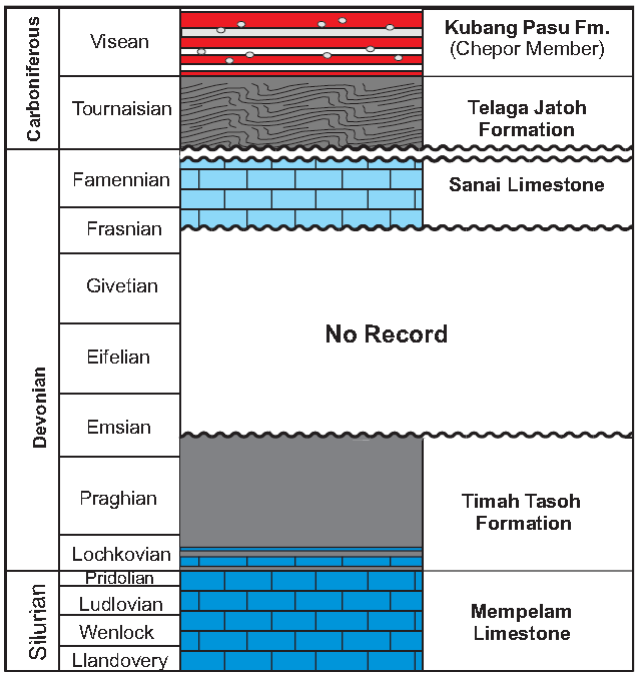

Figure 2: Stratigraphic units exposed at the Sanai Hill B outcrop, Kampung Guar Jentik, Perlis. The stratigraphic scheme used is that of Hassan *et al.* (2015).

Tanjong Dendang Formation (Upper Ordovician to Silurian), Mempelam Limestone (Silurian), Timah Tasoh Formation (Lower Devonian) and Sanai Limestone (Late Devonian); (2) the Lower Carboniferous Telaga Jatoh Formation; (7) the Lower Carboniferous to Lower Permian Kubang Pasu Formation, and; (8) the late Lower Permian to Upper Triassic Chuping Limestone (i.e. Kungurian to early Norian age range in Metcalfe & Crowley, 2020).

The outcrop described in this paper, i.e. Sanai Hill B, at Kampung Guar Jentik, Perlis, exposes only the Silurian-Carboniferous rocks of the Mempelam Limestone, Timah Tasoh Formation, Telaga Jatoh Formation and Chepor Member of the Kubang Pasu Formation (Figure 2). The Mempelam Limestone comprises bedded, nodular, stylolitic, light grey limestone. The age of the unit has been determined from conodonts and trilobites to range from Silurian (*celloni-amorphognathoides* Zone, Late Llandovery at its base) to the Silurian-Devonian (Pridolian-Lochkovian) boundary, which coincides with its boundary with the overlying Timah Tasoh Formation (Igo & Koike, 1966, 1968; Idris, 1989; Kobayashi & Hamada, 1971; Cocks *et al.*, 2005). Scyphocrinoids have been reported from the limestone at Pulau Langgun, Langkawi, as well as at Sanai Hill A, Kampung Guar Jentik, Perlis, which supports the Pridolian-Lochkovian age for the top of the unit (Lee, 2001; 2005).

The Timah Tasoh Formation is made up of fossil-rich black shales which are Early Devonian in age, based on the presence of Lochkovian (*Icriodus woschmidti* Zone) conodonts in the basal beds (Metcalfe, 2017) and late Pragian or earliest Emsian dacryoconarid tentaculitoids and monograptids (*Monograptus yukonensis* Zone) in the upper beds (Hassan *et al.*, 2013). The Sanai Limestone, which is observed only at Sanai Hill B, Kampung Guar Jentik is a grey to black coloured, fine-grained, bedded, nodular and stylolitic limestone containing Late Devonian homoctenid tentaculitoids and conodonts (Frasnian *linguiformis* Zone, and possible Famennian taxa (Hassan & Lee, 2003; Aung *et al.*, 2013; Hassan *et al.*, 2015). The Telaga Jatoh Formation is a thin unit of black ribbon chert and interbedded black to light coloured mudstone overlying the Sanai Limestone at Guar Sanai, but overlies the Timah Tasoh, or its lateral equivalent, the Mahang Formation, in other localities around Perlis and Kedah (Basir, 1995; Basir *et al.*, 2003, 2010; Basir & Zaiton, 2001; Hassan *et al.*, 2014). Radiolaria from the chert indicate an Early Carboniferous (*Albailella deflandrei* and *A. indensis* Zones, late Tournaisian) age (Basir, 1995; Basir &

Zaiton, 2001, 2011a; Basir *et al*., 2003, 2010). The Kubang Pasu Formation overlies the Telaga Jatoh Formation and is characterised by thick mudstone interbedded with quartzitic and feldspathic sandstones and diamictites. The basal-most unit of the Kubang Pasu Formation (i.e. the Chepor Member) is exposed at Kampung Guar Jentik, and contains a rich fossil assemblage of brachiopods, trilobites, ammonoids and corals. Cyrtosymbolid trilobites, ammonoids (?*Goniatites* sp., *Praedaraelites tuntungensis*, *Delepinoceras*) and the bivalve *Posidonia/Posidonomya becheri* indicate an Early Carboniferous (Viséan) age (Kobayashi & Hamada, 1973; Hassan *et al*., 2014; Basir, 2015; Hassan & Becker, 2019). Dropstones and diamictites in the Chepor Member record glacial marine conditions during the Early Carboniferous, which is an older event compared to the dropstone-bearing intervals of the Singa Formation in Langkawi (Hassan *et al*., 2014).

METHODS

This study is an integration of field-based observations, aerial image interpretation and digital photogrammetry, applied on the site known as Sanai Hill B, at Kampung Guar Jentik, Beseri district, Perlis (Figure 1B). Geological mapping of the outcrop was aided by GPS. Studying of the Sanai Hill B site has been very difficult, due to dense vegetation, structural complexities, strong fracturing and weathering. Observations have been collected sporadically as the excavation of the locality by quarrying went on for the past 18 years, with revised maps and logs occasionally made (see Hassan & Lee, 2002, 2005; Hassan *et al*., 2014, 2015 for previous versions of the map).

Geological observations at Sanai Hill B has been continuously conducted for 18 years, and has been a location for University of Malaya undergraduate sedimentology fieldtrips for the past 9 years. The quarry site was extensively exposed in 2018, which provided an opportunity to test past interpretations of the geology. Aerial images were taken using an aerial drone with a high resolution digital camera (DJI Phantom 4 Advance). These were then stitched using Microsoft's Image Composite Editor and calibrated with Google Earth imagery to create the maps shown in Figure 3. The drone images were also used to construct a three-dimensional photogrammetric model in Agisoft Photoscan for post-fieldwork quality control of the mapping.

Four sections have been logged at different locations (Figure 4). The quality of preservation is variable, with some sections being cut by faults. Sections 1 and 2 have been combined into a single log, as they are easily correlatable, being on opposite sides of an excavated path (Hassan *et al*., 2014). Section 3 passes through several faults and was also logged along a dip-parallel fault plane (Aung *et al*., 2013). Section 4 is relatively well-preserved and continuous (Hassan & Lee, 2002).

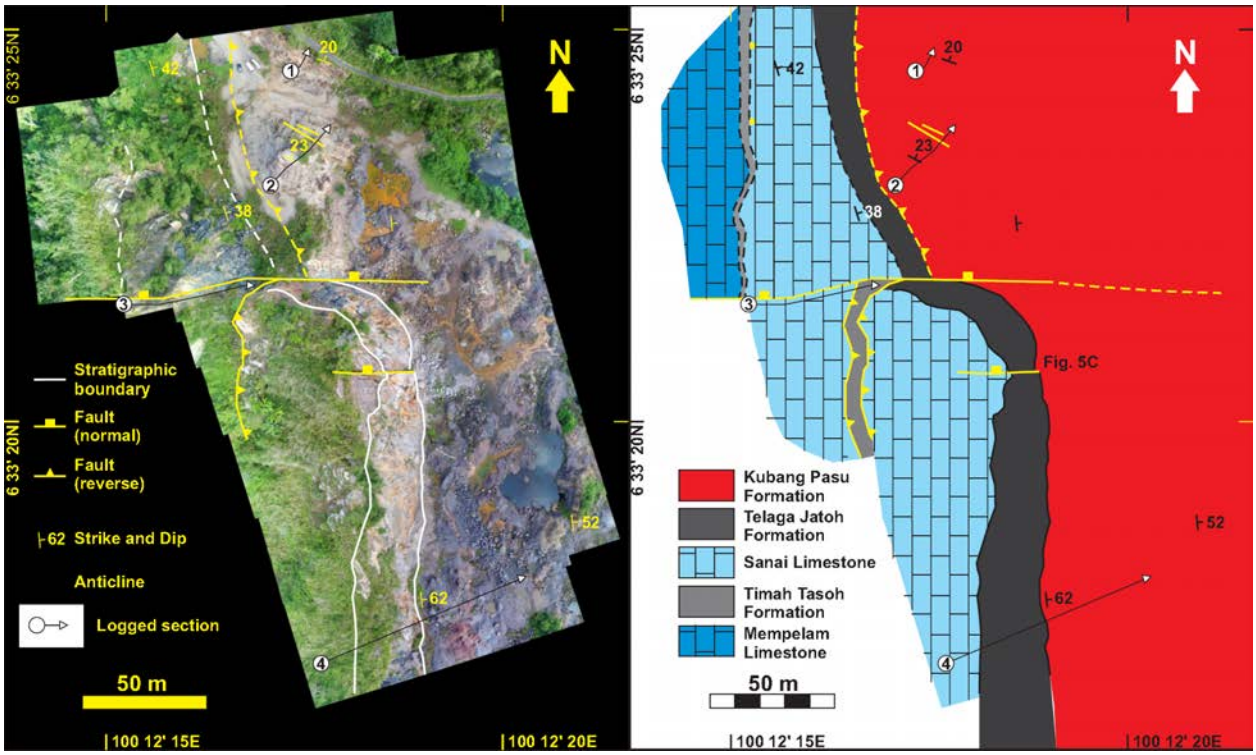

Figure 3: Revised geological map of the Sanai Hill B outcrop, Kampung Guar Jentik, Perlis. The image on the left is a stitched aerial image captured by an aerial drone, with the main stratigraphic contacts and structural features overlain. The image on the right is the geological map. Earlier versions of the map can be seen in Hassan & Lee (2002), Hassan *et al*. (2005, 2013, 2014, 2015).

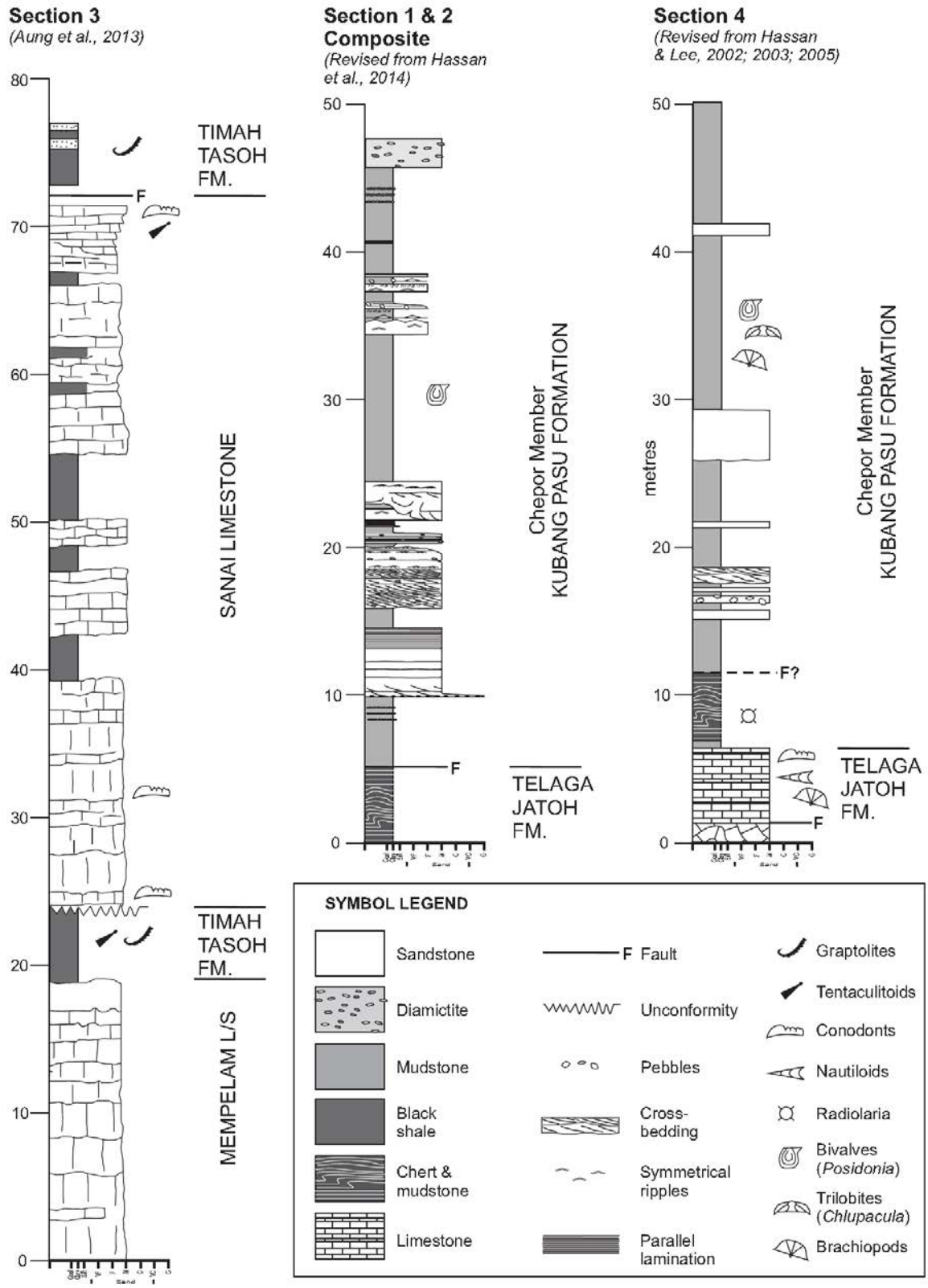

Figure 4: Revised log sections of the Sanai Hill B outcrop. Refer to Figure 3 for the section locations. Earlier versions of the logs can be seen in Hassan & Lee (2002, 2003, 2005) and Hassan *et al*. (2014).

GEOLOGICAL MAP OF SANAI HILL B, KAMPUNG GUAR JENTIK

A geological map of the Sanai Hill B locality at Kampung Guar Jentik, Beseri district, Perlis, is presented in Figure 3. The map covers an area of approximately 200 x 200 metres wide. The sedimentary strata exposed at the locality generally strike N-S, i.e. following the regional structural trend. The strata also dip and young towards the East. The map is separated into two sectors by an E-W trending fault. The fault is near vertical, but in some places it dips 60° toward the North. Slicken-lines along the fault plane are vertical, indicating a normal fault. A smaller E-W trending, vertical normal fault is also observed (Figure 5C). In the northern sector, the sedimentary strata have a gentle dip angle (20°-42°) and with dip directions slightly towards the ENE. In the southern sector, the strata are steeper (52°-62°) and have a N-S trending strike.

Reverse faults are common and are parallel to the bedding orientation, i.e. N-S. In the northern sector, a reverse fault contact is observed between black shales of the Timah Tasoh Formation and the overlying Sanai Limestone, as well as between black cherts and mudstones of the Telaga Jatoh Formation and the overlying Kubang Pasu Formation. The southern sector exposes an imbricate faulted, repeated section. The lower part of the section comprises Silurian Mempelam Limestone overlain by tentaculitoid-rich Timah Tasoh Formation black shales (0-20 m on Section 3, Figure 4). The black shales are then unconformably overlain by the Sanai Limestone (c. 24 m on Section 3, Figure 4). A repeated interval of the Timah Tasoh Formation then overlies the Sanai Limestone (72 m on Section 3, Figure 4). The repeated Timah Tasoh Formation interval at 72 m comprises a slightly folded sliver of the black graptolite and tentaculitoid-bearing shales sandwiched in-between Upper Devonian Sanai Limestone (Figure 5A). The lower and upper boundaries of the sliver are interpreted as faults. The strata are then overlain by the Telaga Jatoh and Kubang Pasu Formation in the eastern half of the map.

THE REVISED SEDIMENTARY SECTIONS OF GUAR SANAI HILL B

Hassan *et al*. (2014) presented a composite sedimentary log to represent the whole Guar Sanau Hill B section. However, there have been several important changes to our understanding of the section. Most importantly is the identification of an E-W trending fault separating the exposure into two sectors. Secondly is the identification of the faulted and repeated nature of the section through the main body of the Sanai Limestone and intercalated Timah Tasoh Formation (Aung *et al*., 2013). Three sedimentary logs of Guar Sanai Hill B are presented in Figure 4 (i.e. a composite Section 1 & 2, Section 3 and Section 4).

Section 3 is the section logged along the exposed E-W fault plane and described in Aung *et al*. (2013). The lowermost 18 m is represented by the Silurian Mempelam Limestone, which is characterized by cm- to dm-thick beds of grey-coloured, fine-grained stylolitic limestone with interbedded thin black shales. Thin black shale intervals become more common upsection.

The Mempelam Limestone is then overlain by the Early Devonian Timah Tasoh Formation, which is represented by an approximately 5 m thick interval of black shale. This is then abruptly overlain by the Late Devonian Sanai Limestone. The contact between the 2 units was interpreted as an unconformity, based on the absence of Middle Devonian strata (Aung *et al*., 2013). The Sanai Limestone exposed in this section is very similar in appearance to the underlying Mempelam Limestone, again being dominated by grey-coloured dm- to cm-thick, bedded, fine-grained stylolitic limestone. However, there are also intervals of black coloured limestone. The limestone is also intercalated with dm- to m-thick intervals of black shale. Homoctenid and conodont fossils collected from this section indicate a Late Devonian (Frasnian) age (Aung *et al*., 2013; Hassan *et al*., 2015). The top of the Sanai Limestone in this section is in fault contact with a repeated interval of the Timah Tasoh Formation. The black shale is rich in dacryoconarid tentaculitoids and monograptids.

The composite Section 1 and 2 record the succession in the sector north of the E-W trending fault and record the strata overlying the Sanai Limestone. The lowermost 5 m comprises the Carboniferous Telaga Jatoh Member, which is characterized by thin-bedded chert and intercalated black mudstone. The unit is then sharply overlain by the Carboniferous Chepor Member of the Kubang Pasu Formation. The contact is observed to be faulted. This part of the Chepor Member was previously logged and presented as the upper part of the composite log in Hassan *et al.* (2014). The new revised log (Figure 4) provides more details on the sedimentary characteristics.

The interval directly overlying the Telaga Jatoh Formation is composed of dark grey to black mudstone, with occasional lighter coloured clay concretions. This basal mudstone is then overlain by an approximately 14 m thick sand-dominated interval. The sand-dominated interval comprises several m-thick, medium to fine-grained sandstone packages which display features such as scoured bases, load casts, basal mud clast conglomerate, cross-bedding, asymmetrical and symmetrical ripples, planar lamination and an upward fining vertical pattern. Several dm- to m-thick sandstone beds also display normal grading with an associated vertical change from structureless into planar laminated and ripple cross-laminated sandstone. Dropstones comprising angular to rounded sandstone/quartzite or quartz pebbles occur within the sandstone beds. Thin (dm- to m-thick) mudstones are intercalated between the sandstones. This sand-dominated interval is then overlain by a thicker mud-dominated interval, which is characterized by up to 10 m thick mudstone with interbedded dm- to m-thick sandstone. The sandstone beds also display features such

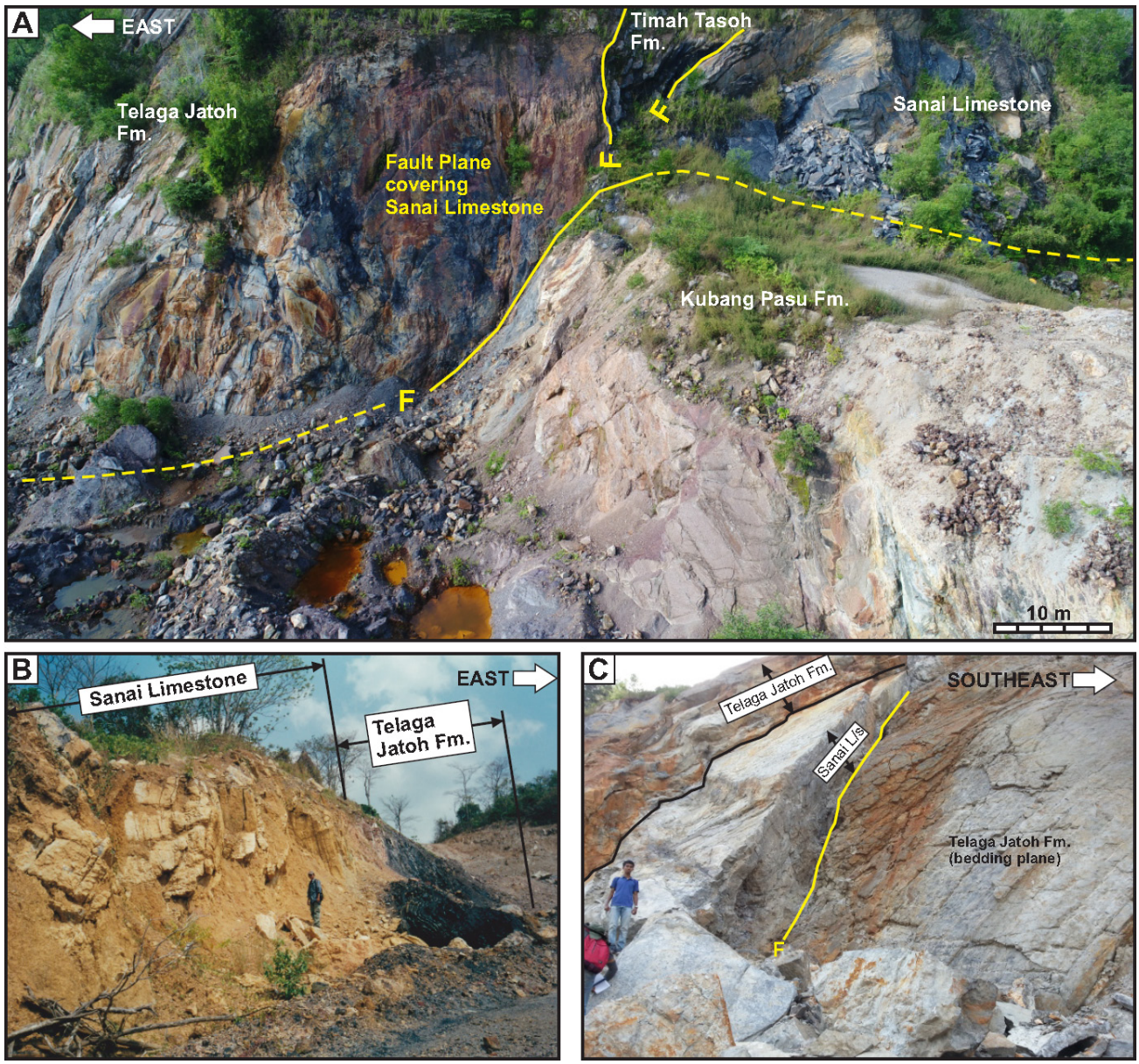

Figure 5: Outcrop photographs of Sanai Hill B, Kampung Guar Jentik, Perlis. (A) Aerial drone photo oriented parallel to the E-W trending fault separating the northern sector (foreground) and southern sector (background). Note the vertical slicken-lines on the fault plane, and the faults bounding the Timah Tasoh Formation between younger Sanai Limestone. (B) Part of the Section 4 exposure, showing the change from Devonian Sanai Limestone to Carboniferous Telaga Jatoh Formation. The boundary between the 2 units is a paraconformity which marks the Devonian-Carboniferous boundary. Younging direction is towards the right. (C) Exposed boundary between the Devonian Sanai Limestone and Carboniferous Telaga Jatoh Formation. Note the presence of kink folds in the topmost beds of the Sanai Limestone, which grade into folds of the overlying Telaga Jatoh Formation. Location of exposure shown in Figure 3.

as symmetrical ripples, planar lamination, normal grading and the presence of dropstones. The logged section is capped by a grey coloured diamictite rich in sandstone and limestone pebbles. Hassan *et al*. (2014) conducted an initial facies analysis of the Chepor Member exposed in the composite Section 1 and 2, and interpreted the succession to represent deposition in a glacial-marine shelf setting, with the sandstones representing shelfal sand ridges/bars and associated turbidites. The sand-dominated packages near the base of the Chepor Member here resembles channel barforms, and probably represent either submarine channel or distributary mouth bar deposits.

Section 4 (Figure 4) was originally logged in Hassan & Lee (2002) and revised in Hassan & Lee (2003, 2005). Some additional details are added based on recent observations. The lowermost part of the section exposes the Sanai Limestone. A fault cuts through the unit, which separates folded limestone beds from the overlying topmost

bed sof the Sanai Limestone, which are not deformed. This part of the Sanai Limesone has been previously described in Hassan & Lee (2003). The unit is composed of tabular bedded, dm-thick, fined-grained, styolitic limestone, with thin shale partings and synaeresis cracks. The succession overlying the Sanai Limestone resembles composite Section 1 and 2 (Figure 4). Chert and interbedded black mudstone of the Telaga Jatoh Formation sharply overlies the Sanai Limestone. The contact between the Telaga Jatoh Formation and overlying Chepor Member, Kubang Pasu Formation, is again faulted. The basal mudstone and overlying sand-dominated interval is also exposed in this section, but the features are not as well preserved as in composite Section 1 and 2. However, cross-bedding, dropstones and diamictites are clearly observed. The overlying mud-dominated interval of the Chepor Member in Section 4 contains a rich fossil assemblage, including Carboniferous taxa such as *Posidonia* and the trilobite *Chlupacula* (Hassan *et al*., 2014).

THE DEVONIAN-CARBONIFEROUS BOUNDARY AT SANAI HILL B, KAMPUNG GUAR JENTIK

A relatively continuous sedimentary succession passing through the Devonian-Carboniferous boundary is preserved at Sanai Hill B (Section 4, Figure 4, 5B. Also see Hassan & Lee, 2002 for the original log). The base of this section exposes well-bedded, stylolitic Sanai Limestone. Thin sections indicate that the rock comprises fine-grained wackestone containing trilobite, tentaculitoid, ostracod and nautiloid fossils (Hassan & Lee, 2003). Some of the black-coloured intervals are rich in homoctenids and amorphous carbonaceous matter, and can be classified as grainstones (Hassan *et al*., 2015). Aung *et al*. (2013) reported Late Devonian (Frasnian, *linguiformis* Zone) conodonts in the Sanai Limestone from Section 3. At Section 4, the limestone is sharply overlain by bedded chert and interbedded black mudstone of the Telaga Jatoh Formation (Figure 4, 5B). The chert beds contain radiolaria of Early Carboniferous age (Tournasian) (Basir & Zaiton, 2011). Therefore, the boundary between the Sanai Limestone and Telaga Jatoh Formation marks the Devonian-Carboniferous boundary. The Frasnian age of the conodont assemblage described by Aung *et al*. (2013) supports the interpretation of an age gap (paraconformity) between the two units, with the latest Devonian (Famennian) missing. However, it should be noted that Aung *et al*. (2013) did not sample Section 4, which exposes the topmost beds directly below the chert. Hassan & Lee (2003) collected conodonts from the topmost beds directly underlying the Telaga Jatoh Formation which appear to be *Palmatolepis glabra*, suggestive of a Famennian age (Hassan & Lee, 2003).

THE BOUNDARY BETWEEN THE TELAGA JATOH AND KUBANG PASU FORMATIONS

In the northern sector of the Sanai Hill B locality, the boundary between the Telaga Jatoh Formation and the overlying Chepor Member, Kubang Pasu Formation is faulted. A similar faulted contact is observed in other exposures in Perlis (e.g. at Sanai Hill C and Hutan Aji). The contact at Section 4 is poorly preserved (intensely weathered and buried under rubble), but has been previously interpreted to be continuous (Hassan *et al*., 2014) (Figure 4). Apart for the basal-most layers, the cherts of the Telaga Jatoh Formation are deformed into what have been described as intraformational folds, because the strong folding is not observed in the underlying Sanai Limestone and overlying Kubang Pasu Formation (Figure 5B). However, a recently exposed part of the section shows that the topmost beds of the Sanai Limestone are also slightly deformed, with kink folds that grade upward into the tighter folds of the Telaga Jatoh Formation (Figure 5C). This provides support for a tectonic origin for the folding. The Telaga Formation is also observed to be folded at Sanai Hill C, but is preserved as discontinuous lenses pinched along a fault, between Devonian Timah Tasoh Formation and Carboniferous Chepor Member of the Kubang Pasu Formation (Hassan, 2013). The faulting and deformation occurred along the bedding plane, which explains the restriction of the folding mainly in the Telaga Jatoh Formation, which was probably more ductile. Despite the faulted contact between the Telaga Jatoh and Kubang Pasu Formations, it is likely that the stratigraphy is still preserved and conformable, given that displacement was along the bedding plane, and the similar stratigraphic arrangement at other localities such as at Hutan Aji further South (Hassan *et al*., 2014).

SUMMARY OF THE DEPOSITIONAL HISTORY ACROSS THE DEVONIAN -CARBONIFEROUS BOUNDARY AT SANAI HILL B

A summary of the depositional history across the Devonian-Carboniferous boundary is provided here, based on Section 4 of Sanai Hill B. The predominantly fine-grained, bedded and nodular facies containing a rich nektonic and planktonic fauna (e.g. tentaculitoids, nautiloids and conodonts) is characteristic of pelagic carbonates deposited in a low energy, relatively deep marine setting below fairweather wave base (Scholle *et al*., 1983). The high percentage of *Palmatolepis* and *Polygnathus* elements in the conodont samples (up to 93% in one of the sampled beds in Aung *et al*., 2013) is characteristic of the polygnathid-palmatolepis biofacies, which has been interpreted to indicate a deeper marine (possibly slope or basinal) setting (e.g. Sandberg & Dreesen, 1984).

The direct overlying of the Late Devonian Sanai Limestone by Tournaisian, radiolarian-bearing ribbon chert of the Telaga Jatoh Formation marks a dramatic change from carbonate- to siliceous deposition across the Devonian-Carboniferous boundary. This change can be interpreted as indicating a relative sea level rise. Radiolarian cherts are typical of deeper marine deposits (Basir, 2018). Abrupt deepening of the basin may have resulted in the seafloor being

below the carbonate compensation depth, thus favouring the preservation and accumulation of siliceous deposits in the form of radiolarian tests. Tournaisian, radiolarian-bearing cherts are common along the Western Belt and the Bentong-Raub Suture of Peninsular Malaysia (Basir, 2018). They have been linked to radiolarian plankton blooms, associated with increased silica and nutrient supply in the seawater (Racki & Cordey, 2000). Basir (2018) interpreted that this increase in silica supply was probably triggered by submarine volcanism and hydrothermal activity due to the opening of the Paleo-Tethys.

Interestingly, the most recent published eustatic curve for the Palaeozoic indicates an abrupt fall in eustatic sea level at the Devonian-Carboniferous boundary (Haq & Schutter, 2008), with an unconformity present in many sections throughout the world just below the boundary (Davydov *et al*., 2012). It is possible that a paraconformity exists between the Sanai Limestone and Telaga Jatoh Formation, marking such a fall.

CORRELATION WITH OTHER DEVONIAN-CARBONIFEROUS BOUNDARY SUCCESSIONS IN PENINSULAR MALAYSIA AND THAILAND

The stratigraphic correlation of several locations throughout Peninsular Malaysia and southern Thailand which expose a relatively undeformed Devonian-Carboniferous (D-C) boundary is presented in Figure 6. A more regional comparison can be found in Metcalfe (2017). Note that all the sections shown in the correlation are from the Western Belt of the Malay Peninsula. There are no known Devonian strata exposed in the Central and Eastern belts of Peninsular Malaysia, with the oldest sedimentary rocks known being Carboniferous in age (Metcalfe, 2017 and references therein). The Western Belt is part of the Sibumasu Terrane, which was originally attached to NW Australian Gondwana until the late early Permian (Metcalfe, 2013). The Central and Eastern belts of Peninsular Malaysia are part of the Sukhotai Arc, which is underlain by an Indochina continental basement (Metcalfe, 2013).

Most of the successions in the NW Domain share a generally similar D-C boundary stratigraphy, with Early Devonian black shales being unconformably overlain by Carboniferous (Mississippian) strata (Figure 6). In Satun, southern Thailand, carbonates of the Kuan Tung Formation contain Emsian conodonts (Long & Burrett, 1989; Wongwanich *et al*., 1990) and trilobites (Fortey, 1989). The limestone is overlain by the Pa Samed Formation. The basal black shales of the Pa Samed Formation (Member 1 of Wongwanich *et al*., 1990) is similar in character and fossil composition with the upper part of the Timah Tasoh Formation in Perlis (Wongwanich *et al*., 1990). Fossils include the dacryoconarid tentaculitoid *Nowakia acuaria* and the graptolite *Monograptus*, which also give an earliest Emsian age (Boucot *et al*., 1999; Agematsu *et al*., 2006). Clastic strata directly and unconformably overlying the Early Devonian black shales are still part of the Pa Samed Formation, but display characteristics resembling the Chepor Member in Perlis, including normal graded Bouma sequences and pebbly sandstones (Wongwanich *et al*., 2004). Goniatites from the upper Pa Samed Formation are slightly younger (Namurian, Wongwanich *et al*., 2004) compared to the Chepor Member, which are Viséan (Hassan *et al*., 2014; Hassan & Becker, 2019).

A very similar stratigraphy is observed on Pulau Langgun, Langkawi (Jones, 1981). Black shales of the Timah Tasoh Formation contain fossils including *Monograptus langgunensis, M.* cf. *yukonensis* and *Nowakia (T.) acuaria acuaria*, which also give an Early Devonian (earliest Emsian) age (Jones, 1973; Hassan *et al*., 2013). Here, the Timah Tasoh Formation is unconformably overlain by the Langgun Red Beds of the Singa Formation, which is identical in terms of sedimentary characteristics and fossil composition to the Mississippian (Viséan) Chepor Member of the Kubang Pasu Formation (Hassan *et al*., 2014).

A slightly different stratigraphy is exposed in southern Perlis and northern Kedah, which can be clearly observed in Pauh and Hutan Aji, Perlis, and the Pokok Sena area in Kedah. Here, the Early Devonian black shales, which are referred to either as the Timah Tasoh Formation or the Mahang Formation, are unconformably overlain by Carboniferous bedded chert of the Telaga Jatoh Formation, which contains Tournaisian radiolarians (Basir, 1995; Basir & Zaiton, 2001, 2011; Basir *et al*., 2003, 2010). The Telaga Jatoh Formation is then overlain by glacial marine deposits of the Chepor Member, Kubang Pasu Formation, which contains Mississippian (Viséan) goniatites (Hassan *et al*., 2014). The Sanai Hill C section described in this paper is different from the other sections of the NW Domain in preserving a Late Devonian (Frasnian) stratigraphic record in the form of the Sanai Limestone. Two unconformities are recorded here, i.e. an older disconformity between Early Devonian Timah Tasoh Formation and Late Devonian Sanai Limestone, and a younger paraconformity between the Sanai Limestone and Tournaisian chert of the Telaga Jatoh Formation. Despite the close distance between sections in Perlis, it is interesting to note that the Sanai Limestone is only observed at a single locality. This is most likey the result of the complicated structural geology, with complex faulting and folding and repeated beds combined with the relative thinness of the unit. There is evidence for fault displacement along bedding planes, in particular the contact between soft Early Devonian black shale and overlying, harder sandstone and mudstone of the Kubang Pasu Formation. The Sanai Limestone exposure is most likely a small sliver of a carbonate body buried in the subsurface.

The D-C boundary succession in the Western Belt of Perak is dominated by carbonates. The Kanthan Limestone is exposed in the Chemor area of the Kinta Valley, Perak and comprises metamorphosed, siliceous and dolomitic limestone with interbedded black limestone, shales, phyllites and

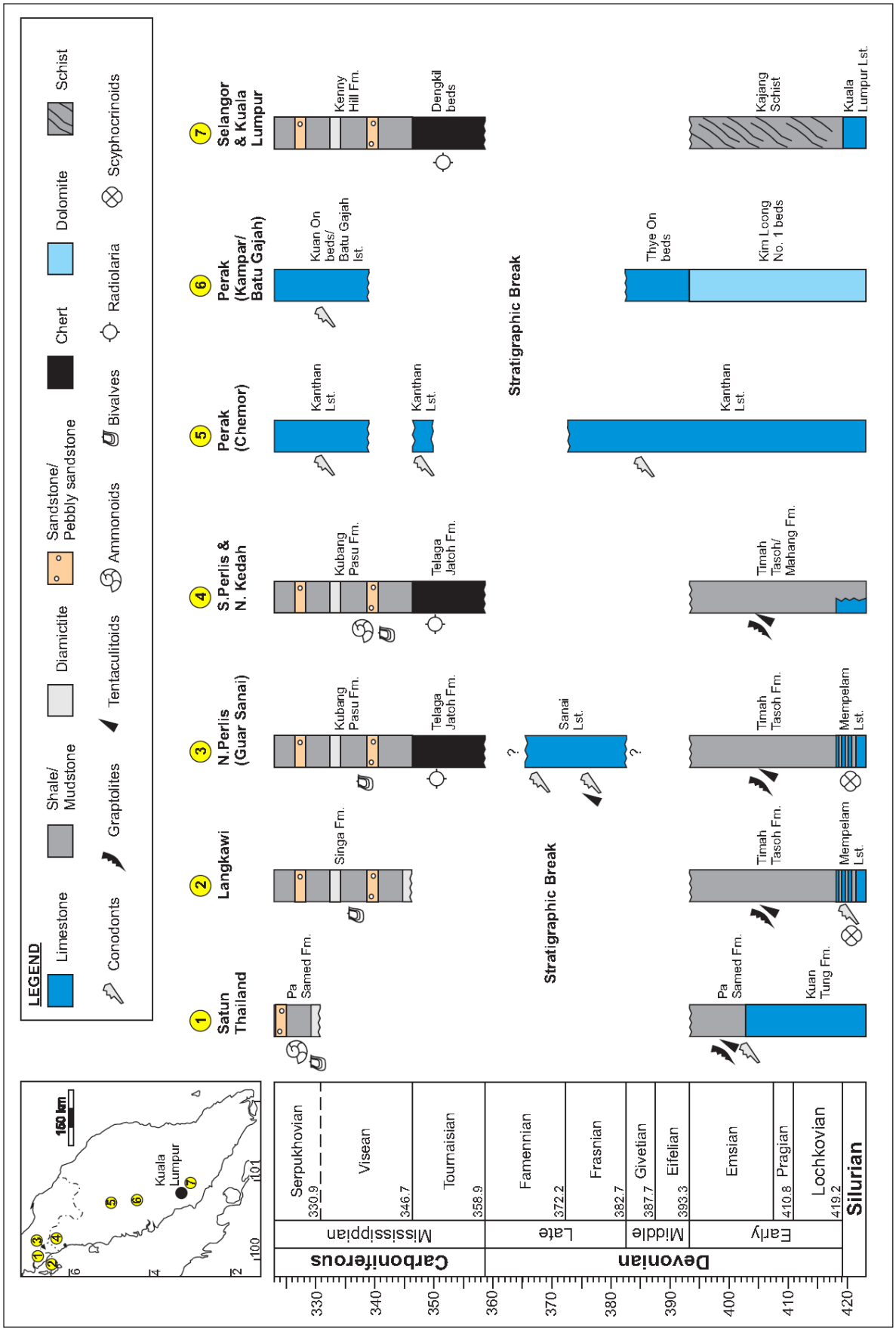

Figure 6: Correlation panel of well-preserved Devonian-Carboniferous boundary succession throughout the Western Belt of the Malay Peninsula. Modified from Hassan *et al.* (2014) and Metcalfe (2017).

schists (Metcalfe, 2002). Breccia, wackestones, packstones and grainstrones of the unit have been interpreted by Pierson *et al*. (2011) as redeposited base-of-slope breccia and turbidites, indicating a deeper marine setting. The biostratigraphy of the Kanthan Limestone is well-constrained by conodonts, with Early Devonian (middle Emsian) (Lane *et al*., 1979), Carboniferous (probable Viséan and Bashkirian/ Moscovian) (Metcalfe, 1979) having been reported and described. Metcalfe (2002) also reported a conodont fauna comprising a mixture of Tournaisian conodonts and reworked Late Devonian taxa, which was used as evidence of a D-C boundary unconformity. There is also a second unconformity separating upper Tournaisian from upper Viséan limestones, with the Viséan beds also containing abundant reworked Devonian conodonts (Metcalfe, 2002). These mixed faunas were interpreted as representing shelf erosion, transportation and redeposition into deeper waters by gravity flows (Metcalfe, 2002).

A relatively continuous, carbonate-dominated D-C boundary succession has also been described by Suntharalingam (1968) from an area exposed by open-cast tin mining, west of Kampar in Perak. Devonian strata are represented by the Kim Loong No. 1 and Thye On beds. The Kim Loong No. 1 beds are predominantly dolomites and dolomitic limestones (Suntharalingam, 1968). The unit is not particularly rich in fossils, but the presence of the tabulate *Thamnopora* sp. and the rugose coral *Amplexus*? suggest a Devonian age (Suntharalingam, 1968). The Thye On beds overlie the the Kim Loong No. 1 beds and comprises limestone containing a rich fossil assemblage, including the brachiopod *Stringocephalus*, which gives a Middle Devonian (Givetian) age (Suntharalingam, 1968). The Thye On beds are then overlain by the Kuan On beds, which is composed of dolomitic limestone, calcitic dolomite and carbonaceous shaley limestone. Oolites associated with the limestone indicate a shallow marine shelf setting (Suntharalingam, 1968). The presence of the coral *Siphonopyllia* sp. indicates a Viséan age (Suntharalingam, 1968). The direct contact between Middle Devonian (Givetian) strata of the Thye On beds and overlying Carboniferous (Viséan) Kuan On beds again indicates a D-C boundary unconformity.

The D-C boundary may also be represented by the contact between the Kajang Schist and Kenny Hill Formation in the Kuala Lumpur and Kajang area of Selangor (Metcalfe, 2017). The Kajang Schist, which is composed of dark-grey to black graphitic quartz-muscovite schist with minor marble and phyllite, does not contain any fossils but has been interpreted as being Late Silurian to Devonian in age, based on its position overlying the Silurian Kuala Lumpur Limestone and underlying the Kenny Hill Formation (Yin, 1976; Lee, 2009). The discovery of Tournaisian radiolarians in chert lenses within mudstone of the Kenny Hill Formation in Dengkil, Selangor, indicates that the unit extends downward into the Carboniferous (Zaiton & Basir, 2003). Prior to this, the only known fossil from the formation was the ammonoid *Agathiceras* sp., reported from Salak (Abdullah Sani, 1985). The Kenny Hill Formation in many ways resembles the Chepor Member of the Kubang Pasu Formation, including its sedimentary features. Personal observation of an exposure of the Kenny Hill Formation near Rawang has uncovered mudstone is interbedded with structureless, ripple cross-laminated, cross-bedded and planar laminated sandstone. Ripple cross-lamination and turbidites were also reported by Dodd *et al*. (2019) from other exposures around Kuala Lumpur, Putrajaya and Selangor. Dropstones have also been reported from the formation by Baioumy *et al*. (2020).

The correlation presented in Figure 6 clearly shows that a regional unconformity marks the Devonian-Carboniferous throughout the Western Belt of the Malay Peninsula. This unconformity is best defined at the Guar Sanai Hill B section described in this paper from Perlis, as well as the Gunong Kanthan section in Chemor, Perak (Metcalfe, 2002). These sections show that platform carbonate deposition continued along the Sibumasu continental margin from the Silurian until the Late Devonian. Carbon-rich shales were deposited in dysoxic/anoxic basins in between the carbonate platforms. The D-C boundary in these two sections is not marked by a distinct erosional surface, but by a subtle paraconformity. The D-C boundary at Sanai Hill B has not been biostratigraphically sampled in detail, but likely represents a period of non-deposition. The presence of reworked D-C conodont assemblages associated with the paraconformity in the Kanthan Limestone has been interpreted to represent shelf erosion and eventual redeposition in deeper marine waters (Metcalfe, 2002). An unconformity is recorded at the D-C boundary in many sections throughout the world, including North and South America, Europe, northern Africa, West Asia, China and Russia (see Kaiser *et al*., 2015 for a review and detailed list). The widespread distribution of a D-C boundary unconformity has been linked to end-Devonian glacioeustatic sea level fall (Kaiser *et al*., 2015). Tournaisian chert and associated black mudstone overlying the D-C boundary unconformity in many sections of the Western Belt marks a rise in relative sea level along the Sibumasu continental margin, with the depositional setting changing from pelagic carbonate platform to deeper marine anoxic/dysoxic conditions. This change can be linked to a Tournaisian eustatic sea level rise and associated transgression (Kaiser *et al*., 2015). The sharp change from Tournaisian chert to Viséan glacial marine mudstone, diamictite and associated dropstones of the Chepor Member, Kubang Pasu Formation and Kenny Hill Formation suggests the presence of another unconformity, which may be linked to the Tournaisian unconformity identified in the Kanthan Limestone by Metcalfe (2002) but this needs further study. The glacial debris may have been transported and deposited by melting icebergs originating from higher latitudes of Gondwana (Hassan *et al*., 2014).

GENERAL STRUCTURAL PATTERNS AND TECTONIC IMPLICATIONS

This work does not include a detailed structural study of the Sanai Hill B locality, but only makes some general observations and interpretations based on the larger-scale features observed. The main structural features are the N-S trending reverse faults. The faults are bed-parallel and tend to develop along the bedding plane associated with contact between brittle (carbonate or hard mudstone) and more ductile (fissile black shale and chert) formations, which display smaller-scale drag folds. Stratigraphic units are also repeated in the section. Bed-parallel reverse faults and repeated sections are also observed in other outcrops in Perlis, e.g. Sanai Hill C and Hutan Aji (Hassan & Lee, 2002; Hassan, 2013; Hassan *et al*., 2014). Additionally, overturned beds and discontinuous lenses of Telaga Jatoh Formation chert are observed at Sanai Hill C (Hassan, 2013). The Kisap Thrust may also be genetically related to these faults (Jones, 1981). All these features have been interpreted by some as evidence of a fold-thrust belt associated with Late Triassic continental collision between Sibumasu and Indochina, i.e. the Indosinian Orogeny (Barber & Crow, 2009; Ridd, 2013). Kubang Pasu Formation strata overturned into a recumbent fold overlying Timah Tasoh Formation at Sanai Hill C are also consistent with thrusting (Hassan, 2013).

The E-W trending normal faults cross-cut through the Silurian-Carboniferous strata and the N-S trending reverse faults. These faults mark a post-Late Triassic extensional phase. They are similar to the E-W trending faults observed throughout Peninsular Malaysia, including those that bound the Layang-Layang Basin in South Johor, thus indicating a Tertiary age for the faults (Mustaffa, 2009).

CONCLUSIONS

A revised geological map of the Sanai Hill B locality at Kampung Guar Jentik, Beseri district is presented. The sedimentary logs of key sections at the locality have also been revised and updated based on new data. The locality is separated into two sectors by an E-W trending normal fault, which is similar to other Tertiary age, E-W trending faults present throughout Peninsular Malaysia. N-S trending reverse faults commonly cut the strata and result in repeated sections of the Timah Tasoh Formation and Sanai Limestone. The imbricate reverse faulting with repeated sections probably records Late Triassic continental collision of the Indosinian Orogeny.

The Frasnian aged Sanai Limestone strata described in Aung *et al*. (2013) is located in a separated fault block eastward of the Sanai Limestone section logged by Hassan & Lee (2003), which makes a Famennian age for the topmost beds of the Sanai Limesone possible. This section (referred in this paper as Section 4) preserves a relatively un-deformed succession which passes through the Devonian-Carboniferous boundary. The Devonian-Carboniferous boundary is marked by an abrupt change from Devonian Sanai Limestone to Carboniferous chert of the Telaga Jatoh Member. The boundary most likely represents a paraconformity and can be correlated to a similar unconformity in the Kanthan Limestone of Perak. This D-C boundary unconformity can be traced throughout the Western Belt of Peninsular Malaysia, and is probably linked to the end-Devonian glacioeustatic sea level fall.

ACKNOWLEDGEMENTS

This work started as an undergraduate Final Year Project and developed into a MSc. at the Department of Geology University of Malaya, both under the supervision of Dr. Lee Chai Peng. Numerous colleagues contributed to the project, through comments, discussions, correspondences, collaboration and support throughout the years, including Prof. Aye-Ko Aung, Prof. Ralph Becker, Prof. Bernd Edrtmann, Prof. Shigeki Hada, Prof. Wang Xiaofeng and many others. Prof. Ian Metcalfe and two anonymous reviewers provided helpful constructive criticism. This study has been supported by a Government of Malaysia Fundamental Research Grant (FP043-2014A).

REFERENCES

Agematsu, S., Sashida, K., Salyapongse, S. & Sardsud, A., 2006. Lower Devonian tentaculite bed in the Satun area, southern peninsular Thailand. Journal of Asian Earth Sciences, 26, 605–611.

Abdullah Sani, H. H., 1985. Discovery of an ammonoid (*Agathiceras* sp.) and crinoid stems in the Kenny Hill Formation of Peninsular Malaysia, and its significance. Warta Geologi, 11, 205–212.

Aung, A-K., Hassan, M.H.A. & Ng, T.F., 2013. Discovery of Late Devonian (Frasnian) conodonts from the "Sanai limestone", Guar Jentik, Perlis, Malaysia. Bulletin of the Geological Society of Malaysia, 59, 93–99.

Baioumy, H., Anuar, M.N.B.A., Mohd Nordin, M.N., Arifin, M.H. & Al-Kahtany, K., 2020. Source and origin of Late Paleozoic dropstones from Peninsular Malaysia: First record of Mississippian glaciogenic deposits of Gondwana in Southeast Asia. Geological Journal, 55(9), 6361-6375. DOI: 10.1002/gj.3809.

Barber, A.J. & Crow, M.C., 2009. Structure of Sumatra and its implications for the tectonic assembly of Southeast Asia and the destruction of Paleotethys. Island Arc, 18, 3–20.

Basir, J., 1995. Occurrence of bedded radiolarian chert in the Kubang Pasu Formation, North Kedah, Peninsular Malaysia. Warta Geologi, 21(2), 73–79.

Basir, J., 2015. *Posidonomya* (Bivalvia) from Northwest Peninsular Malaysia and its significance. Sains Malaysiana, 44(2), 217–223.

Basir, J., 2018. Radiolarian biostratigraphy of Malaysia. Bulletin of the Geological Society of Malaysia, 65, 45–58.

Basir, J. & Zaiton Harun, 2001. Some radiolarians from the Kubang Pasu Formation. In: Teh, G.H., Pereira, J.J. & Ng, T.F. (Eds.), Proceedings Annual Geological Conference 2001, 110-114.

Basir, J. & Zaiton, H., 2011. Lower Carboniferous (Tournaisian) radiolarians from Peninsular Malaysia and their significance. Bulletin of the Geological Society of Malaysia, 57, 47–54.

Basir, J., Zaiton, H. & Siti, N.H., 2003. Black siliceous deposits in Peninsular Malaysia: their occurrence and significance. Bulletin of the Geological Society of Malaysia, 46, 149–154.

Basir, J., Atilla, B., Nazariah, J. & Norhifzan, I., 2010. Occurrence of slate in Perlis and its significance. Bulletin of the Geological Society of Malaysia, 56, 75–78.

Boucot, A.J., Cocks, R.M. & Racheboeuf, P.R., 1999. Early Devonian brachiopods from Satun Province, southern Thailand. Journal of Paleontology, 73, 850–859.

Cocks, L.R.M., Fortey, R.A. & Lee, C.P., 2005. A review of Lower and Middle Palaeozoic biostratigraphy in west peninsular Malaysia and southern Thailand in its context within the Sibumasu Terrane. Journal of Asian Earth Sciences, 24, 703–717.

Davydov, V.I., Korn, D., Schmitz, M.D., Gradstein, F.M. & Hammer, O., 2012. The Carboniferous Period. In: Gradstein, F.M., Ogg, J.G., Schmitz, M.D. & Ogg, G.M. (Eds.), The Geologic Time Scale, Elsevier, 603–651.

Dodd, T.J.H., Ng, T.F., Rosle, Q.A.B., Mohd Noh, R., Leslie A.G., Dobbs, M.R. & Gillespie, R., 2019. New insights into the sedimentology of the Kenny Hill Formation, Peninsular Malaysia. Warta Geologi, 45, 196–197.

Fortey, R.A., 1989. An Early Devonian trilobite fauna from Thailand. Alcheringa, 13, 257–267.

Haq, B.U. & Schutter, S.R., 2008. A chronology of Paleozoic sea-level changes. Science, 322, 64–68.

Hassan, M.H.A., 2013. Post-Conference Field Excursion to Northwest Peninsular Malaysia: Third International Conference on Palaeontology of Southeast Asia: ICPSEA 3, 10th–13th October 2013, 28 p.

Hassan, M.H.A. & Becker, R.T., 2019. Carboniferous ammonoids from the Kubang Pasu Formation. Warta Geologi, 45(3), 201.

Hassan, M.H. & Lee, C.P., 2002. Stratigraphy of the Jentik Formation, the transitional sequence from the Setul Limestone to the Kubang Pasu Formation at Guar Sanai. Guar Jentik, Beseri, Perlis – a preliminary study. Bulletin of the Geological Society of Malaysia, 45, 171–178.

Hassan, M.H. & Lee, C. P., 2003. The Sanai Limestone Member – a Devonian limestone unit in Perlis. Bulletin of the Geological Society of Malaysia, 46, 137–141.

Hassan, M.H. & Lee, C. P., 2005. The Devonian-Lower Carboniferous succession in Northwest Peninsular Malaysia. Journal of Asian Earth Sciences, 24, 719–738.

Hassan, M.H.A., Erdtmann, B.D., Wang, X. F. & Lee, C.P., 2013. Early Devonian graptolites and tentaculitids in northwest Peninsular Malaysia and a revision of the Devonian - Carboniferous stratigraphy of the region. Alcheringa: An Australasian Journal of Palaeontology, 37(1), 49–63.

Hassan, M.H.A., Aung, A-K., Becker, R.T., Rahman, N.A.A., Fatt, N.T. & Ghani, A.A., Shuib, M.K., 2014. Stratigraphy and palaeoenvironmental evolution of the mid- to upper Palaeozoic succession in Northwest Peninsular Malaysia. Journal of Asian Earth Sciences, 83, 60–79.

Hassan, M.H.A., Mustafa, Y.A., Zakaria, M.Z.Z. & Ghani, A.A., 2015. First record of *Homoctenus* (Tentaculitoidea, Homoctenida) from the Late Devonian of northwest Peninsular Malaysia. Alcheringa: An Australasian Journal of Palaeontology, 39(4), 550–558.

Idris, M.B., 1989. Early Silurian multi-element conodont assemblages from Pulau Tanjung Dendang, northeastern Langkawi Islands, Kedah. Warta Geologi, 15, 63–68.

Igo, H. & Koike, T., 1966. Ordovician and Silurian conodonts from the Langkawi Islands, Malaya, Part I. Geology and Palaeontology of Southeast Asia, 3, 1–29.

Igo, H. & Koike, T., 1968. Ordovician and Silurian conodonts from the Langkawi Islands, Malaya, Part II. Geology and Palaeontology of Southeast Asia, 4, 1–21.

Jones, C.R., 1973. The Siluro-Devonian graptolite faunas of the Malay Peninsula. Overseas Geology and Mineral Resources, 44, 25 p.

Jones, C.R., 1981. The Geology and Mineral Resources of Perlis, North Kedah and the Langkawi Islands. Geological Survey of Malaysia District Memoir, 17, 257 p.

Kaiser, S.I., Aretz, M. & Becker, R.T., 2016. The global Hangenberg Crisis (Devonian-Carboniferous transition): Review of a first-order mass extinction. In: Becker, R.T., Königshof, P. & Brett, C.E. (Eds.), Devonian Climate, Sea Level and Evolutionary Events. Geological Society London Special Publications, 423, 387-437.

Kobayashi, T. & Hamada, T., 1971. Silurian trilobites from the Langkawi Islands, West Malaysia, with notes on the Dalmanitidae and Raphiophoridae. Geology and Palaeontology of Southeast Asia, 9, 87–134.

Kobayashi, T. & Hamada, T., 1973. Cyrtosymbolids (Trilobita) from the Langgon Red Beds in Northwest Malaya, Malaysia. Geology and Palaeontology of Southeast Asia, 12, 1–28.

Lane, H.R., Müller, K.J. & Ziegler, W., 1979. Devonian and Carboniferous conodonts from Perak, Malaysia. Geologica et Palaeontologica, 13, 213–222.

Lee, C.P., 1983. Stratigraphy of the Tarutao and Machinchang Formations. Proceedings of the Workshop on stratigraphic correlation of Thailand and Malaysia, 1: Technical Papers, Geological Society of Thailand & Geological Society of Malaysia, 20–38.

Lee, C.P., 2001. Occurrences of *Scyphocrinites* loboliths in the Upper Silurian Upper Setul limestone of Pulau Langgun, Langkawi, Kedah and Guar Sanai, Beseri, Perlis. Proceedings Geological Society of Malaysia Annual Geological Conference 2001, 99–104.

Lee, C.P., 2005. Discovery of plate-type scyphocrinoid loboliths in the uppermost Pridolian-lowermost Lochkovian Upper Setul limestone of Peninsular Malaysia. Geological Journal, 40, 331–342.

Lee, C.P., 2009. Palaeozoic stratigraphy. In: Hutchison, C.R. & Tan, D.N.K. (Eds.), Geology of Peninsular Malaysia. University of Malaya and Geological Society of Malaysia, Kuala Lumpur, pp. 55–86.

Long, J.A. & Burrett, C.F., 1989. Early Devonian Conodonts from the Kuan Tung Formation, Thailand: systematics and Biogeographic Considerations. Records of the Australian Museum 41, 121–133.

Malaysian-Thai Working Group, 2009. Geology of the Bukit Batu Puteh-Satun Transect Area Along the Malaysia-Thailand Border. Geological Papers Volume 8. The Malaysia-Thailand Border Joint Geological Survey Committee, 111 p.

Metcalfe, I., 1979. Carboniferous conodonts from Perak, Malaysia. Warta Geologi, 5, 35–39.

Metcalfe, I., 2002. Devonian and Carboniferous conodonts from the Kanthan Limestone, Peninsular Malaysia, and their stratigraphic and tectonic implications. In: Hills, L.V., Henderson, C.M. and Bamber, E.W. (Eds.), The Carboniferous and Permian of the World, Proceedings of the XIV ICCP, 552–579. Calgary: Canadian Society of Petroleum Geologists, Memoir 19, 552–579.

Metcalfe, I., 2013. Tectonic Evolution of the Malay Peninsula. Journal of Asian Earth Sciences, 76, 195–213.

Metcalfe, I., 2017. Devonian and Carboniferous stratigraphy and conodont biostratigraphy of the Malay Peninsula in a regional tectonic context. Stratigraphy, 14(1–4), 259–283.

Metcalfe, I. & Crowley, J.L., 2020. Upper Permian and Lower Triassic conodonts, high-precision U-Pb zircon ages and the Permian-Triassic boundary in the Malay Peninsula. Journal of Asian Earth Science, 199, Article #104403.

Mustaffa, K.S., 2009. Major faults. In: Hutchison, C.R. & Tan, D.N.K. (Eds.), Geology of Peninsular Malaysia. University of Malaya and Geological Society of Malaysia, Kuala Lumpur, 149–269.

Pierson, B. J., Kassa, S., Haylay, T., Askury, A. K., Chow, W. S., Hunter, A.W. & Zuhar Z. T. H., 2011. Sedimentology of the Paleozoic limestone of the Kinta Valley, Peninsular Malaysia. Workshop on Palaeozoic Limestones of South-East Asia and South China. First EAGE South-East Asia Regional Geology Workshop, Ipoh, Malaysia, 1–4.

Racki, G. & Cordey, F., 2000. Radiolarian paleoecology and radiolarites: is the present the key to the past? Earth-Science Reviews, 52, 83–120.

Ridd, M.F., 2013. A Middle Permian–Middle Triassic accretionary complex and a Late Triassic foredeep basin: Forerunners of an Indosinian (Late Triassic) thrust complex in the Thailand–Malaysia border area. Journal of Asian Earth Sciences, 76, 99–114.

Sandberg, C.A. & Dreesen, R., 1984. Late Devonian icriodontid biofacies models and alternate shallow-water conodont zonation. In: Clark, D.L. (Ed.), Conodont Biofacies and Provincialism. Geological Society of America Special Paper, 196, 143–178.

Scholle, P.A., Arthur, M.A. & Ekdale, A.A., 1983. Pelagic environments. In: Scholle, P.A., Bebout, D.G. & Moore, C.H. (Eds.), Carbonate Depositional Environments. Memoirs of the American Association of Petroleum Geologists, 33, 619–692.

Suntharalingam, T., 1968. Upper Paleozoic stratigraphy of the area west of Kampar, Perak. Bulletin of the Geological Society of Malaysia, 1, 1–15.

Wongwanich, T., Burrett, C.F., Tansathien, W. & Chaodumrong, P., 1990. Lower to Mid Palaeozoic stratigraphy of mainland Satun province, southern Thailand. Journal of Southeast Asian Earth Sciences, 4, 1–9.

Wongwanich, T., Boucot, A.J., Brunton, C.H.C., House, M.R. & Racheboeuf, P.R., 2004. Namurian fossils (brachiopods, goniatites) from Satun Province, southern Thailand. Journal of Paleontology, 78(6), 1072–1085.

Yin, E.H., 1976. Geological Map of Kuala Lumpur. Geological Survey of Malaysia.

Zaiton, H. & Basir, J., 2003. Some Radiolarians from Dengkil, Selangor. Bulletin of the Geological Society of Malaysia, 46, 133–136.

Manuscript received 3 September 2020
Revised manuscript received 10 October 2020
Manuscript accepted 15 October 2020