TROPICAL DELTAS OF SOUTHEAST ASIA—SEDIMENTOLOGY, STRATIGRAPHY, AND PETROLEUM GEOLOGY

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LATE QUATERNARY SEDIMENTATION AND PEAT DEVELOPMENT IN THE RAJANG RIVER DELTA, SARAWAK, EAST MALAYSIA

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Abstract: Thick, domed peat deposits dominate most of the surface of the mesotidal to macrotidal Rajang River delta, tidally influenced alluvial valley, and adjacent coastal plain. Northeast-striking shoreline terrace sands that crop out along the landward margin of the delta and coastal plain and gravel outcrops in the alluvial valley are the surface expression of the VIIa highstand surface of 125 ka (oxygen isotope stage 5e). The upper few meters of the VIIa surface have undergone podzolization, are leached white, and are easily mapped. Near the present coast a peat/lignite bed, at a depth of 80 m, represents the IIIb highstand surface (oxygen isotope stage 3), indicating that 40 m of subsidence has occurred in the last 40 ka. In the alluvial valley, gravel dominates the base of an incised-valley fill 10 km wide and 45 m thick and is overlain by a fining-upward succession, the upper part of which is tidally influenced. Eroded Pleistocene terraces, mantled with thick peat, flank the Recent incised-valley fill. Within interfluve areas in the landward one-half of the northeast delta plain and adjacent coastal plain, thick Recent peat deposits (> 10 m) rest directly on or within a few meters of the buried remains of Pleistocene sediments. These peat deposits began accumulating between 7.3 and 5.8 ka as the rate of sea-level rise slowed. Recent siliciclastic sediments laterally adjacent to these peat deposits are composed of tidally influenced sands, silts, and clays. The seaward one-half of the northeast delta plain, delta front, and prodelta are composed of a seaward-thickening wedge of siliciclastic sediment up to 40 m thick that has accumulated in the last 5 ka. The base of the wedge is marked by a gravel lag that immediately overlies a rooted, yellow-brown alluvial soil. Siliciclastic sediments in this wedge consist of delta-front and prodelta clays and silts, delta-front distributary-mouth sands, and shoreline sands. Young (< 5 ka), reduced-thickness (< 10 m) peat deposits lie conformably on top of this wedge in this part of the delta plain. In contrast, the southwest part of the delta plain is not underlain by shallow-depth Pleistocene sediments, and it started to prograde into the South China Sea prior to 7 ka; its surface is dominated by beach ridges and gley soils mantled by mangrove–*Nipa* vegetation.

INTRODUCTION

In Southeast Asia and the Malay Archipelago many delta systems (e.g., Baram, Fly, Hari, Irrawaddy, Klang-Langat, Mahakam, Mekong, and Rajang) occur, but only a few of these are reported to contain extensive, thick (> 10 m), low-ash (< 5%) autochthonous peat deposits (Baram, Hari, Klang-Langat, Rajang). All of these peat-accumulating deltas are reported to be prograding into their depositional basins with shoreline accretion rates on the order of 10 m/yr. Many differences exist, however, between these peat-accumulating deltaic depositional systems. The most significant differences between these systems are peat thickness and age, indicating that system response to Late Pleistocene–Holocene sea-level rise has not been similar in all systems. In the Baram, Hari, and Klang-Langat the maximum reported peat thickness is on the order of 10 m and maximum peat age is 4.5 ka (Anderson, 1964; Coleman et al., 1970; Esterle, 1990). In the Rajang system maximum reported peat thickness is on the order of 20 m and maximum peat age is 7.3 ka (Anderson, 1964; Staub and Esterle, 1993, 1994).

What causative factors in the Rajang system resulted in peat deposits that are up to twice as thick and 3 ka older than other deltaic peat deposits in the region? This paper examines the Late Quaternary sediments in the Rajang in an effort to determine facies associations and developmental history and to ascertain what factors led to the early formation and spatial distribution of its peat deposits.

PHYSIOGRAPHIC SETTING, CLIMATE, AND PREVIOUS WORK

The Rajang River (Fig. 1) is the largest river in Sarawak and drains part of the Central Borneo Massif. Cretaceous to Eocene sediments dominate the massif; these rocks are accretionary complexes and forearc basin deposits that formed during the Tertiary opening and spreading of the South China Sea (Hamilton, 1979; Hutchison, 1989, 1996). In the Rajang River drainage basin, rock types are composed principally of folded and faulted siliciclastics with minor amounts of carbonates. Additionally, igneous intrusive and extrusive rocks are present, and many sedimentary rocks have been metamorphosed (Lam 1988).

The Rajang River drainage basin is about 50,000 km^2 in size, and elevations exceed 2,000 m. Hill slopes are steep and flood plains are of limited area. Soils are poorly developed and represent the mineral composition of the parent materials (Scott, 1985; McBeth, 1995). The Rajang River delta also receives discharge and sediment from the proximal hills region (Fig. 1) to the immediate south of the Rajang distributary. Four large rivers traverse the coastal plain to the east of the delta plain (Fig. 2). Their drainage basins average about 3,000 km^2 in size, and rock types and soils present are similar to those of the Rajang River drainage basin. The physiographic separation between the delta plain and the coastal plain occurs at the midpoint between the Igan distributary of the Rajang River and the Oya River of the adjacent coastal plain (Fig. 2). The coastal plain extends eastward from this point to the approximate position of Kuala Bintulu.

The Rajang River delta plain (Fig. 3) covers 6,500 km^2, and peat greater than 3 m thick (Fig. 2) covers about 50% of the delta-plain surface, with laterally extensive deposits common to the northeast of the town of Daro. The surfaces of most peat deposits are domed or raised (Fig. 3). The surfaces of the domed peat deposits in the delta plain are as much as 4 to 6 m higher than spring high-tide levels, with elevation differences increasing inland from the coast. Maximum peat thickness is 15 m. To the east the adjacent coastal plain is 4,500 km^2 in area (Fig. 2), and about 80% of the surface is mantled by peat greater than 3 m thick.

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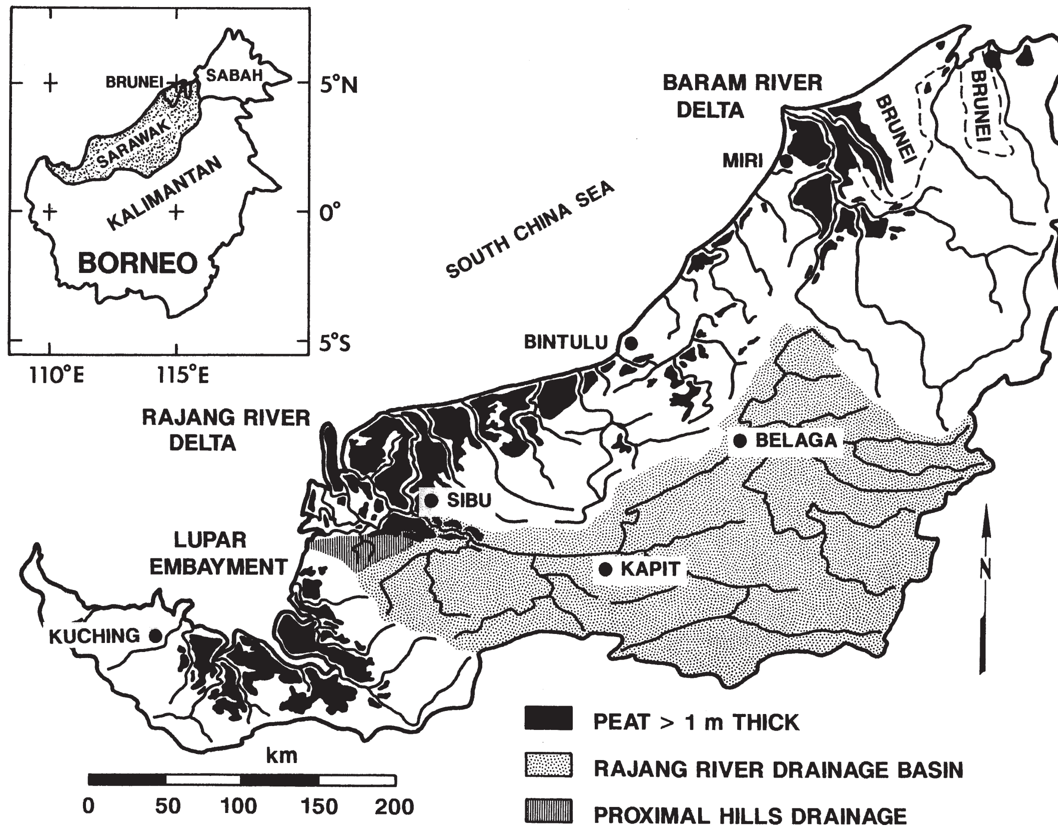

FIG. 1.—Map of Sarawak, East Malaysia, showing the locations of the major peat-forming regions and all peat deposits greater than 1 m thick (from Staub et al., 2000). The location of the Rajang River delta, the drainage basin of the Rajang River, and the proximal hills drainage that is adjacent to the delta are shown.

These coastal-plain peat deposits are also domed and are up to 15 m thick, and their domed surfaces are up to 7 m higher than the adjacent river channels during flood events. The alluvial valley is located between the towns of Sibu and Kanowit (Fig. 3). It covers 400 km^2, and maximum reported peat thickness is in excess of 20 m (Anderson, 1964; Scott, 1985). Peat greater than 3 m thick covers about 75% of the surface area (Fig. 2), and elevation differences between the surfaces of the raised peat deposits and the water level in the Rajang River are as much as 9 m at spring high tide.

Tides along the Sarawak coast (Fig. 1) increase from less than 1 m in the northeast (Baram River delta) to more than 9 m in the southwest (Lupar embayment). Tides are semidiurnal within the delta plain of the Rajang River; they range from mesotidal to macrotidal (Fig. 2, Table 1) and increase in range from northeast to southwest from 2.9 m at Kuala Igan to 5.8 m at Kuala Rajang. Tidal influence extends inland approximately 120 km to the town of Kanowit (Fig. 3). Tides are diurnal to semidiurnal in the coastal plain, with diurnal events occurring periodically during neap phases. In the coastal plain, tides range from microtidal to mesotidal and increase in range from northeast to southwest from 1.5 m at Kuala Bintulu to 2.2 m at Kuala Oya (Fig. 2). Winds and waves from the northeast monsoon (wet season) dominate from December to March and from the southwest monsoon (dry season) during the middle months of the year. Maximum wave heights are on the order of 2 m.

Rainfall averages in excess of 370 cm/yr, with the rainy or wet season coincident with the northeast monsoon. Temperature averages about 25° C, and humidity ranges from 55% in the day to almost 100% at night (Scott, 1985). Climate is classified as tropical ever-wet (Morley and Flenley, 1987). Typical single-month discharge for the Rajang River drainage basin range seasonally from about 1,000 m^3/s to 6,000 m^3/s, and the average monthly discharge is about 3,600 m^3/s (Fig. 4). This substantial variation in discharge causes seasonal changes (dry vs. wet) in estuarine circulation patterns in most of the distributary channel mouths (Table 1), with all distributaries functioning as tide-dominated estuaries for much or most of the year. Peak discharge rates during the northeast monsoon can exceed ≈ 25,000 m^3/s (Jeeps and Gates, 1963) and conversely can drop to less than 250 m^3/s during periods of extended drought (Staub et al., 2000). Typical discharge for the five coastal-plain rivers range from about 250 to 1000 m^3/s seasonally but can be substantially higher and lower during extreme weather events.

During the Quaternary, base-level lowering and/or epeirogenic uplift of the Central Borneo Massif is estimated at 0.19 + 0.03/-0.04 m/ky (Farrant et al., 1995) and, as a result, production of siliciclastic sediment from the upland drainage basin is substantial. Staub and Esterle (1994) estimated that before anthropogenic development the Rajang River drainage basin provided ≈ 30 million metric tons of sediment annually, of which about 24 million metric tons is deposited in the delta front and prodelta primarily during the wet season (Staub et al. 2000).

Inspection of aerial photographs covering the last 50 years reveals that the delta plain has been expanding at a rate of 1.0 to 1.5 km^2/yr (Scott 1985). Vertical changes in foraminiferal assemblages combined with ^{14}C dates in the Lassa distributary

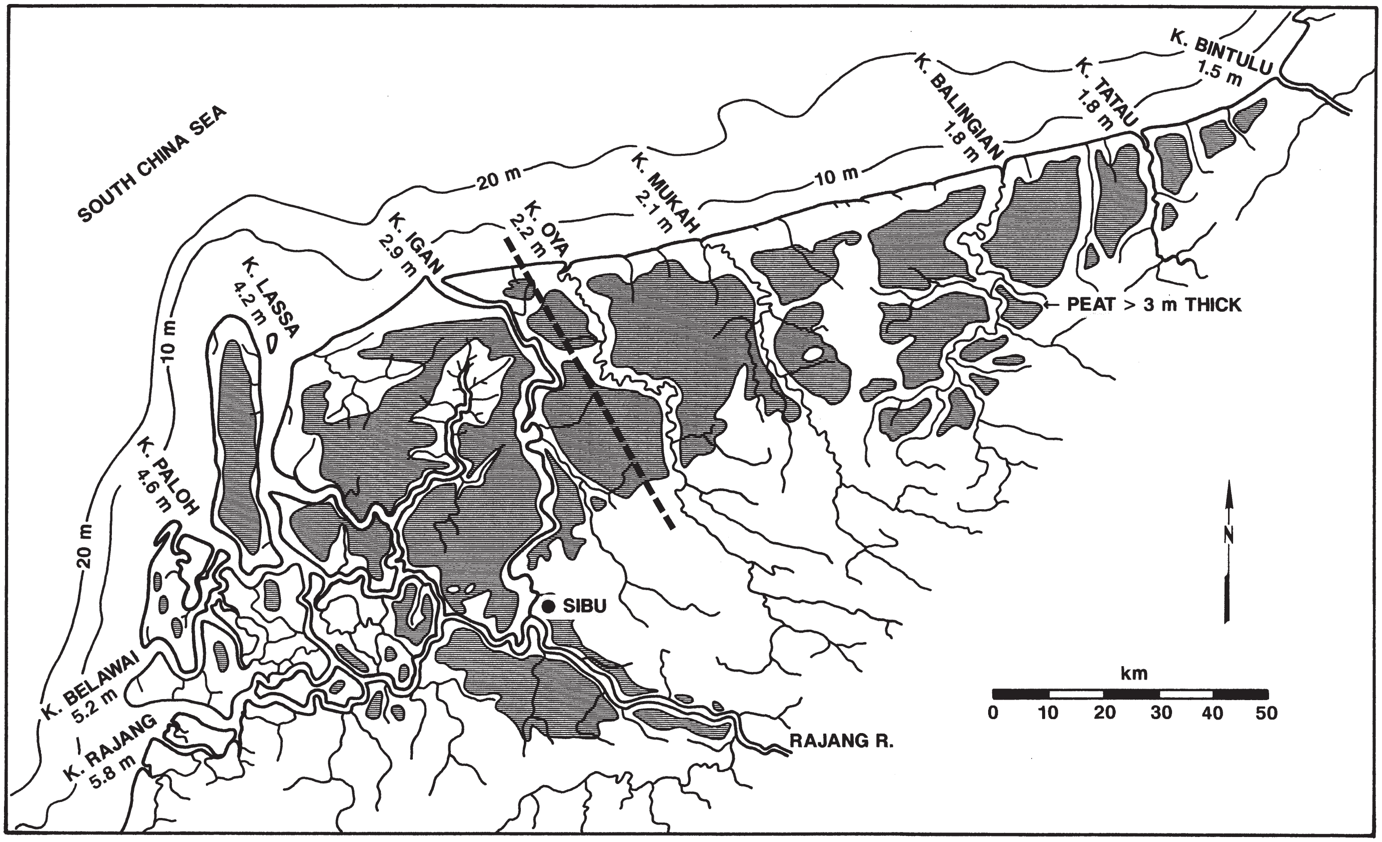

FIG. 2.—Map showing the areal distribution of thick (> 3 m) peat deposits in the Rajang River delta and adjacent coastal plain (modified from Staub and Esterle, 1994). The physiographic break (dashed line) between the delta plain (west) and the coastal plain (east) lies between the Igan distributary of the Rajang River and the Oya River. The alluvial valley is located upriver from the town of Sibu. Also listed is the maximum spring tidal range in meters at the mouth (kuala) of each of the delta distributaries and coastal-plain rivers.

demonstrate an ongoing regressive event for at least the last 2.2 ka in the northwestern part of the delta plain (Murphy, 1996). Long-term accretion rates, on the order of 8 m/yr, and aggradation rates of 1.5 mm/yr have existed in the delta plain for the last 7.5 to 8.5 ka (Staub and Esterle, 1993). The oldest dated peat deposits in the delta plain are in excess of 7.3 ka (Staub and Esterle, 1994).

DATA AND METHODS

Methods employed consisted of the compilation and analysis of published and unpublished data, as well as sampling and coring operations in the alluvial valley and delta plain of the Rajang River and the Oya River in the adjacent coastal plain. During field investigations, peat-swamp traverses were conducted and virtually all channels and major anthropogenic canals in the alluvial valley and delta plain of the Rajang River, as well as the Oya River drainage basin, were reconnoitered. Satellite images, low-altitude aerial photographs, and bathymetric data for coastal areas, distributary channels, and the alluvial valley channel were also analyzed.

Grab samples (Fig. 5) of channel-bottom, delta-front, midchannel-bar, point-bar, and beach sediments were obtained ($n = 173$). All samples were described in the field (grain size and shape, color and composition, and flora and fauna), and a cut of each sample was retained for laboratory analysis.

Subsurface data consists of vibracores, Eykelkamp peat auger cores, Edelman clay auger records, and deep bore-hole records. A total of 80 vibracores (Fig. 5) were recovered from delta-plain, distributary-channel, and delta-front and prodelta environments, and 30 Eykelkamp cores were obtained from peat-swamp environments. An additional 20 Eykelkamp core records with photographs and 120 Edelman clay-auger records (Fig. 5) were obtained from government reports. The records of 33 bore holes in the alluvial valley near Sibu and 10 bore holes in the vicinity of Daro in the delta plain were obtained from industry. Bore-hole records consisted of descriptions of materials encountered at depths of up to 100 m.

All vibracores and Eykelkamp cores were described in the field (peat type, grain size and shape, color and composition, sedimentary structures, and flora and fauna), and all vibracores and most Eykelkamp cores were photographed. Samples from each sediment type present in each vibracore and most Eylelkamp cores were retained for laboratory analysis. Most organic samples were analyzed for ash and sulfur content, and selected organic samples were sent to Krueger Enterprises, Inc., for ^{14}C age determinations.

Grain-size analysis for all siliciclastic-dominated sediment samples was conducted. Organic matter was destroyed with hydrogen peroxide. The > 63 μm part of each sample was analyzed according to Folk (1980), whereas the < 63 μm fraction of each sample was treated with dispersant and sized with a Spectrex

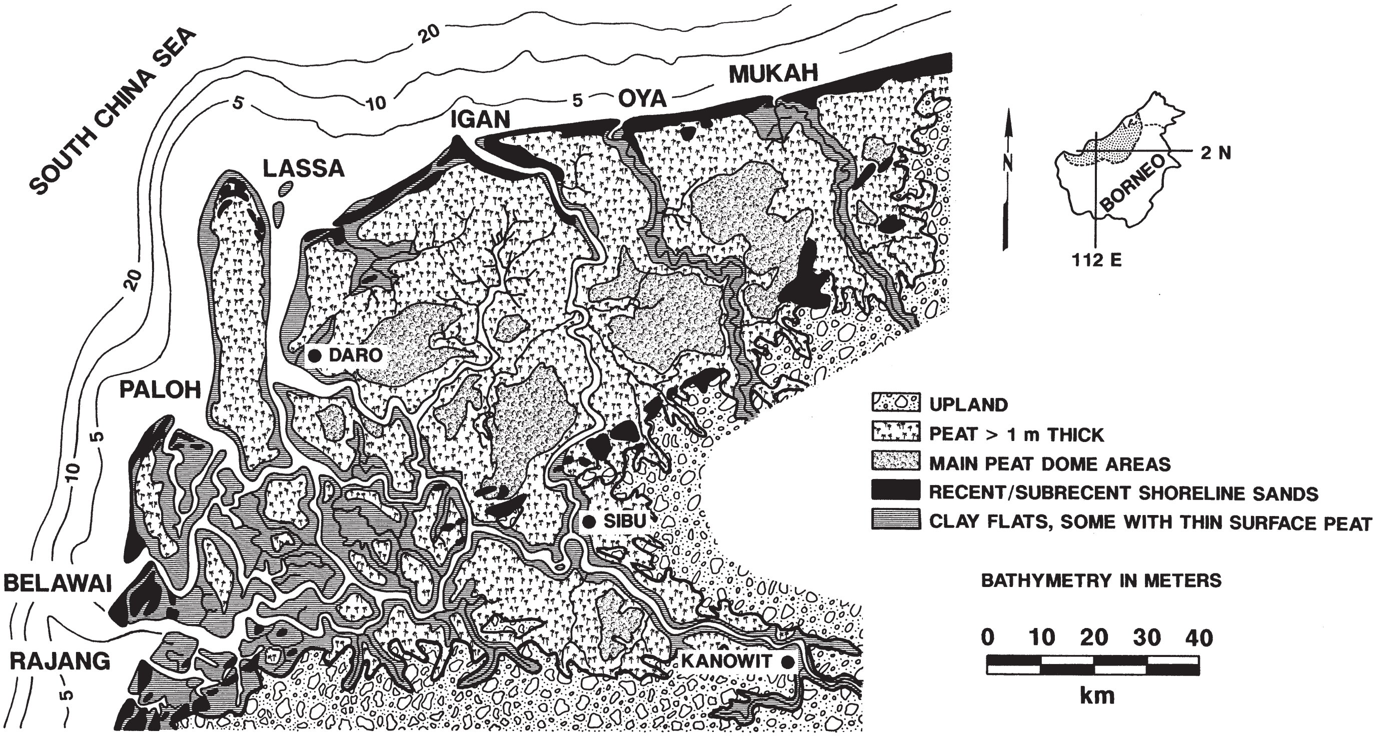

FIG. 3.—Physiography of the Rajang River delta and the part of the adjacent coastal plain (modified from Staub and Esterle, 1994). Peat domes dominate the northeastern part of the delta plain and adjacent coastal plain. Clay flats and shoreline sands dominate the southwestern delta plain.

laser particle counter. Mean ϕ and standard deviation were calculated following McBride (1971).

Sand obtained from grab samples ($n = 137$) and cores ($n = 160$) were subjected to petrographic analysis to determine mineral composition. Whole sand fractions (>63 μm) of sediment samples were used to generate epoxy grain-mount thin sections. Composition was determined by counting 300 grains per section. Angularity of grains was estimated following Powers (1953), and samples were classified according to Folk (1980).

Clays obtained from grab samples ($n = 56$) and cores ($n = 95$) were subjected to x-ray diffraction analysis to determine mineral composition. Sample preparation and identification procedures used were those detailed by Moore and Reynolds (1989).

Sediment types were grouped together into facies associations, and surficial and shallow core data were used to reconstruct the Recent progradation of the delta and coastal plains. Core and bore-hole data were used to construct cross sections. The resultant facies successions, as evidenced in plan maps and cross sections, were used to interpret the Late Quaternary history of the Rajang River alluvial valley, delta, and adjacent coastal plain. Ages of shoreline positions during the Holocene were estimated by using previously published (Staub and Esterle, 1994) long-term accretion rates (8 m/yr), combined with ^{14}C dated materials from 35 locations (Fig. 6) in the delta plain, alluvial valley, and coastal plain.

TABLE 1.—Tidal ranges and seasonal changes in estuary type.

Distributary Channel	Tidal Range[a] (m)	Estuary Type[b] Dry Season	Estuary Type[b] Wet Season
Igan	2.9	Salt Wedge	Partially Mixed
Lassa	4.2	Partially Mixed	Partially Mixed[c]
Paloh	4.6	Partially Mixed	Partially Mixed[c]
Belawai	5.2	Fully Mixed	Partially Mixed
Rajang	5.8	Fully Mixed	Fully Mixed

[a] Maximum spring tide
[b] Classification scheme after Postma (1980)
[c] Increased vertical stratification

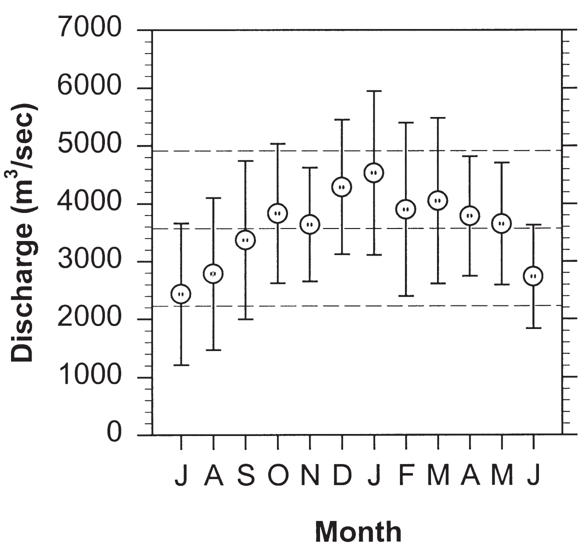

FIG. 4.—Hydrograph showing seasonal variation in discharge from the Rajang River drainage basin. Values are month-long averages based on 30 years of rainfall data. Error bars are one standard deviation (from Staub et al., 2000).

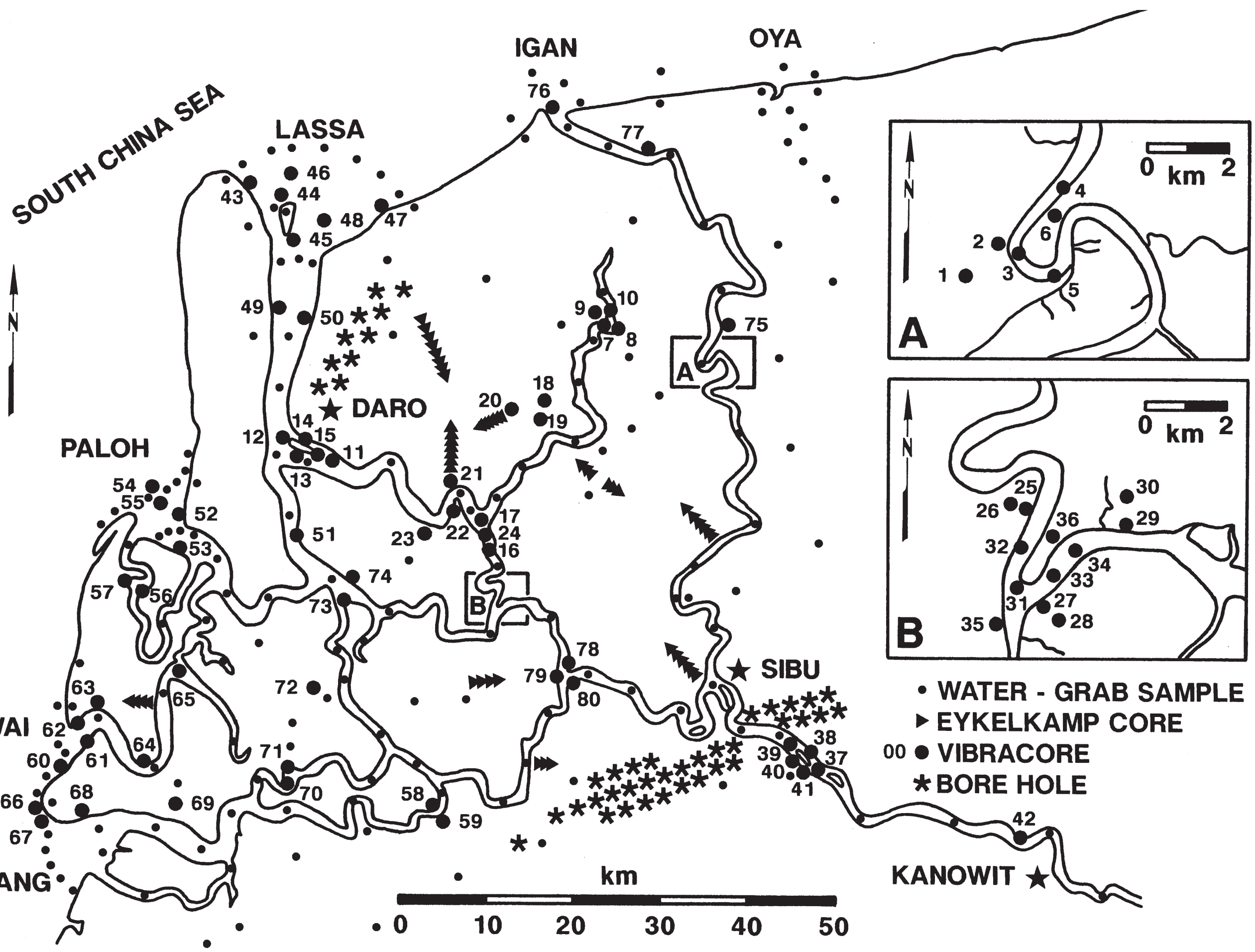

FIG. 5.—Map showing the location of grab samples, vibracores, Eykelkamp cores, and bore holes utilized in this study.

RESULTS

Vegetation Types and Peat Deposits

Mangroves dominate in brackish-water areas and show a general succession of *Avicennia–Rhizophora–Nipa–Oncosperma* that is related to decreasing salt tolerance (Scott, 1985). In coastal areas where shoreline sands are exposed, the freshwater tree *Casuarina* is dominant.

Mangroves, and particularly *Nipa* palms, dominate the surface of the southwestern delta plain. Various freshwater vegetation types dominate the northeastern delta-plain surface and adjacent coastal plain. Nutrient depletion caused by increasing peat thickness results in a general freshwater vegetation succession that culminates with *Shorea albida–Litsea–Parastemon* associations dominating (Anderson phasic community 4; Anderson, 1983) the main peat-dome areas (Fig. 3).

A peat deposit in the Rajang delta plain, where thick, is typically composed of high-ash, high-sulfur, degraded sapric peat at the base (< 50 cm) that is derived from pioneer mangrove–*Nipa* vegetation (Fig. 7). This basal layer is overlain by freshwater hemic peat that is low in ash and sulfur content. A thin sapric peat layer, derived from freshwater vegetation, caps the upper surface of most thick peat deposits. Ash content in this upper sapric layer is much lower than the basal sapric peat and sulfur content is low, unless brackish water siliciclastic sediments overlie it (Staub and Esterle, 1994). The peat deposit (as well as the water table) develops a convex or domed surface, the center of which is several meters higher than the adjacent channel systems.

Staub and Esterle (1994) noted that substrate composition is variable and that the pioneer vegetation in the succession is substrate dependent. If the pioneer vegetation is freshwater rather than brackish-water mangrove–*Nipa* (Fig. 7), then the basal sapric peat layer is reduced in thickness or absent, and ash and sulfur content are reduced.

Siliciclastic Sediments

Soils.—

Three basic siliciclastic soil types were encountered: marine-influenced gley soils, podzols, and freshwater alluvial soils. Gley soils are composed of dark gray clay or silty clay and show evidence of mangrove–*Nipa* root penetration. Clays are composed of mixed-layered illite–smectite, illite, and kaolinite with minor amounts of chlorite. Gley soils dominate much of the central and southwestern part of the delta plain.

Podzols are composed of gray-white to white clay with no or only slight yellow brown (iron) mottling. In some low-lying areas adjacent to uplands, and at locations in the landward part of the delta plain and alluvial valley, they occur as a residuum over noncalcareous sedimentary rocks or consolidated sediments. In

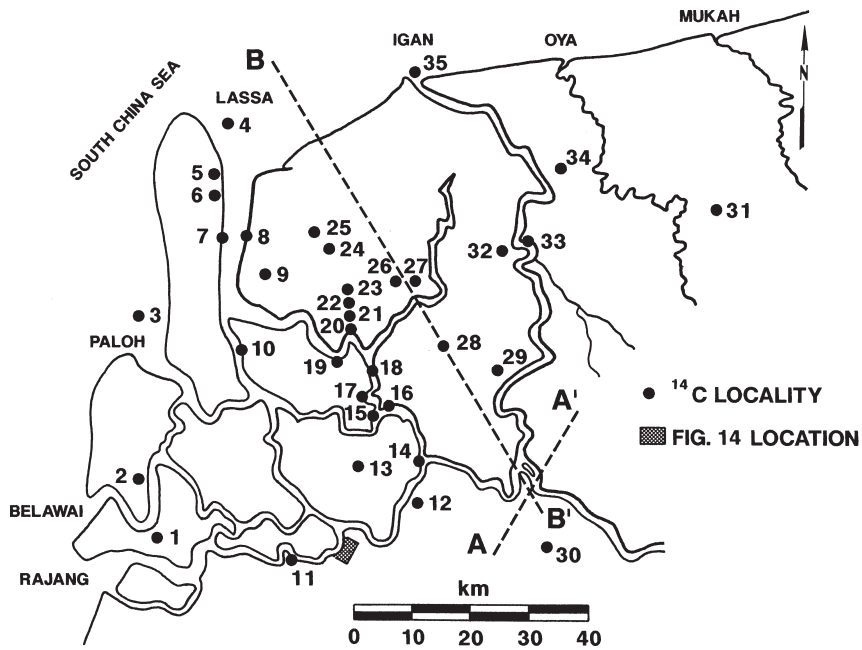

Fig. 6.—Map showing locations where ^{14}C dates were obtained (numbers are keyed to Table 2) and the location of Figure 11. All 120 Edelman auger records are from the Figure 14 location area. Also shown are the locations of cross sections A–A' and B–B' (Figs. 11 and 12, respectively).

the landward part of the delta plain they are found at various depths as a residuum over semiconsolidated intertidal to supratidal siliciclastic sediments in interfluve regions. Clays consist of kaolinite and illite with minor amounts of mixed-layer clays.

Alluvial soils are composed of mottled, yellow to brown clays and silty clays. They show evidence of root penetration of freshwater vegetation and are exposed in riverbanks and levees. Clays in alluvial soils are composed of mixed-layer illite–smectite and illite with kaolinite. Alluvial soils are found in the alluvial valley, in the landward part of the delta plain, and along channel margins in most of the coastal plain.

Alluvial-Valley and Delta-Plain Gravels.—

In the first 30 km upstream from Sibu, several longitudinal bars are present in the alluvial valley channel that contain subrounded to well-rounded pebbles and cobbles composed of siltstones, fine- to coarse-grained quartz arenites, medium- to coarse-grained sublitharenites and litharenites, and aphanitic to porphyritic volcanic rocks. Many sedimentary rock clasts show evidence of strain and/or low-grade metamorphism. Semiconsolidated outcrops (Fig. 8) in the alluvial valley, consisting of the aforementioned materials plus fine-grained sediments and wood fragments, attain heights of 5 to 7 m above MSL. Similar materials are reported at depth in bore-hole records in the alluvial valley.

The Rajang distributary channel at many locations in the southern part of the delta plain, adjacent to the proximal hills region, is floored by very angular to angular granules and pebbles. These granules and pebbles are composed mainly of vein quartz.

Alluvial-Channel and Distributary-Channel Intertidal Sediments.—

Sediment cores recovered from tidally influenced areas contain yellow-brown to dark olive-green laminated silts and sand–silt couplets (or tidal rhythmites) that are often wavy-bedded to lenticular-bedded. Rhythmites are best developed in distributary-channel bar forms in the middle part of the delta plain (Staub et al., 2000); these sediments contain foraminifera in brackish-water areas (Murphy, 1996).

Three other sediment types were observed in channel bar forms: yellow-brown to dark olive-green laminated silts, brown to gray cross-bedded sands, and brown to gray flaser-bedded sands. All contain layers of organic detritus, and many are burrowed when brackish water is present. Laminated silts are most common in the upper few meters of bar forms, whereas flaser-bedded and/or cross-bedded sands are found at greater depth. Sands in bar forms in the alluvial valley and the landward part of the delta plain are litharenites, whereas intertidal sands in the seaward part of the delta plain are sublitharenites.

Tidal-Creek and Tidal-Flat Sediments.—

Sediment cores recovered from brackish-water tidal creeks and the uppermost parts of tidal flats contain yellow-brown to dark olive-green to black laminated silts and clays or laminated clays. Burrowing often disrupts lamination. Evidence of slumping was observed in a few instances. Desiccation cracks develop on the upper surfaces of many tidal flats. Tidal-creek and tidal-flat sediments occur mainly in the southwestern part of the delta plain. Clays in these sediments are mixed-layer illite–smectite and illite with kaolinite incorporating minor amounts of chlorite.

Beach and Distributary-Mouth Sediments.—

The delta coastline is 160 km long and is composed of five distributary-channel mouths (Table 1) separated by sand beaches (Fig. 3). Widths of distributary mouths range from 2 to 12 km, and the intervening beaches are up to 35 km in length. Beach ridges

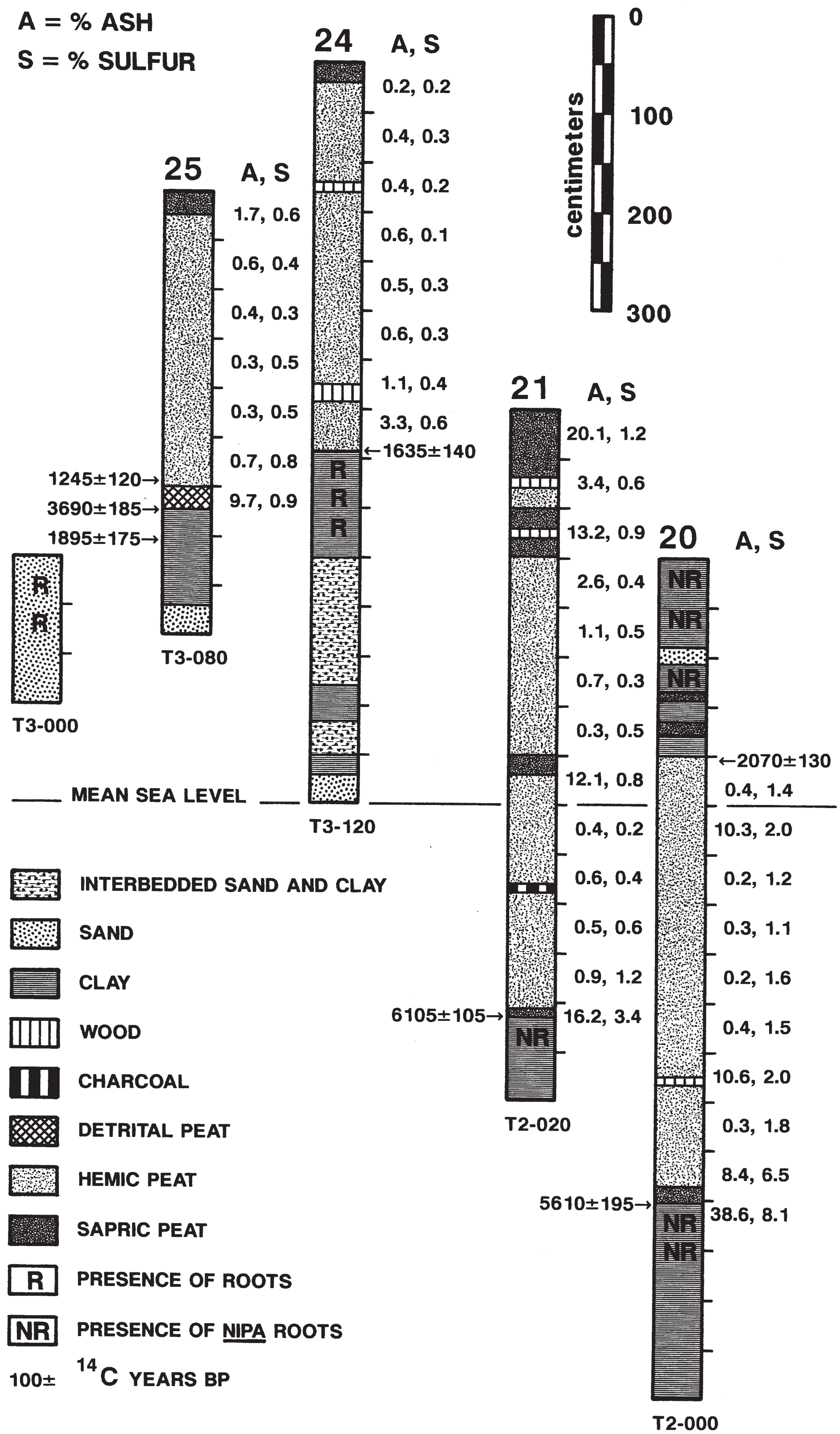

FIG. 7.—Core data showing vertical and lateral relationships of peat and siliciclastic sediment types, ash and sulfur content of the organic sediments, and ^{14}C dates. Hemic peats are better preserved, whereas sapric and detrital peats are more poorly preserved. Core locations (20, 21, 24, and 25) are the same as the ^{14}C locations shown in Fig. 6. Cores are also referenced to transect locations (e.g. T2-000) shown in Fig. 17 (modified from Staub and Esterle, 1994).

FIG. 8.—Pleistocene (VIIa) outcrop in the alluvial valley with gravel layers present. The fine-grained siliciclastic sediments in this outcrop are leached white. Lens cap is 52 mm in diameter.

Fig. 10. Recent shoreline accretion near the mouth of the Igan distributary channel in the northeast delta plain. Note how rapidly shoreline features are obscured by vegetation.

are readily apparent in aerial photographs up to 10 km inland from the coast in the southwestern part of the delta plain (Fig. 9), but ridges are rapidly obscured by vegetation or buried beneath a layer of peat in other areas (Fig. 10). Previous beach-ridge positions in peat-dominated areas can, in many areas, be observed along channel margins at low tide. Intertidal to supratidal beach sands are cross-bedded, brown to gray, and burrowed. Ridge-and-swale topographic relief is about 2 m, and beach sands are up to 5 m thick. Sands range from sublitharenites to quartz arenites, with quartz arenites more common.

Distributary-mouth sediments are composed of massive to cross-bedded, brown to gray, shallow-subtidal to intertidal sands. Layers of organic detritus also are present occasionally in these sands. Distributary-mouth sands are sublitharenites, up to 5 m thick, and sand-body geometry changes from one distributary mouth to the next in response to increasing tidal range. Sand-body geometry at the mesotidal Igan distributary mouth is lobate, at the macrotidal Lassa distributary mouth is elongate tidal-ridged, and at the macrotidal Paloh, Belawai, and Rajang distributary mouths is tidal-ridged (Pigott, 1995).

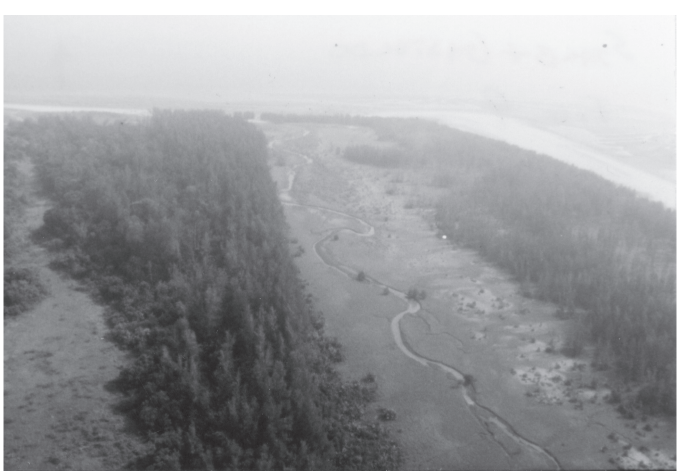

FIG. 9.—Recent beach-ridge deposits in the southwest delta plain near the mouth of the Rajang distributary channel.

Delta-Front and Prodelta Sediments.—

At depths of ≈ 3 m to 25 m below spring low tide, delta-front and prodelta sediments are encountered. The upper limit was determined by Staub et al. (2000); the lower limit is based on the analysis of bore-hole records and the work of Jackson (1962) and Pimm (1964). These sediments consist of gray to olive-black, burrowed, laminated silts and / or laminated silts and sands. Silt laminae and / or silt-and-sand interbeds are sometimes many centimeters thick, but average about 1 cm (Staub et al., 2000). Sands in these sediments range from sublitharenites to quartz arenites, with sublitharenites dominant. Layers of organic detritus and carbonate nodules also are present occasionally in these sediments. Delta-front and prodelta sediments contain a diverse foraminiferal assemblage that is the same as that found in the delta-front and prodelta sediments of the Mahakam River delta (Murphy, 1996).

Coastal-Plain River and Beach Sediments.—

The coastal-plain shoreline starts just to the west of the position of Kuala Bintulu (Fig. 2) and extends to the midpoint between the Oya River and the Igan distributary of the Rajang River. It is about 140 km in length and is composed of four large river mouths, which are separated by intervening areas consisting of sand beaches. Channel mouths are about 200 m wide and floored with quartz arenite sands. In their seaward two-thirds channel courses are floored with silts and clays. Clays are mixed-layer illite–smectite and illite with kaolinite. In the landward one-third, channel courses are floored by angular coarse-grained sand composed almost exclusively of quartz.

Beach ridges are apparent in shoreline areas; ridge-and-swale topographic relief is about 2 m. The prior positions of beach ridges can be observed along channel margins near the coast at low tide. Intertidal to supratidal beach sands are cross-bedded, brown to gray, burrowed, and composed of quartz arenites.

Terrace Deposits.—

A northeast-trending linear shoreline or terrace deposit, 5 to 7 m higher than MSL, is present adjacent to the upland (Fig. 3). It also crops out at several locations in the delta plain adjacent to the alluvial valley along its linear trend. The upper surface of this shoreline or terrace feature is flat and typically is constructed of compact, fine-grained quartz arenite sand.

Lag Deposits.—

Lag deposits are composed of subangular to rounded coarse sands, granules, and pebbles mixed with organic debris. These sediments are encountered at depths of 35 to 40 m below MSL in the vicinity of Daro. Typically, many meters of gray to black laminated silts and sand and silt interbeds immediately overlie them. Compact, rooted, yellow to brown clays and silts (alluvial soils?) immediately underlie lag deposits.

Age of Sediments

Table 2 lists the results of ^{14}C age determinations obtained on 46 samples from 35 different locations (Fig. 6). In general, all sediments in the delta become younger in a seaward direction. Freshwater root samples obtained from white podzols in the landward part of the delta plain average 17 ka, indicating a Pleistocene origin, whereas mangrove and *Nipa* roots in gley soils occurring in the same areas average only 7.4 ka. Basal peats in the landward part of the delta plain, irrespective of a *Nipa* or freshwater origin, average 6.3 ka in age. Overbank siliciclastics that overlie the margins of several peat deposits in the delta plain were deposited at about 2 ka. Mangrove and *Nipa* roots in gley soils at depth in the seaward one-half of the northeast delta plain average 3.4 ka. Basal peats in the seaward part of the northeast delta plain, all of which were of freshwater origin where sampled, average 1.6 ka in age and become progressively younger toward the coast.

Intertidal sediments and gley soils occurring between beach ridges in the southwest delta plain, near the mouth of the Rajang distributary channel, are 4.7 ka in age. Intertidal to subtidal sediments in the lower reaches of the Lassa and Paloh distributary channels are 2.3 ka in age, and sediments obtained at depth in the present delta-front areas average about 0.9 ka.

Samples obtained from within 4 m of the surface of peat domes in the alluvial valley and coastal plain were 6.3 and 5.2 ka in age, respectively. Organic samples obtained from active intertidal to subtidal bar forms in distributary channels ranged in age from 0.3 ka to the present. Finally, in the vicinity of Daro, at a depth of about 80 m, a peat/lignite sample was obtained from a deep well with an age slightly in excess of 40 ka.

Cross Sections

Two generalized cross sections were generated from core and bore-hole data. Datum for the cross sections is approximate mean high tide (MHT). Cross section locations are shown in Figure 6. The first cross section, A–A', traverses the alluvial valley at the position of the town of Sibu (Fig. 11). The valley is floored by weathered Tertiary bedrock, which in most areas is overlain by Pleistocene sediments of varying thickness. Pleistocene sediments range from clay to gravel and generally are well compacted. Sediment color ranges from gray to brown to yellow, and organic matter is common. The transition from Pleistocene to Recent sediments is usually marked by a gray-white to white podzol several meters thick.

Siliciclastic Recent valley-fill deposits are about 10 km wide and up to 45 m in thickness. Gravel, sand, and interbedded sand and silt dominate the lower part of the fill, whereas silt and interbedded silt and clay dominate the upper part of the fill. Sediments in the upper part of the fill succession are tidally influenced. Thick Recent peat deposits, resting mainly on Pleistocene sediments with their bases below MSL, flank the Recent valley-fill sediments. Occasionally Pleistocene and Tertiary outcrops extend upward to the surface through Recent fill materials.

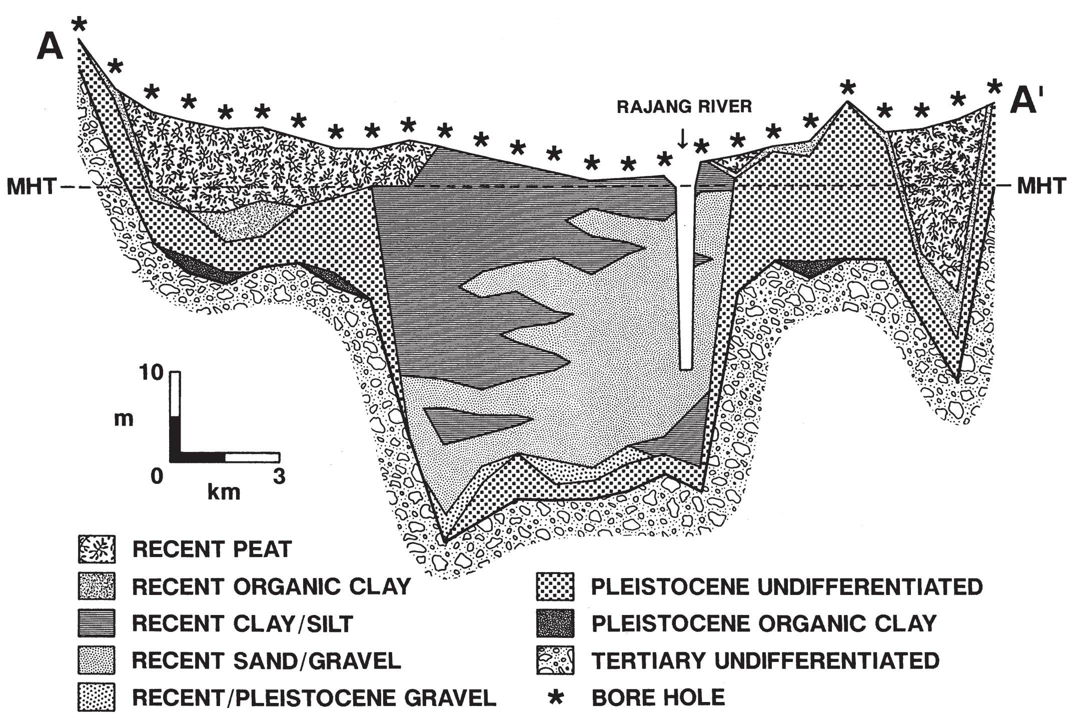

FIG. 11.—Generalized cross section A–A' showing Pleistocene and Recent fill materials, and Recent peat deposits in a northeast-trending transect across the alluvial valley at Sibu.

TABLE 2.—^{14}C dates obtained from all samples analyzed.

Map number	Field location	Age ^{14}C years BP	Elevation (MSL, m)	Material dated
01	Core V-69	4,690 ± 185	- 0.90	Intertidal organic material
02	Core RP-003	2,735 ± 165[a]	- 2.30	*Shorea* root in gley soil
02	Core RP-003	4,620 ± 245[b]	- 2.40	Organic material in gley soil
03	Core V-54	915 ± 90	- 6.80	Wood in delta front sediment
03	Core V-54	610 ± 80	- 4.50	Wood in delta front sediment
04	Core V-44	760 ± 105	- 6.40	Wood in delta front sediment
05	Grab 89-14	760 ± 110[a]	- 1.50	Mangrove root in gley soil
06	Grab 89-16	835 ± 330[b]	- 2.00	Organic material in gley soil
07	Core V-49	2,195 ± 165	- 3.30	Intertidal organic material
08	Core V-50	2,285 ± 160	- 2.80	Intertidal organic material
09	Daro 1F3	40,370 + 2,944 / -2,150	-78.00	Peat/lignite
10	Core V-51	1,955 ± 180	- 3.70	Intertidal organic material
10	Core V-51	2,690 ± 150	- 4.60	Intertidal organic material
11	Grab R-090-1	11,950 ± 250[b]	- 3.00	Freshwater root from white podzol
11	Grab R-090-2	12,480 ± 360[b]	- 3.00	Freshwater root from white podzol
11	Grab R-090-3	7,060 ± 280[b]	-2.70	Basal *Nipa* peat overlying white podzol
11	Grab R-090-4	6,820 ± 325[b]	- 2.70	Basal *Nipa* peat overlying white podzol
12	Core RB-01	7,340 ± 220[b]	- 0.60	Basal *Nipa* peat overlying gley soil
12	Core RB-01	1,895 ± 195[b]	+ 1.50	Upper contact, freshwater peat and siliciclastics
13	Core R-042	8,640 ± 195[a]	- 12.50	*Nipa* root in gley soil
14	Core V-79	26,760 ± 1,360	+ 1.50	Freshwater root from white podzol
15	Core V-35	5,485 ± 385	- 3.40	Freshwater peat matrix
16	Core V-29	230 ± 60	- 0.10	Plant fragments in intertidal sediments
17	Core V-26	7,415 ± 350	- 4.35	Wood fragment in gley soil
17	Core V-26	5,600 ± 60	- 1.35	Organic material in gley soil
18	Core V-16	170 ± 60	- 4.10	Organic material in midchannel bar
19	Core V-23	6,285 ± 270	- 4.40	Wood fragment in gley soil
20	Core T2-000	5,610 ± 195[b]	- 3.95	Basal *Nipa* peat overlying gley soil
20	Core T2-000	2,070 ± 130[a]	+ 0.50	Upper contact, freshwater peat and siliciclastics
21	Core T2-020	6,105 ± 105[a]	- 2.20	Basal *Nipa* peat overlying gley soil
21	Core T2-020	6,105 ± 105[a]	- 2.20	Basal *Nipa* peat overlying gley soil
22	Core T2-100	6,405 ± 120[b]	- 0.30	Basal *Nipa* peat overlying gley soil
23	Core T2-140	5,945 ± 205[b]	- 0.60	Basal *Nipa* peat overlying gley soil
24	Core T3-120	1,635 ± 140[b]	+ 3.60	Basal freshwater peat overlying alluvial soil
25	Core T3-080	1,245 ± 120[a]	+ 3.15	Basal freshwater peat overlying detrital peat
25	Core T3-080	3,690 ± 185[b]	+ 3.00	Detrital peat overlying alluvial soil
25	Core T3-080	1,985 ± 175[b]	+ 2.70	Organic material from alluvial soil
26	Core V-20	4,460 ± 110	- 2.10	Organic material in gley soil
27	Core V-19	2,345 ± 130	- 2.55	Organic material in gley soil
28	Core RL-03	6,055 ± 95	- 0.90	Basal *Nipa* peat overlying white podzol
29	Core RI-06	6,080 ± 100	- 1.60	Basal *Nipa* peat overlying white podzol
30	Grab R-006-1	6,290 ± 100	- 1.50	Freshwater peat from creek bottom in peat dome
31	Grab R-036-1	5,180 ± 220	+ 1.00	Freshwater peat from creek bottom in peat dome
32	Core V-01	4,090 ± 105	- 2.30	Intertidal organic material
33	Core V-03	modern	- 1.10	Organic material in point bar
34	Grab R-116-2	5,830 ± 100	- 1.00	Basal *Nipa* peat overlying white podzol
35	Core V-76	1,390 ± 140	- 6.60	Wood in delta front sediment

[a]from Staub and Esterle (1993). [b]from Staub and Esterle (1994)

The second cross section, B–B', traverses the Rajang valley at Sibu and continues to the northwest across the peat-dominated part of the delta plain (Fig. 12). Thick Recent peat deposits rest on Pleistocene sediments (gray-white podzols) with their bases below MSL in the landward one-half of the cross section (to about 5 km seaward of the abandoned arm of the Lassa). The margins of these thick peat deposits that flank distributary channels rest conformably on Recent sediments. In the seaward one-half of the cross section, thick peat deposits overlie Recent intertidal and shoreline sediments. These sediments, in turn, overlie Recent subtidal sands and deltaic deposits of the Rajang River. A yellow-brown mottled alluvial soil and gravel lag underlies the Holocene deltaic succession.

Channel and Coastal Bathymetry

Depths in the Rajang River channel in the lower part of the alluvial valley, and one-half the distance to the coast in the Lassa and Paloh distributaries, occasionally exceed 45 m (Fig. 13). The abandoned arm of the Lassa distributary, a large channel that drains to the southwest out of the peat-dominated part of the delta plain to join the main Lassa distributary, exceeds 45 m depth for 75% of its length. In contrast, the Igan, Belawai, and Rajang distributaries rarely exceed 20 m in depth. All distributary channels shallow toward the coast. With the exception of the Rajang distributary, distributary-channel mouths are less than 5 m in depth at spring low tide. The coastal-plain rivers have maximum depths of 25 m about half the distance across the coastal plain, and shallow toward both the coast and uplands. Coastal-plain river-mouth depths are less than 1 m at spring low tide.

The delta-front slope averages about 0.15% to depths up to 25 m. Slopes average about 0.10% to depths of 20 m along the coastal-plain shoreface. At depths of < 3 m below spring low-tide surface, sediments typically are sands, whereas at depths of > 3 m surface sediments are clays and silts. Shelf slope averages 0.03%, and shelf sediments, starting at distances of 30 km offshore, are composed of sand (Jackson 1962).

Bathymetric surveys do not reveal the presence of remnant incised valleys on the shelf in the vicinity of the Rajang River delta and adjacent coastal plain (Royal Malaysian Navy, 1990). However, 150 km to the northwest of the delta front, multiple incised valleys about 5 to 7 km wide and up to 60 m deep, trending north-northwest, are present. These incised valleys are attributed to the Lupar River (Haile et al., 1963). In addition, between Kuala Bintulu and Kuala Tatau (Fig. 2) a north-oriented incised valley can be observed traversing the shelf at water depths greater than 30 m. This valley, which is derived from the Tatau and Kemena rivers, is up to 40 m deeper than the flanking shelf.

Lateral Relationship of Pleistocene and Holocene Sediments

Figure 13 is a generalized map showing lateral relationships among Late Quaternary sediments. The distribution of the Pleistocene terrace deposits is shown, and areas where Pleistocene deposits are found in the shallow subsurface are delineated. The upper surface of these deposits consists a of gray-white to white podzol. The positions of the main peat domes also are shown. The bases of all thick peat deposits that overlie the Pleistocene surface are located below MSL. Basal peat ages in these deposits range from 5.8 to 7.3 ka, with an average age of 6.3 ka. Seaward of the area of thick peat and podzol shown in Figure 13 are a series of accretionary shorelines starting at about 7 ka and ending at the present. The first shoreline that can be mapped on a system-wide basis formed at about 5 ka.

Edelman auger borings (Fig. 14) delimit the amount of topographic relief on the podzol surface in a small area along the Rajang distributary channel in the southwestern part of the delta plain. Datum is MHT, and topographic relief on the surface ranges from less than -2 m to more than -6 m. In most areas where this surface is present, former topographically negative areas are filled with Holocene tidal-creek and tidal-flat sediments and capped by gley soils. Figure 15 shows an outcrop where the podzol surface is mantled in peat along the Rajang distributary channel.

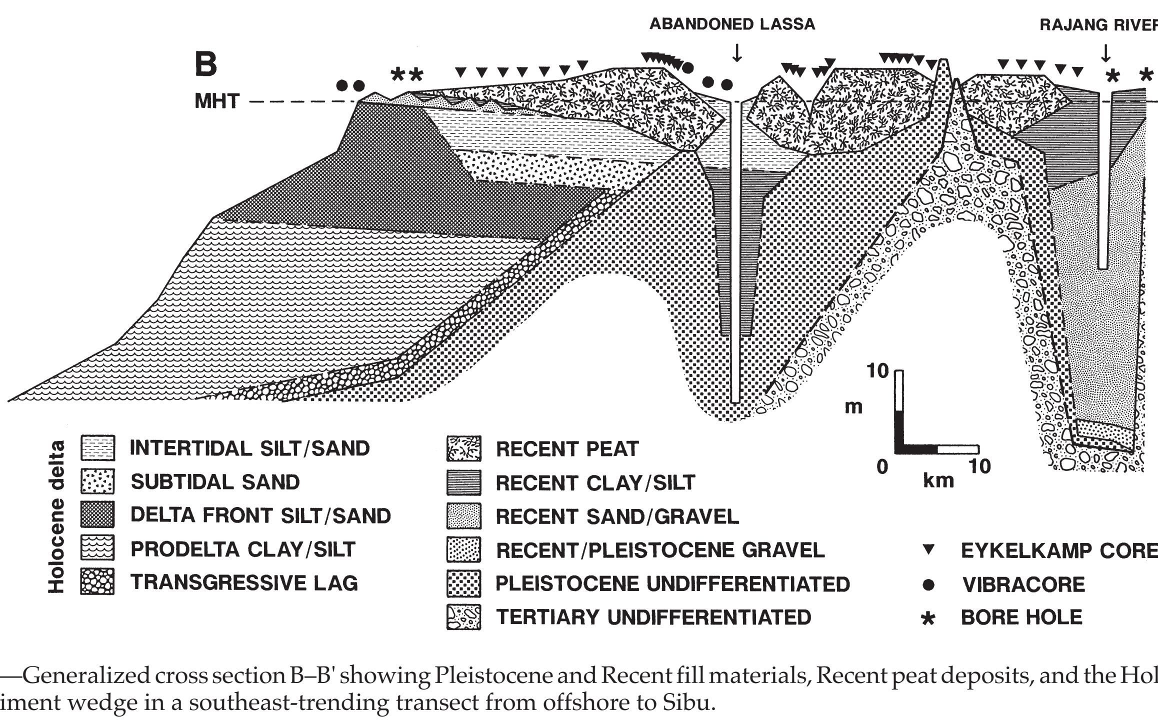

FIG. 12.—Generalized cross section B–B' showing Pleistocene and Recent fill materials, Recent peat deposits, and the Holocene deltaic sediment wedge in a southeast-trending transect from offshore to Sibu.

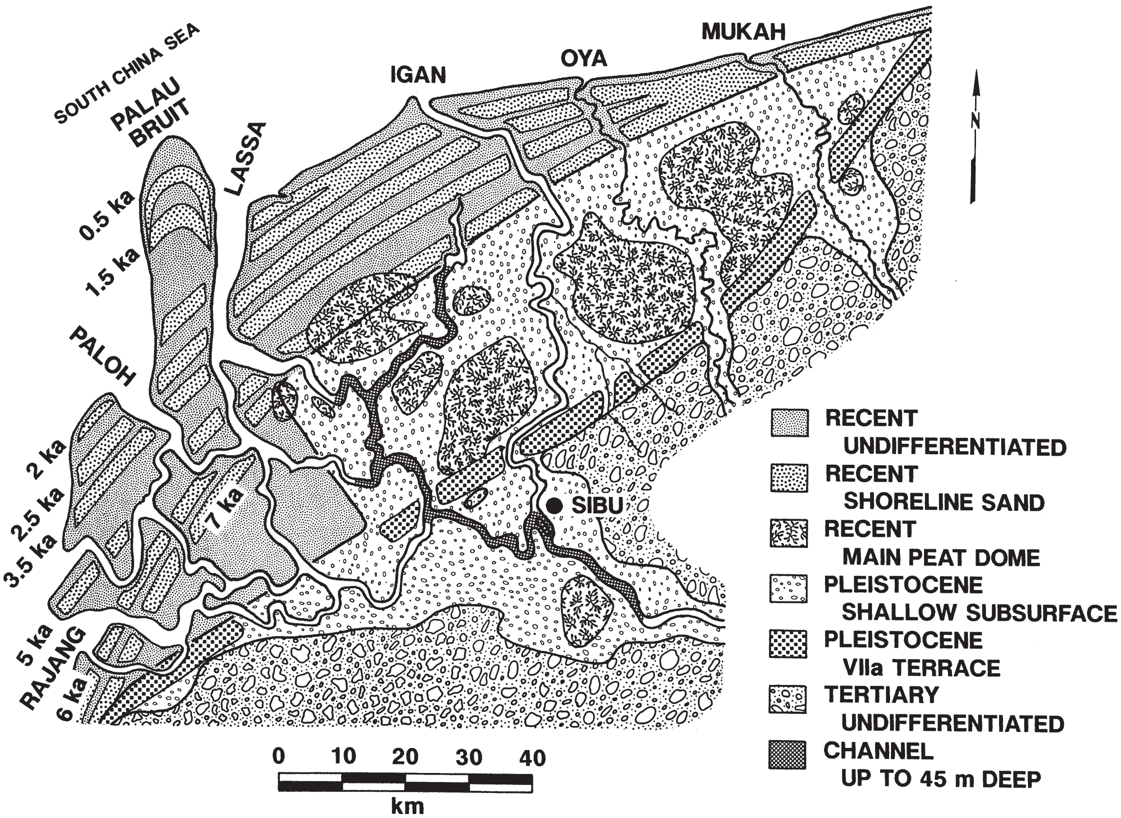

FIG. 13.—Generalized map showing the position of the Pleistocene (VIIa) terrace, areas where Pleistocene deposits are in the shallow subsurface, main peat dome areas, and the positions of accretionary shorelines starting at 7 ka and ending at the present. Also shown are areas where channel depths commonly are 45 m in the alluvial valley and delta plain.

INTERPRETATION AND DISCUSSION

Pleistocene Sediments

Beach or terrace sediments adjacent to upland areas are 5 to 7 m higher than MSL (Fig. 3). In addition, the maximum elevations of gravel outcrops in the alluvial valley are 5 to 7 m higher than MSL. The upper surface of these terrace and outcrop sediments can be correlated laterally in the alluvial valley, delta plain, and coastal plain with the gray-white podzol surface, which at every location dated returned results of more than 10 ka.

Previous studies (Anderson, 1964; Scott, 1985) have suggested that the terrace deposits formed about 5.0 to 5.5 ka during a Holocene elevated stand of sea level. However, studies on the Huon Peninsula in New Guinea (Chappell and Shackleton, 1986) and elsewhere in the region (Fleming et al., 1998) indicate that current sea level is the highest level of the Holocene.

On the Huon Peninsula at least seven reef terrace/highstand events (Fig. 16) have been identified that occurred in the last 125 ka (oxygen isotope stages 1 to 5). ^{14}C age dates plus elevation data indicate that a more accurate interpretation of the Rajang terrace deposits is that they are the local remains of the VIIa highstand event (oxygen isotope stage 5e) of 125 ka. This highstand surface formed at ≈ 6 m above present MSL (Bloom et al. 1974; Chappell and Shackleton 1986; Esat et al. 1999).

In the seaward part of the delta plain near the town of Daro, organic materials (peat/lignite) from a depth of 78 m below MSL returned an age of 40 ka. If peat development in coastal deltaic settings is associated with regressive to highstand system tracts, as proposed by some workers (Aitken and Flint, 1995; Martino, 1996; Bohacs and Suter, 1997; Staub, 2002), then this peat/lignite probably formed as part of the IIIb highstand event of 40 ka. The IIIb highstand event (oxygen isotope stage 3; Fig. 16) occurred at 41 ± 4 m below present MSL (Bloom et al., 1974; Chappell and Shackleton, 1986), indicating that about 40 m of subsidence has occurred. These results demonstrate that substantial subsidence and sediment accumulation has occurred during the Quaternary in coastal areas of the Rajang delta. Published Neogene sediment isopachs of the Rajang delta area indicate a total thickness of 1 to 2 km onshore and more than 4 km offshore (Hutchison 1989).

Although no bathymetric expression of incised valleys can be observed on the shelf in front of the Rajang River delta, an idea of scale can be garnered from other areas. Incised valleys from other rivers are present on the shelf to the east and west of the delta. These incised valleys are on the order of 5 to 10 km wide and 40 to 60 m in depth.

In cross section (Fig. 11), the Pleistocene incised valley in the vicinity of Sibu is up to 45 m deep and 10 km wide. In the alluvial valley and the landward one-half of the delta plain, with the exception of the Igan distributary channel, all major channels are up to 45 m deep (Fig. 13). Eroded remains of the VIIa highstand surface flank all these areas. This commonality in channel depth is thought to represent the maximum amount of incision of the Rajang River in these areas.

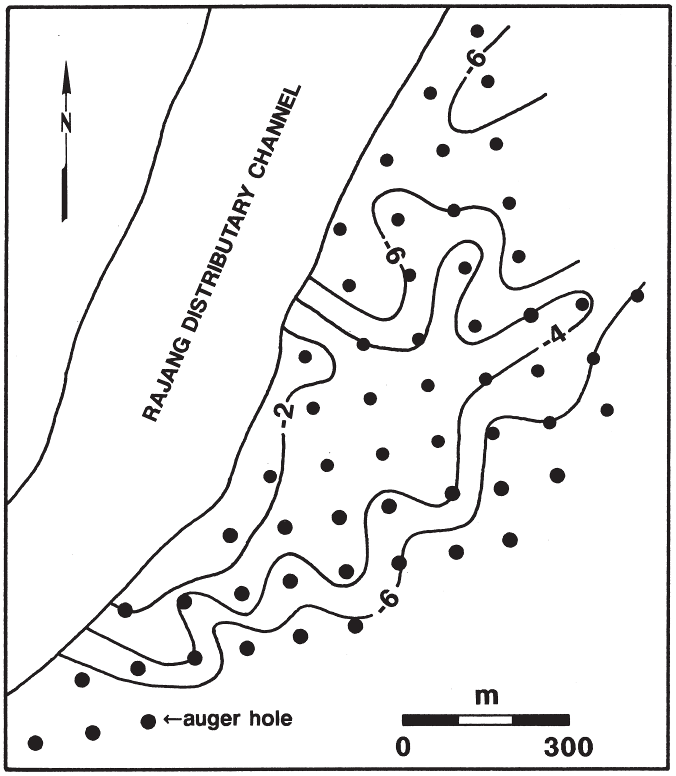

FIG. 14.—Map showing topographic relief on the Pleistocene (VIIa) surface in a small area adjacent to the Rajang distributary channel (see Fig. 6 for location; modified from Kuek, 1991).

Recent Progradation

Regional.—

The incised valley in the Rajang alluvial valley (Fig. 11) is floored with gravel. This material is overlain by a fining-upward succession, the upper part of which is tidally influenced. The depth to which tidal influence extends in this 45-m-thick sediment fill is not known. Most of the surface of the valley floor is mantled in thick peat.

Most thick peat and all main peat dome areas are found in the alluvial valley, the northeastern part of the delta plain, and the adjacent coastal plain. In these areas, thick peat is lying on or in close proximity to the underlying gray-white to white Pleistocene podzol surface (Fig. 13). There is substantial relief on this surface (Fig. 14), and in the delta plain this relief has been filled mainly by intertidal sediments and gley soils. Peat deposition started in most of these areas concurrently at about 6.3 ka, when sea level was several meters below its present level. Accumulation of sediment, both organic and siliciclastic, in these areas has been aggradational since the initiation of peat deposition.

Seaward of the thick peat and podzol area are a series of system-wide accretionary shorelines. The southwestern part of the delta plain represents a reentrant in the general system-wide shoreline trend, and the remains of two older, shorelines of limited extent are present in this reentrant, with ages of 7 and 6 ka. The existence of these prograding shoreline deposits in the southwest delta plain demonstrate that the reentrant was flooded prior to 7 ka, and that the initial development of the Rajang River delta

FIG. 15.—Outcrop of the Pleistocene (VIIa) gray-white to white podzol surface capped by a Holocene *Nipa* peat along the margin of the Rajang distributary channel at mid-tide. The photo is from ^{14}C location 11 (see Fig. 6).

coincided with the Early Holocene deceleration in sea-level rise, as did many other deltas (Stanley and Warne, 1994).

The oldest identified system-wide shoreline formed at about 5 ka and coincides with the seaward margin of the area of thick peat and podzol in the northeast delta plain and adjacent coastal plain. Sands from this shoreline are found in the southwest delta plain, under thick peat deposits in the northeast delta plain, in the upper reaches of the abandoned arm of the Lassa distributary channel, and along the banks of the Igan distributary channel. Age dates from intertidal sediments and gley soils in this shoreline deposit in the southwest delta plain are 4.7 ka, which corroborates its estimated age. Next, a series of shorelines are identified that all weld into a single shoreline feature to the northeast. Estimated shoreline age ranges from about 3.5 to 2.0 ka and age dates from gley soils and peat deposits corroborate the reasonableness of the estimates. More recently, coastline erosion has truncated all of these former shorelines in the southwestern part of the delta plain.

A series of smaller prograding shoreline features can be observed in Palau Bruit (Fig. 13), starting at about 1.5 ka and continuing to the present. At present, the delta shoreline is

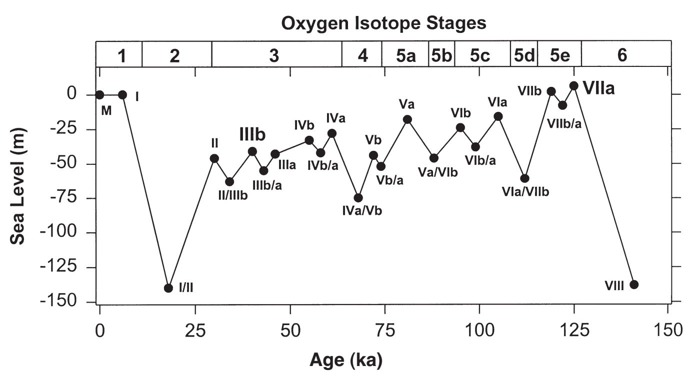

FIG. 16.—Oxygen isotope stages and sea-level changes for the past 140 ka based on correlation of deep-sea core data with ages of uplifted and drowned coral reefs of the Huon Peninsula, New Guinea (modified from Chappell and Shackleton, 1986).

actively prograding (Fig. 10) on the north coast, while some areas of the southwest coast appear to be undergoing erosion and retreat (Fig. 3). This erosion and retreat in the southwest is, in all likelihood, related to the fact that the Rajang distributary channel currently transports the smallest amount of the sediment to the coast on an annual basis. Staub et al. (2000) demonstrated that about 24 million metric tons of sediment is supplied directly to the delta front and prodelta annually, but less than 10% of this total is currently transported via the Rajang distributary.

The Pleistocene–Holocene transition occurs at a depth of about 40 m below MSL at the coast in the northwest part of the delta plain and is identified by a yellow-brown rooted alluvial soil overlain by a gravel lag. A coarsening-upward succession, capped by distributary-mouth sands and/or beach deposits, overlies the lag deposit. This Holocene–Recent deltaic succession, or wedge, thins and shallows in a landward direction to the position of the 5 ka shoreline.

Abandonment of the Lassa.—

Within the northeast delta plain, data indicate that the unusual southwest-flowing channel that presently drains much of the peat-dominated area of the delta plain (Fig. 17) was formerly an active distributary channel flowing north-northeast. It is about 45 deep for most of its length until it intersects the position of the 5 ka shoreline (Fig. 13), at which point it rapidly shallows to less than 5 m depth. The maximum extent of drainage directed to this channel is coincident with the position of the 3.5 ka shoreline. Sand composition in the area between these two shoreline trends is litharenite.

The 5 ka shoreline trend is roughly coincident with the T1 transect shown in Figure 17. At most core locations on this transect the peat is immediately underlain by quartz arenite beach sand. The maximum elevation of this sand is MSL. Mangrove and *Nipa* vegetation dominate the upper end of the drainage network, even though freshwater vegetation associations dominate the rest of the area and water in the channel averages less than 1 ppt salinity. The distribution of the mangrove–*Nipa* vegetation is not dissimilar to the shape of a distributary-channel mouth (e.g., Muara Lassa; Fig. 17). The existing mangrove–*Nipa* distribution in the upper reach of the channel is most likely a relict of the topographically negative area left when abandonment occurred at 3.5 ka.

Recent Peat Development

In the Malay Archipelago a generalized shoreline progradation model has been proposed by many investigators (e.g., Anderson, 1961; Coleman et al., 1970; Anderson and Muller, 1975; Scott, 1985; Esterle, 1990; Staub and Esterle, 1994) for the development of the deltaic peat swamps. In the Baram, Hari, and Klang-Langat river delta systems the maximum reported peat age is on the order of 4.5 ka. The maximum reported peat thicknesses are on the order of 10 m, and the bases of the peat deposits are very near, at or above, MSL (Anderson, 1964; Coleman et al., 1970; Esterle, 1990). Although these delta systems vary greatly in terms of physical processes (e.g., microtidal versus macrotidal; wave dominated versus tide dominated) they all occur in the same climatic setting (ever-wet), and judging from available information the general shoreline progradation model proposed is probably correct.

The Rajang system occurs in the same climatic setting (ever-wet), but unlike these other peat dominated delta systems most thick peat deposits in the Rajang River delta and adjacent coastal plain are found in areas underlain by near-surface Pleistocene erosional remnants. In addition, the Rajang peat deposits are larger and older. They cover two to five times more area than the deposits present in the Baram, Hari, or Klang–Langat systems. They are up to twice as thick (15–20 m), their bases occur well below MSL, and their average age is 6.3 ka, with a limited range of 5.8 to 7.3 ka. This narrow time window for peat development over such an extensive area (≈ 7,500 km^2) and the aggradational nature of the sediments indicates that the general progradation model as proposed in the case of the Rajang is not correct.

In order for peat to accumulate in any depositional system many criteria must be met, but probably the two most important are the presence of a substrate in which the plants can root and a rising water table or base level (McCabe and Parrish, 1992). In addition, if the water table or base level is rising, an equilibrium rate must be attained. If it is too rapid, the surface floods and peat

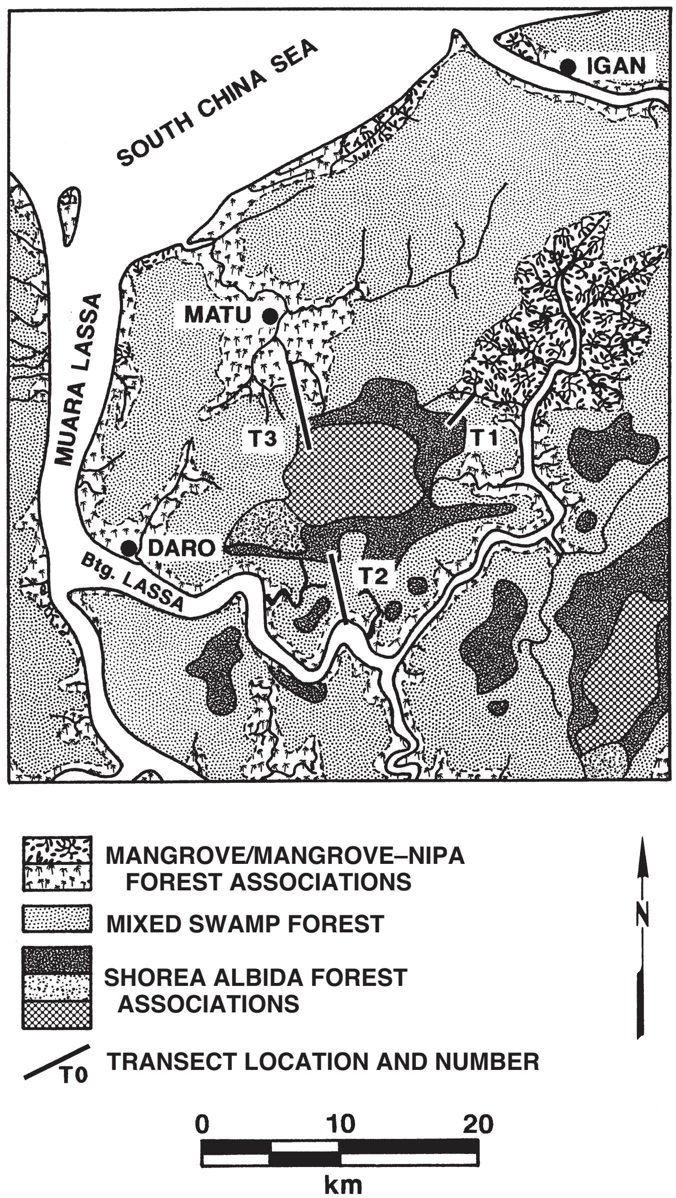

FIG. 17.—Map showing the abandoned arm of the Lassa distributary channel and the active distributary channel (Muara Lassa). Also shown is the surficial distribution of brackish-water and freshwater vegetation types (modified from Anderson, 1961).

accumulation ceases; if it is too slow, the organic material is oxidized and peat does not accumulate.

In the Rajang system, as sea level rose during the Early Holocene the existing topographic relief (minor incised drainage in interfluve areas) in the coastal plain and the northeastern delta plain filled with tidal creek–tidal flat sediments. This created an initial siliciclastic platform, and this platform was rapidly colonized by pioneer mangrove–*Nipa* vegetation. As the water table continued to rise, peat accumulation commenced. It may be coincidental, but the initial peat accumulation in the Rajang system coincides with the end of the catastrophic sea-level rise event 3 (CRE 3) of Blanchon and Shaw (1995). In this case the end of this event reflects the substantial deceleration in the rate of water-table and sea-level rise that was necessary for platform and peat development. Subsequently, as the shoreline has advanced, the peat domes have increased in thickness and expanded seaward. Winston (1994) developed theoretical numerical models that explain the types of domed peat accumulation that have occurred.

In the southwestern part of the Rajang delta plain, little significant peat accumulation has occurred. The surface of the area is dominated by beach ridges, saline gley soils, and *Nipa* palms. Pleistocene sediments are not found at shallow depths, except immediately adjacent to the VIIa terrace (Fig. 13). Data indicate that there was little or no prior existing substrate in this area circa 7 ka. This is also the part of the delta plain that experiences the highest tides. These factors have hindered peat accumulation, but they have not prevented it (see Fig. 2).

As stated earlier, peat accumulation started much later (≈ 4.5 ka) in the Baram, Hari, and Klang-Langat delta systems, and as a consequence the peat deposits are not as thick. Climate and rates of base-level rise have been similar for all four systems (Baram, Hari, Klang-Langat, and Rajang) during the Holocene, so why is there a substantial difference in the age of the peat deposits? Variation in physical processes (e.g., variation in tidal range, wave energy) appears not to be a significant factor. The only viable explanation for the later start in the Baram, Hari, and Klang-Langat delta systems is the absence of a substrate or platform in which plants could take root. The drainage-basin area of each of these systems is much smaller than that of the Rajang (Coleman et al., 1970; Esterle, 1990; Staub and Esterle, 1994), and as a consequence the rate of sediment delivery to the coast is substantially less. This reduced rate of sediment supply slowed the platform development rate, and as a result peat accumulation started about 2 to 3 ka later in these systems.

Deltaic Style

The Rajang River delta is a complex interplay between seasonal variation in discharge, tidal currents, and surface waves. Distributary channels dominated by tidal and estuarine processes (Table 1) and intervening beach-ridge plains characterize much of the Holocene delta. Harris et al. (1993) discussed the importance of tidal currents and surface waves for sediment dispersal and deposition. Galloway (1975) gave strong emphasis to the estuarine component in tide-dominated deltas. Another factor to be considered, according to Staub et al. (2000), is seasonal variation in discharge. All these factors are important.

Seasonal drainage-basin discharge varies by one order of magnitude during average years and two orders of magnitude in extreme years. During the dry season (April to November) much of the sediment supplied by the drainage basin to the delta plain is sequestered in the distributary channels by tidal and estuarine processes. During the wet season (December to March) this sediment is transported to delta-front and prodelta areas from the distributary channels and results in annual sedimentation events. Once sediment is in the delta front and prodelta, some of it is reworked during subsequent dry seasons into beach ridges (Staub et al. 2000).

The Rajang River delta is similar in many respects, in particular physical processes and sediment grain size, to other siliciclastic-sediment-dominated tropical river deltas such as the Fly, Irrawaddy, and Mekong (Harris et al., 1993; Orton and Reading, 1993). Even though the terms wet season and dry season are used to describe monsoon events in Sarawak, the Rajang River system is located in an ever-wet climatic region. The terms wet versus dry locally denote the relative amount of rainfall. In coastal lowland areas this ever-wet climatic regime enables the water table to remain constantly at or within a few centimeters of the surface, even during the dry season, and has enabled the accumulation of thick, extensive peat deposits. In Sarawak the presence of this climatic regime extends well back into the Pleistocene (Morley and Flenley, 1987).

Conversely, the Fly, Irrawaddy, and Mekong deltas are in areas of Southeast Asia and the Malay Archipelago that are truly seasonal in the sense that there is a distinct dry season during which there is little or no rainfall (Whitmore, 1984) and a wet season during which there is substantial rainfall. This climatic difference, in terms of rainfall frequency, means that there is substantial seasonal variation in the position of the water table relative to the ground surface, and this variation has hindered and/or prevented peat development in these deltas by allowing the organic materials to be oxidized.

SUMMARY AND CONCLUSIONS

The oldest identified Quaternary surface in the Rajang system is the VIIa highstand surface of 125 ka. Maximum elevations are 5 to 7 m above MSL, and maximum incision into this surface is on the order of 45 m. The upper part of much of this surface is capped by a gray-white to white podzol several meters thick. In the Rajang system, the alluvial incised valley is floored with gravel. This material is, in turn, overlain by a fining-upward succession, the upper part of which shows evidence of tidal influence.

The next younger Quaternary surface identified is the IIIb highstand surface of 41 ka. This surface is found at a depth of approximately 80 m below MSL in the seaward part of the delta plain, demonstrating that 40 m of subsidence has occurred in this area during the Late Quaternary. In this same region, the Pleistocene–Holocene transition occurs at a depth of about 40 m below MSL and is identified by a yellow-brown rooted alluvial soil overlain by a gravel lag. A Holocene coarsening-upward succession capped by distributary-mouth sands and/or beach deposits overlies lag deposits.

Peat formation started about 7.3 ka. Initial formation was limited to interfluve areas in the alluvial valley, the northwestern part of the delta plain, and the adjacent coastal plain. Development is primarily aggradational in this part of the system, and thick peat may rest in direct contact with Pleistocene podzols or Recent gley soils.

Shoreline progradation started at about 7 ka in the southwestern part of the delta plain. The oldest system-wide shoreline identified is 5 ka in age. Since then, shoreline progradation has been primarily to the north and northwest, and peat deposits have extended seaward with the shoreline.

The southwestern part of the delta plain is dominated by beach ridges, saline gley soils, and *Nipa* palms. This area was flooded by rising sea level prior to 7 ka and, at present, experiences the highest tides. These factors are thought to contribute to the limited peat development in this part of the delta.

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