THE STRUCTURE AND DEVELOPMENT OF THE PEAT SWAMPS OF SARAWAK AND BRUNEI

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PEAT SWAMPS cover extensive areas in the humid tropics and have been recorded from the three main rainforest regions of the world: South-east Asia, tropical America and tropical Africa. In his comprehensive survey of the tropical rainforest, Richards (1) summarizes the available information on the vegetation and nature of peat swamps. Possibly the first person to discover peat in the humid tropics was Beccari (2), but the significance of these deposits was not realized until Potonie and Koorders (3) drew attention to the deep peat of Sumatra. In their paper, and in Tenison-Woods' description of Bornean peats (4), the emphasis is on the tropical origins of coal.

Fundamental studies of peats were made by Polak (5, 6, 7), who recognized two types, the ombrogenous and the topogenous. The first, developed in areas of high rainfall, are analogous to the raised bogs or *hochmoore* of temperate climates. Such formations are often lenticular in shape, with a bleached clay foundation; blackwater streams draining the peat are very acid, with pH values around 3.0 These soils are extremely oligotrophic. Topogenous peats usually evolve at high altitudes as well as along lakes and rivers at low altitudes; they are normally acid rather than alkaline, and therefore not directly equivalent to temperate fen peats. Richards (1) and van Steenis (8) state that topogenous peats cover greater areas than ombrogenous peats, but no comparative data are available. Recently Coulter (9, 10) has studied peat swamps in Malaya to assess their agricultural potential. He estimates that peat covers nearly two million acres in Malaya. Most formations there are relatively shallow, depths exceeding 18 feet being rare, and convex-surfaced formations are not highly developed. For Sarawak, accounts of peat swamps are given by Browne (11) in his book on the forest trees of Sarawak and Brunei; by the author (12, 13), and in the Annual Reports of the Forest Department (14, 15).

TERMINOLOGY

Subcommission 6 of the Second International Congress of Soil Science held in Russia in 1930 recommended that the term 'peat' be restricted to organic soils that are at least 0.5 metres (1.64 ft.) deep, one hectare (2.47 acres) in area, and ~~and Brunei; by the author (12, 13), and in~~ the Annual Reports of the Forest) with a maximum mineral matter content of 35 per cent. Where the mineral matter exceeds 35 per cent but does not exceed 65 per cent the soil is defined as 'muck'.

Peats and mucks may develop in freshwater or peat swamps. However, van Steenis' (8) definitions of freshwater swamp forest as developed on mineral or non-mineral soils and tolerant of climate, and of peat swamp forest as developed on peat and restricted to an ombrogenous climate are too imprecise to be satisfactory. On the basis of his studies in Malaya, Coulter (10) suggested the following classification of peats: (i) eutrophic peats, largely derived from marsh and grass, which have much mineral matter and are neutral or alkaline in reaction; these are basically the fen peats of the temperate zone and do not occur in Malaya or Borneo; (ii) oligotrophic peats, low in mineral content, especially in calcium, and acid in reaction; and (iii) a mesotrophic group, intermediate between the first two types, with a pH of about 5.0 and a rather high level of bases. Coulter proposed that Malayan peats and mucks be termed 'bog soils', which may be convenient pedologically, but is ecologically confusing since it includes the freshwater and peat swamp habitats in a single group. The present writer's work indicates that the most important factors differentiating these two habitats are the surface structure of the swamp and the degree of flooding, which determine swamp drainage, and the mineral content of their soils (as determined by the percentage loss on ignition). The following terminology is proposed: (i) freshwater swamp, which is regularly or occasionally flooded, has peat or muck soils with pH values generally higher than 4.0, a loss on ignition below 75 per cent, and level or barely convex surfaces; (ii) peat swamp, which is not subject to flooding, has a peat soil with a pH value of less than 4.0, a loss on ignition above 75 per cent, and a markedly convex surface. Freshwater swamp may be oligotrophic, but more commonly approaches the mesotrophic group of Coulter, whereas peat swamp is always oligotrophic.

In Sarawak and Brunei, freshwater swamps are largely topogenous, forming along rivers where flooding is prevalent in the wet season. By comparison with peat swamps, they cover a negligible area. The margins of peat swamps, where flooding occurs, and where the soils have a relatively high mineral content may be considered as freshwater swamp. Similarly, a freshwater swamp in which the accumulation of organic matter has raised the soil above flood levels becomes a peat swamp.

CHARACTERISTICS OF THE PEAT SWAMPS OF SARAWAK AND BRUNEI

In Sarawak, peat swamps cover 5,660 square miles, or 12 per cent of its total area. The total area of peat swamps, as computed from the Land Use Map (16) is shown for each administrative division in Table 1:—

TABLE 1: SARAWAK: AREA OF PEAT SWAMPS, IN SQUARE MILES

1st Division	2nd Division	3rd Division	4th Division	5th Division	Total
576	1,072	2,322	1,624	66	5,660

In Brunei, the area of peat swamp is 380 square miles, representing 22.6 per cent of the area of that State. The distribution of peat swamps in both territories is shown in Figure 1.

The coastal and deltaic peat swamps of Sarawak and Brunei have convex surfaces and are markedly oligotrophic. Five swamps in the Rajang delta were surveyed by the writer using a precise level and measuring peat depths with an extensible auger. The profiles obtained are shown in the upper part of Figure 2, where the vertical scale is 6.6 times exaggerated; the datum lines through the profiles indicate the levels of high tides or of river floods at the perimeter of the swamps. The convexity of the swamp surfaces becomes more pronounced with distance from the sea; on the island of Pulau Bruit at the coast, the maximum height of the swamp surface is 12.96 feet and the surface gradient is relatively gentle on both sides of the island. Maximum heights in the Daro Forest Reserve and along the two traverses in the Loba Kabang Protected Forest were 13.13, 15.40 and 13.13 feet respectively. Gradients in these swamps are steeper in the first 100 chains from their margins than at their centres, where the rise is only 1 - 1½ feet per mile. The swamp surface is like that of an inverted saucer, with an almost flat bog plain at the centre. The most remarkable profile is that from the Naman Forest Reserve upriver from the apex of the Rajang delta, and almost certainly the oldest

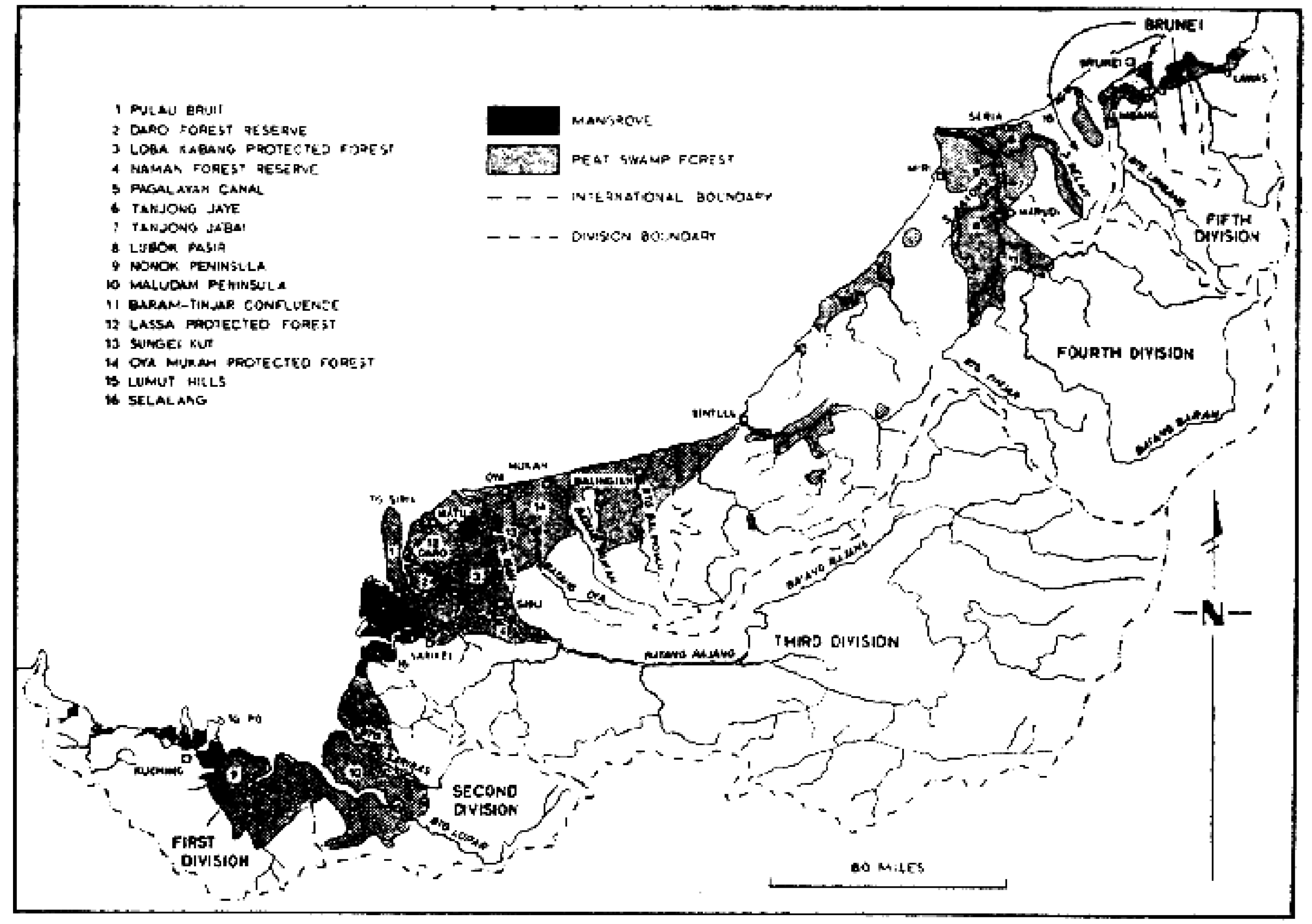

Fig. 1. Distribution of mangrove and peat swamp forest in Sarawak and Brunei.

of the surveyed swamps; here the rise in the first mile is 22.5 feet, and the maximum height at the centre of the swamp is 30.4 feet. Three minor hillocks encountered in the survey are literally being swamped by the gradual accretion of peat.

Greater depths of peat are more likely to be found in inland than in coastal swamps; on Pulau Bruit the maximum depth is 21 ft. 9 ins., whereas the subsoil was not reached with a 50-foot auger in the Naman Forest Reserve. In individual swamps, however, the subsoil surface is frequently irregular and greater depths of peat do not necessarily occur in the centre of the swamps. Thus in the Naman Forest Reserve maximum depths were found at 20 and 100 chains from the swamp margin, while the peat depth in the centre of the swamp was only 43 feet. The subsoil is almost invariably a stiff white or yellow clay, probably of mangrove origin.

Peat swamps of the Baram river are shown in the lower part of Figure 2; the profile of the swamp near the Pagalayan Canal was prepared by the Geological Survey Department and shows in greater detail the nature of the subsoil underneath the peat. At Tanjong Jaye there is a sharp gradient in the first ten chains and an almost flat bog plain thereafter. Levels at Tanjong Jabai show a different pattern; for the first 20 chains there is no pronounced rise and the peat is comparatively shallow. Aerial photographs show clearly that the margins of the swamp were eroded by a former meander of the Baram river, and that following the silting and abandonment of this meander, peat accretion began again. The Lubok Pasir swamp, further upstream near Marudi, has the steepest gradient recorded for any of the swamps surveyed: in the first 5, 10 and 30 chains, heights above the datum of 13.75, 16.25 and 22.5 feet respectively were recorded; towards

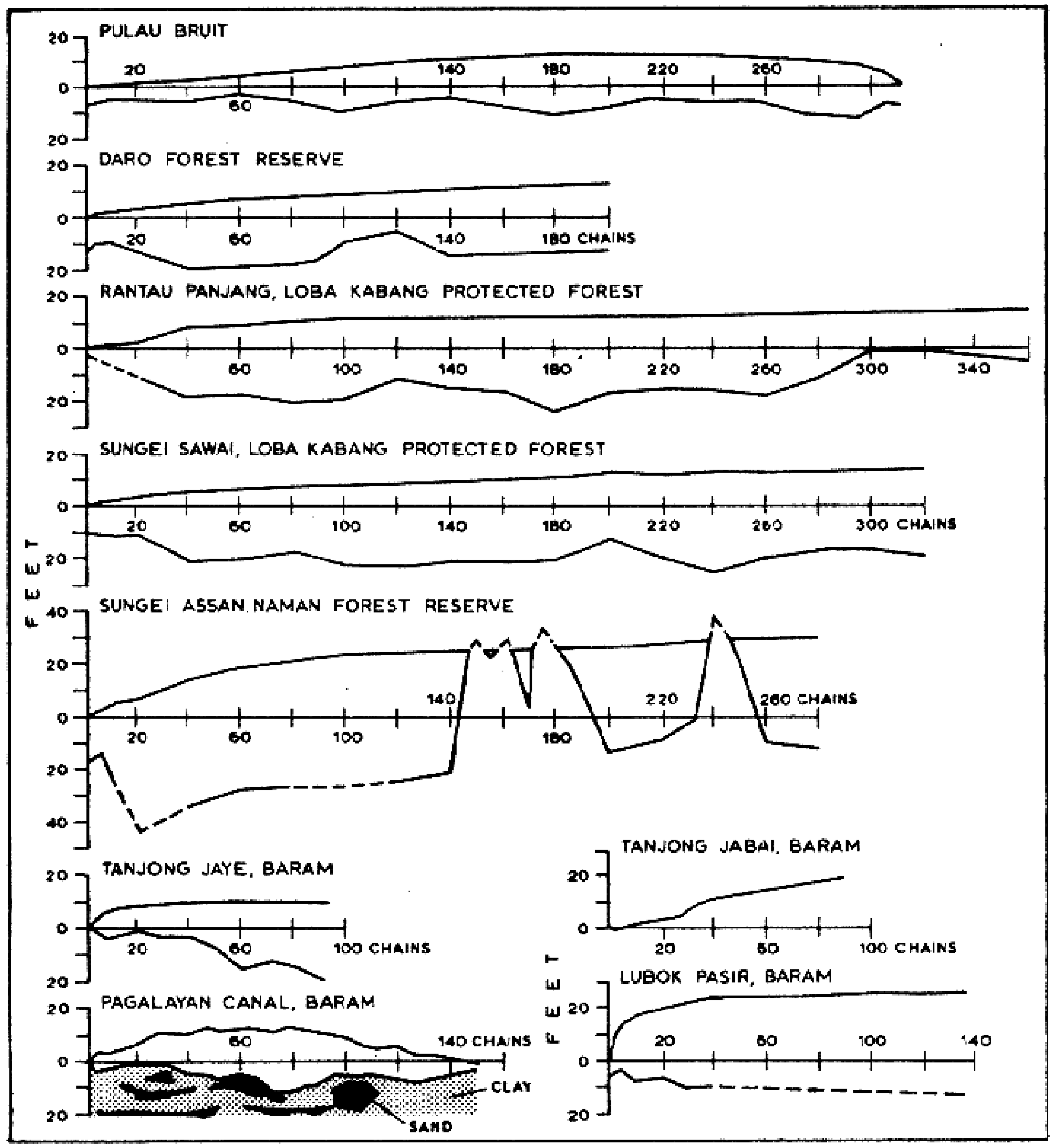

Fig. 2. Peat profiles in the Rajang delta and Baram river.

the swamp centre, the surface levels off to an almost flat bog plain. The greatest depth of peat recorded in the Baram swamps was 39 feet, found at the centre of the Lubok Pasir swamp. Subsoil levels are generally below the datum, but not as low as in the Rajang delta profiles.

Further light on the surfaces of swamps is derived from extensive level surveys across swamps from the Rajang delta to Lawas carried out by seismic parties of the Sarawak Shell Oilfields and Brunei Shell Petroleum Companies. These surveys are correlated with mean sea level, allowing accurate comparisons of swamp levels in different localities. Again, doming is more pronounced in the swamps further inland; in the centre of two swamps up the Baram river, maximum heights of 48 ft. 5 ins. and 45 ft. 7 ins. were recorded, whereas near the coast maximum

heights were only 22 ft. 9 ins. and 15 ft. 8 ins. It is interesting to note that the perimeters of inland swamps along the banks of streams are 16.4 - 19.7 feet above sea level, while the margins of coastal swamps are only 6.5 - 9.8 feet above sea level.

Three further swamp areas were surveyed by Sir Bruce White, Wolfe Barry and Partners in 1954-56 (17, 18, 19), in order to assess their suitability for padi cultivation. The swamp on the Nonok peninsula near Kuching has generally a uniform slope, the typical domed surface developing only near the inland margin. The large peat swamp in the Maludam peninsula between the Saribas and Batang Lupar rivers covers some 260 square miles and was traversed towards its seaward end along two lines of levels, 17.1 and 15.6 miles long. A bog plain was found to extend 9.5 and 6.8 miles along the two transects, with variations in height of less than 2.7 feet, except where the Maludam river forms a re-entrant. The third swamp, at the confluence of the Tinjar and Baram rivers upstream from Marudi, has a highly developed domed surface except in its southern portions where a flat bog plain occurs. The centre of the swamp reaches a maximum height of more than 60 feet above the arbitrary datum on the river bank. Two principal streams draining the swamp, the Sungei Majau and the Peking, form pronounced re-entrants into the peat formation. Unfortunately peat depths greater than 20 feet were not measured so it is not possible to compare structures here with those already described.

The domed surfaces of these peat swamps reduce the extent of flooding. Although precise data are lacking, tidal and river gauge observations made by the above-mentioned irrigation engineers show maximum river levels of 7.43, 10.68 and 11.2 feet above mean sea level at the Nonok and Maludam peninsulas and the Baram-Tinjar confluence respectively. When these levels are related to contoured maps and level surveys, the limit of maximum flooding in the Nonok swamp is seen to be less than half a mile from the margin; in the Maludam peninsula, flooding up to one mile may occur locally, but probably at spring tides only, while the steep doming of the swamp surface in the Baram-Tinjar area probably restricts flooding to less than a quarter of a mile except along streams. The degree of flooding is important when the development and agricultural potential of peat swamps are considered. Marginal floods deposit silt, forming an alluvial soil on river banks which grades into muck soil where flooding is less frequent. The distribution of soil types therefore indicates to some extent the degree of flooding. Wilford (20) notes that the alluvial strip along the Baram river is usually between 100 and 1,000 feet wide.

However, the watertable lies close to the swamp surface, even in highly domed bogs, and in the wet season it may be above the swamp surface, especially near the margins of swamps. The watertable itself was taken as the swamp surface in level transect No. 3 in the Rajang delta (Fig. 2) and in all subsequent surveys in the Baram. Variations in the watertable along Line No. 3 in the Loba Kabang Protected Forest (Fig. 2) were measured from April to October 1954 using graduated stakes. These measurements show that the smallest variation in height, 3.7 - 4.2 inches, occurs near the perimeter, gradually increasing to 7.5 ins. towards the centre of the swamp. Although the full annual height variation is not available since measurements were not made during the wet season, it is probable that the minimum variation observed near the swamp periphery reflects the high surface gradient and rapid runoff. In periods of comparative drought, the watertable at the periphery is maintained by a lowering of the watertable in the central zone.

The converse operates for the centre of the swamp, but further observations in a swamp in the Baram do not support this view entirely and the problem needs further study.

Swamp drainage is entirely at or close to the surface, since the heavily compacted masses of woody peat and the saucer-shaped alluvial subsoils probably prevent lateral drainage. The presence of undecomposed or semi-decomposed woody material at all levels in a peat swamp indicates complete stagnation of drainage. Excess water on the surface collects in minor depressions which tend to coalesce to form rivulets, and finally it drains to larger streams which may form marked depressions in the swamp surface and re-entrants into the bog plain. These streams of dark tea-coloured water provide channels through the larger swamps that are navigable by boats fitted with outboard engines.

Physically these peats are similar to the Malayan formations, consisting of a heavily compacted mass of semi-decomposed woody material. Roots and tree stumps are particularly abundant, but branches and trunks are also common. The centres of large pieces of timber may be quite undecomposed, and these frequently obstruct borings. The peat matrix is dark chocolate-brown in colour, soupy and amorphous; recognizable rootlets, leaves and twigs may be found in various stages of decomposition. The matrix is rich in pollen, and parts of bryophytes may often be identified. The surface peats found in the highly developed central bog plains of the Baram have a different texture, being formed under stunted open vegetation; these are heavily compacted and fibrous, light reddish-brown in colour and with many colourless rootlets. The normal dark fluid matrix is here replaced by a more watery liquid. This peat is more akin to that found in temperate regions.

These studies confirm and elaborate upon Polak's work on the peat swamps of Sumatra and south Borneo. As she points out, the structure of tropical peat swamps is similar to that of raised bogs in the temperate zone, and features of temperate raised bogs such as the lagg, rand and bog plain are repeated in the raised bogs of Borneo. The main differences seem to be the physical nature of the Bornean peats, their immense extent and mode of development.

DEVELOPMENT OF PEAT SWAMPS

The extensive peat swamps of the Rajang delta, Maludam peninsula and the Baram plain overlie a clay subsoil. The clay underneath the peats of the Rajang delta is almost certainly of mangrove origin; the report on the Maludam peninsula (18) states that 'the soil on the river banks is clay and clay underlies the peat deposits in the interior'. This clearly refutes the opinion of Kostermans (21) that peat will only develop on infertile, poorly drained sands; it supports the view of Bramao that reducing conditions, such as occur above clay subsoils associated with waterlogging, are essential (22). There is little evidence from Sarawak to support Wyatt-Smith's original hypothesis that estuarine peat swamps in Malaysia are always associated with coastal sites where a sandbank holds up drainage (22). However, local sandy subsoils have been found in the Baram and Lawas areas, and recent soil surveys report similar subsoils underneath coastal peats in the Mukah-Balingian area (26). The significance of these findings is discussed below.

The initial formation of peat overlying clay is a controversial problem that was discussed at some length in the UNESCO symposium on tropical vegetation (22). Richards supported the view of Mohr (23) that in the lowlands of the humid tropics, a subsoil deficient in bases is as necessary as waterlogging. The fact that in Sarawak and Brunei the alluvium underneath peats originated from generally infertile parent materials from the interior tends to support this hypothesis. However, reports from irrigation engineers (17, 18, 19) indicate that the clay soils below peats may be relatively rich in bases. Mohr and van Baren (24) mention the possible existence of an impediment or poison in the soil flora which might not affect the macroflora; the ecological study carried out by the writer (12, 13) suggests that high sulphur and sodium contents of catclays may be toxic to microbiological activities, but not to the forest flora. It is perhaps significant that the initial accumulation of peat is relatively rapid.

This study also showed that vegetation communities form typical zonal patterns related to swamp structures, so that bogs in different stages of development can be mapped from aerial photographs (13). In addition, a palynological examination of a 42.65-foot core from the centre of a well developed bog at Lubok Pasir in the Baram swamp was undertaken with the cooperation of Mr. J. Muller of the Brunei Shell Petroleum Company. The unpublished results show clearly that the peat swamp there developed over a mangrove clay, and that the horizontal arrangement of vegetation communities represents the natural succession. Samples from cores taken in the same locality were carbon-14 dated by Prof. Hl. de Vries of the University of Groningen in Holland, whose results, shown in Table 2 below, were reported by Wilford (20, 25).

TABLE 2: RESULTS OF CARBON-14 DATING OF SARAWAK PEATS

DEPTH OF SAMPLE (feet)	AGE (years)	DEPTH (feet)	CALCULATED RATES OF PEAT ACCUMULATION (feet per 100 years)
16.40	2,255 ± 60	0.00 — 16.40	0.7271
32.81	3,850 ± 55	16.40 — 32.81	1.0285
39.37	4,270 ± 70	32.81 — 39.37	1.5634

These values show that the rate of peat accumulation decreases towards the surface. For bogs to evolve from the almost perfect convex-topped forms found near the coast, to the flat-topped structures with relatively steep margins typical of advanced bogs, either the rate of accumulation at the margins must increase or the rate of accumulation at the centre must decrease. The meagre evidence of the carbon-datings suggests that the second alternative is the more likely. The rate of accumulation decreases under the more advanced vegetation communities in the succession, hence the gradual flattening of the swamp surface as a bog plain towards the perimeter.

Thus the following phases in the evolution of peat swamps may be distinguished:—

Phase 1: Deposits of alluvium in bays, deltas or sheltered embayments along the coast are colonized by mangrove. With continued deposition further offshore the more inland mangrove is progressively replaced by transitional communities and a shallow peat, overlying mangrove clays, is formed.

Phase 2: With the continued deposition of alluvium on the seaward perimeter the swamps advance replacing mangrove. Consequently as the distance from the sea of the original swamp increases, rivers tend to back up and begin depositing alluvium along their banks, which consequently are raised above the level of the original swamp subsoils. This is how the characteristic saucer-shaped foundations of peat swamps evolve. In this phase peat accretion proceeds rapidly and a shallow lenticular structure develops.

Phase 3: The rate of peat accumulation in the swamp centre falls and a typical flattened bog plain develops, usually occupied by a vegetation community dominated by *Shorea albida.*

Phase 4: This phase has only been found in the Baram and Belait rivers. As the rate of peat accumulation in the bog plain continues to diminish, the plain extends laterally. The radial distribution of vegetation communities tends to become restricted except on the bog plain itself. In this and the preceding phase, more alluvium may be deposited along the rivers as further backing-up of stream flow continues.

These phases may be modified by erosion. In 1961, nearly half a mile of peat swamp collapsed as a result of erosion undermining a levee in a meander of the Baram river. If such meanders are subsequently abandoned and a peat swamp is re-established, a succession of peat-clay/silt-peat may develop, as has been recorded by the seismic parties and by the irrigation engineers at Kuala Tinjar (19). Changes in offshore currents can also erode peats, as on the west coast of Pulau Bruit in the Rajang delta, where seven feet of peat have been exposed.

GEOMORPHOLOGICAL SIGNIFICANCE

This outline of the evolution of peat swamps helps in interpreting the post-glacial history of the Sarawak-Brunei coastline. Wilford (20) has shown from carbon-14 dating that the sea reached its present level 5,400 years ago, when the coastline may have followed the inland margins of the present peat swamps (Fig. 1). Since then, the Baram and Limbang floodplains have been extended seawards at an estimated rate of 30 feet per year. This seaward extension, and that of the associated peat swamps may not have occurred uniformly. The dominantly clay subsoils of the peat swamps indicate faster growth in bays or sheltered localities where offshore currents were slack and deposition faster.

The most developed swamps are found in the Baram upriver from Kuala Bakong. The high land on both sides of the Baram north of Marudi formed the mouth of the large bay which was rapidly filled in 5,400-4,000 years ago. This is suggested by the age of the peat at Lubok Pasir: 4,270 $\pm$ 70 years old (Table 2). When this bay was filled in, a second and larger embayment would have been formed between Miri and the high land east of Seria. It is likely that the coast at Seria then was a long spit of land running from the coast near the Lumut Hills. Evidence for this is provided by the highly developed bog immediately behind the littoral, the only place in the region where a bog dominated by *Shorea albida* occurs close to the coast. This bog must have originated on alluvium deposited 3,000-4,000 years ago. After this embayment had been filled in, changes in the smoothed coastline were small, and the present littoral fringe of marine sand colonized by *Casuarina* indicates relative stability.

In the immediate post-glacial period, the mouth of the Rajang river was close to the site of Sibu town. The wide estuary upriver from Sibu must have been rapidly filled in, as the deepest recorded peats (over 50 feet) occur there in the Naman Forest Reserve. A shallow embayment would then have been formed between the highlands in the Sarikei area and those between the Mukah and Balingian rivers. Here the most highly developed swamps are found in a wide arc running through the Daro Forest Reserve, Lassa Protected Forest, the area south of Sungei Kut, and the Oya Mukah Protected Forest. Outside this arc, the structures of raised bogs in Pulau Bruit, Jemoreng Protected Forest and Matu Daro Protected Forest indicate relatively recent origins. Today the coastline between Tanjong Sirik and Bintulu is smooth, with parallel sandy beaches and offshore bars. Recent peat formation has occurred between the beach lines; a similar development occurs in the Mukah-Balingian area (26), where peats over 10 feet deep correspond closely to clay subsoils. Variations in peat depth of from 2 to 10 feet may occur within a horizontal distance of 300 to 400 feet.

The large peat swamps in the First Division and those between the Batang Lupar and Saribas rivers probably evolved fairly uniformly within the sheltered embayment between Tanjong Po and the high ground near Selalang. It is only in this region, especially in the Maludam and Nonok peninsulas, that the rapid seaward progression of mangroves on coastal silts or clays, followed by peat swamp, is taking place along the open sea coast today.

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