Sedimentary facies development of breccia deposit in Tanjung Sekakap-Tanjung Murau area, near Mersing, Johor, Peninsular Malaysia

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Abstract: Breccia dominated rocks outcropping in the Tanjung Murau – Tanjung Sekakap area have been deposited in a composite system of alluvial fans and Gilbert-type deltas. The sedimentary facies ranges from boulder-dominated facies at the bottom to gravelstone-sandstone-dominated facies at the top of the succession. Other recognized facies are disorganized boulder-cobble-supported breccia (Bd), crudely stratified cobble-boulder-rich breccia (Bs), crudely stratified cobble-rich gravelstone (Gs-1), disorganized clast-supported gravelstone (Gd), crudely stratified pebble-rich gravelstone (Gs-2), normally-inversely-graded gravelstone (Gn-i), crossbedded gravelstone (Gc), stratified sandstone (Ss), massive sandstone (Sm) and homogenous mudstone (Mh) facies. Alluvial fan association feature discontinuous breccias and gravelstones (facies Bd and Bs), where sheet-floods and debris flows are dominant. The gravelstone dominated facies Gd, Gs-1 and Gs-2 intercalated with facies Gc are associated with the topset–foreset of a Gilbert-type fan-delta. The Gilbert-type topset are represented by facies Gc, Gn-i and Gs-2 as well as facies Ss. The dominance of breccia and gravelstone facies of alluvial fan and Gilbert-type topset – foreset delta facies associations suggest that these sediments were deposited on a steeply sloping continental margin with a rate of deposition similar to the rate of subsidence.

INTRODUCTION

Rudaceous rocks or rudrock (Laznicka, 1988) are prominent along the east coast of Johor from Tanjung Sekakap to Tanjung Tenggaroh (Figure 1) with isolated occurrence at Pulau Batu Chawang (Ibrahim Abdullah *et al.*, 1991) and at Tanjung Leman (Suntharalingam, 1991). This rock unit was described by Koopmans (1968) as Triassic Murau Conglomerate Member of the Tembeling Formation. He regarded this rudaceous unit as the basal member of the formation based on the presence of an unconformable boundary between the rudrock and the underlying metamorphic rocks. However, because of its geographic isolation, Burton (1973) suggested that the Murau Conglomerate be removed from the Tembeling Formation. Khoo (1977) upgraded the Tembeling Formation to Tembeling Group status with Murau Conglomerate being excluded from it. Later, Ahmad Jantan *et al.* (1988) suggested the Murau rudaceous unit to be upgraded to the Murau Formation and suggested a Jurassic-Cretaceous age for the Formation. Meanwhile, Che Aziz Ali and Kamal Roslan Mohamed (1997) suggested that the Murau Formation has a close genetic affinity with several other conglomerate units exposed along the coast and offshore Terengganu, and indicating a possible Triassic or Permian age for the rock unit under discussion.

The present study tentatively divides the Murau Formation into three separate units, which are the Murau, Tenggaroh, and Tanjung Leman units. These units differ from one another in terms of facies assemblages, sedimentary environments and depositional mechanisms. The Tanjung Leman unit consists of alternating mudrock and rudrock in the bottom part, with thick fine sandstone and shale in the upper part. The clasts of rudrock at Tanjung Leman are mostly rounded to very well rounded, moderate to well sorted, grain supported, with average clasts of pebble to cobble size. The sedimentary textures and structures suggest that the depositional process was dominated by traction flow. On the other hand, the Murau and Tenggaroh units are dominated by thick beds of breccia in the lower part, followed by gravelstone facies and sandstone and mudstone in the upper part. The clast textures in Murau and Tenggaroh units are mainly angular to very angular, poorly sorted with dominant clast of cobble size, occasionally up to boulder size. These sedimentary textures suggest that the depositional process was dominated by debris flow. Mineralization is common in both matrix and clasts of the Tenggaroh rudaceous rock, but apparently absent in other units. This mineralization must be carefully studied in order to understand the relationship between the mineralization and depositional history.

BRECCIA OR CONGLOMERATE?

In widely used geological glossaries, such as that of Bates and Jackson (1987), breccias are often described as coarse-grained clastic rock, composed of angular broken rock fragments held together by mineral cement or in a fine-grained matrix. This differs from conglomerates in that the fragments have sharp edges and unworn corners. Laznicka (1988) states that there is no established boundary between conglomerate and breccia, but Reimold (1998) proposed that the term conglomerate be restricted to clastic rock, whereas breccia is more universal in usage. However, in day-to-day geological work this distinction is often

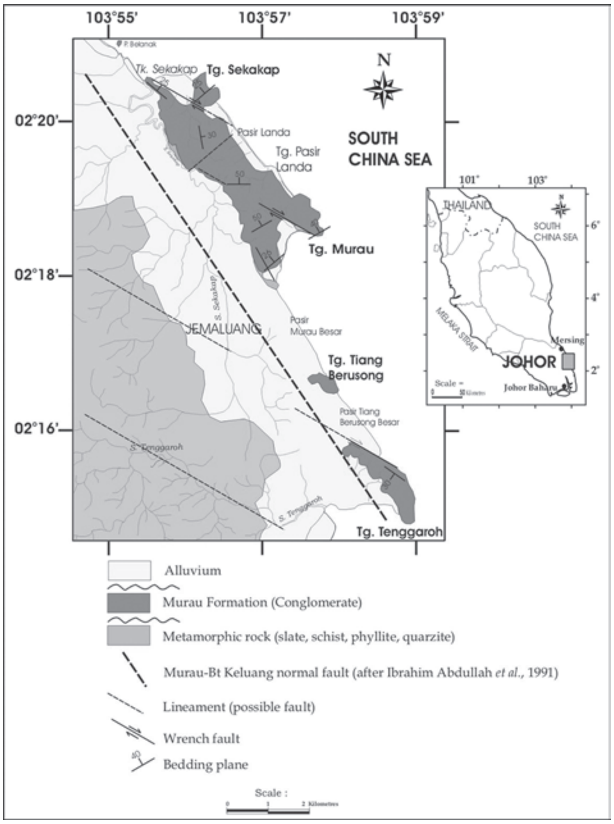

Figure 1. Distribution of Murau rudaceous rocks between Tanjung Sekakap and Tanjung Murau, Johor.

neglected. In general, sedimentologists are inclined to employ the term conglomerate regardless of the high percentage of angular clasts in the rock. Thus, rocks with over 50% and up to 90% of angular fragments are still commonly termed conglomerate (Laznicka, 1988).

As for the Murau rudrock unit, previous authors including Koopmans (1968), Ahmad Jantan *et al.* (1988), Che Aziz Ali and Kamal Roslan Mohamed (1997), among others described this rock unit as conglomerate, although they recognized that the clasts are predominantly angular to very angular. The present study refers to this rudrock as breccia rather than conglomerate, implying a different perspective in terms of its facies development and hence the depositional environment and processes. Laznicka (1988), for example regards most breccia is formed rapidly at or near the point of transition between one system, environment or depth level to another. In his study at Dwarkeswar River, India, Sengupta (1994) has shown that the roundness of pebbles changed from subangular to rounded over a distance downstream of 100 km.

FAN DELTA SETTING

Gravels are normally transported in a wide spectrum of physical conditions leading to a range of textural and structural variations in the ensuing deposits (Miall, 1996). Sediments dominated by breccias or conglomerates have commonly been interpreted as a product of fan-delta or alluvial fan sedimentation (Chough *et al.*, 1990; Hwang *et al.*, 1995; Dickie & Hein, 1995; Kim *et al.*, 1995; Kim and Chough, 2000; Benvenuti, 2003). A fan-delta, is defined by Holmes (1965) as an alluvial fan that progrades into a standing body of water and is a common depositional system in various tectonic and geological settings.

Based on basinal setting, both Wescott and Ethridge (1980) and Postma and Roep (1985) suggested three end-type models for fan-deltas, which are the shelf-, slope- and Gilbert-types. These models contain numerous variants depending on the complex interplay of uplift-subsidence of the adjacent highlands, fluvial and marine processes, sediment supplies, sea level changes and several other factors (Chough *et al.*, 1990). Postma and Roep (1985) divided the Gilbert-type delta into a tripartite facies association, i.e., the topset, foreset and bottomset based on its morphology. In some cases, a fan-delta is not developed as a single-type, but rather formed as a composite type. Chough *et al.* (1990), for example, determined the Doumsan Fan-Delta in Southeast Korea as a composite fan-delta system and classified their rock assemblages into seven facies associations including alluvial fan, Gilbert-type topset, Gilbert-type foreset, Gilbert-type toeset, prodelta, slope apron and basin plain.

This paper addresses the sedimentary facies development of breccia-dominated deposits exposed in Tanjung Sekakap – Tanjung Murau area, taking into consideration both vertical and lateral facies development based on lithological logs from measured sections. This is followed by discussion leading towards interpretation on the possible sedimentary environments and processes.

GEOLOGICAL SETTING

The breccia deposit in Murau area are composed of polymict clasts comprising schist, phyllite, slate, shale, quartzite, sandstone and mudstone, and apparently devoid of volcanics. The clasts are generally angular to very angular in shape, with sizes ranging from granule to boulder, poorly sorted and randomly oriented, in places poorly imbricated. The deposit unconformably overlies the older metamorphic rock of Mersing Formation. The unconformity can be seen at Tanjung Murau (Figure 2a) and at a small hill near Pasir Landa beach, 1.5 km south of Tanjung Sekakap (Figure 2b). In the lowermost part of the succession, the clast composition seems to be entirely of metamorphic rocks. At Tanjung Murau, for example, the clasts of the breccia are mainly made up of schist, phyllite and quartzite.

The Murau breccia formed a thick sedimentary rock sequence with bedding orientation only visible in the sandstone or mudstone facies. The strata have a roughly northeast – southwest (230°-240°E) strike, dipping 30° - 50° to the northwest (Figure 1). The facies succession is repeated both laterally and vertically. The total thickness of the sequence varies from 50 meters to more than 100 meters.

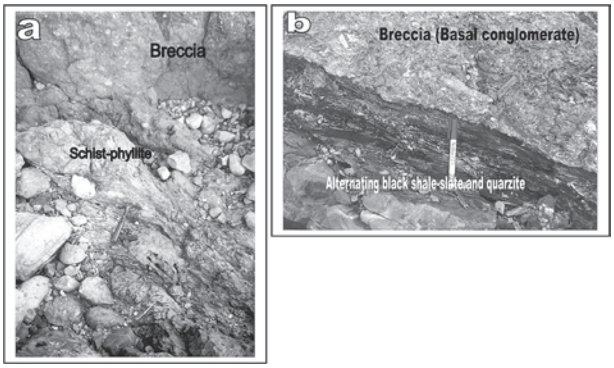

Figure 2. a – Angular unconformity between schist-phyllite and breccia at Tanjung Murau. b – Disconformity contact between black shale-slate and breccia (basal conglomerate) at Pasir Landa, near Tanjung Sekakap.

Apart from the Murau Conglomerate and Mersing Formations, the Jasin Volcanics are also well developed around the Mersing coast in the north of the Mersing River and on several offshore islands east of Tanjung Sekakap – Tanjung Murau. The volcanic rocks were described by Cook and Suntharalingam (1970) as the part of the Late Permian – Early Triassic Jasin Volcanic unit. Another series of volcanic sequence, the Middle Permian Sedili Volcanic (Suntharalingam, 1991) is best developed in Ulu Sedili area, southwest of Tanjung Murau. The absence of clasts of volcanic origin suggest that the Murau Formation is older than the late Permian Jasin Volcanic unit and perhaps also older than the Middle Permian Sedili volcanic unit. The granite that intrudes the Jasin Volcanic unit at Pulau Babi Besar is the youngest rock unit in the area around Tanjung Sekakap – Tanjung Murau.

SEDIMENTARY FACIES ANALYSIS

Nine lithological logs were constructed based on studied sections outcropping along the coastline between Tanjung Sekakap and Tanjung Murau and several man-made slope cuts within Sungai Sekakap area. Ten sedimentary facies (Table 1) have been recognized from these logs based on physical characteristics such as grain size distributions, textures and sedimentary structures.

The sedimentary facies of Murau rudaceous rocks can be described as follows:

Facies Bd: Disorganized, boulder-cobble supported breccia (Figure 3a,b)

The Facies Bd is generally thick to very thickly bedded. Tanjung Murau lithological log 07 (Figure 6) shows the total thickness is up to 20 meters, whereas in the Tanjung Sekakap lithological logs 02 and 05 (Figure 6) the thickness is significantly less. The bed is dominated by tightly packed, poorly sorted and randomly oriented granule- to boulder-sized clasts. The clasts are angular to very angular in shape. The occurrence of schist rock chips in the lower part of Tanjung Murau sequence suggest the source rocks came directly from the underlying metamorphic rock. The largest clast found is a 60 cm long quartzite (Figure 3a,b) indicating short distance and fast sedimentation. Inverse grading is seen at the base of the facies in both lithological logs 05 and 07 (Figure 6). A sharp contact with the underlying beds is observed in lithological logs 02 and 05 (Figure 6), and a weak wavy base is exhibited in lithological log 07 (Figure 6). The matrix is made up of poorly sorted sand. Shultz (1984) interpreted a similar facies formed from turbulent sub-aerial debris flow, while Kim and Chough (2000) only suggested a debris flow origin.

Facies Bs: Crudely stratified cobble-boulder-rich breccia (Figure 3c,d)

The Facies Bs refers to moderate to thickly bedded (20-150 cm), crudely stratified cobble-rich breccia with very coarse sandy matrix (Figure 3c,d). Poor to moderate imbrications sometimes developed within the pebbly horizons. Gradual diffusion is common within the cobble-boulder layers, showing repetition of graded bedding with obscure facies boundaries. This structure is well developed in the lower part of lithological log 05 (Figure 6), in close association with Facies Bd. In the Tanjung Murau lithological log 07 (Figure 6), the cobble-boulder layers are developed without a distinct pattern of fabric and thus difficult to trace laterally due to the amalgamation, thinning and wedging-out of layers. The Facies Bs is usually found immediately above the Facies Bd as seen in the Tanjung Murau lithological log 07 (Figure 6) and in the Tanjung Sekakap lithological log 05 (Figure 6). For the Late Palaeozoic Cutler Formation in western Colorado, USA, Shultz (1984) suggested that Facies Bs is also resulted from turbulent sub-aerial debris flow.

Facies Gs-1: Crudely stratified cobble-rich gravelstone (Figure 3e,f)

The Gs-1 facies appears to be similar to the facies Bs but with predominantly smaller clasts (Figure 3e, f). The thickness of the bed is moderate to thick (20-100 cm). The facies is characterized by mixtures of pebble and cobble clasts with coarse to very coarse-grained sandy matrix. The clasts are either floated within matrix or formed imbrication with indistinct boundaries between layers. Toward the top of the facies, the smaller clasts gradually diffuse to the overlying facies. Facies Gs-1 is usually found in association with facies Bs, Bd and Gd as in the Tanjung Murau lithological log 07 and Tanjung Sekakap lithological log 05 sections (Figure 6). Shultz (1984) interpreted facies similar to Facies Gs-1 as well as Facies Bd and Bs as part of a turbulent sub-aerial debris flow deposit, but according to Hwang *et al.* (1995) in the Miocene Pohang Basin of SE Korea the facies is deposited by density-modified grain flow or by cohesion-less debris flow.

Table 1: Diagnostic features arising from the studied sedimentary facies.

Facies Type (Code)	Characteristics
Disorganized, boulder-cobble supported breccia (Bd)	Thick to very thick beds of randomly oriented, tightly packed, poorly sorted, very angular to angular granule- to boulder-sized clasts. Beds usually with basal inverse grading and sharp planar base.
Crudely stratified cobble-boulder-rich breccia (Bs)	Moderate to thick beds of alternating cobble-bouldery layer, pebbly layer and very coarse sandstone with moderate to poor imbrication. Beds usually with gradual diffusion, thinning and wedging-out of layers.
Crudely stratified cobble-rich gravelstone (Gs-1)	Moderate to thick beds of alternating pebble-cobbly layers and coarse to very coarse sandstone with moderate imbrication, floating clasts, gradual diffusion and diffused boundaries.
Disorganized, clast-supported gravelstone (Gd)	Thick to very thick beds of randomly oriented, partly imbricated, tightly packed clasts, moderate to poorly sorted, angular to sub-angular, granule-to cobble-sized clasts, sharp and flat base, several as channel infills.
Crudely stratified pebble-rich gravelstone (Gs-2)	Moderate to thin beds of alternating pebbly layers and coarse to very coarse sandstones with moderate imbrication. Beds with gradually diffused boundary, several thinning and wedging-out layers.
Normally-inversely graded gravelstone (Gn-i)	Moderate to thick beds of imbricated granule- to small cobble-sized clasts in poorly to moderately sorted sand matrix. Beds with inverse to normal grading. (Inverse grading is common in basal conglomerates).
Cross bedded gravelstone (Gc)	Moderate to thick beds of granule- to small cobble-sized clasts. Beds with normal or inverse grading and thinly bedded foresets, usually mound shaped, commonly amalgamated with facies Gs-2 or Gn-i.
Stratified sandstone (Ss)	Moderate to thin beds of reddish, very fine- to coarse-grained sandstone. Beds with obscure normal grading, sharp amalgamated contacts, commonly cut by pocket breccias or channel infills.
Massive sandstone (Sm)	Moderately bedded reddish, fine- to coarse-grained sandstone. Beds with obscure normal grading and some bioturbation, associated with facies Ss.
Homogenous mudstone (Mh)	Thickly bedded reddish mudstone with gravel pockets and lenses, structureless or with weak bedding orientation.

Facies Gd: Disorganized, clast-supported gravelstone (Figure 3g,h)

The beds in Facies Gd are generally thick to very thick (100 cm – 3 m). Apart from having relatively smaller clasts, this facies is texturally and structurally similar to the Facies Bs. The bed is dominated by tightly packed, moderate to poorly sorted, randomly oriented or partially imbricated clasts of angular to sub-angular granule to cobble (Figure 3g,h). Th e fabric is crudely imbricated or stratified clasts in the lower to middle part of the succession in Tanjung Sekakap lithological log 05, and Tanjung Murau lithological log 09, (Figure 6). Hwang *et al.* (1995) and Kim and Chough (2000) interpreted similar facies as debris flow or channelized debris flow deposits.

Facies Gs-2: Crudely stratified pebble-rich gravelstone (Figure 4a,b)

The crudely stratified pebble-rich gravelstone facies is characterized by alternation of pebbly gravelstone and coarse to very coarse sandstone layers (Figure 4a,b). The gravelstones contain tightly packed to gradually diffused pebbles, whereas the sandstone layers contain some unsupported clasts. Each facies unit ranges in thickness from 10 cm to 100 cm, usually thinning or wedging-out to form lateral transition to other facies. In Tanjung Murau lithological log 09 (Figure 6) the Facies Gs-2 is associated with facies Gd, while in Tanjung Sekakap lithological log 02 and 03 (Figure 6) it is associated with facies Ss and Gn-i. Based on their study on the bouldery deposits of the Korean Kyokpori Formation, Kim *et al.* (1995) interpreted that the Facies Gs-2 is developed in an unstable region within a cohesion-less debris flow. However, Benvenuti (2003) inferred the facies as a sub-aerial deposit formed by unconfined hyper-concentrated flow, related to gravity transformation in the lower fan delta depositional environment.

Facies Gn-i: Normally-inversely graded gravelstone (Figure 4c,d)

Generally the Facies Gn-i comprises medium to thick gravelstone beds (30-150 cm) with poor to moderately sorted clasts of granule to cobble sizes (Figure 4c,d). The clasts sometime are poorly imbricated in a sandy matrix. The gravelstone facies is inversely graded and commonly overlain by the Facies Bd in association with basal conglomerates as in the Tanjung Murau lithological log 07 and Tanjung Sekakap lithological log 02 (Figure 6).

The normally-inversely graded gravelstone facies associated with sandy facies Ss and Gc is best developed in the upper half of the facies succession in Tanjung Sekakap lithological logs 03 and 04 (Figure 6). Hwang *et al.* (1995) interpreted that such facies is deposited by cohesive or highly turbulent debris flow. These gravel-sand beds were considered as a density-layered flow deposits by Benvenuti (2003), though Kim and Chough (2000) have previously interpreted overall features of inverse grading, high clast content and clast imbrication as originated by a cohesionless debris flow.

Facies Gc: Cross-bedded gravelstone (Figure 4e,f)

The Facies Gc has a thickness of 40-100 cm and is composed of granule- to cobble-size clasts aligned in crossbeds at angles between 15^{o}-25^{o}. The beds usually show normally graded foresets with planar geometry (Figure 4e,f). In Tanjung Sekakap area, the facies passes vertically to Facies Gs-2 or Gn-i with rather amalgamated contacts (lithological logs 03 and 05, Figure 6). According to Miall (1977) the Facies Gc can be formed due to migrating gravel bars such as transverse or linguoid bars or channel-fills. Dickie and Hein (1995) inferred the graded to cross-bedded gravelstone as bed load deposit on the slip face of a linear-crested gravel dune or small bar foreset during high velocity flow in coastal fan delta depositional environment. Meanwhile, Hwang *et al.* (1995) suggested that the Facies Gc might be resulted from progradation of a Gilbert-type microdelta towards shallow marine environment.

Facies Ss: Stratified sandstone (Figure 4g,h)

The Facies Ss is characterized by thin to moderate beds (30 – 100 cm) of fine- to coarse-grained sandstone, typically reddish in color. The beds show poor normal grading from coarse sandstone to the very fine sandstone. They have sharp to amalgamating contacts with adjacent beds and are commonly incised by pocket or channel filled breccias (Figure 4g,h). Facies Ss is predominant in the upper part of Tanjung Sekakap lithological log 03 and 05 and in the upper part of Tanjung Murau lithological log 09 associated with facies Gs-2, Gc and Gn-I (Figure 6). For the Korean Doumsan Fan Delta, Chough *et al.* (1990) interpreted Facies Ss as product of low-density turbidity currents, whereas for the Canadian Jurassic Laberge Group Fan Delta, Dickie and Hein (1995) suggested that Facies Ss were deposited as a product of upper flow regime tractive transport of sand grains. In the Miocene Pohang Basin of Korea, pocket or channel filled breccias in the Facies Ss were inferred by Hwang *et al.* (1995) as a small-scale down-slope running chutes on a steeply inclined slope.

Facies Sm: Massive sandstone (Figure 5a,b)

The massive sandstone facies is moderate to thickly bedded (commonly 60-120 cm) with typical reddish color and consisting of moderate to well sorted, fine- to coarse-grained sandstone. The grains are angular to sub-rounded. Some layers exhibit normal grading with sharp basal contacts. Some horizons contained numerous trace fossils (Figure 5a,b) such as those found at Tanjung Sekakap lithological logs 03 (Figure 6). The Facies Sm is commonly associated with the Facies Ss. For the Doumsan Fan Delta, Chough *et al.* (1990) interpreted the Facies Sm as possibly resulting form high- or low-density turbidity currents, while Kim and Chough (2000) interpreted its deposition as possibly resulted from amalgamation of recurrent flows.

Facies Mh: Homogenous mudstone (Figure 5c,d)

The Facies Mh is found only in Tanjung Sekakap lithological log 04 (Figure 6) and is typically composed of structureless reddish mudstone to sandstone. The beds have a thickness range between 50 cm to 2.5 m. Scattered pebble clasts sometimes occur within the mudstone intervals. In the Korean Doumsan Fan Delta, Chough *et al.* (1990) suggested that this facies was deposited by the settling of suspended sediments on floodplain or inter-channel areas. However, according to Kim and Chough (2000) scattered pebble clasts are also found within a mixed deposit of the same fan delta, which they interpreted as deposits representing thick muddy debris flows.

FACIES DEVELOPMENT

Analyses on facies development were conducted from nine lithological logs representing various coastal exposure in the Tanjung Murau and Tanjung Sekakap area (Figure 6) supported by data from several shorter lithological logs and observation on smaller outcrops in the inland. A model for lateral facies development (Figures 7,8) was constructed in order to understand the development of sedimentary facies along the Tanjung Sekakap - Tanjung Murau section.

In general, the lower part of the lithological logs in Tanjung Sekakap and Tanjung Murau are dominated by breccia-rich facies (Facies Bd and Bs), attaining a maximum thickness of about 20 m and may also re-appear in the upper part of the lithological log 05 in Sekakap area (Figure 6) in association with the Facies Gc. In the middle of the succession, normally gravelstone-rich facies (Facies Gs-1 – Gd, or Gs-2 – Gd) are more dominant, reaching a total thickness of up to 60 m in the Tanjung Sekakap area and up to 40 m in the Tanjung Murau area. The sandstone-rich facies generally dominate the upper part of the succession mainly in the Tanjung Sekakap area. In the Tanjung Murau area, succession of the Facies Gs-1 – Gd, or Gs-2 – Gd are noted mostly along the coastline. The

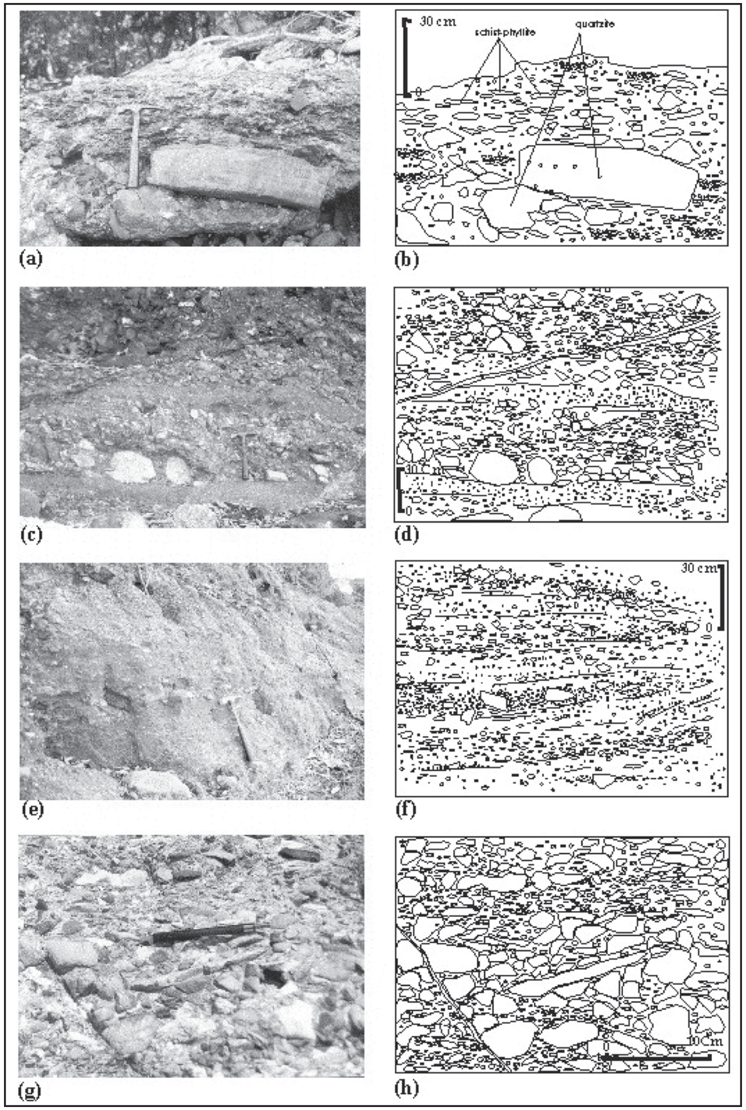

Figure 3. Some typical facies developed in Tanjung Sekakap –Tanjung Murau rudaceous rocks: photographs (left column) and schematic sketches (right column). a,b – Facies Bd: Disorganized, boulder-cobble supported breccia; c,d – Facies Bs : Crudely stratified cobble-boulder-rich breccia; e,f – Facies Gs-1: Crudely stratified cobble-rich gravelstone; g,h – Facies Gd: Disorganized, clast-supported gravelstone.

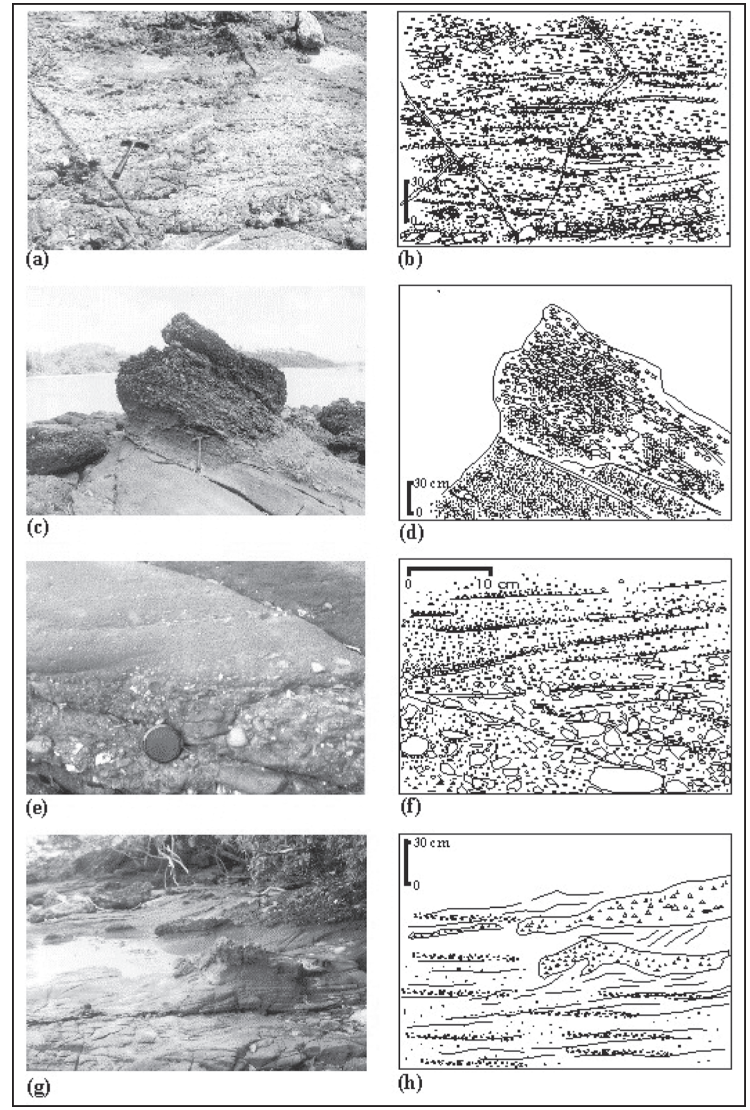

Figure 4. Some typical facies developed in Tanjung Sekakap - Tanjung Murau rudaceous rocks: photographs (left column) and schematic sketches (right column). a,b – Facies Gs-2: Crudely stratified pebble-rich gravelstone; c,d – Facies Gn-i: Normally-inversely graded gravelstone; e,f – Facies Gc: Cross-bedded gravelstone; g,h – Facies Ss: Stratified sandstone.

sandstone-rich facies form more than half of the lithological sequences in the Tanjung Sekakap lithological logs 03 and 04 (Figure 6), associated with Facies Ss – Gs-2 and sometimes Ss – Gn-i. The Facies Sm and Mh only occur locally in the sandstone succession found in Tanjung Sekakap lithological log 04 (Figure 6).

The lithological logs (Figure 6) clearly indicate that the successions commenced with breccia dominated facies, followed gradually by gravelstone, sandstone and mudstone dominated facies, before the return to coarse-grained breccia at the top of the succession. The most complete sedimentary facies development can be observed in the Tanjung Sekakap lithological logs 02-05. However, details in lithological log 03 (Figure 6) show several fining and coarsening upward sequences, though the facies succession shows a general coarsening upward from sandstone-dominated facies to the gravelstone-dominated facies especially towards the top of the succession.

In the Tanjung Murau area, only the breccia- and gravelstone-rich facies are well developed, thus the gradation to the sandstone-rich succession is poorly established. The uppermost part of the facies succession in Tanjung Murau is perhaps only equivalent to that of the middle part of Tanjung Sekakap succession. The total thickness from coarser facies (Facies Bd-Bs) to finer facies (Facies Gs-2-Ss-Sm) in Tanjung Murau is fairly similar to that of Tanjung Sekakap, but is significantly lesser in Sekakap lithological log 02 (inland Sekakap).

The modern Yallahs Fan Delta described by Wescott and Ethridge (1980), the Pliocene Esperituro Santo Fan Delta described by Postma and Roep (1985) and the Miocene Doumsan Fan Delta described by Chough *et al*. (1990) and Hwang *et al.* (1995) are chosen as provisional models for comparing the facies development of the Murau rudrock unit. These rudrocks exhibit close resemblance in terms of their facies and facies association, and thus should share a common depositional setting and processes, as discussed in the next section.

FACIES ASSOCIATION AND DEPOSITIONAL ENVIRONMENT

Facies association is generally used to determine the depositional environment as single facies often occurs in several depositional environments. For example, the thick rudrock dominated by cobble-pebble clasts without apparent internal structure such as in facies Bd or Bs of this paper, have been commonly interpreted as debris flow deposits (Wescott & Ethridge, 1980; Lowe, 1982; Postma & Roep, 1985; Coussot & Meunier, 1996; Chough *et al.*, 1990; Kim & Chough, 2000; Benvenuti, 2003). Debris flow, on the other hand, could be developed in various environmental conditions from sub-aerial (Wescott & Ethridge, 1983) to transitional (Benvenuti, 2003) as well as deep-water environments (Walker, 1975, 1978; Visser, 1983). The facies, could formed on any fan topography such as on alluvial fan, fan-delta or even submarine fan. In this case, facies associations are vitally important for interpreting the fan type and hence the whole depositional environment.

Three major facies associations were identified in the Murau rudaceous rocks. They are alluvial fan (AF), Gilbert-type topset – foreset fan delta (GTF) and Gilbert type-topset fan delta (GT). The determination of each facies association is based on the co-occurrence of inter-related facies in terms of their sedimentary textures, depositional processes and possible depositional sub-environments. The Murau rudrock facies associations were designated based excellent works on similar rudrock by Chough *et al.* (1990) for the Miocene Doumsan Fan-Delta in SE Korea, Hwang *et al.* (1995) for the Miocene Pohang Fan-Delta system, also in SE Korea and Benvenuti (2003) for the Pliocene-Pleistocene lacustrine fan-delta in Central Italy, among others. The composition of Murau rudrock facies association and its interpretation are summarized in Figure 6.

Alluvial Fan Facies Association

Chough *et al.* (1990) interpreted the disorganized breccia of the Doumsan Fan Delta in Korea as being deposited by alluvial fan systems where debris flows are dominant. In this study, such facies association is represented by the disorganized boulder-cobble supported breccia facies (Facies Bd) and the crudely stratified cobble-boulder-rich breccia facies (Facies Bs). Angular clasts and clast composition that are similar to the underlying rocks suggest a close source, shortly transported down a steep slope to form the basal conglomerate (Figure 8) as seen in Tanjung Murau and westernmost Tanjung Sekakap. This interpretation supports the earlier depositional model reconstructed by Ibrahim Abdullah *et al.* (1991) who suggested that the sedimentation process is controlled by a normal fault tentatively named as the Bukit Keluang-Murau Fault. The thick breccia and gravelstone deposits associated with alluvial fan and Gilbert-type foreset to topset facies at Tanjung Sekakap and Tanjung Murau were possibly formed due to the basin infill with sedimentation rates almost similar to the subsidence.

For the Murau rudrock, the alluvial fan depositional environment is represented by the whole of Tanjung Murau lithological log 07 and the bottom parts of Tanjung Sekakap lithological logs 02 and 05 (Figure 06). Based on their thickness, the alluvial fan in Tanjung Murau lithological log 07 and in Tanjung Sekakap lithological log 05 seem to be relatively larger than that of the Tanjung Sekakap lithological log 02.

Gilbert-Type Topset-Foreset Facies Association

A possible Gilbert-type topset-foreset facies association is seen in the lower part of lithological log 09 at Tanjung Murau and middle part of lithological 05 at Tanjung Sekakap (Figure 6). These sections are dominated

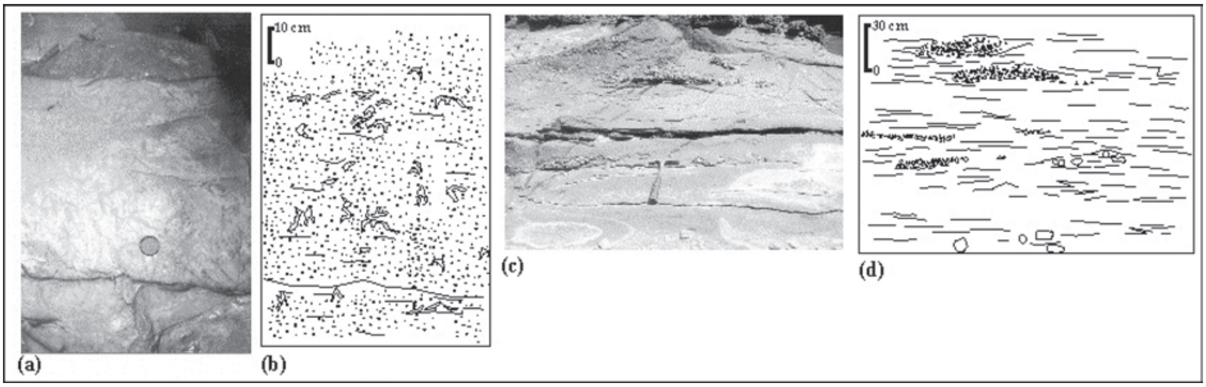

Figure 5. Some typical facies developed in Tanjung Sekakap - Tanjung Murau rudaceous rocks: photographs (left column) and schematic sketches (right column). a,b – Facies Sm: Massive sandstone; c,d – Facies Mh: Homogenous mudstone.

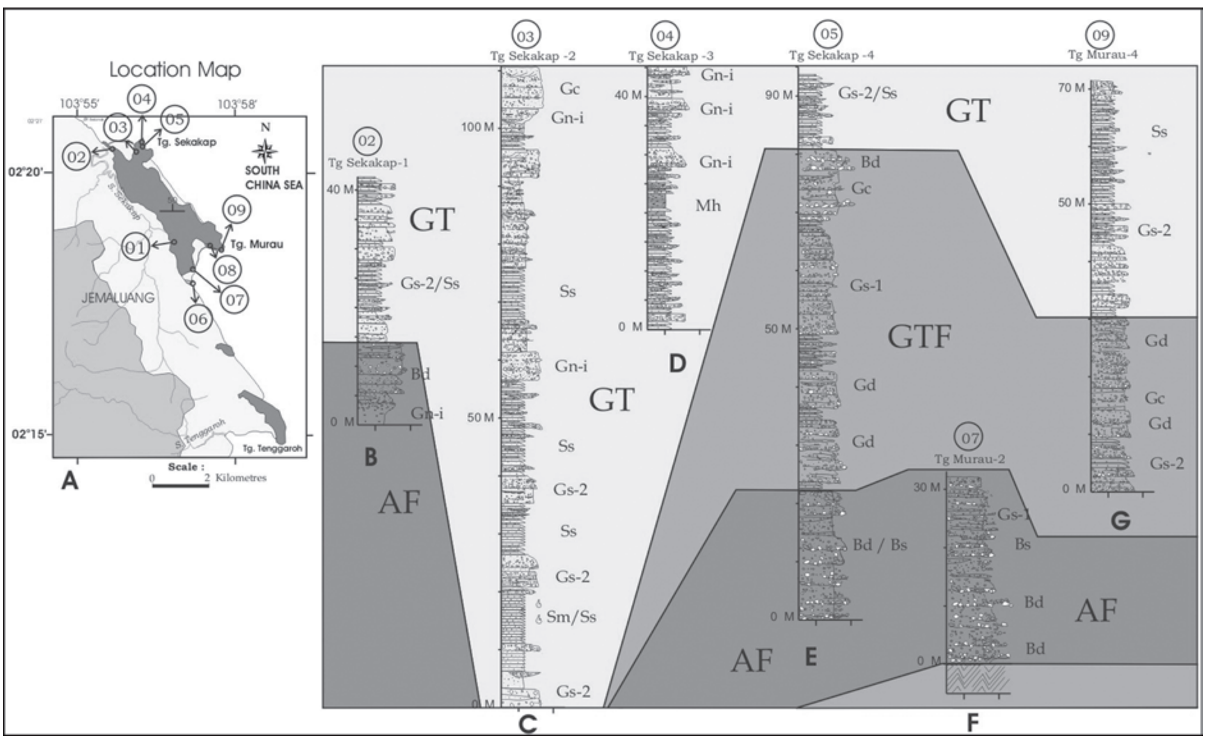

Figure 6. Lithological logs from representative outcrops between Tanjung Sekakap and Tanjung Murau and their facies associations. A – Distribution of lithological log and observation localities. B-G – Lithological logs at localities 02, 03,04, 05, 07 and 09. [AF – Alluvial fan. GTF – Gilbert-type topset – forseset fan delta. GT – Gilbert-type topset fan delta].

by disorganized gravelstone (Facies Gd), crudely stratified gravelstone (Facies Gs-1 and Gs-2) and cross-bedded gravelstone (Facies Gc) that were possibly formed on both the Gilbert-type topset or foreset fan delta (Chough *et al.*, 1990, Hwang *et al.*, 1995). The Gilbert-type foreset fan-delta is best characterized by the presence of steeply inclined beds (initial slope between 20^o-25^o) of disorganized and crudely stratified gravelstone (Facies Gd, Gs-1 and Gs-2). In the Murau rudaceous rock, the initial slope is difficult to be determined due to the presence of extensive faulting and folding throughout the studied sections of the formation. The present interpretation is only based on the above facies association, which is best exhibited in the middle part of lithological log 05 and bottom part of lithological log 09 (Figure 6). Within this facies succession, Facies Gd, Gs-1 and Gs-2 are closely related to the Gilbert-type foreset delta and are intercalated with Facies Gc, which is usually interpreted as Gilbert-type topset deposits. Therefore, as a whole, the best possible facies association of the mention facies succession is the Gilbert type foreset – topset (GTF). The possible depositional environment of such facies association is in the transitional or shallow marine environment, within which Hwang *et al.* (1995) interpreted the progradation of river mouth bar or lobe to shallow marine environment and progradation of Gilbert-type microdelta to shallow-marine environment has occurred.

Gilbert-Type Topset Facies Association

The Gilbert-type topset facies association is developed in the upper part of lithological log 09 (Tanjung Murau) and the upper part of most lithological logs in Tanjung Sekakap (Figure 6). This association is represented by the Facies Gc, Gn-i and Gs-2 (cross bedded-, normally-inversely- and crudely stratified pebble-rich- gravelstone) as well as the stratified sandstone facies (Facies Ss). According to Chough *et al.* (1990), the alternation of Facies Ss and layered or channelized breccia indicates lateral grading of breccia dominated small alluvial fans into a large-scaled stream dominated alluvial fan. This sedimentary process resulted in migrating gravel bars and secondary channel fills, eventually forming disorganized and cross-bedded gravelstones (Miall, 1977). Chough *et al.* (1990) interpreted that these processes possibly occur in a shallow marine environment within a Gilbert-type topset environment. The interpretation of shallow marine depositional environment is supported by the presence of bioturbated sandstone (Facies Sm) as observed in Tanjung Sekakap. This particular bioturbated sandstone represents brackish or shallow marine sediments (Chough *et al.*, 1990).

Wescott and Ethridge (1980) mentioned that a Gilbert-type topset sediments are mainly deposited by channel shifting and possibly also as a part of alluvial fan, braided stream systems. The occurrences of homogeneous mudstones (Facies Mh) are indicative of flood plain deposits. The presence of clustered clasts in the mudstone (Facies Mh) as seen at Tanjung Sekakap probably resulted from traction movement, associated with the waning of turbulent debris flow (Kim *et al.*, 1995). The debris fall deposits were probably supplied from the upper slope, intermittently exceeding the reposed angle.

A possible lateral repetition of the sequence started from the southeast (Tanjung Murau) where proximal facies assemblages are prominent, to the northwest (Tanjung Sekakap), which represents distal facies of the fan complex forming several lobes of fan-delta system (Figure 7). Most of the delta and alluvial fan lobes show that the source of sediments came from the south-southwest and the basin is relatively deeper to the north-northeast (Figure 8). The complete basin-ward lateral facies development, however, cannot be observed as only part of the sequence is exposed at the present erosion level.

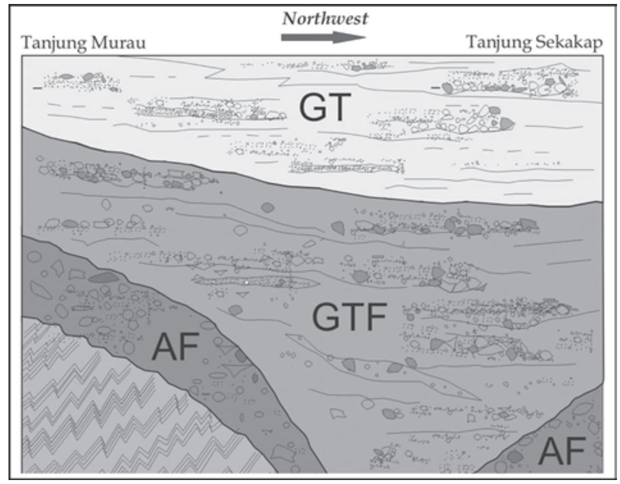

Figure 7. Murau rudrock facies associations and lateral facies development. AF – Alluvial Fan. GTF – Gilbert-type topset – foreset fan-delta. GT – Gilbert-type topset fan-delta.

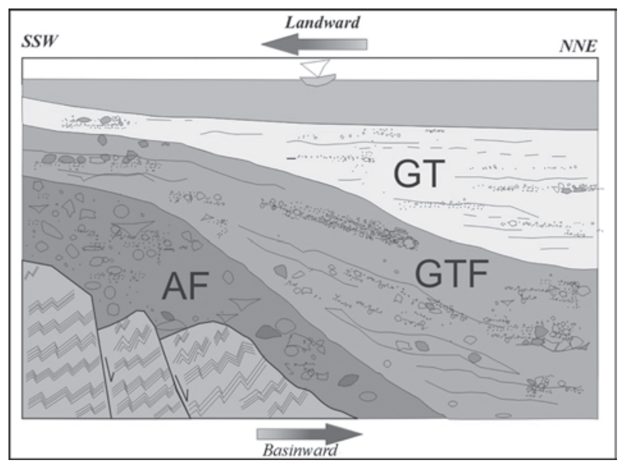

Figure 8. Depostional Model for fan-delta sequences as interpreted for the Murau rudrock outcrops.

Murau Basin development

Sub-aerial alluvial, transitional delta and deep-water sub-marine fans are all special depositional environments developed on foot slopes commonly found along scarps of normal fault. Normal faults are common feature of extensional tectonics, often associated with the formation of horst and graben topography. The latter provides best post-tectonic depositional environment especially for coarse-grained sediments. As for this study case, the Murau basin was interpreted by Ibrahim Abdullah *et al.* (1991) as a half graben resulted from the development of a local normal fault referred as the Murau fault. This fault was thought to be part of the more regional North-South trending Murau-Bukit Keluang fault, extending from Bukit Keluang area in North Terengganu to Tenggaroh area in East Johor. The exact timing for the faulting and the filling of the basin is still uncertain, but it is most likely older than the neighbouring Middle Permian Sedili Volcanic since there is apparently lack of volcanic clast in the resulting breccia of Murau Conglomerate.

In east Johor, the oldest rock unit i.e. the Mersing Formation was deposited in a relatively shallow marine environment. Subsequent tectonic event has turned these sedimentary rocks into a low to medium grade metamorphic rocks prior to the formation of the Murau half graben basin. The initial basin filling by alluvial fan and part of the following delta fan was thought to have taken place concurrent with the subsiding of the basin, hence while the fault is still relatively active. As a result, thick succession of rudaceous rock with clasts mainly originated from the bedrocks was formed within reasonably short time span. Stratigraphically, the development of Gilbert-type topset-foreset delta fan deposit over the alluvial fan deposit marked prominent changes of palaeoenvironment from sub-aerial to shallow marine, while the succeeding Gilbert-type topset delta fan indicated that the basin is eventually shallowing and filled up completely.

CONCLUSIONS

Due to dominance of rock chips and angular clasts within it, the rudaceous rock sequence in Tanjung Sekakap – Tanjung Murau area should be classified as a sedimentary breccia rather than conglomerate. The Murau breccias are a sequence of rudrocks deposited within a complex series of alluvial fan, topset-foreset and topset Gilbert-type delta systems. The Murau rudaceous rocks were deposited within a half graben basin controlled by subsidence of Murau faulted block. The sediment source is mostly derived from the underlying pre-Permian bedrock of Mersing Formation consisting of schist, phyllite and quartzite. The rudrock deposition is dominated by a fluvial system controlled by slope gradient and debris-turbidites and fluvial developments on the fan-delta system within a continental margin environment. The absence of basin plain, slope apron as well as pro-delta associated facies and the dominance of shallow water – sub-aerial transitional facies association is probably due to unstable condition resulting from active subsidence during sedimentation. The repetition of facies succession in the Murau rudrocks probably represents multiple lobes of a fan-delta system with sediment sources derived from the south-southwest. The Murau Conglomerate is probably correlatable with some other genetically similar late Palaeozoic conglomerate units dominating the coast and offshore of Terengganu such as the Bukit Keluang, Redang and Pulau Kapas Conglomerates.

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