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## Geomorphology and Biological Erosion of Limestone Coasts in Malaysia

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**Abstract:** Marine intertidal erosion of limestone at two localities in Malaysia is described. At Semporna, Sabah, uplifted Quaternary coral rock forms a group of islands, and at Pulau Langkawi, Kedah, crystalline Palaeozoic limestones form part of an archipelago. The erosional features at Semporna are similar to those described in coral rock elsewhere; there is a visor, an intertidal notch, and a low tide platform which may extend 30 meters or more from the notch. At Langkawi many of the islands have sea cliffs, which continue below sea level; intertidal notches are cut into them but there are no low tide platforms.

The form of the notch is similar in the two places. Amplitude is related to tidal range and wave action; the height approximates spring tide range where the sea is generally calm, but increases with exposure to wave action. In the coral rock the surface of the upper notch is rough and pitted and there are few sedentary animals. The crystalline rock is generally much smoother above the level of mean high water neap tides while below this it is heavily encrusted with oysters and barnacles. At both places the surface rock is bored by endolithic algae and these are rasped by chitons and other browsing molluscs. The boring sponge *Cliona*, the bivalve mollusc *Lithophaga* and other boring organisms riddle the outer few cm of the Langkawi rock up to about mean high water neaps, but are much less common in the coral rock.

It is concluded that these boring organisms are the main agents responsible for erosion in the notches. The rate of this bioerosion is not known but is considered to be at least fast enough to have cut notches up to four meters deep during the Holocene. Massive breaks in the upper cliff appear to have resulted from undercutting by notching combined in some instances with the hydraulic action of waves.

Some examples of possible higher level notches are discussed, but no unequivocal examples were seen. Holes made by bivalve molluscs several feet above the level at which living animals occur afford more reliable evidence of former higher sea level. Oyster shell encrustations are similarly found several feet above living animals.

### INTRODUCTION

The characteristic erosional forms of limestone shores are well known and have been described from many parts of the world. They are particularly well developed in Quaternary rocks of low latitudes, both in coral rock in the tropics and in dune rock (eolianite) which extends to rather higher latitudes. Kuenen (1933) and Verstappen (1960) have described examples of erosion of coral rock coasts on Indonesian islands, but dune rock is poorly developed in the equatorial region and probably the nearest examples are in Western Australia (Fairbridge, 1950).

Erosion of older and harder limestones by freshwater is well known and examples from Sabah are described and illustrated by Wilford (1964) and from northern Malaya by Paton (1964) and Jones (1965). However, few examples of marine erosion of such rocks are recorded from the tropics.

There has been much discussion about the nature of the processes responsible for marine erosion of limestones, but there is still no general agreement as to causation. Notches and intertidal platforms are often termed 'wave cut', and erosion has been attributed both to chemical solution and to 'bioerosion' by algae and various boring animals. Guilcher (1953) has shown that erosional forms change with latitude and he associates the differences with water temperature and probable rate of *dissolution*. There is little direct evidence of the rate of erosion.

Most published work relates to erosion of Quaternary rocks; observations on older, denser rocks are therefore of particular interest. In the present study it has been possible to compare shore forms developed in hard, Palaeozoic rock with similar forms in Quaternary coral rock in the same climatic region, at the two geographical extremes of Malaysia (Fig. 1).

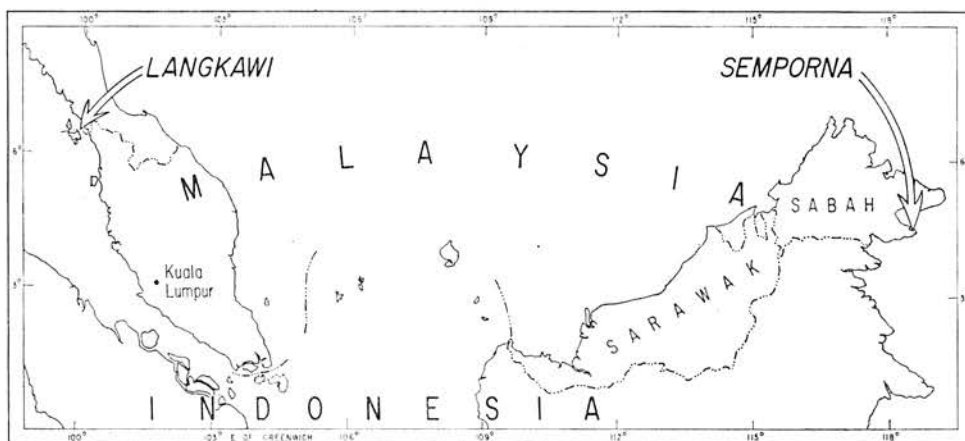


Fig. 1. Map of Malaysia to show location of Langkawi Islands and Semporna

Quaternary coral limestone, uplifted by recent tectonic movements, forms a group of islands and part of the mainland near Semporna at the south east tip of Sabah, East Malaysia (Borneo). A large part of the shoreline of these islands show a typical notched cliff and low tide platform, beyond which shallow lagoonal waters with live coral extend out to the present reef margin at varying distances from the cliff. Bajau fishermen's houses are built on poles over the platform or lagoon and have plank walks to land; the floors are often less than a meter above high tide level, clear evidence that there is normally little wave action.

Crystalline limestones of Ordovician-Silurian and Permian age form part of the archipelago of Pulau Langkawi and the nearby Thai islands off the north west coast of West Malaysia. These show typical karst topography similar to that of the Kedah coastal plain nearby. The shore line is often cliffed and the cliffs are deeply notched

at water level, giving the smaller islands the appearance of floating on the water. Paton (1964) illustrates one of the Langkawi notches and Jones (in manuscript) has briefly described them. In an earlier paper Scrivenor and Willbourn (1923, p. 341) mention that one islet is "strongly undercut by the warm sea water".

Brief visits were made to both places by the writer in connection with studies of the erosion of dune limestone on the coast of Western Australia, and rock samples were studied in the laboratory. The observations recorded here are necessarily incomplete, but are nonetheless of interest for the study of the erosional processes, the geomorphology of Malaysian coasts, and evidence of former higher sea level. Inevitably they pose more questions than they answer and it is to be hoped that someone able to make a more thorough study, of Pulau Langkawi in particular, will follow them up.

Heights on the shores are indicated by reference to tide levels: MHWS—mean high water spring tides; MHWN—mean high water neap tides; MSL—mean sea level; MLWN—mean low water neap tides; MLWS—mean low water spring tides; LW—low tide level on the day of the observations.

SEMPORNA

Raised coral limestone forms the tip of the Semporna Peninsula, Pulau Bum Bum, and several smaller islands (fig. 2) and covers an area of over 40 square miles (Kirk, 1962). Similar coral rock occurs in the nearby islands of the Sulu Archipelago

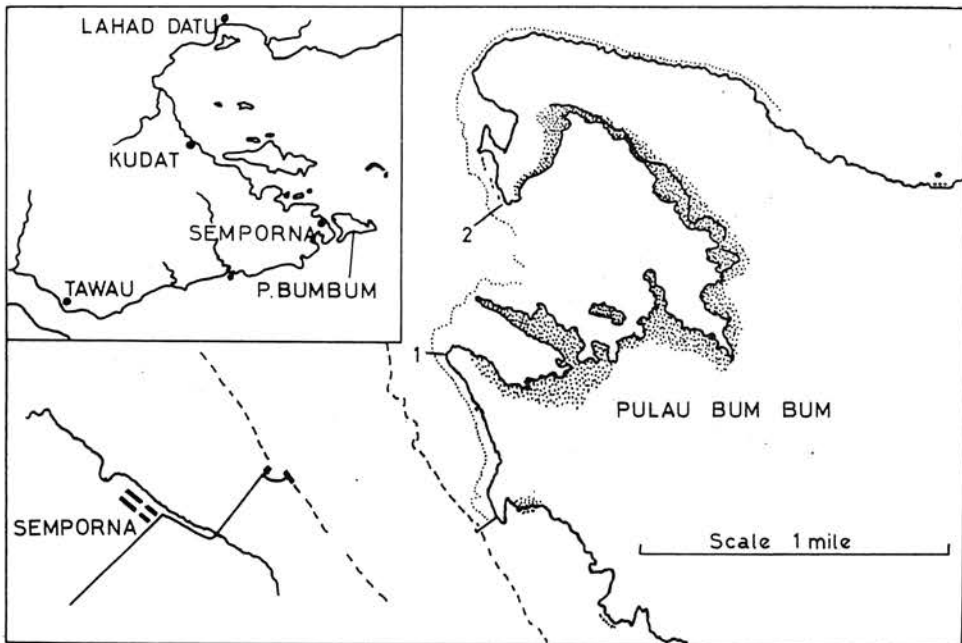


Fig. 2. Map of the Semporna area traced from air photos. Numbers indicate sites studied. Stippled area—mangrove and other tree cover Dotted line—apparent edge of shore platform. Dashed line—outer edge of present reef.

and raised coral beaches also form narrow fringes around islands composed of other rocks. The rock rises 6 to 8 meters above low tide level, presumably representing an old reef platform. Kirk classifies the rock as of younger Quaternary age and records (p. 109) a date of "not younger than 28,000 years  $\pm$  600 before 1950" for an oyster shell from a shore bench on Sipango Island. He describes the limestone (on Selangan Island) as having "a lightly consolidated upper layer and a lower layer heavily cemented with secondary tufa" (p. 109); coral is embedded in it in growth position and there are abundant shells.

Rainfall at Semporna averages 2150 mm a year, without pronounced rainy or dry seasons. Tides are mainly of semi-daily type, with a spring tide range of 1.58 m and neap range of 0.37 m, but maximum daily range may exceed 2.1 m. These figures are derived from the Tawau data (Tide Tables for Malaysia and Singapore) and are given here with reservations. From these predictions, tide level was 45 cm above MLWS at the time of observation (low water) when live coral was already exposed, and high tide the same day was higher than expected on the basis of the predictions.

Two sites were examined, both of them on the north-west of Pulau Bum Bum (fig. 2). The visit was made on 18th November 1968 over the period of low tide when both notch and platform were uncovered for some hours; water level reached the foot of the notch about noon. Approximate heights were estimated relative to LW.

At site 1 the small peninsula has a well developed notch around it, the forms and dimensions of which are shown in figs. 3 and 4. The upper limb has fallen away in a few places, but apart from this the notch is continuous.

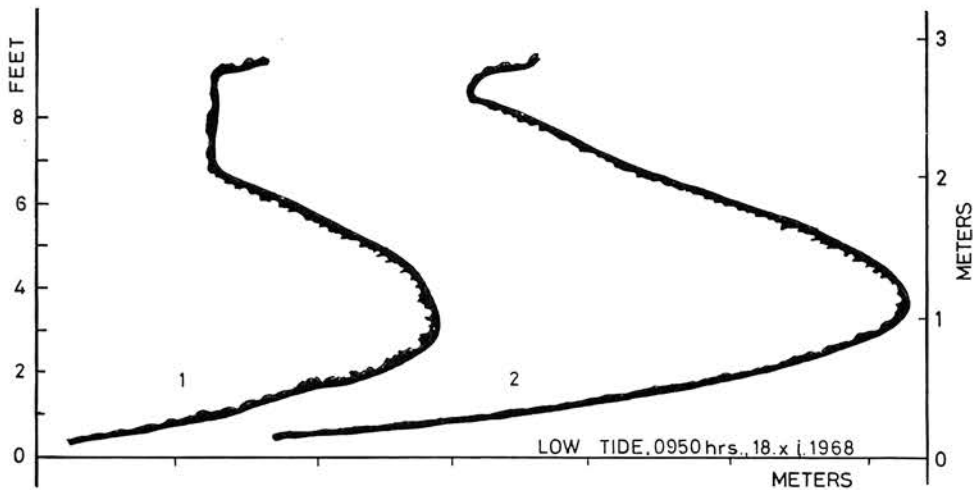


Fig. 3. Notch profiles at two sites on Bum Bum Island, Semporna.

Table 1 summarises structural and biological features of the rock surface as seen at low tide. Successive colour zones can be clearly seen in the notch, with a black band at about 140 cm above LW. They are not as prominent as on some similar shores, e.g. those of Barbados (Lewis, 1960).

Table 1. Principal features of the rock in the notch at site 1, Bum Bum Island

Approximate height above LW, cm	180	130	90	60	30
Surface of rock	hard, rings to a hammer			soft, hammer penetrates	
Macroscopic appearance	sharp and much pitted			shallow pits	rounded
Detailed appearance	polished	smooth		smooth	mud
Colour	brown, white pale grey	black to dark grey		grey	grey
Surface algae	thin, dry	smooth green felt	sparse corallines	smooth green felt encrusting corallines small sporelings	
Surface organisms	algae evident to 1 to 2 mm (green, pink, purple)			algae evident to 0.5 mm sponge ++, bivalves +, worms +	
Surface fauna	(terrestrial)				
<i>Acanthochiton</i>			++	++	+++
<i>Nerita</i>			+	—	—
<i>Siphonaria</i>			+	—	—
<i>Onchidium</i>			—	++	++
Hermit crabs			—	+++	+++
Radula marks			++	+++	+
Faecal pellets	+	+	++	+++	+

At site 2 the notch is both higher and deeper than at site 1; it is up to 3 meters deep in places (figs. 3 and 5). The lower limb rises higher and extends out 10 meters or more in an unbroken slope. Round the point to the south of this site the notch continues for another 50 meters, but beyond this the upper limb has fallen away and lies on the lower slope, and within the bay there is only an irregular slope and mangroves. The rock surface shows essentially the same features as at site 1, except for the smoother and almost unbroken surface of the lower slope. Many small stones were lying here and even if their presence is attributable to human activity, their persistence is further evidence of the relatively weak wave action.

Similar notches were seen along the north shore of Pulau Bum Bum, round small islands immediately north of Semporna, and even at Semporna itself though here they are much disturbed by human activity. Air photos must be interpreted with

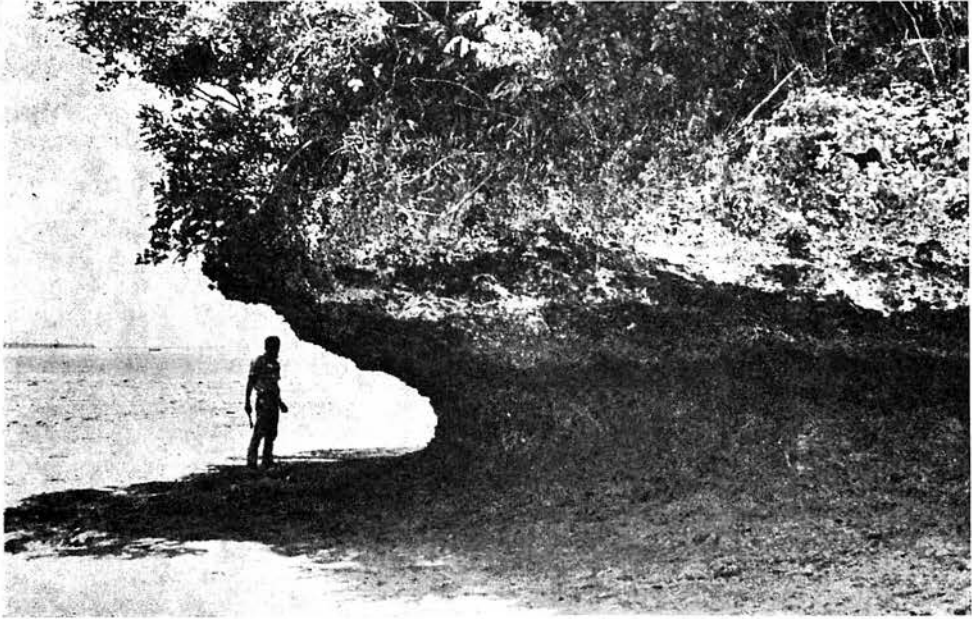


Fig. 4. Notch at site 1, Bum Bum Island.

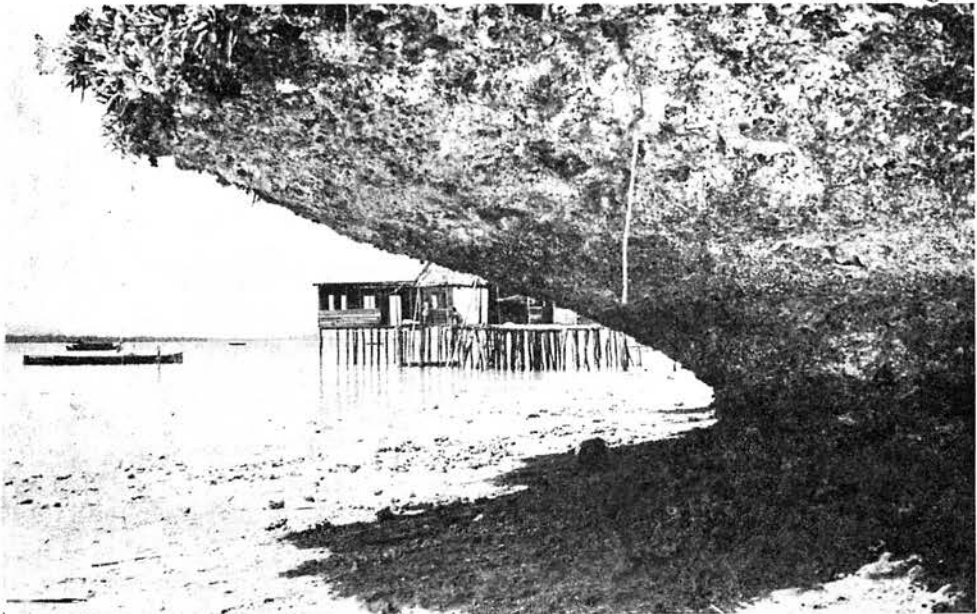


Fig. 5. Notch at site 2, Bum Bum Island.

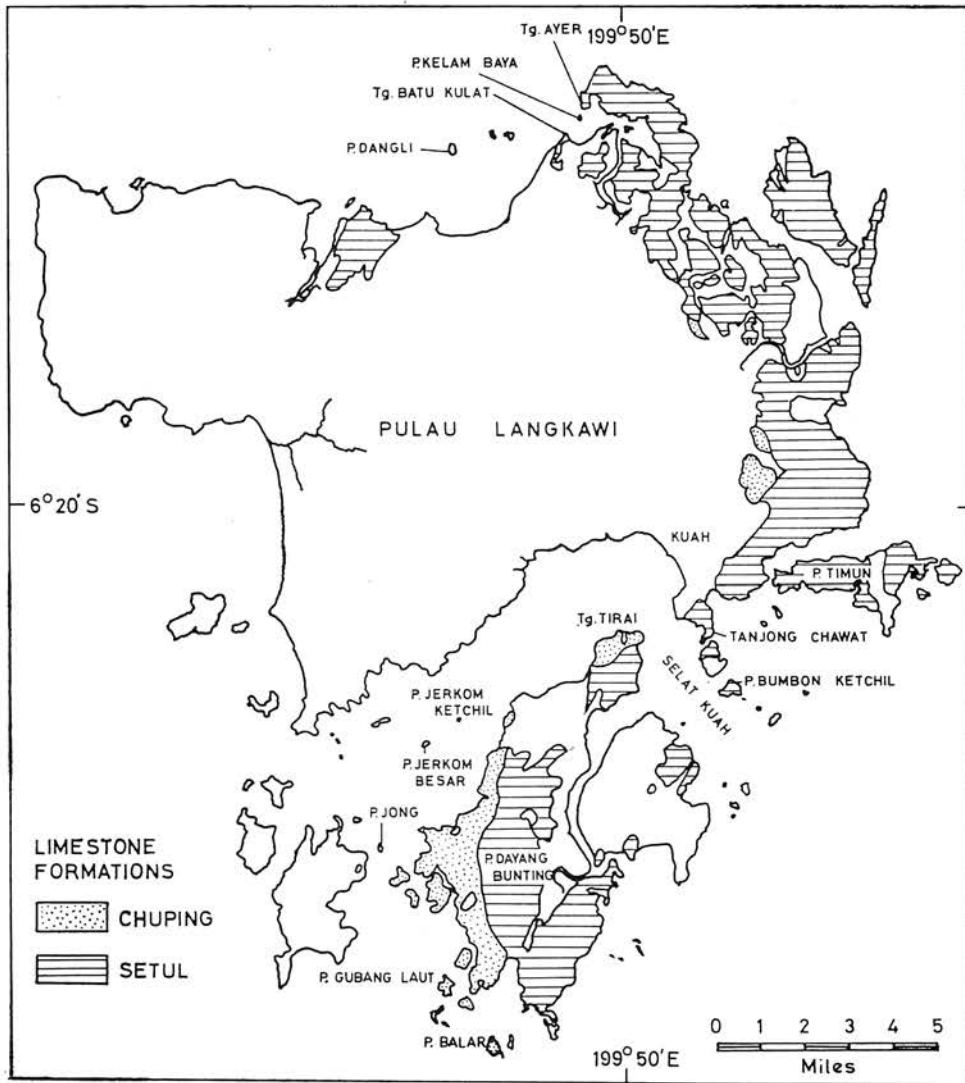


Fig. 6. Map of the Langkawi Islands



caution for such vertical or overhanging features, but it is evident from them that there are notches along much of the shore line of all the coral limestone islands. Notches are notably absent from the more sheltered shores such as that of the bay between sites 1 and 2, though even here an overgrown cliff line can still be seen in places among trees. Kirk (1962, Pl. 35) illustrates a cliff on Selangan Island which rises to 25 feet, but the notch at the foot of it has the usual form and dimensions.

These two sites were not seen at high tide, but at Semporna water reached high on the upper slope in notches of much the same height. It is evident that the rock is regularly wetted, probably daily to the top of the black zone (about 140 cm above LW), by tides alone or by tides and waves; above this the surface is probably dry for days at a time and receives only infrequent splash.

### LANGKAWI ISLANDS

Limestones form most of the eastern side of the main island (Pulau Langkawi), a large part of Pulau Dayang Bunting and many of the smaller islands of this archipelago (fig. 6). They are briefly described by Jones (1965) and more fully in an unpublished manuscript by the same author. The Setul formation of Ordovician to Lower Devonian age is a thickly bedded, generally dark grey, crystalline limestone. It is not a pure carbonate and contains considerable amounts of fine detrital material. The Chuping formation is Permian, more massively bedded than the Setul, of light grey rock, finely crystalline, and purer. The white marble which is quarried at the north end of Pulau Dayang Bunting is in this formation.

Rainfall averages about 2150 mm a year, with a relatively dry period from December to February. Tides are mainly of semi-daily type with a spring range of 2.25 m and neap range of 0.65 m; however daily range at spring tides averages about 2.60 m (1968) and may be as much as 2.90 m (Tide tables for Malaysia and Singapore, 1968).

In the enclosed waters between the islands the water is calm much of the time, but to the west the sea has considerable fetch and the western and, to a lesser degree, northern and southern shores are exposed to constant wave action. In narrow channels between the small islands there are depths of up to 20 meters and it is evident from the Admiralty chart that there is scour with sediment transport towards Selat Kuah where there are shallow banks.

The sites studied are shown in fig. 6. Brief visits were made to a number of sites from Tanjong Chawat through the Straits between the islands to Pulau Balar (19 October 1968). More prolonged study was possible at low tide at Tanjong Chawat (18 October), Pulau Jong and Pulau Bumbon Kechil (19 October), and Tanjong Batu Kulat (20 October). Low tide on 19th October was 15 cm above MLWS. Heights given below are relative to chart datum (fig. 7); they were estimated visually against a cord marked in feet and hung from the top of the notch.

#### Notches

The following localities were studied:—

##### *Pulau Bumbon Kechil*

A small island on the leeward side of Pulau Langkawi where there is normally little wave action. Much of the shore line is deeply notched (fig. 8), but there are



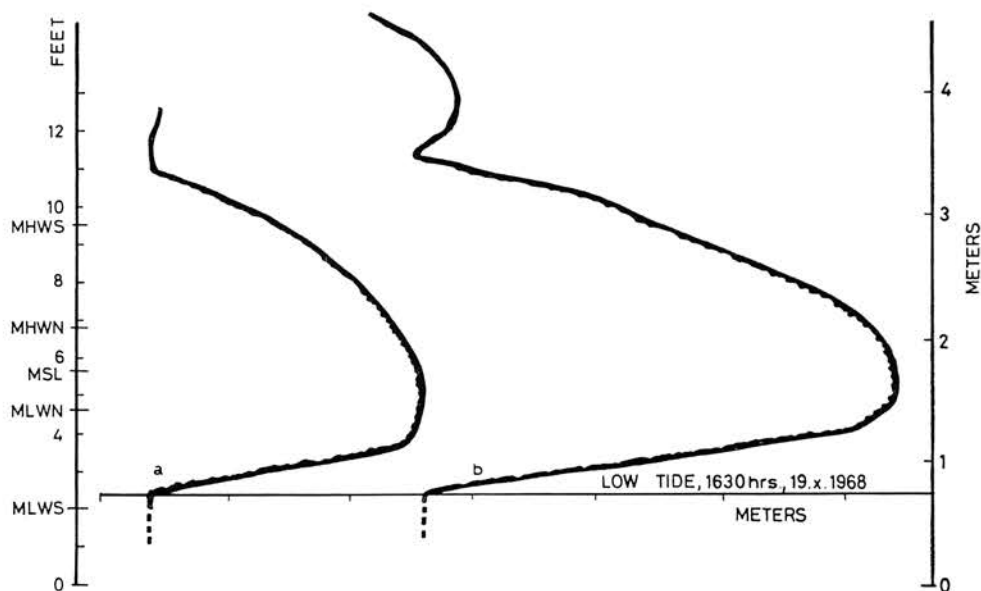


Fig. 7. Notch profiles at P. Bumbon Kechil, Langkawi.

also more open sections with fallen rocks lying on the slope (fig. 9). These appear to have broken from the over-hanging part of a former notch. A number of caves penetrate into the cliff intertidally. The notch was examined on the north-west side of the island near its western point and had the features shown in fig's 7 & 10 and described below.

Upper notch, above + 210 cm: Surface of rock generally smooth with shallow scalloping and abundant radula marks to about 300 cm near the top of the notch. No boring animals found. A thin coat of endolithic algae.

Back of notch, + 120 to + 210 cm: Surface of rock covered with barnacles and oysters and the rock riddled with the borings of bivalve molluscs, sponges, and other boring organisms almost to the same level.

Lower slope: A uniform slope of about  $10^\circ$  which ends abruptly below the face of the cliff; the water is 6 meters deep. Surface of slope smooth or rough and pitted, sometimes ridged. Considerable boring by sponges and bivalve molluscs, but more careful study is required to determine the extent of this.

#### *Pulau Jong*

A notched cliff surrounds the greater part of the island (fig. 11). The notch is both higher and deeper than at P. Bumbon Kechil; it is also less regular in form, partly because there have been relatively recent rock falls from the roof of the notch and partly from heavy encrustation with oysters and barnacles. It was examined on the east side of the island shortly before low tide.

Upper notch: Surface clean or with an encrustation with oyster shells at about MHWS and pendent masses of cemented shells, but no living oysters seen above

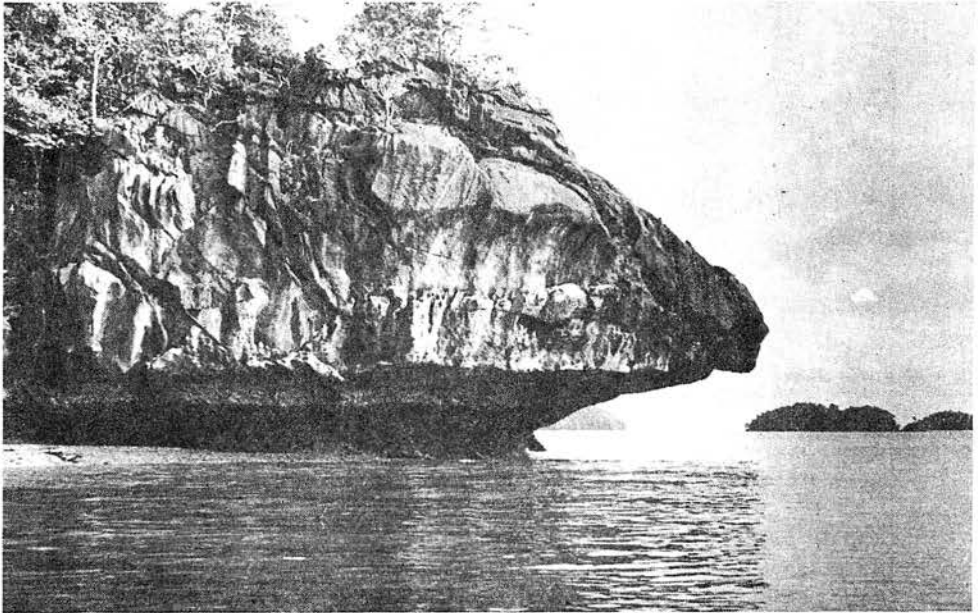


Fig. 8. Cliff and notch, south side of P. Bumbon Kechil, Langkawi.

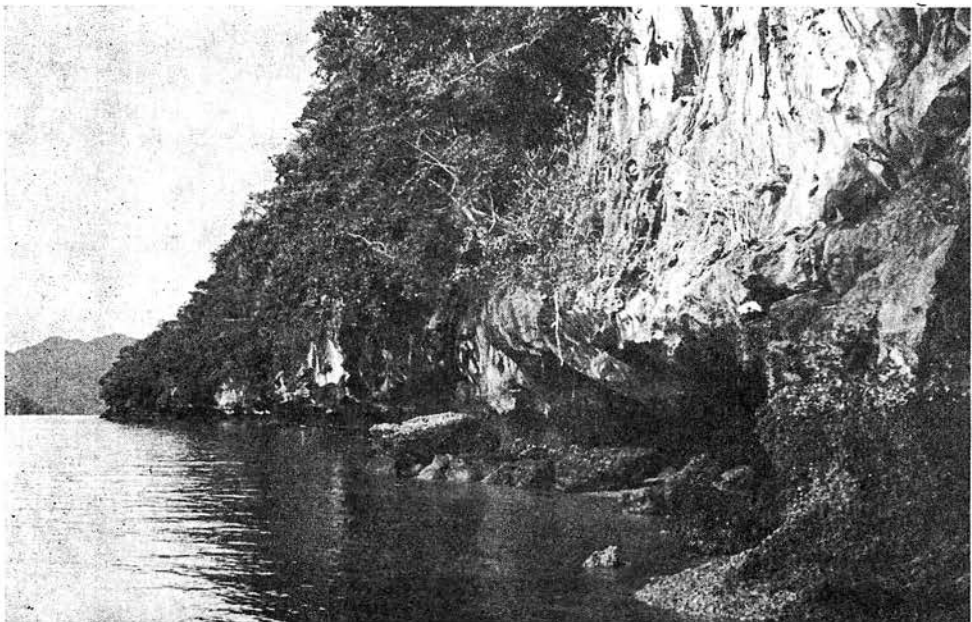


Fig. 9. Open notch and fallen rock, north west side of P. Bumbon Kechil.

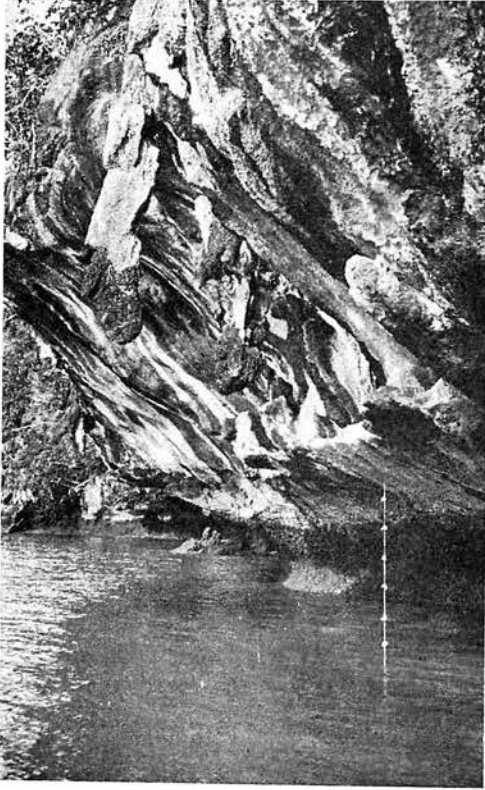


Fig. 10. Cliff and notch, west end of P. Bumbon Kechil, Langkawi. Cord marked in feet.

top of present oyster zone at about MHWN.

Back of notch: Thickly covered with barnacles and oysters which form a shelf at the back or irregular projections. Bare rock shows bivalve borings.

Lower slope: This carries both loose rocks and small bosses of live coral, other encrusting animals include the bivalve *Chama* and serpulid *Pomatozeros*. There are abundant sea urchins (*Diadema*) and other fauna which do not stand drying. Rocks lying on the slope are riddled by boring organisms. Some silt is here, unlike the almost bare lower slope at Bumbon Kechil. The slope ends below the overhanging cliff and the water is 6 meters deep.

*Pulau Jerkom Besar and P. Jerkom Kechil*

These small islands lie in the main channel; the water here is 8 to 12 meters deep but with shallow banks to the northeast of both islands. The islands were visited briefly both near high tide and near low tide. The southeast face of the large island lacks a well developed notch and there have

evidently been relatively recent rock falls from the face of the low cliff.

The northeast corner of the small island has the only examples of low tide platforms that were seen at Langkawi. These surround small stacks (fig. 12) and are nowhere more than about two meters wide; this is no greater than the depth to which a notch might have been cut into a cliff. The surface of these platforms is level, at about + 1 meter, in contrast to the slope which is characteristic of the lower limb of most notches.

*Pulau Balar*

This is the southernmost of the Langkawi islands and, like P. Gubang Laut nearby, it is exposed to maximum wave action for the area. It was only visited at high tide and waves about a meter high made it impossible to examine the intertidal rock. On the west side the notch is considerably higher than at P. Bumbon Kechil, the top being about two meters above MHWS, and it is up to four meters deep (fig. 13).

*Tanjong Batu Kulat*

This is near the northern tip of the main island and is exposed to waves and swell from the northwest. The notch is high and of irregular form, with some small



Fig. 11. P. Jong, Langkawi, North side.

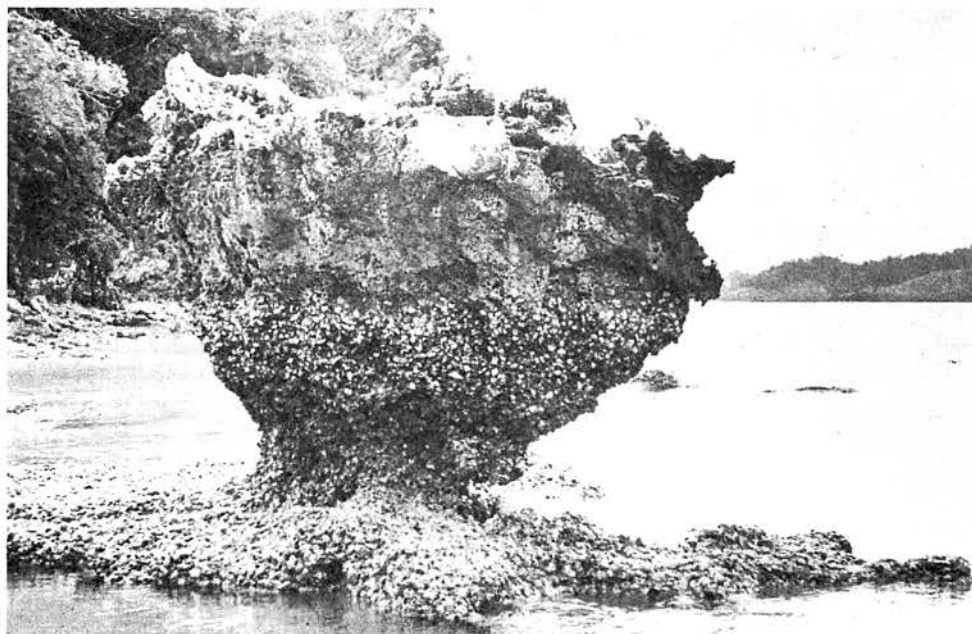


Fig. 12. Small stack and platform, P. Jerkom Kechil, Langkawi.

caves. There is sand along the shore and the rock is abraded. Nevertheless the surface is extensively bored by the same organisms as are found elsewhere and it is concluded that the sand is of intermittent occurrence here or has covered the shore relatively recently. The rock is bored by sponges to + 180 cm and by bivalves and worms to 240 cm. There are empty borer holes to 3 meters in places. Live oysters and barnacles reach up to the same level in contrast to about two meters (MHWN) on the leeward side of P. Kelam Baya nearby where there is a characteristic oyster 'shelf'. There are pulmonate limpets (*Siphonaria*) to 3 meters (many in shallow depressions which they fit) and periwinkles (*Littorina*) are common even higher. At this level there is both fine pitting of the rock surface and radula marks characteristic of chitons. Chitons were common among the oysters where they probably retreat with the tide. An algal film covers the rock to at least 3.5 meters and there are small patches of macroscopic algae.

The picture here is of a wave-beaten shore, with the vertical zonation of the fauna and flora extended several feet in comparison with a sheltered shore such as P. Bumbon Kechil. Massive breaks can be seen in the cliffs of Tanjong Ayer nearby and one particularly large fall there shows a prominent notch.

#### *Tanjong Chawat*

The west side of this cape has an irregular shoreline with a shallow notch in places, but most of it has an open, irregular, sloping surface with evidence of fresh-water erosion above MHWS. There is a sparse cover of oysters and barnacles to MHWN and the usual range of boring animals are present in the rock to about + 120 cm only. The prominent stylolite ridges which project from the rock at all levels have been described and illustrated by Hutchison (1963). Although derived from the limestone they are non-calcareous and are more resistant to erosion than the calcium carbonate. In a rock sample from + 120 cm the stylolite protrudes from the limestone which, at the junction, has the appearance of having been plastered onto it. The limestone has been rasped by molluscs, the radula marks of which are clearly visible. It is evident that the form of the shoreline here is modified by the lithology of the rock.

#### *Tanjong Tirai*

The rock here is of white marble and presents a roughly vertical face throughout the tidal range, in contrast to a typical notch in black rock immediately to the east. Barnacles and oysters encrust the rock to about MHWN. From this level to a little above MHWS the rock shows two types of erosion, small irregular pitting and smooth rounded hollows (fig. 14). The rock surface shows radula marks and *Acanthociton* was present. A narrow tongue of white marble projects seawards from the south-eastern corner of Pulau Balar and shows similar features: a vertical rock face in contrast to notches in grey rock nearby, massive fracturing of the rock, and the characteristic rounded hollows above MHWN.

### **Other coastal features**

The notches described above are the most characteristic feature of the limestone shores of Langkawi, but it would be misleading to imply that there are not other important features which must be considered in any appraisal of the events which have produced the topography of these coasts. In a number of places the shore line is formed by boulders and it appears that there has been relatively recent massive collapse, sometimes leaving high cliffs behind. Collapse on a smaller scale was noted





Fig. 13. P. Balar, Langkawi. West face at high tide.

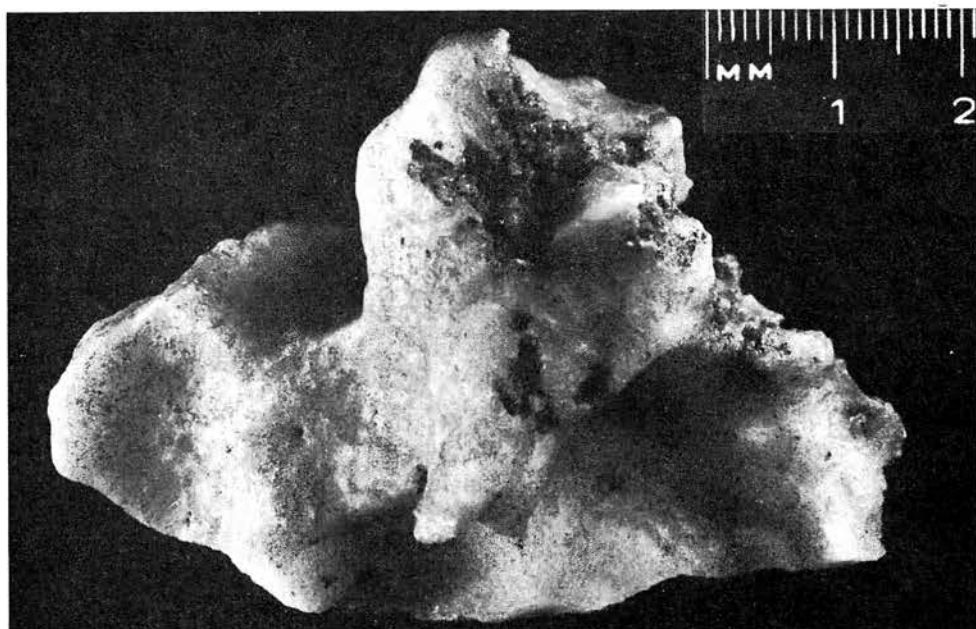


Fig. 14. White marble from near MHWS, Tanjong Tirai, Langkawi.

above at P. Bumbon Kechil where the upper notch and cliff appear to have broken away. In this case rocks still lie on the lower slope in places. At P. Jong massive breaks were noted in the roof of the notch on the plane of the strata, without collapse of the cliff above. At P. Jerkom Besar the low cliff is roughly vertical from above high water to below low water. Breaks must have been both recent and relatively small since they transect fresh borings of bivalve molluscs as described below.

Above the notch the cliff varies considerably in height and form, but at P. Bumbon Kechil and on the east side of Tanjong Chawat where there is minimal wave action it is commonly vertical or overhanging and there is often a small shelf at about MHWS (figs. 10 & 15). The rock surface is streaked with grey, white, black and yellow; the white is apparently a secondary deposit coating the rock. In more steeply overhanging places there are pendent structures which would repay further study, they may be stalactitic or the remnants of hanging oyster bosses from a former high sea stand. On the southwest side of Pulau Jong stalactitic masses hang from the face of the cliff as well as pendent oyster bosses. Where there is more wave action, as at P. Balar and P. Gubang Laut, the upper cliff may show similar features but they appear less regular and higher, the top of the notch being well above MHWS.

#### High-level erosion by marine organisms

Evidence of present borer activity was only found below about MHWN in all the more sheltered situations, as at P. Bumbon Kechil, and even at Tanjong Batu Kulat fresh borings were not found much higher than this level. However there are empty borer holes at greater heights in a number of situations. At Pulau Jerkom Besar, a sheltered locality, breaks in the grey rock of the cliff have exposed holes made by *Lithophaga*, other bivalve molluscs, and worms (fig. 16). These are at about 30 to 70 cm above MHWS. The rock is often clean, smooth, and fresh both on the general surface and in the bored holes, except that it is etched in deep holes which may have held water. It has a thin secondary deposit on the surface. The freshness of this surface is certainly attributable to its having only recently been exposed and other parts show more evidence of subaerial erosion, but the holes are unequivocally the result of boring by organisms which, at the present time, are only active at a level nearly two meters lower, at +120 cm. Part of the general surface shows the furrows that are so characteristic of surfaces over which chitons have browsed; these do not however show radula marks and it is unlikely that chitons could be active there now.

Similar borings at levels well above that of present borer activity were also seen at P. Balar, P. Jong, and at Tanjong Batu Kulat.

## DISCUSSION

#### Comparison between the localities

The localities studied, with their very different types of limestone and different tidal range, show remarkably similar marine erosional features, but with important differences of detail. In both areas the shore line is notched intertidally and notches surround the greater part of the shore line, but they are conspicuously absent in the most sheltered situations where there is an accumulation of sediment and also where there have been extensive rock falls. In relatively sheltered places where there is normally little or no wave action the notches at P. Langkawi have the height of the



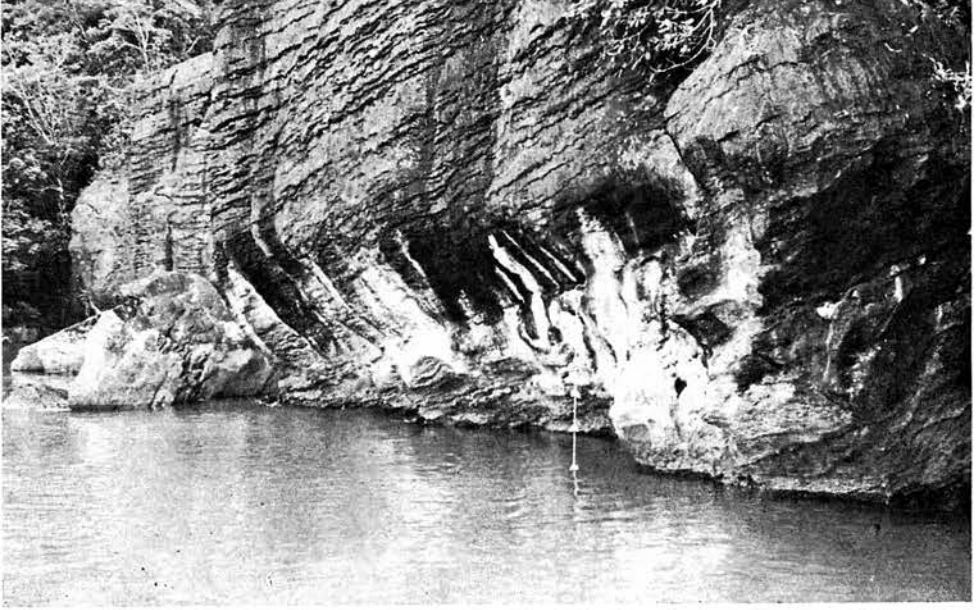


Fig. 15. Cliff at high tide, Tanjong Chawat, Langkawi. Note stylolite ridges above and coloured surface deposits below.

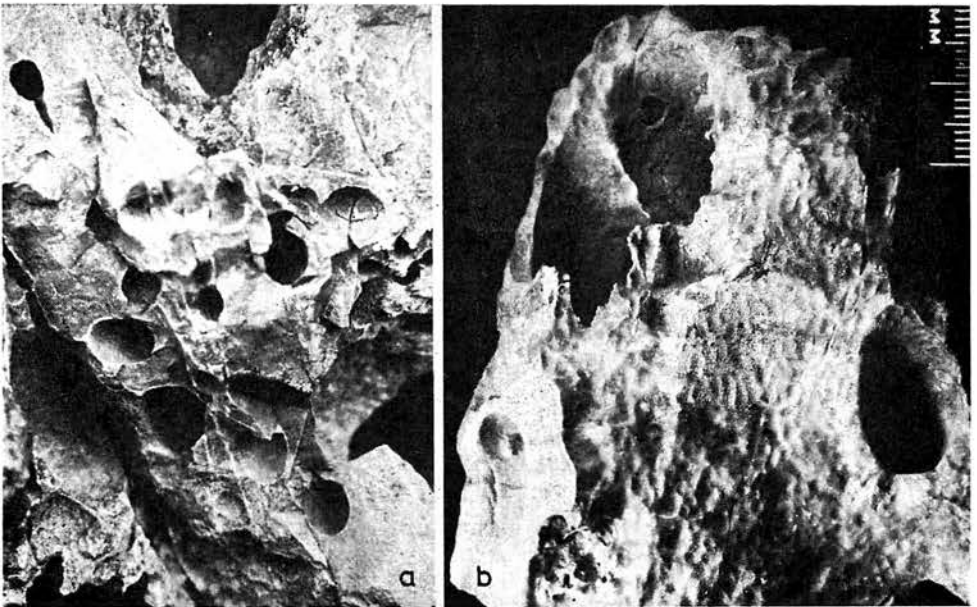


Fig. 16. Rock bored by *Lithophaga* above MHWS, P. Jerkom Besar, Langkawi. A. in situ. B. hand sample.

spring tide range, the top of the notch being at about MHS and the bottom near MLWS. Where there is greater and more continuous wave action the height is proportionately greater. At Semporna the amplitude appears to be rather greater than spring tide range and this is probably attributable to more continuous, though slight, wave action which splashes sea water into the upper notch.

In each area the notches are remarkably uniform in shape and those of the two areas are of very similar form. It would require a more thorough study than the present to establish real differences between them. Form moreover is independent of lithology, with the significant exception that notching is poorly developed in the one locality studied at Langkawi where there are bands of non-calcareous rock. Notches in dune rock in Western Australia may also take much the same general form, but there is more variation and a lower slope is seldom developed, the platform being flat to the foot of the notch. Here again lithology influences form of notch very little.

However, there are differences in the surface of the rock in the notches of the two shores. The porous coral rock of the Semporna notches has a rough, deeply pitted surface, making the bare rock sharp and jagged, even more so than in dune rock notches. At Langkawi, on the other hand, rock above MHWN is generally smooth or at the most with shallow, rounded pits, while below this level it is heavily encrusted with barnacles and oysters.

Gross differences between the shores at the two localities are (a) the presence of a 'visor' at Semporna and its absence at Langkawi where the cliff above the notch shows features of a very different nature, (b) the presence of a low tide platform at Semporna and its absence from Langkawi shores. The visor, or projecting rock ledge above the notch, is a common feature of coral rock shores, e.g. those described by Macfadyen (1930) and Guilcher (1952) in the Red Sea or by Fairbridge (1948) at the Abrolhos Islands, Western Australia. It is also developed on dune rock shores (Fairbridge, 1950). In the view of the writer the visor is a residual feature and should not be expected in a cliff that rises well above the level of marine action. There is no visor on coral rock shores where there are cliffs to well above present sea level, such as those described by Verstappen (1960), and a photograph of the highest part of Selangan Island, Semporna (Kirk, 1962, Pl. 35) shows a low cliff above the notch.

The extent of the erosion platform at Semporna could only be determined with certainty by a more prolonged study because it merges into the present lagoon with living and dead coral. From gross inspection it appeared to be of the order of 30 meters wide. Certainly it extends well beyond the limits of the notch as a flat, or gently sloping, firm rock surface, giving clear evidence that it has been left by retreat of the cliff. At Langkawi, on the other hand, the only platforms seen are those which surround small stacks (fig. 12); they are of notch-width and must be assumed to be the remnants of notches.

The typical coastal cliffs of Langkawi continue from above sea level to well below it. the notch merely interrupts them at sea level. Three alternative hypotheses can explain this morphology: (a) retreat of the cliff has been at the same rate above and below water, (b) the present notch has been cut into a pre-existing cliff during the present stand of the sea, (c) retreat of the cliff has been mainly the result of undermining well below sea level, with rapid development of notches between falls. Of these, (a) is inherently unlikely, (b) is the most likely hypothesis on the evidence available, but (c) needs to be considered seriously. Neumen (1966) showed the rapid rate of destruction of sublittoral calcarenite at Bermuda by sponges and other borers. This is immediately below low water in a relatively sheltered situation with very small

tidal range. The undermining has resulted in collapse of the cliff above. Dune rock platforms are often deeply undercut a few feet below low water, where again boring organisms are common.

#### Nature of the erosion

Two principal types of shore erosion are seen at these localities: massive fracturing in which large pieces are broken away, and small scale corrosion of the rock surface. The first process is seen as (a) small breaks such as those which are probably responsible for the exposure of old borer holes at P. Jerkom Besar, (b) falls from the roofs of notches such as were seen in some of the more wave-exposed situations at Langkawi (P. Balar and Tanjong Ayer), (c) collapse of the upper notch as seen at Semporna and Langkawi, e.g. P. Bumbon Kechil (fig. 9), (d) possibly even larger falls involving whole hillsides. That the second process, corrosion of the rock surface, is at least as important in shaping the coast line is evident from the continuity of notches and their remarkable uniformity along a great part of the shoreline.

It is sometimes loosely stated that limestone is eroded by water movement, whether fresh or salt, but water by itself does not erode (except where there is sufficient hydraulic force). Rock may be eroded by abrasive tools, sand or stones, carried by water—corrosion. These tools are conspicuously absent on most limestone shores at Langkawi, and where there is sand, at Tanjong Batu Kulat, exposed rock surfaces are smooth, rounded and polished, quite unlike the rock elsewhere. At Semporna the surface of the notch is pitted and sharp throughout and there is no evidence of abrasion by the fine calcareous sand or stones which sometimes lie on the lower slope.

Corrosion of limestone by fresh water is attributed to surface solution by dissolved acids derived from the air or soil. It has been postulated that a similar process takes place on shore rock, despite the alkalinity of sea water and its supersaturation with calcium carbonate. It is argued that the film of water on the rock has different properties from those of the general water body and may be corrosive. This may well be true, but water can only corrode if it is actually in contact with the rock surface. However, contrary to what at first sight appears to be the case, sea water is not generally in contact with the intertidal limestone of these shores. It is in contact with an algal film which coats the rock.

#### The role of plants and animals

Epilithic algae, particularly encrusting coralline algae, are often evident on rocky shores and sometimes form massive growths. However they do not survive prolonged drying and are poorly developed above MLWS on both of the shores studied. A variety of green and blue-green algae also occur patchily above this level. Endolithic algae are present over the entire vertical range of the tides and into the splash zone where there are waves. The whole rock surface is penetrated by them, and this is as true of hard crystalline rock at Langkawi as of more porous coral rock, or dune rock. The algae are best seen in coral rock where they show as green, pink, or purple discolouration in the surface varying in depth from 0.2 mm to 2.0 mm. That this is a dense felt of matted algal filaments is at once evident if a small slice of rock is slowly dissolved in acid. When solution is complete a "felt" remains which retains the form of the original rock slice; the network is dense and filaments penetrate to a much greater depth than is visible in the slice. Algae can also be seen penetrating the crystalline rock and show as a thin green layer up to 0.5 mm thick in pale rock.

In both rock types further dramatic evidence of penetration by algae is afforded by the observation that the surface layer is browsed by molluscs. In many places radula marks can be seen over the whole rock surface (fig. 17), they penetrate the algal felt and the browsing molluscs remove both algae and rock particles embedded in it. Rock particles form the bulk of fecal pellets passed by such molluscs. This surface layer is soft to a depth of about 0.2 mm and is readily scraped off by a much softer tool than the hard, chitinous, radula teeth. It must be emphasised that this is not just a superficial film of algae, it is the outermost layer of rock from which cementing material has been dissolved.

Samples of rock from the two localities showed a considerable variety of algae and among them the known endolithic forms *Hyella caespitosa* Born. and Flah. (Cyanophyceae, Pleurocapsales), *Entophysalis* (Cyanophyceae, Chroococcales), and *Gomontia*-like bodies (Chlorophyceae, Chaetophorales). *Melobesia* and other coral-line encrusting forms were common at the lower levels.

In all well formed notches at Langkawi there is an abundance of boring animals in the rock face, of which the most important are the sponge *Cliona*, the bivalves *Lithophaga lima* Lamy and *Gastrochaena cuneiformis* Spengler, and unidentified sipunculid and polychaete worms (fig. 18). These riddle the surface of the rock nearly to MHWN beneath the coating of barnacles and oysters. They were noticeably absent from the open rock face at Tanjong Chawat above about MLWN. In coral rock at Semporna only *Cliona* was common on the lower slope, though small numbers of the other borers were also found, including *Lithophaga lima*, *L. lithura* Pilsbury, *L. malaccana* (Reeve), *L. nasuta* (Phil.), and *Gastrochaena cuneiformis*. Even *Cliona* was not common in samples from the back of the notch and was absent from the upper slope.

Thus there is a continuous coat of endolithic algae over the greater part of the tidal range, and into the splash zone, and an abundance of boring animals at lower levels which riddle the rock surface to a depth of several centimeters. It is concluded that intertidal erosion of these limestones is primarily biological and that this 'bio-erosion' is particularly rapid on notched shores.

Ginsberg (1953) has similarly shown the important part played by boring algae and a variety of animals in erosion of the Florida Keys (coral rock and beach rock). He also states that "surficial induration which accompanies erosion produces a spongework of rock which is more resistant than the original limestone". This may well be true also at Semporna, particularly in the upper limb of the notch, but it can be of no significance in the dense Palaeozoic rock of Langkawi.

The precise nature of the boring mechanisms is outside the scope of the present study. Warburton (1958) concluded that boring by *Cliona* was mainly mechanical, Yonge (1963) has reviewed the subject with special reference to bivalve borers, but little seems to be known about how algae penetrate rock. The part that molluscs and other browsing animals take in the process also requires investigation. They undoubtedly keep the algal "turf" closely cropped and remove considerable quantities of loose rock particles with it, and this may well influence the rate of penetration by algae. This is analogous to the part which Neuman (1966) suggests the echinoid *Lytechinus* performs in sublittoral erosion in Bermuda.

Mollusc browsing results in characteristic features of the rock surface. This is true particularly of browsing chitons; their method of feeding produces the parallel



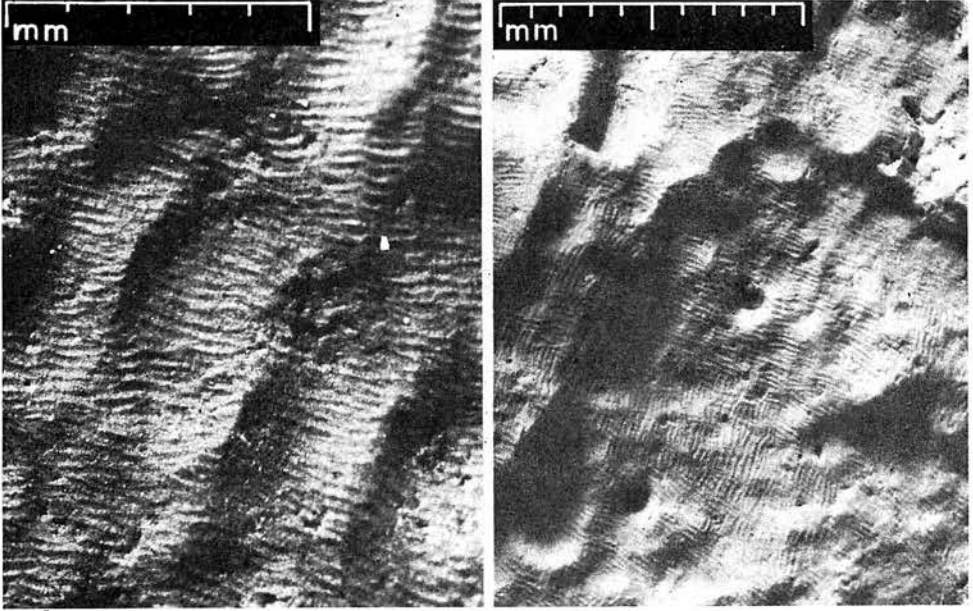


Fig. 17. Coral rock showing chiton radula marks and furrows. Bum Bum Island, Semporna.

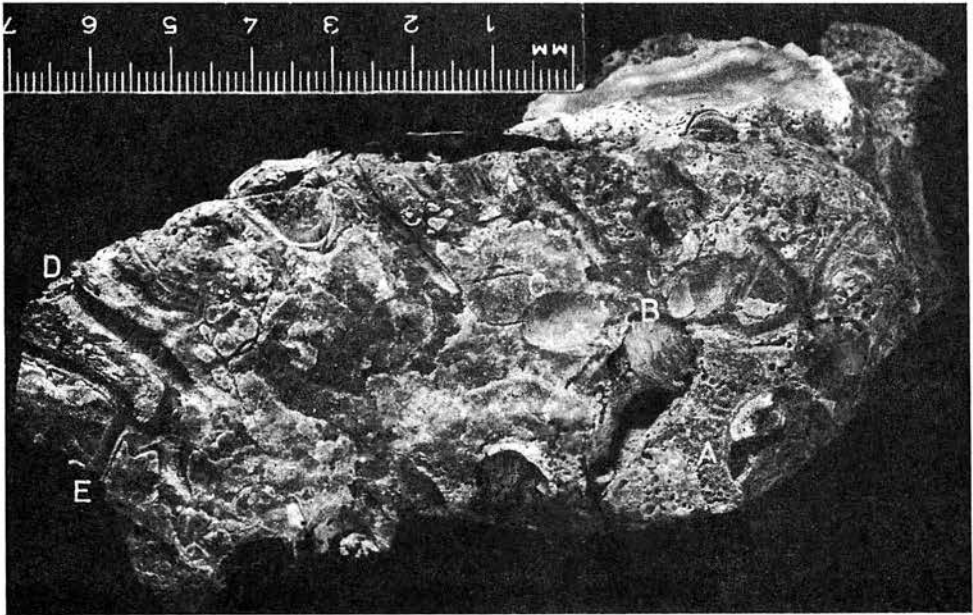


Fig. 18. Intertidal rock from Tanjong Batu Kulat, Langkawi. Boring by: A. *Cliona*, B. *Gastrochaena*, C. *Lithophaga* D. and E. probably caused by sipunculid and polychaete worms respectively.

furrows traversed by radula scratches shown in fig. 17. On a larger scale they form smooth, flat areas in the deeply pitted coral rock and they also form the shallow scalloping noted in the upper notch at Langkawi, oval depressions about 60 cm in length. These are presumably the "shallow rounded hollows worn into the rock by the clinging mollusc *Chiton*" noted by Jones (in manuscript, p. 245). It is probable that the much deeper hollows noted in white marble at Tanjong Tirai and Pulau Balar have been formed in the same way, their greater depth being associated with the deeper penetration by endolithic algae. The very rough surface of the more porous coral rock at Semporna may also be indirectly the result of differential browsing by molluscs. Ginsberg (1953) suggests that the characteristic irregular projections on similar rock surfaces of the Florida Keys may result from more rapid drying making them less habitable to boring algae than in the depressions.

### The zonation of bioerosion

If it is accepted that intertidal erosion on these shores is largely biological then the characteristic shore forms described here require a biological interpretation. In particular, the form of the notches needs to be explained and also the apparent anomaly that the notches at Semporna and Langkawi have essentially the same form and dimension, relative to tide range, despite the different rock type and different rock boring organisms, at least within the neap tide range where erosion appears to be most rapid. The similarity of form extends to dune rock too, in a different climatic zone, as noted above.

At this stage only hypotheses can be offered as the basis for further observation and experiment. It is well known that plants and animals of rocky shores display a vertical zonation relative to tide levels, that amplitude of the zones increases with exposure to wave action, and that the composition of the fauna and flora also differs as between sheltered and exposed shores (see e.g. Southward, 1958). Purchon and Enoch (1954), and Berry (1964) have described zonation on rocky shores in Singapore and Penang respectively. Further, marine animals are very sensitive to heating and drying and it is to be expected that both zonation and composition of fauna and flora will differ between rock surfaces exposed to the sun and those in shade, and possibly also as between porous and non-porous rocks.

It is to be expected that boring organisms will also be zoned and that their abundance and rate of erosive action will vary with level in the intertidal zone and consequent duration of submergence and emergence. This is obviously true of boring animals at Langkawi. A superficial examination of the endolithic algae indicates the same may be true of these also. Moreover encrusting coralline algae tend to replace endolithic algae at lower levels, coating the rock with a protective layer. What is required now is an assessment of the relative importance of the various erosive processes and some measure of rate of erosion throughout the intertidal zone in the different rock types.

Verstappen (1960) estimated the rate of notch formation in a coral boulder thrown on a moderately exposed coast of the Sunda Straits by the Krakatoa eruption at 5 mm a year, equivalent to 5 m per 1,000 years. However even this is not fast enough to account for formation of shore platforms 100 m wide during the Holocene by the "sawing" action of the sea cutting notches, as postulated by Kuenen (1933) and others. Hodgkin (1964) measured the rate of erosion in dune rock near Perth, Western Australia (32°S) and found a maximum rate of 1 mm a year, in the back of the notch. Here again platforms are up to 100 m wide. In the upper notch,

erosion was at a rate of only 0.02 mm a year. Differential rates can explain the form of the upper notch, but with continued activity of borers below low water it is difficult to understand why gross erosion apparently ceases or slows greatly at the level of permanent wetting, to leave wide shore platforms in Quaternary rocks.

#### Evidence of former sea levels

The characteristic erosional forms described here can provide clear evidence of former sea levels if they are well preserved and can be differentiated from similar freshwater erosional forms. Verstappen (1960) attributes the high level notches he describes on the coasts of Celebes and Moluccas to active uplift of the land. Most of the horizontal "nips", "grooves", or "undercuts" described in Malaysian limestone by Wilford (1964), Paton (1964), and Jones (1965) are of freshwater origin, but some are remarkably similar in form to marine notches and it would be difficult to be certain of their origin on form alone.

Wilford suggests that some grooves in the Niah caves, Sarawak, may be marine in origin; they are 120 to 140 feet above present sea level. Paton (1964) discusses the origin of the grooves in limestone hills of northern Malaya and suggests that one at Bukit Koplu (now spelled Kepelu), Kedah (his Plate 5) may be of marine origin. Jones (1965) attributes some of the undercuts in Perlis and north Kedah hills to a marine origin; "when the sea was raised to around 20 feet above its present-day level during the latter phases of the Quaternary Period" (p. 27). Those at Bukit Kodiang do not have the regularity of form of marine notches at Langkawi and in the view of the present writer are unlikely to be of marine origin. Jones also illustrates the groove at Bukit Kaplu (Kepelu) (his Plate 3) and ascribes a marine origin to it. This is certainly very similar to the Langkawi notches, except that the lower slope is noticeably steeper; nevertheless its height is significantly less, implying a spring tide range at the time of its formation of not more than about 1.5 m.

At Langkawi a number of cliffs show notch-like features above MHWS, as described and figured above (figs. 10 & 15) and these could be interpreted as notches in an early age of formation. They are very similar to raised notches illustrated by Verstappen (1960), in coral rock. However they also resemble some cave walls illustrated by Wilford (1964), especially his Plate 26. Further evidence of their origin is needed.

Possibly more reliable evidence of higher sea levels is afforded by marine borer holes in rock above the level at which the animals now live. Borer holes are described above as being found at about two meters above where there are now living animals at Langkawi. Jones (personal communication) has found borer holes and shell deposits at about 7 meters above sea level where limestone overlies siltstones at Kuala Kubang Badak on the north coast of Pulau Langkawi. At Gunong Keriang (5 miles north of Alor Star, Kedah) recent quarrying has obscured most of a nip at the foot of a cliff on the west side of the hill and the parts which could be examined do not have the form of marine notches. However some rock at the base of the nip is riddled with holes which show the characteristic form of boring by marine bivalves and to a lesser extent by sponge. This is at the level of the coastal plain. The rock is still remarkably fresh though not as clean as the Langkawi examples.

The masses of old oyster shells well above the level of living animals, seen at Langkawi, may also be evidence of former higher sea levels. Likewise the characteristic chiton type of erosion noted in association with some of the high level borer holes.



No evidence of higher sea levels was seen at Semporna, other than the general level of the top of the coral rock itself. From air photographs this appears to change abruptly in places, particularly on Larapan Island. However Kirk's Plate 25 of the highest cliff on Selangan Island (19 feet above high tide level) does not show evidence of a higher 'notch'. There are believed to have been Quaternary tectonic movements in the area which Wilford (1967, 1968) says probably continued into recent times.

#### Examples of similar shore erosion elsewhere in Malaya

On Bangi and Balembang islands at the northern tip of Sabah, hard limestone of Eocene-Pliocene age is eroded into notches at sea level. Wilson (quoted by Wilford, 1964) described some of these as parabolic, but modified by the irregular bedding. Haile and Wong (1965) describe and figure intertidal limestone on the south side of Sandakan Bay. Although this displays curious erosional forms the beds are probably not thick enough for development of notches.

Notch-like erosion is seen at Tanjong Lobang near Miri, Sarawak in sandstone of the Miri Formation: "a bed of soft clayey sandstone" (Wilford, 1964). The intertidal rock is riddled with borings of bivalve molluscs, though few live animals could be found during a brief visit to the north side where there appears to be incipient notching and an irregular platform at probably about MSL. The borers seen were all *Gastrochaena* which probably bores mechanically, unlike *Lithophaga* spp. which bore by means of an acid secretion. Soft sandstone of the Kulapis Formation (Upper Miocene to Pliocene) exposed on islands in Sandakan harbour also shows similar intertidal erosion (Haile and Wong, 1965, Plate 6). A massive rock on

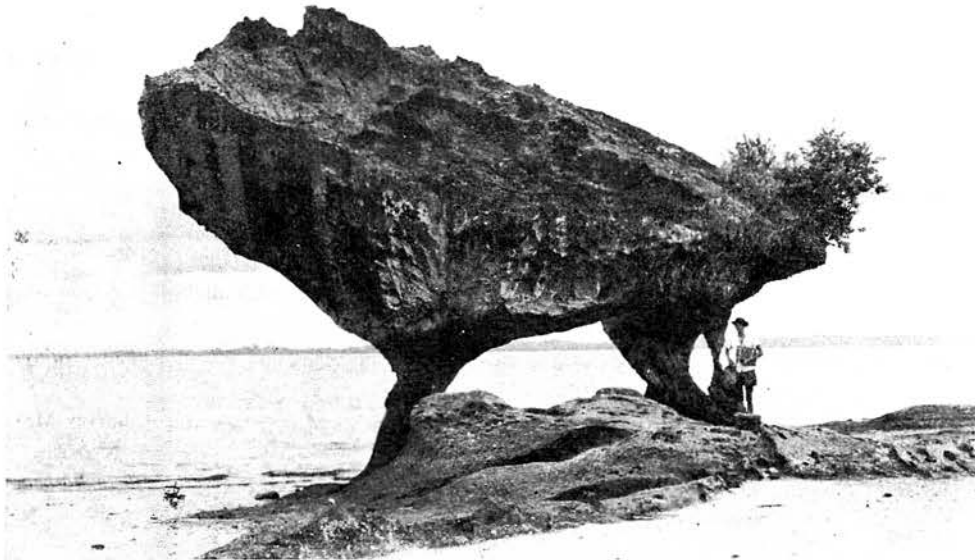


Fig. 19. "Tripod Rock", sandstone. Sandakan, Sabah.

three small "legs" appears in tourist photographs (fig. 19). These features are on platforms a foot or two above low water, the rock of which again appears to be riddled with small holes.

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