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Synsedimentary deformation of the Kapas Conglomerate, Pulau Kapas, Terengganu

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Abstract: Late Paleozoic continental conglomerates are widely distributed in the Eastern Belt of Peninsular Malaysia. In Terengganu, it primarily occurs in Pulau Kapas as a wedge shaped basin, thought to be formed within a strike slip fault system. A structural and sedimentological study of the Kapas Conglomerate provides insight into its sedimentary tectonic history. The initial tectonic activity in the basin can be traced to movement along two major splaying strike-slip faults, the dextral NS Kapas Fault Zone and a sinistral NNW fault, which enclose the Kapas Conglomerate. When these faults were concurrently active, a region of compression and uplift developed where they converged. Correspondingly, extension and subsidence occurred where they diverged. This setting produced a major source area, which supplied relatively constant detritus to the adjacent fault-wedge basin. In the Late Palaeozoic, a braided alluvial fan developed in the region, as represented by the Kapas Conglomerate. The fan evolved in a semi-arid climate, and flows were generally from the west. The development of the fan is coeval with synsedimentary volcanism.The overall trend of the sedimentary sequence is the result of the strike slip faulting along the active margin of the subsiding basin. Active faulting activities continued during the deposition leading to synsedimentary deformation of the conglomerate. A NS dextral strike slip fault system at the western margin of the Kapas Conglomerate provides clear evidence for this tectonic phase. The influence of this tectonic phase is recorded in the coarsening upward cycles of the sedimentation. Due to ongoing synsedimentary strike slip deformation, the sediments show sets of small-scale conjugate normal faults creating a pattern of horst and graben structures, internally progressive tilting of the strata and an internal angular unconformity. This Late Palaeozoic dextral transpressive deformation, and rapid uplift followed deposition of continental sediment coeval with volcanism, in a tectonically active strike slip basin is a major orogenic event which can be considered as part of a large scale deformation in the Eastern Belt that may have accommodated the oblique convergence of the two tectonic blocks of Peninsular Malaysia.

Abstrak: Konglomerat benua banyak terdapat tertabur di jalur Timur Semenanjung Malaysia. Di Terengganu ia terdapat di Pulau Kapas dalam satu lembangan berbentuk baji, yang dipercayai terbentuk akibat sistem sesar gelinciran jurus. Satu kajian struktur dan enapan Konglomerat Kapas dapat menyingkap sejarah tektoniknya. Aktiviti tektonik awal lembangan ini boleh dikaitkan dengan pergerakkan sepanjang dua sesar gelinciran jurus yang besar, iaitu Zon Sesar Kapas (dekstral, U-S) dan satu sesar sinistral yang menjurus B-BL, yang membendung Konglomerat Kapas. Apabila sesar-sesar ini aktif serentak, satu kawasan mampatan dan terangkat terbentuk. Apabila mereka mencapah, berlaku pula keadaan ekstensi dan penurunan. Keadaan ini menghasilkan kawasan sumber yang membekalkan detritus kepada lembangan tersebut. Pada Paleozoik Lewat, satu kipas lanar terbentuk yang diwakili oleh Konglomerat Kapas. Kipas lanar ini terbentuk pada kawasan separa kering dan aliran secara umumnya ke arah barat. Pembentukan kipas ini berlaku semasa dengan aktiviti volkanisma. Corak keseluruhan turutan enapan yang terhasil adalah hasil sesaran gelinciran jurus sepanjang tepian aktif lembangan yang sedang menurun itu. Aktiviti sesaran berlanjutan semasa dengan pengenapan menyebabkan canggaan syn-sedimen konglomerat tersebut. Kehadiran satu sistem sesar gelinciran jurus dekstral pada sempadan barat Koglomerat Kapas adalah bukti untuk fasa tektonik ini. Pengaruh fasa tektonik ini direkodkan dalam bentuk kitaran enapan yang bercorak mengasar keatas. Disebabkan oleh aktiviti canggaan gelinciran jurus syn-sedimen yang berterusan, enapan ini menunjukkan beberapa set sesar normal konjugat, penyegetan progresif strata dan satu ketakselarasan dalam. Canggaan transpresi dekstral ini diikuti dengan pengenapan enapan benua semasa dengan volkanisma, dalam suatu lembangan gelinciran jurus boleh dikaitkan dengan canggaan rantau di jalur Timur yang terhasil akibat penumpuan serong kedua-dua bungkah tektonik Semenanjung Malaysia.

INTRODUCTION

Continental conglomerates are widely distributed in the Eastern Belt of Peninsular Malaysia. These conglomerates are the Murau Conglomerates, the Redang Conglomerates, the Bukit Keluang Conglomerates and the Kapas Conglomerates. They unconformably overlie Permo-Carboniferous metasediments basement, suggesting that they are the basal conglomerates of the continental sediments of the Eastern Belt.

These conglomerates are believed to be deposited in tectonically active basins. The Murau Conglomerates are believed to be deposited on the downthrown side of a normal fault scarp (Ibrahim Abdullah *et al.*, 1991). The Kapas Conglomerates are believed to be deposited on the downthrown side of a normal fault that was reactivated as a dextral strike slip fault (Ibrahim Abdullah, 2002) or within a wedge-shaped depression associated with dextral strike slip fault zone (Mustaffa Kamal Shuib, 2003).

This paper presents the results of detailed study on

unravelling the complex stratigraphic and structural evolution of the Kapas Conglomerates. The good exposures of the Kapas Conglomerates and its underlying basement rocks in Pulau Kapas (Figure 1) provide an excellent setting to evaluate the structural controls on stratigraphic evolution of the tectonically active continental basin. A structural study based on the presence of synsedimentary deformational structures in the deposits, provides insight into its sedimentary tectonic history. It will be shown that the deposition of the Kapas Conglomerates exposed in a wedge shaped outcrop, bounded within a transpressional/ transcurrent fault system was controlled by dextral strike slip faulting activities.

GENERAL GEOLOGY

Pulau Kapas is located about 3 km off Marang, Terengganu. The island is underlain by strongly deformed Permo-Carboniferous metasediments; an unconformably overlying mildly deformed conglomerate sequence (The Kapas Conglomerate, Figure 1) and intruded by dolerite dykes of probable Cretaceous age. The metasediments may initially have been deposited in a shallow marine environment or near to a delta whilst the Kapas Conglomerate may have been deposited on an alluvial fan or fluvial environment (Kamal Roslan Mohamed *et al.*, 1999).

The Kapas Conglomerate has been correlated to the Jurassic-Cretaceous Gagau Group (Rishworth, 1974) and the Tembeling Formation (Koopmans, 1968). It was assigned to a Triassic-Jurassic age by Mohamad Barzani (1988). Recently the conglomerate was correlated to the Late Permian Bukit Keluang Conglomerate (Mohd Shafeea *et al.*, 1999) by Che Aziz & Kamal Roslan (1997) and Kamal Roslan *et al.* (1999), suggesting that the age of the Kapas Conglomerate could be Late Permian to Triassic. However, there is a possibility that the conglomerate may still be of Jurassic-Cretaceous age (Kamal Roslan *et al.*, 1999).

STRUCTURAL GEOLOGY

Previous detailed structural study on the island was done by Mohamad Barzani (1988), Ibrahim Abdullah (2002) and Mustaffa Kamal Shuib (2003). Mohamad Barzani (1988) suggested that the island could have undergone three episodes of deformation. Ibrahim Abdullah (2002) concluded that the island has been affected by multiple deformation episodes and that the Kapas Conglomerate was deposited on the downthrown side of earlier N-S normal faults that was reactivated later into dextral strike-slip faults. Detailed structural mapping and kinematic analysis of the structures in the island by Mustaffa Kamal Shuib (2003) showed that the island has suffered dextral transpressive deformation episodes that led to the development of a strike-slip basin where the Kapas Conglomerate was deposited.

The structures found in Pulau Kapas are shown in Figure 1. The Permo-Carboniferous metasediments maintained a near constant bedding orientation throughout the area. Bedding generally strikes NNW to NS and dips steeply to either east or west. They have been folded into a series of close to tight folds trending NNW-SSE to NS. These folds are commonly cut by NNW to NS axial plane parallel faults and shear zones with both strike-slip and reversed sense of displacement. These structures are attributed to the first phase of brittle-ductile deformation (D_1).

BASIN BOUNDING FAULTS

A broad 150 meter wide NS fault zone (The Kapas Fault Zone, Figures 1 & 2) characterized by a network of steep to sub vertical strike-slip and reversed faults is found at the southern part of the island. Smaller NNW striking sinistral and NNE dextral strike-slip faults are found outside

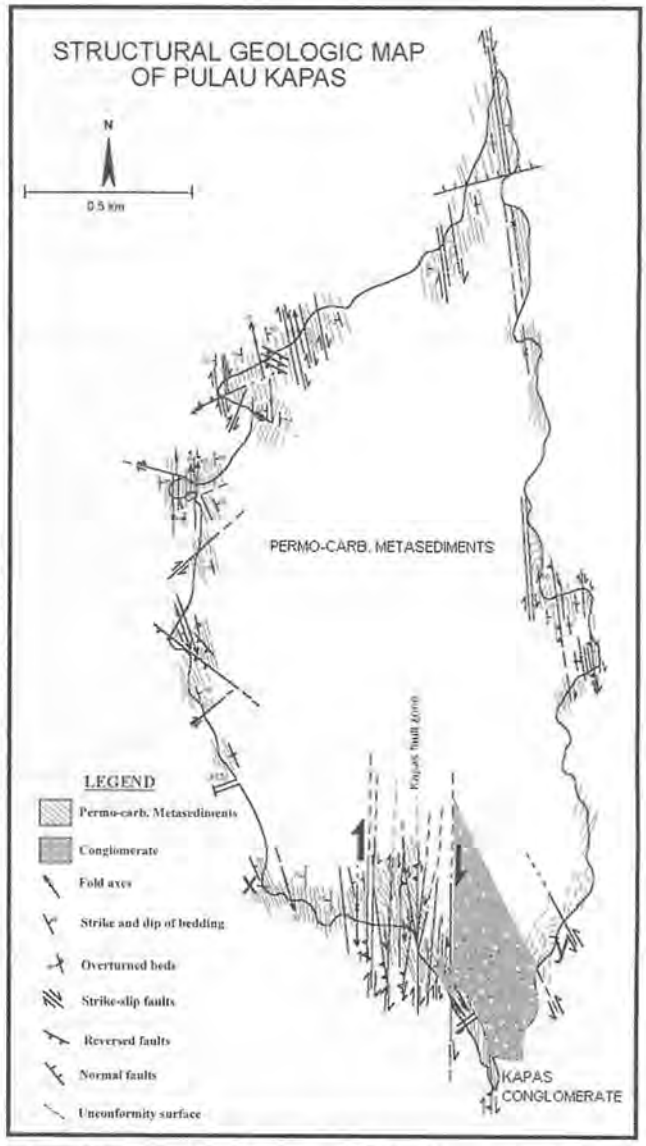

Figure 1. Structural geology map of Pulau Kapas (modified after Mustaffa Kamal Shuib, 2003).

the fault zone. These structures are attributed to the second phase of brittle-ductile deformation (D_2). These early structures are overprinted by later NNE striking dextral strike-slip faults, NNW sinistral strike-slip faults, NNW and ENE oblique reversed faults and ENE normal faults (Figure 2). These structures are attributed to the later phases of brittle deformation (D_{3-4}).

The NS Kapas Fault Zone forms the western boundary of the Kapas Conglomerate (Figure 1). The eastern boundary of the wedge-shaped conglomerate exposure is defined by NNW sinistral strike slip fault zone along the eastern coast of the island (Figure 1). The conglomerate has been deformed into a broad doubly plunging NNE-SSW gentle synclinal structure and cut by EW dextral, NNW sinistral and NS dextral strike-slip faults (Figure 2) attributed to the later phases of brittle deformation (D_{3-4}).

THE KAPAS CONGLOMERATE

Characteristics of the alluvial deposits are well illustrated in the stratigraphic section shown in Figure 3. The depositional sequence measured is about 40 m thick. During geological mapping it has been determined that the investigated deposits at the base of the sequence pass upward from massive clast-supported conglomerates into massive reddish shales and silts with thin conglomerate lenses, with rare lenses of gravel exhibiting low-angle cross bedding. These deposits are overlain by thick beds of coarse massive matrix-supported and clast-supported conglomerates. It is noted that the shales are tuffaceous and the matrix of the conglomerates have a high content of tuffaceous materials. The vertical succession of the deposits is dominantly composed of fining-coarsening upward cycles. The vertical succession starts off with small fining upward cycles that change into coarsening upward cycle at the top of the succession within a general coarsening upward sequence (Figure 3). The succession also shows thickening of beds up the section.

The main characteristics of these deposits are as follows: a domination of coarse-grained over fine-grained deposits; conspicuous variations in grain size; very rapid lateral and vertical facies alternations; changes in composition; and lack of fauna. Deposits in the measured sections were grouped into the following facies units:

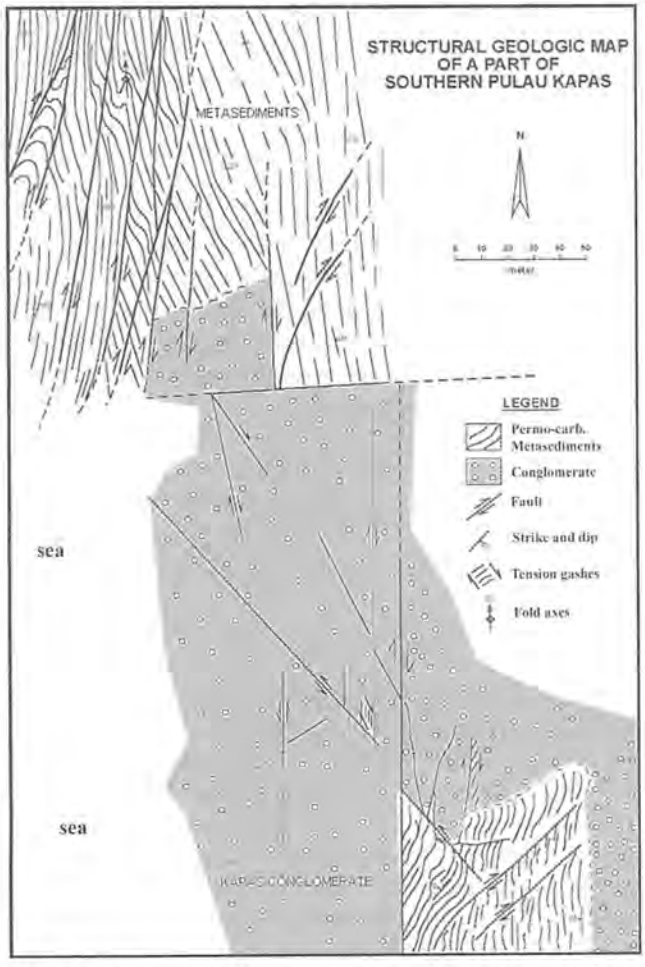

Figure 2. Structural geology map of a part of southern Pulau Kapas (modified after Mustaffa Kamal Shuib, 2003).

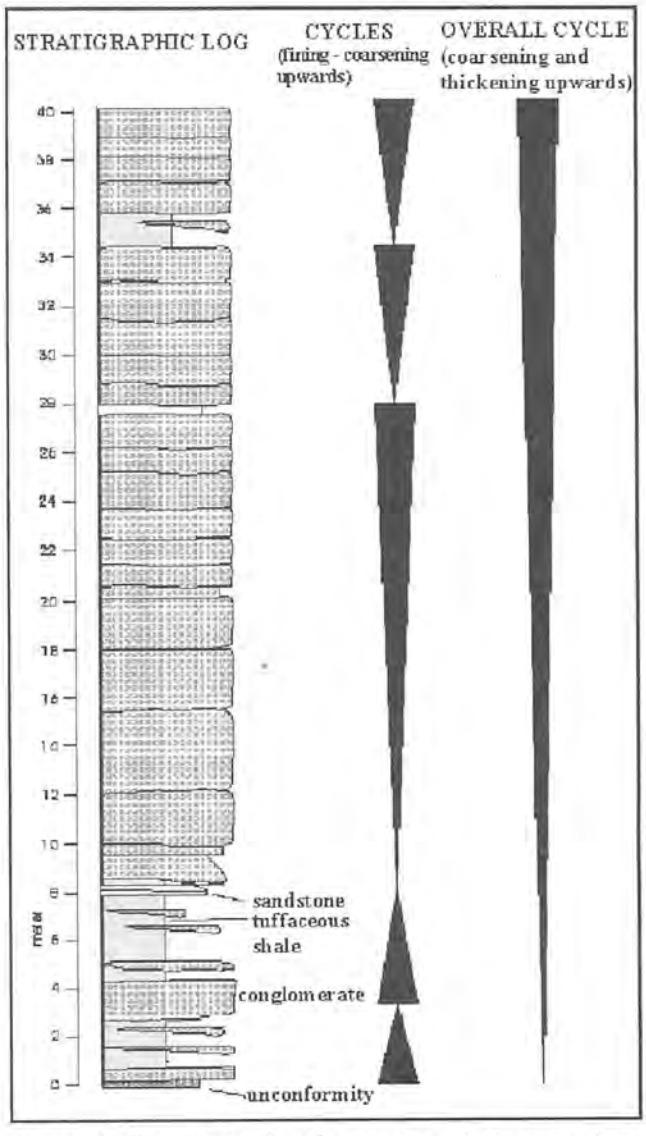

Figure 3. The Kapas Conglomerate vertical successions. (stratigraphic log modified after Kamal Roslan *et al.*, 1999).

1) massive matrix-supported conglomerates (plastic debris flow),
2) massive matrix- to clast-supported conglomerates (pseudoplastic debris flow),
3) massive clast-supported conglomerates (main fan-trench, longitudinal bar, channels),
4) lenses of pebble to granule conglomerates (stream flows), and
5) shales (flood plain),

The association of sediments deposited by debris flows mechanisms with deposits of traction currents and sediments of flood-plains indicates deposition in alluvial environments, relatively close to the source area, probably in a braided alluvial fan (Miall, 1978a, 1978b, 1990, 1996). The fan evolved in a semi-arid climate, as indicated by the associated occurrence of common gravitational flows, red pigmentation and absence of coal.

The clast ranges in size from 5 cm to 50 cm in diameter. They range in shapes from angular to sub-rounded. Tang (2003) determined the palaeo-transport directions of imbricated platy fragments in coarse-grained facies. A total of 66 fragment orientations were measured by Tang (2003). In the entire succession a very wide dispersion of flow orientation data was recorded. Her results indicate a general palaeo-transport direction from the west.

The conglomerates are composed of predominantly quartzite; slates, parallel laminated shales and siltstone with rare quartz clasts. The main characteristics of the sediment composition suggest that the source area of deposits observed in the section was predominantly composed of metamorphic rocks, originated by erosion of metasedimentary rocks. The basement below the Kapas Conglomerate deposits is composed of metasedimentary rocks of Permo-carboniferous age. Therefore, it may be concluded that a source area for deposits of the section, according to the reconstructed palaeotransport directions, was probably located west of the present Pulau Kapas.

FAULT CONTROL OF THE KAPAS CONGLOMERATE SEDIMENTATION

An indication of the fault control in sedimentation of the Kapas Conglomerate is the presence of coarse mass flow deposits bounded by strike slip faults. The thick accumulation of coarse-grained deposits most likely reflects rapid subsidence of the basin floor during the opening of the basin. The presence of tuffaceous shales and the matrix of the conglomerates having a high content of tuffaceous materials testify to synsedimentary volcanism during the development of the basin.

The vertical succession of the deposit is dominantly composed of small fining upward cycles followed by coarsening upward cycles within a general coarsening upward sequence and corresponding thickening upwards successions (Figure 3). In addition to the presence of strike slip basin bounding faults and synsedimentary volcanism; this reflects the irregular pattern of tectonic/faulting activity recorded in the sedimentary patterns within the alluvial fan conglomerates. In strike slip setting the development of the fan would primarily depend on its lateral shift along the fault, as well as the systematic progradation of the fan itself (Steel, 1988). In the example presented by Steel (1988), contemporaneous lateral shift and progradation of alluvial fan in strike slip setting will result in the likely possibility of the formation of predominantly coarsening-upward or fining-coarsening upward cycles and megacycles. The overall trend of the Kapas Conglomerate sequence is coarsening upwards, typical of most strike-slip basins, interpreted as the result of strike slip faulting along the active margin of the subsiding basin.

SYNSEDIMENTARY DEFORMATION OF THE KAPAS CONGLOMERATE

The Kapas Conglomerate has recorded various syndepositional tectonic deformations that reflect the states of stresses successively prevailing during the deposition. Numerous basement faults extend upward into, and displaced the Kapas Conglomerate strata and the unconformity surface (Figure 2). Depositional features and facies relationships suggest that much of this faulting occurred prior to and during the Kapas Conglomerate deposition. The Kapas Conglomerate is cut by a series of north-trending faults, creating a series NS synsedimentary blocks.

A NS dextral strike slip fault system (the Kapas Fault Zone) at the western margin of the Kapas Conglomerate provides clear evidence for this tectonic phase (Figures 1, 2 and 4). The faults not only bound the Kapas Coglomerate, but in places it is truncated by the unconformity surfaces and in other places it truncates the unconformity surfaces (Figure 4 A-D). This suggests that the fault system was initiated prior to, and continued during and after the deposition of the conglomerate.

Due to ongoing synsedimentary strike slip deformation, the sediments show, internally progressive tilting of the strata (Figure 5A and 5B), internal angular unconformities (Figure 5D) and sets of small-scale conjugate normal faults creating a pattern of horst and graben structures (Figure 5D). Here, progressive tilting of the strata resulted in NW trending gentle synclinal warps (Figure 5C) and angular unconformities in the basal conglomerates sequence illustrate the synsedimentary displacement of the fault system. The presence of NE striking conjugate faults within the tilted strata below the internal uinconformity suggests NW extension accompanied the general tilting of strata. The oldest sediments of this succession were tectonically affected. The oldest and thickest depositional units are situated along the present western basin margin. This as well as onlap relations towards basement at low stratigraphic levels indicates a significant component of north-westward tilt of the basin floor during the earliest stages of deposition.

The north-westward tilt was most likely produced by north-westwards extension during early stages of basin formation.

Small scale basement NE and EW conjugate strike slip faults (Figures 2 and 6A) also extend upwards into the Kapas Conglomerate strata but were truncated by the overlying strata and show rapid termination of fault displacement upwards in the stratigraphy. Along the faults the conglomerates were tilted and stretched. Their geometry shows that at the initial stage of basin deposition, the basin was extending in a NW-SE direction

Higher up the stratigraphic level, synsedimentary conjugate oblique-normal faults recorded the prevailing transtensional strike slip stress at that time. Sets of NE-SW small-scale normal faults created a pattern of horst and graben structures (Figure 6). The fault zones of the small scale synsedimentary intrabasinal conjugate faults (Figure 6B) are commonly filled with fluidized sand and clay as shown by the cuspate structures at the intersection between the faults and the base of the conglomerates.

These observations strongly suggest a syndepositional origin for the faults described earlier. Other evidences for syndepositional fault activity include thickness variations across faults, rapid termination of fault displacement upwards in the stratigraphy and wedges of coarse sediment that thin away from the fault planes and intercalate with sandstones distally.

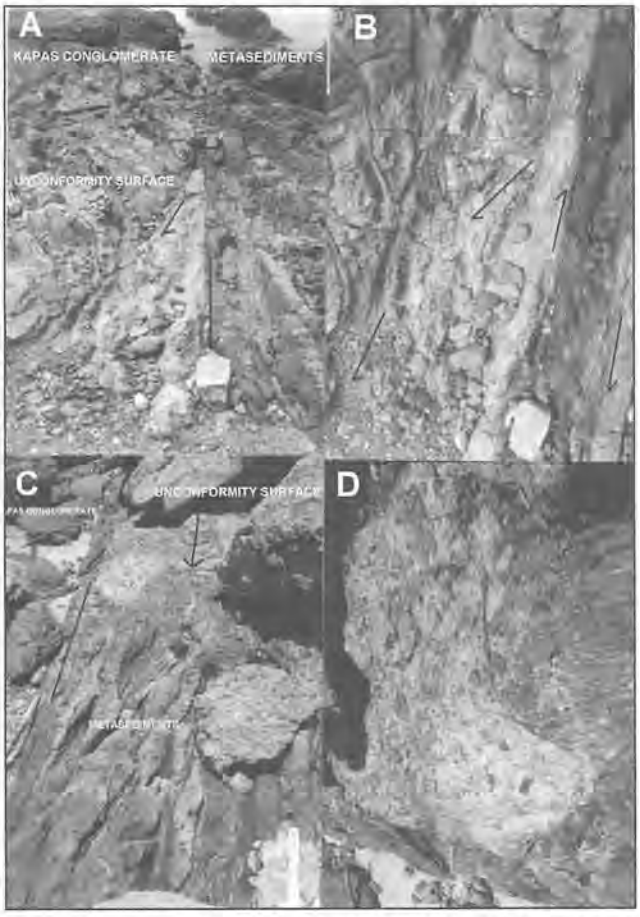

Figure 4. Photographs showing A) the NS dextral strike slip fault system (the Kapas Fault Zone) at the western margin of the Kapas Conglomerate, B) close-up showing details of the dextral fault zone, C) the faults not only bound the Kapas Coglomerate, but in places it is truncated by the unconformity surfaces and D) in other places it truncates the unconformity surfaces, suggesting that the fault system were initiated prior to, continued during and after the deposition of the conglomerate.

SYNDEPOSITIONAL DEFORMATIONAL HISTORY

In Pulau Kapas, the deformation history results mainly from the superposition of two finite strain patterns and later less significant brittle deformations (Mustaffa Kamal Shuib, 2003). The D_1 strain pattern is characterized by doubly plunging, cleavage-transected folds cut by axial plane parallel NNW to NS faults and dextral shear zones. The D_1 strain pattern shows a strong partitioning between the sub-vertical shear zones and the folded blocks. The E-W horizontal shortening and N-S dextral shearing is accommodated by folding and strike-slip faulting in the shear zones. Thus D_1 strain pattern reflects a transpressive deformation regime as defined by Sanderson and Murchini (1984).

The D_1 structures were reworked by D_2 events, which amplified, rotated clockwise and refolded the earlier structures. These led to the stretching and near transposition of the earlier structures along N-S D_2 dextral fault zones. The interaction of D_2 dextral fault zone with NNW striking sinistral faults led to differential uplift and subsidence of the faulted blocks. Subsequent weathering and erosion of the metasediments led to the deposition of the Kapas Conglomerate within the subsided blocks.

In Late Palaeozoic, a braided alluvial fan coeval with volcanism, developed in the region, as represented by the Kapas Conglomerate. The fan evolved in a semi-arid climate, and flows were oriented generally from the west. The overall trend of the sedimentary sequence is the result of the strike slip faulting along the active margin of the subsiding basin. Active faulting activities continued during the deposition leading to synsedimentary deformation of the conglomerate. Due to ongoing synsedimentary transtensional deformation, the sediments show sets of small-scale conjugate normal faults creating a pattern of horst and graben structures, internally progressive tilting of the strata and some angular unconformaties. Here, progressive tilting of the strata and angular unconformities in the basal conglomerates sequence illustrate the synsedimentary displacement of the fault system. The presence of conjugate faults suggests NW extension accompanied the general tilting of strata. In addition, the overall trend of the Kapas Conglomerate sequence of coarsening upwards succession, illustrate the strike slip tectonic control of the Kapas Conglomerate sedimentation. The fact that the Kapas Conglomerate is cut by a series of north-trending faults, creating a series NS fault-bounded blocks suggest that D_2 continued after the deposition of the conglomerates. The Kapas Conglomerate was further subjected to later brittle deformations.

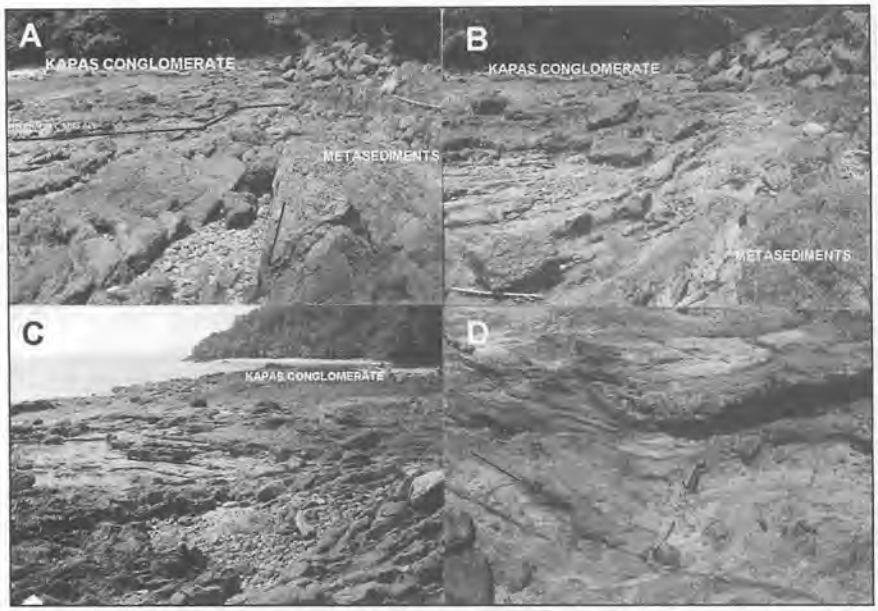

Figure 5. Photographs showing the internally progressive tilting of the strata (A & B), internal angular unconformities (A) and sets of small-scale conjugate normal faults creating a pattern of horst and graben microstructures (D). Here, progressive tilting of the strata resulted in NW trending gentle synclinal warps (C) and angular unconformities in the basal conglomerates sequence illustrated the synsedimentary displacement of the fault system.

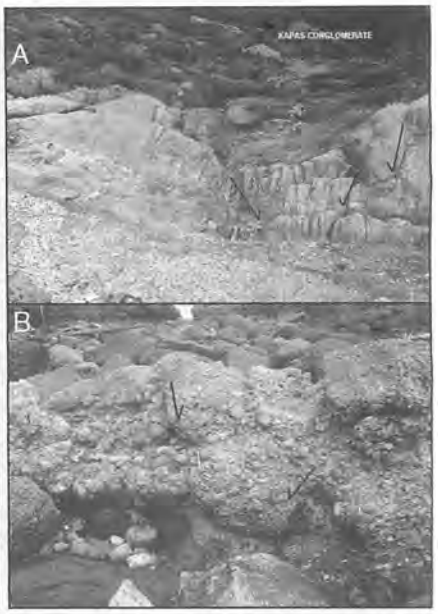

Figure 6. Photographs showing sets of NE-SW small-scale oblique-normal faults (A & B). The fault zone of the small scale synsedimentary intrabasinal conjugate faults are commonly filled with fluidized sand and clay.

CONCLUSION

The initial tectonic activity in the basin can be traced to movement along two major splaying strike-slip faults, the dextral NS Kapas Fault Zone and a NNW fault, which enclosed the Kapas Conglomerate. When these faults were concurrently active, a region of compression and uplift developed where they converged. Correspondingly, extension and subsidence occurred where they diverged. This setting produced a major source area which supplied relatively constant detritus to the adjacent fault-wedge basin. Active strike-slip faulting activities continued during the deposition leading to synsedimentary deformation of the conglomerate.

Late Palaeozoic continental conglomerates are widely distributed in the Eastern Belt of Peninsular Malaysia. It is highly likely that a similar sedimentary tectonic history can be deduced for these deposits. A detailed structural and sedimentological study of its rocks may provide insight into its sedimentary tectonic history. This Late Palaeozoic dextral transpressive deformation, and rapid uplift followed by the deposition of continental sediment in a strike slip basin is a major orogenic event which can be considered as part of a large scale deformation in the Eastern Belt that may have accommodated the oblique convergence of the two tectonic blocks of Peninsular Malaysia.

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