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The geology of Pulau Tekong, Singapore

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Abstract: A geological reconnaissance survey of Pulau Tekong revealed the presence of three lithological units: the Bukit Resam Member of the Jurong Formation, Quaternary Alluvium and some thermal metamorphic rocks. The stratigraphic relationships between the metamorphic rocks and the Jurong Formation are uncertain.

The oldest sediments are possibly of Lower Triassic age and were subjected to thermal metamorphism by an igneous intrusion. Deposition was reestablished afterwards and the clastic sediments of the Bukit Resam Member of the Jurong Formation were laid down in a molasse facies during the Upper Triassic. After a long period of uplift and non-deposition in the later Mesozoic and Tertiary, Quaternary alluvium was deposited as a result of galcio-eustatic sea level changes.

The Triassic rocks are broken up by faulting and folding and in view of the small catchment area and the relatively high amount of Fe-ions dissolved in the water the existence of a large and good quality aquifer is unlikely.

INTRODUCTION

Pulau Tekong is situated in the Straits of Johore, near the mouth of Sungei Johore (latitude 1°25'N. and longitude 104°05'E.). The island is elliptical in form, 6.3km at its greatest length and 4.3km at its greatest breadth, and has an estimated area of approximately 22 square kilometers.

Information regarding the geology of Singapore is scattered in publications of the Geological Survey of Malaysia and in papers by Logan (1851), Scrivenor (1924) and Alexander (1950). These studies deal mainly with the geology of Singapore Island and little attention has been paid to Pulau Tekong.

The geological map (Fig. 1) that accompanies this paper shows on the island the limits of the different lithological units. However, owing to the extent to which the rocks are weathered and the prolific vegetation, these limits can only be taken as rough estimates. Furthermore, large outcrops are rare and strongly weathered resulting in scanty structural data.

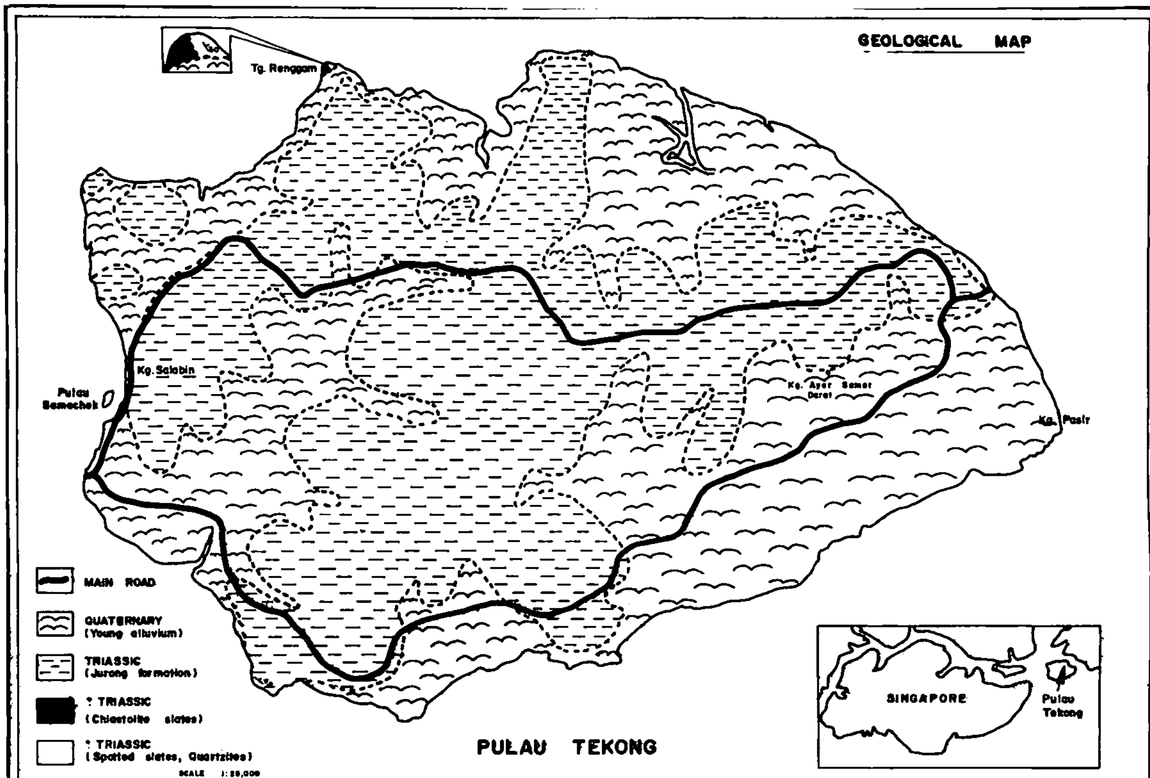
GEOLOGICAL MAP
Tg. Renggam
Kg. Salabin
Pulau Semechek
Kg. Ayer Samak Darat
Kg. Pasir
MAIN ROAD
QUATERNARY (Young alluvium)
TRIASSIC (Jurong formation)
? TRIASSIC (Chiastolite slates)
? TRIASSIC (Spotted slates, Quartzites)
SCALE 1:25,000
0
1
2 Km.
SINGAPORE
Pulau Tekong
PULAU TEKONG

Fig. 1

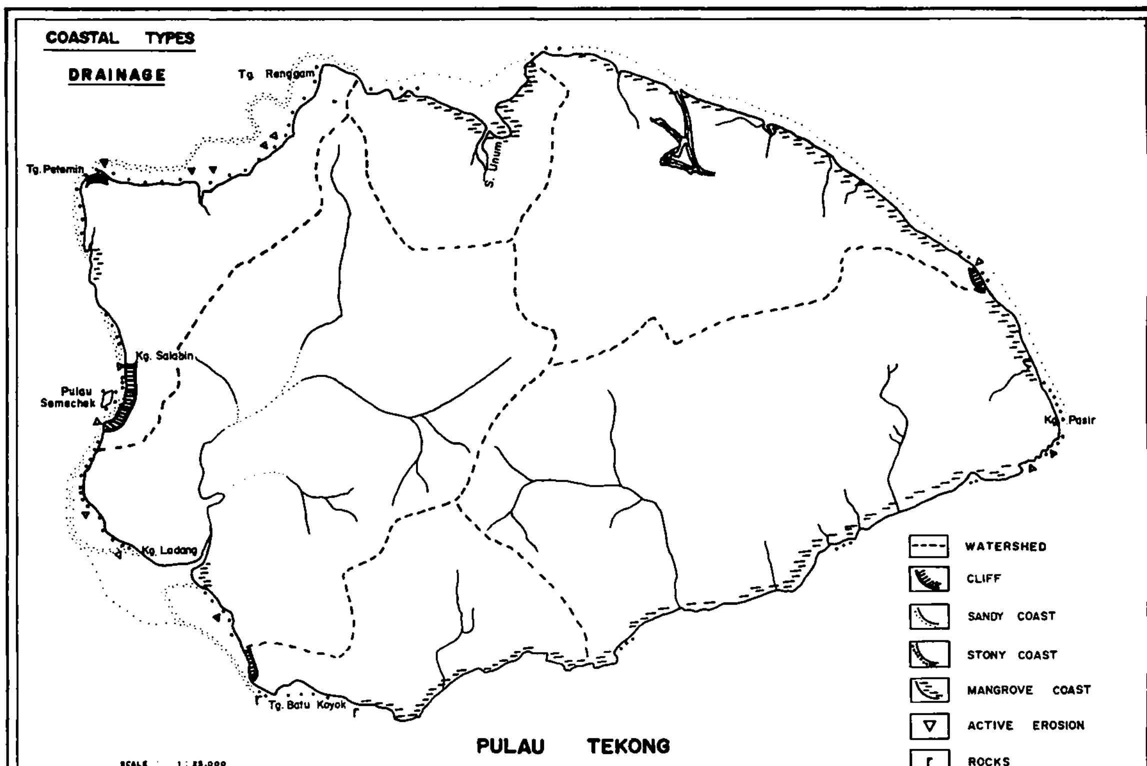
COASTAL TYPES
DRAINAGE
Tg. Renggam
Tg. Petemin
S. Unum
Kg. Salabin
Pulau Semechek
Kg. Pasir
Kg. Ladang
Tg. Batu Kayok
WATERSHED
CLIFF
SANDY COAST
STONY COAST
MANGROVE COAST
ACTIVE EROSION
ROCKS
PULAU TEKONG
SCALE 1:25,000
0
1
2 Km
Coastal types after P.P. Wong, Geography Dept., Singapore

Fig. 2

MORPHOLOGY, WEATHERING AND DRAINAGE

Morphology

Pulau Tekong is formed of a central region of undulating low hills which attain a maximum height of 58 metres above sea level. These hills are flanked by coastal flats reaching up to 7.5 metres above sea level, and terminate seawards in a rather flat coast which is punctuated by occasional cliffs.

The hills consist mainly of weathered rocks with abundant iron-pan which exhibits a nodular or spongy texture. The latter rocks are lithified while the shallow valleys between the hills contain structureless masses of alluvium and lateritic soils.

The result of a Quaternary sea-level rise is still apparent along the coast. Land below 7.5 metres is covered with beach sands and mangrove mud. Various coastal types can be recognised (Fig. 2): cliffs at Tanjung Petemin and Tanjung Batu Koyok, sandy coast at Kampung Pasir and north of Kampung Salabin, stony coast at Tanjung Petemin and Pulau Semechek, and mangrove coast at Sungei Unum and near Kampung Ladang (Wong, 1968). In most of the cliffs undercutting, wave action and slumping of the weathered bedrock are important factors of the erosion process. Boulders and cobbles at the foot of cliffs consist mainly of iron concretions and are rounded in the surf zone. The sandy coast is characterised by sandy beaches, the sand having been transported by longshore currents in the Straits of Johore. The mangrove coast is largely a continuation of the mangrove-fringed estuaries of the island; it is essentially a semi-submerged and water-logged coast.

Weathering

To a large extent, the topography and relief of the island are influenced by its geologic structure, particularly the weathering residues of the original sedimentary rocks. Therefore, some attention has been paid to the weathering processes, which can be divided into the chemical breakdown of minerals and the reprecipitation of some dissolved mobile products.

As in the other humid equatorial regions, chemical weathering processes are dominant because of the constant high temperatures, the availability of water and the resulting dense vegetation. The climate of Singapore is hot and humid all year round; temperatures vary little throughout the year and values below 23°C are rare. The annual average precipitation is around 262cm. Rain falls in all months and maxima are recorded in the period of the northeast monsoon (November to January).

Heavy rainfall and deep weathering of the original rocks result in the development of more drainage units per area than in similar rock types under different climatological conditions. Denudation rates consequently are relatively high and may be of the order of a few millimetres each year. As a result, bedding, faults and other structural features as well as lithological changes are largely obliterated in the upper rock layers.

Alexander (1959) presented observations on tropical weathering of rocks on Singapore Island and drew attention mainly to the phenomena connected with the mobility of iron, silicon and aluminium in the weathering of rocks. It is generally assumed that these products are leached out of the weathering rock into the drainage waters, but the weathering of sedimentary rocks demonstrates most clearly some reprecipitation of the products of weathering.

Iron-oxide concretions with smooth, mamillated surfaces and occasional irregular swellings are not uncommon in the more argillaceous rocks of the area (Logan, 1851). These sheets of iron oxide may lie at any angle to the bedding and sometimes follow the shape of the ground surface. They frequently form complex networks in the rocks, the pattern being related to the joint and bedding-plane structure of the weathered rocks. The concretions are frequently composed of haematite, though other oxides of iron are generally present. It appears probable that the iron oxide was first precipitated from the weathering solution as a gel and that the gel later dried and crystallised, amorphous limonite being changed to haematite. Limonite and haematite nodules dominate the beach at Tanjung Petemin and near Pulau Semechek.

Drainage

The development of a river valley and a drainage basin depends on the original surface slope, the rainfall, and the underlying geological structure which determines the varied resistance to erosion offered by the rocks encountered. The small rivers on Pulau Tekong are partly fed from ground-water, but their main source is from surface run off as a result of the usual heavy equatorial rainfall. This carried away the rock-waste produced during weathering.

The drainage system of Pulau Tekong is influenced by the undulating and relatively low relief, a small catchment area and a flat coastal zone with extensive brackish mangrove belts upstream along the rivers.

The island can be divided into six minor drainage basins (Fig. 2), of which the southwest and southeast ones are the largest. Abundant equatorial rainfall and small springs provide the rivers with water, which is rapidly channelled to the brackish mangrove swamps making it unsuitable for human consumption.

The weathered rocks are probably quite porous and might be expected to hold water. However, the presence of dissolved iron in such water would make it inferior for human consumption.

The existence of a large artesian basin is also unlikely since the sedimentary rocks, which might hold water, are broken up by faulting. The assumed occurrence of igneous masses with a poor porosity, in the subsurface of Pulau Tekong also makes the existence of a large artesian basin unlikely.

GEOLOGY

Geological and structural setting

It has long been recognised that the Malay Peninsula forms part of an elongate orogenic belt extending south of Singapore and north through Thailand and Burma. The southern part of this zone was called Malayan Orogen by Westerveld (1952).

The rocks present on Pulau Tekong are mainly late Triassic sediments of the so-called "Argillaceous Series" (Alexander, 1950) and are considered to be equivalent to the Bukit Resam Member of the Jurong Formation (Burton, 1973a). Other sedimentary rocks have been metamorphosed by an igneous intrusion and form a second rock unit which is thought to be older than the Jurong Formation strata. A third rock unit recognisable on Pulau Tekong consists of alluvial deposits.

Thermal metamorphic rocks

The intrusion of a large igneous mass in the area, probably shortly before the deposition of the late Triassic sedimentary rocks, resulted in the development of thermal metamorphic rocks around the intrusion. A part of this thermal metamorphic zone is exposed at Tanjong Renggam and three different types, quartzites, chiastolite slates and spotted slates, have been recognised.

This shallow thermal or contact metamorphism generally occurs under very low fluid pressures (less than 1500 bars) and temperatures higher than 400°C. The presence of accessory chlorite granules in the quartzite indicates a temperature not higher than about 500°C., since chlorite in the presence of quartz reacts above this temperature. The upper stability limit of pyrophyllite is also between 430°–500°C (Winkler, 1967) above which it is converted to chiastolite, which is present in the chiastolite slates. A metamorphic grade in the albite-epidote-hornfels facies (Winkler, 1967) may be suggested, therefore, with a maximum temperature of formation of around 500°C.

Quartzite

In hand specimen the quartzite is a very hard whitish-grey rock in which separate quartz grains are not distinguishable; green chlorite veins occur regularly.

Microscopic examination reveals that the quartzite consists of quartz with a few per cent chlorite in veins. Two types of quartz grain can be recognised. The first type is fine-grained and occurs as a recrystallized clear quartz mosaic without any trace of the original clastic character. The second type consists of elongated quartz grains (up to a few millimetres), which all show the same orientation and obviously have developed under some strain. The quartz mostly shows microstylolitic (highly sutured) grain contacts (Fig. 3) and some intersitial chlorite granules may be observed (Fig. 4).

The quartzite was formed from a highly quartzose fine-grained and well sorted sandstone which contained a small amount of clay.

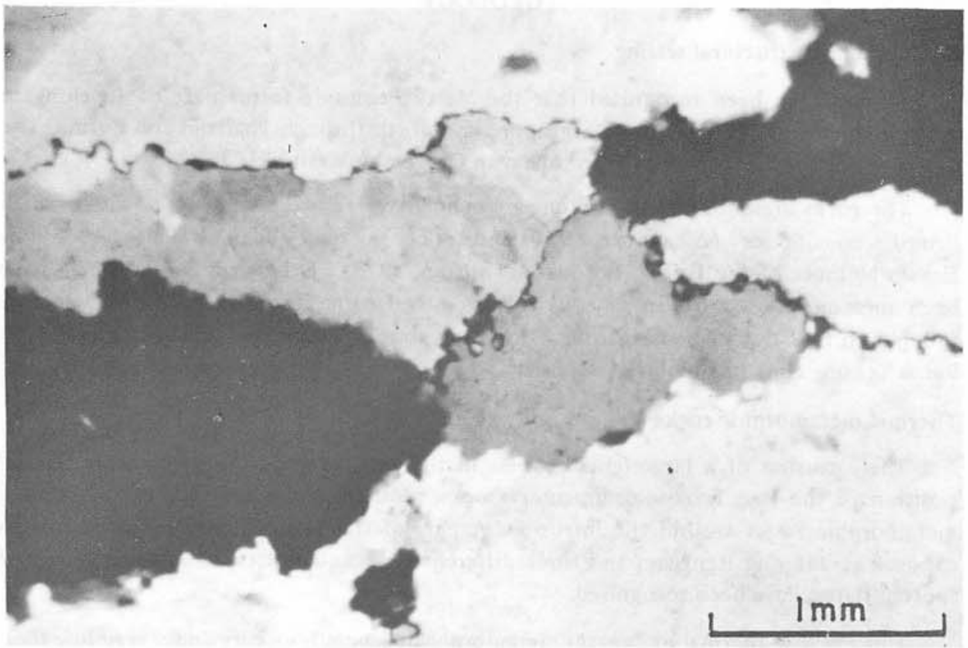

Fig. 3

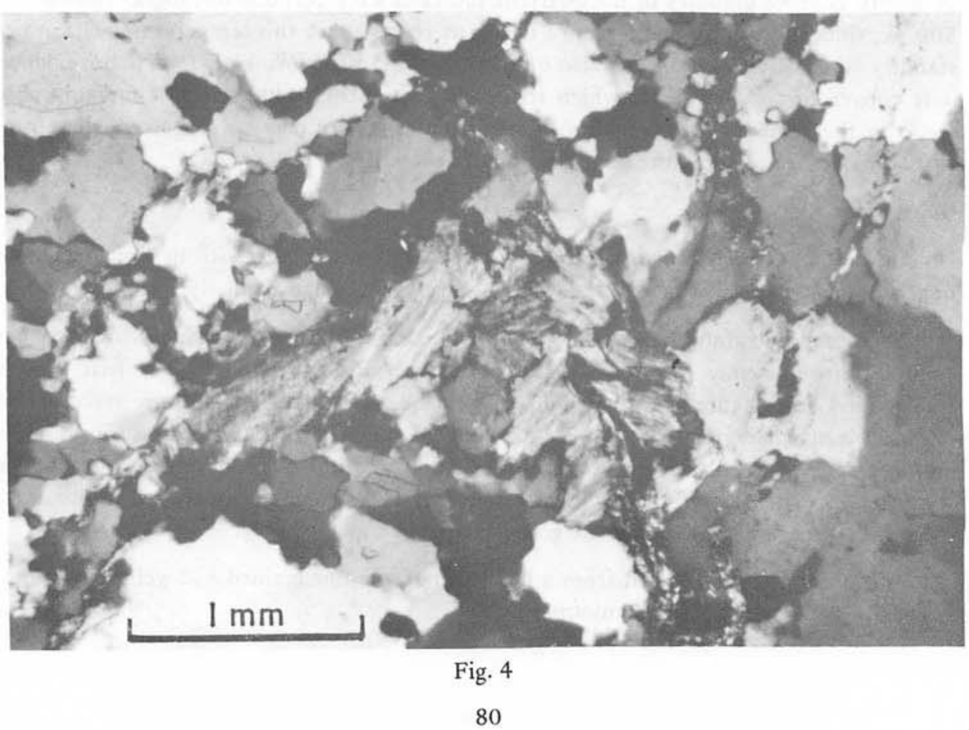

Fig. 4

Chiastolite Slate

In hand specimen the chiastolite slate is a greenish-grey sandy slate.

In thin section the rock consists of about 30% porphyroblastic crystals embedded in a fine-grained groundmass. The predominant mineral is chiastolite and is characterised by the presence of a "chiastolite-cross" (Fig. 5). The length of the crystals varies between 0.4 mm and 1 mm, and they are randomly orientated throughout the rock. Some chiastolite crystals have altered to fine micas, possibly due to the intense weathering. Other larger crystals include quartz and muscovite in radially grown booklets, while the groundmass is mainly composed of very small quartz and micas.

The chiastolite slate was formed from an argillaceous rock with high content of kaolinite and a relatively low silica content. The presence of kaolinite favours the development of chiastolite during the early stages of thermal metamorphism.

Spotted slate

In hand specimen the rock is a black slate, which shows microlamination and contains numerous small quartz veins.

In thin section the slate consists of a fine matrix of quartz and micas. Some dark spots are present which are clots and patches of carbonaceous matter that has been recrystallized by heating to graphite. Small quartz veins, folded under tectonic pressure, contain accessory minerals such as rutile needles and apatite.

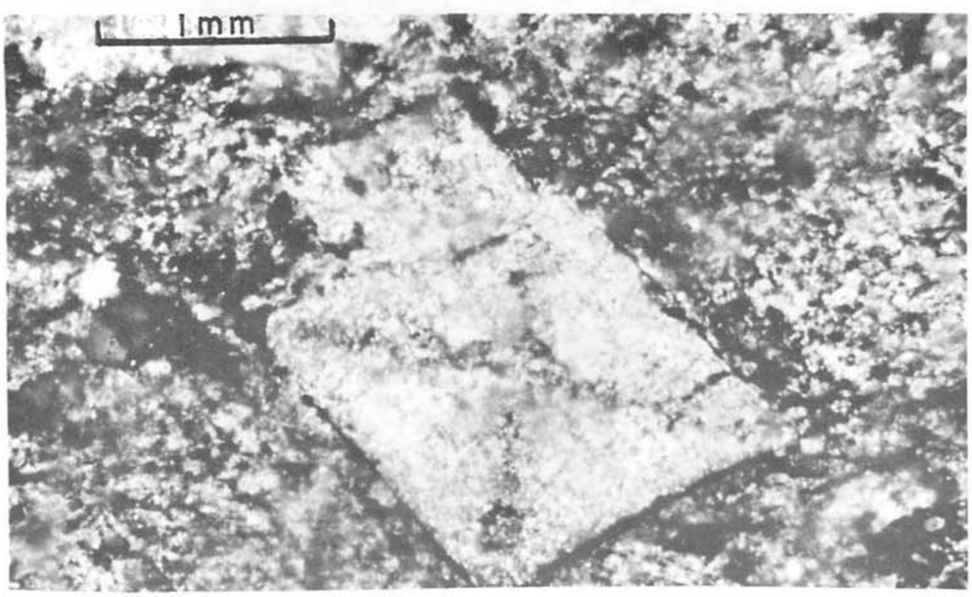

Fig. 5

This slate has a marked cleavage due to abundant micas following the old bedding planes in the rock. (Fig. 6).

The spotted slate represents a low grade thermally metamorphosed argillaceous rock in which thin silty laminae are present.

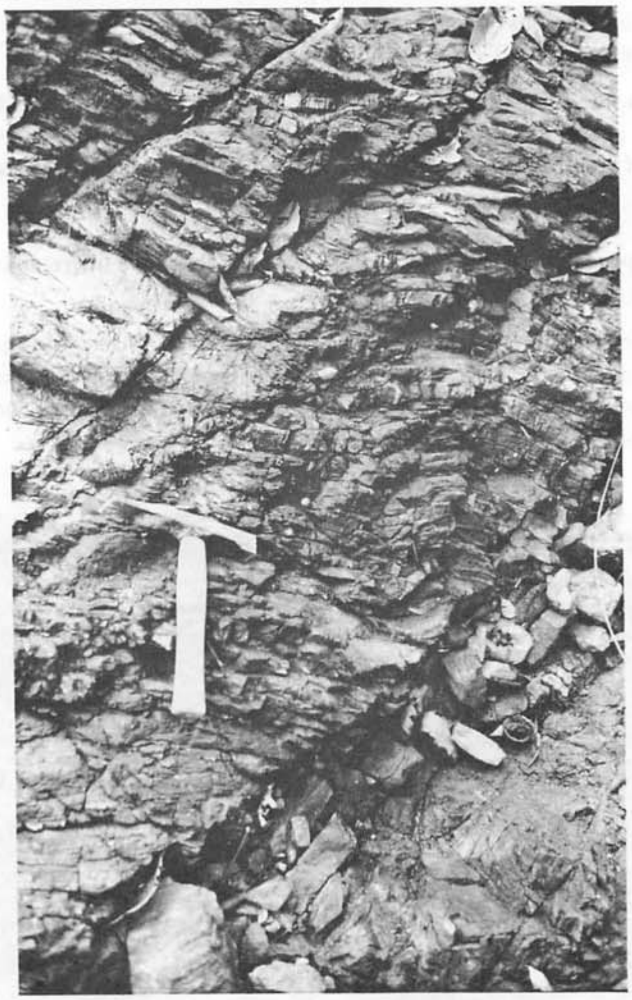

Fig. 6

Triassic Sedimentary Rocks

The Bukit Resam Member of the Jurong Formation, as defined by Burton (1973b, p. 18), consists mainly of frequent alternations of shale and sandstone, with minor beds of siltstone and conglomerate, together with a few of volcanic tuff. Individual beds are usually rather thin. Shale is the most abundant rock type, normally being carbonaceous and dark grey although in some places it exhibits shades of purple and red. The sandstone is obviously of immature character, apparently lying in the range protoquartzite-subgreywacke-greywacke.

The sedimentary rocks of the Bukit Resam Member of the Jurong Formation on Pulau Tekong consist mainly of frequent alterations of shale and sandstone (Fig. 7) with minor intercalations of siltstone and clay. Beds range in thickness from a few centimetres up to fifteen metres but are usually thin. Due to poor exposures and intense weathering, sedimentological structures are difficult to distinguish.

Fig. 7

Red-brown, yellow, orange, white mottled clays and shales are the most common rock types and they are all weathered to structureless clay masses or lateritic soils. Nodules are often found in these weathered clays and they must be considered to be a result of the accumulation of iron oxides in the tropical weathering process (Fig. 8).

Most of the sandstone is strongly weathered and the different constituents may be broken down to produce an argillaceous sandstone. In hand specimen the sandstones are generally immature in character with dominant quartz and micas together with small chert fragments, while the feldspars are broken down into clay minerals. This type of composition may suggest that the rock was originally a greywacke.

Thin Sections

a. Detritals: The predominant detrital mineral of the sandstones is quartz which occurs as single grains displaying undulose extinction. Other detrital minerals include muscovite, which is fairly plentiful. Detrital rock fragments, especially chert, some quartzite and feldspar pseudomorphs, occur in small quantities in most of the sandstones.

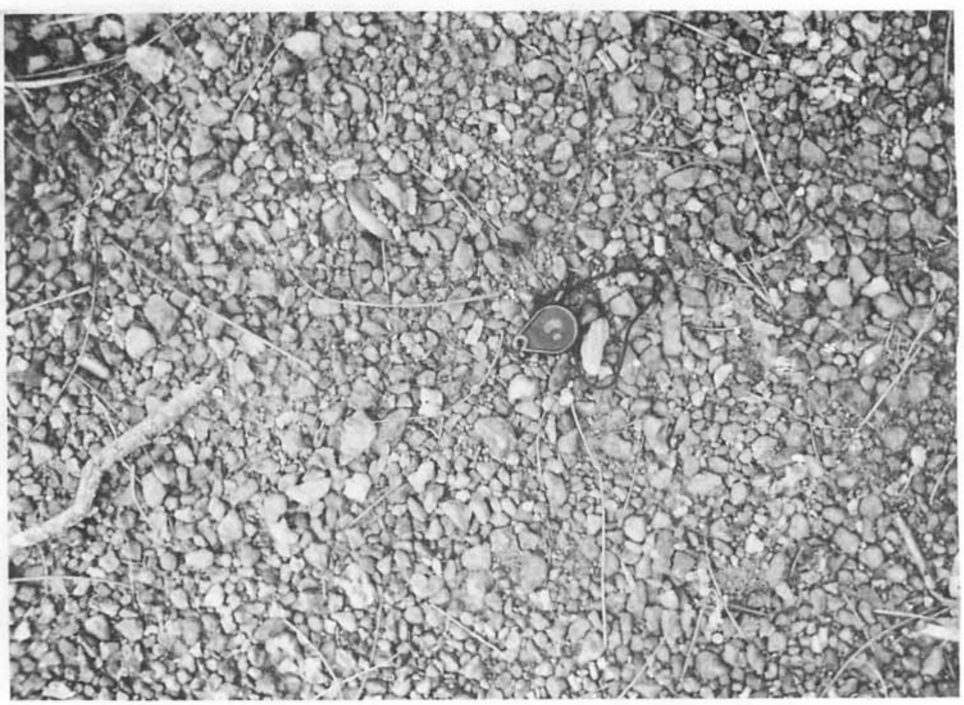

Fig. 8

b. Matrix: The matrix of the sandstones, which varies between 30% and 60% (due to ?weathering) is usually very fine grained. Under high power magnification, however, it is seen in all samples to consist of small detrital grains, principally quartz, and clay minerals. An interesting feature of the clay mineral flakes is their occurrence as rims around some of the detrital grains.

c. Cement: Small to moderate amounts of iron-oxide occur throughout the sandstones and have produced a strong lithification as evidenced by the hard nature of most samples. This iron-oxide cement, however, is secondary and the origical cement, which most likely has been siliceous, is not distinguishable.

d. Sorting and Roundness: Sorting of the medium and coarse grained sandstones is poor due to the presence of fine and very fine sand grains between the larger grains. On the other hand, the very fine and fine grained sandstones are modearately sorted. Roundness is less variable between the fine and medium to course grained sandstones and grains are generally angular to subangular.

e. Porosity: The intergranular pore space is completely infilled by silt and clay grade matrix. Any original depositional porosity that may have existed within the sandstones has been obliterated by the weathering and cementation of the rock with iron-oxides to the extent that it is no longer visible.

Quaternary

The Quaternary of Pulau Tekong includes extensive deposits of unconsolidated sand, silt and clay, occupying the coastal plain and the floors of some inland valleys. These sediments form a superficial layer over much of the Mesozoic deposits in the coastal area below about 7.5 metres.

After the deposition of the Triassic rocks and their uplift in the Late Mesozoic and Tertiary , the present drainage systems developed and the island attained its present shape in the Quaternary. Small rivers transported the weathered clay and sands and deposition occurred in the valleys and round the coast. Both fresh-water and mangrove swamps developed and swamp clays were laid down with some thin sandy beds deposited during a higher energy level of the rivers or a rise in sea level.

On the other hand, generally fine to medium grained sand is transported in the Straits of Johore and is laid down at the beaches. Marine transport of sand, resulting in the development of beaches, accumulation of mud in swamps, and transport of weathered material from the hilly region of the island to the coast, may be considered as the main factors which are responsible for the Quaternary sedimentatiön at Pulau Tekong.

The occurrence of well-sorted medium grained beach sands at approximately 7 metres above preesent sea level west of Kampung Ayer Samat Darat can only be explained by a rise in sea level during the Pleistocene and these old beach sands may well represent the oldest Quaternary sediments of the island.

Age and depositional environments

No direct age data or indication of the depositional environments of the Pre-Quaternary rocks at Pulau Tekong are available because of the poor outcrops and the intense tropical weathering. Suggestions of a possible age and depositional environment of the rocks are based on the work of Alexander (1950) in West Singapore and Burton (1973a) on the Mesozoic of Johore. The interpretation of these data, related to Pulau Tekong, must therefore be considered as tentative.

It appears that early Triassic diastrophism in the Malayan region resulted in the erosion of most of the lowermost Triassic and older strata. Sedimentation was reestablished in the Upper Triassic, which resulted in the deposition of most of the sedimentary rocks at Pulau Tekong. These sedimentary rocks correspond with the "Argillaceous Series", established by Alexander (1950) on Singapore Island and with the "Bukit Resam Member of the Jurong Formation", described by Burton (1973b).

Most of the Bukit Resam Member in Johore seems to be Upper Triassic in age, but a Lower Triassic age may not be completely excluded since dfefinite Upper Triassic marker fossils are absent. Deposition under shallow marine conditions is indicated by the presence of shallow-water benthonic lamellibranchs, especially species belonging to the *Myophoria* biofacies. The lithology of the Bumit Resam Member, characterised by a repeated interdigitation of shale and immature sandstone, may point to a molasse facies, but there is no clear sedimentological evidence to prove this.

The thermal metamorphic rocks may be similar to the "Older Schist", which is described by Alexander (1950) from west of Murai in Singapore. She mentioned an abrupt change in strike between the older schist and the Argillaceous Series, which indicates at least a different age and consequently suggests a pre-sedimentary intrusion. Burton (1973a, p. 105) also mentions that the Bukit Resam Member of the Jurong Formation appears to post-date the granite. Since the granite itself is not exposed, definite arguments for a pre- or post-sedimentary age of the granite intrusion will not be found at Pulau Tekong.

The glacio-eustatic fluctuations of sea level during the Quaternary may be responsible for deposition of most of the fine to medium grained beach sands and mangrove muds along the coast and in the low lying valleys of Pulau Tekong.

ACKNOWLEDGEMENTS

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