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Sedimentology of the Permian *Monodiexodina*-bearing bed of the uppermost Kubang Pasu Formation, northwest Peninsular Malaysia: Interpretation as storm-generated, transgressive lag deposits

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Abstract: The Permian fusulinoid *Monodiexodena* commonly forms dense accumulations associated with siliciclastic marine strata. The *Monodiexodina*-bearing bed of the uppermost Kubang Pasu Formation of Perlis, northwest Peninsular Malaysia is 0.5 to 1.5 m thick and sharply overlies an approximately 15 m thick coarsening upward succession interpreted as a regressive, wave-influenced, coastal shallow marine parasequence. Petrographic analysis of thin sections indicates that it is a mixed siliciclastic-carbonate, sandy allochem limestone. The grains are predominantly composed of a mixture of *Monodiexodina* tests, bryozoan fragments (*Rhombopora* sp.), brachiopod shells and crinoid ossicles, but with a significant amount of fine-grained quartz grains (up to 27% rock volume). The long axes of the skeletal grains are generally oriented parallel to bedding. The *Monodiexodina*-bearing bed is also characterised by giant, round-crested, symmetrical ripples developed on its bedding plane, with wavelengths of up to 1.6 m and amplitudes of up to 10 cm. Smaller, sharp-crested symmetrical ripples are superimposed on the giant ripples. A cross-section of one giant symmetrical ripple indicates the presence of unidirectional cross-stratification. The giant symmetrical ripples are interpreted as storm-generated, coarse-grained, combined oscillatory and unidirectional current flow bedforms, based on the symmetrical profile, unidirectional cross-stratification and close vertical association with other wave- and storm-generated facies. Giant symmetrical ripples are characteristic of coarse-grained storm deposits (commonly referred to as coarse-grained ripples, or CGR), while hummocky cross-stratification is developed in beds of very fine- to fine-grained sand. Palaeocurrent analysis of the ripple marks on the top surface of the *Monodiexodina*-bearing bed indicates a roughly NW-SE strike orientation for the ripple crests of both the giant and smaller superimposed wave ripples. Modern-day CGRs display ripple crest orientations which are parallel to bathymetric contours, thus it is interpreted that the palaeoshoreline during deposition of the *Monodiexodina*-bearing bed was generally NW-SE, which is consistent with current palaegeographic reconstructions of Sibumasu during the Permian. The stratigraphic position of the *Monodiexodina*-bearing bed sharply overlying a regressive unit or parasequence, and successively being overlain by another parasequence indicates that it is a transgressive deposit overlying a flooding surface, with the predominance of wave- and storm-generated facies indicating wave ravinement.

Keywords: Monodiexodina, Kubang Pasu Formation, transgressive deposits, Permian

INTRODUCTION

The Permian fusulinoidean genus *Monodiexodina* is very distinctive, with a large, elongated, fusiform or subcylindrical shell morphology and strongly but irregularly fluted septa. *Monodiexodina* is of great palaeobiogeographic significance. The genus is antitropical in nature, being restricted to the mid latitudes of the northern and southern hemispheres (Shi *et al*., 1995; Shi & Grunt, 2000; Ueno & Tazawa, 2003; Ueno, 2006). The taxon is normally associated with coarse-grained facies (commonly sandy limestone or calcareous sandstone) where it can occur in dense, sometimes monospecific assemblages (e.g. Amir Hassan *et al*., 2013). These coarse-grained, *Monodiexodina*-bearing beds have generally been interpreted as high energy, current- and/or wave-generated deposits. Unfortunately, few workers have focused on the sedimentary aspect of these *Monodiexodina*-bearing beds. This paper presents a detailed sedimentological study of the *Monodiexodina*-bearing bed of the Permian (Kungurian) Kubang Pasu Formation in Perlis, Peninsular Malaysia, which leads us to interpret them as wave- and storm-reworked, transgressive deposits.

GEOLOGICAL BACKGROUND

Sedimentological descriptions of *Monodiexodina*-bearing beds are rare and, when present, are very general, mainly focusing on the lithology and grain size. An extensive review by Ueno (2006) of the literature on *Monodiexodina* indicates that the taxon occurs exclusively in arenaceous sediment. Some authors record the association of *Monodiexodin*a with what is termed "sandy limestone" or "arenaceous limestone" containing a large amount of detrital quartz grains (e.g. Ingavat & Douglass, 1981; Charlton *et al*., 2002; Ueno & Tazawa, 2003). Many others describe a calcareous sandstone bed (e.g. Basir, 1991; Morikawa, 1960; Morikawa *et al*., 1958; Niwa *et al*., 2004; Ueno & Tazawa, 2004; Ueno & Charoentitirat, 2011). Other *Monodiexodina*-bearing beds have also been described as highly packed, coarse grainstone or rudstone (e.g. Ueno, 2006).

Descriptions of sedimentary structures associated with the *Monodiexodina*-bearing beds are rarer. Kawamura & Machiyama (1995) describe *Monodiexodina*-bearing beds displaying parallel and cross-stratification, while Ueno (2006) describes a *Monodiexodina*-bearing rudstone/grainstone displaying cross-bedding and preferred orientation, including imbrication of tests, from a locality south of Oinlasi, West Timor. Preferred orientation of *Monodiexodina* tests has also been observed in beds from the Kubang Pasu Formation of NW Peninsular Malaysia by Ueno (2006). In summary, the lithology and sedimentary structures of the *Monodiexodina*-bearing beds indicate that they are high energy, current and/or wave generated deposits.

In terms of stratigraphic position, *Monodiexodina*-bearing beds on the Sibumasu Block are associated with transitional successions between an underlying siliciclastic unit and an overlying carbonate unit. In northwest Peninsular Malaysia, the *Monodiexodina*-bearing beds occur as units intercalated between mainly siliciclastic sandstone and mudstone beds, in the uppermost Kubang Pasu Formation (early Permian), directly underlying the Chuping Limestone (Amir Hassan *et al*., 2013). A similar association is also found in age equivalent rocks of adjacent Peninsular Thailand, where the beds are associated with the transitional succession between the mainly siliciclastic Kaeng Krachan Group and overlying Ratburi Limestone (Ueno, 2003; 2006). In northwest Thailand, *Monodiexodin*a-bearing beds are associated with sandstone, mudstone and banded limestone of the Pharaka Formation (Ingavat & Douglass, 1981).

Continued quarrying of an exposed section of the uppermost Kubang Pasu Formation previously described in Amir Hassan *et al*. (2013) has uncovered an aerially extensive *Monodiexidina*-bearing bed with its bedding plane exposed and preserving numerous sedimentary structures. This provides the first glimpse into the detailed internal architecture of the bioclastic beds and helps us in understanding their genesis.

STUDY AREA AND STRATIGRAPHIC FRAMEWORK

The Kubang Pasu Formation is a 1373 m thick, mainly siliciclastic succession comprising quartz and feldspathic sandstone interbedded with thick mudstone of various colours, including red, white, grey, brown and black (Jones, 1981) (Figure 1A). The unit can be divided into 3 general stratigraphic divisions: (1) the basal Chepor Member, which is Carboniferous (Mississippian) in age and characterised by fossiliferous mudstone associated with sandstone, diamictites and dropstones interpreted as glacial marine shelfal deposits; (2) the Undifferentiated upper Kubang Pasu Formation, referring to the poorly exposed siliciclastic succession overlying the Chepor Member and forming the bulk thickness of the Kubang Pasu Formation, and; (3) the uppermost Kubang Pasu Formation, which is late Early Permian (Kungurian-Roadian), based on the presence of *Monodiexodina shiptoni* (Basir & Koay, 1990; Ueno, 2003; 2006). The uppermost Kubang Pasu Formation represents the transitional beds between the siliciclastic Kubang Pasu Formation and the overlying Chuping Limestone (Amir Hassan *et al*., 2014).

This study focuses on two sections of the uppermost Kubang Pasu Formation exposed at two small hills in the Beseri area of Perlis state, northwest Peninsular Malaysia: (1) Bukit Chondong and; (2) Bukit Tungku Lembu (Figure 1C). The two sections are located close to each other (less than 300 m distance) and show the uppermost Kubang Pasu Formation being conformably overlain by carbonates of the Chuping Limestone. The strata generally strike NNW and dip gently (30-59 degrees) towards the east. The thickness of the sections are approximately 75.5 m for Bukit Chondong and 37.8 m for Bukit Tungku Lembu (Figure 2). Amir Hassan *et al*. (2013) conducted a detailed facies analysis of the two sections. The facies are dominated by wave- and storm-generated deposits (Hummocky cross-stratification, symmetrical ripples, normal graded beds, shelly lag deposits), with associated cross-bedding. Mudstone facies are strongly bioturbated with a marine trace fossil assemblage, including *Palaeophycus*, *Skolithos*, *Thalassinoides* and *Taphrhelminthopsis*. The strata are arranged into several coarsening upward cycles up to 25 m thick, composed of interpreted Offshore and Lower Shoreface Facies Associations. The coarsening upward cycles are interpreted as distal coastal parasequences developed on a wave- and storm-influenced marine shelf (Amir Hassan *et al*., 2013).

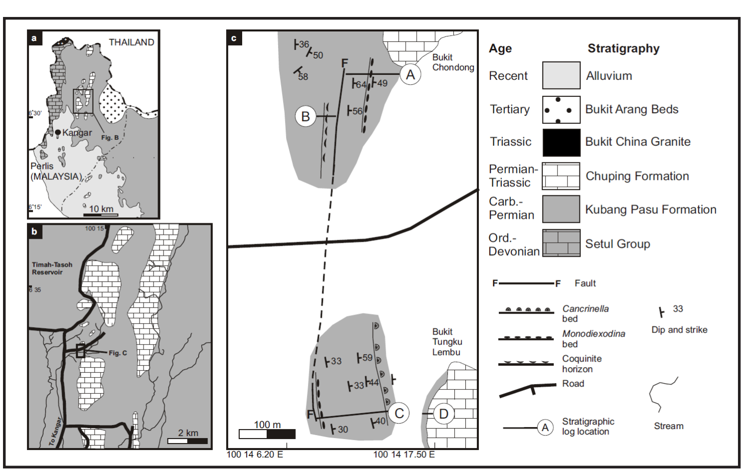

Figure 1: Study area. (a) General geological map of Perlis, Malaysia, (b) Geological map of the Beseri area and (c) Close-up of the study location, with stratigraphic sections marked. Modified from Amir Hassan *et al*. (2013).

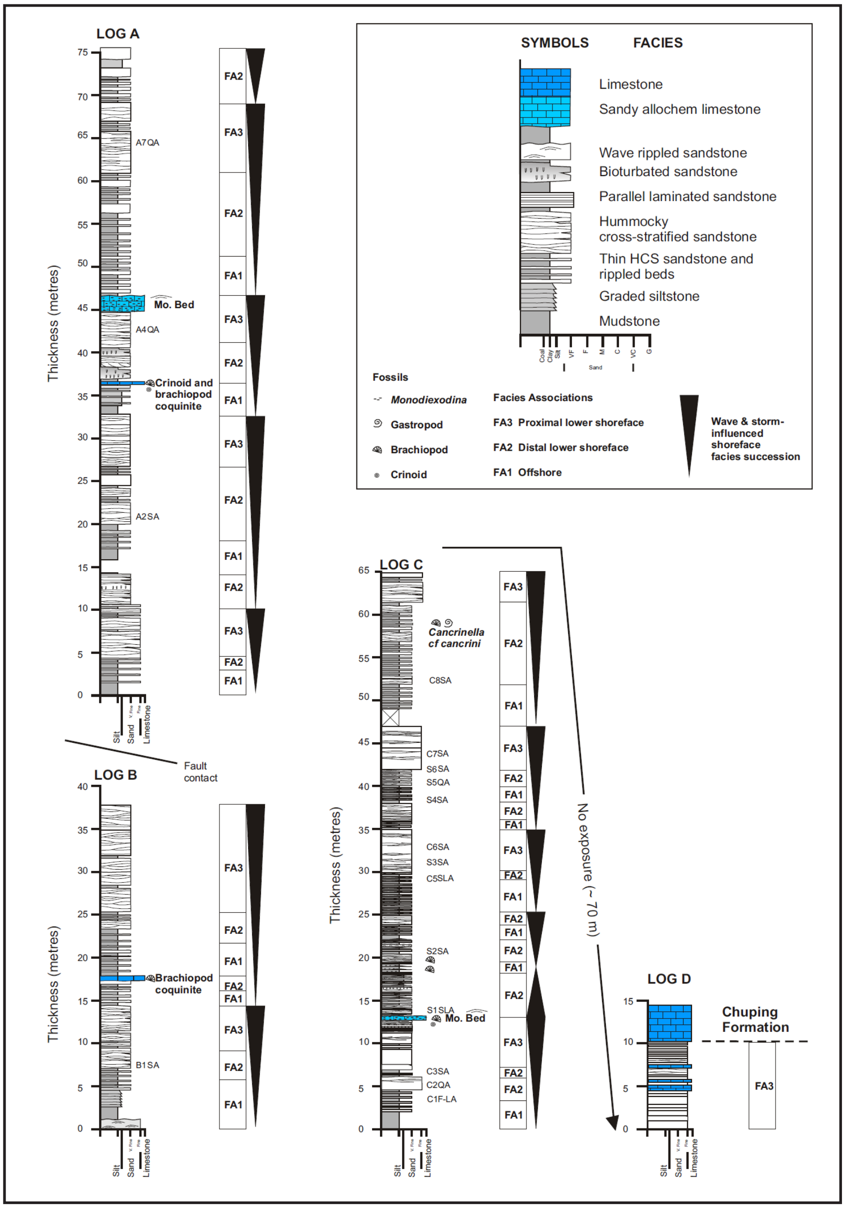

Figure 2: Logged stratigraphic sections of the uppermost Kubang Pasu Formation 'Passage Beds', underlying the Chuping Limestone at Bukit Chondong and Bukit Tungku Lembu, Perlis. Refer to Figure 1 for locality of measured sections. Logs refined and modified from Amir Hassan *et al.* (2013).

A *Monodiexodina*-bearing sandstone bed was reported from the top part of the section at Bukit Chondong (Amir Hassan *et al*., 2013). The bed was poorly exposed and of limited lateral extent, but displayed an undulating upper surface (Figure 3A). No internal sedimentary structures were described from the poor exposure, but the *Monodiexodina* tests displayed preferred orientation. The *Monodiexodina*-bearing bed was previously not observed at the adjacent Bukit Tungku Lembu section. However, continued quarrying and disintegration of the section has exposed the bed, including a wide area of the bedding plane, which preserves abundant sedimentary structures (Figure 3B-D). This provided an opportunity to study the sedimentological characteristics of the *Monodiexodina*-bearing bed in detail.

METHODS

The results of the detailed facies analysis conducted by Amir Hassan *et al*. (2013) were used as the geologic and stratigraphic framework for the current study. The previous logs were refined based on additional sedimentological data collected during recent fieldtrips. Samples of the *Monodiexodina*-bearing sandstone bed were collected and 9 thin sections were prepared for petrographic analysis under a polarizing microscope. Sedimentary structures associated with the bed were recorded and described. The orientation of ripple crests preserved on the tilted bedding plane were recorded using a compass clinometer and mapped using photogrammetric analysis (Agisoft Photoscan). The ripple crest orientation readings were then corrected to horizontal. The angle value normal to the crest orientations were interpreted as the direction of wave approach that produced the ripples. All measured ripple crest orientations were plotted on rose diagrams in order to identify the general palaeoshoreline orientation. A similar method was also used to study the preferred orientation of *Monodiexodina* tests on the bedding plane. The sedimentological characterististics,

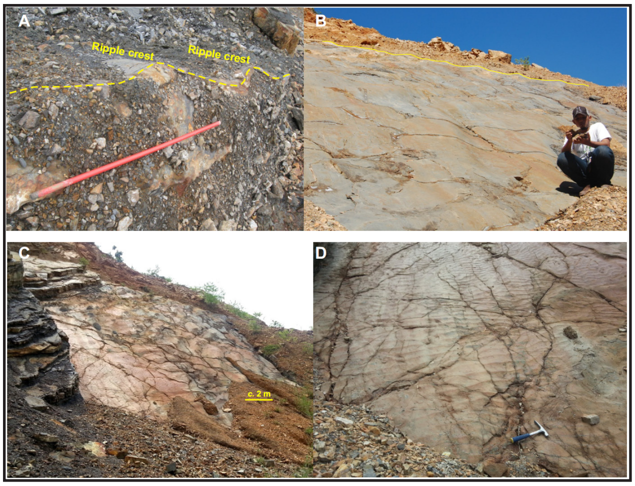

Figure 3: Outcrop photos of the *Monodiexodina*-bearing bed, uppermost Kubang Pasu Formation, Perlis. (A) Cross-section of the bed at Bukit Chondong, showing symmetrical ripple profile, Jacob staff is 1.3m long. (B) Close-up view of the bedding plane at Bukit Tungku Lembu, showing the undulating surface comprising giant ripple marks. (C) Overall view of the bedding plane exposed at Bukit Tungku Lembu. (D) Small symmetrical wave ripples superimposed onto the giant symmetrical ripples at Bukut Tungku Lembu.

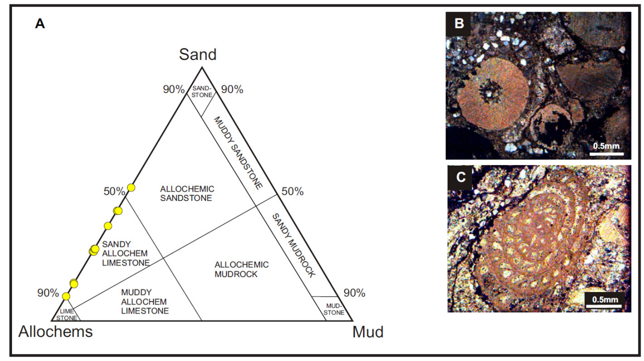

Figure 4: Petrography of the *Monodiexodia*-bearing bed. (A) One side of Mount's (1985) tetrahedra for classification of mixed siliciclastic and carbonate sediments, with sand, carbonate allochem and mud end-members. Most of the thin sections plot as sandy allochem limestone, with quartz grains making up more than 10% of the rock (yellow points). (B) Thin section from Bukit Tungku Lembu described as grainstone, with crinoid ossicles. Quartz grains make up only 6% of the rock. (C) Thin section from Bukit Tungku Lembu described as sandy allochem limestone, with *Monodiexodina* test and associated bryozoa and crinoid fragments. Quartz grains make up 27.5% of the rock.

petrographic data and ripple crest orientations were then integrated to construct a depositional model for the *Monodiexodina*-bearing bed.

RESULTS

Facies and facies relationships

Geologic mapping and correlation between the two logged sections indicate that both *Monodiexodina*-bearing beds are laterally equivalent to each other (Figure 2). Thus, at outcrop scale, the *Monodiexodina*-bearing bed is laterally continuous for at least 700 m. There is some difference in the thickness of the bed between the Bukit Chondong and Bukit Tungku Lembu sections. The bed is 1.5 m thick at Bukit Chondong, but is approximately 0.5 m thick at Bukit Tungku Lembu. Thus, it appears that the bed is thinning towards the south.

The *Monodiexodina*-bearing bed is stratigraphically positioned at the top of an approximately 15 m thick, coarsening upward, wave-and storm-influenced, distal coastal parasequence, about 128 m below the Chuping Limestone. The contact between the lower shoreface deposits and overlying *Monodiexodina*-bearing bed is sharp.

Using Mount's (1985) classification for mixed siliciclastic and carbonate sediments, the *Monodiexodina*-bearing bed is classified as a sandy allochem limestone, based on the high amount of quartz sand grains (>10%) and the absence of mud (Figure 4). However, the concentration of skeletal grains in some parts of the bed reaches 90% and can be classified as a grainstone (Dunham, 1962) or biosparite (Folk, 1962), while in other parts, quartz sand grain content can exceed 50% (allochemic sandstone, Mount, 1985)

Skeletal grains, in the form of *Monodiexodina* tests, bryozoan fragments (*Rhombopora* sp.), brachiopod shells and crinoid ossicles make up between 17-54% of the rock volume (Figure 4B, C). There is also a significant amount of siliciclastic quartz grains (6-27%). The interparticle areas are filled in with fine-grained, sparry calcite cement (37-61%) and minor iron cement (3-12%).

The *Monodiexodina* tests reach 16 mm in length, with a diameter of up to 3 mm (Figure 4C). Bryozoan fragments can reach up to 4 mm long. The skeletal grains generally have their long axes oriented parallel to bedding. The siliciclastics are composed of fine-grained quartz sand. The grains typically display angular to subangular roundness, although sub-rounded grains are also present in some thin sections.

Sedimentary structures and bedforms

The *Monodiexodina* tests in the studied bed show preferred orientation with their long axes parallel to bedding. The bedding plane surface exposed at Bukit Tungku Lumbu preserves two types of sedimentary structures: (1) small symmetrical ripples, and; (2) giant symmetrical ripples.

Giant symmetrical ripples

Very large symmetrical ripples cover the top surface of the *Monodiexodina*-bearing bed at Bukit Tungku Lembu (Figures 3A-C, 5A). The ripples display wavelengths of up to 1.6 m and wave amplitudes of up to 10 cm. The wave crest is rounded, while the troughs in between are flat. A broken piece of one giant symmetrical ripple displays the presence of unidirectional, low angle cross-stratification, distinctly marked by aligned and dipping *Monodiexodina* tests (Figure 5B). The cross-stratification foresets dip 10-11 degrees. However, the actual foreset dip orientation could not be determined due to it being a broken piece. The ripples are continuous at the outcrop scale, forming a sinuous pattern

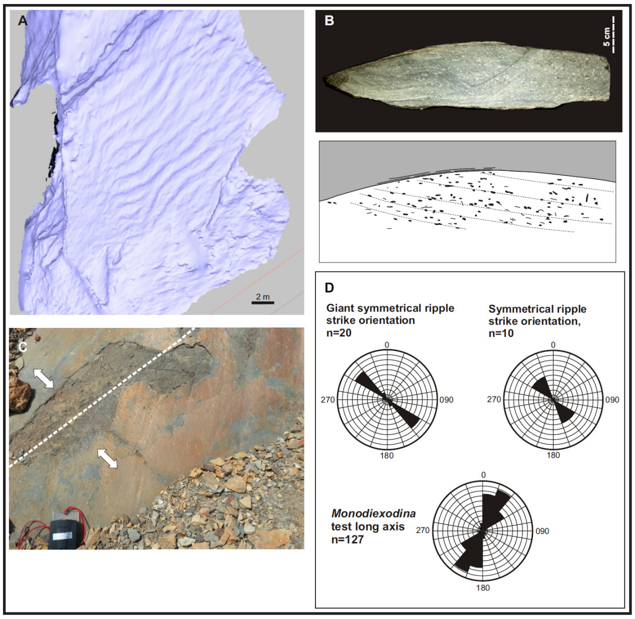

Figure 5: Directional data from the bedforms on the *Monodiexodina*-bearing bed at Bukit Tungku Lembu, Perlis. (A) Three-dimensional photogrammetric model of the bedding plane, showing the sinuous and bifurcating pattern of the giant symmetrical ripples. (B) Cross-section of one giant symmetrical ripple, showing the symmetrical ripple and rounded crest. Sketch below the photo shows the preferred and dipping orientation of many of the *Monodiexodina* tests, forming cross-stratification. (C) Top view of one giant symmetrical ripple, with *Monodiexodina* tests showing preferred orientation normal to crest strike. Wave crest strike marked by dashed line. Arrows mark orientation of *Monodiexodina* test long axes. (D) Clockwise from top left: orientation of giant ripple crests generally trending NW-SE; orientation of smaller symmetrical ripple crests again trending NW-SE, and; orientation of *Monodiexodina* test long axes, generally trending NE-SW.

with bifurcations (Figure 5A). Twenty ripple crest orientations of the giant symmetrical ripples were collected, corrected to horizontal and plotted on a rose diagram, based on direct observations and photogrammetric analysis. The readings indicate that the ripple crests generally strike NW-SE (Figure 5D). As the giant ripples are symmetrical, this indicates that wave propagation was either in a NE or SW direction.

Small symmetrical ripples

Smaller symmetrical ripples are superimposed on the giant symmetrical ripples at the top surface of the *Monodiexodina* bed at Bukit Tungku Lembu (Figure 3D). The small ripples are sharp and straight crested, with trochoidal troughs. The ripples are also sinuous with bifurcations. Ripple wavelengths range between 10-14 cm. A rose diagram plotting ripple crest orientations from 20 small symmetrical ripples along the top surface of the *Monodiexodina*-bearing bed indicate a general NW-SE strike, after horizontal correction of the bed (Figure 5D). This indicates that wave movement was also either in a NE or SW direction for the small symmetrical ripples, which is parallel with the wave movement of the giant symmetrical ripples.

Preferred orientation of *Monodiexodina* tests

The *Monodiexodina* tests in outcrop and thin section generally show preferred orientation, with their long axes oriented parallel to bedding. General observations also show that most of the tests have their long axis oriented normal to the giant ripple crest strike (Figure 5C). The long axis orientation of 127 *Monodiexodina* tests were measured from a small area of the *Monodiexodina*-bearing bedding plane at Bukit Tungku Lembu. The tests have their long axes oriented NE-SW, i.e. normal to the strike of the giant ripple crests (Figure 6D).

SEDIMENTOLOGICAL INTERPRETATION OF THE *MONODIEXODINA*-BEARING BED

The giant symmetrical ripples at Bukit Tungku Lembu are identified as wave-formed, coarse-grained ripples. The symmetrical profile of the ripples is consistent with a wave-generated bedform interpretation (de Raaf *et al*., 1977). Despite being large bedforms, the *Monodiexodina*-bearing bedforms are not 'dunes', as they were not formed by moderate velocity unidirectional currents (Ashley, 1990). Giant symmetrical ripples, with amplitudes of between 70-200 cm are interpreted as high energy wave/combined flow generated bedforms associated with storm deposition (Leckie, 1988). Hummocky bedding, which displays hummocky cross-stratification (HCS) in cross-section, is commonly associated with fine-grained storm deposition (very fine- to fine-grained sand). However, HCS does not form in coarser-grained sediment. Giant, two dimensional symmetrical ripples form when the grain size is coarser (medium- to coarse-grained sand to gravel) (Cheel & Leckie, 1993; Dumas *et al*., 2005; Cummings *et al*., 2009). Leckie (1988) coined the term "coarse-grained ripples" (CGR) for these large symmetrical ripples composed of a coarse sand or gravel lithology, consisting of any type of mineral composition (carbonate debris, volcanic debris, biogenic debris, terrigenous clastics). His survey indicates that modern CGR have been observed on transgressive, relict Pleistocene deposits on the continental shelf and upper shoreface depositional environments. A detailed survey of modern-day CGR by Leckie (1988) indicate that they occur as irregular gravel patches or linear stripes normal to shoreline and bounded by finer grained sand. Water depth is variable, between 3-160 m. Modern-day CGR do not require extremely large storms to produce.

Some interpretations regarding wave movement and palaeogeography can be extracted from the symmetrical ripple crest orientatons. Wave ripple crest orientation is generally perpendicular to wave approach. However, the presence of bottom currents, Coriolis effect and local topography may modify their orientation (Swift *et al*., 1983; Allen, 1997). Modern-day CGRs display average ripple crest orientations which are parallel to local bathymetric contours and therefore, shoreline trends. This is due to refraction of approaching waves reaching shallow waters. Thus, it can be interpreted that the local palaeoshoreline during deposition of the *Monodiexodina*-bearing bed had a generally NNW-SSE orientation. This is consistent with current palaeogeographic reconstructions of the Sibumasu Block facing Palaeo-Tethys during the Permian, with the coastline roughly parallel to the present-day long axis of the Malay Peninsula (e.g. Metcalfe, 2013). The smaller wave ripples superimposed onto the CGRs at Bukit Tungku Lumbu were probably formed during the waning period of storm deposition.

Preferred orientation of *Monodiexodina* tests

The *Monodiexodina* tests from the *Monodiexodina*-bearing beds display preferred orientation, with the long axis parallel to bedding plane. The long axes are also generally oriented perpendicular to ripple crest orientation. This is somewhat counterintuitive, as studies of shell orientation indicate that the long axis of elongate shells tend to be parallel to ripple crest orientation if the deposit has been modified by waves (e.g. Nagle, 1967; Futterer, 1982). Elongate shells or grains oriented perpendicular to ripple crest orientation are common in current-modified deposits (e.g. Rusnak, 1957; Nagle, 1967; Futterer, 1982).

However, the relationship between elongate shell orientation and wave ripple orientation is probably not straightforward, as orientation of the tests may be influenced by numerous factors, including shell composition, density, ornamentation and asymmetry.

Another more likely explanation is that there was a significant current influencing the formation of the giant symmetrical ripples, suggesting that the giant ripples are combined-flow storm bedforms, rather than produced from a purely oscillatory wave motion. The combination of slow, unidirectional geostrophic flows formed from wind stress on the sea surface, and rapid oscillatory flow produced by wave motion propagating on the seabed, have been used to explain the formation of hummocky cross-stratification (e.g. Hunter & Clifton, 1982; Swift *et al*., 1983; Allen, 1985; Nøttvedt & Kreisa, 1987).

Depositional setting

The *Monodiexodina*-bearing bed at Bukit Chondong and Bukit Tungku Lembu is interpreted as a wave-reworked, transgressive lag deposit, based on the predominance of storm-generated, combined flow facies and associated oscillatory wave-generated facies and its stratigraphic position sharply overlying a coarsening upward parasequence on overlying shales of a successive parasequence.

The sharp base of the *Monodiexodina*-bearing bed indicates that it represents an erosive surface. The predominance of wave generated structures overlying the erosional surface suggests erosion by wave- and storm-related combined flow processes. This is consistent with the genetic association of the bed with underlying and overlying, wave- and storm-influenced facies (Amir Hassan *et al*., 2013). Thasinee Charoentitirat (personal communication, 2013) also reported that *Monodiexodina*-bearing intervals in the Pharaka Formation of Western Thailand are also associated with hummocky cross-stratified storm beds.

The *Monodiexodina*-bearing bed is stratigraphically positioned at the top of a coarsening upward coastal parasequence and underlying offshore mudstone of a successively overlying, coarsening upward parasequence (Amir Hassan *et al*., 2013). Thus, the *Monodiexodina*-bearing bed directly underlies a flooding surface representing transgression between 2 regressive units or parasequences (Van Wagoner *et al*., 1990). Coarse-grained, wave- or current-winnowed deposits are commonly associated with transgressive or flooding surfaces, and are known as transgressive lag deposits. The predominance of wave- and storm-generated facies in the *Monodiexodina*-bearing bed leads to the interpretation of the basal erosion surface as a wave ravinement surface, again associated with transgression (Posamentier & Allen, 1999; Cattaneo & Steel, 2003). Thus, the *Monodiexodina*-bearing bed probably represents the winnowed coarser-grained material of a transgressive shoreface deposit subsequently destroyed by wave ravinement associated with continued transgression. This is consistent with the observation that modern-day, coarse-grained ripples are most commonly associated with transgressive sands on the continental shelf composed of relict Pleistocene sediment reworked during the Holocene eustatic sea level rise (Leckie, 1988).

Previous workers have already mentioned the allochthonous nature of the *Monodiexodina* accumulations (Igo, 1989; Uneo 2006). The exclusive association of *Monodiexodina* with arenaceous sediments suggest that the genus was adapted to a high energy, shallow marine environment, possible sand shoals or beaches (Igo, 1989; Ueno, 2006).

CONCLUSIONS

Fossils of the Permian fusulinoid *Monodiexodina* are concentrated in an up to 1.5 m thick bed overlying a wave- and storm-influenced, coastal parasequence in the uppermost Kubang Pasu Formation of Perlis. Petrographically, the *Monodiexodina*-bearing bed is classified as a sandy allochem limestone, with a significant amount of siliciclastic grains (>10%) forming the rock framework. The bed is characterised by giant symmetrical ripples with internal unidirectional cross-stratification, interpreted as representing coarse-grained, combined-flow bedforms associated with storm deposition. Strike readings from the giant coarse-grained ripple and smaller, superimposed wave ripple crests indicate a roughly NW-SE palaeoshoreline configuration. The *Monodiexodina*-bearing bed represents a wave- and storm-reworked, transgressive lag deposit overlying a regressive coastal parasequence.

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