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Early Permian sequence from Sungai Itau quarry, Langkawi: its age, depositional environment and palaeoclimatic implication

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Abstract: A sequence of thickly bedded sandstone, massive mudstone, silty shale and massive sandstone exposed at a quarry in Kampung Sungai Itau, Langkawi is described herein. In the lower part, sandstone with calcareous horizons is rhythmically interbedded massive black pebbly mudstone or diamictite indicates sea level fluctuation influenced by glaciation and deglaciation of the Gondwana supercontinent. The deposition took place in the outer shelf. The silty shale yields an Early Permian (late Asselian-Sakmarian) brachiopod assemblage of strong Gondwanan affinity. The massive sandstone on the top part of the section represents a storm deposit.

Abstrak: Makalah ini memperihalkan mengenai jujukan lapisan tebal batu pasir, batu lumpur masif, syal berlodak dan batu pasir masif yang tersingkap di kuari Kampung Sungai Itau, Langkawi. Di bahagian bawah jujukan, batu pasir dengan lapisan berkapur berselang berirama dengan batu lumpur masif hitam berpebel atau diamiktit menunjukkan perubahan aras laut yang dipengaruhi pengglasieran dan pencairan glasier di superbenua Gondwanaland. Pengenapan batu lumpur berpebel ini berlaku di pelantar luar. Syal berlodak mengandungi himpunan brakiopod berusia Perm Awal (akhir Asselian-awal Sakmarian) yang banyak kesamaan dengan fauna Gondwana. Batu pasir masif di bahagian atas jujukan Sungai Itau merupakan enapan ribut.

INTRODUCTION

Although the Singa Formation is largely exposed on the Langkawi main island, very little is known about its geological section and the depositional environment in this area. This was mainly due to the lack of fresh rock outcrops in the Langkawi main island in the past. Gobbett (1973) and Jones (1981) described the Singa Formation based mainly on the coastal exposures of small islands in the southwestern part of Langkawi Islands. Ahmad Jantan (1973, unpublished) subdivided the Singa Formation based on the natural outcrops at Pulau Rebak, Pulau Kentut, Pulau Ular and Pulau Selang. Stauffer & Lee (1986) also described the pebbly mudstone sequence of the Singa Formation from these natural exposures. On Langkawi main island, valuable information on various aspects of the Singa Formation were only recently exposed at several road cuts, quarries and construction sites following recent rapid infra-structural development of the island.

The areas in the north and northeastern flank of Gunung Raya has been marked by Gobbett (1973) and Jones (1981) as part of the Singa Formation, but no detail information given. Later, Basir Jasin *et al.* (1992) described the bryozoan limestone exposed at Kilim Quarry as part of an undifferentiated Singa Formation, regarding them as a transition bed from the Singa Formation to the overlying Chuping Limestone. Mohd Shafeea Leman (1996), however, discovered that the Kilim brachiopod fauna is very closely related with pebbly mudstone of possible marine glacial origin, and that the brachiopod faunal assemblage has a very strong affinity with the Early Permian Gondwanan fauna. Mohd Shafeea Leman (1997), Mohd Shafeea Leman & Shi (1998) and Shi *et al.* (1997) correlated the Kilim Quarry section as part of the Selang Member, based on the age and the presence of pebbly mudstone in the sequence.

An active earth quarry at Kampung Sungai Itau exposed an excellent lithological section, comprised of sandstone interbedded with mudstone, silty shale and limestone. Several sedimentary facies are recognised within this quarry section, the assemblage of which indicates an offshore marine depositional environment greatly influenced by the fluctuation of sea level. This sea level fluctuation could be closely related with the changes in palaeoclimatic condition of the Langkawi islands during the deposition. The age of the Sungai Itau section is Early Permian (late Asselian-early Sakmarian), based on the brachiopod assemblage found in the middle part of the section. This paper will describe the sedimentary facies and discuss their depositional environment as well as their bearing on the palaeoclimatic changes in Langkawi Islands during the Early Permian time.

SUNGAI ITAU SECTION

The Kampung Sungai Itau earth quarry is located in the southwest of Kampung Sungai Itau, about 500 m from the Kampung Sungai Itau-Durian Perangin road junction (see the insert map in Fig. 1). The Sungai Itau quarry operation cut almost the entire northwestern tip of the

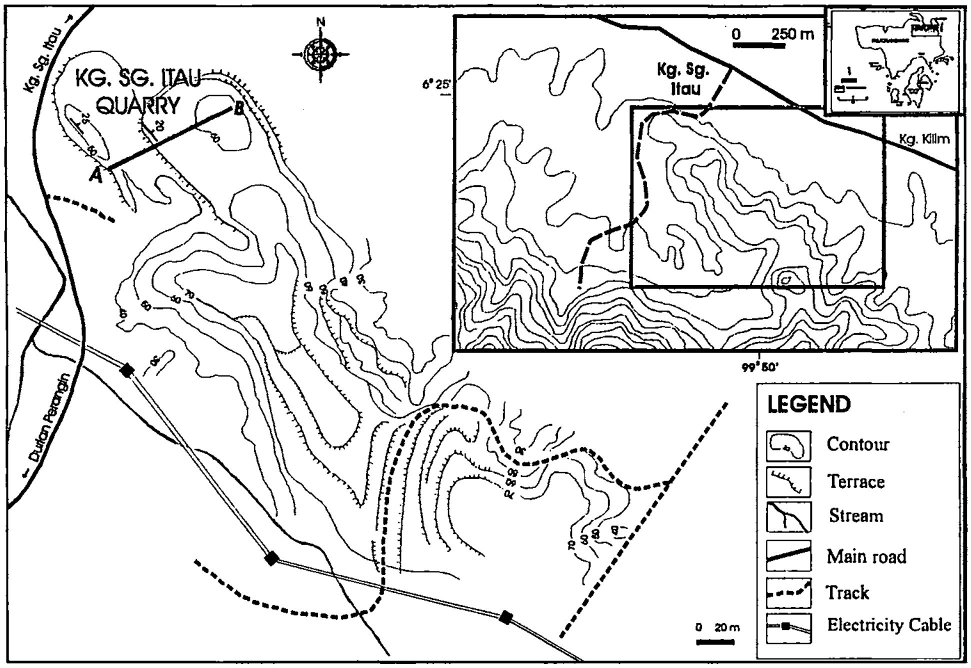

Figure 1. Locality map showing the position of Kampung Sungai Itau quarry and the measured section.

NW-SE trending ridge connecting this quarry and the Kilim quarry described earlier in Basir Jasin *et al.* (1992), Mohd Shafeea Leman (1996, 1997) and Shi *et al.* (1997). The geology of the Kampung Sungai Itau quarry is dominantly made of thick to massive sandstone and mudstone with subordinate silty shale and limestone. The beds are generally moderate to gently dipping to the east-northeast. In the lower part of the section, several normal and lateral faults repeatedly cut the rock sequence almost parallel to the bedding strike. These faults are usually marked by intense shearing within the thick to massive mudstone, and rarely cut across the more competent sandstone. A major lateral fault with strike and dip of about 285°/80° can be seen at the western foot of the quarry. The sheared black mudstone in the south-southwestern fault block exhibits several drag folds indicating left lateral movement. The black mudstone is faulted against more resistent sandstone beds forming the west-northwestern boundary of the Sungai Itau ridge. Intense shearing of the faulted mudstone in places transformed this fine-grained sediment into mylonite.

A sedimentological section has been logged roughly across the strike along the line marked as A–B in Figure 1. The exact geographic position of point A (the base of the section) is at latitude 6°24.787'N; longitude 99°49.484'E and altitude 46 m above m.s.l., while point B (the top of the section) is at latitude 6°24.817'N; longitude 99°49.545'E and altitude 64m above m.s.l. The data were obtained from a Magellan GPS Tracker instrument.

SUNGAI ITAU SEDIMENTARY SEQUENCE

More than 55 meters of sedimentary rocks were recorded from the Sungai Itau quarry section. Based on its lithology, sedimentary structures and fossil contents this lithological section can be divided into four major sedimentary facies, namely the thin to moderately bedded sandstone, massive mudstone, silty and sandy shale and thickly bedded to massive sandstone facies. The first two facies are found interbedded with one another (Fig. 2) in the lower half of the section, with total thickness exceeding 35 m. The upper part of the section is made of silty and sandy shale facies, succeeded by the thickly bedded to massive sandstone facies. The detail relationships between all these facies are shown in Figure 3.

Thin to moderately bedded sandstone facies – This facies comprises fine- to medium-grained gray sandstone. The sandstone beds range in thickness from 2–30 cm but occasionally reach 1.2 m thick. The thinner sandstone is generally homogenous in texture. However, the thicker one sometime shows grading at the base where coarse-grained sandstone graded into medium-grained sandstone (Fig. 4) or at the top of the bed where the fine-grained sandstone graded into siltstone or silty shale. Thin shale laminae are found interbedded with the thinner sandstone. The interbedded thin shale-sandstone often contains numerous trace fossils dominated by surface grazers. The bedding plane is planar in most cases, but irregular erosion base and broad lenticular sandstone bodies are occasionally present (see Fig. 3). Cross-laminated sandstone (Fig. 5) and laminated sandstone are also present. Other sedimentary structures include small-scaled transverse catenary ripples (Fig. 6) and transverse sinuous ripples indicate palaeo-current directions towards N20°E and N65°E, respectively. Small assymetrical sandstone lenses found at the bottom of the Sungai Itau Section may represent climbing ripples formed by a stronger palaeo-current at N45°E direction. The colour of the sandstone is

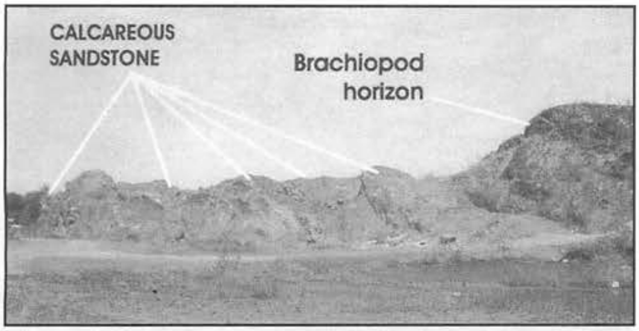

Figure 2. Sungai Itau quarry section viewed from south showing sandstone intebedded with massive mudstone.

gray when fresh, but the weathered sandstone is brownish to whitish in color. Petrographically, the sandstone can be classified as quartz arenite with angular to sub-rounded quartz grains and rare sub-angular fresh feldspar grains.

At particular horizons, the sandstone gradually becomes calcareous, both vertically and laterally. The weathered calcareous horizon is often marked by its coarser textures (Fig. 7), resulting from the weathering or dissolution of coarse calcite grains or fossils. There are at least 5 calcareous horizons at Sungai Itau quarry. These calcareous horizons are dominantly made up of calcareous sandstone where calcite occurs both as clasts and fine-grained matrix. With increasing amount of calcite, some of the calcareous sandstone becomes bioclastic packstone with crinoid stem and bryozoan skeleton as major allochem. A marly bioclastic wackestone horizon is also present, where bryozoan thicket dominated the allochem and the matrix is a mixture of clay, fine quartz and calcite. This bioclastic wackestone sometimes exhibits parallel lamination made of flattened mats of fenestellid bryozoan.

Massive black mudstone facies – Massive dark grey to black mudstone occurs in the lower part of the Sungai Itau section, interbedded with the sequence of thin to moderately bedded sandstone described above (see Fig. 3). Rounded pebbles of 2–10 cm diameter are commonly sparsely distributed in the lower part of the massive mudstone (Fig. 8). The clasts are mostly made up of sandstone and quartz (vein origin). The base of the mudstone beds sometimes are a little sandy, while thin sandstone and calcareous sandstone lenses are occasionally developed at the top of the bed. The thickness of the mudstone ranges from 0.8 m to 4.8 m. However, the unmeasured mudstone in the south-southwestern block seems to be much thicker.

Silty and sandy shale facies – Thick to massive silty shale with sandstone lenses were deposited at an interval in between the interbedded sandstone – mudstone facies and the thickly bedded to massive sandstone facies (see Fig. 3). The silty shale is usually light gray to greenish or brownish gray in colour. The thickness ranges from 0.6 m to 2.1 m. The silty shale bed is usually laminated in its lower part, while the top part of the bed is usually highly bioturbated. The bioturbated upper part contains numerous

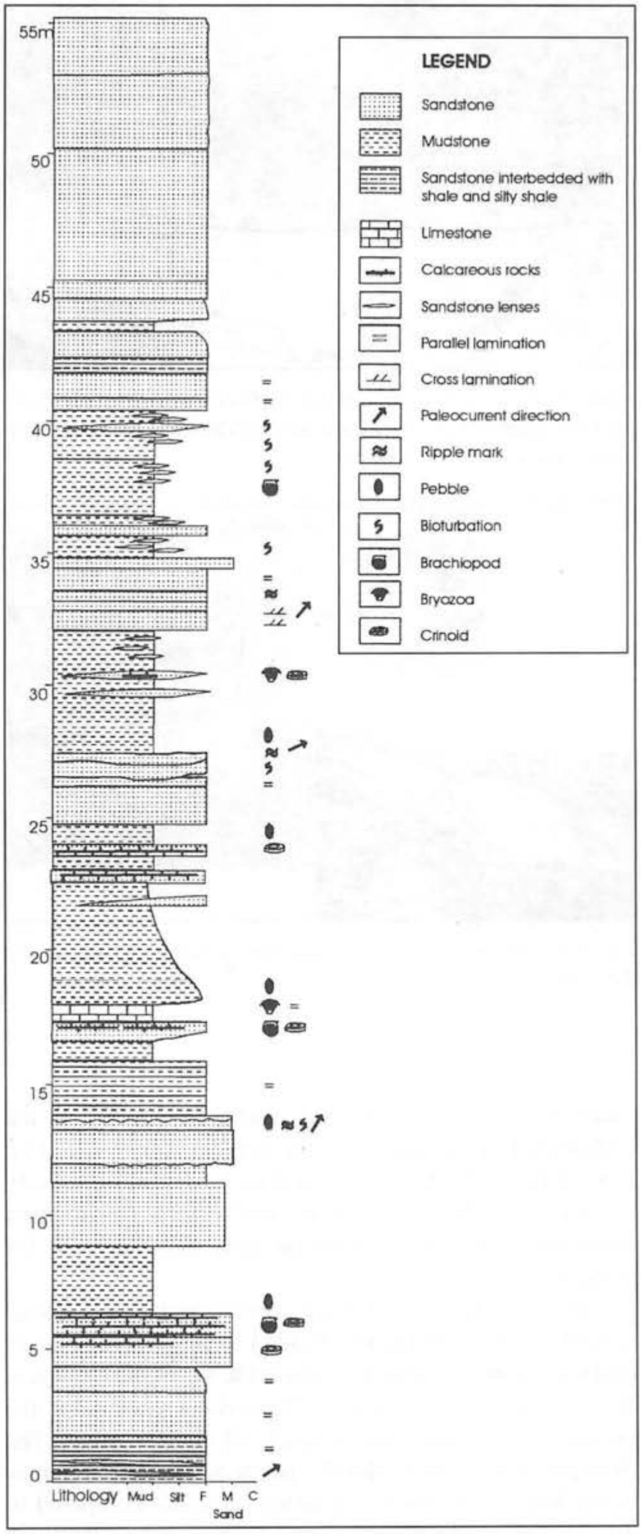

Figure 3. Lithological log of Sungai Itau quarry section from locality A (bottom) to B (top).

Figure 4. Coarse-grained sandstone with erosive base grading into medium-grained sandstone. Note white rectangular feldspar grains in the coarse-grained sandstone.

Figure 5. Thinly bedded sandstone showing parallel and cross-lamination.

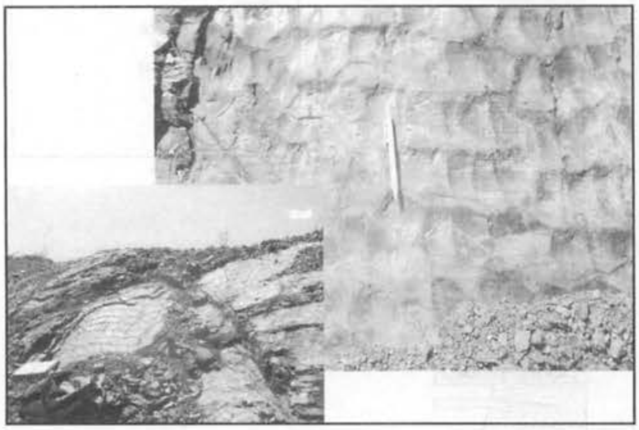

Figure 6. Transverse catenary ripples showing palaeo-current direction towards N20°E.

Figure 7. Calcareous sandstone bed (where the hammer is placed) on top of a sequence of thin to moderately bedded sandstone.

small lenses of light coloured sandstone (Fig. 9). In the middle part of the sequence, the massive silty shale (Fig. 10) yields a highly fossiliferous horizon of mainly brachiopod and bryozoan fauna. The fossil horizon ranges in thickness from 10 cm to 30 cm, and extends laterally for more than 80 m.

Thickly bedded to massive sandstone facies – a total of more than 15 m thickly bedded to massive light gray medium grained sandstone occur at the top of the sequence. The sandstone is generally structureless, except for the presence of parallel thin laminae of shale parting. The shale partings are more closely spaced and more continuous in the lower part of the sandstone sequence compared to the top of the sequence. This give an impression that there is a general thickening upward in the succession. In the lowermost part, however, several thinning and fining upward sequences prevail.

THE AGE OF SUNGAI ITAU SEQUENCE

The Sungai Itau sequence is very rich in fossils. Body fossils are found in several calcareous horizons and the silty shale, while trace fossils are found in the thinly interbedded sandstone – shale as well as in the silty shale. Body fossils are dominantly made up of bryozoans and brachiopods with less common echinoderms. Bryozoans and echinoderms (crinoid stems) dominated the calcareous horizons while brachiopods are more abundant in the silty shale. The brachiopod fauna consists of *Spirelytha petaliformis* Pavlova, *Spirelytha buravasi* (Hamada), *Sulciplica thailandica* (Waterhouse), ?*Lamniplica sapa* (Waterhouse), *Spiriferella* sp., *Rhynchopora culta* (Waterhouse), *Bandoproductus* cf. *monticulus* (Waterhouse), *Arctitreta percostata* Waterhouse, *Taeniothaerus* sp. and *Elasmata* sp. Figure 11 shows

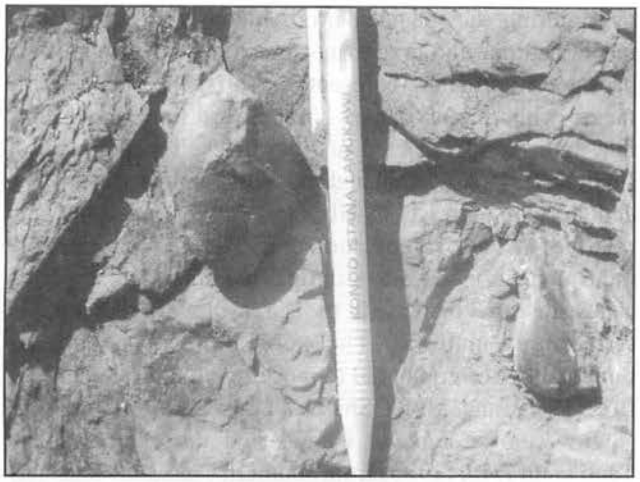

Figure 8. Rare rounded sandstone pebbles set at random in the massive black pebbly mudstone.

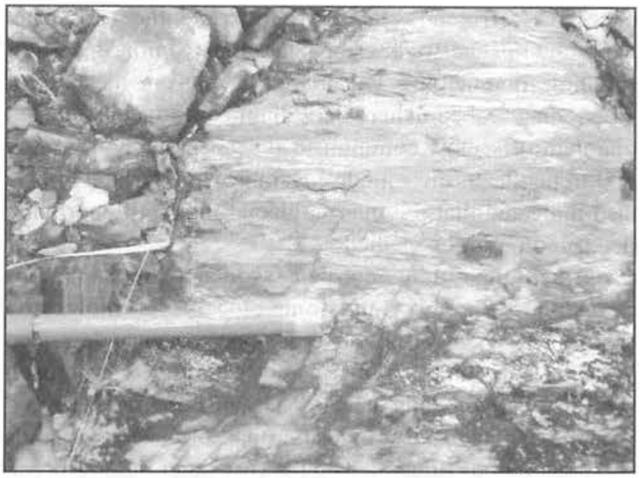

Figure 9. Bioturbated silty shale showing numerous lenses of sandstone.

representative fossils found in the silty shale horizon at Sungai Itau quarry. The brachiopod assemblage is very close to the Early Permian (late Asselian-early Sakmarian) brachiopod assemblage of Ko Muk in Southern Thailand described by Waterhouse (1982) and the Kilim fauna described by Mohd Shafeea Leman (1996). Although Shi *et al.* (1997) generalised the age of the Kilim brachiopod fauna as of Sakmarian age, their close affinity with the Ko Muk fauna suggests a possible late Asselian – early Sakmarian age to the Kilim fauna too. Thus, the Sungai Itau brachiopod horizon may represent a northernmost extension of the late Asselian – early Sakmarian Kilim – Sungai Itau brachiopod bed. Meanwhile, the bryozoan dominated limestone fauna is stratigraphically older than the brachiopod dominated silty shale discussed above. Therefore, the bryozoan limestone may represent the oldest Permian fauna ever recorded in Malaysia.

Figure 10. Brachiopod fossil horizon in the middle of thick silty shale.

DEPOSITIONAL ENVIRONMENT

The presence of calcareous horizons in the Singa Formation has been a very interesting topic of discussion, lately. Basir Jasin *et al.* (1992) described this phenomenon as the evidence of climatic changes from cold polar to warmer climate as Sibumasu Block drifted from Gondwanaland. However, the presence of dropstones above the Kilim bryozoan limestone (Shi *et al.*, 1997) suggests that the climate was still rather cold during the deposition of the limestone, as dropstones normally deposited during the warmer deglaciation period (Mohd Shafeea Leman, 1997, 2000). The presence of marine glacial diamictite in the Singa Formation has been described and discussed by Stauffer & Mantajit (1981), Stauffer & Lee (1986) and Mohd Shafeea Leman (2000). These glacial diamictite were used by Gatinsky & Hutchison (1986), Hutchison (1987) and Metcalfe (1984, 1996) as the key evidence for connecting Langkawi Island together with Western Sumatra, West Thailand and Shan State in Burma as Gondwanan derived terrane. Fossil findings by Mohd Shafeea Leman (1996, 1997) and Shi *et al.* (1997) not just strongly confirmed the earlier presumption on cold climate of Langkawi islands, but also dated some of the dropstone bearing horizons.

In this study, the pebble-bearing massive mudstone facies in the lower part of the Sungai Itau section is well interbedded with the limestone-bearing sandstone facies (see Fig. 2). The massive black pebbly mudstone matches the description of marine glacial diamictite deposit described by Stauffer & Mantajit (1981), Stauffer & Lee (1986) and Mohd Shafeea Leman (2000) from other parts of the Singa Formation. The rhythmic limestone – pebbly mudstone has been well documented in the Early Permian of Tasmania, which was positioned at a palaeo-latitude of 80°S by Rao (1981). According to him, the carbonates (calcareous sandstone and argillaceous limestone, rich in bryozoan skeleton) were accumulated during the terrigenously-starved glacial phases of marine low-stand, and the dropstones were deposited from ice-bergs as warmer climate brought excessive terrigenous material to dilute the carbonate. Henrich (1991) also described an almost similar record of rhythmic diamicton – calcareous ooze from the present Norwegian seabed, where dark diamicton (unconsolidated diamictite) is most common in the open shelf of around 200 m depth. In their model, Hambrey & Harland (1981) also indicated that the marine glacial diamictite normally deposited on an open shelf.

The Sungai Itau alternate sequence of calcareous sandstone – pebbly mudstone closely resembles the rhythmic limestone – pebbly mudstone sequence described by Rao (1981) and therefore can be interpreted as an open shelf deposit where the calcareous sandstone interfingered with the basinal massive mudstone. The bryozoans, crinoids and brachiopods flourished on the very quiet shallow ocean floor during the glacial period. Inden & Moore (1983) mentioned that the bryozoan – brachiopod – crinoid lime packstone normally represents an offshore open marine facies, while the bryozoan – brachiopod lime wackestone may indicate a restricted marine facies. The presence of small scale ripples, laminated and cross-laminated sandstone and horizontal trace fossils also suggests a quiet and relatively shallow environment. The massive pebbly mudstone was deposited during the interglacial period following rapid increase in the sea level with high input of terrigenous material. The percentage of pebbles is remarkably low compared to those reported by Stauffer & Lee (1986) and Mohd Shafeea Leman (2000) from the southwest of Langkawi Islands and those reported by Tantiwanit *et al.* (1983) from southern Thailand. This may

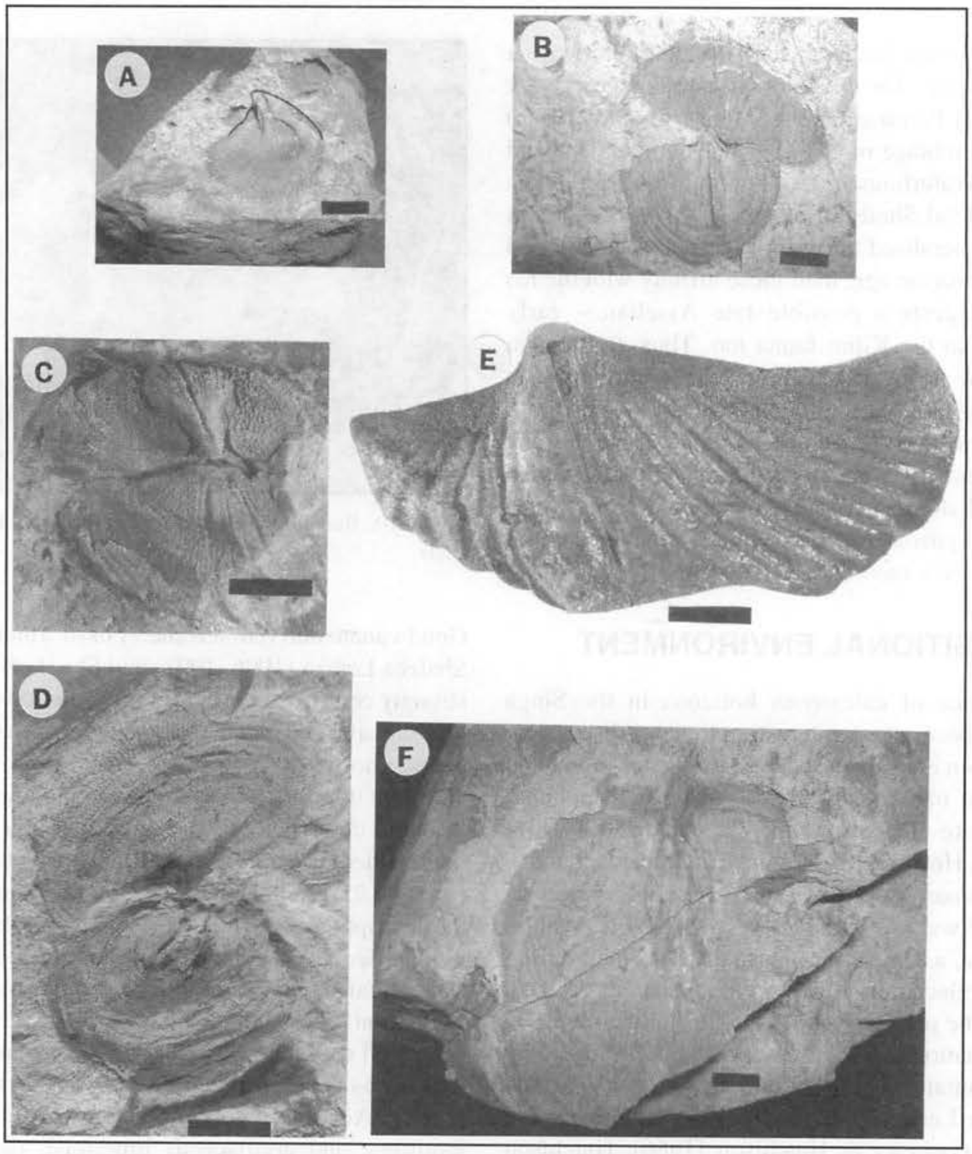

Figure 11. Representative brachiopods from Sungai Itau, Langkawi. **A** – *Arctitreta percostata* Waterhouse (ventral valve); **B** – *Spirelytha buravasi* (Hamada) (conjoin valves); **C**, **D** – *Spirelytha petaliformis* Pavlova (**C** – internal mould; **D** – external mould); **E** – *Sulciplica thailandica* Waterhouse (ventral internal mould); **F** – *Taeniothaerus* sp. (dorsal internal mould); bar scale is 10 mm.

indicate that the depositional setting is very far away from the source of glacier as is shown in models drawn by Hambrey & Harland (1981) and Hendrich (1991).

The succeeding fossiliferous and bioturbated silty shale represent another quiet environment. This is followed by thickening upward sequences of sandstone indicating a continuous prograding of the submarine fan as a result of another sea level fall. Meanwhile, the massive sandstone at the topmost part of Sungai Itau section may be deposited by the storm current.

PALEOCLIMATIC IMPLICATION

The alternating sequence of massive pebbly mudstone and bedded sandstone with calcareous horizons in the lower part of the Sungai Itau section represents several cycles of high and low stands, respectively. This sea-level fluctuation corresponds closely with the climatic changes related to the glaciation and deglaciation of the nearby continent, which supplies sediments to the Langkawi basin. During the extreme glacial period, sediment supply to the sea is almost entirely stopped due to the extensively frozen continent. This will create a clear and quiet sea-floor condition, suitable for the cold water bryozoa, brachiopod and crinoid to thrive. As a result, calcareous horizons are developed together with reworked sandstone. The sea level drops gradually as a result of a prolonged glacial period. During the interglacial period, the glacial melt water usually carries a high amount of suspended particles to the sea, while large iceberg carries larger particles. The fine-grained sediment was deposited together with dropstones from melted iceberg to form the marine glacial diamictite. The melting of the continental glacier resulted in the rapid rises in sea level. The climatically controlled sea levels, clearly show that the deposition of the Sungai Itau sequence is strongly influenced by the Early Permian major glaciation of the Gondwana supercontinent.

CONCLUSION

The Sungai Itau sequence is made up of massive pebbly mudstone interbedded with calcareous sandstone, succeeded by silty shale and then by massive sandstone. The massive pebbly mudstone is a marine glacial diamictite. The sandstone contains several calcareous horizons rich in bryozoan and crinoid skeletons. The rhythmically interbedded pebbly mudstone – calcareous sandstone indicates sea level fluctuations highly influenced by climatic changes. The silty shale contains Early Permian (late Asselian – early Sakmarian) brachiopod fauna of strong Gondwanan affinity. The sedimentary sequence and fauna of Sungai Itau strongly suggest that Langkawi Island was located on the periphery of the Gondwana supercontinent during the Early Permian.

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