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Facies Analysis of the Uppermost Kubang Pasu Formation, Perlis: A Wave-and Storm-influenced Coastal Depositional System

(Analisis Fasies Turutan Teratas Formasi Kubang Pasu di Perlis: Penafsirannya Sebagai Satu Sistem Pengenapan Pesisir Pantai Kuno yang Dipengaruhi Proses Ombak dan Ribut)

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ABSTRACT

A detailed sedimentological study and facies analysis of the Permian age, uppermost succession of the Kubang Pasu Formation in Perlis was conducted in order to reconstruct the palaeo-depositional environment. Four stratigraphic sections of the uppermost Kubang Pasu Formation were logged at Bukit Chondong and Bukit Tungku Lembu, Perlis. The sections were divided into facies based on lithology and sedimentary structures. Large scale patterns in the form of facies associations and facies successions were also identified. The uppermost Kubang Pasu Formation can be divided into several coarsening upward facies successions. Each facies succession grades upward from an offshore facies association (FA1) composed of bioturbated mudstone and minor thin sandstone, into a distal lower shoreface facies association (FA 2) composed primarily of mudstone interbedded with hummocky cross-stratified sandstone (HCS) and finally a proximal lower shoreface facies association (FA 3) composed of amalgamated hummocky cross-stratified sandstone beds. The facies succession is interpreted as representing a wave- and storm-influenced coastal depositional environment. The gradual transition from siliciclastics to carbonates is probably related to post rift thermal subsidence and tectonic quiescence due to separation of Sibumasu from Gondwana during the Permian.

Keywords: Kubang Pasu Formation; Perlis; Permian; shoreface

ABSTRAK

Satu kajian sedimentologi terperinci dan analisis fasies telah dijalankan ke atas turutan teratas Formasi Kubang Pasu berumur Permian, yang tersingkap di Perlis. Tujuan kajian ini adalah untuk menafsirkan sekitaran pengenapan kuno unit stratigrafi ini. Empat singkapan stratigrafi turutan teratas Formasi Kubang Pasu di Bukit Chondong dan Bukit Tungku Lembu, Perlis, telah dilog. Turutan-turutan ini telah dibahagikan kepada unit-unit fasies berdasarkan litologi dan struktur sedimen. Tren-tren berskala besar (kumpulan fasies dan jujukan fasies juga telah dikenal pasti). Turutan teratas Formasi Kubang Pasu terdiri daripada beberapa jujukan fasies yang mengasar ke atas. Setiap turutan fasies menunjukkan penggredan ke atas daripada kumpulan fasies luar pesisir (FA 1) yang terdiri daripada batu lumpur dan sedikit perlapisan batu pasir yang nipis, ke kumpulan fasies muka pesisir bawah distal (FA 2) yang terdiri daripada batu lumpur yang bersaling-lapis dengan perlapisan batu pasir berstruktur lapis silang membusut (HCS) dan akhirnya ke kumpulan fasies muka pesisir bawah proksimal (FA 3) yang hanya terdiri daripada batu pasir berstruktur lapis silang membusut (HCS). Jujukan fasies ini ditafsirkan sebagai mewakili satu persekitaran enapan pesisir pantai yang dipengaruhi arus ombak dan ribut. Perubahan beransur-ansur daripada pengenapan klastik kepada karbonat yang ditunjukkan oleh turutan teratas Formasi Kubang Pasu mungkin adalah akibat kesan amblesan termal semasa fasa pasca rekahan dan ketiadaan aktiviti tektonik akibat pemisahan Sibumasu dari benua Gondwana pada zaman Permian.

Kata kunci: Formasi Kubang Pasu; muka pesisir; Perlis; Permian

INTRODUCTION

This study focuses on the sedimentology and facies composition of the uppermost beds of the Kubang Pasu Formation, exposed in Perlis, Malaysia, with the objective of determining the palaeo-depositional setting of the succession.

The Palaeozoic stratigraphy of northwestern Peninsular Malaysia has been studied extensively (Cocks et al. 2005; Jones 1981; Meor & Lee 2002, 2005), due to interest in its history as part of a Gondwana-derived continental terrane, called Sibumasu, that rifted away from Australian Gondwana sometime during the Permian (Metcalfe 1984, 2011).

Sedimentological studies have mainly focused on the glaciomarine deposits of the Singa and middle part of the Kubang Pasu Formation (Stauffer & Lee 1986). Detailed sedimentological studies of other stratigraphic units in northwest Peninsular Malaysia are rare and only of a general nature (Meor & Lee 2004). This is unfortunate, as interpretations of depositional models and depositional histories of the Palaeozoic succession of Sibumasu may help provide additional information regarding the tectonic history of the region. The objectives of this study were to conduct a detailed facies analysis of the uppermost Kubang Pasu Formation exposed in Perlis; to interpret the depositional environment of the uppermost Kubang Pasu Formation and to understand the factors that influenced the transition from uppermost Kubang Pasu Formation clastic deposition to Chuping Formation carbonates during the Permian. We describe here the presence of prograding shoreface deposits in the uppermost part of the Kubang Pasu Formation, also known as the 'Passage Beds' (Jones 1981).

GEOLOGICAL SETTING OF THE KUBANG PASU FORMATION

The Kubang Pasu Formation comprises of thick mudstone of various colours interbedded with sandstone. Stratigraphically, it overlies Lower Devonian tentaculitid shales of the Timah Tasoh Formation (Setul Group) and conformably underlies Permian limestone of the Chuping Formation (Jones 1981; Meor & Lee 2005) (Figures 1 and 2). This paper considers the previously named Bukit Raja Member, Chepor and Binjal Formations (*sensu* Meor & Lee 2005) as representing the basal unit of the Kubang Pasu Formation based on the discovery of the fossil *Malayanoplia* at the Bukit Raja Member of Perlis, which is abundant in the Chepor and Binjal Formations and the difficulty in differentiating the units from the Kubang Pasu Formation without any fossil data. Pebbles in the Chepor Formation sandstone resemble the dropstones of the Singa and Kubang Pasu Formation. It is more practical to classify the Bukit Raja Member, Chepor and Binjal Formations of Meor and Lee (2005) as part of the Kubang Pasu Formation. Meor et al. (2012) have now downgraded the units to member rank, with the Bukit Raja Member, Chepor and Binjal Formations of Meor and Lee (2005) now grouped together as the Chepor Member of the lower Kubang Pasu Formation.

The age of the lowermost unit of the Kubang Pasu Formation is Early Carboniferous (Tournaisian -- Visean), based on cyrtosymbolid trilobite assemblages and the presence of a chert unit containing Tournaisian radiolarians at the base of the formation (Basir & Zaiton 2001, 2011; Basir et al. 2003). The uppermost Kubang Pasu Formation is dated as late Early Permian (Kungurian) based on the presence of the fusulinid *Monodiexodina* (Basir & Koay 1990; Ueno 2003).

STUDY AREA AND METHODOLOGY

The study area encompasses two small hills in the Beseri area of Perlis: Bukit Chondong and Bukit Tungku Lembu (Figure 1). The uppermost Kubang Pasu Formation is exposed at both hills, where they are conformably overlain by the Chuping Formation. The facies analysis presented here comprises a three step work flow: description, classification and interpretation. Description includes recording of sedimentological characteristics such as lithology, grain size and primary sedimentary structures. We use the logging method preferred by Anderton (1985) in which sedimentary structures and bedforms are drawn

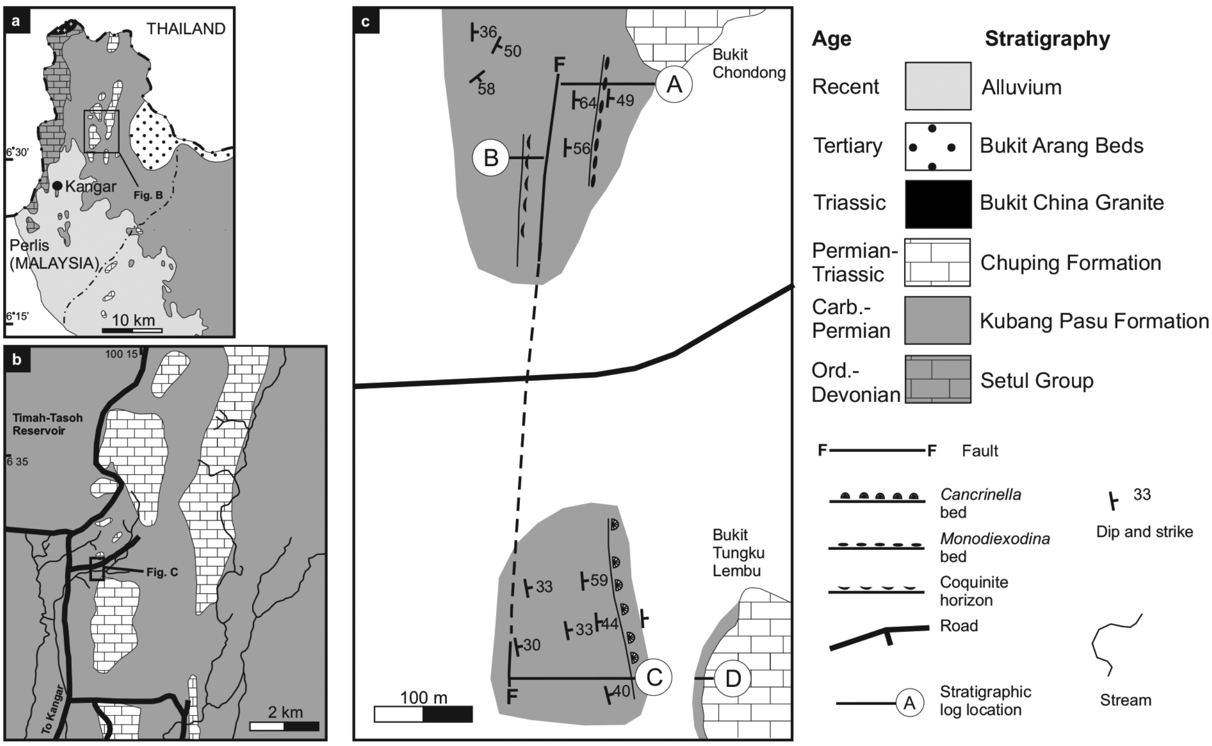

FIGURE 1. Study area. (a) General geological map of Perlis, Malaysia, (b) Geological map of the Beseri area and (c) Close-up of the study location, with stratigraphic sections marked

as detailed and as realistic as possible, so as to minimize any loss of data which would be of value in a detailed sedimentological study. The rocks are then classified into distinct facies. Our use of the term facies is descriptive and follows the definition given in Anderton (1985), i.e. 'A certain volume of rock that can be characterized by a set of features …. that distinguish it from other rock units'. The set of features used here are mainly lithology and sedimentary structures. These facies are then lumped together to form facies associations. The facies associations that are constructed here are interpretative in nature, meaning that each facies association constructed would refer to a certain depositional environment. Facies successions composed of repeatable patterns of stacked facies associations are then identified based on larger scale vertical facies trends.

Four stratigraphic sections were logged (Logs A, B, C and D) (Figure 3). Logs A and B are from Bukit Chondong and separated from each other by a reverse fault. The thickness of the logs are about 75.5 m and 37.8 m, respectively. Logs C and D are from Bukit Tungku Lembu. They are separated from each other by an approximately 70 m gap due to soil cover. The thickness of the logs are approximately 60.9 m and 14.8 m, respectively.

RESULTS: SEDIMENTOLOGY AND FACIES ANALYSIS

FACIES

Eleven facies were recognised in the studied sections of the uppermost Kubang Pasu Formation. The facies and their characterictics are listed in Figure 4. Siliciclastics are dominant, comprising 8 of the facies (Facies M, Stg, Wb, Sr, Sc, Shcs, Sm and Sb). The mudstone facies (Facies M) comprises of dm to m thick mudstone displaying faint, very fine grained sandstone to siltstone laminae, streaks and lenses and moderate to strong bioturbation. The facies is interpreted as representing a combination of quiet water deposition from suspension and occasional distal storm deposition (reflected in the thin silt and sand streaks and laminae). The graded siltstone facies (Facies Stg) comprises of mm to cm thick, sharp based beds displaying normal grading from siltstone displaying undulating lamination and micro-hummocky cross-stratification, into mudstone.

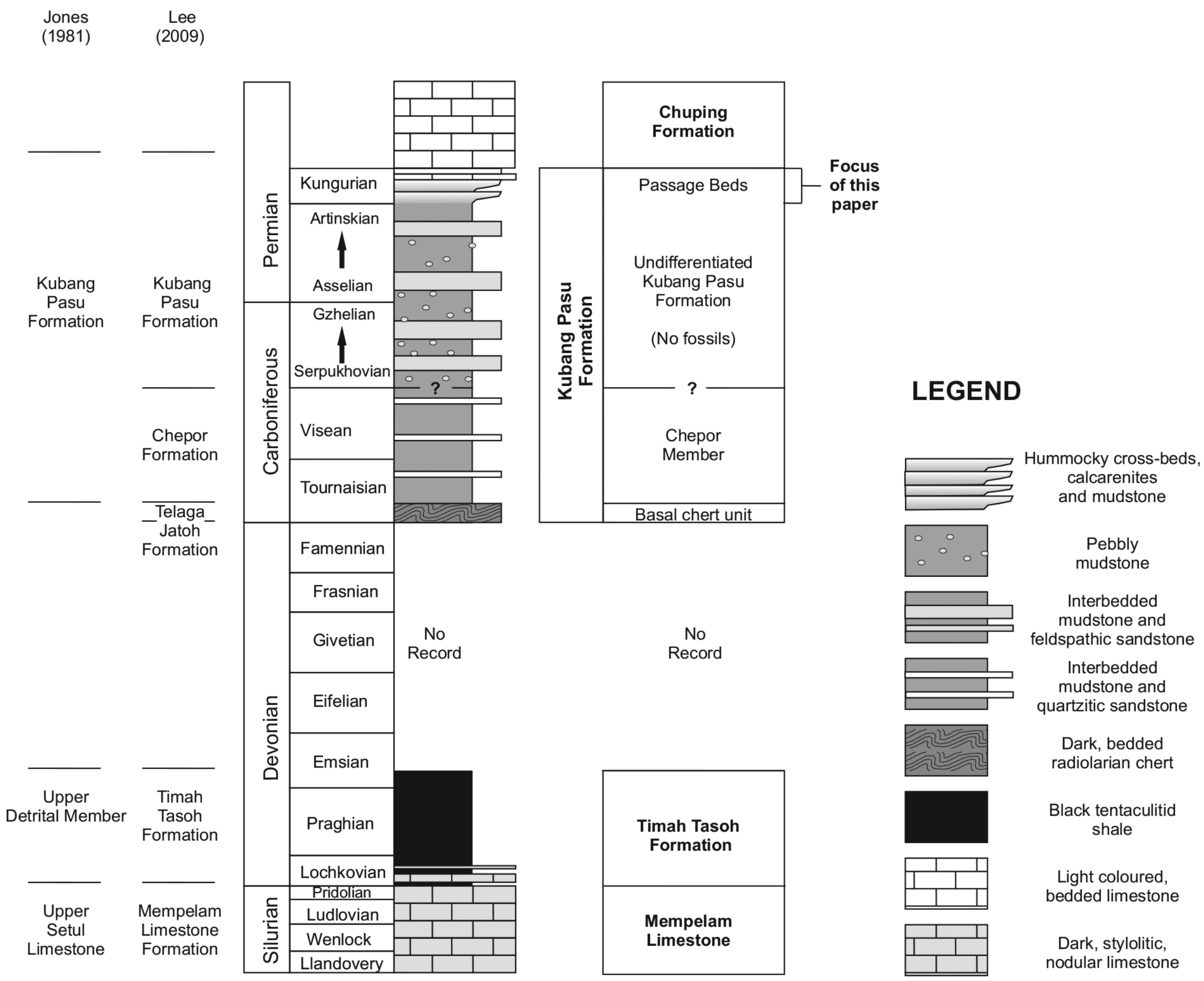

FIGURE 2. Stratigraphic summary of the Palaeozoic of Perlis, Malaysia

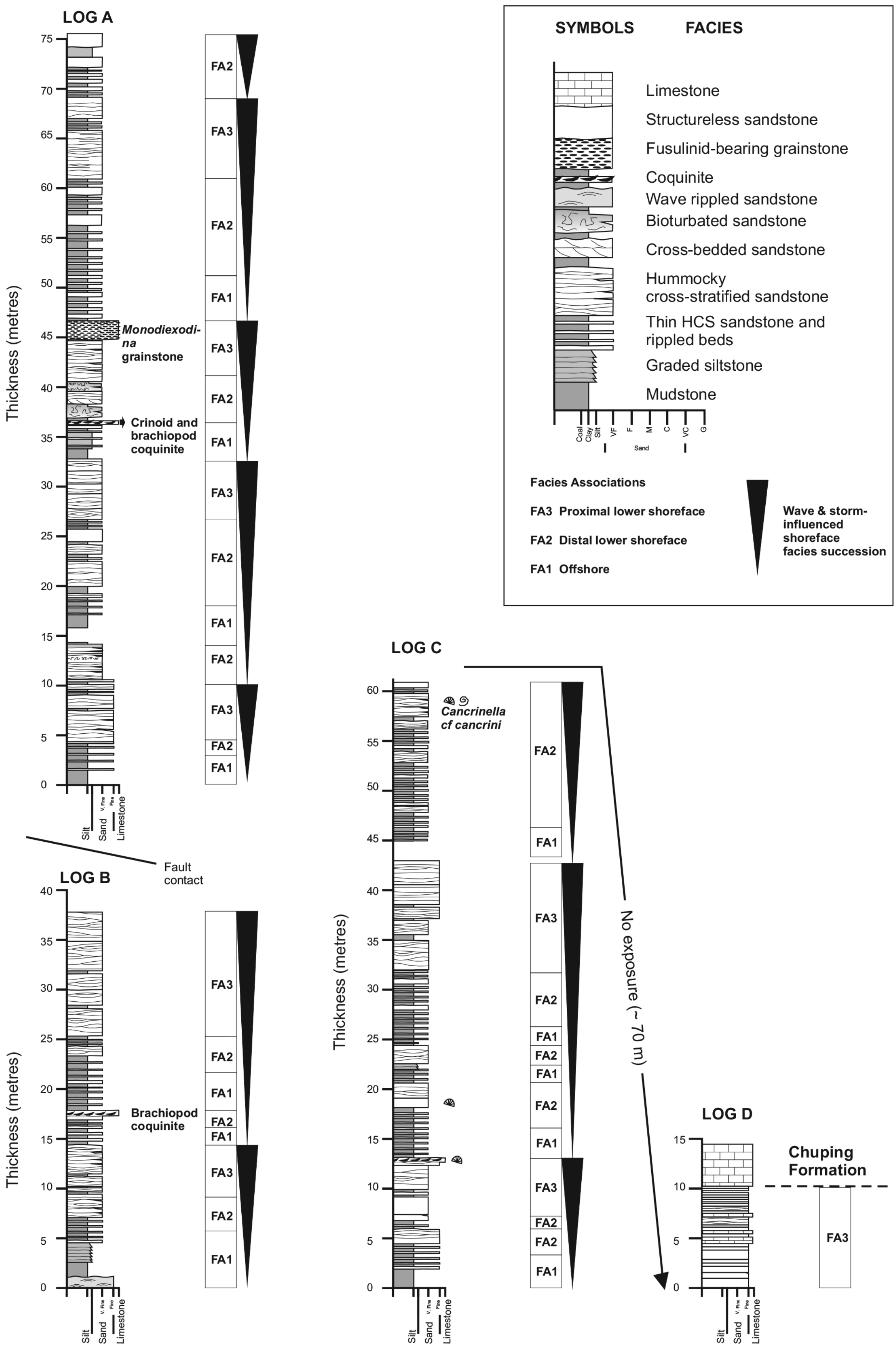

FIGURE 3. Logged stratigraphic sections of the uppermost Kubang Pasu Formation 'Passage Beds', Bukit Chondong and Bukit Tungku Lembu, Perlis. Refer to Figure 1 for locality of measured sections

	Facies	Lithology	Sedimentary Structures	Interpretation
M	Mudstone Dm - m	Carbonaceous or silty mudstone with faint parallel lamination. Displays moderate to strong bioturbation	Occasional sand/silt streaks, organic debris. Moderate-strong bioturbation	Subtidal suspension deposits, fluid muds and occasional thin storm deposits
Stg	Graded siltstone Mm - cm's	Silty mudstone - siltstone - very fine grained sandstone	Normal gradedd beds with basal scour, undulating lamination, micro-hummocky cross-stratification	Subtidal storm deposits
Wb	Wavy bedding Cm's	Very fine to fine grained sandstone with inter-layered mudstone Sand content 40-60%	Sand-mud inter-layering, wavy and flaser bedding. Ripples, thin hummocky and micro-hummocky cross-stratification	Intervals of current, wave or storm flow regularly interspersed with quiet water periods. Subtidal
Sr	Rippled sandstone mm's - cm's	Very fine to fine grained sandstone	Symmetrical and/or asymmetrical ripples	Low energy current or wave transport
Sc	Crossbedded sandstone dm - m	Fine grained sandstone	Trough and tabular crossbedding	Lower flow regime current transport
Shcs	HCS sandstone dm - m's	Very fine - fine grained sandstone	Hummocky cross-stratification (HCS)	Oscillatory or combined flow, storm deposits
Sm	Structureless sandstone dm - m's	Fine - coarse grained sandstone		Intense bioturbation?
Sb	Bioturbated sandstone Dm	Vey fine - fine grained, muddy sandstone	Moderate - intense bioturbation, mottled texture	Periods of quiescence, usually post-storm fairweather period
Cq	Coquinite/shelly limestone cm - dm	Biosparite	Packed shell fragments	High energy current or wave transport. Storm lag deposits
Fs	*Monodiexodina* sandstone m	Carbonate grainstone	*Monodiexodina*, bryozoa and shell particles	High energy current or wave transport
L	Limestone	Limestone		Precipitation and accumulation of skeletal material

FIGURE 4. Summary of the characteristics and interpretation of 11 facies identified in the uppermost Kubang Pasur Formation, Perlis, Malaysia

Facies Stg is interpreted as distal, muddy storm deposits, based on evidence of waning flow (normal grading) and hummocky cross-stratification.

The wavy bedding facies (Facies Wb) is composed of interbedded, cm thick mudstone and very fine to fine grained sandstone displaying ripple cross lamination and micro-hummocky cross-stratification. Facies Wb is interpreted as representing intervals of wave, current and/or storm deposition separated by slackwater intervals. The rippled sandstone facies (Facies Sr) is represented by very fine to fine grained, ripple cross-laminated sandstone beds. Ripple profiles may either be symmetrical or asymmetrical. Facies Sr is interpreted as representing low energy current or wave deposition. The cross-bedded sandstone facies (Facies Sc) comprises dm to m thick, fine grained sandstone beds displaying trough or tabular cross-bedding. These represent higher energy current deposition. The hummocky cross-stratified sandstone facies forms dm to m thick, very fine to fine grained sandstone beds and represent large amplitude oscillatory flow and/or combined flow storm deposition. The structureless sandstone facies (Facies Sm) commonly forms dm to m thick beds of fine to coarse grained sandstone displaying no distinct sedimentary structures. This may be either due to intense bioturbation or poor preservation due to weathering of the exposed surface. The bioturbated sandstone facies (Facies Sb) preserves no sedimentary structures and displays moderate to intense bioturbation. The grain size indicates high energy deposition, while significant bioturbation indicates quiet waters after deposition. Petrographically, the sandstones include poorly sorted feldspar greywacke and quartz wacke, poor to moderately sorted subarkose, well rounded quartz arenites and calcarenites.

Carbonates gradually become more common as the Kubang Pasu Formation grades upward into Chuping Limestone. The coquinite/shelly limestone facies (Facies Cq) forms cm to dm thick beds mainly composed of packed shell fragments. Based on the thin section petrography, the facies is considered a biosparite. Facies Cq is interpreted as representing high energy storm lag deposits. The *Monodiexodina* sandstone facies (Facies Fs) is a grainstone composed of elongate tests of the foraminifera *Monodiexodina*. Facies Fs is also interpreted as representing high energy current or wave deposition. Limestone beds (Facies L) become more common in the uppermost Kubang Pasu Formation. However, the limestone was not studied in detail, but initial observations indicate the presence of hummocky cross-stratified grainstone in the lowermost 10 m of the Chuping Limestone.

FACIES ASSOCIATION

Three facies associations are identified, based on repetitive packages of facies (Figure 5). FA 1: Offshore Facies Association; FA 2: Distal Lower Shoreface Facies Association and FA 3: Proximal Lower Shoreface Facies Association.

FA 1: OFFSHORE FACIES ASSOCIATION

FA 1 is usually less than five m thick and characterised by a coarsening upward trend from thick mudstone into thin interbedded sandstone, siltstone and mudstone (sand:mud ratio less than 0.5). The mudstone displays parallel lamination. Thick mudstone grades upward into mudstone interbedded with cm-thick siltstone layers and cm-thick, rippled sandstone lenses. The mudstone displays moderate to strong bioturbation. The siltstone layers display parallel lamination, with graded laminae. Interbedded mudstone and sandstone overlies the fine grained facies. The sandstone is mm-cm thick, very fine-fine grained and is usually represented by ripple or thin beds displaying hummocky cross-stratification and associated plane parallel lamination (Figure 5(c)).

Interpretation: FA 1 is interpreted as wave- and storm-influenced offshore deposits based on the predominance of mudstone facies with thin sandstone beds displaying wave- and storm-generated structures (hummocky cross-stratification, wave ripples and normal graded lamination). The predominance of mudstone indicates a low energy, quiet water environment, with deposition mainly from suspension. Thin interbedded sandstone and siltstone indicate occasional disturbance by high energy events transporting and depositing coarser material. Sharp based, normal graded siltstone beds probably represent waning flow deposits of either gravity flows or distal storm generated deposits (Aigner 1982; Walker & Plint 1992). Hummocky cross-stratified sandstone or HCS, (Harms et al. 1975) indicates transport and deposition of sand by storms (Dott & Bougeois 1982; Duke 1985). Lateral transition from HCS into plane parallel lamination is common in tempestite beds (Craft & Bridge 1987; Dott & Bourgeois 1982; Quin 2001; 2011).

A depositional setting above storm-weather wave base, but below normal fair-weather wave base (i.e. offshore depositional environment) is supported by the predominance of quiet water suspension deposition with occasional storm deposition.

FA 2: DISTAL LOWER SHOREFACE FACIES ASSOCIATION

FA 2 differs from FA 1 in being sandier. FA 2 ranges between 3-15 m in thickness. The facies association is characterised by frequent interbedding of cm-dm thick, very fine-fine grained sandstone and cm-thick mudstone (Sand: mud ratio about 0.5) (Figure 5(d)). Sandstone beds are sharp-based and display hummocky cross-stratification, which commonly grades laterally into plane parallel lamination. Rare high-angle cross-beds are sometimes present in between HCS beds. The top of HCS beds is capped by a thin, symmetrical ripple layer, before being overlain by cm-thick, bioturbated mudstone (Figure 5(d)). Individual HCS beds pinch out laterally to form lens shaped geometries encapsulated in mudstone. Some beds are composed of ripple cross-lamination. Cm-thick layers of broken brachiopod shell and/or crinoid ossicle fragments (coquinites) are present at certain horizons of FA 2. Thin layers of coquinite are also present at the base of some of the HCS beds (Figure 5(d)). Some intervals display intense bioturbation with sandstone beds being poorly sorted and strongly bioturbated, but with local preservation of relict parallel lamination and HCS bedding.

Interpretation: FA 2 is interpreted as wave- and storm-influenced, distal lower shoreface deposits based on the occurrence of HCS sandstones frequently intercalated with bioturbated mudstone and wave generated ripples. HCS and associated plane parallel laminated sandstone fining upward into wave ripples are interpreted as storm deposits (Dott & Bougeois 1982; Duke 1985; Quin 2011). High sand content in the form of frequent intercalations of storm

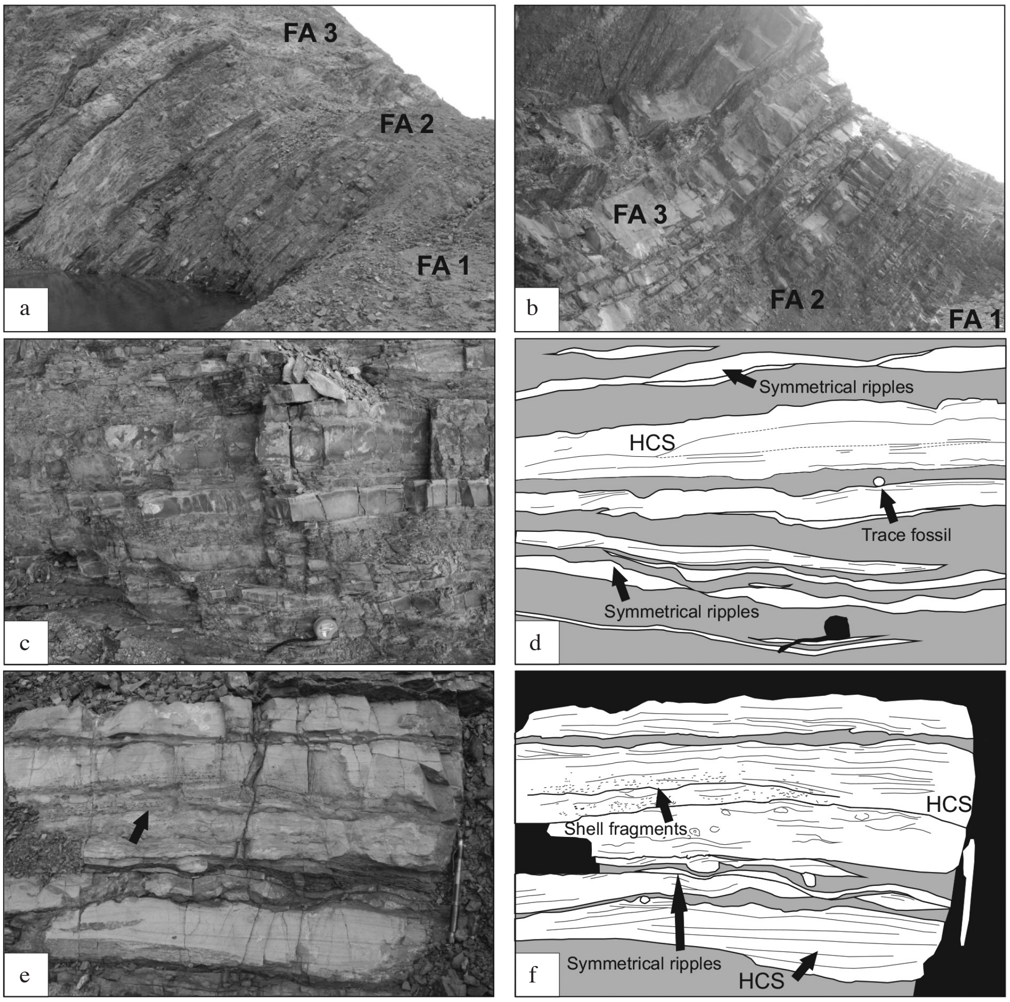

FIGURE 5. Sedimentary facies of the uppermost Kubang Pasu Formation 'Passage Beds'. (a) Coarsening upward shoreface facies succession at Bukit Chondong (interval 0-10m, Log A), (b) Coarsening upward shoreface facies succession at Bukit Chondong (interval 0-15m, Log B), (c) Offshore facies association (FA 1) composed of mudstone interbedded with thin ripple and hummocky cross-stratified sandstone (HCS). Measuring tape case for scale, (d) Sketch of the offshore facies association photo of (c), (e) Distal lower shoreface facies association (FA 2) composed of HCS sandstone and interbedded mudstone. Shell fragments are abundant near the base of a HCS bed (marked and labelled). Pencil for scale and (f) Sketch of (e)

deposits in between mudstone indicates a depositional setting in the shoreface zone. The significant presence of mudstone and siltstone interbedded between the HCS beds indicate that FA 2 represents deposits of the lower shoreface. The high mud content and thin HCS sandstone beds indicate a more distal location on the lower shoreface (distal lower shoreface).

FA 3: PROXIMAL LOWER SHOREFACE FACIES ASSOCIATION

The facies composition of FA 3 is similar to FA 2 but is sandier (sand: mud ratio about 0.8) (Figure 5(a), 5(b)). Cm- to dm-thick, hummocky cross-stratified sandstone beds are amalgamated together to form stacks between 1-10 m thick. Mudstone is only present as mm- to cm-thick layers in between the sandstone. Some of the stacked sandstones appear to be structureless, although some show relict preservation of parallel lamination. Thin sections indicate that these apparently structureless sandstones are quartz arenites. The absence of carbonaceous debris, hematite or muscovite (which forms the visible laminations in the HCS beds) explains the poor preservation of sedimentary structures.

Coquinite layers and lags are present, composed of brachiopod shell and/crinoids ossicles. Limestone beds become more common in the topmost part of the studied section (just 5 m below the Chuping Formation). The limestone is well bedded, bioclastic and petrographically described as biosparite and biosparudite. An approximately 1.5 m carbonate grainstone bed is present at thickness interval 45 m of Log A, Bukit Chondong. The grains are composed of large *Monodiexodina* foraminifera. The bed is described as a parallel laminated sandstone, based on the preferred alignment of *Monodiexodina* tests parallel to bedding.

Interpretation: FA 3 is interpreted as wave- and storm-influenced, proximal lower shoreface deposits based on the occurrence of amalgamated HCS sandstones intercalated with thin bioturbated mudstone and wave generated ripples. HCS is again interpreted as storm deposits (Dott & Bougeois 1982; Duke 1985; Quin 2011). The structureless sandstone may represent strongly bioturbated beds, where sedimentary structures have almost been completely obliterated. The coquinite layers represent winnowed storm lag deposits. The *Monodiexodina* beds are also interpreted as winnowed, shelly storm deposits.

The high sand content and significant presence of mudstone also indicates a lower shoreface depositional environment for FA 3. However, the relatively low mud content of FA 3 compared with FA 2 indicates the FA 3 represents a higher energy, more proximal lower shoreface setting (proximal lower shoreface).

FACIES SUCCESSION

The facies associations of the uppermost Kubang Pasu Formation at Bukit Chondong and Bukit Tungku Lembu form larger-scale facies successions (Figure 3). The facies successions range in thickness between several metres to 25 m. They coarsen upward from the offshore (FA 1), distal lower shoreface (FA 2) to proximal lower shoreface (FA 3) facies association (Figure 3; Figure 5(a), 5(b)). Each facies succession is sharply overlain by a successive coarsening upward facies succession. A thin coquinite layer or a *Monodiexodina* bed caps some of the thinner facies successions.

Interpretation: The facies succession probably represents a prograding wave- and storm-influenced coast, based on the coarsening upward pattern of the facies association and the predominance of wave- and storm-generated facies (Clifton et al. 1971; Plint 2010).

The absence of upper shoreface and beach deposits at the top of the facies successions suggests that facies successions represent distal expressions of the wave-dominated system and were located farther away from the shoreline (Figure 6).

Each individual facies succession represents a genetically related parasequence, indicating a single seaward movement of the shoreline. The sharp tops bounding successive facies successions which are sometimes capped by transgressive lag deposits are interpreted as marine flooding surfaces representing relative rise in sea level.

DISCUSSION

Limestone beds become gradually thicker and more common upsection of the uppermost Kubang Pasu Formation, eventually culminating in thick bedded limestone of the overlying Chuping Formation. The change from siliciclastic to carbonate dominance is gradual and there is no evidence of an unconformity between the two units.

The Chuping Formation has been interpreted as representing temperate-subpolar carbonate deposits formed in a shallow, high energy environment, based on the fossil assemblage, occurrence of detrital grains interpreted as derived from ice-rafting and oxygen and carbon isotope values from brachiopods (Rao 1988).

The transitional succession from the uppermost Kubang Pasu Formation into the Chuping Formation is interpreted as representing gradual depletion of a clastic sediment source, resulting in gradual increase in and eventual dominance of carbonate deposition. This is associated with transgression either due to eustatic or tectonically-driven relative sea level rise. The presence of hummocky cross-stratification associated with the lowermost limestone beds of the Chuping Formation

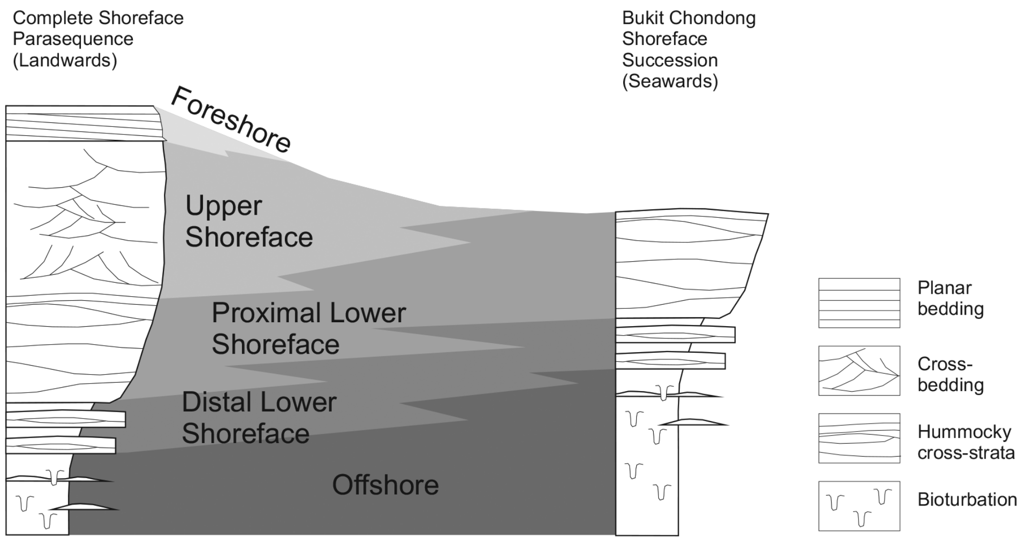

FIGURE 6. Depositional model for the coarsening upward facies successions in the uppermost Kubang Pasu Formation, interpreted as part of a prograding, wave-dominated shoreline. The absence of upper shoreface and beach deposits indicates a more distal, seaward position

at Bukit Tungku Lembu indicates no drastic change in hydrodynamic regime or water depth. This, combined with current understanding of the regional geologic setting strongly suggests that tectonics was the main influence. The region of Perlis is part of the Sibumasu continental terrane which rifted from Gondwana during the Permian (Metcalfe 1984, 2011).

The Late Palaeozoic, diamictite bearing rocks of Peninsular Thailand and northwest Peninsular Malaysia (which includes the Kubang Pasu Formation) have been interpreted as the infill of rift basins formed due to the separation and northward drift of Sibumasu from Gondwana during the Permian (Ridd 2009). The extensional tectonic regime continued after initial break away of Sibumasu from Gondwana. Carbonates of equivalent age to the Chuping Formation also gradually overlie Permian siliciclastics in Peninsular Thailand (Ratburi Limestone) (Baird & Bosence 1993). The Permian carbonates probably represent part of the post rift phase of deposition on a passive continental margin (Read 1985). Post rift subsidence would have resulted in transgression of the shelf. This, combined with clastic supply depletion due to land denudation and cessation of tectonic activity, may have resulted in the transition from clastic to carbonate deposition.

Conclusion

The uppermost Kubang Pasu Formation directly underlying the Chuping Formation in Perlis is exposed at Bukit Chondong and Bukit Tungku Lembu, Perlis. The sedimentary succession is composed of metres to tens of metres thick, coarsening upward siliciclastic parasequences. The parasequences are interpreted as representing prograding, wave- and storm-influenced coastal deposits. The transition from siliciclastics of the Kubang Pasu Formation to carbonates of the Chuping Formation was gradual. The gradual transition is interpreted as probably representing post rift subsidence and transgression and depletion of clastic supply due to tectonic quiescence and denudation.

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