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Deformation of the Upper Paleozoic rocks at Tanjung Gelang, Pahang.

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Abstract: Structural mapping and detailed study of the Tanjung Gelang headland revealed that the Paleozoic metasedimentary sequence exhibits a variety of structural features ranging from complexly faulted, tightly folded and torn apart structures to gently folded rocks. Many of these features cannot be easily explained as resulting from simple tectonic processes thus a combination of soft sediment deformation and tectonism is favoured. The complex geometrical forms of the rocks in this headland indicate that paleocurrent and paleo-stress determinations from such sequences assuming a simple deformation model may be erroneous.

INTRODUCTION

The rocky headland at Tanjung Gelang adjacent to the new Kuantan Port (Fig. 1) is one of the best locality along the East Coast of Peninsular Malaysia for studying the metamorphosed clastic sequence. This sequence consisting predominantly of alternating beds of sandstone and mudstone is the dominant rock type of this eastern region and is very well exposed at several headlands and islands along the East Coast. A common and interesting feature of these rocks is the wide range of deformation structures exhibited, ranging from superposed folding to recumbent folds, open folds and faults of various kinds. The age of these rocks is generally accepted to be Upper Paleozoic probably Carboniferous. The easy accessibility and the good exposures have combined to make the Tanjung Gelang headland a favourite field stop for geological and geographical field trips. This headland forms part of the study area of one of the author's (LSY) B.Sc. (Hons.) dissertation.

In recent years, some interest have been shown in the deformation pattern and sedimentary features displayed by the Upper Paleozoic rocks at Tanjung Gelang and other areas to the north. Stauffer (1976) measured 20 sets of medium-scale cross bedding at Tanjung Gelang and the resulting distribution of foreset dip direction after restoring the main bedding to the horizontal about its strike shows an apparently complete spread through 360°. No mapping was carried out and the fold axes of these complexly folded rocks was assumed to be horizontal in the restoration. The spread of the foreset dip directions was made to group more tightly by rotation of the north and south side of the headland about a steeply plunging or vertical axis based on a yet to be proven assumption that the strikes of the beds were formerly parallel and trending north-west–south-east. The palaeocurrent pattern was interpreted as representing marine currents mainly parallel to a north-south shoreline to the east. Tjia (1974, 1978) studied two areas to the north of Tanjung Gelang where similar Upper Paleozoic metasediments are exposed. From these complexly folded and faulted rocks with overturned to recumbent folds and low angle thrusts, he deduced that the deformation was due to at least two different stress systems occurring during the Permian and the Triassic-Jurassic orogenies. In Tanjung Geliga, a nearby headland, Goh (1974), found that the metasediments have undergone low grade regional metamorphism equivalent to the Abukuma Type Greenschist Facies. Two periods of folding with earlier isoclinal folds refolded coaxially by open folds were postulated.

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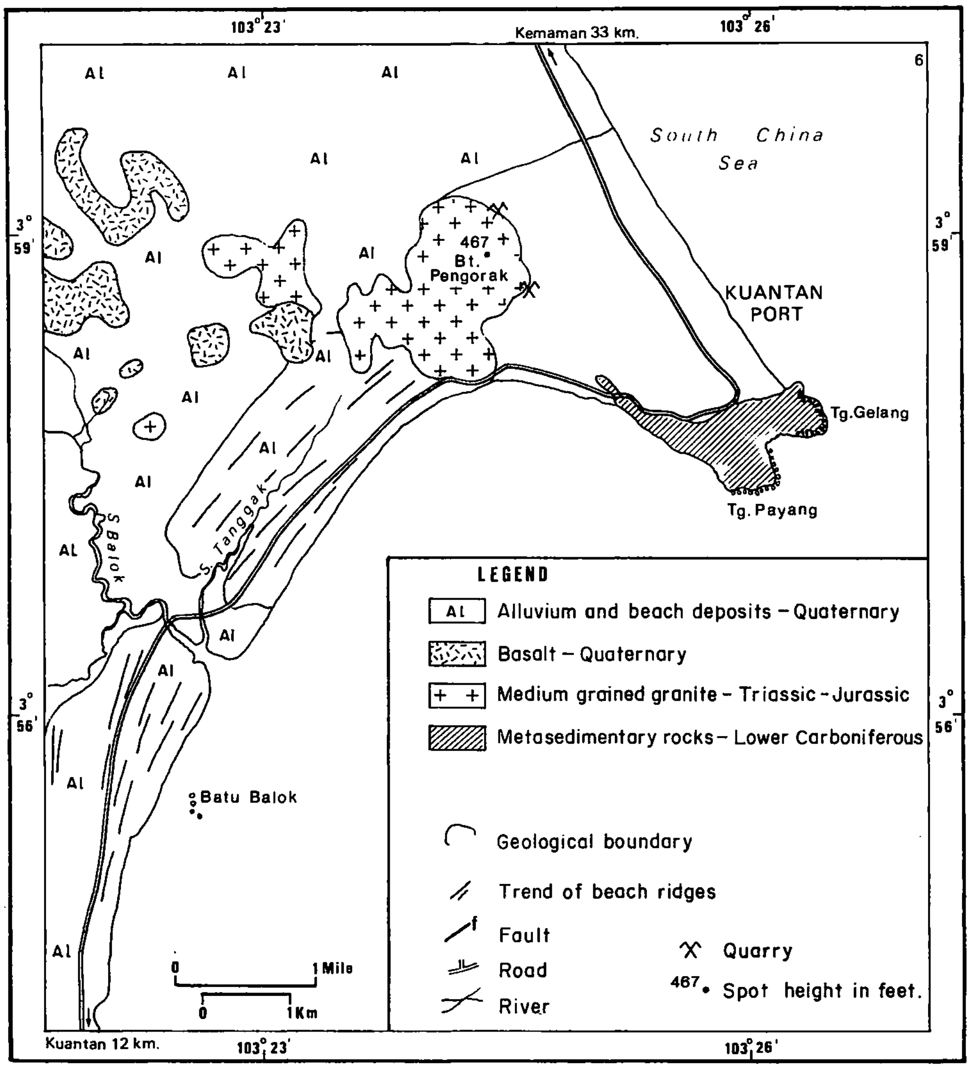

Fig. 1. Geological sketch map of Tanjung Gelang and the adjacent areas.

Good exposures of Upper Paleozoic rocks are generally restricted to coastal areas, the inland areas having only isolated outcrops scattered too far apart to permit detailed structural mapping to be undertaken with any confidence. In view of the complexity of the deformation and the relatively small scale of the structures, detailed mapping of a scale of 1:2500 or less is necessary to clearly display the variations in the deformation style. It is the purpose of this paper to illustrate and to interpret the structural features present in Tanjung Gelang and to discuss some of the implications arising out of this study on the geology of the east coast region.

GEOLOGICAL SETTING

The interbedded metaquartzites, slates and tuff at Tanjung Gelang were mapped by Fitch (1952) as part of the Arenaceous Series which was thought to be of Triassic age. These rocks are now generally believed to be of Upper Paleozoic, probably Carboniferous, in age. Plant fossils found by Yap (1976) at the southern part of Tanjung Gelang suggest a Lower Carboniferous age. The assemblage include *Lepidodendron* sp., *Bergeria* sp., *Neuropteris* sp., *Rhodea* sp., and *Carpolithus* sp. The metasediments are intruded by granite which is exposed at a quarry adjacent to the northern extremity of the headland. The granite at this locality has not been dated but its similarity with the nearby Kuantan granite suggests a Triassic age (Bignell and Snelling, 1977). A distinct contact aureole is present around the granite with sillimanite, garnet, cordierite, andalusite and micas being the most common metamorphic minerals in the hornfelses.

At Tanjung Gelang, interbedded metaquartzites and slates are the dominant rock types with the metaquartzites being more prominent in the northern part of the headland while the slates occur more widely in the south. A few thin beds of crystal tuff with thickness averaging 15cm occur within this sequence. The metaquartzite and slates beds have variable thicknesses ranging from less than 10cm to 5m but are generally less than 70cm thick. A characteristic feature of these sediments is their high content of carbonaceous material especially in the slates. Highly sericitised, buff coloured dykes cross cutting the bedding occur at the southernmost tip of the headland.

STRUCTURAL GEOLOGY

A variety of structural features are well exposed in the coastal exposures at Tanjung Gelang. The most prominant of these features are the major folds and faults which are responsible for the extremely complex geometry of the rocks in a number of localities. Primary structures, such as cross-bedding, graded bedding and animal burrows are also present. Small scale soft-sediment deformation structures such as convolute laminations, microslumps and "pillow-like" structures (Stauffer, 1976) also occur in these rocks. A detailed systematic mapping of the headland was undertaken by one of the authors (LSY) to produce the structural map shown in Figure 2. Mapping was carried out at a scale of 1:2500 using a base map prepared from a rope and compass traverse.

Structurally, the rocks at the headland strikes approximately east-west with northerly dips in the western and southern portion while the eastern and northern sides have more northerly strikes and varying dip directions. At several exposures along the beach, abrupt changes in the geometry of the uniformly dipping beds resulting in strongly folded, refolded and faulted blocks are encountered. These structurally complex blocks are too small to be adequately represented in the structural map and the geometry of some of these blocks will be described separately. The coastline along the eastern and southern part of the headland follows the strike in places and the rugged eastern coast is often fault bounded but a large portion of the coastline do not display any obvious structural control.

DEFORMATION STYLE

The folded rocks at the headland display a variety of fold shapes and orientation. Most of these folds can be grouped into two main folding styles, an earlier tight, steeply inclined to recumbent fold and a later open to moderately tight fold. The relative

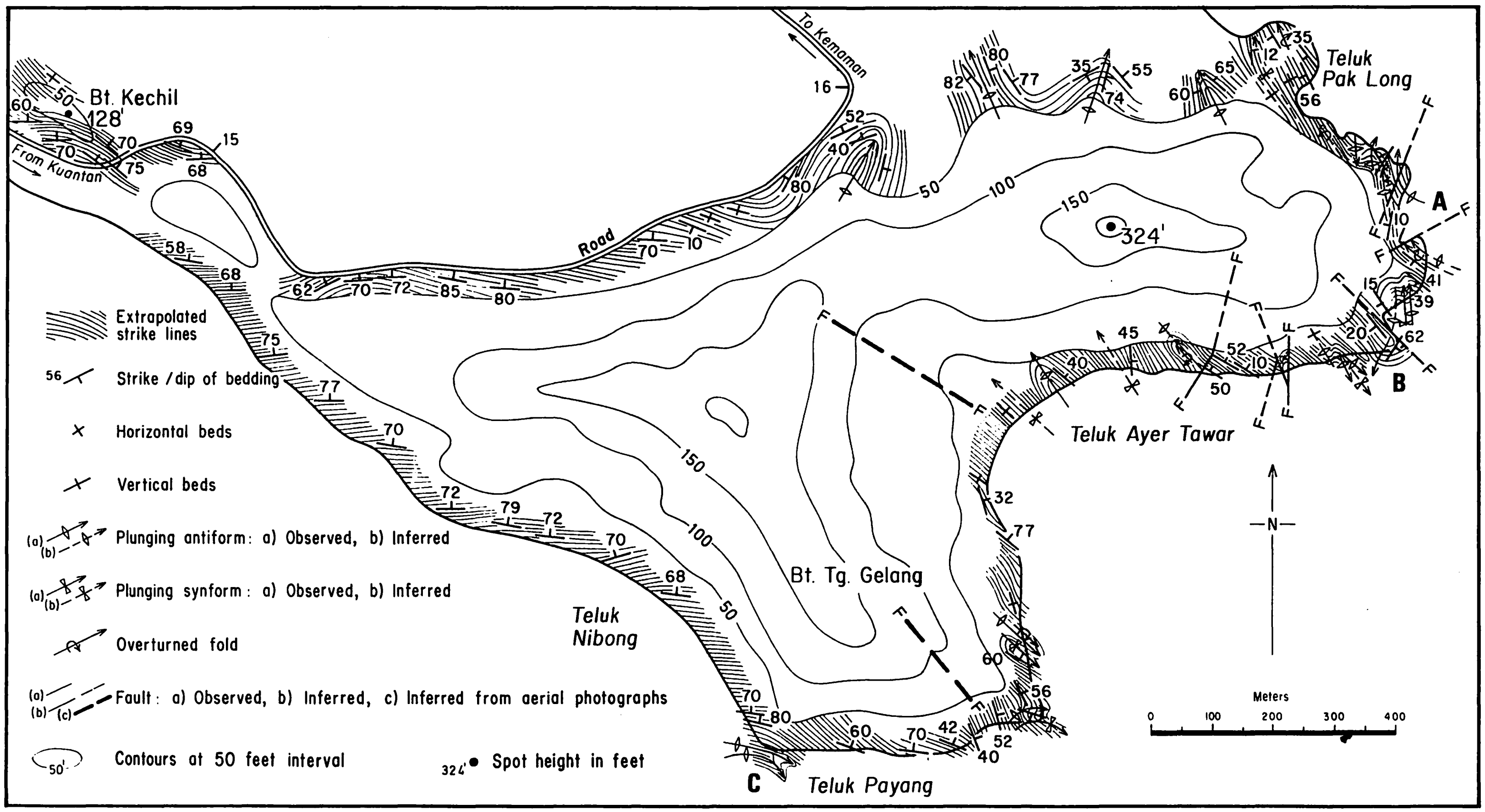

Fig. 2. Structural map of the metasedimentary sequence at Tanjung Gelang.

timing of these two folding events is clearly shown wherever these two folding styles are superimposed. Refolded folds from this headland have been described by Yap (1976). A weak axial plane cleavage is present in some of the tightly folded rocks. This cleavage is best displayed in the carbonaceous slate and are caused by parallel alignment of platy minerals.

The orientations of the bedding and fold axes over the entire area do not show any distinct fold axis direction. The stereographic plots of these structures are widely scattered. This result is not surprising in view of the marked differences in the fold axes trend and the curved nature of some of the fold axes as shown in Fig. 2. Over smaller areas, it is possible to infer the dominant structural trend. In the western and southern sections, an east-west trend is prominent. This trend swings gradually to the northwest-southeast in the more intensely folded and faulted eastern portion of the headland and become more northerly towards the north.

Faulting is a common feature in these rocks. Most of the faults are either steeply dipping with normal movements or low angle thrust faults. Strike slip faults are rare. Faulting is often accompanied by the formation of small drag folds and brecciation of the adjacent rocks. The faults do not show any marked preferred orientation and cannot be traced over distances greater than 200 metres. Thrust faults are usually associated with recumbent isoclinal folds and are especially common in areas with complex structures.

An interesting feature of the deformation at this headland is the abrupt change in the deformation style from uniformly dipping beds to intensely folded, faulted and at times chaotic masses. Rocks exhibiting such unusually complex geometrical forms occur at several localities in the area studied. Three examples of these highly varied structures have been selected for detailed studies. Of these, two are exposed on near vertical cliff sections and the sketches of the structures, Figs. 3 and 4, are drawn from photographs. The third is exposed on an uneven wave cut surface and a detailed map of this outcrop, Fig. 5, has been prepared. All these structures are characterised by recumbent folding, faulting and the presence of displaced blocks of sandstone enclosed in a pelitic matrix. The locations of these 3 outcrops are indicated in Fig. 2.

The structure shown in Fig. 3 is exposed on a vertical north-south striking fault plane. The close relationship between folding and faulting is clearly displayed in this exposure. The beds have been strongly disrupted by the steeply dipping faults resulting in folded and torn-apart lensoid masses of metaquartzite. The pelitic beds adjacent to these metaquartzite blocks show contorted flowage structures. The tight recumbent fold at the southern end of this outcrop indicate the presence of a pre-faulting folding phase. The abrupt termination of the fault planes in the centre of the diagram suggest the continuation of the ductile deformation process after the formation of the faults.

Large scale recumbent folding is probably a common feature in these rocks. Such structures are however difficult to detect as the coastal exposures are restricted in their vertical extension. Figure 4 shows one of the few exposures in which this structure is clearly displayed. The east-west profile shows part of a large recumbent fold with its more intensely deformed overturned limb brecciated and sheared off along a low angle thrust suggesting the movement direction was from the east. This recumbent structure rests on thinly bedded and gently folded metaquartzite beds. Metaquartzite units at the core of the recumbent fold display similar torn-apart features as in the exposure described earlier.

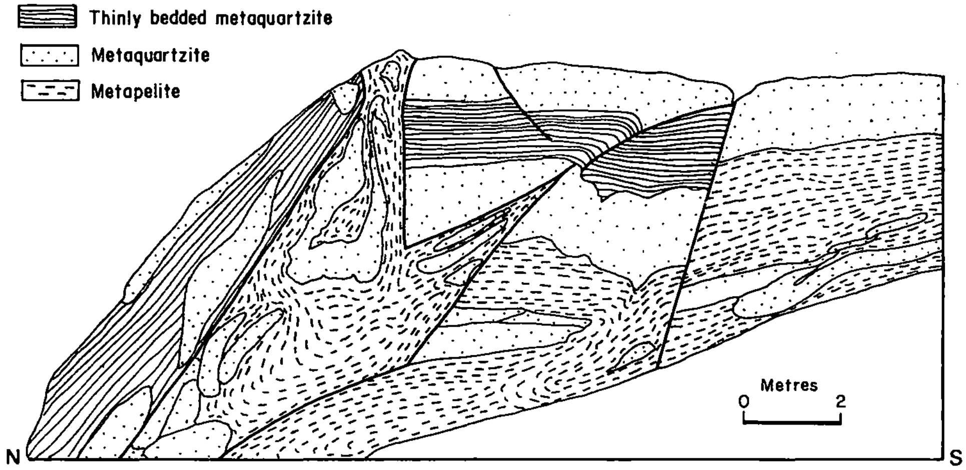

Fig. 3. Sketch, drawn from photograph, showing folded and faulted metasediments exposed on a vertical fault plane. Location is indicated by A in Fig. 2.

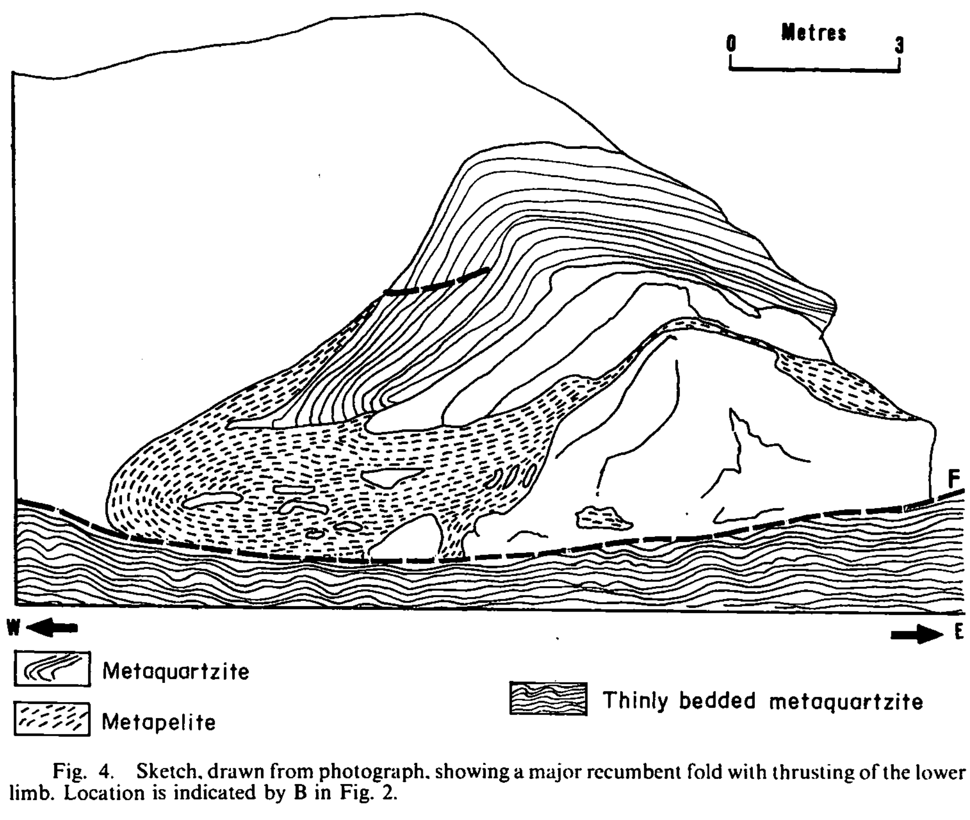

Fig. 4. Sketch, drawn from photograph, showing a major recumbent fold with thrusting of the lower limb. Location is indicated by B in Fig. 2.

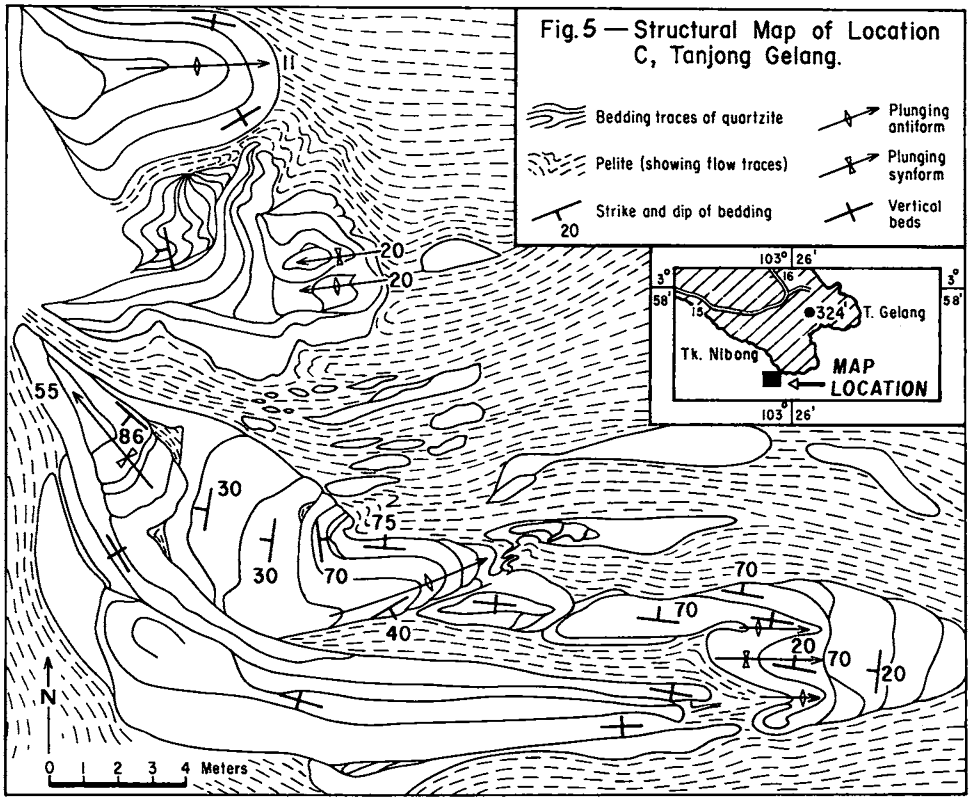

Fig. 5. Structural map of location C, Tanjung Gelang.

Folded metaquartzite blocks completely enclosed in the pelitic matrix occur at several localities. The largest and best exposed outcrop exhibiting this feature is shown in Figure 5. The individual metaquartzite block may range from less than a meter to more than 20 meters in length. The fold style and axis orientation in the different blocks may differ widely resulting in the outcrop having a geometrically complex appearance. The complexity of the outcrop patterns cannot be easily illustrated on a map because of the uneven surface exposures and the common occurrence of recumbent folding. The pelitic matrix have been affected by intense shearing and breaks off easily into small elongated fragments of a few centimetres in length.

DISCUSSION

Detailed mapping of the rocks exposed at this headland has revealed the extremely complex geometry of the metasediments especially in the northern and eastern portions. No distinct deformation pattern could be deduced from the orientations of the structures seen in the field. The marked differences in structural styles between the strongly folded and faulted rocks and the gently folded open folds in different parts of the headland indicate that the rocks have been subjected to varied deformation processes. The transition from the gently folded rocks to the tightly folded and faulted sequence is extremely abrupt and at Tanjung Gelang this occurs near Telok Payang. Although the eastern part of the headland, where the strongly distorted sequence occur, are characterised by numerous faults, not all the deformation could be attributed to the fault movements. Several areas of detached tightly folded metaquartzites in pelitic matrix similar to the structures shown in Fig. 5 do not exhibit any prominent faults.

The origin of the deformation processes giving rise to the structure present at this headland is problematical. It may be tectonic, sedimentary or a combination of both. A solely tectonic origin with deformational stresses acting on well consolidated sediments seems to be unlikely as the great difference in the deformation style over the headland where the rocks are essentially similar would require a marked change in the intensity of tectonism over a relatively small area. The detached folded metaquartzite blocks with varied fold shapes and fold orientations have many features similar to slump folds. Some of the features displayed in the faulted rocks such as in Fig. 3 appear to indicate that the sediments were still soft during the faulting movement. The criteria for distinguishing between sedimentary and tectonic structures are rarely definitive (Hobbs, et al., 1976, Ch. 3), especially as it is possible that folds may form in soft sediments in response to tectonic stresses. Some of the large upright open folds shown in the map (Fig. 2) and the faults may be due to tectonic processes but to attribute all the structures found to tectonism acting on well consolidated sediments would require an unduly complicated interpretation of the deformation history.

The presence of a weak axial plane cleavage in some of the tightly folded to isoclinal folds has to be considered in any interpretation of the structures. Axial plane cleavage has long been regarded by many writers to be diagnostic of hard rock deformation (e.g. Nevin, 1949) but recent observations suggests that such structures could be formed in penecontemporaneous fold structures (William, et al., 1969; Moore and Geigle, 1972). Following the earlier well established criteria, the presence of axial plane cleavage in Tanjong Gelang may indicate the existence of a tectonic folding phase after the early faulting and consolidation of the sediments. However, it is difficult to resolve with any certainty the origin of the cleavage in this headland and this matter needs to be further investigated.

The gently folded structures and the late faults which truncate all the other structures are uniformly widespread and are the latest structures developed in these rocks. The timing of this later folding phase and faulting cannot be ascertained with any certainty but the sediments are probably well consolidated before these events.

Structurally and lithologically, the exposures at Tanjong Gelang are similar to many of the exposures of metasedimentary rocks along the east coast of the peninsula. These metasediments extend from Pulau Redang in the north to the southern tip of Johore. To the west, the lateral extension is not clearly defined but is likely to extend for more than 50 km in places. Tightly folded upright to recumbent folds associated with thrust faults and a later phase of open folds and faults are commonly found in these rocks. The complexity of the structures is often not easily seen in the inland outcrops due to the weathering and the limited areal extend of the exposures. The exception is the large roadcut at Bukit Jaya, 58 km west of Kuantan where the slump origin of the folding is clearly displayed (Azhar, 1977). Many of the well exposed structures in the coastal exposures are illustrated in Tjia (1974, 1978) and in University of Malaya's students' theses, Goh (1974), Yap (1976), Yaw (1978) and Lee (1979).

Although most of the geologists working on these metasedimentary rocks have noted the folded and faulted nature of the sequence, the high degree of complexity of the structures and the possibility for a soft sedimentary deformational origin for some of the larger features and their implication on the interpretation of the tectonic history, stress systems and sedimentary processes have often been overlooked. Paleo-stress systems worked out from such rocks would be highly dubious as the pre-folding bedding surfaces are likely to have varied orientations and when folded would have variable geometry and fold axes orientation. At Tanjung Gelang, the complexity of the geometry revealed in this study shows that arbitrary restoration of the sedimentary layers to their original orientation for paleocurrent analysis are unlikely to give meaningful results. The correlation of the two tectonic events at Bukit Cenering by Tjia (1978) with Permian to early Triassic diastrophism and Late Triassic to Early Jurassic orogenesis needs also to be reappraised. It is yet to be proven that the folding and faulting are directly correlatable with the granite intrusions. For soft-sediment deformation and slumping, the deformation process could be either synchronous with or shortly after the sedimentation. In Tanjung Gelang, this early event could correspond to the Carboniferous age of the rocks.

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