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Transpression in the strata of Pulau Kapas, Terengganu

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Abstract: The Kapas Island has suffered two successive dextral transpressive deformation episodes that lead to the development of a dextral strike-slip basin where the Kapas Conglomerate was deposited. During the first phase of brittle-ductile deformation (D_1) a series of close to tight folds trending NNW-SSE to NS were formed in the Permo-Carboniferous metasdiment. These folds are commonly associated with NNW to NS axial plane parallel faults and shear zones with both strike-slip and reversed sense of displacement. The D_1 structures were reworked by D_2 events which amplified, rotated clockwise and refolded the earlier structures, along N-S D_2 dextral shear zones and NNW striking sinistral faults. This caused differential uplift and subsidence of the faulted blocks. Subsequent weathering and erosion of the metasediments caused deposition of the Kapas Conglomerate within the subsided blocks. Continued deformation during this deposition lead to the syn-sedimentary deformation of the conglomerate. If the conglomerate is Late Permian to Triassic in age, then this would imply that the D_1 and D_2 deformation must be of late Permian age with D_2 continuing into the Permo-Triassic. The D_1 and D_2 Late Permian dextral transpressive deformation, and rapid uplift followed by 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 relate to the oblique convergence of the two tectonic blocks of Peninsular Malaysia.

INTRODUCTION

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) and intruded by dolerite dykes of probable Cretaceous age.

Pulau Kapas is of particular interest because of the presence of an unconformity that can be used to constrain the timing of geologic events on the island. But unfortunately, the exact ages of the metasediments and the Kapas Conglomerate are still unknown. No fossil have been found in both units. Similar metasediments at Batu Rakit Terengganu, yields a Carboniferous age fossils (Idris and Zaki, 1986). In Pulau Redang, similar metasediments underlying an unconformity yield Early to Late Permian plant fossils (Khoo *et al.*, 1988). Late early Permian limestones have been found in southern Terengganu (Fontaine *et al.*, 1998). Thus the age of the metasediments in Pulau Kapas could be Permo-Carboniferous.

The Kapas Conglomerate has been correlated to the Jurassic-Cretaceous Gagau Group (Rishworth, 1974) and the Tembeling Formation (Koopmans, 1968). It was assign to a Triassic-Jurassic age by Mohamad Barzani (1988). Recently the conglomerate was correlated with the Late Permian Bukit Keluang Conglomerate (Mohd Shafea *et al.*, 1999) by Che Aziz and 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).

Previous detailed structural studies on the island were done by Mohamad Barzani (1988) and Ibrahim Abdullah (2002). Mohamad Barzani (1988) suggested that the island has undergone three episodes of deformation. Ibrahim Abdullah (2002) concluded that the island had been affected initially by an ENE oriented compressive stress, followed a NNE compressive stress (in the Late Palaeozoic) which reactivated earlier N-S normal faults that formed the boundary of the Kapas Conglomerate into dextral strike-slip faults. Ibrahim Abdullah (2002) suggested that after the deposition of the Kapas Conglomerate, the stress reverted to an ENE orientation (during Triassic-Jurassic), and formed strike-slip faults which constrained the deposition of the conglomerate. This was followed by the intrusion of the dolerite dykes which was further subjected to a final SE-NW compressive deformation.

Detailed structural mapping and kinematic analysis of the structures in the island was undertaken to better understand the structural development of the area. This paper will show that the island has suffered dextral transpressive deformation episodes that lead to the development of a strike-slip basin where the Kapas Conglomerate was deposited. The structures and their timing are relevant to the tectonic evolution of the Eastern Belt.

STRUCTURAL GEOLOGY

The structures found in Pulau Kapas are shown in Figures 1 and 2. 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. At both the southern and

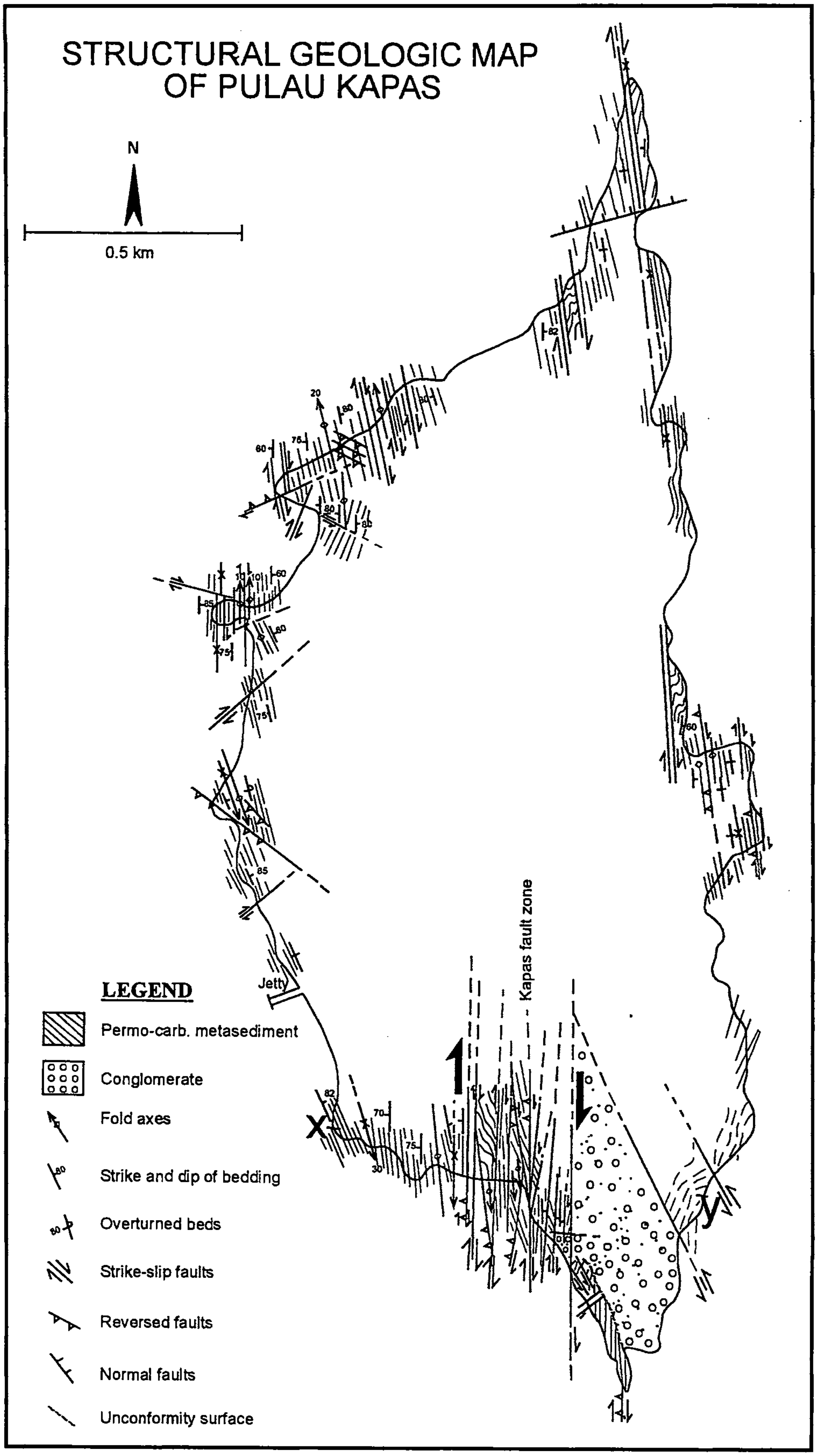

Figure 1. Structural geologic map of Pulau Kapas.

northern region of the island the beds are distinctively NS striking and sub vertical. 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). The structural elements of D_1 are plotted in Figures 3A and B.

A broad 150 meter wide NS fault zone (The Kapas Fault Zone, Figs. 1 and 4) characterized by a network of steep to sub vertical strike-slip and reverse faults is found at the southern part of the island. Smaller NNW striking sinistral and NNE dextral strike-slip faults are found outside the fault zone. The structural elements of D_2 are plotted in Figures 3C and 3D and they are attributed to the second phase of brittle-ductile deformation (D_2). The early D_1 and D_2 structures are cut by later NNE striking dextral strike-slip faults, NNW sinistral strike-slip faults, NNW and ENE oblique reversed faults and ENE normal faults all of which are attributed to a later phases of brittle deformation (D_{3-4}).

The NS Kapas Fault Zone forms the western boundary of the Kapas Conglomerate (Figs. 1 and 5). 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. The conglomerate has been deformed into a broad doubly plunging NNE-SSW gentle synclinal structure and cut by EW dextral, NNW sinistral, NS dextral strike-slip faults attributed to the later phases of brittle deformation (D_{3-4}).

EVIDENCES FOR TRANSPRESSIVE DEFORMATIONS

The rocks in Pulau Kapas have suffered two early phases of dextral transpressive deformations (D_{1-2}).prior to and during the deposition of the Kapas Conglomerate. Their characteristics and the evidences for dextral transpressive deformations are described below.

D_1 transpressive deformation

The features of D_1 are pervasive. Several lines of evidences document a dextral transpressive deformation during D_1. These include:

Doubly plunging folds

F_1 folds formed by the D_1 deformation are abundant on the island. The folds display considerable variation in style and geometry, but most are of similar type. The folds ranges from close to tight and in places are slightly overturned to the east with NNW-SSE to NS trending fold axis. At the boundary between the metasediments and the Kapas conglomerate, within the NS high strain zone, these folds are tight to isoclinal with steep to subvertical fold axes and have been refolded. In the northern part of the island, these F_1 folds are plunging gently to the north or north-northwest but in the south these folds plunges gently to the south (Fig. 3B). These suggest that Fl are doubly plunging folds.

Cleavage-transected folds

A series of gently plunging folds are associated with a set of cleavages that clearly transect the folds. These cleavage-transected folds show both clockwise axial and profile cleavage transection (Figs. 6A and 6B). Based on the occurrences of cleavages that show sigmoidal geometry due to shearing along the bedding plane, it is suggested the cleavage developed early during folding. This would suggest that the clockwise cleavage transection implies that the folds have undergone a dextral non-coaxial strain in a dextral transpressive regime.

Opposing fold vergence

On the western coast of the island F_1 folds are slightly overturned to the west suggesting westerly vergence (Fig. 6C). But on the eastern coast, the folds overturned to the east associated with westerly dipping dextral reversed faults suggesting easterly vergence (Fig. 6D). This opposing vergence is typical of transpressive deformation.

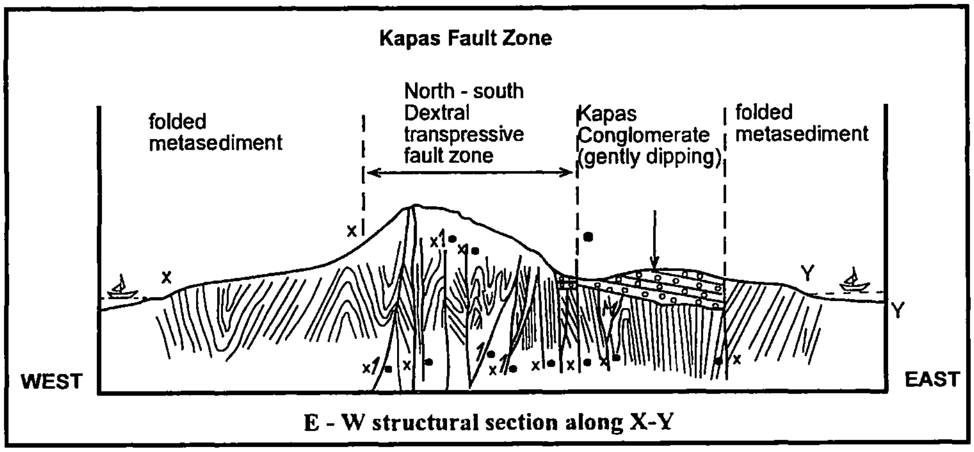

Figure 2. E-W cross-section along X-Y of Figure 1.

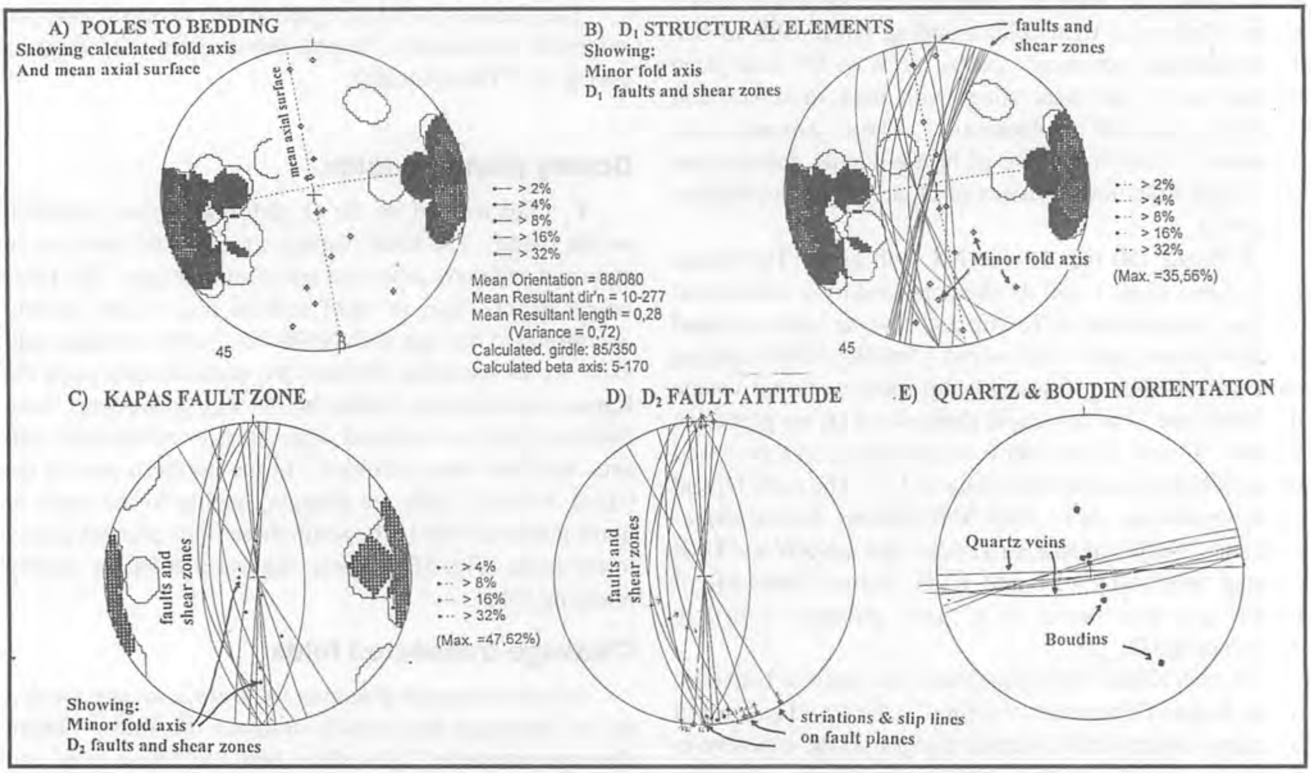

Figure 3. Stereonet lower hemisphere plot of structural data of Pulau Kapas. A) bedding and minor fold axis attitudes. B) D_1 structural elememts showing fault and shear zones attitudes. C) D2 structural attitudes along the Kapas Fault Zone. D) Striations on D_2 faults. E) Attitude of veins and boudins.

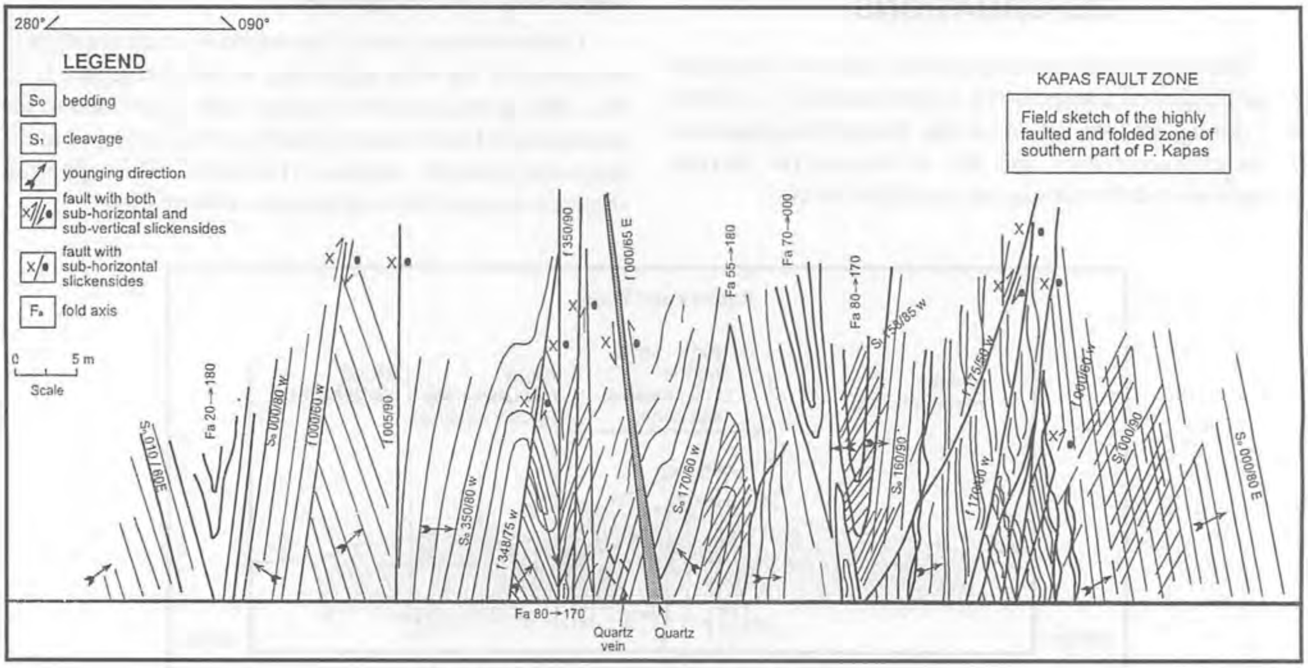

Figure 4. Field sketch of the Kapas Fault Zone.

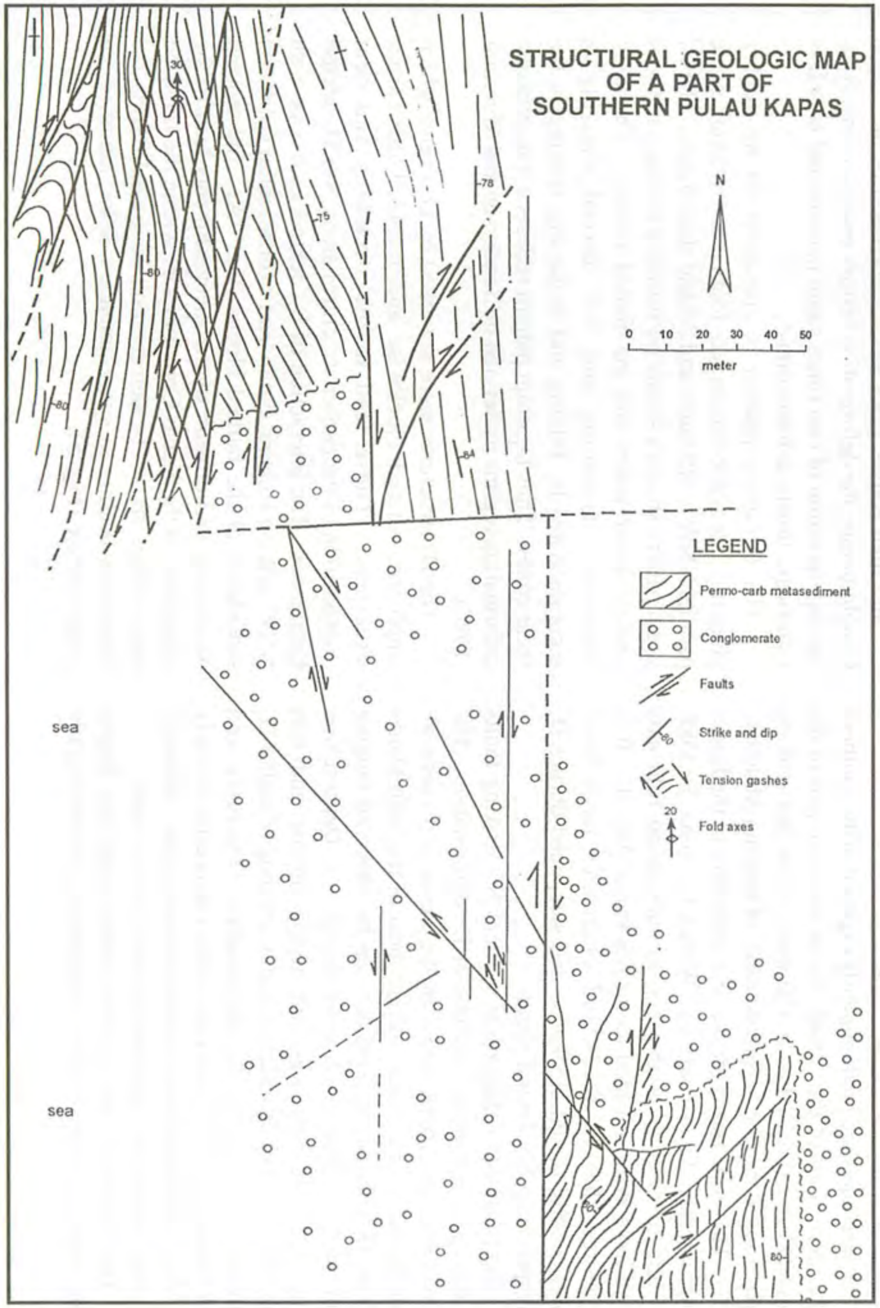

Figure 5. Structural geologic map showing the relationship between the Metasediments and the Kapas Conglomerate.

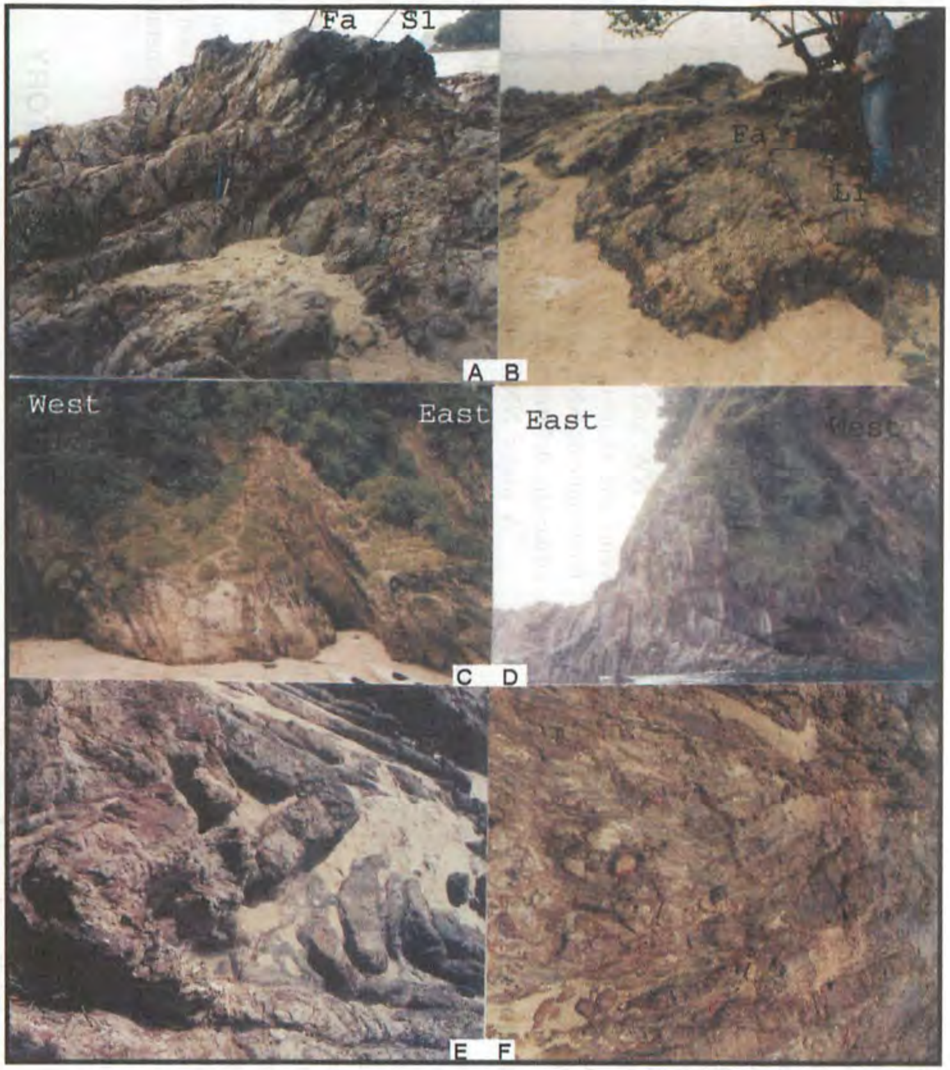

Figure 6. Photographs showing A) a cleavage transacted fold (profile transection) B) axial transection, C) West verging folds bounded by easterly dipping faults D) Eest verging folds bounded by westerly dipping faults, E) Steeply plunging Z-shaped asymmetric folds along a NS shear zone, F) Asymmetric structures (boudins and shear bands along a NS shear zone.

Strike parallel dextral faults

The F_1 folds are bounded by steeply dipping to sub vertical N to NNW strike parallel brittle faults and fault zones (Figs. 6C and D). The fault zones are characterized by the presence of a network of deformed quartz veins and drag folds and Riedel shears along these faults indicate dextral slip. Slickenlines on the fault planes provide evidence for dip slip movements with thrust/reversed sense, oblique and horizontal dextral movements. The presence of deformed early gently dipping quartz veins and later sub-vertical extensional veins suggest early reverse movement was followed by later strike-slip movement.

Strike parallel dextral shear zones

More commonly, the limbs of these folds are sheared along N to NNW strike parallel brittle-ductile shear zones. Kinematic indicators found within these shear zones include 'Z'-shaped asymmetric drag folds with steep to sub vertical fold axis, asymmetric boudins, dextral shear bands and sub vertical planar extensional and left stepping en echelon quartz veins (Figs. 6E and 6F). The kinematic indicators indicate strike-parallel sub horizontal extension and consistently show dextral strike-slip movements along the shear zones.

The distinct parallelism between the fold axis, various types of faults and dextral shear zones (Fig. 1) is not consistent with pure compression or pure strike-slip movements but is consistent with dextral transpression.

D_2 transpression/strike slip deformation

D_2 structures are predominantly exposed in the southern and eastern coast of the island. In the southern part of the island D2 is expressed as a 150 meter wide NS striking Kapas Fault Zone (the 'tight fold zone' of Ibrahim Abdullah, 2002). This zone forms the western boundary of the Kapas Conglomerate (Figs. 1 and 2). Within the zone, F_1 folds are tight to isoclinal with steep to subvertical fold axis which have been refolded along NS faults (Fig. 4). It is suggested that F_1 folds and cleavages have been progressively rotated clockwise and steepened during D_2 in response to NS dextral shear.

Steep, westerly dipping to vertical NS striking faults are the most significant features of D_2 deformation. The D_2 fault zones are characterized by the presence of a network of deformed quartz veins. Along most of the fault planes at least two sets of slickenlines can be observed ranging from sub-horizontal to sub-vertical (Fig. 3c). Deformation along the fault zone was particularly intense and was probably amplified by rotation and steepening of earlier D_1 structures. Drag folds, asymmetric structures and slickensides on fault planes provide evidence for an early dip slip movements with thrust/reversed sense, followed by later oblique and horizontal dextral movements.

The NS fault zone at the contact with the Kapas Conglomerate shows various asymmetric brittle-ductile structures suggestive of dextral strike slip displacement. The presence of a series of vertical duplexes at the boundary between the western margin of the Kapas Conglomerate is consistent with dextral strike slip deformation and displacement along the fault zone.

Outside the NS fault zone, D_2 structures occur as isolated sub-vertical NS dextral faults and associated with NE synthetic dextral and NNW antithetic sinistral faults (Fig. 5). Drag folds along this faults plunges steeply to the WNW, NW, and NNW. Sub-vertical extensional quartz veins and sigmoid tension gashes associated with these faults indicate NNE extension (Fig. 3E) consistent with NS strike-slip deformation

A major NNW antithetic sinistral faults forms the northeast boundary of the Kapas Conglomerate and the Kapas Conglomerate was deposited in the depression between the NS dextral fault zone and its NNW antithetic sinistral or splay fault. Some of the dextral NS and NNW sinistral faults cut across the unconformity and sheared the conglomerates. But others are truncated by the unconformity surface. These observations suggest that D_2 deformation initiated prior to the deposition of the Kapas Conglomerate, gave rise to a basin for the deposition of the conglomerates, and continued during the deposition of the sediments. This implies that the Kapas Conglomerate was deposited in a strike-slip basin.

DEFORMATIONAL HISTORY

In Pulau Kapas, prior to the deposition of the Kapas Conglomerate, the deformation history results mainly from the superposition of two finite strain patterns and later less significant brittle deformations.

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 lead 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 lead to differential uplift and subsidence of the faulted blocks (Fig. 7A). Subsequent weathering and erosion of the metasediments lead to the deposition of the Kapas Conglomerate within the subsided blocks (Fig. 7B). The deformation continued during the deposition leading to synsedimentary deformation of the conglomerate (Fig. 5).

AGE OF DEFORMATION

The age of deformation cannot be definitely constraint due to the absent of fossil in the Kapas Conglomerate. If the conglomerate is Late Permian to Triassic in age, then this would imply that the D_1 and D_2 deformation must be of Mid to late Permian with D_2 continuing into the Permo-Triassic time. However, if the deposit is of Jurassic-Cretaceous age then, there are two possibilities. Either, D_1 and D_2 deformation were of Late Triassic with D_2 continuing into the latest Triassic time, or D_1 was of Late Permian age, to take into account the unconformities at Pulau Redang and Bukit Keluang and D_2 was of Late Triassic with D_2 continuing into the latest Triassic time.

CONCLUSION

The Kapas Island has suffered two successive dextral transpressive deformation episodes that led to the development of a dextral strike-slip basin in which the Kapas Conglomerate was deposited.

During the first phase of brittle-ductile deformation (D_1) a series of close to tight folds trending NNW-SSE to NS were formed in the Permo-Carboniferous metasediment. These folds are commonly associated with NNW to NS axial plane parallel faults and shear zones with both strike-slip and reversed sense of displacement. The D_1 structures were reworked by D_2 events which amplified, rotated clockwise and refolded the earlier structures, along N-S D_2 dextral fault zones and NNW striking sinistral faults, causing 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. Syn-sedimentary deformation of the conglomerate continued during this deposition.

If the conglomerate is Late Permian to Triassic in age, then this would imply that the D_1 and D_2 deformation must be of late Permian age with D_2 continuing into the Permo-Triassic.

Similar deformational histories have been reported elsewhere in the Eastern Belt. Tajul Anuar *et al.* (1999), Mustaffa Kamal *et al.* (1999), Mustaffa Kamal and Tajul Anuar (1999) have also reported D_1 and D_2 transpressional phases followed by a later milder strike slip deformation in South-east Johore. Multiphase deformation and strike-parallel extensional deformation has also been reported by Mustaffa Kamal and Abdul Hadi (2000a, b) in the late Palaeozoic strata of Raub Gold Mine in Raub area and Mustaffa Kamal (2000a) in the Bentung-Raub Zone area. Similar deformational and depositional history had been interpreted for the Central belt of Peninsular Malaysia (Mustaffa Kamal, 2000a, b).Therefore this D_1 and D_2 Late Permian dextral transpressive deformation, and rapid uplift followed deposition of continental sediment in a strike slip basin observed at Pulau Kapas is a major orogenic event which can be considered as part of a large scale deformation in the Eastern Belt that may accomodated the oblique convergence of the two tectonic blocks of Peninsular Malaysia.

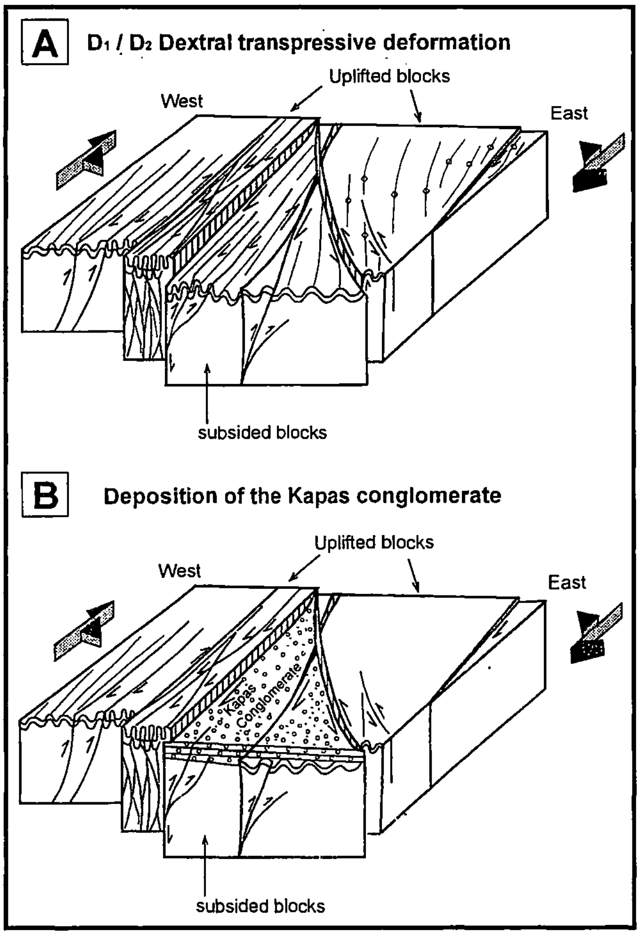

Figure 7. Block diagrams illustrating the dextral transpressive deformation of the Permo-Carboniferous metasediments (A), leading to the deposition of the Kapas Conglomerate in a strike-slip basin (B).

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