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The depositional environment of the Mid-Palaeozoic red beds at Hutan Aji, Perlis and its bearing on global eustatic sea level change

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Abstract: Late Devonian – Early Carboniferous red coloured mudstones and sandstones are widely distributed in northwest Peninsular Malaysia. A relatively complete and well preserved sequence is exposed at Bumita Quarry, Hutan Aji, Perlis, and is described herein. The facies associations observed are indicative of a marine prodelta-delta front depositional environment for the Mid-Palaeozoic red beds. A thin (9m) black mudstone facies in the middle of the Bumita Quarry sequence may represent the Latest Devonian Hangenberg Anoxic Event. The occurrence of a Mid-Palaeozoic orogeny is refuted. The major regression just after the global Hangenberg Event transgressive episode is proposed as the cause of the major, pre-Carboniferous paraconformity observed in mid-Palaeozoic successions of the Sibumasu/Shan-Thai Terrane.

Abstrak: Batu lumpur dan batu pasir merah berumur Devon Akhir – Karbon Awal tersingkap secara meluas di beberapa bahagian barat laut Semenanjung Malaysia. Satu turutan Devon Akhir-Karbon Awal yang hampir lengkap terdedah di Kuari Bumita, Hutan Aji, Perlis, diperihalkan di sini. Gabungan-gabungan fasies yang dikenalpasti di lapangan ditafsirkan sebagai menunjukkan sekitaran enapan palaeo prodelta – hadapan delta marin bagi batuan merah Palaeozoik Tengah ini. Kehadiran fasies batu lumpur hitam yang nipis di tengah-tengah turutan Kuari Bumita mungkin mewakili Peristiwa Anoksik Hangenberg yang berlaku pada Akhir Devon. Tiada peristiwa orogen berumur Palaeozoik Tengah yang berlaku pada benua Sibumasu/Shan – Thai. Regressi pasca Peristiwa Hangenberg dicadangkan sebagai punca paraselarasan berumur pra-Karbon yang diperhatikan dalam turutan batuan benua Sibumasu/Shan-Thai.

INTRODUCTION

Red coloured mudstones and sandstones of Late Devonian to Early Carboniferous age are widely distributed throughout the states of Perlis, Kedah, and the islands of Langkawi. These beds, popularly known as the Langgun Red Beds (Kobayashi & Hamada, 1973) or the Rebanggun Beds (Gobbett, 1972), have been little studied in the past decade, and very little is known of their sedimentology, stratigraphic position and exact depositional environment. The red colouration and abundance of benthic marine fossils have led to a shallow marine, lagoonal to nearshore environment interpretation for the red beds by Hamada (1968a) and Kobayashi & Hamada (1973), with the red colouration associated with a regressive phase. Jones (1968, 1973) considers the Langgun pebbly red beds a basal conglomerate overlying an unconformity. A tidal environment interpretation suggested in Lee & Azhar (1991) for the Wang Kelian Red Beds involves a different, younger, red coloured stratigraphic unit (Unit 6, see Meor & Lee, 2002). This paper attempts to interpret the depositional environment of the Mid-Palaeozoic red beds as a relatively deep water prodelta to delta front on a continental shelf. This new interpretation of the red beds is important in unravelling the geological history of the region.

STUDY LOCALITY

The main study area is located in a well known earth quarry site, called the Bumita Quarry, at Kampung Binjal, Hutan Aji (6° 33.2'N and 100° 12.4'E), Perlis (Figures 1 and 2). It is just 5 km south of Kangar. The quarry is situated around the remnant of a small hill, at Kampung Binjal and adjacent Kampung Behor Chepor. Similar to Kampung Guar Jentik, the exposure is also a large, isolated, faulted block, surrounded by villages. This area has been studied before by Kobayashi & Hamada (1973) and Jones (1981). The Bumita Quarry exposure represents the thickest and most complete exposure of the Late Devonian-Early Carboniferous red beds. Comparisons are made with the Unit 3 red bed exposures at Hill C and A, Kampung Guar Jentik (Meor & Lee, 2002) and the Pulau Langgun exposure (Jones, 1981).

STRATIGRAPHY

The stratigraphic nomenclature of the Devonian red beds is still being worked on, with major revisions of the stratigraphy still in progress and unpublished. The beds were tentatively assigned as Unit 3 of the Jentik Formation in Meor & Lee (2002). This unit encompasses the Devonian red beds previously known as the Langgun Red Beds or Rebanggun Beds (Kobayashi & Hamada, 1973; Gobbett, 1972). It's upper part is the lateral equivalent of the Sanai Limestone in the north (Meor & Lee, 2003). Ahmad Jantan (1973) used the name Rebak Member for this unit, with the red beds considered as the base of the Singa Formation. The red beds contain fossils indicative of the Upper Devonian to Lower Carboniferous (Hamada, 1968b, 1969; Kobayashi & Hamada, 1973; Yancey, 1972) Red mudstone containing Mid-Devonian fossils are known from the Satun province of southern Thailand, where it is known as Member

2 of the Pa Samed Formation (Wongwanich *et al.*, 1990), and similar red beds considered Late Devonian to Early Carboniferous in age are known in the Fang region of northern Thailand (Hamada, 1968a).

The red beds are observed to be overlying light coloured areno-argillites of Unit 2 (Meor & Lee, 2002), also known as the Upper Detrital Member (*sensu* Jones, 1981). The contact between the two units is observable at Pulau Langgun, Kampung Guar Jentik and Hutan Aji but unfortunately is marked by a thrust fault at all three sites (eg. Figure 2). There seems to be no indication of an angular unconformity as proposed by Jones (1968, 1973, 1981). The thickest exposure of the unit is at the Bumita Quarry, Hutan Aji. Based on mapping, the whole unit reaches 130 m in thickness in Hutan Aji. The thickness at Pulau Langgun is unreliable as the unit is greatly deformed and faulted, with only the lower part of the unit exposed.

The authors realize that the exposures of the rocks at Hutan Aji have been influenced by transpressional shearing, strike-slip faulting and thrust faulting (Zaiton Harun & Basir Jasin, 2000), but the deformation has mostly been parallel to strike (north northwest – south southeast), and the general stratigraphic position of the units in the logged sections were preserved. Faulted blocks do occur, displaced by lateral strike slip faults trending roughly east – west, but these were easily corrected using fossil correlation.

Unfortunately, the upper boundary of the Unit 3 red beds is not exposed at Hutan Aji. It might be represented by light grey mudstone observed underlying Lower Carboniferous black cherts of Unit 5 (*sensu* Meor & Lee, 2002) at Kampung Jelutong, north Kedah (the Tournaisian cherts of Unit 5 are considered part of the base of the Kubang Pasu Formation by Basir Jasin, 1995), but no fossils were found from that locality. The red beds are overlain by Late Devonian limestone of the Sanai Limestone at Kampung Guar Jentik (Meor & Lee, 2003).

SEDIMENTOLOGY

Based on lithology, texture and sedimentary structures, the rocks of Unit 3 can be divided into eight main sedimentary facies. The logged sections with these facies are shown in Figures 3 and 4.

Facies A: Massive mudstone facies

This is the predominant facies in the unit (Figure 5). The mudstone is usually red, white or grey in colour, homogeneous, with no observed internal structures, and beds can reach 5 m in thickness. Some parts (in the upper subunit) show abundant bioturbation in the form of small *Chondrites*. Unaltered red mudstone is usually soft and easily broken into conchoidal fragments, but mudstone units adjacent to shear zones are somewhat indurated, and their fossils deformed, due to tectonic activity. Occasionally, isolated pebbles are found floating in the mudstone. The pebbles are usually rounded, widely dispersed and supported by the mud matrix. Thin coquina layers made up of broken fossil fragments occur as 1-3 cm thick laminations in the mudstone. Siltstone inter-laminations are also common in between the mudstone. But most of the fossil remains are randomly dispersed in the mudstone.

Relatively large, white coloured, possibly tuffaceous nodules are present in certain horizons. These are usually oblong, and form irregular clumps parallel to bedding. They tend to form iron-rich cemented red-coloured layers when weathered.

Facies B : Thin mudstone and sandstone couplet facies

This facies is common in the lower part of the unit (eg. Section C4). The mudstone beds are 10-40 cm thick, red in colour and contain broken fossil fragments. Again the mudstone is homogeneous with no internal structures. The sandstone beds range from 5 to 20 cm thick, and are fine grained and silty. Fragments of siltstone, mudstone and white calcitic material are occasionally found floating in the fine sandstone. Some beds show well developed normal grading from fine sandstone to siltstone and mudstone. These sandstone beds also show scoured bases, rip-up clasts and ripple marks. Others are tabular.

Facies C : Massive sandstone facies

Thin to medium thick (5 cm - 2 m), medium grained tabular orthoquartzite sandstone beds can be seen interbedded between thick mudstone units (Figure 5). The sandstone is very clean and well sorted, and thin sections show that they are texturally mature, almost wholly made up of recrystallized quartz grains (orthoquartzite). Some sandstone beds are stacked on top of each other with no mudstone intercalations. Planar bases are common, but some show uneven and undulating bottoms.

Facies D :Black mudstone facies

A thin band (9 m thick) of darker coloured massive mudstone is present in the middle of Unit 3. The mudstone

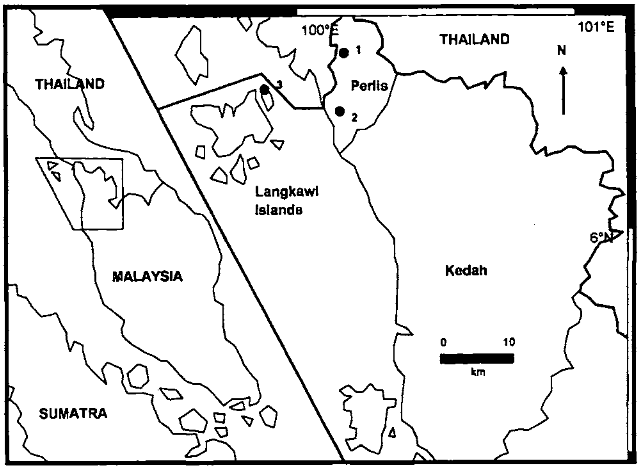

Figure 1. Locality map of major outcrops of the mid-Palaeozoic red beds of Unit 3, Jentik Formation in northwest Peninsular Malaysia. 1, Kampung Guar Jentik, Beseri district, Perlis; 2, Hutan Aji, Perlis; 3, Pulau Langgun, Langkawi Islands.

is black to dark grey in colour, and is massive, with no observable internal structure. Pyrite is finely dispersed throughout the rock, and thin films of white, calcitic material is observed. Some horizons are rich in fossils, especially bivalves, while some parts contain sparse pyritised remains of only pelagic organisms (ammonoids).

Facies E: Pebbly sandstone facies

Several sandstone beds contain pebble sized grains floating in a medium grained sandstone matrix. The sandstone beds range from 30 cm to 50 cm in thickness.

Facies F : Laminated sandstone

Medium grained sandstone beds showing parallel laminations usually form beds ranging from 30 cm to 50 cm in thickness. These are well sorted and can be massive or grading upwards into mudstone. Some sandstone beds show deformed laminations in the form of convoluted bedding (Figure 6).

Facies G : Cross-stratified sandstone

Some of the sandstone beds show cross-stratification. These beds are usually thick, reaching up to 1.5 m in thickness, of medium grain size, well sorted, and vertically grade upwards into fine sandstone and mudstone. The cross-stratification is in the form of planar cross-bedding and cross-laminations. These are observed to be unidirectional, dipping roughly towards the east. No bidirectional cross-stratification is observed in the outcrops.

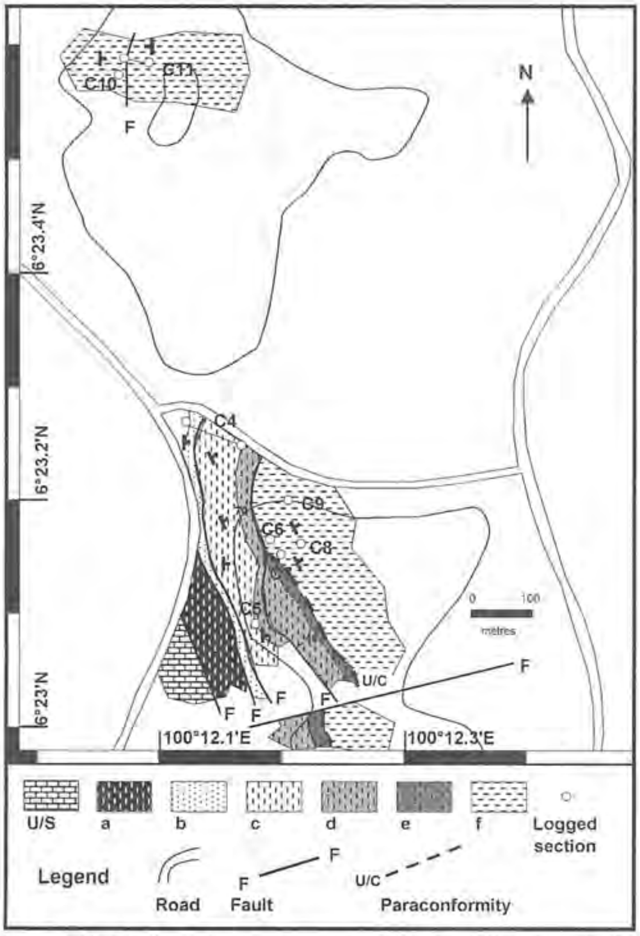

Figure 2. Geological outcrop map of Hutan Aji exposure. U/S=Upper Setul Limestone. a-f, Jentik Formation: a, Unit 1; b, Unit 2; c, lower part, Unit 3 ; d, lower part, Fammenian beds, Unit 3; e, black mudstone facies, Unit 3; f, upper part, Unit 3. C4-C11 represent locations of logged sections shown in Figures 3 and 4.

Facies H : Hummocky cross-laminated sandstone

Small sized, undulating sets of cross-laminae occurring as a mixture of convex and concave upwards sand sheets identified as hummocky cross-laminations characterize the sandstone beds in this facies. The thin layers of fine sandstone are interbedded with darker coloured mudstone. They are found associated with thick grey mudstone and graded sandstone beds. Rare thin, cm-bedded limestone beds are found in the upper parts of this unit.

DEPOSITIONAL ENVIRONMENT

Unit 3 is mainly composed of massive mudstone, thin mudstone – sandstone couplets and thin tabular sandstone. This facies association shows all the characteristics of a marine prodelta environment. Prodelta environments are usually predominated by fine grained siliciclastics, with a maximum grain size of very fine sand, and beds showing planar and cross laminations, and abundance of shell accumulations (Allen, 1964). The Unit 3 red beds differ only in having a coarser grained element, up to medium grained sand, but generally fits well with a prodelta depositional model.

The thick mudstone beds represent muddy shelf deposits laid down mainly through suspension. The mud may have been transported by turbidity currents going down the delta slope. Upon reaching the delta front, the abrupt change in slope gradient resulted in sudden deposition of coarse grained material and a hydraulic jump which put the fine grained sediments in suspension in the form of surface plumes, before slowly settling down on the prodelta and outer shelf area. The massive characteristic of the mudstone suggests active disturbance of the sediment through intense bioturbation. Coquinite indicates deposition above storm wave base. The thin sandstone – mudstone couplet facies is interpreted as deposits of turbidity currents (turbidites), based on the occurrence of normal grading, scoured bases and rip-up clasts. The lateral extent of the tabular sandstone beds are limited, and some parts show channel shaped erosive bases. These may represent submarine channels transported from the delta slope and deposited on the prodelta through turbidity currents. Similar facies associations can be seen in parts identified as prodelta deposits of the Late Cretaceous Izumi Basin of Japan (Tanaka & Maejima, 1995).

The pebbly sandstone facies shows features similar to turbidite deposits, such as normal grading and sole marks. The graded beds actually represent complete and incomplete Bouma sequences, another characteristic of turbidite deposits, with Bouma divisions such as massive, pebbly or cross stratified sandstone, convoluted bedding, laminated sandstone/mudstone, and massive mudstone (Figure 6). The normal grading is a result of settling and deposition of suspended particles from a waning sediment density flow. Gravity driven turbidite deposits are common in deep sea basins and also on steep delta slopes. Based on discovered fossils, it is more likely that the turbidites were associated with delta deposits. The interbedded mudstone between the turbidite sands are hemipelagic deposits laid down through suspension. Hummocky cross-laminations are indicative of storm deposits. This suggests that the depositional environment was above storm wave base.

A black to dark grey mudstone facies is observed forming a thin band in the middle of the red bed outcrop at Bumita Quarry. The rock is massive, with no signs of bioturbation. The black colouration is due to high carbon content. Pyrite is also finely dispersed in the rock, and fossils collected from the facies are pyritized. High carbon content and finely dispersed pyrite indicates either anoxic or dysoxic conditions. Absence of sedimentary current structures and fine grain size suggests that the rock was deposited in a low energy environment. All these characteristics are used to interpret the environment of this facies as a dysoxic to anoxic, calm water environment. The characteristic fossils found are abundant, large *Posidonomya* and ammonoids, and gastropods. Low abundance (only two benthic taxa) and monospecific faunal compositions (abundant *Posidonomya*) are characteristics of a stressed environment, occupied by opportunistic fauna. The low energy setting, lack of benthos, and the presence of pelagic ammonoids indicate a deepwater, pelagic facies.

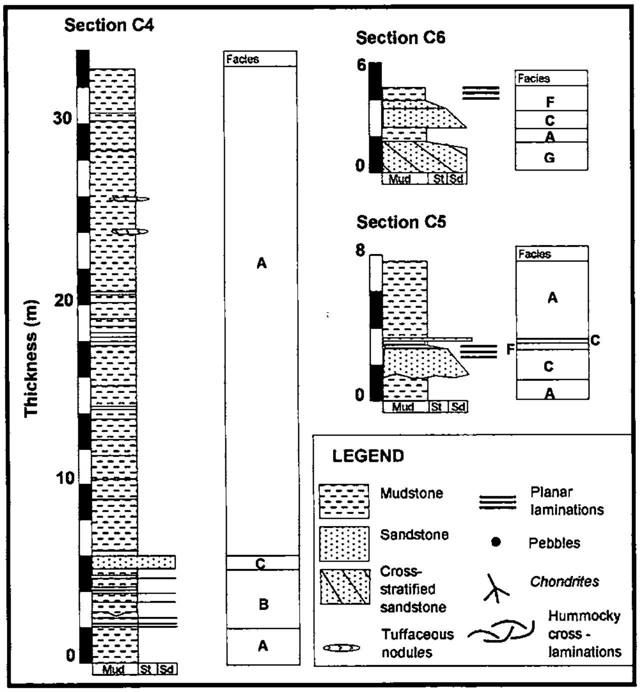

Figure 3. Sedimentological logs of outcrops at Bumita Quarry of the lower part of Unit 3. Location of logged sections shown in Figure 2.

Overall, the depositional environment of the Late Devonian – Early Carboniferous red beds of Unit 3 was a relatively deeper water, prodelta to delta front setting above storm-wave base. The black mudstone facies represents an abrupt, and short-lived, transgressive phase during deposition of the red beds, and delta front deposition continued after the event.

PALAEONTOLOGY

Most of the taxa from the red beds are benthos adapted to living on soft substrate. The faunal association is very similar to that of the *Rhipidomella* Community of the Upper Devonian Sonyea Group of New York (Bowen *et al.*, 1974 ; Thayer, 1974), which is also dominated by brachiopods, including ambocoeliids and chonetoids, and also contained archaeogastropods, trilobites and bivalves. This community is characteristic of outer shelf mud deposits, especially delta front or prodelta environments.

The peculiar ambocoeliid brachiopods *Echinocoeliopsis sculpta, "Emanuella malayensis"* and *Echinocoeliopsis ladjioidea* are characteristic of the red beds (Figure 7). The ambocoeliids provide the biofacial evidence of a prodelta to delta front interpretation, as they are often associated with such deposits (Bowen *et al.*, 1974; and Goldman & Mitchell, 1990).

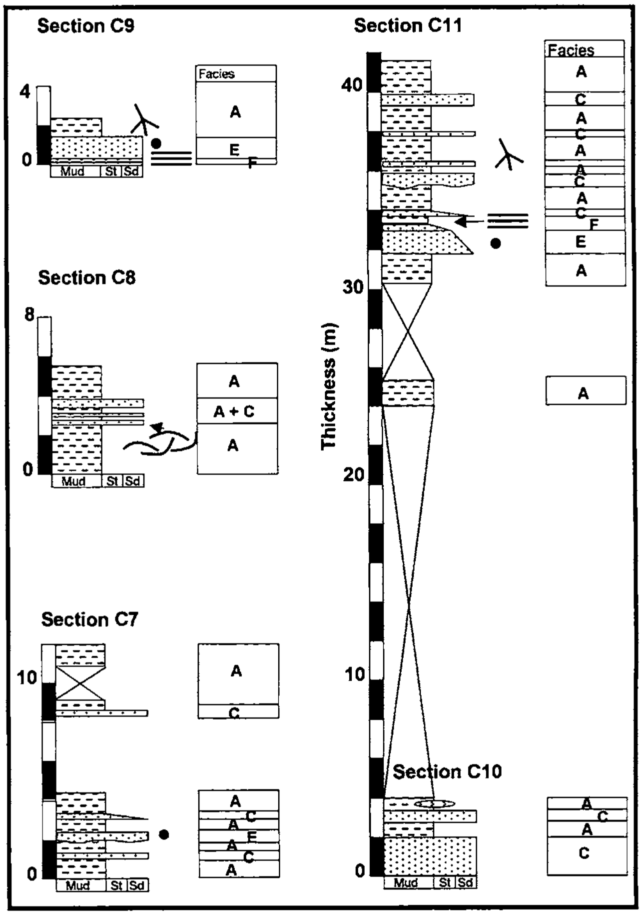

Figure 4. Sedimentological logs of outcrops at Hutan Aji of the upper part of Unit 3. Location of logged sections shown in Figure 2. Legend shown in Figure 3.

IMPLICATIONS FOR TECTONIC MODELS OF THE SIBUMASU/SHAN-THAI TERRANE

A mid-Palaeozoic orogeny has been suggested for the rock succession of the Shan-Thai Terrane by numerous authors. Koopmans (1965) interpreted a mid-Palaeozoic orogeny (Langkawi Folding Phase) based on differences in deformation, regional metamorphism and granite intrusion between the lower and upper Palaeozoic successions in northwest Peninsular Malaysia, but this interpretation was rebutted by Yancey (1975). A Devonian unconformity between Early Devonian tentaculitid shales (Unit 1, Jentik Formation, basal Upper Detrital Member), and Late Devonian – Early Carboniferous red beds in northwest Peninsular Malaysia was suggested by Jones (1973), which was interpreted as an uplifting event (Hutchison, 1996, p.236). Again this interpretation was proved to be erroneous (Ahmad Jantan, 1973; Yancey, 1975; Meor & Lee, 2002). The interpretation of the red beds in this paper as deeper water, outer shelf, prodelta deposits further weakens the mid-Palaeozoic orogeny hypothesis. But the idea persists, due to the scanty distribution of Devonian aged sedimentary rocks. Wongwanich (in prep., cited in Boucot, 2002) reports the possible occurrence of a major disconformity between Early Devonian tentaculitid shales and Namurian aged shales. The absence of pre-Carboniferous rocks in Sumatra (Fontaine & Gafoer, 1989) also supports the idea of a widespread orogenic event near the Devonian–Carboniferous boundary.

The authors of this paper are in favour of a simpler explanation for the limited distribution of the Devonian in the Shan-Thai/Sibumasu Terrane. There was no mid-Palaeozoic orogeny, but a disconformity/paraconformity did occur near the Devonian-Carboniferous boundary, triggered by eustatic sea-level fluctuations.

Evidence for the Hangenberg Event near the D/C boundary

Palaeontological evidence shows that the rocks of Unit 3, Jentik Formation, pass through the Devonian-Carboniferous boundary (Figure 7). A Tournaisian aged fauna occurs in the upper part of the Bumita Quarry section, while the dark grey mudstone near the top of the lower part still contain trilobites and gastropods of Devonian affinity.

A thin (9 m thick) band of black coloured, pyritic mudstone occurs in the middle of the Bumita Quarry section. The upper and lower boundary of the band is sharp, showing abrupt lithological transitions.The black band is also barren of benthic fossils, except for abundant large bivalves of the genus *Posidonomya* and unidentified ammonoids. This is a drastic change from the diverse benthic fauna in the underlying Famennian grey shales. Black shale deposits in uppermost Famennian beds have been reported throughout the world, where they are interpreted to indicate a mass extinction during the end-Famennian, called the Hangenberg Event (for a review of the event, see Hallam & Wignall, 1997, chapter 4). The stratigraphic position of the uppermost black mudstone facies at the top of the lower subunit correlates well with other End Famennian black shale deposits throughout the world. The Hangenberg Event occurred before the beginning of the Carboniferous. There is no observed drastic change in faunal composition from the Late Devonian to the Early Carboniferous in the Unit 3 red beds. Three taxa from the Late Devonian of the lower subunit emerge again in beds of the upper subunit. Five new taxa not found in the Frasnian-Fammenian beds (main lower part of the section) are observed in the upper beds, including *Tournquistia*, which gives the Tournaisian age. This absence of major faunal turnover in the benthic communities of the red beds after the Hangenberg Event is to be expected, as the event had minor effects on shallow

Figure 5. Section C7, Bumita Quarry. Thick, red mudstone (Facies A) interbedded with graded sandstone (Facies C). View towards the east.

Figure 6. Complete Bouma sequence, grading from massive sandstone (Facies C) to massive mudstone (Facies A). Beds are near vertical and slightly overturned due to folding. Section C11, Kampung Binjal, Hutan Aji. View towards the south.

water benthic communities, but was devastating for pelagic and deep water fauna, including the dacryoconarid tentaculitids, ammonoids, and deep water trilobites. The change from a characteristically Famennian benthic fauna to a Tournaisian benthic fauna was gradual, with Tournaisian fauna already emerging in the latest Famennian (eg. *Waribole, Chonetipustula*).

The uppermost Famennian is represented by the *Siphonodella praesulcata* conodont zone. This was a time of rapid global, sea-level fluctuations. A transgression is recorded from rocks from the Early to Mid *S. praesulcata* zone, leading to the deposition of the Hangenberg Event black shales. This was followed by a major regression during the Late *S. praesulcata*, which is represented by an erosive hiatus in many sections worldwide (Schonlaub, 1986; Xu *et al.*, 1986; Bai & Ning, 1988; Chlupac, 1988; Krstic *et al.*, 1988; Ulmishek, 1988; Feist, 1990; Klemme & Ulmishek, 1991; Paproth *et al.*, 1991; Wang *et al.*, 1993).

The lower half of the Bumita Quarry section shows the deposition of prodelta and delta front sediments from the Frasnian to the Late Famennian, followed by abrupt deposition of black shales indicating an abrupt transgressive event, followed by an equally drastic regression marked by a paraconformity and followed by progradation of prodelta to delta front deposits in the Carboniferous.

Sea-level fluctuations

The relatively well preserved sequence at Hutan Aji, which crosses the Devonian-Carboniferous boundary, enables us to compare sea-level fluctuations with the Devonian-Carboniferous boundary sequence recorded at Hill B, Kampung Guar Jentik (Meor & Lee, 2003). The lower subunit is exposed in both localities. The Sanai Limestone can be correlated to the grey mudstone just below the black mudstone band exposed at Hutan Aji, which contains the trilobite *Waribole* associated with Late Devonian brachiopods and gastropods, indicative of the Famennian. The bedded cherts of Unit 5 at Kampung Guar Jentik are definitely Early Carboniferous, Late Tournaisian (Basir Jasin, 1995; Basir Jasin *et al.*, 2003). The cherts are not exposed at Hutan Aji, but Unit 3 is most probably underlying Unit 5, as similar red and white mudstones are observed underlying the bedded cherts at Kampung Jelutong, north Kedah.

A generalized sea-level curve for the Devonian-Carboniferous boundary sequence is reconstructed using sedimentological and palaeontological data presented in this paper (Figure 8). Several trends are observed here.

Late Famennian transgressive episode

A major flooding event is marked by an abrupt transition from relatively shallow water red mudstone to a thin band of black, pyritic mudstone at the top of the lower subunit in the Unit 3 red beds at Bumita Quarry. As has been discussed earlier, this probably marks the Hangenberg Event, a transgressive episode recorded worldwide, and was contemporaneous with a major extinction event.

Post Famennian regressive episode (Mid-Palaeozoic paraconformity), and Tournaisian transgressive episode

A major paraconformity marks the boundary between the Mid-Famennian aged Sanai Limestone and the Early Carboniferous cherts of Unit 5, exposed at Hill B, Kampung Guar Jentik. The Late Famennian record is absent here. The paraconformity may have been caused by global regression occurring during the End Fammenian, just below the D-C boundary (*praesulcata* Zone), and just after the Hangenberg Event. This same regressive episode is marked by the abrupt transition from deepwater black mudstones at the top of the lower subunit, to shallower prodelta to delta front deposits of the upper half of the Bumita Quarry section. The sharp boundary is interpreted as evidence of a depositional hiatus, i.e. a paraconformity. This major regression explains the occurrence of post-Devonian disconformities and limited distribution of pre-Carboniferous sediments on the Shan-Thai Terrane.

A major transgressive episode occured worldwide during the Tournaisian (Burlington Cycle). This event is marked by the deepwater chert deposition of Unit 5.

CONCLUSIONS

The Late Devonian – Early Carboniferous red beds of Unit 3, Jentik Formation, exposed in Perlis are identified as mainly of prodelta to delta front deposits. The presence of massive mudstone, thin mudstone – sandstone couplets and thin tabular sandstone, is interpreted as representing marine prodelta deposits. The black mudstone facies represents an abrupt but short transgressive, anoxic, event, and its upper boundary forms a depositional hiatus/ paraconformity. The upper part of Unit 3 is composed of massive mudstone, pebbly sandstone, cross-stratified sandstone and hummocky cross-laminated sandstone, and is also interpreted as representing prodelta-delta front deposits. The occurrence of abundant ambocoeliid brachiopods is also indicative of a prodelta-delta front environment. The Hangenberg Event may be represented by the black mudstone facies in the Bumita Quarry section, and is proposed as the possible cause of the major mid-Palaeozoic paraconformity observed on the Shan-Thai/ Sibumasu Terrane.

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REFERENCES

Ahmad Bin Jantan, 1973. *Stratigraphy of the Singa Formation (Upper Paleozoic) in the southwestern part of the Langkawi Island Group, West Malaysia*. Unpublished MSc. Thesis, University of Malaya, Kuala Lumpur, 250 p.

Allen, J.R.L., 1964. Sedimentation in the modern delta of the River Niger, West Africa, *In:* van Straaten, L.M.J.U (Ed.) *Deltaic and Shallow Marine Deposits*. Elsevier, Amsterdam, p. 26-34.

Bai, S. & Ning, Z., (1988). Faunal change and events across the Devonian – Carboniferous boundary of Huangmao Section, Guangxi, South China. In: McMillan, N.J., Embrey, A.F., Glass, D.J. (Ed.s) *Devonian of the World. Proceedings of the Canadian Society of Petroleum Geologists International Symposium, Devonian System* III, p. 147-157.

Basir Jasin, 1995. Occurrence of bedded radiolarian chert in the Kubang Pasu Formation, north Kedah, Peninsular Malaysia. *Warta Geologi* 21(2):73-79.

Basir Jasin, Zaiton Harun & Norhajar Hassan, 2003. Black siliceous deposits in Peninsular Malaysia: their occurrence and significance. *Geological Society of Malaysia Bulletin* 46:149-154.

Boucot, A.J., 2002. Some Thoughts about the Shan-Thai Terrane. *Proceedings, Symposium on Geology of Thailand. 26-31 August 2002, Bangkok Thailand*, p. 4-13.

Bowen, Z.P., Rhoads, C. & McAlester, L., 1974. Marine benthic communities in the Upper Devonian of New York. *Lethaia* 7:93-120.

Chlupac, I., 1988. The Devonian of Czechoslovakia and its stratigraphic significance. *In*: McMillan, N.J., Embrey, A.F., Glass, D.J. (Ed.s) *Devonian of the World. Proceedings of the Canadian Society of Petroleum Geologists International Symposium, Devonian System* I, p. 481-497.

Feist, R. (Ed.), 1990. Guide book of the field meeting, Montaignie Noire 1990. Montpellier, *Int. Union. Geol. Sci. Subcomm. Dev. Stratigr.*, p. 1-69.

Fontaine, H. & Gafoer, S., 1989. The pre-Tertiary fossils of Sumatra and their environments. *CCOP/TP19*, 356 p.

Gobbett, D. J., 1972. Geology of the Rebak Islands, Langkawi, West Malaysia. *Geological Society of Malaysia Newsletter* 37:3-2.

Goldman, D. & Mitchell, C.E., 1990. Morphology, systematics, and evolution of Middle Devonian Ambocoeliidae (Brachiopoda), Western New York. *Journal of Paleontology* 64(1):79-99.

Hallam, A. & Wignall, P.B., 1997. *Mass Extinctions and Their Aftermath*. Oxford University Press, Oxford, 320 p.

Hamada, T., 1968a. *Swaicoelia*, a new ambocoeliid genus (Brachiopoda) from north Thailand. *Geology and Paaeontology of Southeast Asia* 5:1-12.

Hamada, T., 1968b. Ambocoeliids from Red Beds in the Malayan Peninsula. *Geology and Palaeontology of Southeast Asia* 5:13-25.

Hamada, T., 1969. Late Palaeozoic brachiopods from redbeds in the Malayan Peninsula. *Geology and Palaeontology of Southeast Asia* 6:251-264.

Hutchison, C.S., 1996. *Geological Evolution of South-East Asia*. Geological Society of Malaysia, Kuala Lumpur, 368 p.

Jones, C.R., 1968. The Lower Palaeozoic rocks of the Malay Peninsula. *American Association of Petroleum Geologists Bulletin* 52:1259-1278.

Jones, C.R., 1973. Lower Paleozoic. *In:* Gobbett, D.J. & Hutchison, C.S. (Ed.s) *Geology of the Malay Peninsula, West Malaysia and Singapore*. New York, Wiley – Interscience, p. 25-60.

Jones, C.R., 1981. The Geology and Mineral Resources of Perlis, North Kedah and the Langkawi Islands. *Geological Survey of Malaysia District Memoir* 17, 192 p.

Klemme, H.D. & Ulmishek, G.F., 1991. Effective petroleum source rocks of the world: stratigraphic distribution and controlling depositional factors. *American Association of Petroleum Geologists Bulletin* 75:1809-1851.

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.

Koopmans, B.N., 1965. Structural evidence for a Palaeozoic orogeny in north-west Malaya. *Geological Magazine* 102:501-520.

Krstic, B., Gubric, A., Ramovs, A. & Filipovic, I., 1988. The Devonian of Yugoslavia. *In*: McMillan, N.J., Embrey, A.F., Glass, D.J. (Ed.s) *Devonian of the World. Proceedings of the*

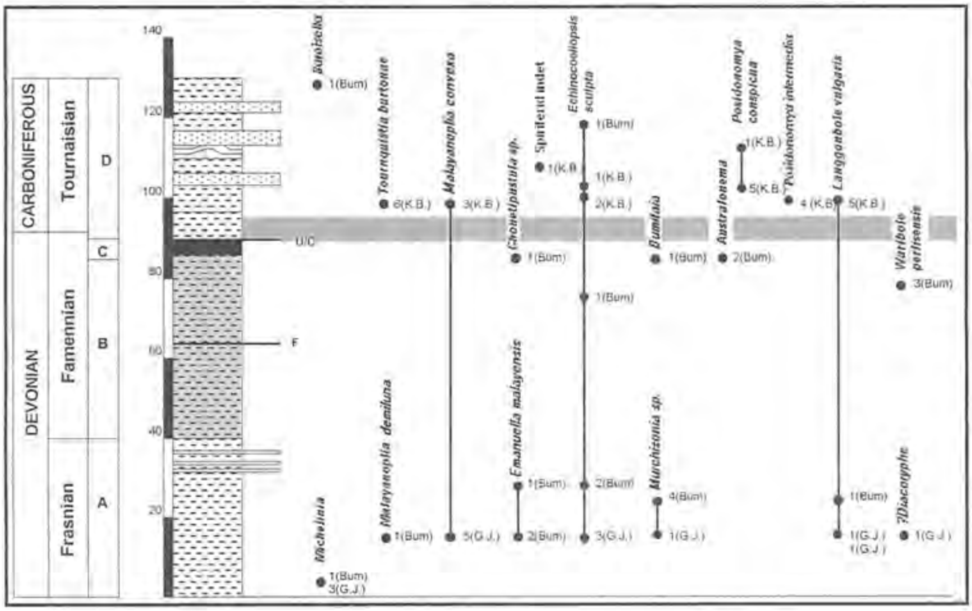

Figure 7. Stratigraphic distribution of major taxa in the mid-Palaeozoic red beds of northwest Peninsular Malaysia. Data plotted next to Bumita Quarry composite section. Bum= Bumita Quarry; K.B.= Kampung Binjal; G.J.= Guar Jentik. Numbers represent number of specimens collected. A=lower part of Unit 3; B=Fammenian beds of lower part; C=Black Mudstone Facies; D=upper part of Unit 3. Scale bar in metres. Legend shown in Figure 3.

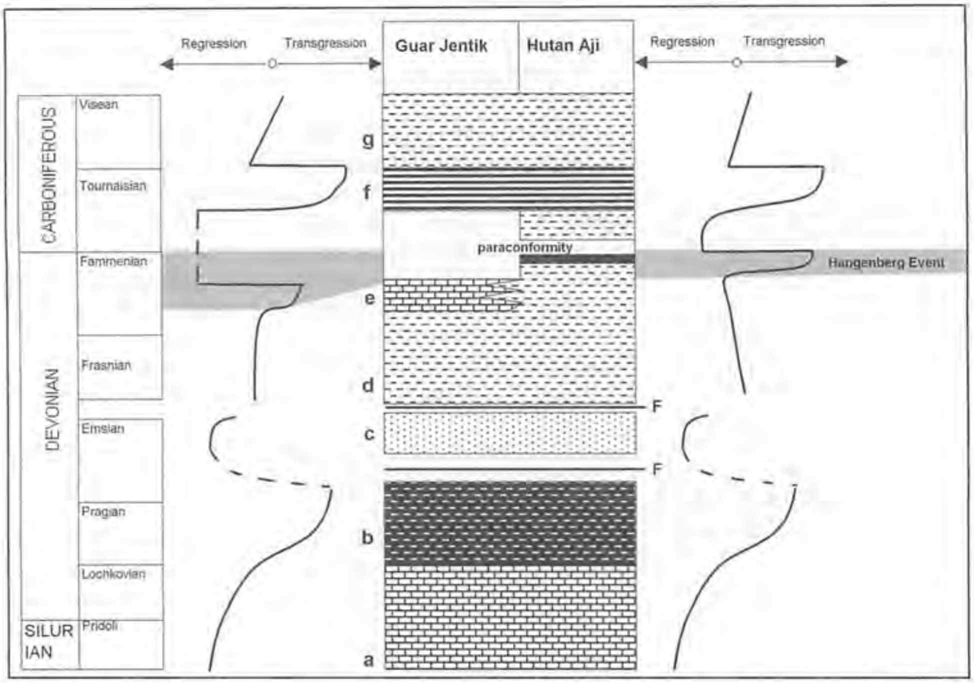

Figure 8. Reconstructed sea - level curves for the Mid-Palaeozoic of northwest Peninsular Malaysia. The left curve is for the Kampung Guar Jentik composite section. The right curve is for the Hutan Aji composite section. a, Upper Setul Limestone; b-g, Jentik Formation; b, Unit 1; c, Unit 2; d, Unit 3 red beds; e, Sanai Limestone; f, Unit 5 chert beds; g, Unit 6, Wang Kelian red beds.

Canadian Society of Petroleum Geologists International Symposium, Devonian System Memoir 14: I, 499-506.

Lee, C.P. & Azhar Hj. Hussin, 1991. The Wang Kelian Redbeds, a possible extension of the Unnamed Devonian Unit (Rebanggun Beds) into Perlis?. (abstract) *In:* GSM Annual Geological Conference, Kuching, Sarawak, 4th & 5th May 1991. *Warta Geologi* 17(3):160.

Meor Hakif Hassan & 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. *Geological Society of Malaysia Bulletin* 45:171-178.

Meor Hakif Hassan & Lee, C.P., 2003. The Sanai Limestone Member – a Devonian limestone unit in Perlis. *Geological Society of Malaysia Bulletin* 46:137-141.

Paproth, E., Feist, R. & Flajs, G., 1991. Decision on the Devonian – Carboniferous boundary stratotype. *Episodes* 14:331-335.

Schonlaub, H.P., 1986. Significant geological events in the Palaeozoic record of the Southern Alps (Austrian part). In: Walliser, O.H. (Ed.) Global Bio-Events: A Critical Approach. *Lecture Notes in Earth Science* 8:163-167.

Tanaka, J. & Maejima, W., 1995. Fan-delta sedimentation on the basin margin slope of the Cretaceous, strike-slip Izumi Basin, southwestern Japan. *Sedimentary Geology* 98:205-213.

Thayer, C.W., 1974. Marine paleoecology in the upper Devonian of New York. *Lethaia* 7:121-155.

Ulmishek, G.F., 1988. Upper Devonian – Tournaisian facies and oil resources of the Russian Craton's Eastern Margin. *In:* McMillan, N.J., Embrey, A.F., Glass, D.J. (Ed.s) *Devonian of the World. Proceedings of the Canadian Society of Petroleum Geologists International Symposium, Devonian System Memoir* 14: I, 527-549.

Wang, K., Attrep Jr., M. & Orth, C.J., 1993. Global iridium anomaly, mass extinction, and redox change at the Devonian – Carboniferous boundary. *Geology* 21:1071-1074.

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):1-9.

Xu, D.Y., Yan, Z., Zhang, Q.W., Shen, Z.D., Sun, Y.Y., Ye, L.F., 1986. Significance of an anomaly near the Devonian/ Carboniferous boundary at Muhua section, South China. *Nature* 321:854-855.

Yancey, T. E., 1972. Devonian fossils from Pulau Rebak Besar, Langkawi Islands, West Malaysia. *Geological Society of Malaysia Newsletter* 37:10-12.

Yancey, T. E., 1975. Evidence against Devonian Unconformity and Middle Paleozoic age of Langkawi Folding Phase in northwest Malaya. *American Association of Petroleum Geologists Bull.* 59:1015-1019.

Zaiton Harun & Basir Jasin, 2000. The occurrence of thrusts in north Kedah and Perlis. *Proceedings, Annual Geological Conference, Geological Society of Malaysia, Shangri-La Hotel, Penang, 8-9 September 2000*, p. 17-20

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