Recognition of High-Frequency Sea-Level Fluctuations in Late Silurian to Early Permian Deposits, Perlis, Malaysia.

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Research Article

Keywords: Late Silurian-Early Permian age, Fischer plots, regressive-transgressive cycles, sea-level fluctuations

Posted Date: July 30th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-659953/v1

Abstract

The purpose of this paper is to present information on the past sea-level fluctuations of sedimentary rock succession of the Perlis area that covers the Mempelam Limestone, Timah Tasoh Formation, Sanai Limestone, Telaga Jatoh Formation, Kubang Pasu Formation, and Chuping Formation at Bukit Tungku Lembu and Guar Sanai, Perlis, Malaysia. Based on sedimentology logging, cycle stacking patterns, and accommodation variations revealed by Fischer plots, 51 cyclic sequences of third-order depositional sequences are recognized. These sequences generally consist of transgressive and regressive events. As the thickness of the cycle column increases, it forms an increase in accommodation space and subsidence rate and results in rising sea level. As the thickness of the cycle column decreases, it will form a decrease in accommodation space and subsidence rate and resulting in sea-level fall. Generally, the facies of the cycle are vertically arranged, forming coarsening and fining upward patterns observed from sedimentology logging. The Silurian Mempelam Limestone-Carboniferous Chepor Member sequence is characterized by a progressive increase and decrease in accommodation space, indicating a rise and fall in sea level. In contrast, the Carboniferous Uppermost Kubang Pasu-Permian Chuping Limestone sequence is characterized by a progressive decrease in accommodation space, indicating a longer-term fall in sea level. The regressive-transgressive cycles recognize deviations in the accommodation space and sediment supply from the cyclic successions. In turn, these cycles are expressing the long-term of Perlis's sea-level fluctuations. The results notably reflect the cycles consistent with the long-term rising and falling trend on different regions globally in Paleozoic times.

Introduction

Jones (1981) and Gobbett (1973) elucidated the Paleozoic to Mesozoic sedimentary successions in the north-western part of Peninsular Malaysia. It exhibits an in-depth study on the geological work sequence of Upper Cambrian to Holocene. These rock stratigraphies are grouped into the oldest to youngest, the Machinchang Formation, Setul Formation, Singa Formation, Chuping Formation, Bukit Arang Coal Bed Granite, and Alluvium. Foo (1983) quoted that these rocks are comprised of clastics and carbonates sedimentary rock. Its depositional environment is primarily in shelf sediments of shallow marine settings (Foo, 1983).

Lee (2009) and Meor et al. (2013) had also introduced a revised Paleozoic rock of Perlis into several separated subunits, from oldest to youngest; Timah Tasoh Formation, Sanai Limestone, Telaga Jatoh Formation, Kubang Pasu Formation, and Chuping Limestone (Figure 1). In addition, Meor and Lee (2005) discovered a new stratigraphic formation of the Early Carboniferous-Devonian Jentik Formation that represents the transitional boundary between the underlying Ordovician-Silurian Setul Formation and the overlying Carboniferous Kubang Pasu. Figure 1 provides an updated regional stratigraphic succession chart/column of Perlis.

The lithostratigraphy and depositional environment of the transitional zone from the Setul Limestone to the Kubang Pasu Formation studied in Guar Sanai, Kampung Guar Jentik, Beseri, Perlis on the sedimentology and paleontology analysis (Meor & Lee, 2002). A new lithostratigraphic unit has been distinguished; the Jentik Formation consists of six informal units: Unit 1, Unit 2, Unit 3, Unit 4, Unit 5, and Unit 6 (Meor & Lee, 2002). Unit 1 predominantly comprises black shales that are of an early Devonian age-dating faunal assemblage (*Dacryoconarid-Monograptus-Plagiolaria*). Light-coloured, unfossiliferous sandstones and shales are fall in Unit 2. In addition, Unit 3 consists primarily of thick and red sandstone, interbedded with sandstone and occasionally showing graded layer/bed. Unit 4 allocates a dark well-bedded limestone layer having straight coned *nautiloid* fossils. As for Unit 5, it is made up of interbedded layers of cherts and slump structure in beds of black mudstone. Fossil of brachiopod and gastropod is found at the base of the bed unit. Unit 6 comprises primarily brownish to red thickly bedded of mudstone, interbedded with sandstone. *Macrobole*-crinoid fossil assemblage in the thick-redded mudstones resembled the Early Carboniferous dating age. The Jentik Formation is located underlying the Kubang Pasu Formation. Thus, these features generally suggested that the environments reflect depositional settings within relatively deep water marine environments.

The Unit 3 of the Jentik Formation (Meor & Lee, 2002) or the Rebanggun Beds (Gobbett, 1972) or the Langgun Red Beds (Kobayashi & Hamada, 1973) is exposed in the Hutan Aji District, conformably overlying the light-coloured areno-argillites of Unit 2 (Meor & Lee, 2002) or the Upper Detrital Member (Jones, 1981). The Mid-Paleozoic red beds have indicated that this formation corresponds to the transgressive event documented worldwide, the Hangenberg Event. Hassan and Peng (2004) presented comprehensive sedimentology and paleontology studies to determine the depositional environment of the Late Devonian-Early Carboniferous red beds sequence. The sedimentological logged revealed that the formation is constituted by massive mudstone, thin mudstone to sandstone couplets, and thin tabular sandstone. The rocks of the Jentik Formation in Unit 3 can be divided into eight facies which; massive mudstone facies, thin mudstone and sandstone couplet facies, pebbly sandstone facies, massive sandstone facies, cross-stratified sandstone facies, black mudstone facies, hummocky cross-laminated sandstone facies, and laminated sandstone facies. These findings demonstrate that it was deposited in a marine prodelta to delta front environment with conditions above the storm-wave base of deep water. According to these data and field observations, the red beds’ sequence can be considered part of the Jentik Formation deltaic marine deposits.

Meor et al. (2013) studied the sedimentology and facies analysis of Perlis’s geological rock formations. The uppermost section of Kubang Pasu Formation clastic deposition shifts to Chuping Formation carbonates using the logging method in Bukit Chondong and Bukit Tunku Lembu. For which three facies associations (with eleven facies) have been identified reflecting different depositional settings. The stack facies’ patterns show a gradually coarsening upward sequence ranging from the offshore to distal lower shoreface to proximal lower shoreface facies. As a result, a depositional-environmental model depicting a prograding storm- and wave-influenced coast, attributed to the upward shoaling pattern of the facies association predominance of a storm- and wave-generated facies.

This paper reviews the sedimentological variation of Perlis’s rock formation to correlate with the major eustatic sea-level history during the Palaeozoic time scale. Because there is no information on sea-level history based on stratigraphy studies from the previous researcher.

Previous studies have not explained the sea-level fluctuation activities in North-western Peninsular Malaysia. Thus, this study is significant to reveal Silurian-Permian relative sea-level changes of the sedimentary formations in north-western Peninsular Malaysia. A precise and accurate sea-level model is essential to verify the events imprinted in the rock record. We suppose that correlations must be sufficiently accurate to demonstrate the synchronous occurrence of rising and falling events in different regions of the world. Hence, it is now possible to interpret the Silurian-Permian sea-level activities through sedimentology logging and Fischer plotting. The study's main objective is to construct and correlate the Devonian-Permian sea-level fluctuations to Paleozoic major eustatic sea-level history. Previous studies have not explained the sea-level fluctuation activities in North-western Peninsular Malaysia. Therefore, this study is significant to reveal Devonian-Permian relative sea-level activities of the sedimentary formations in north-western Peninsular Malaysia. A precise and accurate sea-level model is essential to verify the events imprinted in the rock record. Furthermore, we suppose that correlations must be sufficiently accurate to demonstrate the synchronous occurrence of rising and falling events in different regions of the world. Hence, the cycle stacking patterns and the lithology correlatability of Fischer plots may define a eustatic control on sea-level fluctuation on the sedimentary formations.

Materials And Methods

Fischer plot is a valuable instrument for graphically portray the sea-level correlation in cyclic sequences of varying thicknesses. Fischer (1964) was first established a vertical space-time diagram to expound the cyclic events seen in the calcareous Alps of peritidal Triassic Lofer cyclothems. There are no assumptions made regarding the elapsed time between the cycles of the sequence cyclic events. Hence, Sadler (1993) renamed the axes “cumulative deviation from mean cycle thickness” for the vertical axis and “cycle number” for the horizontal axis. Day (1997) suggested that the traditional Fischer diagram (event-domain diagram) is converted into the depth domain to distinguish the stratigraphic sequence features, especially when dealing with log and core data. Hence, stratigraphers will analyse the stratigraphic unit data when integrating both materials from the event-domain and the depth-domain diagrams.

Husinec et al. (2007) developed the FISCHERPLOTS program using an Excel Spreadsheet computer program to construct Fischer plots. It plots the cumulative departure from mean cycle thickness against the cycle number or stratigraphic distance. The Fischer plots are used to recognize changes in accommodation space from cyclic carbonate successions (Husinec et al., 2007). Fischer plots of long-term relative sea-level changes from major formations in Perlis were extracted by keying in the cycle thickness to the excel spreadsheet. The cycle thickness was determined based on the sedimentology log and facies association.

The Western longitudinal belt of Peninsular Malaysia forms part of the Sibumasu terrane that was rifted from Northwestern Australian Gondwana in the early Permian period (Metcalfe, 1984; 2011). Perlis is part of the fold-thrust belt developed due to the collision between the Sibumasu and East Malaya/Indochina blocks during the Late Triassic (Metcalfe, 2011). Thus, the main outcrop areas which have been chosen for this study are indicated by numbers in Figure 2 and as below;

1) Guar Sanai, Kampung Guar Jentik

2) Bukit Tungku Lembu, Beseri

This study focused on several outcrops in the Northwest of Peninsular Malaysia, Perlis. Jones in 1981 reported that Perlis sedimentary sequence typically begins to young eastward from the Setul Boundary Range. However, east of the Chuping Hills is repeating the formation itself in the other direction, forming the axis of a large syncline. Carbonates are exposed by steep karst hills, and towers expose the carbonates, either standalone or part of extensive ranges (Meor et al., 2013). Clastic strata have been uplifted as small hills or ridges due to transpressional and thrusting deformation (Zaiton & Basir, 2000).

Results And Discussions

The SL1 and SL2 composited section of Guar Sanai, Kampung Guar Jentik area comprises Mempelam Limestone, Timah Tasoh Formation, Sanai Limestone, Telaga Jatoh Formation, and Chepor Member of Kubang Pasu Formation (Figures 3 and 4). SL1 and SL2 sedimentology logs can be divided into five facies: limestone, black shale, chert and mudstone, sandstone, and mudstone. Meanwhile, SL3 and SL4 logs for Bukit Tungku Lembu, Beseri of Uppermost Kubang Pasu Formation, have five different facies: coal facies, silty shale facies, shale, sandstone, and silty shale interbedded with sandstone facies (Figure 5). The SL5 comprises of Chuping Formation (Figure 6). SL3 sedimentology log has been identified to have six different facies, which are: limestone interbedded with black mudstone, black shale interbedded with sandstone, black mudstone interbedded with chert, mudstone, sandstone, and diamictite facies.

These facies are interbedded with different thickness, grain size, and a difference in the content of fossils. From the interbedded facies, some cycle patterns can be formed, which are coarsening upward and fining upward. Besides, there is also a distinct transition, changed from carbonate rocks to clastic rocks.

The Fischer plots are used to recognize changes in accommodation space from cyclic carbonate successions (Husinec et al., 2007). Therefore, this study yields to extract long-term relative sea-level changes from the Perlis's Formation. The thickness between two maximum regressive surfaces equals a cycle thickness.

From the composited section of Mempelam Limestone, Timah Tasoh Formation, Sanai Limestone, Telaga Jatoh Formation, Kubang Pasu Formation, and Chuping Formation, some cycle patterns can be formed, which are coarsening upward and fining upward. Besides, there is also a distinct transition, changed from carbonate rocks to clastic rocks.

The Fischer plots are used to recognize changes in accommodation space from cyclic carbonate successions (Husinec et al., 2007). Therefore, extracting long-term relative sea-level changes from sedimentary formations of Guar Sanai, Kampung Guar Jentik in this study. Fischer plots of major formations of Perlis were generated by keying in the cycle thickness to the excel spreadsheet. The cycle thickness was determined based on the sedimentology log and facies association done in this study. The thickness between two maximum regressive surfaces equals a cycle thickness.

Thus, concerning the composited logs, the formations can be divided into 51 sedimentary cycles. The sedimentary logs can be observed from Figures 3, 4, 5, and 6, and from there, the cycle thickness can be determined using the Excel spreadsheet program to generate the Fischer plot (Husinec et al., 2007). The Fischer plots generated by using this excel spreadsheet are shown in Figure 7.

Figure 7 conveys the transgressive-regressive cycle’s deposition trend via the Fischer plot method by defining cumulative departure from mean cycle thickness versus the cycle number. The plot shows the third order of sea level and a long-term rise and fall. According to Haq et al. (1987), the third-order sequences were said to have durations of 0.5±3 million years ago.

The column beside the relative sea-level curves contains the interpretation of the systems tracts represented by a negative trend and a positive trend of the Fischer plots and sedimentary cycles, associated with each identifiable facies for Perlis’s stratigraphic nomenclature. The regression and transgression cycle showed one complete cycle of rising and falling sea level. In most cases, the transgressive system tracts (TST) are known rather than regressive system tracts (RST) in rock history. In most cases, for regressive systems tracts (RST) associated with the sea-level fall, the sea-level reaches a minimum represented by **low-stand systems tract (LST)** and is overlain directly by transgressive deposits.

The first accommodation events of the third-order Silurian-Permian age happened with a complete fall sea-level cycle in Mempelam Limestone Formation and Timah Tasoh Formation. There is a good match between the regressive and sea-level curves as interpreted from the Fischer plots. Immense thickness in Cycle 5 indicates a eustatic sea level is rising or subsidence activity of basin. No transgressive episode during this period. This sediment’s formation indicates an upward deepening and fining sequence. Also, the Fischer plot illustrated that the accommodation space of sea-level cycle 2 begins to increase up to cycle 9 and decrease to cycle 12 in Sanai Limestone, positioned in Jentik Formation. Several cycles of continuous rising and falling of sea-level can be seen in the lowermost section of Kubang Pasu Formation and decreasing accommodation space at sea level for the rest of the Kubang Pasu Formation and Chuping Limestone Formation.

There is an unconformity developed between the Timah Tasoh (black shale) and Sanai Limestone. Hence, it is interpreted as a sequence boundary at the base of the Sanai Limestone Formation. The lower Sanai Limestone sequence is classified into a highstand system tract (HST) and transgressive system tract (TST). The conodonts limestone indicates the transgression surface and the start of transgressive system tracts (TST). This sequence shows a shallowing and thickening upward sequence. A pro-gradational stacking pattern throughout the highstand systems tract is usually shown by the coarsening-upward trend from shore (Kwon et al., 2006). Also, the Fischer plot illustrated that the accommodation space of sea-level cycle 5 to 6 increases in Sanai Limestone, positioned in Jentik Formation (Hassan & Peng, 2003). Sea-level cycle 7 to 11 shows the accommodation space decreases in the upper part of the Sanai Limestone Formation, followed by little increasing accommodation space in sea-level cycle 12 and 13. The sea level reaches the maximum flooding surface in this cycle. It stands at the boundary underlain by transgressive system tract (TST) and overlain by high stand system tract (HST). The Sanai Limestone depicts a long-term cycle of sea-level rise that portrays a good match between transgressive cycles and the sea-level curve as interpreted from the Fischer plots. This was inferred from the distinct transition of limestone to black shale cycles. It portrays a good match between transgressive and regressive cycles and the sea-level curve interpreted from the Fischer plots.

The Sanai Limestone in the sections underlies the Telaga Jatoh Formation paraconformably. This sediment pattern of limestone gradually transited into black mudstone and cherts indicates sea-level falling. According to Meor and Lee (2005), major regression activity had taken place after the Hangenberg Anoxic Event. These cycles show the falling stage systems tract (FSST) and low-stand system tract (LST). When the sea level is falling, it will expose the shelf deposits and consequently develop an unconformity.

The cycles of Chepor Member of Kubang Pasu Formation) show a good match between the regressive cycles for Kubang Pasu Formation and the sea-level curve as interpreted from the Fischer plots. Following with the Chuping Formation will have a rapid fall fluctuation to the end of the Perlis's rock sequence.

The Chuping Formation of Guar Sanai is interpreted as shallowing upwards, or regressive cycle with the regression peak begin at cycle 30. From the sedimentology log in Figure 6, carbonates gradually become more common as the bed is graded upward from Kubang Pasu Formation into Chuping Limestone Formation. The lithological change from a siliciclastic sequence and gradually to a carbonate sequence is possibly closely related to sea-level fluctuations. The coarsening-upward sequence was presumably aroused in response to the occurrence of the high-frequency eustatic sea-level regression process. This process contributes to changes in the sediment deposition, where the finer ones in the bottom and the coarser ones at the top.

The first accommodation events of the third-order early Permian age happened with a complete fall sea-level cycle in Chuping Formation cycle 30 to cycle 51. A clear downward trend in sea level is observed. The documented relative sea-level falling by Ross and Ross (1985) is most likely related to worldwide Carboniferous eustatic episodes.

All in all, there are 51 sedimentology cycles found from sedimentary rock succession of Perlis comprising Mempelam Limestone, Timah Tasoh Formation, Sanai Limestone, Telaga Jatoh Formation, Chepor Member of Kubang Pasu Formation, Uppermost Kubang Pasu Formation, and Chuping Formation. The sea-level curve was successfully constructed to manifest several cycle patterns and putative links to eustatic sea-level fluctuations using Fischer plot analysis. The interpreted transgressive-regressive cycles from the Fischer plots are then compared with the eustatic sea-level fluctuation studied by Haq & Schutter, 2008; Bahlburg & Breitkreuz, 1993; and Veevers & Powell, 1987 Johnson et al. (1985) (Figure 8).

The interpreted transgressive-regressive cycles of the Silurian Mempelam Limestone Formation to Early Permian Chuping Formation from the Fischer plots are compared with other Late Silurian to Early Permian relative sea-level studies from other parts of the world (Figure 8). Eustatic sea-level activities curve (transgressive-regressive cycles) are correlated with events of Paleozoic-aged sea-level changes (Haq & Schutter, 2008) and transgressive-regressive trends in N. Chilean Andes (Bahlburg & Breitkreuz, 1993) and transgressive-regressive trends in Russian Platform (Veevers & Powell, 1987).

Sometimes the global events are applicable worldwide, or their magnitude of change at various places may differ depending on local conditions, such as local tectonic changes (Haq & Al-Qahtani, 2005). The third-order sea-level curve illustrated based on the studied formations sedimentology log using Fischer Plots correlates well with the third-order sea-level defined by Haq and Schutter (2008).

From Figure 8, these four curves have a particular trend. First, there is a beginning of sea-level rising at the early Carboniferous age. It represents the worldwide extinction event called the Latest Devonian Hangenberg Anoxic Event. (Walliser, 1984). There was a major transgressive episode recorded worldwide during the Tournaisian (Burlington Cycle). This event is marked by the black shales (Racka et al., 2010) or deepwater chert deposition of Unit 5 of Jentik Formation (Meor & Lee, 2002) or Lower Part of Kubang Pasu Formation (Malaysia Working Group, 2009). Third, the ice sheets began to shed icebergs over the Himalayan–NW Australian Gondwana bound. Meor et al. (2014) reported that the deposition of glacial-marine diamictites marks this event in the Kubang Pasu Formation of Chepor Member. Finally, an apparent declining trend towards the Permian age shows a fall in sea-level fluctuations. Hassan and Peng (2004) concluded that the pre-Carboniferous paraconformity seen in the middle of Paleozoic aged successions of Sibumasu/Shan-Thai Terrane is caused by major regression immediately followed after the global transgressive event of the Hangenberg episode. Tectonically, the glaciation of the Gondwana was at its peak during Late Carboniferous until the Early Permian.

Conclusion

Therefore, this research can elucidate the sedimentary succession of Perlis comprising (from youngest formation to the oldest): Chuping Formation of Permian-aged, Chepor Member of Kubang Pasu Formation of Carboniferous-aged, Telaga Jatoh Formation of Tournaisian-aged, Sanai Limestone of Late Devonian-aged, Timah Tasoh Formation of Early Devonian-aged and Mempelam Limestone of Late Silurian-aged. The methodology used is sedimentological logging, facies analysis study, and Fischer plot analysis. In addition, this research incorporated information on sedimentary facies and sea-level fluctuations history at the North-western Domain of the Malaysia Western Belt within Guar Sanai, Kampung Guar Jentik, Beseri Bukit Tungku Lembu, Beseri in Perlis state. Thus, the objectives of this research study have been successfully achieved, and these results and discussion had led to the conclusion of our research study.

Twenty sedimentology cycles have been recognized from sedimentary rock succession of Perlis at Guar Sanai, Kampung Guar Jentik area. The cycles showed that during sedimentary processes of Late Silurian Mempelam Limestone-early Carboniferous Kubang Pasu Formation showed transgression and regression and then transgression. Meanwhile, thirty-one cycles of coarsening and fining-upwards sequence comprising the uppermost Kubang Pasu Formation and Chuping Formation. These depositional sequences in the Guar Sanai outcrop represent a regressive cycle found in the Early Permian of the Chuping Formation. Ross & Ross (1985) advocated a substantial decrease in sea level for the Late Paleozoic Ice Age.

The diversity of data is needed to connect the facies evolution of the Perlis's formations with worldwide relative sea-level fluctuations. The results of Fischer's transgressive-regressive cycles during sedimentary processes of Carboniferous to Devonian showed the synchronous occurrence of falling and rising events in different regions of the world from past studies. Summarising, the transgressive character of the rocks in the Bukit Tungku Lembu area suggested the global event of Hangenberg Anoxic Event. On the other hand, the shallowing in Guar Sanai Area has been attributed to the Permo-Carboniferous Gondwana glacial.

With that, the resulting integration of the sedimentology logging from geological and Fischer plotting from stratigraphical framework approaches has undoubtedly shown a good relation. These techniques give considerable information to unveil the history of Devonian to Carboniferous age relative sea-level changes. The regressive and transgressive cycles recognize deviations in the accommodation space and sediment supply from the cyclic successions. In turn, these cycles are expressing the long-term of Perlis's sea-level fluctuations in this study. The third-order sea-level curve illustrated based on the sedimentology log correlates with the third-order sea-level defined by other previous works (Veevers & Powell, 1987; Bahlburg & Breitkreuz, 1993; and Haq & Schutter, 2008).

Declarations

Funding

Universiti Sains Malaysia funded the research with the grant number (203/PFIZIK/6711896).

Acknowledgements

The authors express their appreciation for the Universiti Sains Malaysia Research University Grant for supporting this research project. Above all, we gratefully acknowledge all the Geophysics team for their kind support throughout the research work.

Conflict of Interest

The authors declare no conflict of interest.

References

1. Adenan, N., Ali, C. A., and Mohamed, K. R. (2013) Sedimentologi Lapisan Perantaraan Formasi Kubang Pasu dan Formasi Chuping, Beseri, Perlis (In Malay), Sedimentology of the Passage beds between the Kubang Pasu Formation and Chuping Formation, Berseri, Perlis. *Bulletin of the Geological Society of Malaysia,* 59.
2. Bahlburg, H., & Breitkreuz, C. (1993). Differential Response of a Devonian-Carboniferous Platform-Deeper Basin System to Sea-level Change and Tectonics, N. Chilean Andes. *Basin Research, 5*(1), 21–40.
3. Day, P. I. (1997). The Fischer Diagram in the Depth Domain: A Tool for Sequence Stratigraphy. *Journal of Sedimentary Research*, *67*(5), 982–984.
4. Fischer, A. G. (1964). The Lofer Cyclothems of the Alpine Triassic. In: Symposium on Cyclic Sedimentation. *Kansas State Geological Survey Bulletin, 169*(1), 107–149.
5. Foo, K. Y. (1983). The Paleozoic Sedimentary Rocks of Peninsular Malaysia- Stratigraphy and Correlation. In: Workshop on Stratigraphic Correlation of Thailand and Malaysia. *Warta Geologi (Geological Society of Malaysia Newsletter), 9*(5). Haad Yai, Thailand.
6. Gobbett, D. J. (1972). Geology of the Rebak Islands, Langkawi, West Malaysia. *Geological Society of Malaysia Newsletter, (37)*, 3–2.
7. Gobbett, D. J., & Hutchison, C. S. (1973). *Geology of the Malay Peninsula*. Wiley-Interscience., New York, United States of America.
8. Haq, B. U., & Al-Qahtani, A. M. (2005). Phanerozoic Cycles of Sea-level Change on the Arabian Platform. *GeoArabia*, *10*(2), 127–160.
9. Haq, B. U., & Schutter, S. R. (2008). A Chronology of Palaeozoic Sea-level Changes*. Science, 322*(5898), 64–68.
10. Haq, B. U., Hardenbol, J., & Vail, P. R. (1987). Chronology of Fluctuating Sea Levels since the Triassic. *Science, 235*(4793), 1156–1167.
11. Hassan, M. H. A. (2013). Post-Conference Field Excursion to Northwest Peninsular Malaysia. In: Third International Conference on Palaeontology of South East Asia: ICPSEA 3, Universiti Teknologi PETRONAS, 10th-13th October.
12. Hassan, M. H. A., Aung, A. K., Becker, R. T., Rahman, N. A. A., Ng, T. F., 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.
13. Hassan, M. H., & Peng, L. C. (2004). The Depositional Environment of the Mid-Palaeozoic Red Beds at Hutan Aji, Perus and Its Bearing on Global Eustatic Sea Level Change. In: Annual Geological Conference 2004, Kangar, Perlis, Malaysia, 4th-6th June. *Bulletin of the Geological Society of Malaysia, 48*, 65–72.
14. Husinec, A., Basch, D., Rose, B., & Read, J. F. (2007). FISCHERPLOTS: An Excel Spreadsheet for Computing Fischer plots of Accommodation Change in Cyclic Carbonate Successions in Both the

Time and Depth Domains. *Computers & Geosciences, 34*(3), 269–277.

15. Johnson, J. G., Klapper, G., & Sandberg, C. A. (1985). Devonian Eustatic Fluctuations in Euramerica. *Geological Society of America Bulletin*, *96*(5), 567–587.
16. Jones, C.R. (1981). The Geology and Mineral Resources of Perlis, North Kedah, and the Langkawi Islands. *Geological Survey of Malaysia District Memoir, 17*, 1–257.
17. Kobayashi, T., & Hamada, T. (1973). Cyrtosymbolids (Trilobita) from the Langgun Red Beds in Northwest Malaya, Malaysia. *Geology and Palaeontology of Southeast Asia, 12*, 1–28.
18. 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, 55–86.
19. Malaysia–Thai Working Group (MT-JGCS). (2009). Geology of The Bukit Batu Puteh-Satun Transect Area Along the Malaysia-Thailand Border. *Geological Papers, Volume 8*.
20. Meor, H. A. H., & Lee, C. P. (2005). The Devonian–Lower Carboniferous succession in Northwest Peninsular Malaysia. *Journal of Asian Earth Sciences, 24*, 719–738.
21. Meor, H. A. 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.
22. Meor, H. A. H., 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, 37*(1), 49–63.
23. Meor, H. A. H., Sim, Y. B., Lee, C. P., & Abdul Hadi, A. R. (2013). Facies analysis of the uppermost Kubang Pasu Formation, Perlis: A wave-and storm-influenced coastal depositional system. *Sains Malaysiana, 42*(8), 1091–1100.
24. Meor, H. A. H., Yeow, B. S., Lee, C. P., Abdul Rahman, A. H. (2013). Facies Analysis of the Uppermost Kubang Pasu Formation, Perlis: A Wave- and Storm-influenced Coastal Depositional System. *Sains Malaysiana, 42*(8), 1091–1100.
25. Metcalfe, I. (2011). Palaeozoic–Mesozoic History of Southeast Asia. In: Hall, R., Cottam, M., Wilson, M. (Eds.), The Southeast Asian Gateway: History and Tectonics of Australia–Asia Collision. *Geological Society of London Special Publications, 355*, 7–35.
26. Metcalfe, I. (2013). Tectonic Evolution of the Malay Peninsula. *Journal of Asian Earth Sciences, 76*, 195–213.
27. Racka, M., Marynowski, L., Filipiak, P., Sobstel, M., Pisarzowska, A., & Bond, D. P. (2010). Anoxic Annulata Events in the Late Famennian of the Holy Cross Mountains (Southern Poland): Geochemical and Palaeontological Record. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *297*(3-4), 549–575.
28. Ross, C. A., & Ross, J. R. P. (1985). Late Paleozoic Depositional Sequences are Synchronous and Worldwide. *Geology*, 13, 194–197

29. Sadler, P. M., Osleger, D. A., & Montanez, I. P. (1993). On the Labeling, Length, and Objective Basis of Fischer plots. *Journal of Sedimentary Research, 63*(3), 360–368
30. Veevers, J. J., & Powell, C. M. (1987). Late Paleozoic Glacial Episodes in Gondwanaland Reflected in Transgressive-regressive Depositional Sequences in Euramerica. *Geological Society of America Bulletin, 98*(4).
31. Walliser, O. H. (1984). Pleading for a natural Devonian/Carboniferous-boundary. In: Paproth, E. & Streel, M. (Eds.), The Devonian-Carboniferous Boundary. *Courier Forschungsinstitut Senckenberg, 67*, 241–246.
32. Zaiton, H., & Basir, J. (2000). The Occurrence of Thrusts in North Kedah and Perlis. In Proceedings Annual Geological Conference, 17–20.

Figures

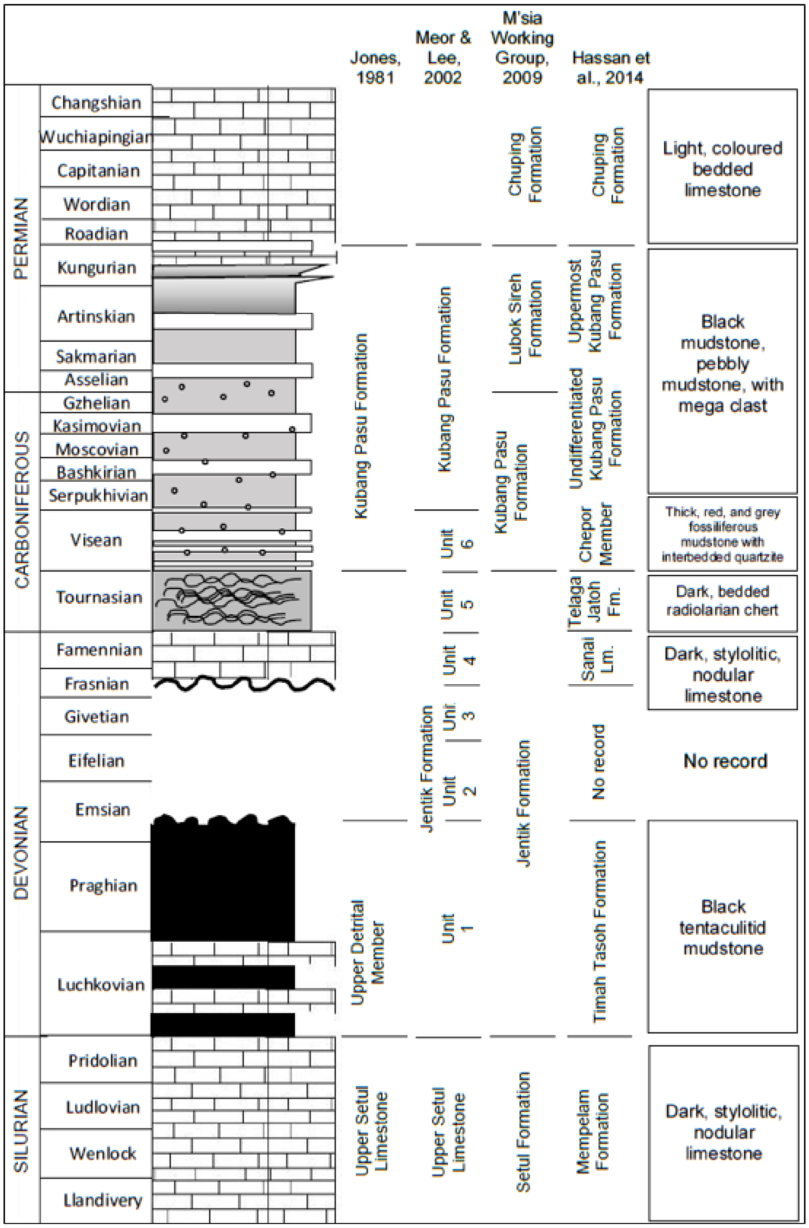

Figure 1

Correlation of rock units in Perlis area (modified after Jones, 1981; Meor & Lee, 2002; The Malaysia-Thailand Joint Geological Survey Working Groups, 2009; Hassan et al., 2014)

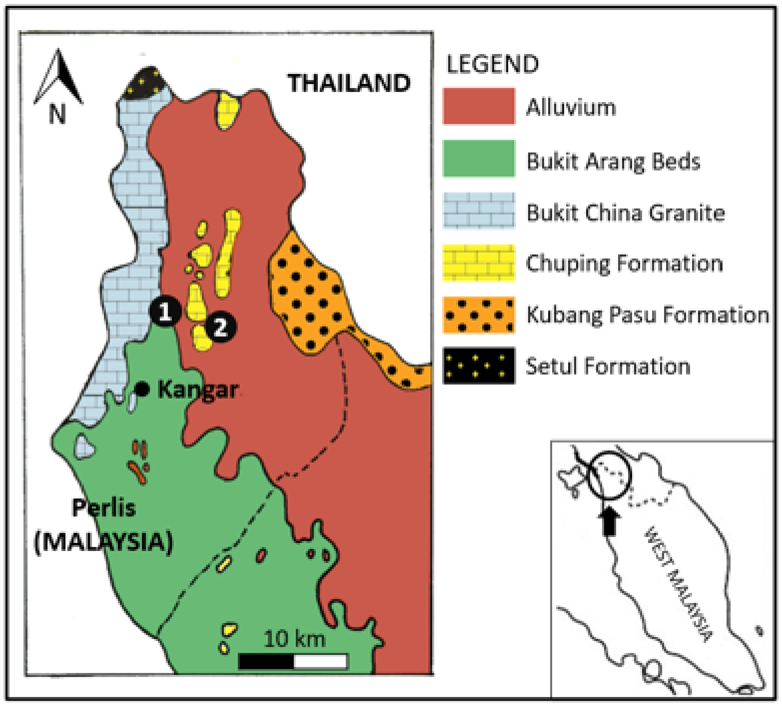

Figure 2

The geology map of North-western Peninsular Malaysia with the labelled studied area (modified after Hassan, 2013)

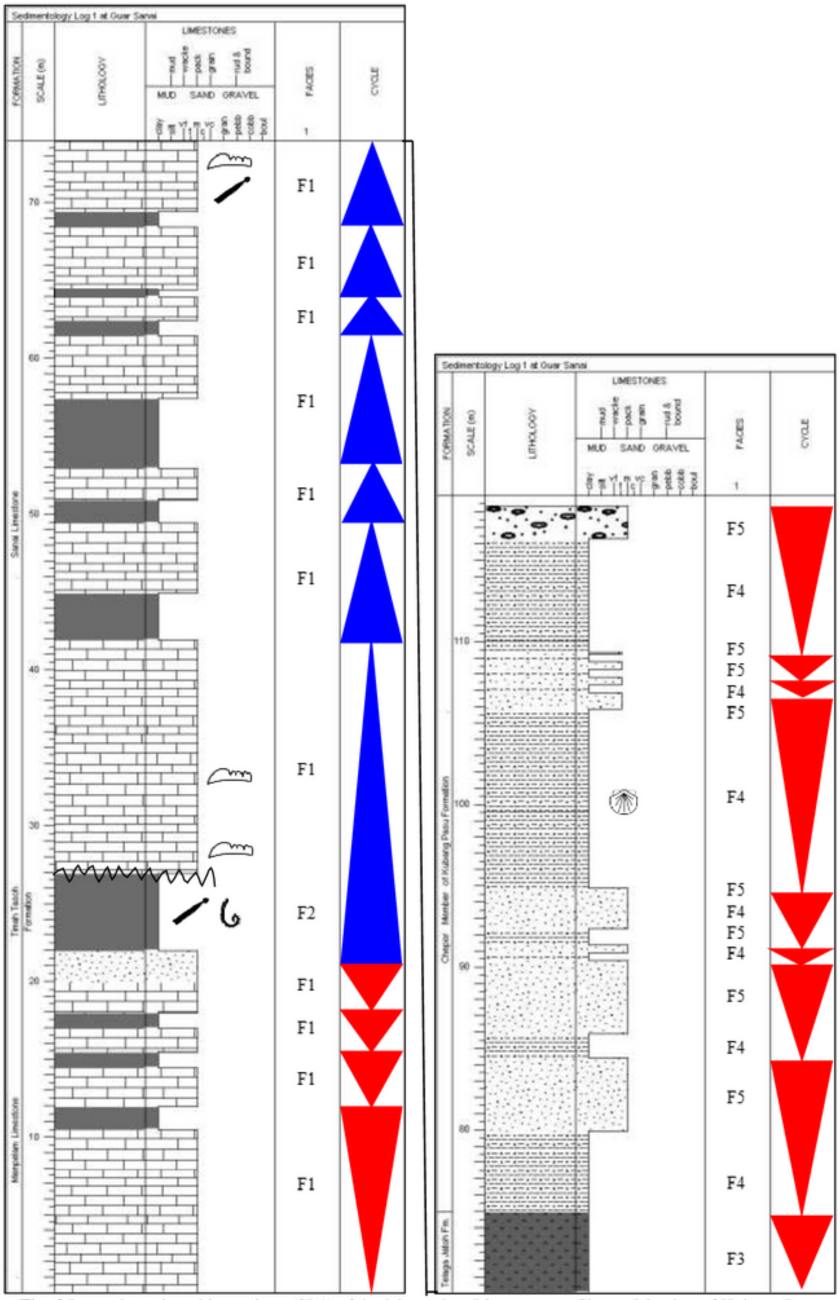

Fig. 3 Logged stratigraphic sections (SL1) of the Mempelam Limestone to Chepor Member of Kubang Pasu Formation at Guar Sanai, Perlis (modified after Hassan et al., 2014)

Figure 3

See image above for figure legend.

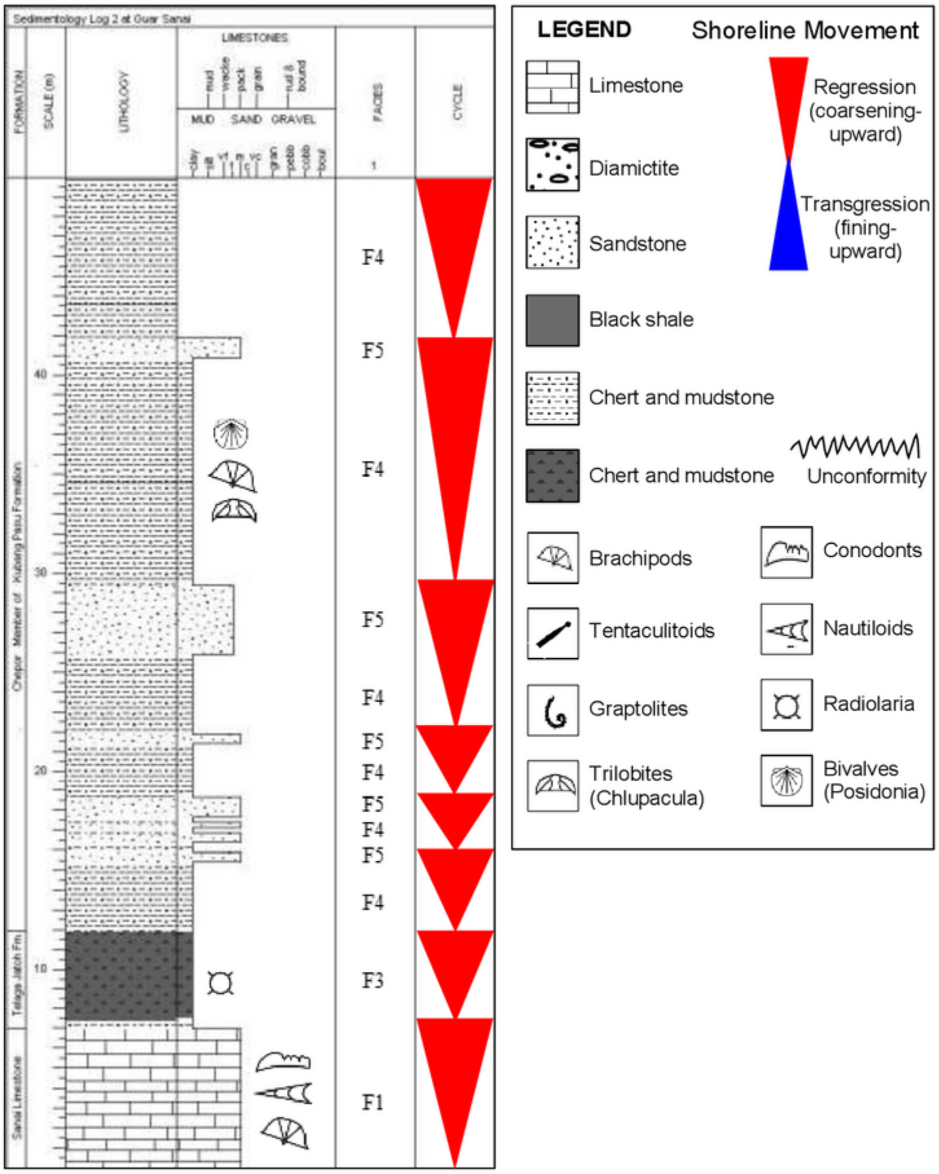

Fig. 4 Logged stratigraphic sections (SL2) of the Sanai Limestone to Chepor Member of Kubang Pasu Formation at Guar Sanai, Perlis (modified after Hassan et al., 2014)

Figure 4

See image above for figure legend.

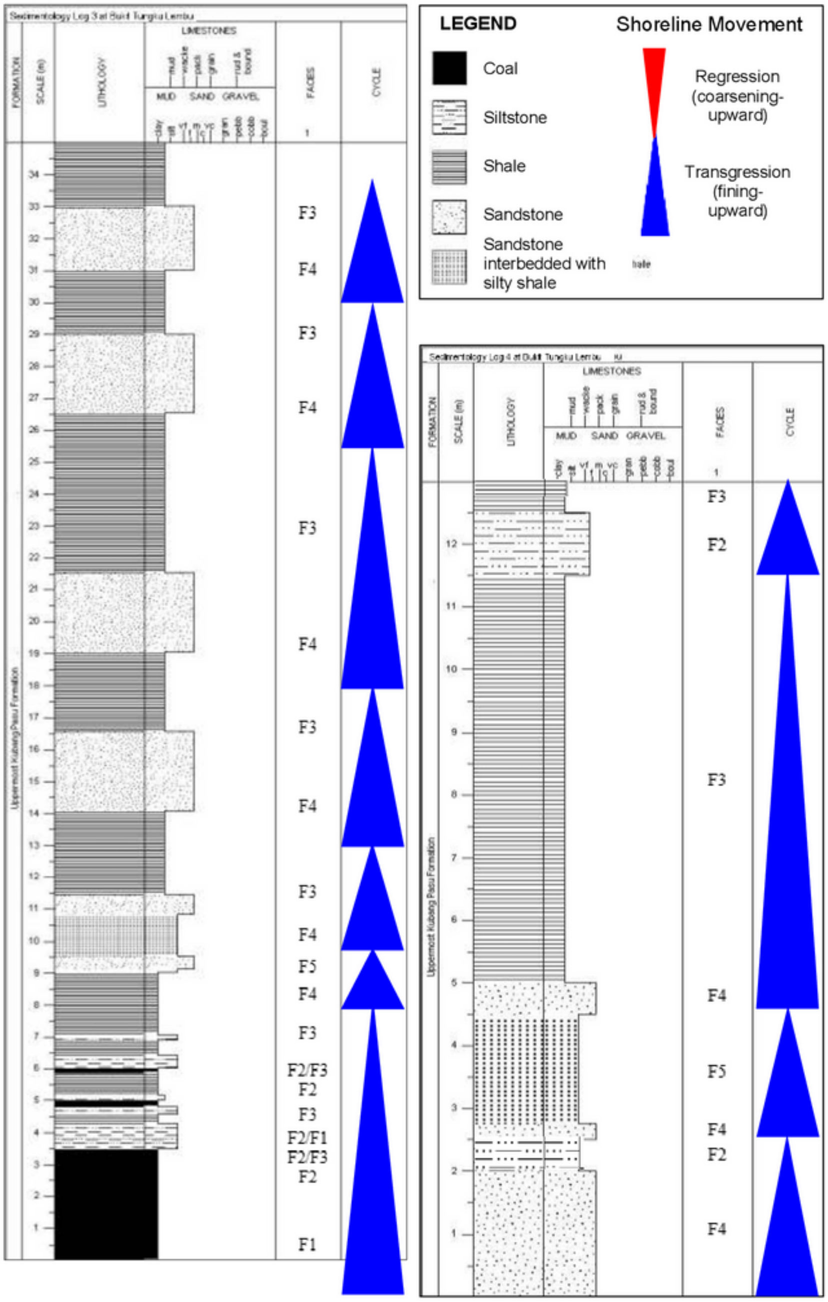

Fig. 5 Logged stratigraphic sections (SL3 and SL4) of the uppermost Kubang Pasu Formation at Bukit Tungku Lembu, Perlis

Figure 5

See image above for figure legend.

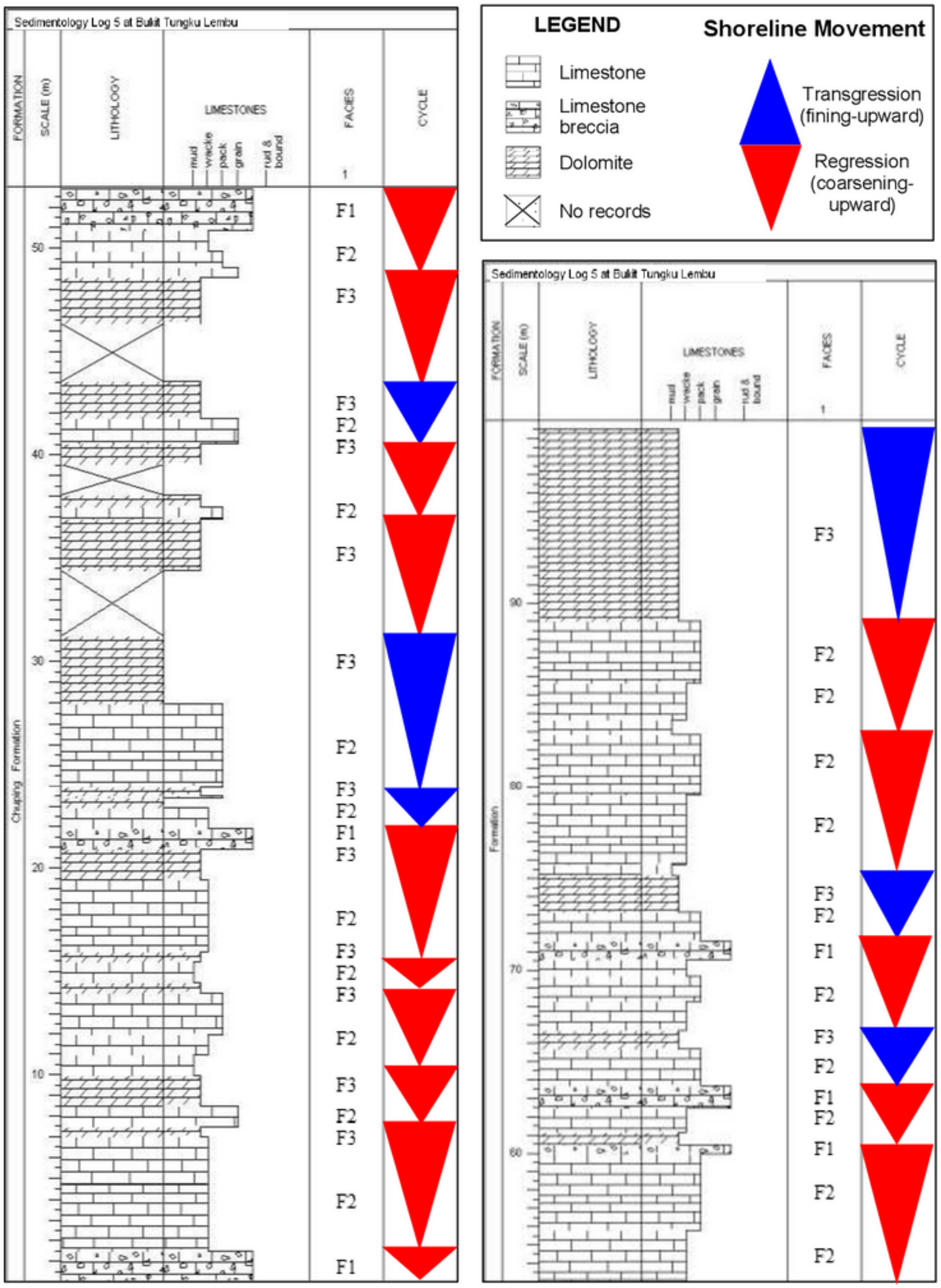

Fig. 6 Logged stratigraphic sections (SL5) of the Chuping Formation at Bukit Tungku Lembu, Perlis (modified after Adenan et al., 2013)

Figure 6

See image above for figure legend.

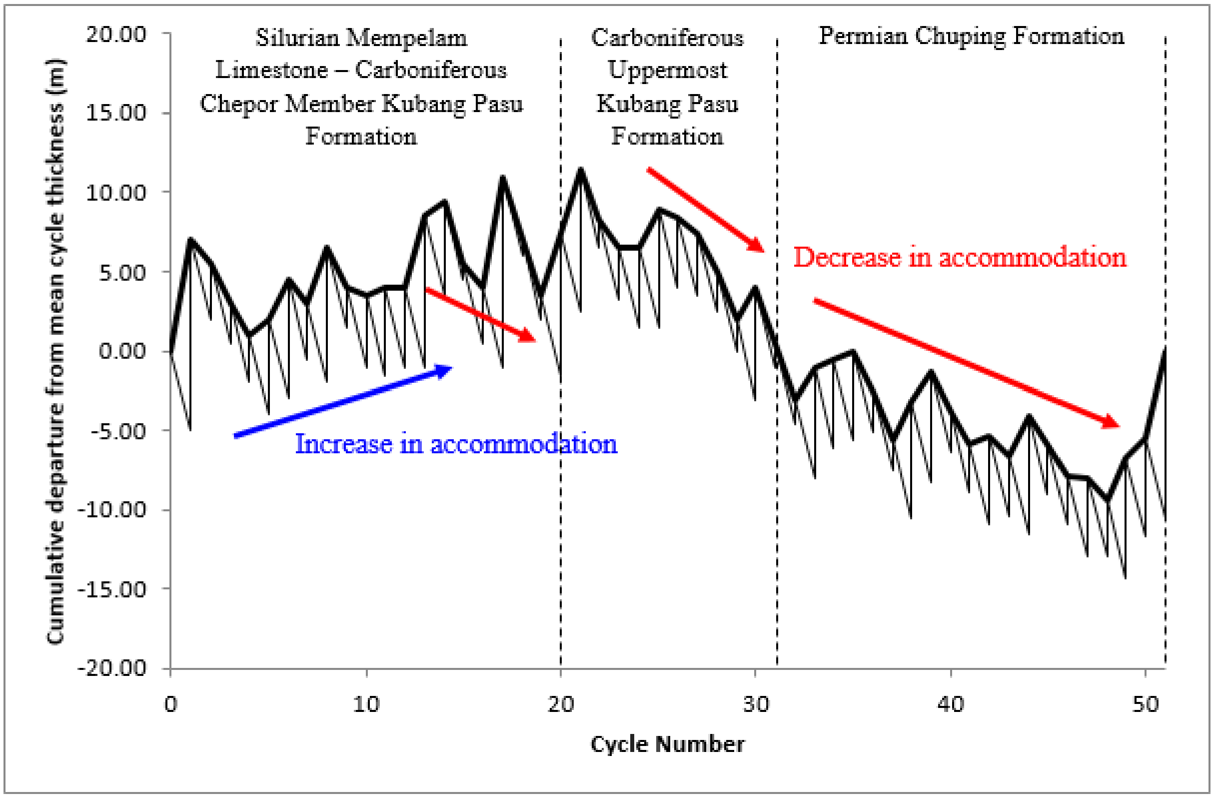

Figure 7

Fischer plot curve of Silurian Mempelam Limestone to Chuping Formation derived from the Guar Sanai and Bukit Tungku Lembu outcrops. The plot is produced using the FICSHERPLOT Excel spreadsheet program from Husinec et al. (2007)

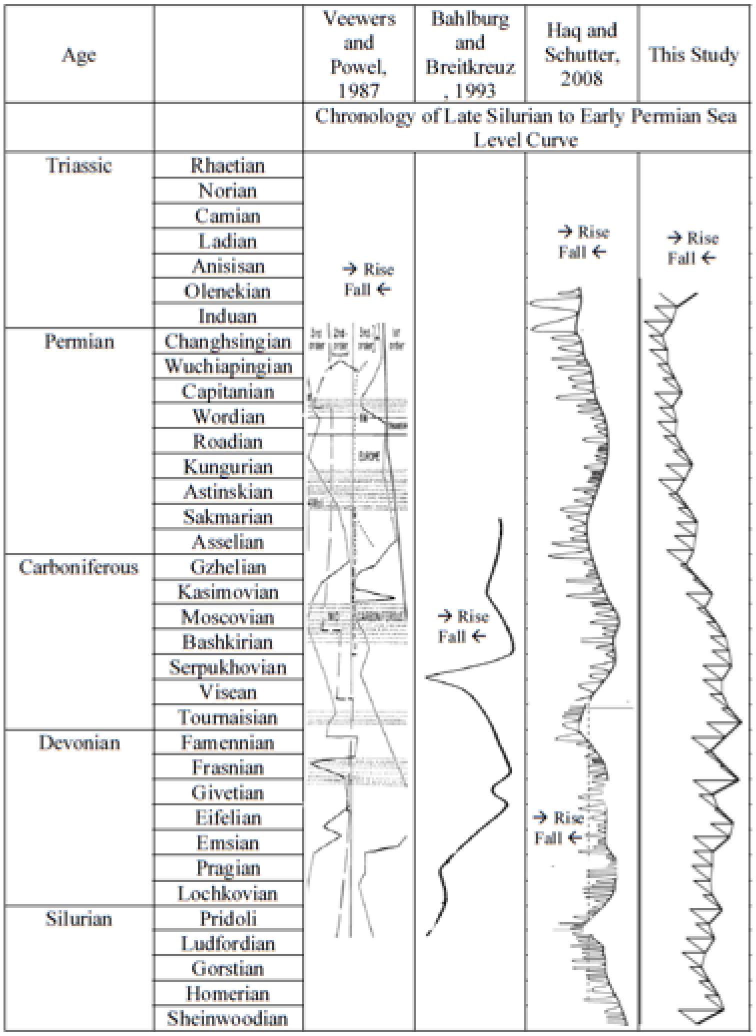

Figure 8

Comparison of third-order sea-level curves of the Carboniferous to Permian deposits with previous studies (Haq & Schutter, 2008; Bahlburg & Breitkreuz, 1993; Veevers & Powell, 1987) and the present study