

Late Pleistocene sedimentation and landform development in western Kalimantan (Indonesian Borneo)

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Abstract

Widespread Quaternary alluvial sediments occur around the coastal margins of western Kalimantan. These strongly podzolised 'white sands' occur as major alluvial bodies that may be 15–20 m higher than Holocene/contemporary floodplains inland but converge and pass beneath them towards a near coastal hinge line. It is presumed that the sediments continue off-shore and correlate with previously documented 'Alluvial Complex' sequences on the submerged areas of Sundaland. Microscopic and SEM examination of quartz indicates minimum wear on most grains, and the alluvial sediments can be distinguished clearly from those of contemporary beach environments. Their extent, morphology and sedimentary characteristics indicate rapid aggradation within coastal catchments, and some formations appear to be low angle, wet alluvial fans. Radiocarbon assay indicates ages greater than 40 000 RC yr BP for the sediments with 2 finite dates of 54 200 + 3400/– 2400 RC yr BP and 51 000 + 2100/– 1700 RC yr BP. It is concluded that they were laid down during low sea levels and by rapid erosion and deposition possibly caused by increased seasonality of rainfall, decreased total precipitation and associated ecological changes. Neogene tectonic movements may also affect their disposition.

Introduction

Off-shore sedimentation around the islands of the Sunda Shelf has attracted attention as a result of the search for economic placer deposits of cassiterite and stratigraphies have been described, particularly by Aleva (1973, 1985) and Batchelor (1979a). Additional interest in this area derives from the probability that, during periods of low Quaternary sea level, the entire area of 'Sundaland' between Sumatra, Djawa, Kalimantan and West Malaysia was exposed as dry land, the present rivers flowing across broad alluvial plains either northwards to the South China Sea or southwards

into the Java Sea (Molengraff, 1921; Haile, 1971; Tjia, 1980) (Fig. 1). The equatorial latitude and present high rainfall (up to 5 m) place the landmasses centrally in the humid tropics, and much speculation exists concerning the impact of Quaternary environmental changes in this zone (Verstappen, 1975, 1980; Williams, 1985).

Recent studies of Sundaland have focussed upon the Malacca Straits (Emmel & Curry, 1982), West Malaysia (Batchelor, 1979b), Singapore (Gupta et al., 1987), and the Indonesian 'Tin Islands' (Aleva, 1973), but little attention has been paid to Quaternary sedimentation on the present landward areas of western Borneo (Kalimantan) since Smit

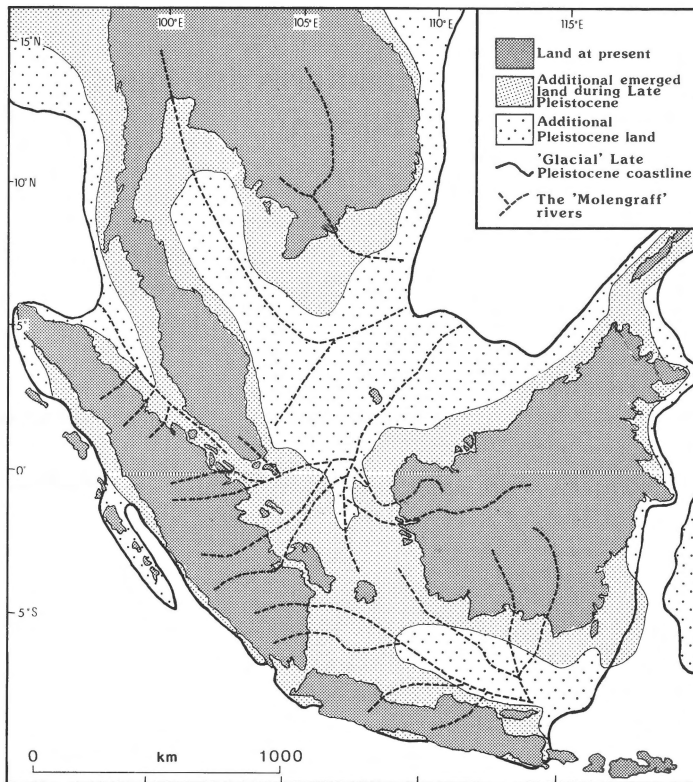


Fig. 1. Sundaland during periods of Pleistocene low sea level after Gupta et al. (1987).

Sibinga's review in 1956. Liechti et al. (1960), Wilford (1967), Woodroffe (1980) and Rose (1984a, b) and Smart et al. (1985) describe alluvial geomorphology for Sarawak to the north east.

The present study describes Late Pleistocene 'white sand' terraces in northwestern Kalimantan, Indonesia, located between the deltas of the Sungai Kapuas in the south and the S. Sambas in the north (Fig. 2). Morphologically the terraces stand up to 15 m higher than the Holocene sedimentary terrain of the coastal plains and valley floodplains and are slightly dissected. Sedimentologically they are distinguished by their white to light grey colour and sandy texture; ecologically they are characterised by 'giant' podzols associated with a 'heath forest' (kerangas) cover.



Fig. 2. Location of the study area in Kalimantan, Indonesia.

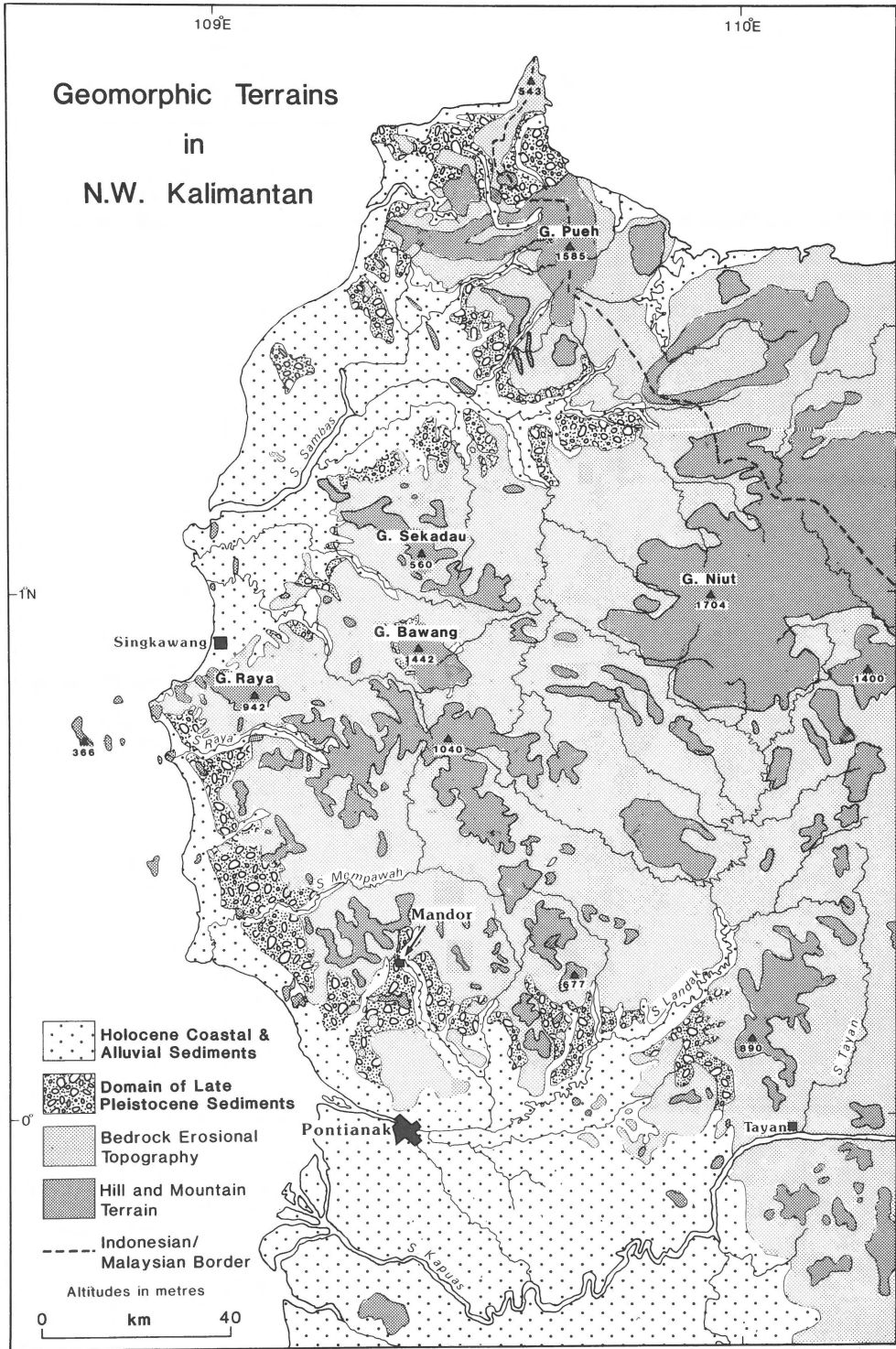


Fig. 3. Aspects of geomorphology and Quaternary sedimentation in W. Kalimantan.

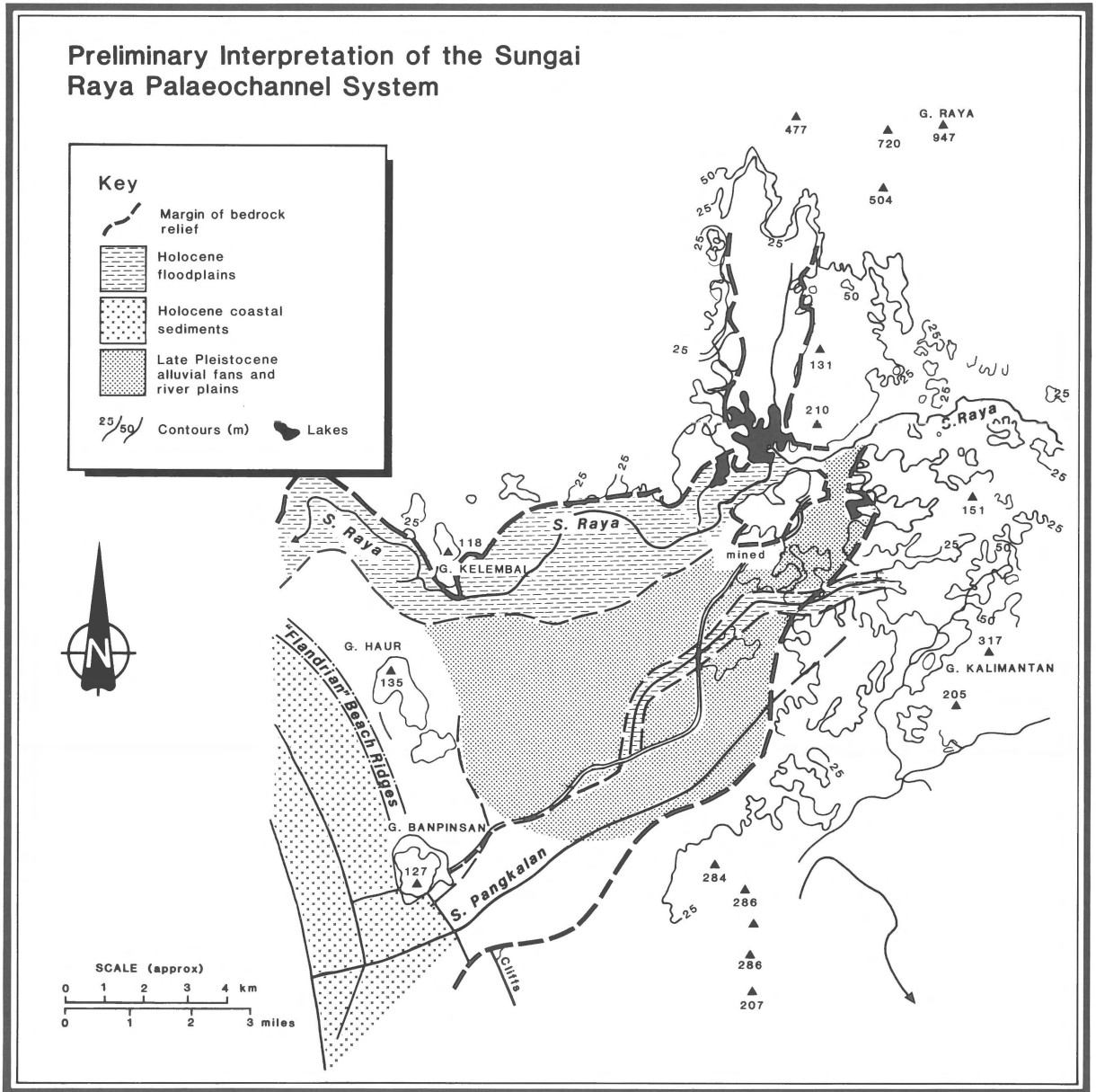


Fig. 4. Geomorphology of the lower Sungai Raya catchment, showing relationships between Late Pleistocene and Holocene sediments and Holocene coastal sediments.

The on-shore late Pleistocene alluvial sediments

Location and morphology

Recognition and mapping of these deposits (Fig. 3) has depended upon a combination of Landsat image analysis, aerial photograph interpretation, ae-

rial reconnaissance, field mapping and banka drilling.

They generally lie immediately inland of extensive coastal lowlands comprising Holocene deltaic, estuarine, paralic and alluvial sediments and swamps (Fig. 9). The terraces repose upon a low-lying gently undulating erosional bedrock terrain

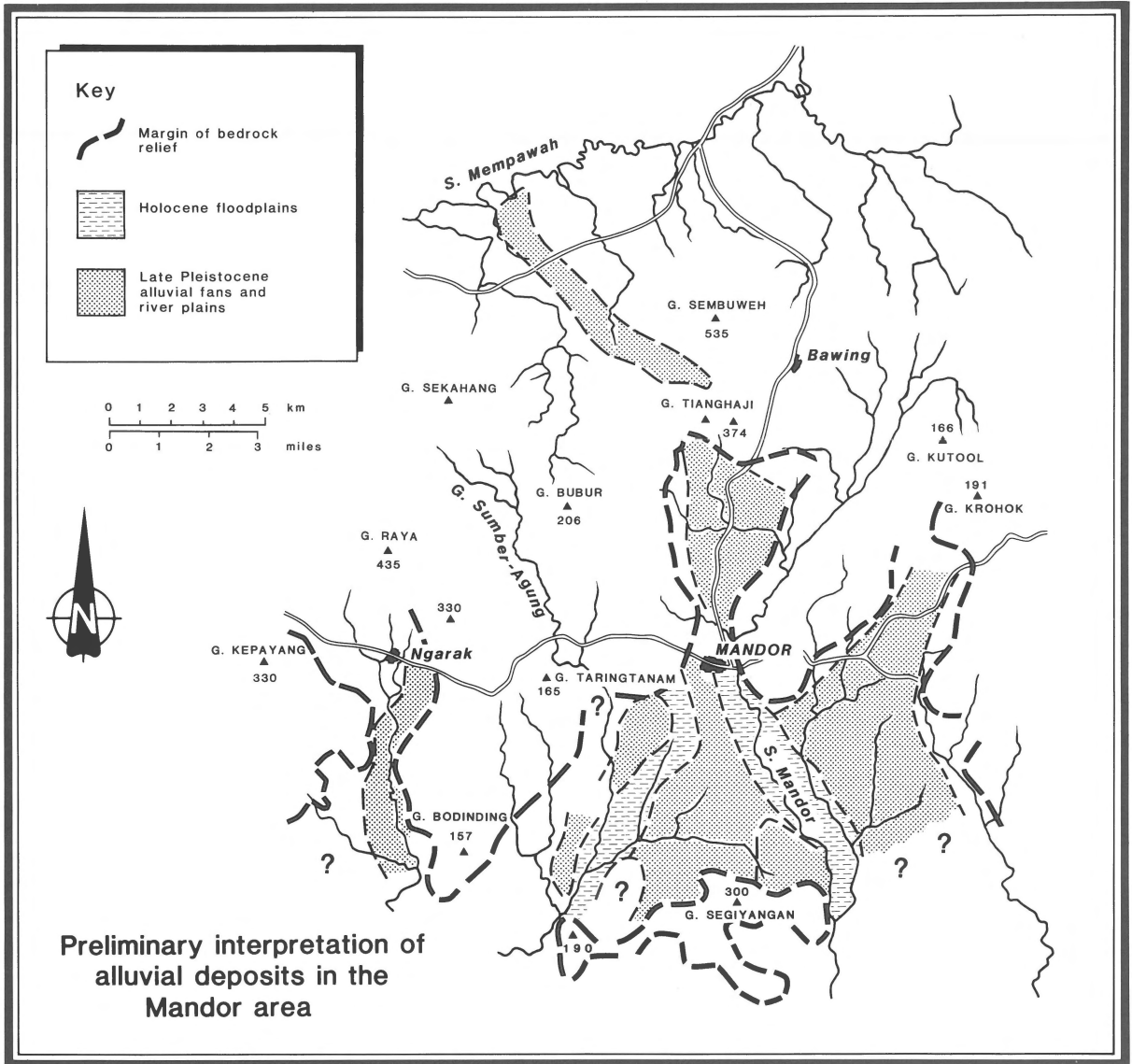


Fig. 5. Geomorphology and alluvial sediments in the Mandor area.

which, together with several mountain massifs and numerous inselbergs, characterises much of western Kalimantan. Rarely do they rise above 25 m asl. they dip beneath the Holocene coastal sedimentary plains. Locally they are associated with drainage basins varying in size from 10's–100's km² and contrasting relative relief, and with all the major lithologies. They attain their greatest extent, however, in the larger catchments and with rocks possessing abundant free quartz such as the Paleo-

gene and Mesozoic quartzitic sandstones and the more granitic ones of the cretaceous batholiths.

Exposed axial lengths of the terraces range from 2 to 20 km and widths vary from 0.1 to 4 km. Reconstruction of the former extents of several of the terraces using air photo interpretation and ground survey, suggests that most of them belonged formerly to much broader floodplains than possessed by the present day rivers (Figs 4 and 5). Usually a series of hill foot or upper catchment tributary

valleys appear to have coalesced into broad fan shaped bodies. However, topographic constrictions caused by inselbergs and ridges commonly pinch the fans into beaded planforms. The sediments vary generally between 5 and 35 m in thickness and form a wedge thickening coastwards. They slope towards the coast at gradients of 1/250–1/350 in marked contrast to gradients of the current floodplains which range from 1/1300–1/2500. The original form of these alluvial bodies has been slightly modified by stream dissection, surface erosion and colluviation, and by Holocene wave trimming in coastal locations.

Stratigraphy

Deep but laterally limited exposures at some Chinese gold mining sites show unmistakable fluvial structures.

Basal gravels vary from being compact, clast supported to coarse sand matrix supported and in general are poorly sorted. Gravel clasts vary from angular to sub angular vein quartz to well rounded sandstone, mudstone and quartz pebbles. Gravel thickness varies with catchment size and generally lies between 2 and 5 m although a maximum value of 15 m thick in a total sedimentary depth of 25 m has been recorded in one of the bodies. Where they have been systematically drilled, gravel calibre is seen to diminish rapidly down stream.

Above the gravels is a series of alternating strata and lenses including sands and fine gravels which grade upwards into less obviously stratified finer sands and eventually into clayey sands. Other terraces show alternating beds and lenses of coarse and fine sand, silty clay, stiff white clay, gravel, and structureless clayey sands enclosing rare, thin horizontal bands of dispersed pebbles. There is a general tendency for fining upwards through the terraces as a whole. Sediment grain size also fines towards the edges of the bodies and there sandy clay sediments tend to dominate the sequences.

Lithofacies and structures include massive, crudely to flat bedded gravels; truncated sandy fine-gravel bars; massive unbedded sand layers; trough, cross, and planar cross bedded sands and

pebbly sands; planar sand beds; flat bedded and laminated sands, sandy clays and clays; clay drapes showing desiccation cracks; sand bed scour hollows filled with fine clays and leaf trash, internal cut and fill channels with fining upward cycles; several layers of heavy mineral concentration usually in hi-regime planar sand beds; and buried humicretes. No pedogenic or organic structures have been seen.

Architectural elements include channels, gravel bar bedforms, sandy bedforms, foreset macroforms, laminated sand sheets. Missing are thick overbank fine elements.

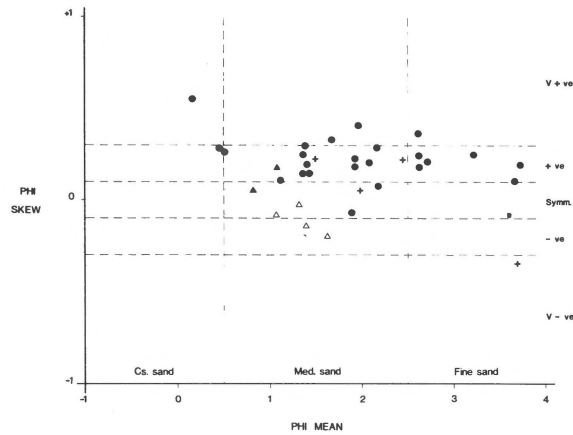
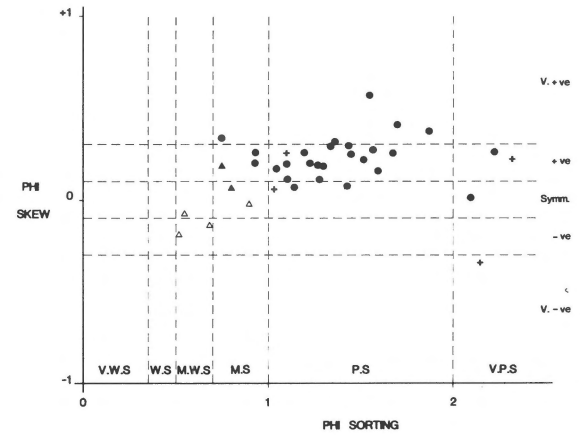
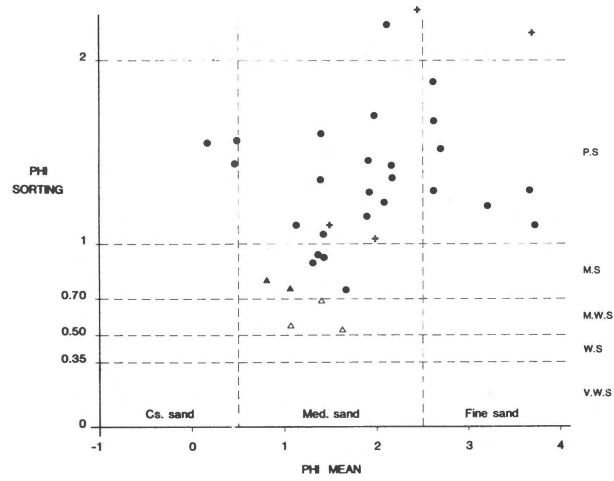
A variety of cut and fill structures, such as local scour channels and gullies, sometimes containing clay balls, appear to be characteristic, whilst others constitute channel and terrace features within the alluvial body as a whole.

The sediments rest unconformably upon erosional deeply weathered bedrock topographies including smooth-floored saucer shaped valleys and low, undulating polyconvex hills with stonelines in ferallitically weathered saprolite. Deeper parts of the buried valley floors sometimes contain shallow bedrock channels containing their own clast supported gravels.

Soils developed on these sediments are always 'giant' podzols with homogenised, bleached and leached Ae horizons 1–3 m deep. This is underlain by a Bh horizon 0.2–2 m thick, part of which is usually indurated into a humicrete.

At some sites the humic material has also been carried several metres down open vertical joint like fractures and deep root tubes in the sediments. They cannot be attributed to simple desiccating and de-watering and, since they occur in relatively elevated exposures of the sediments, the possibility of cambering, possibly assisted by neotectonic movements, should not be ignored. The humicrete in such fissures is usually hard, glossy and brittle.

Colours in the sedimentary bodies beneath the white surface horizon are always pale and dominated by white and dirty white to light grey except when humus and humicrete produce their distinctive black colour. Despite the adjacent and subjacent bright red ferrallitic weathering profiles on bedrock no metal oxide colours have been observ-



WEST KALIMANTAN

Bivariate Scattergrams Sedimentary Particle Sizes

- + - Weathered B/R Δ - Raised Beach
- ▲ - Beach ● - Fluvatile

Fig. 6. Bivariate scattergrams for sediments from four different environments in NW Kalimantan.

ed, save a tendency for very pale pinks in clay matrix layers at the margins of the bodies.

Sedimentology

Particle size analyses show great diversities and the size distribution curves, statistical moments and bivariate scattergrams (Fig. 6) are intermediate between those for in situ bedrock saprolites on the one hand and beach sands on the other and, in general, are not very discriminative.

Sand grains from a number of sites were examined under optical and scanning electron microscopy for signs of etching, wear and other diagnostic features to establish whether any major part of the sediments was marine in origin and whether conditions or duration of transport could be determined (Fig. 7).

Quartz grains from granodiorite saprolites are regular polycrystalline grains with sharp edges and marked secondary silica precipitation on the crystal faces. There is no indication of mechanical wear. Tertiary sandstone quartz grains showed, in addition, slight edge rounding and wear, strong etching and secondary silica precipitation which is thought to be the result of post depositional diagenesis.

Quartz sand from beaches and raised beaches showed abundant well rounded and highly polished grains with surface textures typical of high energy environments. In contrast, samples from the podzolised Ae horizons on the terraces revealed irregular, angular, clean, strongly etched sharp grains and silt sized shards.

Samples from within the terraces were a mixture of irregular angular quartz grains, chemically etched but scarcely worn, and grains with slight wear on some edges and impact marks. Many grains retain sharp protuberances and edges. Chemical dissolution and silica precipitation was always evident. Grains from coarse gravels and current bedded sands also retain their angularity and show little more than edge wear. On the other hand, quartz and zircons originally derived from Mesozoic sedimentary rocks show more pronounced edge rounding, in contrast to those de-

rived from the intrusive rocks or Paleogene sandstones.

Collectively, these wear properties indicate, for the most part, that the quartz grains in the Late Pleistocene alluvials have not been subject to repeated or sustained high energy transportation processes, that they have not travelled far (possibly less than 10 km), that they have not been substantially reworked after initial deposition and that the grains have not been deposited or modified in a beach environment. No samples from the presumed alluvial bodies contained sand grains exhibiting the shape and wear textures on grains from beaches and raised beaches.

X-Ray diffraction analyses on clay from several sites and strata (Fig. 8, see page 142), show quartz, gibbsite, illite/muscovite, kaolinite, chlorite, and serpentine. Gibbsite will be produced during the podzolisation process and with the desilication of kaolinite, and its presence is expected in freely draining materials in this environment. The presence of 2:1 lattice clays in the finer sediment is possibly indicative of rapid erosion and deposition of immature saprolite formed within the upper catchments. Although the weathering of the granodiorite and country rocks will lead to ferrallitic dominance, the regolith on steep slopes will contain intermediate 2:1 clays. It is not possible in this study to verify whether neof ormation of 2:1 clays has occurred within the profiles sampled.

Age and conditions of sedimentation

Age (cf. Table 1)

The alluvial sediments contain abundant and well preserved organic matter ranging from leaf trash in clay lenses to portions of trunks and branches.

Five initial radiocarbon determinations on timber and leaf trash from various depths in the paleo alluvial bodies of the S. Mandor, S. Raya and Pasir Panjang all returned ages of greater than 40 000 radiocarbon years BP. Two further samples were assayed at Groningen and gave finite dates of 54 200 + 3400/- 2400 RC yr BP (GRN14865) from

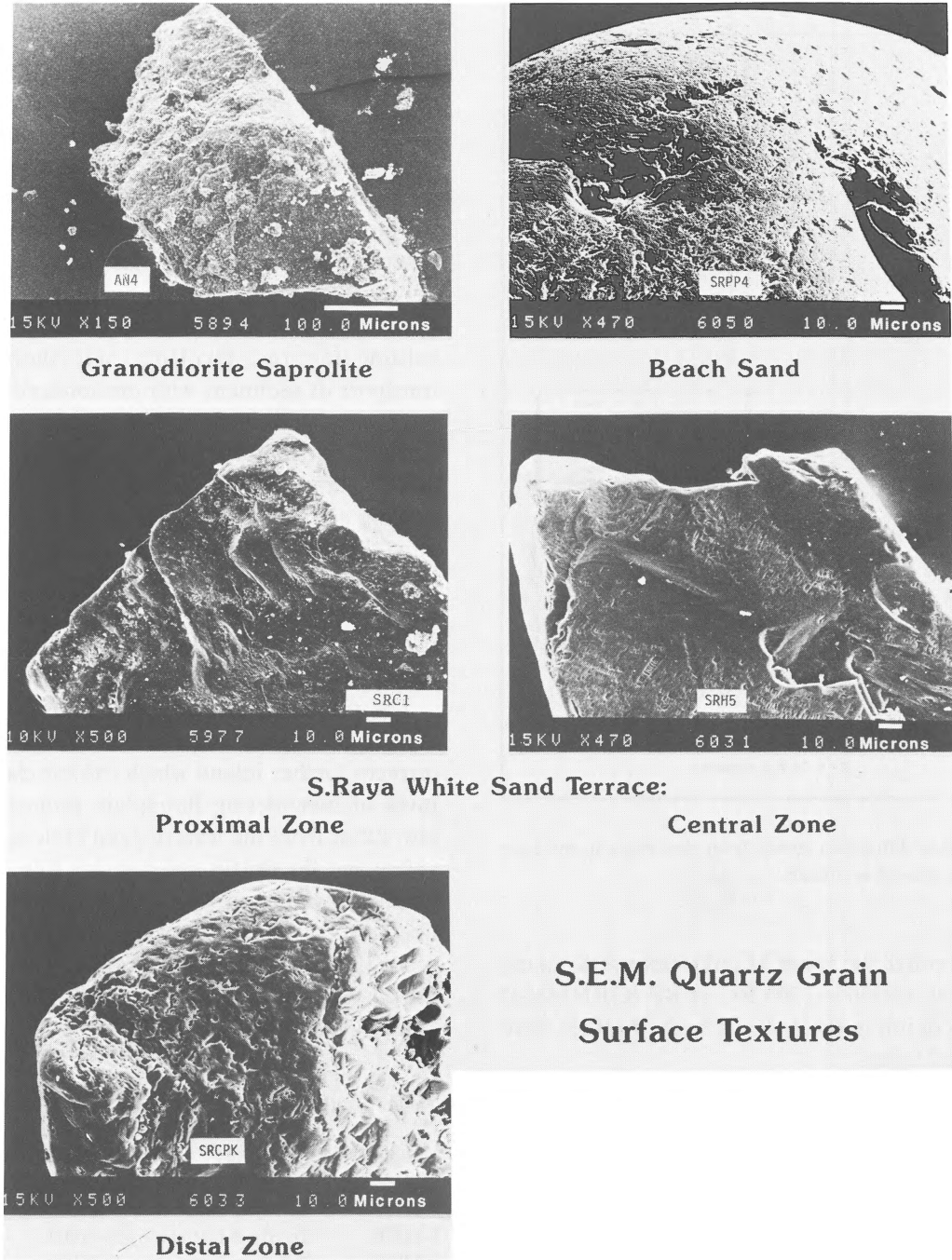


Fig. 7. Scanning electron photomicrographs illustrating quartz grain textures from bedrock and five sedimentary environments in NW Kalimantan.

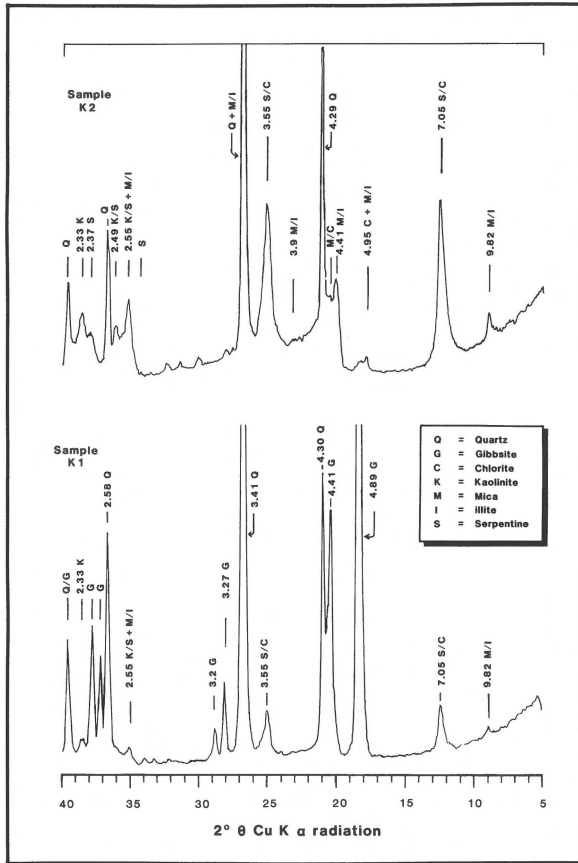


Fig. 8. X-Ray diffraction curves from clay strata in the Late Pleistocene alluvial sediments.

11.5 m depth in the lower Mandor body at Koping and 51 000 + 2100/– 1700 RC yr BP (GRN14864) from 6 m depth in the S. Raya body. Neither were from basal layers.

Conditions of sedimentation

Lack of exposures, varied extrinsic catchment controls, down system and temporal variations render fluvial interpretation of the structures and architectural elements difficult. The combinations of structures and architectural elements fits no one of the several lithofacies or architectural style models exclusively. There is evidence for channel stability and instability; for meandering, braiding, anastomosing channel morphologies and for sheet flow.

Architectural style models as diverse as low sinuosity stable anastomosing floodplain systems, sheet flood alluvial plains subject to flashy discharge, classic sandy mixed load meandering river floodplains, and low sinuosity wide shallow platte type channels with linguoid bars, can be applied to the range of structures.

The sedimentary and morphological properties described above suggest that these sedimentary bodies were formed by aggradation of sediments close to source areas, mainly hill slopes and pre-existing terraces, involving only short distance transport of sediment with pronounced distal fining. They were built by single axial streams and by converging tributary streams, which varied in their lateral stability over time and between valleys, flowing across broad alluvial surfaces with fluctuating flow depths and velocities in sheet floods and channel flows. Multiple channels may have characterised proximal zones of the fans. Groundwater conditions remained high and swamps were occasionally present.

The properties of these Late Pleistocene alluvials contrast markedly with the Pleistocene river terraces further inland which exhibit classical features of meandering floodplain sediments. They also differ from the waterlogged Holocene swamp valley and floodplain sedimentary fills. These are characterised by grey to dark brown organic rich fine sand clay sediments over matrix supported and often discontinuous basal gravels. Large timbers are usually present throughout the soft, wet swampy fills.

Table 1. Details of radiocarbon dates

Sample No.	Laboratory	Age in RC Yr. BP
I-14869	Teledyne Isotopes	> 40 000
I-14870	Teledyne Isotopes	> 40 000
I-14871	Teledyne Isotopes	> 38 000
I-14872	Teledyne Isotopes	> 40 000
I-14873	Teledyne Isotopes	> 40 000
I-15440	Teledyne Isotopes	4 830 ± 210
I-15691	Teledyne Isotopes	9 970 ± 150
I-15692	Teledyne Isotopes	10 250 ± 150
GRN14864	C10 Groningen	51 000 + 2 100/– 1 700
GRN14865	C10 Groningen	54 200 + 3 400/– 2 400

Just as today within the same region there are fluvial morphologies and alluvial habits varying with lithology and catchment dimension, so at any time in the past functional differences may be expected. The following range of Late Pleistocene alluvial conditions, therefore, may be envisaged.

In small catchments or those whose rocks yielded predominantly fine grained sediments, wet swamp-like valley fills may have been built when former suspended load multiple channels – not unlike those in the present day swamp valleys – became braided as aggradation took place. This may have been induced when bedloads increased in either amount or calibre, sufficient to allow bar formation under long term conditions of fluctuating discharge and enhanced sediment yield from the catchment slopes experiencing changed ecological conditions.

Where rocks and terraces yielded a higher proportion of sand and fine gravel sized sediment an increased sediment yield from the catchment may have led to continuous braiding in mainly sand bed rivers which constructed low angle ‘wet fans’ with more varied granulometries and sedimentary structures.

In the larger valleys, under conditions of one or both of reduced and fluctuating discharge and increased catchment sediment yield, the rivers may have been able to redistribute much of their sediment throughout a multi-channel aggrading floodplain displaying highly varied internal architecture and progressively burying the valley bottoms as the fills thickened and spread. Sediments may still have contained a high proportion of fines and it is not necessary to envisage a change to a fluvial system dominated totally by coarse bedload transport.

We infer discharge regimes associated with a more seasonal, cooler and drier climate and more open vegetation than today. However, sustained high watertables in the sediments both during and since their deposition are also required; neither is it easy to reconcile inferred active erosion of catchment slopes with the thick ferallitic weathering profiles on the present-day granodiorite hill slopes.

The formation of the upper ‘white sand’ horizon

The upper, structureless white sand horizon, together with a general coastal distribution has led to some conjecture concerning a possible marine or beach origin, in whole or in part, for these sedimentary bodies or for the upper white sand layer. There is, however, no evidence from the grain morphology to support this view, except where the sands occur as part of an unambiguous raised beach deposit. Other striking superficial white sand formations and podzols in Kalimantan Barat have developed on sandstone bedrock, on locally redistributed sands derived from adjacent sandy textured regoliths, and on Holocene raised beach sands.

Similar coastally located deep podzolic soils on sandy materials in Sarawak have been described by Liechi et al. (1960), Wall (1964), Klinge (1965), Andriesse (1968, 1970) and Woodroffe (1980). Bleackley (1956) and Bleackley & Kahn (1963) described the formation of the superficial white sands in unconsolidated Pleistocene sedimentary formations in coastal Guyana using terms that would be called podzolisation. Heyligers (1963) considered that similar white sands in Surinam had originated as a superficial blanket by colluvial redistribution of older fluvial sediments under increased rainfall and which had since become bleached by leaching of iron and other constituents.

Regarded as characteristic of the sandy coastal plains of the very humid equatorial regions, Duchaufour (1982) classifies such soils as ‘Tropical Hydromorphic Podzols’ developing in response to special site conditions that contrast markedly with the ferallitisation of well drained areas elsewhere. According to Duchaufour (p. 332) these conditions are “(i) the presence of a permanent water-table; and (ii) a parent material impoverished in weatherable minerals and with a sandy texture”. The Late Pleistocene alluvial deposits satisfy these requirements.

The west Kalimantan ‘white sands’, therefore, are not a sedimentary unit per se; rather they are the upper, spodic, leached Ae layer of a podzol characteristically formed within a limited range of

dominantly sandy sediments, most of which are fluvial in origin.

Subsequent development

Figure 9 schematically presents the essential stratigraphic relationships as understood at the present. Today, many of the paleo alluvial bodies are dissected and form slightly elevated topography relative to the valley floors. Several of the larger bodies are crossed by streams almost in a superimposed manner, others pick out the junctions or feather-edges between the porous sediments and the flanking ferallitically weathered bedrock terrain. These streams have trimmed back the edges of the original bodies and have also initiated interior dissection. During this dissection, it would appear that, in many valleys, the adjacent weathered bedrock terrain has undergone volumetrically more erosion than the paleo alluvial bodies probably because of the protection accorded to the terraces by their high porosity and humicretes. Bedrock floors beneath the adjacent Holocene valley fills are lower and far more irregular than those beneath the paleo alluvials inland of the long profile crossover zone.

No indications of any paleo channel morphology have been seen on the upper surface of the terraces and it appears that the original surface of the terraces has undergone slight stripping and redistribution of sediments. However, heavy mineral concentrations in the podzolised white sands and the thickness of Bt horizons suggest that any surface erosion may not have removed more than one to two metres of former sedimentary cover.

Following this incision and dissection, sea level rose, eventually building several beach ridges at ca. +2 to +6 m. Vegetation trash in fine grained sediments that are banked against the seaward face of one of these ridges north of Singkawang has yielded a radiocarbon date of 4830 + 210 yr BP (I-15440). During this Holocene transgression basin peat swamps and humus rich sandy clay accumulated in the larger river estuaries and behind beach ridges in lagooned coastal valleys whilst conventional floodplain sequences with back swamps

and peat basins accumulated in the valleys of the larger rivers. Basal sandy gravels in contemporary floodplains adjacent to the white sand terraces have yielded ^{14}C dates of 9970 ± 150 yr BP (I-15691) and 10250 ± 150 yr BP (I-15692). The Paleo Alluvials were intensively podzolised and humicretes developed.

Discussion

Causes of sedimentation

Eustatic, bio-climatic and tectonic hypotheses can be advanced in an attempt to explain the formation of these late Pleistocene sedimentary bodies.

Eustatic hypotheses. Smit Sibinga (1956) explained Pleistocene alluvial sedimentation and fluvial incision in Borneo in terms of the effects upon river base levels of sea level maxima and minima respectively. Consequently, his 'high terrace', which is widespread and may in fact be correlated with paleo alluvial bodies being described here, is correlated with the Riss-Würm Interglacial high sea level. This mechanistic coupling is no longer tenable and its chronological basis is incorrect.

White sand sedimentary bodies in Sarawak and Brunei, perhaps comparable with those being described here, have been explained in terms of high sea level beach constructions (Liechti et al., 1960; Wall, 1964; Andriess, 1968; James, 1984) and until Haile (1971) the 'Old Alluvium' of West Malaysia also was regarded largely as of marine origin.

The traditional model for relative sea level changes during the Quaternary for this part of SE Asia (Tjia, 1980), holds that there were several Pleistocene transgressions producing raised shorelines, sediments and platforms up to 50 m asl. Haile (1971) and Batchelor (1979a) have shown that the evidence upon which these higher marine levels are based is either ambiguous, wrongly interpreted or not indicative of high sea levels.

There is evidence, however, for several transgressions and regressions over the Sunda Shelf but at levels below present day sea levels (Biswas, 1973; Aleva, 1973; Aleva et al., 1973) whilst Tjia

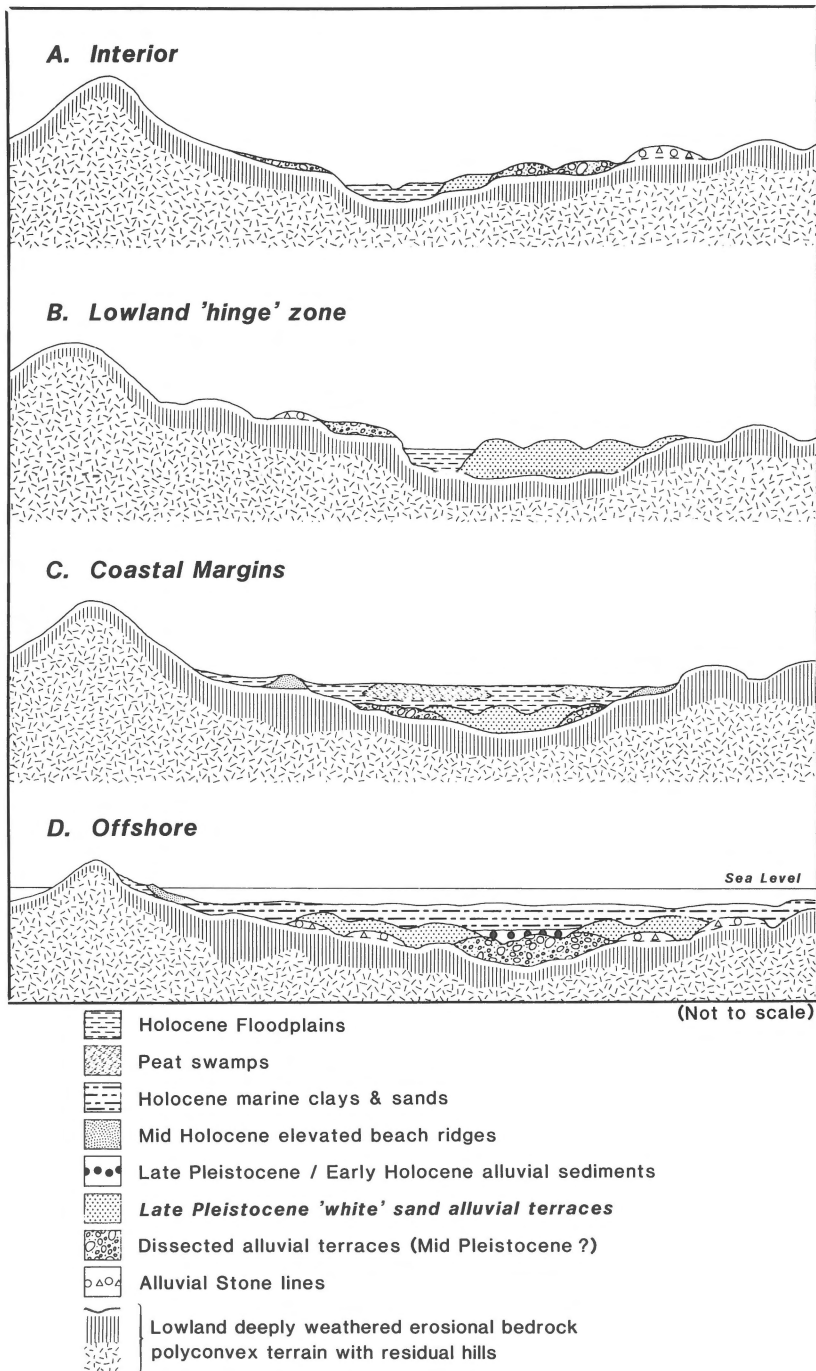


Fig. 9. Schematic cross sections illustrating the sedimentary sequence as found in valley profiles at different locations in NW Kalimantan.

(1988) suggests that some of the supposed high sea level features may have been elevated by on-going uplift.

Batchelor (1979a and b), on the other hand, argues for a continuous rise of sea level since the Miocene at a rate of some 10 cm/1000 yr, upon which glacio-eustatic variations have been superimposed. According to his model the Sunda Shelf was first partially flooded by the sea during the last interglacial, and the highest sea levels, of 3–6 m, were attained during the Holocene transgression ca. 5500 yr BP.

We have seen no evidence for sea levels higher than the suggested Holocene maximum in the study area. In view of the conclusion in this paper, that uplift has affected western Kalimantan during the Quaternary, any inland marine sediments would be difficult to interpret as such, while subsidence of the Sunda Shelf will have carried any former shorelines below present sea level.

Tectonic hypotheses. During the Neogene NW Kalimantan has experienced major uplift, block faulting, igneous intrusions and vulcanicity and there is clear evidence for igneous activity continuing through the Pleistocene (Viaene et al., 1981; Metal Mining Agency Japan, 1982; Williams & Harahap, 1987). The Sunda Sea has clearly flooded a sub-aerial topography whose bedrock surface is morphologically similar to the on-land erosional terrain and is of Neogene age.

It is quite possible, therefore, that the sediments found in western Kalimantan could have formed mainly in response to flexuring of the landmass along a hinge line between landward uplift and seaward subsidence of the Sunda Shelf. The accumulation of the deposits described here could have occurred over quite a short period (10^3 yr), suggesting that a trigger mechanism operated to start the process and that it may have been ended by incision into the sedimentary pile and development of lower alluvial plains, possibly but not necessarily by a second and similar energy pulse delivered to the system.

Gradients of the bedrock floors of the paleo alluvials are steeper than those of the adjacent Holocene alluvials and the two profiles cross over

today inland of the coast. This may be interpreted, in part, as a consequence of the river regimes of the time, but possibly also as a reflection of continuing crustal tilting and subsidence around the margins of the Kapuas and Sambas tectono-sedimentary basins.

Evidence from peninsular Malaysia indicates that the 'Old Alluvium' is found inland at heights of at least 75 m, and similar deposits (Simpang Formation) are also described from coastal basins in Perak down to –66 m (Suntharalingam, 1980, 1983). There is also reference to warping and slight faulting, as well as to Pleistocene vulcanism (Stauffer, 1973).

Bio-climatic hypotheses. Morphologically and ecologically these terraces bear similarities with those in the Melinau drainage in Sarawak described by Woodroffe (1980) and Rose (1984 a & b) and Smart et al. (1985). Rose argues that there the sedimentation was a response to a runoff-sediment yield balance similar to the present day and he proposed a Last Interglacial age with the subsequent dissection being a response to both lowered sea levels and reduced sediment yield during the Last Glacial Cycle.

In western Kalimantan, however, there appears to be no present day analogue for the terrace sedimentation. The 'white sand' alluvials differ from the Holocene swamp valley and floodplain sedimentary fills which are dominated by soft, organic muds and fine sandy clays and thin basal gravels. Rivers adjacent to the terraces have stable, single, straight to meandering channels or anastomosing, swampy seepages. Sediment loads in the 'black-water' rivers are low and dominated by humic acids, suspended clays and silts and fine sands. Within channel bars are rarely seen but in streams with hilly catchments sand and gravel is transported as bedload during flash floods.

Whether repeated transgressions and regressions over the Sunda Shelf or progressive submergence is the preferred Eustatic model for the Sunda Shelf, and whether or not the global climatic changes of the Last Glacial Cycle directly and significantly affected western Kalimantan, the climato-geomorphic implications for NW Kalimantan of an

emergent Sunda Shelf are immense (Fig. 1). They include a catastrophic reduction in rainfall, derived as it is today from the Inter Tropical Convergence and passage of the two monsoons across the warm waters of the Java and South China Seas. Only the northern, winter monsoon, would have crossed warm ocean water to the north east of Borneo. The summer, southern monsoon after crossing the Djawa and Sumatra mountain ranges would have encountered no extensive water bodies between them and western Kalimantan. Verstappen (1975, 1980) suggests that in this area the whole of this period was characterised by a glacial 'dry' climate with strong seasonal contrasts, total amounts of annual rainfall reduced by at least 30%, low sea level and tree savanna vegetation. It is possible to argue, therefore, that the construction of these sediments was a response to the accelerated sediment yields and reduced and more flashy stream discharges associated with such bio-climatic conditions.

The apparently limited age span of the sediments when compared with the total period of the Last Glacial Cycle may reflect insufficient dates and exposures but also perhaps the crossing of an erosional threshold during the sustained bio-climatic deterioration of the last cold cycle.

The date of sediments, ca. 60 000 to 50 000 yr BP, places the construction of these alluvial bodies within the Vostok deuterium isotope stage C (Jouzel et al., 1987) and the ocean oxygen isotope stage 3, 58 000–30 000 yr BP, (Shackleton & Opdyke, 1976). This period, regarded as an interstadial, was characterised by a sudden minor but marked rise in global temperatures and possibly in available precipitation. Therefore it can be suggested that the erosion and sedimentation was triggered by this slight amelioration in the 'glacial' climate at the Emiliani Termination 4/3 of 60 000–56 000. The basal sediments at least, are older than 54 000 yr BP. A similar geomorphological response has been identified for the period 13 000–8000 yr BP at the end of Late Glacial Maximum in monsoonal West Africa (Thomas & Thorp, 1980, 1985).

In our opinion, the cause of this Late Pleistocene sedimentation, at least in NW Kalimantan, lies in a combination of low sea level, bio-climatic change and the effects of differential warping. As in many

other coastal areas of the world these factors must have operated together, but to unravel the separate strands and their share of causality remains difficult and, in this case, conjectural.

Regional correlations

Comparison and correlation of the paleo alluvial sedimentary bodies with other Pleistocene stratigraphies on Sundaland is, at the present, difficult, largely due a lack of absolute dates, to spatial discontinuities and to the erosional and pedogenic modification of surviving on-land depositional units.

Comparable terrace deposits, warped in some places, in Sarawak and Brunei have been described by Liechti et al., 1960; Wilford, 1967; James, 1984 where they have been called the 'Jerudong Cycle'. Their age has not been absolutely determined but they have been accorded a mid Pleistocene age.

Whilst multiple alluvial sedimentary terraces have been identified in the orogenic areas of Kalimantan, Sarawak and Brunei and accorded broad Pleistocene age ranges, most of the on-land stratigraphies come from peninsular Malaysia and the Indonesian 'Tin Islands'. For West Malaysia and Singapore an 'Old' and 'Young' Alluvium is widely recognized. Ages proposed for the 'Old Alluvium' range from Late Pliocene to Late Pleistocene, the older ages on the bases of pollen, fossils, paleomagnetic reversals, tektites and stratigraphic similarities. In contrast to these, radiocarbon dates of timber from the 'Old Alluvium' in peninsular Malaysia (Sivam, 1969; Bin Ayob, 1970), although mostly greater than 39 000–41 500 years BP, include one reported date from Sungai Besi of 36 420 + 1255/– 1085 yr BP. Gupta et al. (1987) found no datable material in the Singapore 'Old Alluvium' and did not suggest a precise age range for their sediments. Sivam gives a date of 3070 ± 100 yr BP for part of the 'Young Alluvium' in the Kinta Valley, which elsewhere in West Malaysia is undissected.

A synthesis of work on off-shore sedimentation was published by Batchelor in 1979b drawing heav-

ily on work by Aleva (1973). The stratigraphic relationships he proposed may be summarised:

1. the 'Sundaland Regolith', late Miocene to Pliocene;
2. an 'Older Sedimentary Cover' of piedmont fan and alluvial plain facies dating from the late Pliocene to early Pleistocene;
3. an occasional 'Transitional Unit' of varied lithology associated with marine sediments assumed to date from the last interglacial, and
4. a 'Younger Alluvium' deposited in valleys cut within these units. It is divided into
 - (a) an 'Alluvial Complex' of meander channel and floodplain deposits shown to have alluvial fan facies towards its landward margins and deposited in broad valleys incised down to -120 m below sea level. This formation is considered to be late Pleistocene and broadly correlated with the last major glacial cycle, and
 - (b) a 'Younger Sedimentary Cover' of Holocene age, comprised of up to 30 m of neritic muds and beach sands, overlying and blanketing all older formations.

Correlations between the on-land and the off-shore stratigraphies which are supposed to be spatially continuous are confused. Batchelor (1979b) suggests that the 'Old Alluvium' is continued off-shore in the Older Sedimentary Cover and the 'Young Alluvium' is continued off-shore in the Alluvial Complex. However, the Alluvial Complex shows a weathered top surface and is buried by up to 20 m of neritic and marine sediments of the Holocene Transgression, early stages of which have yielded a date of $11\,170 \pm 100$ yr BP (Biswas, 1973) and whose peak has now been widely dated around Sundaland at 5000–6000 yr BP (Tjia et al. 1984).

Consequently, we would prefer to correlate the 'older alluvia' of West Malaysia with the off-shore Alluvial Complex and accept that both were formed sometime during the last global 'glacial' climate cycle of 140 000–20 000 yr BP. It is quite possible, however, that the cut and fill structures characteristic of the off-shore Alluvial Complex were built over a greater part of the Pleistocene in response to the numerous global cold climatic cycles. It is clear that many more dates are required to

demonstrate the real ages of the Old and Young Alluvia and the Alluvial Complex.

Gupta et al. (1987) interpret their 'Old Alluvium' of Singapore Island as "proximal facies of an extensive, braided river deposit that was laid down on the Sunda Shelf when much of the bed of the South China Sea was exposed". This resembles our own conclusions for the NW Kalimantan terraces. The architecture, geomorphology and stratigraphic position of the off-shore 'Alluvial Complex' also resembles these terraces.

We propose, therefore, that the NW Kalimantan Late Pleistocene Alluvials are a part of a major sedimentary episode, that they are continued off-shore in the 'Alluvial Complex', that these sediments were deposited between ca. 60 000–45 000 yr BP during low sea level and in response to a more seasonally pronounced and drier climate with associated more open vegetation, enhanced upper catchment erosion and down catchment aggradation, triggered by the interstadial of isotope stage 3 and C and perhaps reinforced by tectonic coastal flexuring.

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