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QUATERNARY STRATIGRAPHY OF ASIA AND THE PACIFIC IGCP 296

QUATERNARY STRATIGRAPHY AND PALEOENVIRONMENTS OF AUSTRALIA, CHINA, INDONESIA, PHILIPPINES, REPUBLIC OF KOREA, THAILAND AND VIET NAM

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FOREWORD

This publication, fourth in a series devoted exclusively to the study of Quaternary stratigraphy in the Asia-Pacific region, contains a selection of papers presented at the third and fourth regional meetings of Project 296 of the International Geological Correlation Programme (IGCP) held in Phuket, Thailand from 14 to 21 October 1991 and in Ho Chi Minh City, Viet Nam from 13 to 15 December 1992.

The meeting in Phuket was combined with field studies in both Malaysia and Thailand. A field trip from Kuala Lumpur to Phuket made it possible to directly compare Quaternary stratigraphic sequences in both countries. The papers presented at this meeting reflect recent work done and progress made in Quaternary stratigraphy and its correlation in Australia, China, Indonesia, the Philippines, Malaysia, the Republic of Korea, Thailand and Viet Nam. A tentative framework for correlation of Quaternary sequences in Southeast Asia was submitted and discussed at the Phuket meeting (see Chart in Volume XII of the ESCAP Atlas of Stratigraphy).

The papers presented at the meeting in Ho Chi Minh City focused on the problems of stratigraphic correlation between China an adjacent areas as well as on the stratigraphy of Quaternary sediments and events in Viet Nam and their comparison with neighbouring countries. The study of paleoclimatic cycles during the Late Quaternary in Australia and their comparison with paleoclimatic events brought further evidence for the correlation of pluvial with interglacial and glacial with interpluvial stages. Detailed studies of tin-bearing Quaternary deposits in Malaysia enabled their stratigraphic assignment within the framework of Quaternary stratigraphic correlation for Southeast Asia.

The eolian sediments of tropical areas in Southeast Asia have been studied further in both Viet Nam and Thailand and were the topic of a field trip leading from the vicinity of Ho Chi Minh City to the coastal area surrounding the town of Vung-Tau.

The results achieved so far support the possibility of a wide correlation both of Quaternary stratigraphy and paleoclimatic cycles found in this part of Asia and the Pacific region; some data point to important affinities to Quaternary events on a global scale.

These recent observations will undoubtedly have their impact on solutions of problems of applied geology, related e.g. to mineral exploration, environmental studies, engineering geology and so on.

The objectives of project IGCP 296 could not have been achieved without such sponsoring organizations as UNESCO, the International Union of Geological Sciences (IUGS) and the Committee for Coordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas (CCOP) to which the Economic and Social Commission for Asia and the Pacific (ESCAP) added its continuing assistance. Nor would the project have been as successful without the active support and participation of national institutions, in particular the Geological Survey of Malaysia, the Department of Mineral Resources of Thailand and the Geological Survey of Viet Nam.

Although this volume, as mentioned, contains papers presented on two different occasions, they have here been combined in a logical, rather than chronological order. Meanwhile, the need to reach a wider audience has been recognized, a.o. to get more involved in current global discussions on environmental issues, such as climate change and associated topics. A direct consequence is, that text should avoid non-essential academic terminology or technical 'jargon' to render it more transparent even to readers without a specialized background. Hence 26 ka BP may now read 26,000 years ago, to name but one example.

Finally, a few words of appreciation to the Project Leaders, Drs. Jon Rau and Vladimír Šibrava, not only for their role in organizing the meetings, but for apparently solliciting such enthusiasm from the members of the various national working groups on IGCP 296. We are confident that the following pages will convey some of this enthusiasm.

Bangkok, 12 November 1993
The Secretariat

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LATE QUATERNARY ENVIRONMENTS OF TROPICAL AUSTRALASIA[1]

by

Peter Kershaw[2], Tonia Stokes[2] and Paul Bishop[2]

IGCP 296

1. INTRODUCTION

This paper examines the environmental history of tropical Australasia from a comparison of results from three areas that provide fairly continuous records through the effective period of radiocarbon dating, i.e. the last 35,000 to 40,000 years. The areas are the Atherton Tableland, the Carpentaria Basin and the highlands of New Guinea. It is expected that this synthesis will provide some basis for comparison with records from similar latitudes in the adjacent southeast Asian region of the Northern Hemisphere.

2. DATA SOURCES

The three areas being discussed differ in their environmental settings, the evidence from which these histories are derived, and in their sensitivity to various environmental variables. Sites from the Atherton Tableland are situated along climatically sensitive precipitation and altidudinal gradients, and are located close to the major rainforest-savanna boundary. Sediment and pollen analysis from crater lake and swamp deposits at these sites record variations in lake level and the surrounding dryland vegetation. A number of scattered palynological sites across the highlands of New Guinea provide data largely on temperature derived from changes in the altitudinal distribution of vegetation types. Evidence is primarily from pollen accumulated in river valley swamps and glacier cirque lake sediments. The record from the Carpentaria Basin is one of coastal lake, estuarine and marine environments, and provides evidence of sea levels, water chemistry (particularly salinity), precipitation and hydrology, and the surrounding vegetation. Evidence is derived from the nature of sediments, the taxonomy and Mg/Ca, Sr/Ca and Mg/Sr ratios of ostracod shells, eolian dust peaks and pollen analysis. From these records four periods (circa 40,000 to 26,000 years BP, around 26,000 to 15,000, about 15,000 to 7,000, and around 7,000 years BP to the present) have been chosen to facilitate discussion and record correlations. The locations of the study areas, together with a generalised vegetation cover for the present day and an inferred cover for the height of the last glacial period 18,000 years ago, are shown on Figure 1.

3. FROM 40,000 TO 26,000 BP

The record from the Carpentaria Basin indicates the existence of a large (reaching more than 29,000 km^2), rather shallow (less than 10 m) lake: Lake Carpentaria, from about 35,000 BP when sea levels were substantially lower than today (see Figure 2). Prior to this time the record is complicated by the effects of the Fly river that flowed southward from the New Guinea highlands. It was tectonically diverted to the southeast sometime between 40,000 and 35,000 years ago (Torgersen et al., 1988).

Early Lake Carpentaria deposits (around 35,000 to 26,000 years BP) of shelly mud indicate fresh to brackish water conditions with no connection to an open marine environment (De Deckker et al.,1988) despite the evidence from the Huon Peninsula raised coral reefs for a sea level rise sufficient to drown the lake (Chappell 1983). It is considered by Torgersen et al., (1988) that the degree of sea level rise must have been overestimated. The regional vegetation was open savanna, similar to that found on the black soil

[1] *Paper presented at the IGCP 296 regional workshop held in Phuket, Thailand from 14-21 October 1991*

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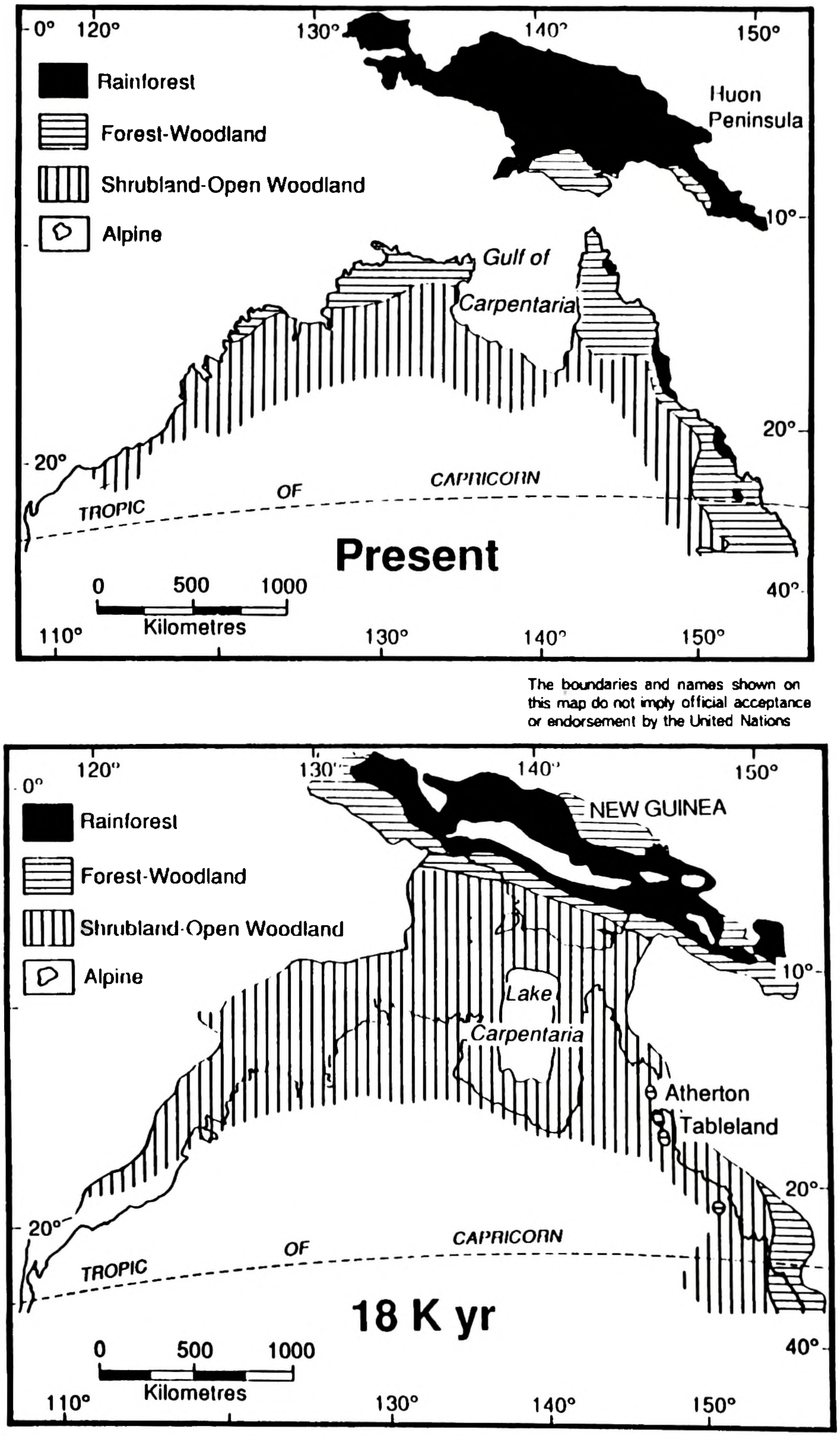

Figure 1. Reconstruction of vegetation in tropical Australasia, at present and 18,000 years ago (modified from Markgraf *et al.*, 1991)

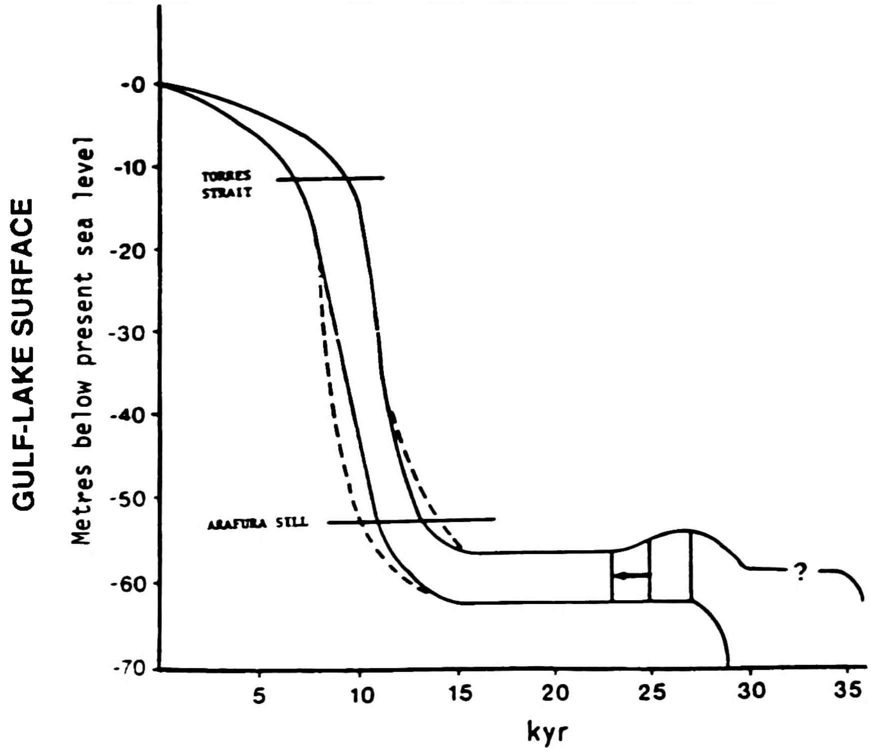

Figure 2. Water level curve for the Carpentaria Basin. The Arafura sill marks the divide between lake and marine conditions (modified from Torgerson *et al.*, 1988)

plains of the Carpentaria lowlands today, to the south of this area. High pollen concentrations, particularly of aquatic taxa, indicate that the lake was surrounded by swampy floodplain environments suggesting the occurrence of an intense seasonal wet season. However, effective precipitation is considered to have been substantially lower than present.

On the Atherton Tableland this period represents a transition from dry rainforest to sclerophyll vegetation under rainfall levels possibly as low as half of those of today (see Figure 3). This transition is marked by increased burning, indicated by high charcoal levels in the sediment cores. Although burning may have been facilitated by a slight reduction in precipitation about 40 ka (indicated by lower lake levels), it is considered that changes resulted primarily from the firing activities of Aboriginal people (Kershaw, 1991).

The available pollen records from the highlands of New Guinea dating back to c.35 ka suggest that vegetation patterns in this period may not have been substantially different from those of today (Kershaw, 1988). Tree lines were lower but probably not as low as suggested on Figure 4 before 30,000 BP (Kershaw, 1988). The first significant charcoal representation occurs around 30,000 years ago and this is considered to indicate burning of swamp vegetation and possibly the presence of people (Swadling and Hope, 1991).

4. FROM 26,000 TO 15,000 BP

The beginning of this period (from 26,000 to 23,000 BP) is marked by the deposition of highly laminated sediments containing abundant calcite crystals but the environmental conditions associated with these sedimentary features have proved difficult to determine (Torgersen et al., 1988). From about 23,000 years BP, though, regionally drier and more seasonal conditions, with the average runoff to evaporation ratio approximately half the present day value, are inferred from a reduction in aquatic and swamp plant pollen, increases in pollen of the savanna components, grasses and Myrtaceae, and higher levels of charcoal (Torgersen et al.,1988). Drier conditions may have been enhanced locally by lower sea levels.

Throughout this period and extending to about 11,000 BP, seven dust peaks occurring at a periodicity of 2,265 years are recorded in cores from the Carpentaria Basin (De Deckker et al., 1991). These peaks are considered to represent 600 year long dry periods of eolian dust deposition and dune reactivation over northern Australia, separated by 1,500 years of wetter conditions. It is suggested that this activity was caused by the intensification of the easterly trade winds over northern Australia, the failure of monsoons and the intensification of the Southern Oscillation over the Pacific for these periods (De Deckker et al., 1991). The largest dust peak dating at 17.8 ka BP corresponds with the commonly accepted time for the height of the Last Glacial Maximum, and more particularly with the maximum glacial extent in New Guinea (Hope, 1983).

Sclerophyll vegetation continued to dominate the Atherton Tableland under conditions of low rainfall and relative high burning levels, and rainforest remained restricted in distribution to locally favourable sites (Kershaw, 1991). There is a band of evaporitic gypsum in the sediments at one site (Strenekoffs Crater). This is dated to 23,000 years BP (Baird, 1985) and suggested a very marked reduction in precipitation from the 3000 mm per annum received around the site today.

In New Guinea during this period, treelines were 1,700 m lower than present, with the depauperate nature of the surviving forests indicating that climates were drier as well as cooler than today (Markgraf et al., 1991). Maximum glaciation in New Guinea, under temperatures estimated to have been about 6°C cooler than today, was achieved during this period.

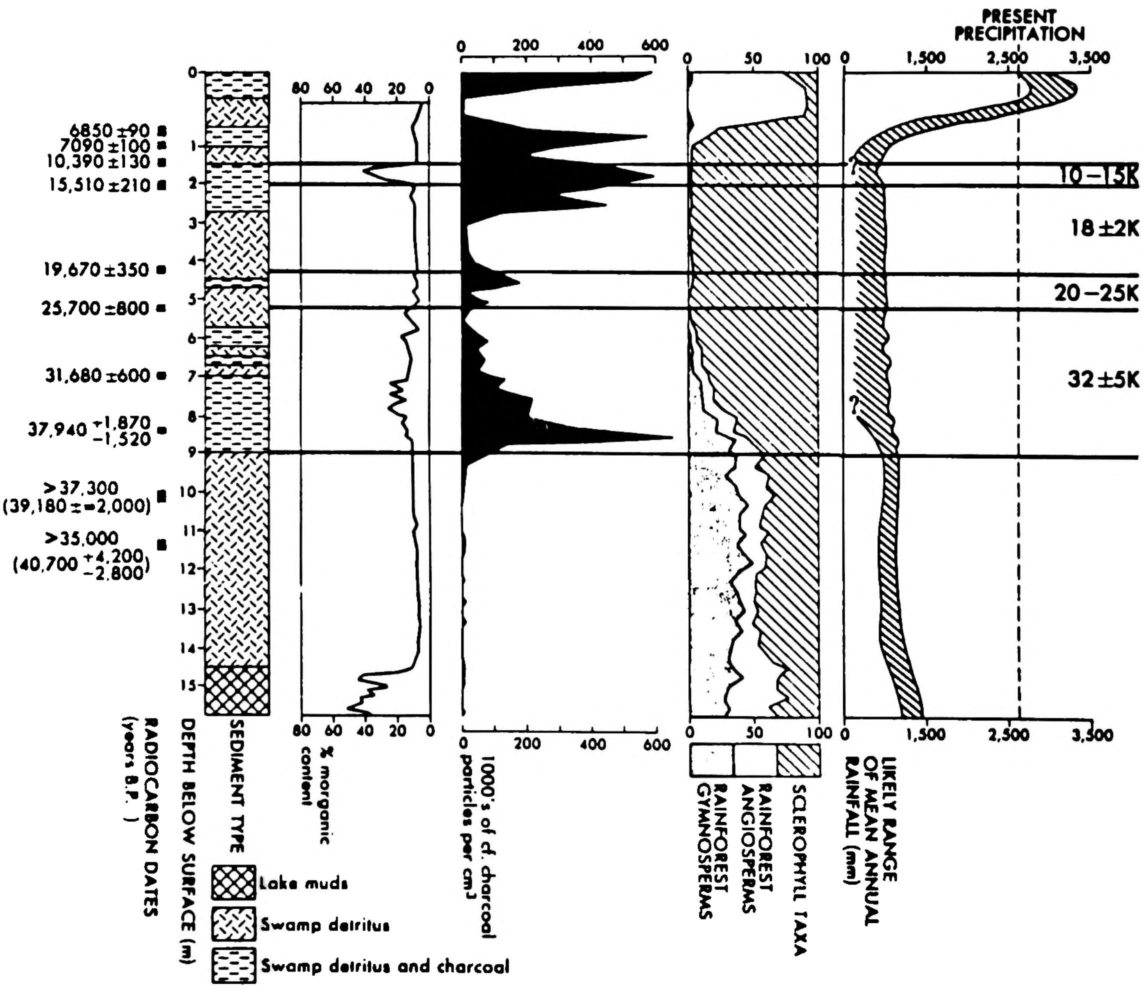

Figure 3. Selected features of the top section of the pollen record from Lynch's Crater on the Atherton Tableland (modified from Kershaw, 1983)

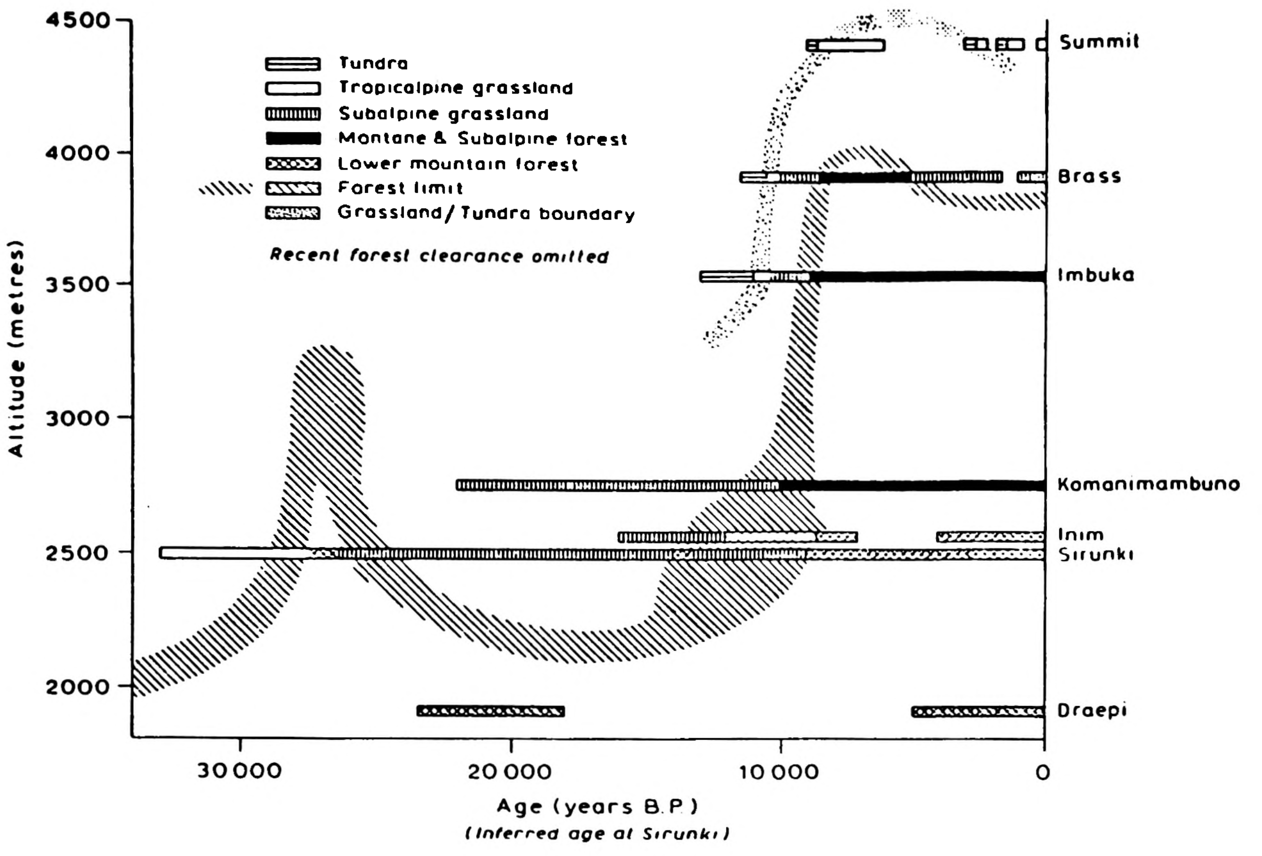

Figure 4. Summary diagram of Late Quaternary vegetation changes in the New Guinea Highlands (after Flenley, 1979)

5. FROM 15,000 TO 7,000 YEARS BP

Rapid sea level rise from about 13,000 BP onward introduced estuarine conditions to the Carpentaria Basin, with the transition to full marine conditions occurring 8,500 years ago (Torgersen et al.,1988). Restricted water exchange across the continental shelf and possibly wetter conditions kept salinity levels low initially. A significant dust peak between 11,375 and 10,430 BP was simultaneous with the Younger Dryas cool period recognised predominantly in the Northern Hemisphere and suggests that this feature may have had global expression (De Deckker et al.,1991).

Low sedimentation rates recorded in sites on the Atherton Tableland between 15,000 and 11,000 BP indicate that this may have been the period of lowest effective precipitation in the whole record, perhaps due to rising temperatures following the height of the glacial period (Kershaw, 1983). After this time, particularly from 10,000 onward, increasing sedimentation rates and the beginning of organic sedimentation in some sites marks the start of a rise in effective precipitation which continues through the period. See Figure 5.

Conditions suitable for the expansion of rainforest over the Tableland did not occur until 8,000 to 7,000 years ago but this may have been the result of slow migration potential or retardation by burning rather than insufficient moisture (Hiscock and Kershaw, 1991 – Walker and Chen, 1987).

In the New Guinea highlands, snowlines were retreating by 15,000 BP with most summits free of ice by 11,000 BP (Swadling and Hope, 1991). Rainforest expansion occurred from 13,000 reaching present limits by about 9,000 years ago (Hope, 1989). There is some indication of reduced precipitation between 13,000 and 11,500 BP (Markgraf et al.,1991).

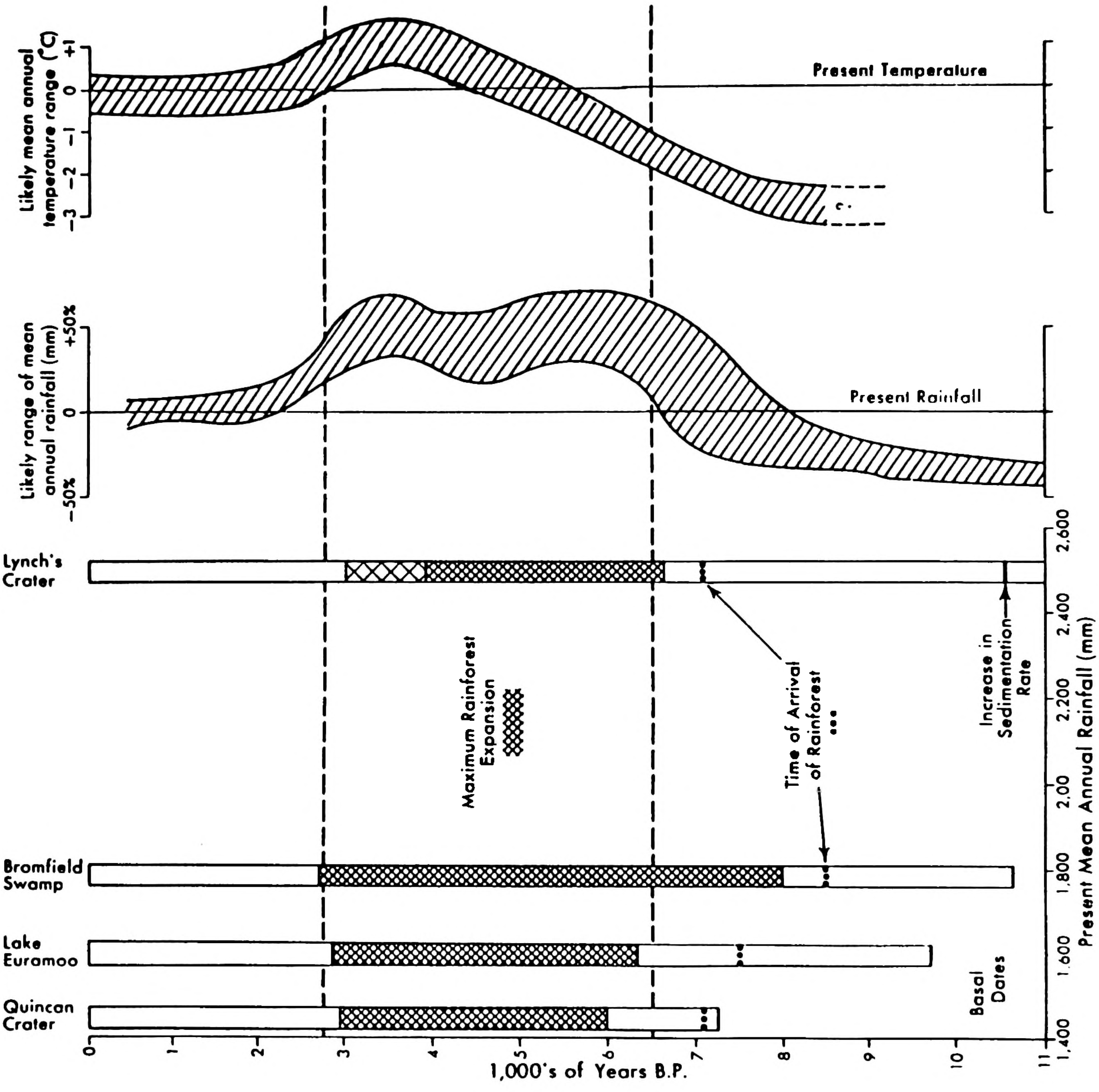

Figure 5. Summary of vegetation and environmental changes from pollen-analytical sites on the Atherton Tableland through the last 11,000 years (updated from Kershaw, 1983)

6. FROM 7,000 BP TO THE PRESENT

Full marine conditions have existed in the Gulf of Carpentaria since about 8,500 years ago.

Rainforest reached its maximum extent in northeast Queenland between 6,000 and 3,500 under the highest effective precipitation levels for the last 40,000 years (Kershaw, 1983). In contrast to the global early Holocene thermal maximum, temperatures inferred from Atherton pollen records remained lower than those of today between 7,000 and 5,000 BP. However, apparantly lower temperatures may have been more a function of local cloud cover than of reduced regional solar radiation (Kershaw, 1991). Subsequently, temperatures achieved levels at least 1 °C higher than at present around 4,000 years ago (Kershaw and Nix, 1988). Precipitation was lower and more variable after 5,000 BP, particularly from 3,000 years ago, as evidenced by the opening up of the rainforest canopy and expansion of sclerophyll vegetation (Markgraf et al., 1991).

Rainforest and shrublands reached their greatest extent in New Guinea between 8,000 and 5,000 years ago under maximum Holocene temperatures and precipitation (Markgraf et al., 1991). Evidence for a climatic deterioration since 5,000 BP is complicated by forest disturbance due to agricultural activities. During the last 3,500 years there have been at least four glacial advances, the last of which occurred from approximately 500 to 200 years ago (Swadling and Hope, 1991).

7. DISCUSSION AND CONCLUSIONS

There is close correlation between times of change in the records from the three areas despite the different environments represented and kinds of evidence revealed. It is clear that changing sea levels and global temperatures have been major controls on precipitation within the region with generally lowest moisture levels occurring during the height of the glacial period and higheast rainfall indicated during the mid-late Holocene. This pattern is broadly consistent with the results from the regional climatic models of Nix and Kalma (1972) and Webster and Streten (1978).

At a more detailed level, there are apparent differences between regions. A precipitation rise in the Carpentaria Basin is inferred from about 13,000 BP at a time when precipitation levels were low on the Atherton Tableland and where there is evidence for a decrease in precipitation in the New Guinea Highlands. Dry conditions during this time can be explained by a global increase in temperature occurring before a response in sea level and sea surface temperature, resulting in an increase in evaporation without a concomitant increase in precipitation. It is difficult to explain the apparent early increase in moisture levels in the Carpentaria Basin. During the Holocene, the patterns of temperature and precipitation rise appear to be broadly synchronous in New Guinea yet they are diachronous on the Tableland. This may be the result local climatic variation or more detailed analysis of the Atherton data. Alternatively it may reflect the fact that on the Atherton Tableland the climate signal from pollen data is clearer due to lower levels of human disturbance to the vegetation.

Superimposed on these generalised climatic patterns are greater frequency variations. Of perticular interest are the dust peaks in the Carpentaria record that suggest that the Younger Dryas period may be just one indication of an oscillatory climatic system. Fluctuations in charcoal abundance in the Atherton records might also be relatable to similar scales of climatic variation. Within the last 5,000 years, the evidence for increased disturbance to, and variation within, vegetation may be largely a function of a more active El Niño-Southern Oscillation system (McGlone et al., 1991).

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LATE QUATERNARY ENVIRONMENTS IN AUSTRALASIA[1]

by

Paul Bishop[2]

IGCP 296

1. INTRODUCTION

Research in the Quaternary of the Australasian region (Australia, New Zealand, Papua New Guinea and the neighbouring islands of the South Pacific, has been undertaken largely in the context of palaeoenvironmental and palaeoecological reconstructions (Bishop, 1991). Few long, continuous terrestrial or marine records of the Quaternary have yet been obtained, although recent drilling by the Ocean Drilling Programme (ODP) off the northeastern and northwestern coasts of Australia promises great returns of considerable significance for Quaternary correlation in Southeast Asia and the Pacific. Long terrestrial lithostratigraphic type sections remain to be defined for the region.

On the other hand, excellent reconstructions of late Quaternary Australian environments are now available, and significant efforts have been made to correlate across the full latitudinal range covered by Australia (10°S to 44°S) as well as into Papua New Guinea (Figure 1). These correlations are fullest for the time period covered by radiocarbon dating, and the use of thermoluminiscence (TL) dating is developing rapidly.

Recent compilations and attempts at correlations are those by Swadling and Hope (1992), Hiscock and Kershaw (1992) and Ross et al. (1992) (all contained in a recent examination of prehistory and environmental change in Australia and the southwest Pacific), and those by Kershaw et al. (1991), Colhoun (1991) and Nanson et al. (1992). This present paper uses these to summarize late Quaternary sedimentation and environments in Australia and Papua New Guinea. A few concluding remarks arising from the author's research in the Holocene of northern central Thailand and related to regional correlations are made at the end of the paper.

2. THE SETTING

Modern Australian environments range from the periglacial uplands of the southeast of the continent and the island of Tasmania to the continent's central hot, dry deserts with their thousands of kilometres of active linear sand dunes. The northern (hotter) half of the continent may be broadly thought of as tropical monsoonal with a summer rainfall maximum, whereas the southern half experiences either a uniform annual distribution of rainfall or a winter rainfall maximum. The broad latitudinal range and diverse environments covered by the Australian continent have made correlations difficult, even within the continent, let alone between Australia and neighbouring areas, such as Papua New Guinea and Southeast Asia.

The Australian continent is the most arid continent on the globe (except for Antarctica) because of several factors, including the continent's general location within the subtropical belt of stable high pressure climatic systems, the great continental area of the Australian land mass, and cool ocean currents off the coast of Western Australia.

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[1] *Paper presented at the IGCP 296 regional workshop held in Ho Chi Minh City, Viet Nam from 13-15 December 1992*

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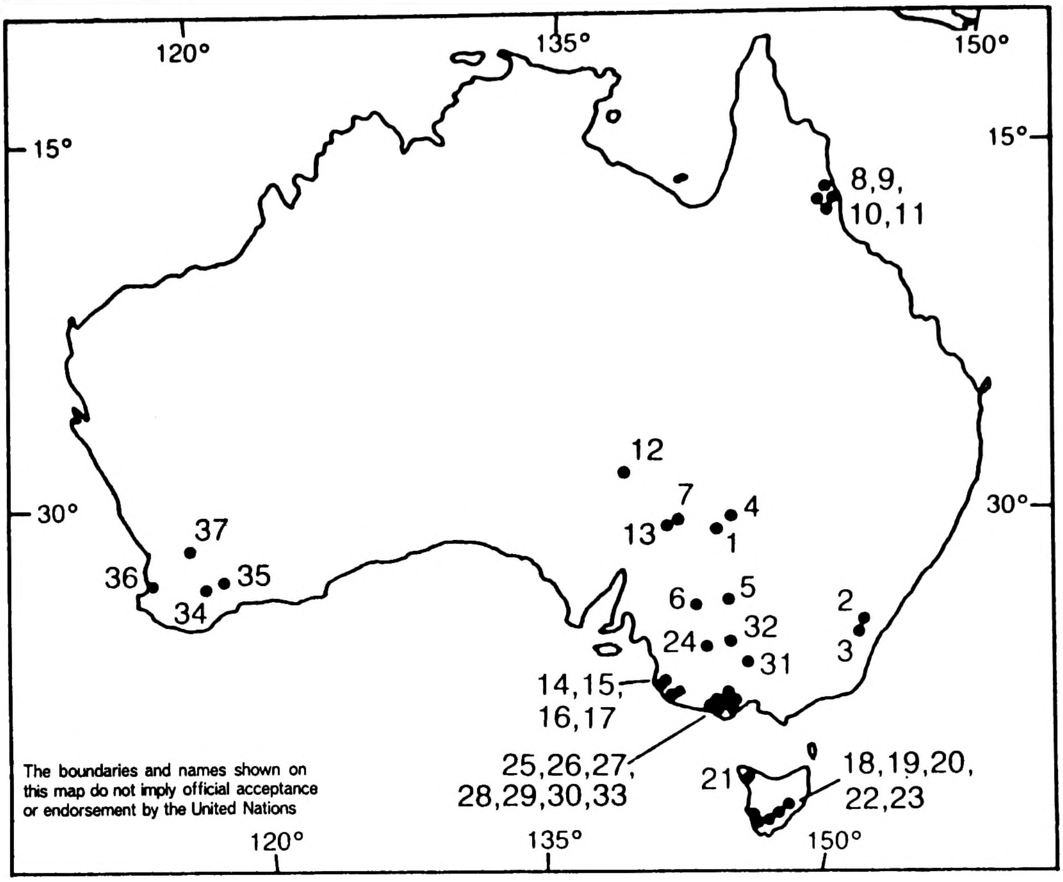

Figure 1. Lake sites in Australia from which lake level fluctuations have been reconstructed by Harrison, 1989

Two of the most important determinants of the region's climate are the Southern Ocean and Antarctica, influences of which were increasingly felt throughout the Tertiary, as Australia and other Gondwanan continents drifted north, away from Antarctica, and the essentially modern circulation of the Southern Ocean was established. These two changes facilitated the formation of the Antarctic ice-cap, which grew rapidly from the Middle Tertiary onwards, in turn resulting in diminished sea-surface temperatures around Australia and the emergence of the general aridity of the continent. Whereas Australian vegetation was characterized by temperate rainforest dominated by Nothofagus species during the early to middle Cainozoic, the later Cainozoic saw general replacement of this by the characteristic sclerofyllous (drier) modern Australian vegetation, dominated by Eucalyptus species. The modern environments of Papua New Guinea are dominantly tropical below 3,000 m elevation, with tropical rainforest the characteristic vegetation; temperate rainforest and grasslands (which may be anthropogenic) occur at higher elevation.

Finally, as background, the Australian and Papua New Guinean land masses contrast in their physical character. Papua New Guinea is latitudinally narrow, characterized by high elevation (the highest mountains are over 5 km, and many mountains are over 3 km), high relief and extreme seismicity (the result of active convergence between the Australian and Pacific plates along the axis of Papua New Guinea). This high relief and seismicity combine with the region's very high rainfall to produce some of the highest rates of erosion on the earth's surface. By contrast, Australia is characterized by some of the lowest erosion rates in the world as a result of its tectonic stability, general aridity and low relief. "High" landscapes in Australia are generally only about 1 km in elevation, and the highest altitude on the continent is only a little over 2 km.

Significant Cainozoic terrestrial sedimentary basins in Australia include the Great Artesian and Murray Basins in the dry interior of the continent, and a series of continental marginal basins (notably the Gippsland and Otway Basins) related to Late Mesozoic and Cainozoic continental extension and rifting in the southeast. The Murray Basin has been extensively investigated because of its groundwater potential, and the marginal basins hold significant hydrocarbon and coal reserves. The low rates of continental denudation are indicated by the fact that the maximum thickness of sediment in the Murray Basin, which contains sediments covering virtually the whole of the Tertiary, is only about 500 m.

3. THE EARLY QUATERNARY IN CONTINENTAL AUSTRALIA

The opening of the Quaternary in Australia was marked by the continuation of the long decline into aridity that had characterized much of the Tertiary, in parallel with the declining sea-surface temperatures in the Southern Ocean (Kemp, 1978). Temperate rainforest, typified by a very distinctive pollen assemblage with significant representation of *Nothofagus* (Southern Beech) taxa, characterized much of the early and middle Tertiary, but this was progressively replaced by more Myrtaceous (sclerophyllous) vegetation, particularly from the Late Oligocene/Early Miocene onwards (Figure 2). This transition was probably diachronous, starting earlier in the potentially drier interior of the continent, and radiating outwards over time towards the more humid coastal areas (Martin, 1991). This replacement of temperate rainforest by sclerophyllous forest and woodland was also characterized by a rise in other taxa indicative of drier climates, such as Poaceae (grasses) and Asteraceae which are generally indicative of drier (and sometimes colder) conditions. The brief recovery of *Nothofagus* in the Pliocene (Figure 2) was probably related to a marine incursion into inland Southeast Australia and correspondingly elevated precipitation levels (Martin, 1991).

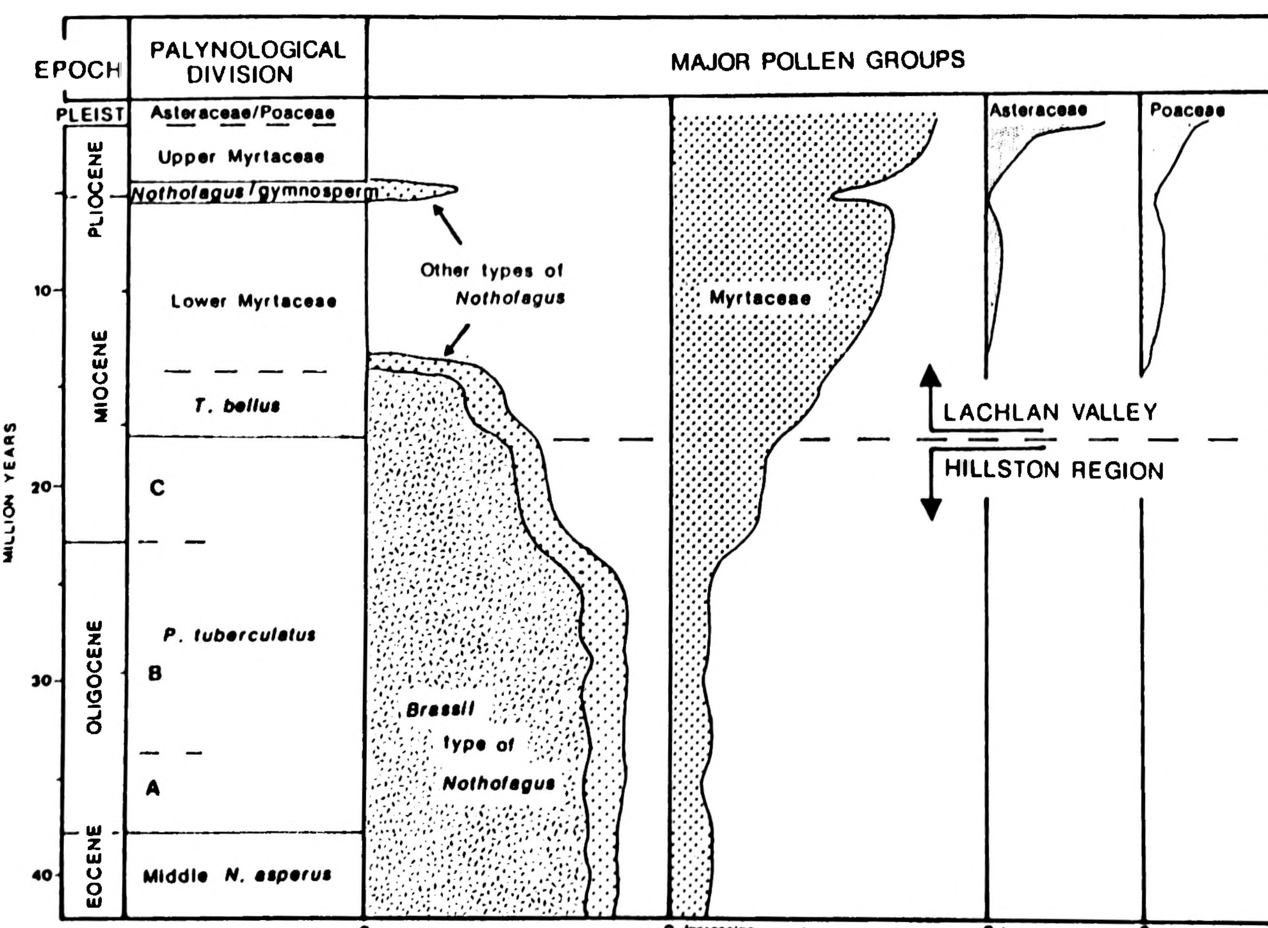

Figure 2. **Summary diagram of the palynological subdivisions and the major pollen groups for the Late Eocene to Miocene in the Lachlan River region (modified from Martin, 1987). The Pleistocene-Late Miocene palynological divisions follow Martin (1973, 1987) and the Middle Miocene and older subdivisions are from Stover and Partridge (1973) and Partridge (1975), as modified for the Murray Basin (Martin 1984a).**

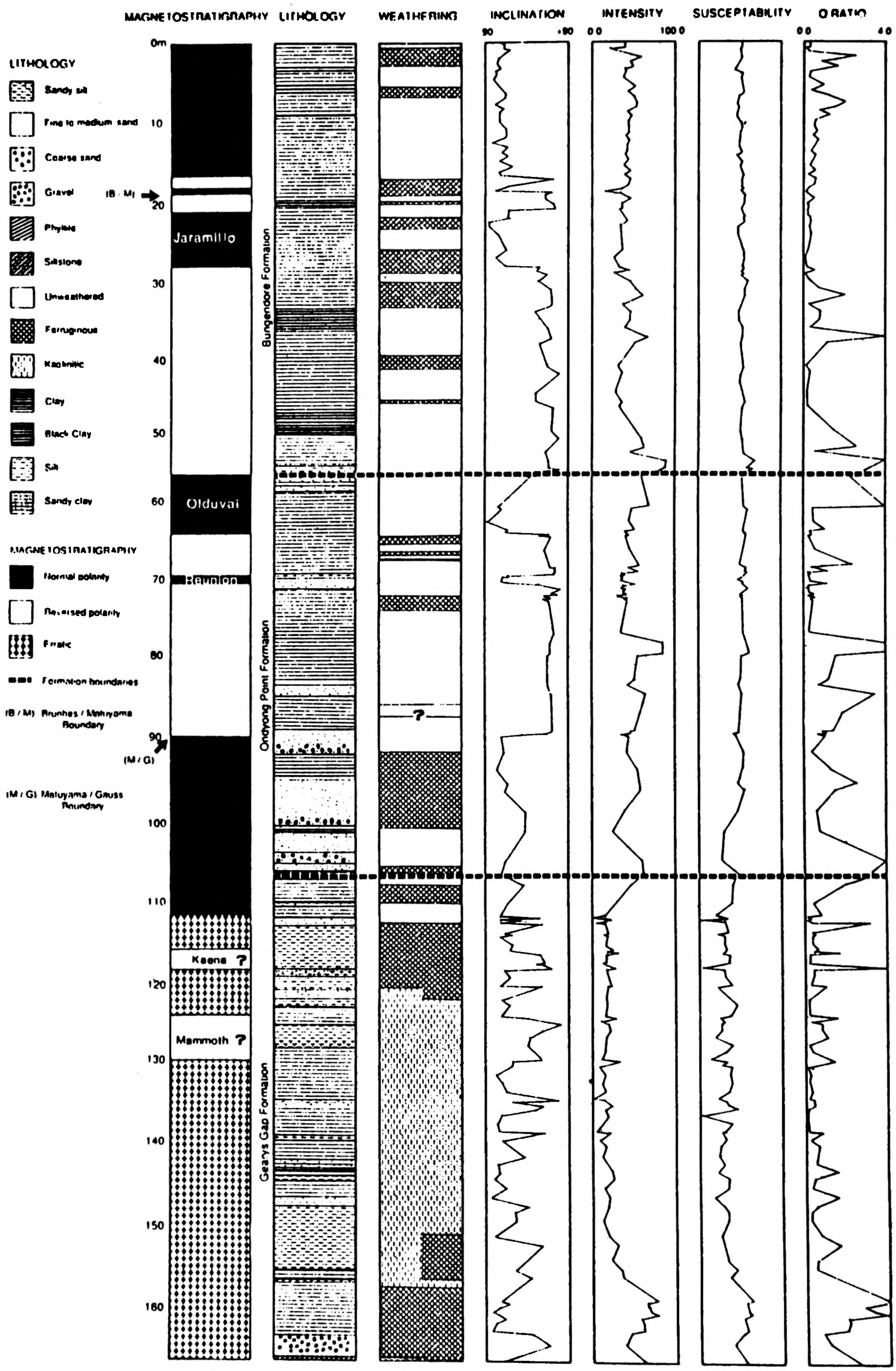

Figure 3. Lithology, weathering and magnetic characteristics of Lake George core C_{354}, site 3 of Figure 1

Broadly similar conclusions emerge from a palaeomagnetically dated core from Lake George, a tectonic basin containing a maximum of at least 166 m of sediments (Figure 3; McEvan Mason, 1991). The Brunhes-Matuyama boundary occurs at a depth of about 19 m in this core and the Matuyama-Gauss boundary at -90 m. Sediments from about -110 m (Late Pliocene) have yielded a temperate rainforest flora dominated by *Nothofagus*, whereas sediments from about -100 m to -50 m (Late Pliocene to Pleistocene) yield a flora that is indicative of drier conditions, the significant taxa Asteraceae, *Casuarina*, Poaceae and Myrtaceae.

4. LONG RECORDS OF THE LATE QUATERNARY

The middle Quaternary is generally absent from Australian records that have been determined so far. A recent compilation of 75 TL and 18 U/Th dates from fluvial and arid environments, however, covers the last 300 ka and relates environmental fluctuations deduced for this time interval to changes in sea level, North Pacific and Vostok dust flux, and Vostok temperature (Nanson et al., 1992). Relatively long and detailed records of late Quaternary terrestrial environments have also been obtained from volcanic craters in the far northeast and southeast of the continent (Kershaw et al., 1991). These two complications are now being discussed.

The fluvial and arid zone records

Nanson et al.'s (1992) TL and U/Th chronology from eastern Australia (Figure 4) is a simple frequency compilation of dates from i) materials indicative of pluvial (high rainfall) conditions (mainly dates from fluvial deposits), and ii) materials indicative of arid conditions (evaporic/groundwater deposits and dunes). Fluvial conditions characterized part of the last two interglacials (stage 5 and 7) resulting in large sand loads in rivers in present desert and humid environments. During the last interglacial fluvial activity in central Australia peaked at about 110 ka (stage 5 pluvial). This peak in fluvial activity was probably 5 to 10 ka behind the world-wide temperature and sea level maxima (Figure 5).

After this pluvial phase, precipitation generally declined progressively to the arid phase of the full glacial which was marked by dune building throughout most of the continent from the interior to the now-humid margins. Indeed, this progressive drying moved outwards from the interior of the continent to the margins, but was locally interrupted by a stage 3 "subpluvial" which was marked by high lake levels in some areas and by renewed flow in some palaeochannels in the southeast.

The Northeast Australian record

The Lynch's Crater site, one of the longest, most famous and well studied of all Australian records (Figure 6; Kershaw et al., 1991), is a tropical rainforest site on the tablelands close to the Northeast Australian coast; it receives between 2500 and 3000 mm of annual rainfall, mostly in the summer. Radiocarbon dates provide chronologies in the upper parts of the record, and beyond the limit of radiocarbon dating, age control is provided by extrapolations based on sedimentation rates and by correlations with the marine record and the history of glacials and interglacials that these represent. The variations in vegetation recorded at this site can be explained largely by variations in precipitation, but fire has become an important component of the environment over the last 40,000 years. Zones L11 and L8 (fig. 6) are characterized by pollen assemblages indicative of precipitation levels similar to the present (L1). Characteristic taxa during these phases were the rainforest angiosperms, Cunoniaceae and *Elaeocarpus*. Intermediate precipitation levels characterize zones L10 and L7 as indicated by the slightly more abundant sclerophyllous and rainforest gymnosperm taxa.

Low precipitation levels can be inferred for phases L9 an L3-5, in which sclerophyll and rainforest angiosperm taxa are strongly represented, and indicate that the vegetation was notophyll pine forest. The lowest precipitation levels, however, may be indicated for the later part of Zone L3 and for L2. Open sclerophyll woodland characterized by abundant *Casuarina* and *Eucalyptus*, gradually replaced the *Auracaria* dominated pine forests, before the pine forests recovered in the Holocene (L1). The sudden increase in charcoal levels from about 38,000 years ago may be related to the burning activities of early

Australian (Aboriginal) people. This burning, which has been shown to be one element of the Aborigines' land management strategies, encouraged the replacement of the rainforest elements by the sclerophyllous taxa, but only moderate levels of charcoal are associated with the peaks of *Casuarina* and *Eucalyptus* at the start of L2, suggesting that climate must also have been playing an important role in the decline of the rainforests. This major decline coincides, of course, with the glacial maximum which is discussed in more detail below.

Other Australian compilations

Figures 7 to 15 from Ross et al. (1992) summarize a great wealth of other data relevant to regional palaeoclimatic reconstructions in Australia. It will be seen that there are many parallels within and between regions in Australia, which are particularly clearly demonstrated by the composite data shown in the top curve in each Figures 7 to 10. Figure 12 also makes similar comparisons. These will be considered again below in the discussion of glacial maximum environments.

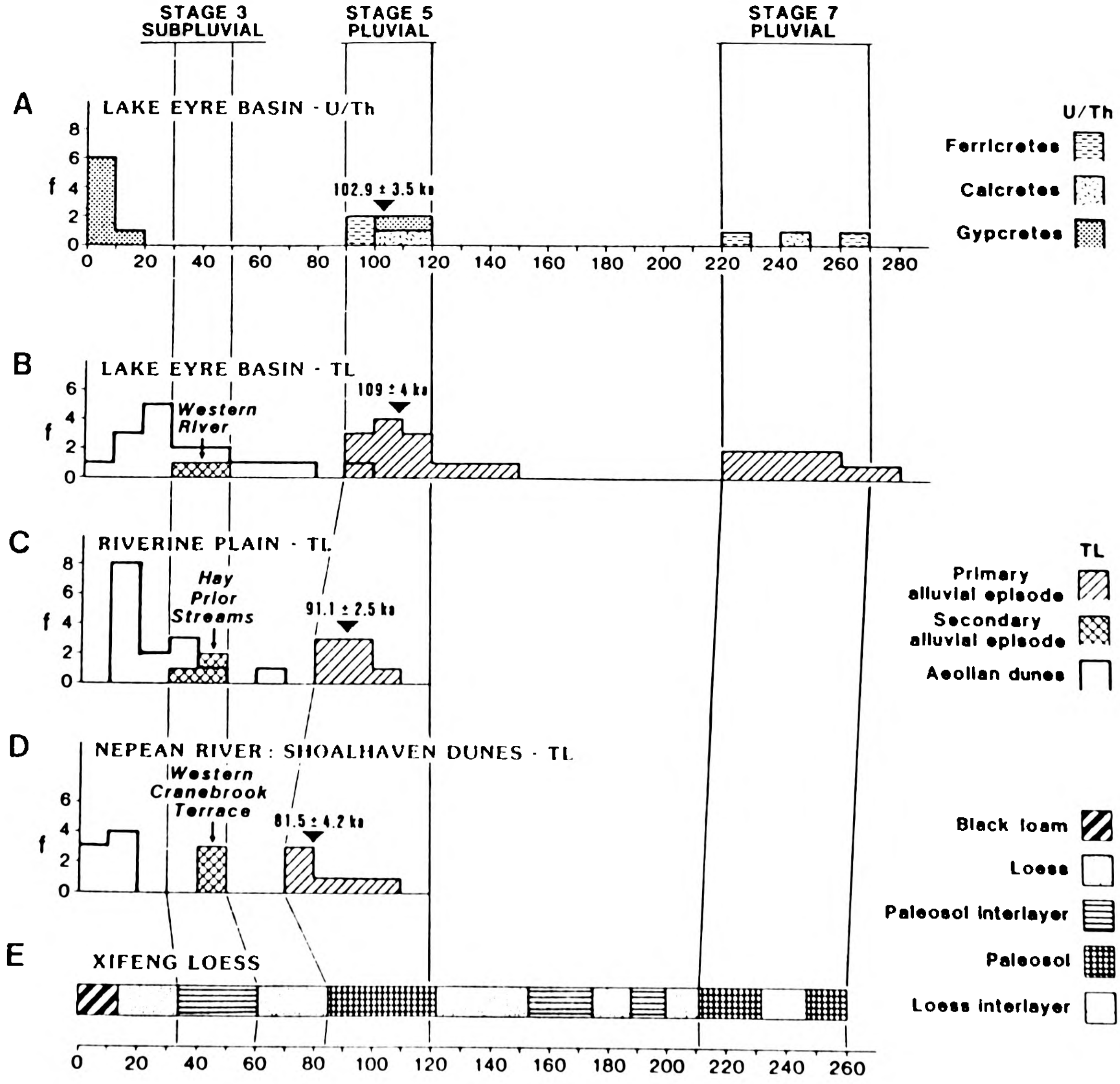

Figure 4. Frequency histograms of pedogenic U/Th and sedimentary TL dates from Australian aeolian and alluvial deposits

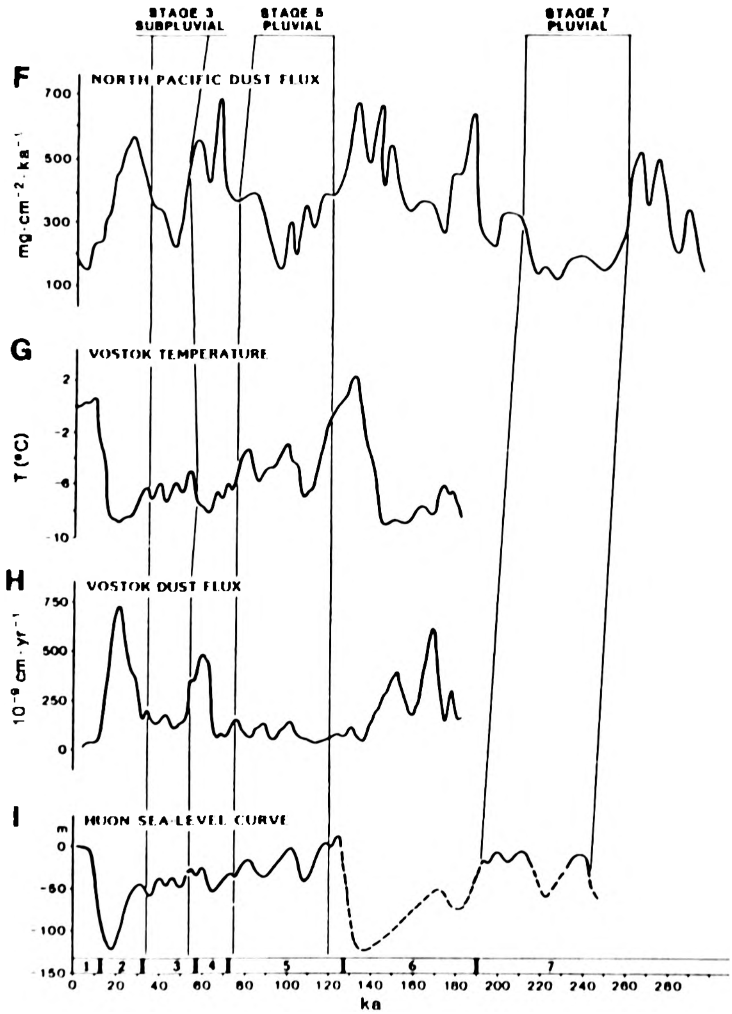

Figure 5. Aeolian and alluvial chronologies compared to chronologies of Chinese loess, North Pacific marine core, Antarctic ice core, and New Guinea sea level

5. THE QUATERNARY OF PAPUA NEW GUINEA AND THE GULF OF CARPENTARIA

Papua New Guinea

Long Quaternary records have yet to be obtained from Papua New Guinea and here we summarize data from only the late Quaternary (Colhoun, 1991; Swadling and Hope, 1992). Evidence from the period before about 28,000 years ago is not conclusive. Swadling and Hope (1992) suggest that the period from about 32,000 to 28,000 years BP seems to be a time that was slightly warmer, as indicated by a general advance or expansion of forest conditions. On the other hand, Colhoun (1991) suggests that before about 27,000 to 25,500 years ago, the climate was cool, moist and cloudy with mean temperatures at least 1.5 to 3.5 °C cooler than present. From about 27,000 years ago, the climate became progressively cooler, culminating in the glacial maximum that occurred between 18,500 and 16,000 years ago. The maximum fall in temperature to the glacial maximum varied between 7 and 11 °C below present and was accompanied by a descent of the treeline from about 3,500 m to between 2,200 m and 2,500 m. A more widespread distribution of *Nothofagus* forests during the glacial indicates that the highlands were also cloudier at this time.

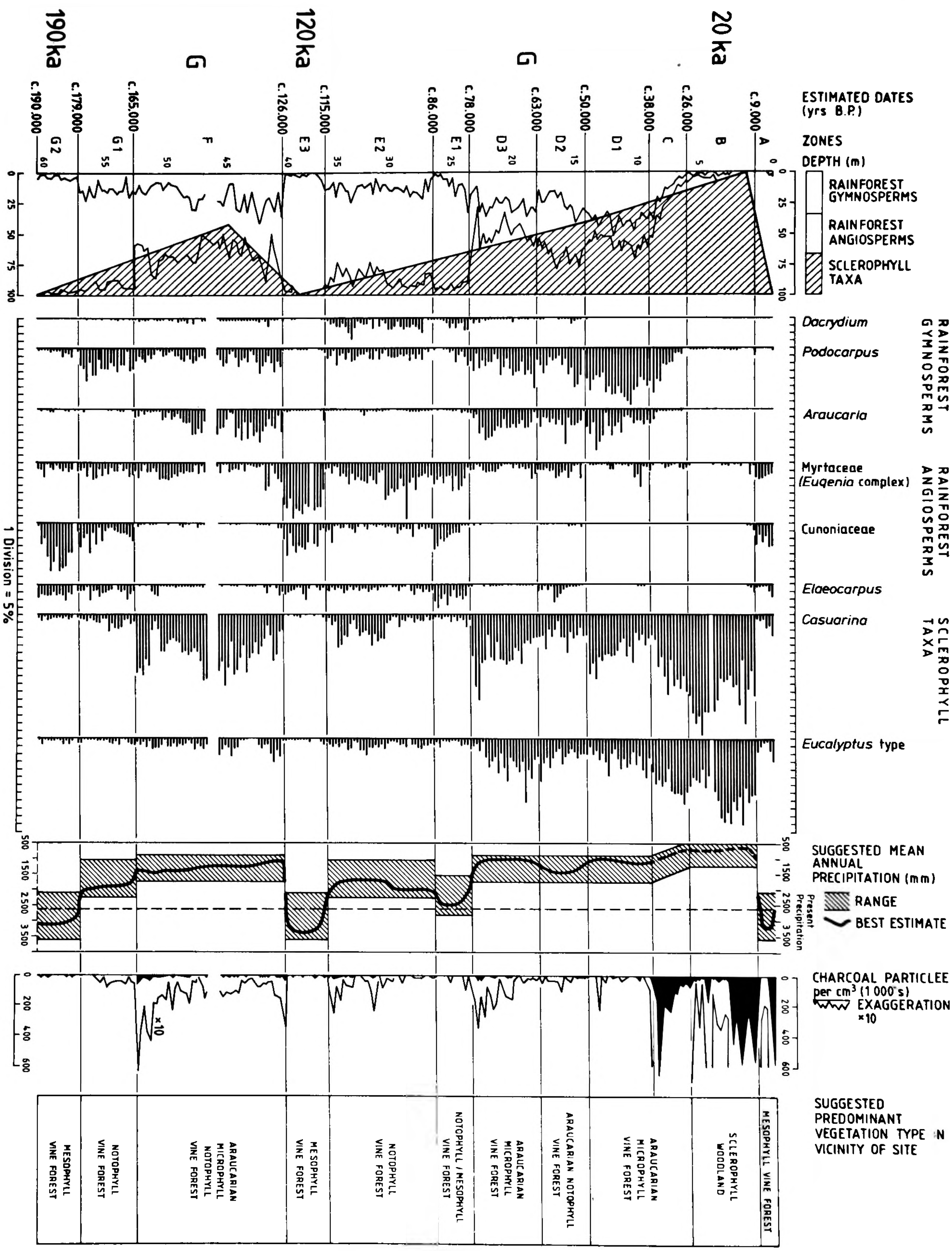

Figure 6. Selected attributes of pollen diagram from Lynch's Crater, Atherton Tableland. The frequencies of pollen of all taxa are shown as percentages of the dry-land-plant pollen total (modified from Kershaw, 1986 in *Nature* 322, p. 47-49)

At glacial maximum, many of the high mountains in Papua New Guinea and Irian Jaya had small ice caps and valley glaciers down to about 3,000 m or so, and the snow line was depressed by about 1,000 m; a total area of about 2,000 km^2 was glaciated at glacial maximum. Ice began to recede 15,000 to 14,000 years ago and most mountains were free of glaciers by the opening of the Holocene (about 9,500 years ago). Climates became similar to present at about this time, and this post-glacial climatic amelioration was marked by a re-invasion of the mountains by forest.

Early to middle Holocene environments may have been warmer than present, with higher treelines, locally about 150 m higher than at present. During the middle and late Holocene, temperatures were generally close to present ones, although there were three small glacial advances in Irian Jaya in the late Holocene.

Gulf of Carpentaria

The present Gulf of Carpentaria in northern Australia was sub-aerially exposed during the last glacial and was the location of a persistent lake that has been called Lake Carpentaria (Torgersen et al., 1988). The lake is identifiable from before 40,000 years ago and a drier phase seems to be indicated about the same time (40 ka BP). Thereafter, the lake was continuously present from about 35,000 to 12,000 years ago, when it was transgressed by the post-glacial sea level rise.

From about 35,000 to 26,000 ago, the lake was fresh to brackish and lake levels may have been enhanced by a relative high in the sea level (a short-lived reversal of the general sea level fall to the glacial maximum). This relative high sea level possibly contributed to an intense wet-season precipitation and to high abundance of aquatic pollen. From about 26,000 BP onwards, the lake remained permanent but its waters were distinctly continental and preserved authigenic calcite laminae.

In the period which includes the glacial maximum, the lake remained permanent, but it fluctuated in size and depth in response to pronounced wet and dry seasonality. The lake catchment was savannah-like, and dominated by grasses which figure strongly in the pollen record, as do elevated levels of charcoal. The latter may indicate increased burning of the area at this time, which may also be a reflection of the seasonality.

The record from the post-glacial era largely concerns the marine transgression, but there are indications that increasing precipitation may be associated with the rising sea level. Increasing amounts of pollen from the aquatic taxon, Typha, may indicate more extensive fresh water conditions associated with increased precipitation.

6. THE GLACIAL MAXIMUM IN THE AUSTRALIAN REGION

The last glacial maximum (LGM) is an important time-line in regional late Quaternary correlations because it had a widespread environmental impact. It is now well-dated in the Australasian region to between 20,000 and 16,000 BP, with most authors using a date of 18,000 BP as the time of the LGM. As well as being a very useful tool in regional correlations, the environments that are deduced to have existed during full glacial times provide important data on global atmospheric circulation during the Quaternary. Holocene environments provide similar information. This section, and the following, examine the nature of regional environments during full glacial times and the Holocene, respectively, drawing heavily on the compilations of Ross et al. (1992) (Figures 7-16).

It is obvious, of course, that LGM environments were colder than those of the post-glacial times. This is seen in the lowering of the snow-line and the tree-line throughout the region, from Tasmania in the south to Papua New Guinea in the north. Small valley glaciers were active in Tasmania, the southeast of continental Australia and in the Papua New Guinea region, and, at slightly lower elevations in the same regions, periglacial activity was also more widespread.

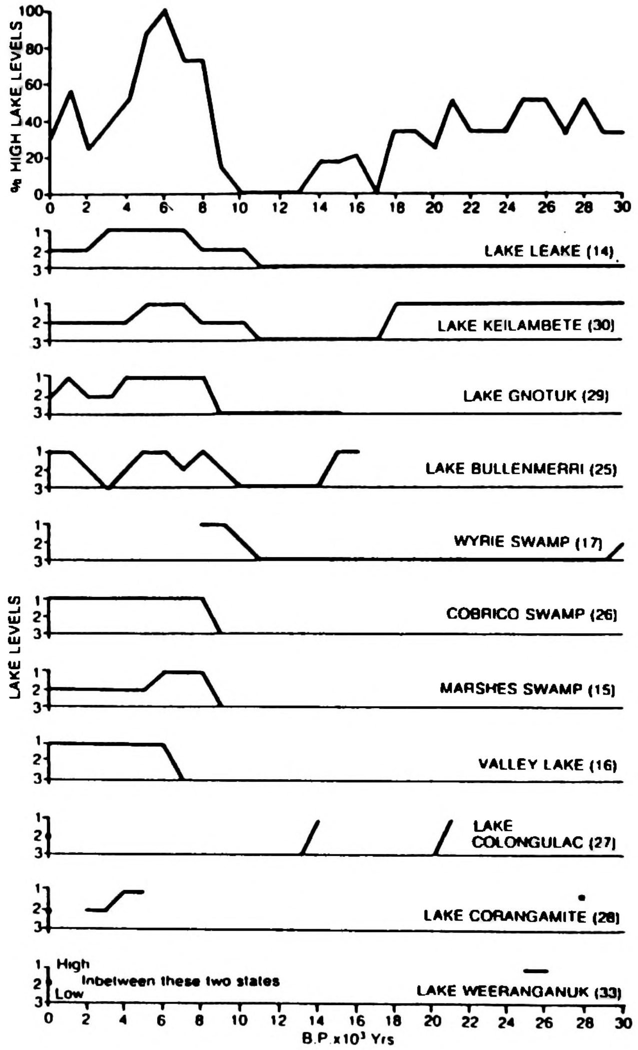

Figure 7. Lake level fluctuations from near-coastal South Australian and Victorian lakes. Numbers refer to locations on Figure 1

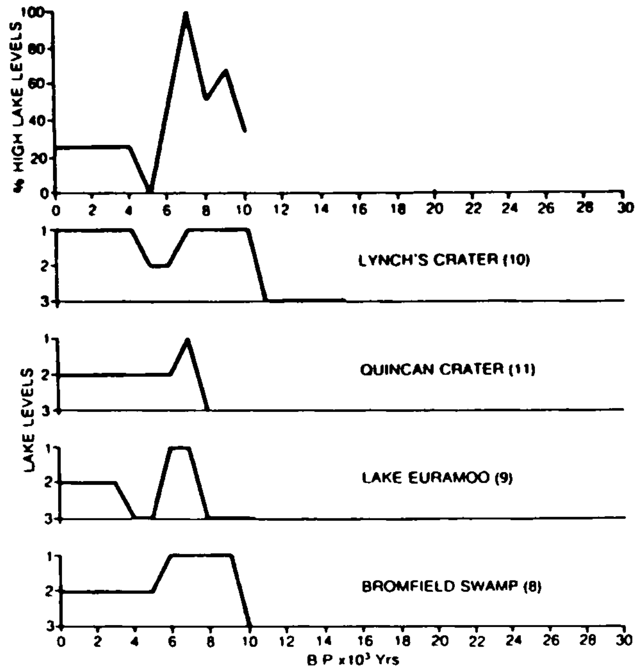

Figure 8. Lake level fluctuations from northeastern Queensland lakes. Numbers refer to locations on Figure 1

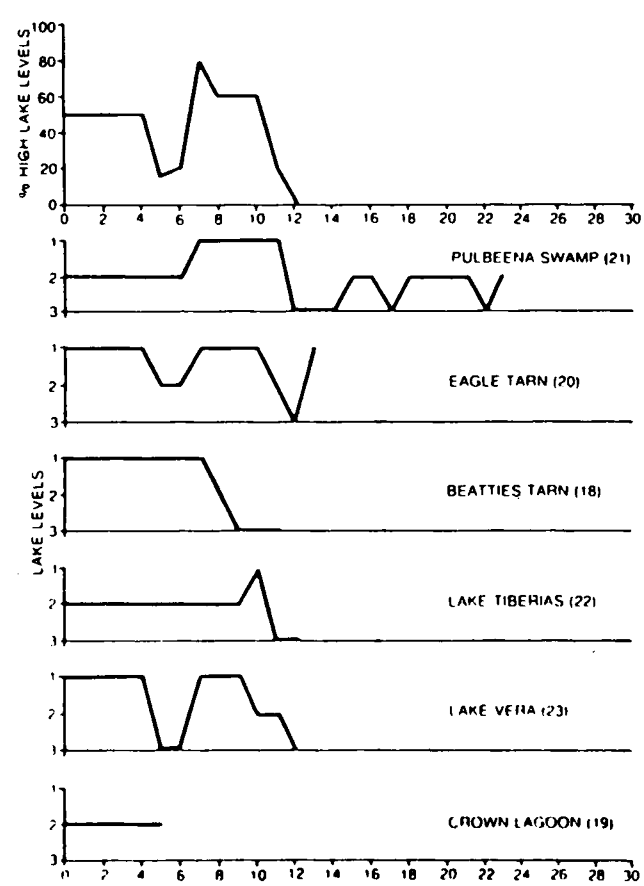

Figure 9. Lake level fluctuations from Tasmanian lakes. Numbers refer to locations on Figure 1

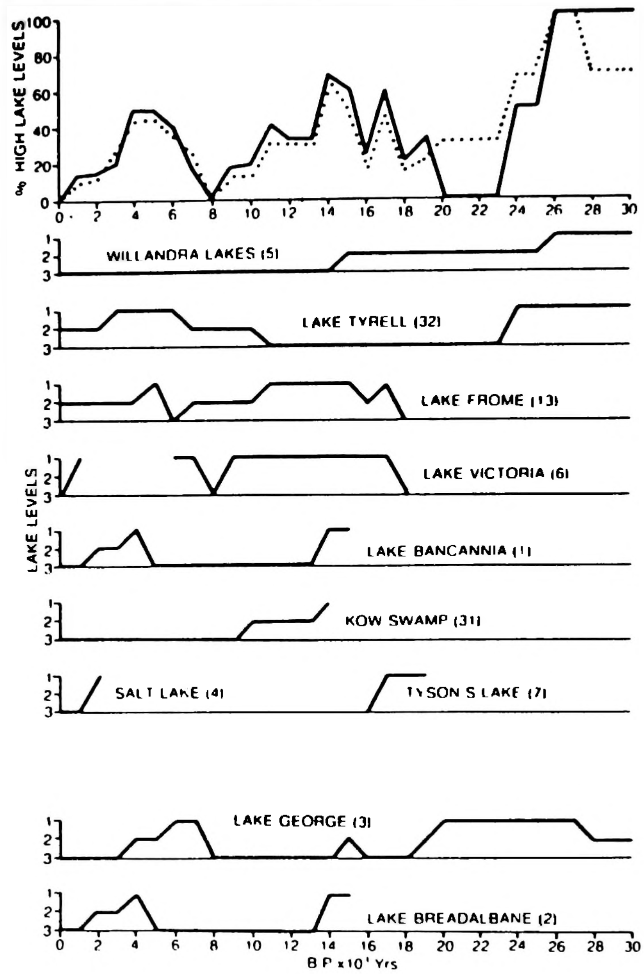

Figure 10. Lake level fluctuations from inland Australian lakes. Numbers refer to locations on Figure 1

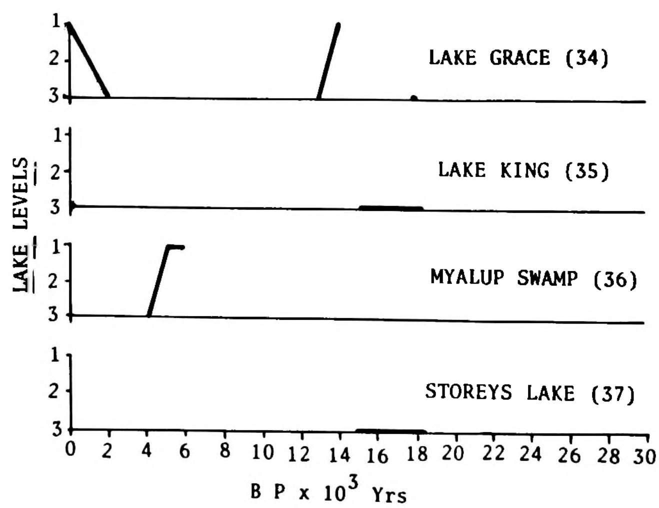

Figure 11. Lake level fluctuations from southwestern Australian lakes. Numbers refer to locations on Figure 1

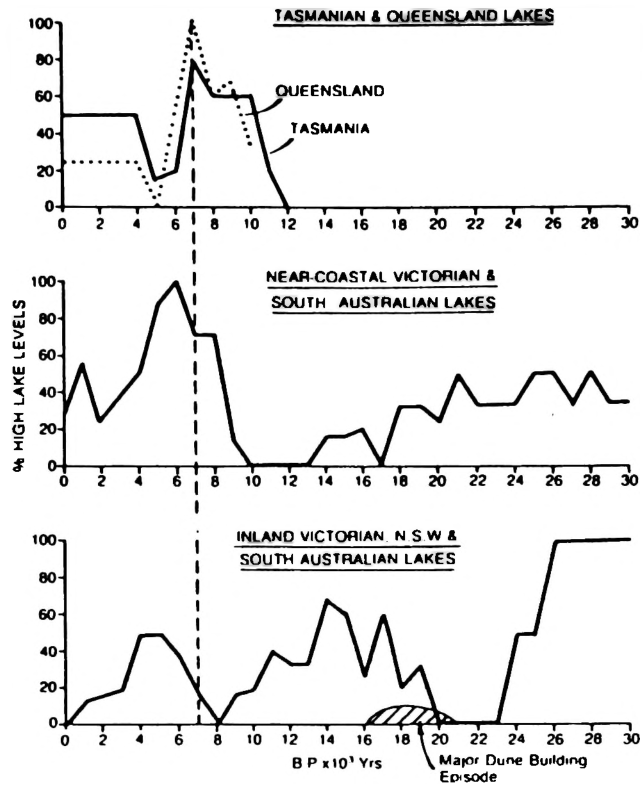

Figure 12. A composite of composite lake level fluctuation diagrams

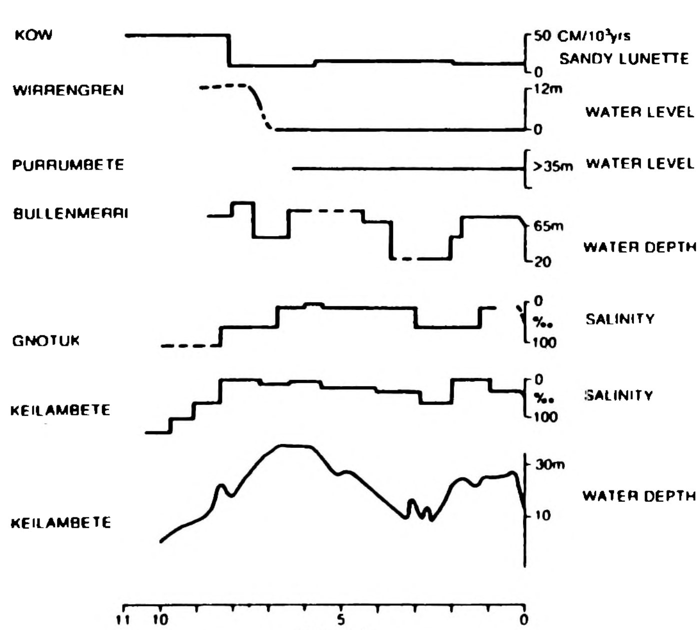

Figure 13. Lake level and salinity records from selected western and northern Victorian sites

An important regional accompaniment of this greater cold was decreased vegetation cover, and a general shift in the pollen record towards fewer tree taxa and greater representation of grasses (Figures 6 and 15). This, again, is quite expected, but an important related effect appears to have been enhanced catchment instability, with greater rates of erosion and increased sediment flux from catchments. This increased sediment flux (perhaps increased even further by greater amounts of wind-blown sediment in catchments – see below) and the high peak discharges of the inland rivers during the spring melt of the glaciers and periglacial areas meant that the inland rivers were large and carried high sediment loads.

These vegetational changes resulted from the fact that full glacial times were times of greater aridity (Figures 7 to 18) (Colhoun, 1991). Fossil desert dunes on the now-humid fringes of the said interior of the continent were active in LGM times and are now stabilized and re-vegetated (Figures 14, 15 and 16). In some localities (e.g. the northwest of the continent), desert dunes can be seen to pass below present sea level, demonstrating that they were active during times of lowered sea level at the LGM (Jennings, 1975).

This phase of increased dune activity at full glacial times demands at least two causal factors, namely increased aridity and increased windiness. The increased aridity probably resulted from lowered sea-surface temperatures during the Last Glacial Maximum, such lowered temperatures resulting in lowered oceanic evaporation and therefore decreased precipitation on adjacent terrestrial areas. Another important effect of the depressed temperatures was lower sea levels during the LGM (120-130 m lower) and an expansion of land area and increased continentality and aridity (the land area of Australia and Papua New Guinea was about 25 per cent larger during the Last Glacial Maximum; Colhoun, 1991). A related effect of the lowered sea level was to decrease the area of tropical oceans available for evaporation, especially in the Papua New Guinea area, where the continental shelf is wide and shallow; this reinforced the tendency to aridity. The marine regression in Torres Strait between Australia and Papua New Guinea also meant that these two land masses were connected by a broad land bridge, and that the warm South Equatorial Current, which flows through the Strait during high sea level times, could not flow. This stopped the flow of warm water into the Indonesian region.

The Last Glacial Maximum was also a time of greater windiness (higher wind speed – fig. 16), probably in response to enhanced stability of the lower atmosphere and the resultant more intense sub-tropical high pressure systems. This increased intensity of the high pressure systems probably also resulted in part from northward movement of the Polar Front and compression of climatic zones towards the equator (Markgraf et. al., 1992). The greater windiness is also important in explaining the increased dune building activity of the LGM. Dust fluxes into the Tasman Sea (east of Australia) were enhanced during the LGM (Paul Hesse, pers. comm.; work in progress), as was the amount of dust blown into Lake Carpentaria in the north (De Deckker et al., 1991). This greater aridity is consistent with a runoff/precipitation ratio for Lake Carpentaria of about one half of the present value (Torgersen et al., 1988).

At many places in the continental interior, clay dunes dating from the Last Glacial Maximum are found on the down-wind side of saline lakes (Figures 14 and 16). The formation of these "lunettes" demand very specific conditions, including lake levels that fluctuate seasonally between full and empty, saline lake water and clayey sediments that can be deflated from the dry lake bed to form the clay dune. The evidence that some lake levels were high, at least seasonally, during the LGM seems to contradict the abundant evidence for full glacial aridity. This apparent paradox is generally explained by the fact that the lower temperatures of the LGM resulted in decreased evaporation. That is, some lakes continued to hold water during the glacial maximum (Figure 12), even though precipitation was lower in this time.

The final point to note here concerning full glacial conditions is that the increased strength of the subtropical high pressure system over Australia and the lower sea-surface temperature probably acted together to suppress the strength of the northwest monsoon, the major driving force for the summer rainfall maximum in northern Australia (Torgersen et al., 1988; Colhoun, 1991). It seems reasonable to suggest that the southwest monsoon should be similarly weakened during the Last Glacial Maximum and this is confirmed by data from a core off southwest India (Van Campo, 1986). A general weakening of the monsoonal circulation has been suggested for the northern hemisphere, by Kutzbach and Street-Perrot (1985), both as a result of changes in orbital parameters and associated atmospheric forcing. It seems, therefore, that lowered sea-surface temperatures and associated changes in atmospheric circulation may

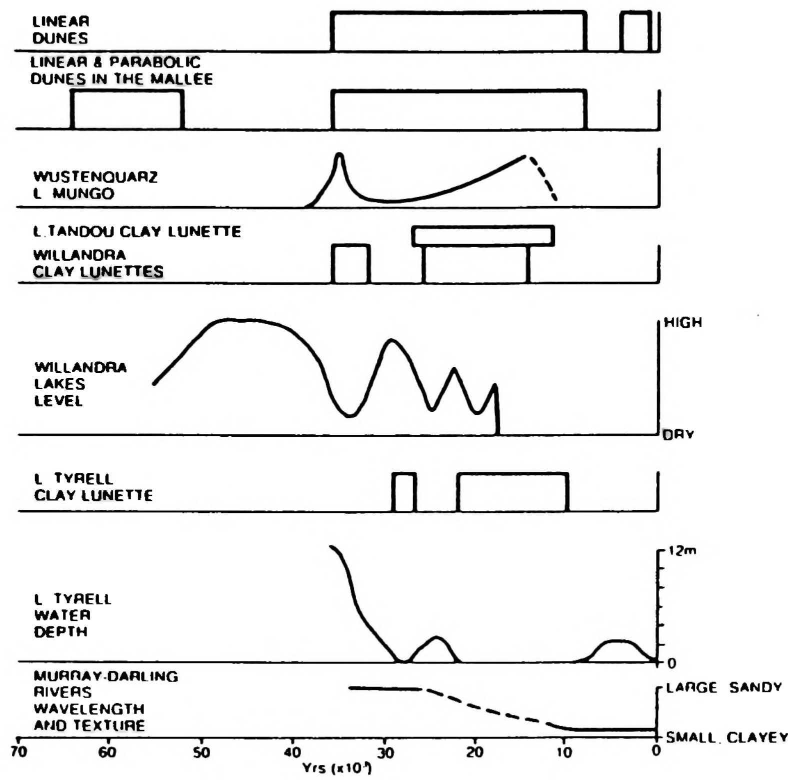

Figure 14. Data of palaeoclimatic significance from the Murray Basin of southeastern Australia

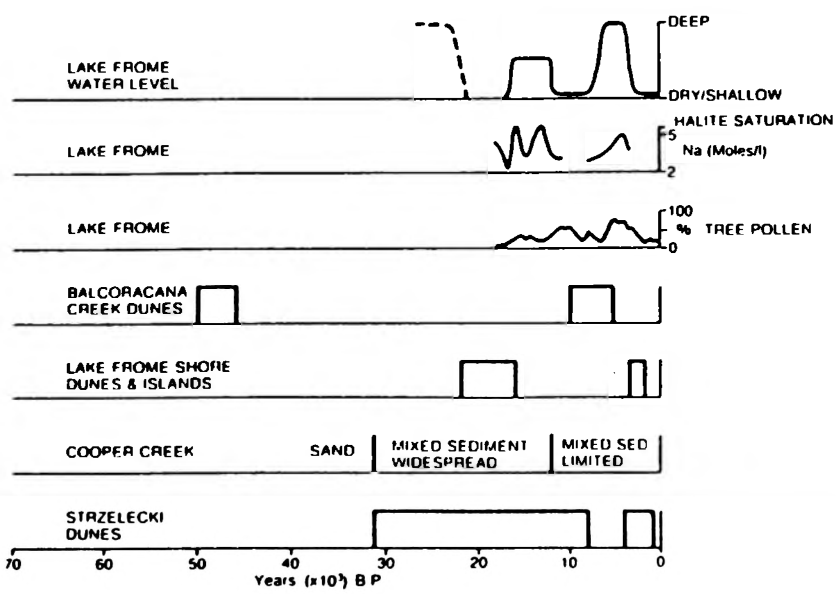

Figure 15. Palaeoclimatic time series from the Lake Frome-Strzelecki dune field region of South Australia

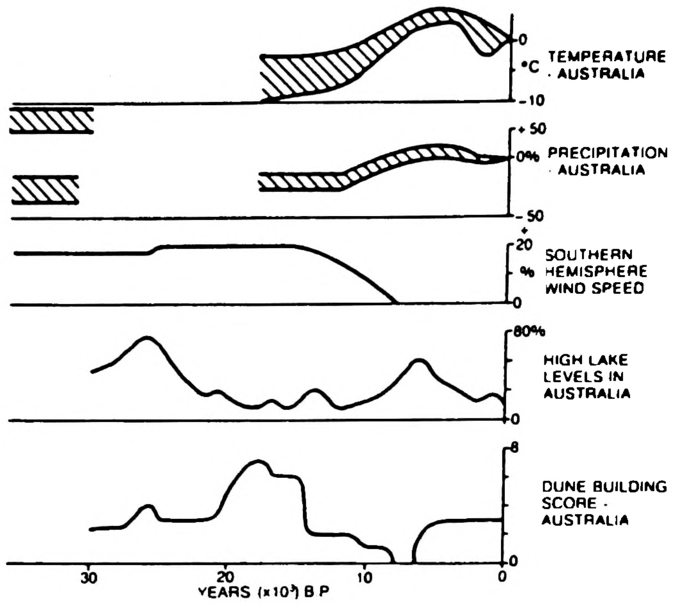

Figure 16. Summary of major climatic changes from the Australian region

have also played a role (see below). Whatever the cause, post-glacial times saw an amelioration of climates, and the apparent re-establishment of the monsoonal circulation during the Holocene, the climates of which are now considered.

7. THE HOLOCENE IN THE AUSTRALASIAN REGION

The environments

The Australian palaeo-environmental records from many sites across the continent very consistently suggest a period of increased precipitation in the early to middle Holocene (Figures 7 to 16). This interpretation is derived from a wide range of evidence including high lake levels (evidence from stratigraphical sedimentology and lake shore features), the re-establishment of tree species (palynology), and dune stabilization in many environments. This period represents a period of slightly higher temperature and higher rainfall than present.

The middle to late Holocene was a time of generally lower rainfall (and temperatures?). Lees et al. (1990) noted a decline in wet season precipitation over northern Australia between about 2,700 and 1,800 years ago, and a series of glacial advances and retreats in Papua New Guinea within the last 3,500 years (Swadling and Hope, 1992) may have been accompanied, as was the Late Pleistocene glacial maximum, by significantly drier climates. Higher precipitation levels were apparently re-established in the very latest Holocene (Figures 7 to 16).

The strength of the monsoon

The consistency of this early Holocene climatic signal suggests a regional control and this is generally interpreted to be the re-establishment of the northwest monsoon. Many authors invoke this interpretation and it seems to fit the data well. It must be noted, however, that the Milankovitch orbital forcing mechanism invoked by Kutzbach and Street-Perrot (1985) to explain the increased strength of the northern hemisphere's monsoon in the early to middle Holocene demands northern and southern hemisphere's monsoons that are out of phase. This is clearly not indicated by evidence from the region stretching from Australia to China (including Tibet), India, the Arabian peninsula, and the northern Arabian Sea (Wasson, 1992).

Wasson suggests that if the orbital forcing mechanism is indeed an appropriate explanation for the fluctuations in the strengths of the northern and southern hemisphere monsoons, there must be some mechanism to account for the transfer of heat between the hemispheres so that both monsoons can be re-established at roughly the same time. He suggests that this mechanism may have been provided by the oceans, for with the postglacial marine transgression, oceanic circulation through the Southeast Asian region would have been re-established, permitting the transfer of warm oceanic water from the north to the south.

8. POTENTIAL QUATERNARY CORRELATIONS BETWEEN AUSTRALASIA AND SOUTHEAST ASIA

Many studies of Late Quaternary environments in the East and Southeast Asian region and adjacent areas identify a cooler and usually drier late Pleistocene glacial maximum followed by an early to middle Holocene that is wetter and warmer (East Asia: Tianchi, 1988; Indonesia: Stuijts et al., 1988; van der Kaars, 1991). Moreover, a shift from Early Holocene environments of elevated temperatures and precipitation to cooler (and drier?) conditions about 3,500 years ago can also be identified in East Asia (Tianchi, 1988). The palynostratigraphy of the oceanic cores from the Indonesian region (van der Kaars, 1991) does not seem to indicate significant Holocene environmental fluctuation however, perhaps reflecting the greater sensitivity to climatic change of the monsoonal and savanna environments of northern Australia and east Asia and the lesser sensitivity of the equatorial regions.

Recent results from Thailand

Data on Late Quaternary environments in northern Thailand are still rare, although the glacial maximum in northeastern Thailand, as elsewhere, was probably drier, cooler and windier (Löffler et al., 1984; Heaney, 1991). Nutalaya et al. (1989) described loess deposits from northeast Thailand, containing organic material that yielded a radiocarbon age of about 8,200 years BP. They argued in a somewhat circular way, that the loess must date from glacial maximum (Late Pleistocene) times, and that the Early Holocene radiocarbon age determination dates a post-glacial humid phase, during which the dated organic material grew in the loess sediments (see also Boonsener, 1991). Löffler et al. (1984) also identified a post-glacial humid phase in the northeast, but they were not able to date it to the Holocene.

Hastings and Liengsakul (1983, 1984) have characterized all Holocene environments of northern Thailand as generally uniformly warm and moist. They presented palynological data from a swamp at 2500 m elevation near Chiang Mai, northern Thailand, that show, however, a Middle Holocene (4.3 ka) shift from a climate with a pronounced dry season to one more like the present "ever wet" environment. They identified this shift with a mid-Holocene higher sea level that transgressed the lower Central Plain as far as Ayuthaya and argued that this caused the increase in precipitation levels. Nutalaya et al. (1989) also reported a mid-Holocene moist phase in the northeast, with a change to drier conditions and further loess deposition at about 3,500 years BP. About 2,000 years ago, northeastern Thailand experienced a major phase of flood activity resulting in significant thicknesses of flood deposits (Nutalaya et al., 1989).

The Holocene chronology reported from northern Thailand to some extent parallels the one presented in a recent study in the northern part of the Central Plain of Thailand (Bishop et al., in press). The channel and bedload characteristics of a series of dated Holocene palaeochannels in this area suggest varying climates during the Holocene, with high discharges in the oldest palaeochannel (Early to Middle Holocene) and the present channel system, and lower discharges in two palaeochannels of intervening age (Middle to Late Holocene).

9. CONCLUSIONS

Despite the large latitudinal range of the region considered here and the varied environments that are found within it, it seems that broad regional correlations can be made. One of the most striking aspects of the material presented here is that there is a strong convergence from a range of sources of evidence, including fluvial and lacustrine stratigraphy, arid zone and fluvial geomorphology, and terrestrial and marine micro-palaeontology, with generally good absolute chronological control. It has also been possible to make some contributions to the understanding of global atmospheric circulation patterns during the Last Glacial Maximum and the Holocene, at least for the Southern Hemisphere.

The clearest correlations can be made for the late Pleistocene glacial maximum and for an early to middle Holocene phase of increased precipitation and perhaps temperature. Clear positive feedback loops can be discerned in the deduced environments: lower sea level resulted from late Pleistocene cooling and the growth of the Antarctic ice cap at the Last Glacial Maximum and this lower sea level promoted increased continentality and aridity. The aridity was further enhanced by the cooler sea-surface temperatures because these lower temperatures resulted in decreased evaporation from the oceans.

The chances for continued advances in regional correlations seem good, especially with the application of dating techniques that extend the absolute chronologies. Thermoluminiscence (TL) offers good possibilities in this regard.

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PROPOSALS FOR QUATERNARY CORRELATION IN CHINA AND ADJACENT AREAS[1]

IGCP 296

by

Yang[2] Zigeng and Lin[2] Hemao

Abstract

In this paper, 1) the first apparent disappearance (FAD) of *Globorotalia truncatulinoides* or the lower boundary of the Olduvai Subchron (1.9 Ma), 2) the horizon of the Brunhes-Matuyama magnetic reversal (0.73 Ma), 3) the beginning of isotope stage 5 (128 ka) and 4) 10 ka BP are taken as the respective lower boundaries of the Lower, Middle and Upper Pleistocene and the Holocene. Quaternary sequences are correlated within China as well as with adjacent areas, including Northern Siberia of the Russian Federation, Boso and Osaka of Japan, the Mekong Lower Plain of Viet Nam, the Central Plain of Thailand, Sangrian of Indonesia and the Wanganui Terraces and West Land of New Zealand, based mainly on radiometric dating and magnetostratigraphy and supported by as many other indications or marker horizons as possible, such as hominid fossils, biological fauna, climatic changes, marine transgressive beds, tektites, isotope stages and so on (Figure 1).

1. PRINCIPLES FOR QUATERNARY CORRELATION

As all indications for stratigraphic division and correlation are diachronous, (biological, lithological, climatological, environmental, geotectonic, etc.), the "Golden Spike" should be adopted as a measure for Quaternary subdivision and correlation in regional stratotypes, which should be identical with or at least as close as possible to the assigned time line.

Radiometric dating and identifiable magnetic polarity reversal horizons, for example the Brunhes-Matuyama boundary and the top or base of the Olduvai Subchron, have become world-wide criteria for the chronostratigraphic subdivision of the Quaternary. They should be supported by as many additional indications of time correlation as possible, including biostratigraphic and climatostratigraphic ones, etc.

2. PROPOSED TIME LINES FOR QUATERNARY DIVISION AND CORRELATION IN THE REGION

In marine deposits, the FAD of *Globorotalia truncatulinoides*, i.e. the base of Foraminifera Zone N22 is found widely and quite consistently at or near the lower boundary of the Olduvai Subchron; along the west Pacific margin area it has been proved that this boundary can be recognized and correlated easily. So the FAD of *Globorotalia truncatulinoides* or the base of the Olduvai Subchron at 1.9 Ma has been proposed as the lower boundary of the Quaternary in the region. The equivalent time line in terrestrial deposits is the base of Member 3 of the Nihewan Formation in Northern China, corresponding to the beginning of the Late Villafranchian in Europe.

The XIIth INQUA Congress (1987) recommended that the Lower to Middle Pleistocene boundary be placed provisionally at the Matuyama-Brunhes paleomagnetic reversal (0.73 Ma). The equivalent boundary in China is the base of the famous Zhoukoudian Formation.

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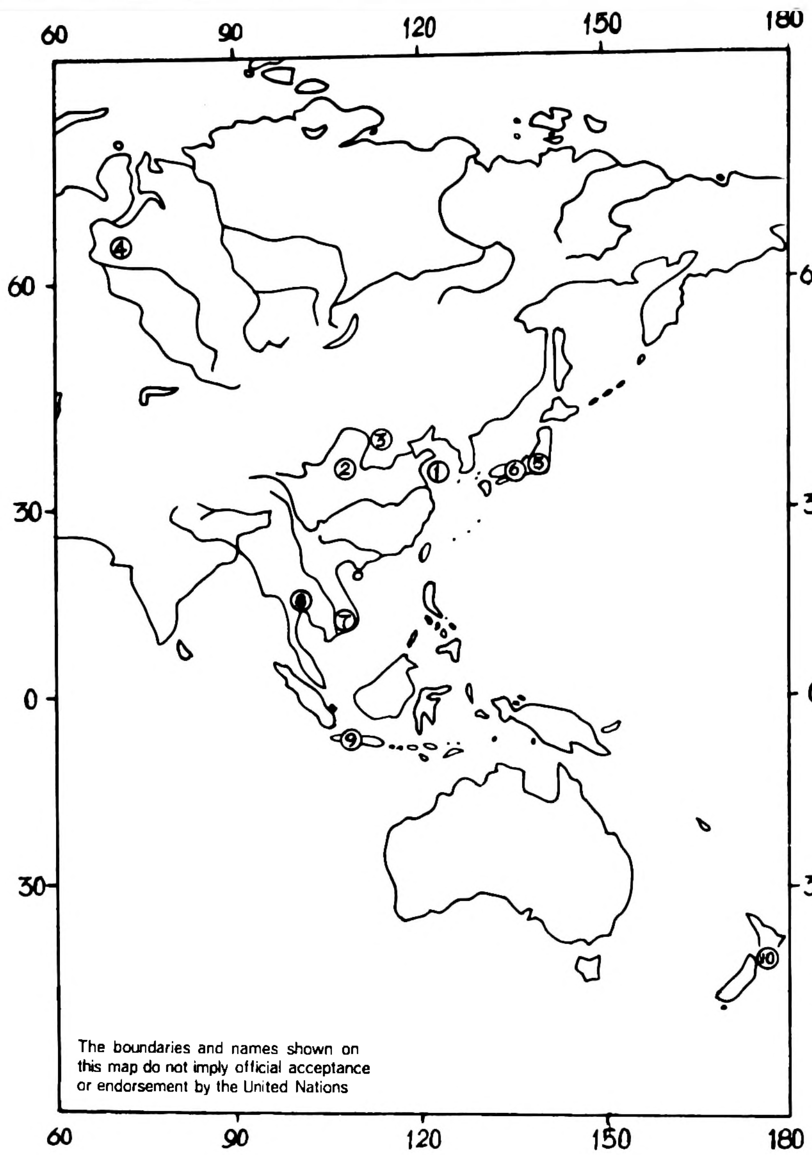


Figure 1. Locations of the sections studied

The boundary between the Middle and Upper Pleistocene has provisionally been placed at the beginning of oxygen isotope stage 5, i.e. the base of stage 5 (128 ka) or its equivalent in non-marine deposits as also proposed by the INQUA Congress. It represents the start of the Last Interglacial Period or the global high sea level period.

The Holocene-Pleistocene boundary has been set at about 10,000 years BP as proposed by the IXth INQUA Congress. It represents a climatic turn for the better at the onset of the current Postglacial. Before the start of the Holocene however, an important event occurred in the Younger Dryas (11,000 to 10,300 years ago), that was reflected in a marked decline in temperature.

3. PROPOSALS FOR QUATERNARY CORRELATION OF CHINA AND ADJACENT AREAS

According to the principles and proposed time lines mentioned above, geological events are taken as the basis for Quaternary subdivision and correlation, and include data from radiometric dating and magnetostratigraphy which are likely to be available world-wide, in addition to hominid fossils, fauna, marine transgressive beds, climatic changes and tektites, as well as oxygen isotope data, etc. (Figure 2).

LOWER PLEISTOCENE

As said, the first apparent disappearance of *Globorotalia truncatulinoides* is proposed as the lower boundary of the Quaternary in marine deposits. A series of significant foraminiferal events, represented by this first apparent disappearance of *Globorotalia truncatulinoides* are revealed in the China Sea and adjacent seas and coastal areas (Yang & Lin, 1991).

The FAD of *Globorotalia truncatulinoides* has been found widely and consistently in East and Southeast Asia. It appears on the base or a little beneath the base of the Olduvai Subchron in Boso, Takanabe and Kakegawa of Japan (Nirei et al., 1987 and Nakagawa, 1987).

In New Zealand the base of *Globorotalia truncatulinoides* is found at 1.75 Ma in the Olduvai Subchron (Beu et al., 1987).

In sections without *Globorotalia truncatulinoides*, it is suggested to take the base of the Olduvai Subchron as the lower boundary of the Pleistocene, supported by other data such as radiometric dating, etc. for correlation and division of Quaternary sequences. For instance, in core QC_2 a normal polarity interval determined at its end has been identified as the upper part of the Olduvai Subchron (Zheng Guangying, ed., 1989). In the Osaka Group of Japan, the Olduvai Subchron at its lowermost part has been located by a series of age datings above it (Itihara et al., 1987). In the Mekong Lower Plain, The Q/N boundary is placed at the base of the Thieu Can Horizon between two normal polarity intervals (Hoang Ngoc Ky, 1989).

In terrestrial deposits, represented by the Nihewan Formation in China, the Q/N boundary should be at the base of the 3rd Member of the Nihewan Formation, i.e. at the very first level of the Olduvai Subchron (1.9 Ma). The Nihewan fauna *in sensu strictu* is represented in the 3rd Member by *Equus Sanmeniensis* coexisting with *Proboscidipparion sinensis*, corresponding to the Late Villafranchian (Yang & Lin, 1991). A new section was studied by the authors last year in the Nihewan area and a mammalian fauna with *Orientalis nihewanicus*, *Lasiopodomys probrandti* and *Mimomys orientalis* etc. collected by scientists from the Institute of Vertebrate Paleontology and Paleoanthropology of the Chinese Academy of Sciences. These species can be correlated with those of mammalian Zone MN18 or Mm Q-1 (Azzaroli, 1991) in the Lower Pleistocene of Europe. Among these, the more progressive species *Lasiopodomys probrandti* occurs at the lowermost horizon as far as has been revealed to date. This provides new data for Quaternary subdivision and correlation in the region. It further reminds us that more efforts should be made to seek out small mammal fossils in the terrestrial Quaternary.

Marine transgressive beds provide another indication for Lower Pleistocene correlation. Transgressive bed H_{VII} found between the boundaries of the Brunhes and Matuyama (0.73 MA) and the base of the Jaramillo event (0.97 Ma), have been found in cores QC_2 and QC_1 in Huanghai (Yellow) Sea and QC_3 in its coastal area. Five samples collected from H_{VII} in core QC_2 were dated from 779.3 ka to 906.0 ka by the ESR method last year. This dating agrees with magnetostratigraphic data. There are corresponding marine beds in Japan, for example, the marine beds Ma1, Ma2 and Ma3 in the Osaka Group, which can be correlated with H_{VII}. The marine beds in the Ca Mau Horizon of Viet Nam and the "Grenzbank" Zone of Indonesia may fall within the same period as H_{VII}. The H_{VII} transgressive bed may well have a wide distribution in the region, but more research is needed.

Lower Pleistocene sequences in China and adjacent areas are shown in Figure 2.

MIDDLE PLEISTOCENE

As proposed by the XIIth INQUA Congress, the Lower to Middle Pleistocene boundary has been placed at the Brunhes-Matuyama magnetic polarity reversal horizon (0.73 Ma). Taking core QC_2 as an example from the China Sea, it is seen to be identical to the base of terrestrial bed C_{VI}. ESR dating yields an age of 631.2 ka – a little above the boundary.

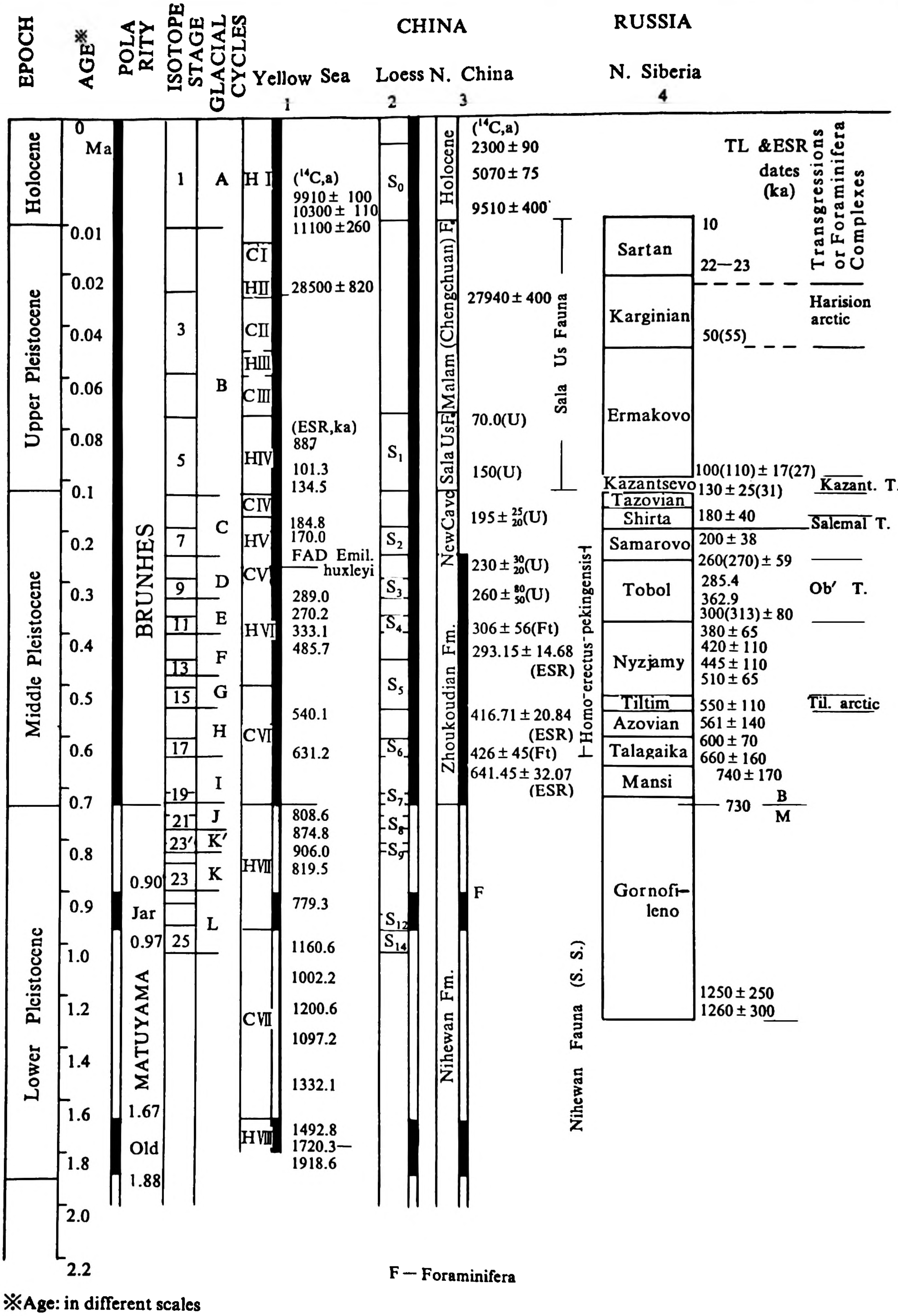


Figure 2. Quaternary correlation of China and adjacent areas

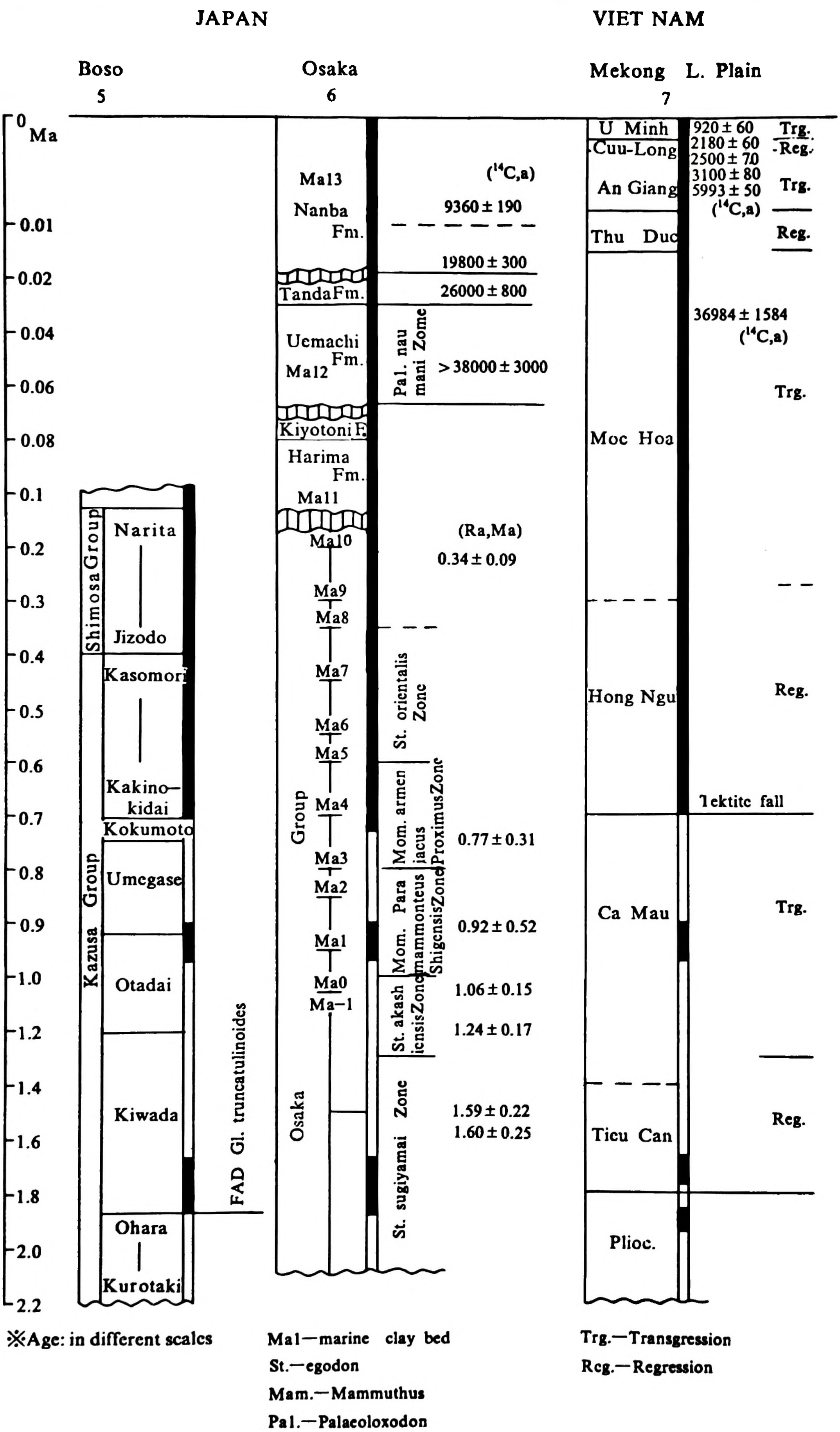
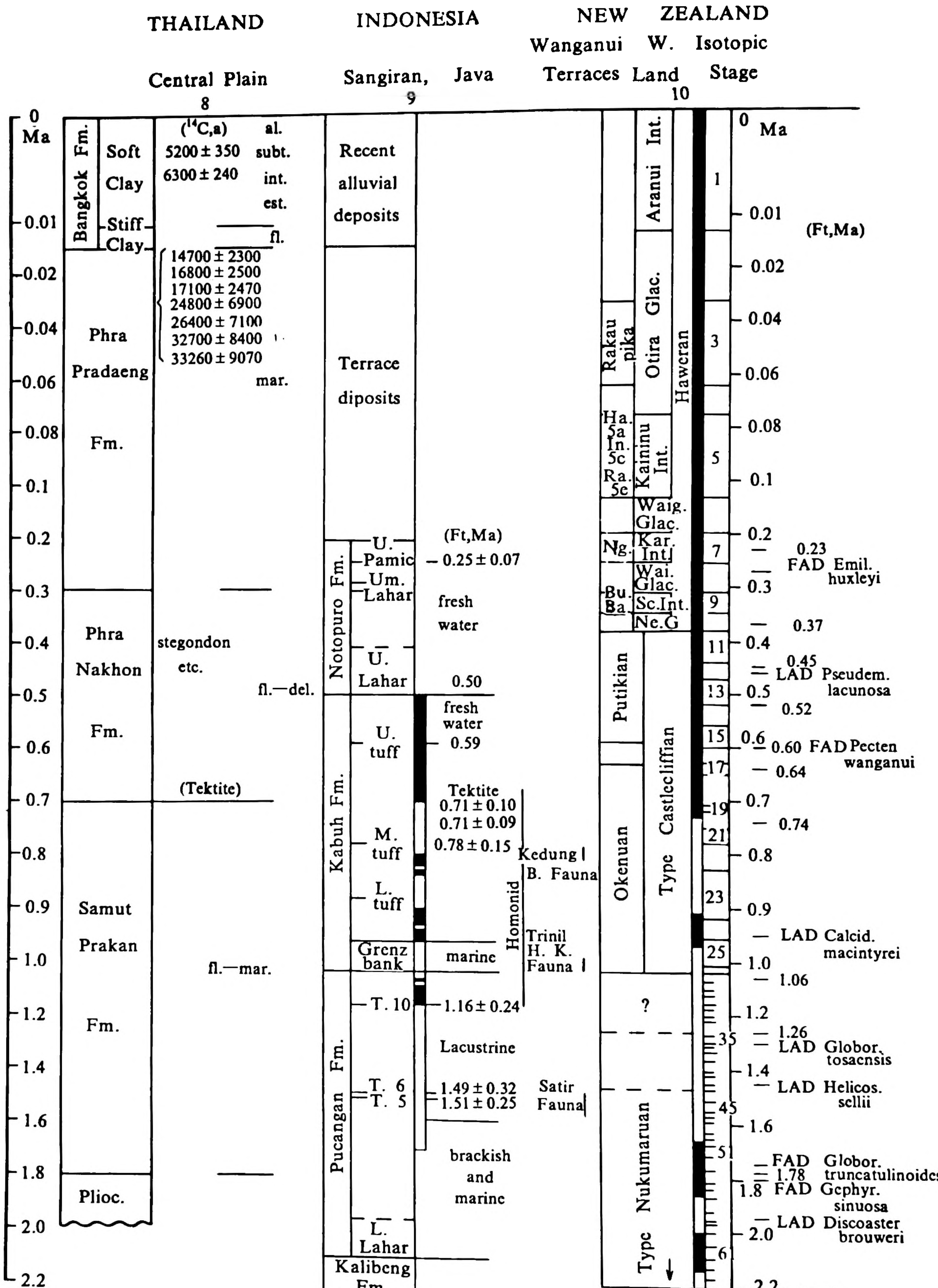


Figure 2a. Continuation of Figure 2



※Age: in different scales

al.—alluvial subt.—subtidal

int.—intertidal est.—estuary

mar.—marine fl.—fluvial

del.—deltaic

Ha.— Hauriri In.— Inana Ra.— Rapanui

Ng.— Ngarino Bu.— Brunswick Ba.— Braemore

Waim.—Waimea Kar.—Karoro Ne.— Nemova

Waig.— Waimaunga SC.— Scandinavia

Figure 2b. Continuation of Figure 2

In terrestrial deposits in China, the Lower to Middle Pleistocene boundary is situated at the base of the Zhoukoudian Formation. In the loess area of Northwest China, the Brunhes-Matuyama paleomagnetic boundary has been determined within loess bed L_8 (Liu et al., 1991) as well as at the base of paleosol bed S_7 (Nishida et al., 1984).

Tektites

In the gigantic Asian-Australian tektite field, extending from the Indian Ocean trough Australia to the southern Pacific as well as to East and Southeast Asia, tektites and microtektites occur in a stratigraphic position close to the Brunhes-Matuyama boundary. In China, tektites have been found in many places of Guangdong and Hainan Provinces, and have lately also been discovered in the areas of Maoming and Dianbai of western Guangdong, showing ages of 0.71 ± 0.14 Ma as determined by fission track analysis of two samples (Zhang et al., 1991). Microtektites were found in boreholes in the Northern China Plain as well as the Subei Plain. Tektites are widespread in Southeast Asian countries such as Viet Nam, Thailand, Indonesia and the Philippines as well as in the Lao People's Democratic Republic. Their age datings range between 0.5 Ma and 0.9 Ma. However, most of them are 0.7 Ma in age and represent an excellent marker horizon for regional correlation (Yang & Lin, 1991 – see Table 1).

Hominid fossils

On the basis of age data published so far, the major hominid fossils of the Lower and Middle Pleistocene in China and Indonesia can be roughly ordered and compared as follows:

Homo erectus pekinensis 0.23 - 0.6 Ma	(Yang & Lin, 1991)
Homo erectus chenjiawoensis 0.65 Ma	*Homo erectus erectus* 0.7 - 1.0 Ma
Homo erectus lantianensis 1.1 - 1.15 Ma (An et al., 1990)	*Homo erectus modjokertensis* 1.0 - 1.16 Ma (Itihara et al. in Watanabe & Kadar, 1985)

According to the above-listed ages, *Homo erectus pekinensis* undoubtedly lived in the Middle Pleistocene and *Homo erectus chenjiawoensis* in the early Middle Pleistocene. *Homo erectus lantianensis*, however, would be late Early Pleistocene of age. *Homo erectus modjokertensis* of Indonesia also belongs to the late Early Pleistocene, and to the same period as *Homo erectus lantianensis* of China. Nevertheless, *Homo erectus* is found mainly in the late Early Pleistocene and continues into the early Middle Pleistocene, in which skull P_{VI} is situated at the horizon above, while the others are found beneath the tektite layer (Watanabe & Kadar, 1985). Referring to the Middle Pleistocene hominid fossils in China, there are the others such as the *Homo erectus* of Wushan (2.01 Ma), *Homo erectus* of Hexian, which is younger than *Homo erectus pekinensis* and the disputed *Homo erectus* of Yuanmo (0.7 Ma, 0.9 Ma or 0.6 – 0.5 Ma). The fossil *Homo sapiens* collected from the layer corresponding to the end of the Middle Pleistocene to Late Pleistocene, is not only widespread in China but in East and Southeast Asia as well.

Mammalian fauna

The Middle Pleistocene fauna collected from the Zhoukoudian Formation is known as the *Homo erectus pekinensis-Megaloceros pachvosteus* Fauna. The genus *Megaloceros* is distributed widely in East Asia, and migrated from China to Japan during the early Brunhes Subchron. The similar genus *Sinomegaceros* belongs to Mammalian Zone MQ_4 of the Middle Pleistocene in Japan. In Southern China the corresponding fauna is called *Stegodon-Ailuropoda* Fauna which is a part of Sino-Malayan Fauna. The representative species of the fauna *Stegodon orientalis* has been found in China, Japan, Ryukyus and the island of Taiwan. The genus *Stegodon* is also widespread in the same horizon in Southeast Asia.

Table 1. Age dating of some tektites from China and Southeast Asia

PLACE	POSITION	LEVEL	AGE (Ma B.P.)	METHOD	REFERENCES
Beijing Plain	40°03'N. 116°33'E	Zhaili Formation	>0.73	geomagnetism	Li Dingrong et al. 1980
Diluzai, Hainan		sand in the lower of Beihai Fm.	0.687		
Longlouxi, Hainan		ibid.	0.728	fission track	Yan Zheng et al. 1979
Wenchang Middle School. Hainan	19°36'N. 110°42'E	ibid.	0.703		
Tanniu, Hainan	19°45'N. 110°33'E	ibid.	0.733		
Lam Dong Plateau Viet Nam	11°50'N. 108°10'E	laterite surface of bauxite mine	0.57		
Quang Ngai, Viet Nam	15°20'N. 108°30'E	laterite surface under silty sand-clay loess	0.63		
Phan Rang, Viet Nam	11°30'N. 108°30'E	3rd erosional terrace	0.65		
Dai Ning, Viet Nam	14°10'N. 109°30'E	2nd erosional terrace	0.66		
Thu Dau Mot. Viet Nam	11°20'N. 106°30'E	laterite surface, under loess	0 67	radioactive dating	Hoang Ngoc Ky 1989
Tam Ky Da Nang, Viet Nam	15°20'N. 108°30'E	erosional terrace	0.70		
Tuy Phong Viet Nam	12°10'N. 107°40'E	red sand layer	0.72		
Cheo Rco. Viet Nam	12°15'N. 107°20'E	pebble layer. 2nd river terrace	0.77		
Naghia Binh. Viet Nam	14°30'N. 107°25'E	under sand clay loess layer	0.80		
Buri Ram and Nakorn Ratchasima. Thailand	14°20'-15°40'N. 101°30'-103°30'E	carbonate-rich zone in the mid-lower of Kham Sakae Sagne Fm.	0.70	K-Ar & fission track	S. Wongsomsak 1987
		20 m above the bottom of Trinil Beds	0.70	K-Ar & Ft.	T. Nilsson 1987
Sangiran, Java, Indonesia 1987	7°20'S.111°0'E	Bapang Formation	0.51-0.69 0.67	K-Ar	S. Sartono.
			0.71±0.10 0.71±0.09	fission track	Sudijono. 1987
Cagayan Valley of northern Luzon, Philippines	17-18°N. 121°30'E	Awidon Mesa Fm	0.90		R. Shutler Jr. et al., 1987

Transgressive beds and climate

Two transgressive beds, H_V and H_{VI} were found in the Middle Pleistocene of core QC_2 obtained from the Yellow Sea. The age of H_V is 184.8 ka and 170.0 ka by ESR dating. Nanofossils of *Emiliana huxleyi* have often been found in bed H_V but never in the underlying strata. Thus the base of bed H_V can be regarded as the FAD of *Emiliana huxleyi* and its age should not exceed 0.27 Ma. According to the data obtained so far, the age of bed H_V is approximately between 0.17 Ma and 0.27 Ma. The ESR age of bed H_{VI} is between 270.2 and 485.7 ka BP.

The age of bed H_V corresponds roughly to isotope stage 7 which was one of two important warm periods in the Middle Pleistocene in Europe (Bonifay, 1980). The following horizons in other areas may be correlated with bed H_V, the Ob transgression of the Tobol horizons in Northern Siberia, marine beds Ma9 and Ma10 in the Osaka Group of Japan and the Karoro Interglacial or the Ngarino horizon in New Zealand. The maximum of the transgression, represented by bed H_{VI}, corresponds to isotope stage 13. Nevertheless, paleosol S_5, which is a product of a warm period, is regarded as corresponding to isotope stage 13-15 representing yet another important warm period reflected in Chinese loess sequences. The Ma8 and Ma7 (and some Ma6?) in the Osaka Group may be compared with bed H_{VI}. The age datings of 510 ± 65 ka to 550 ± 110 ka of the horizon of the Titlimian Arctic Foraminifera complex in Northern Siberia shows a higher age than that of H_{VI}. It is difficult to decide whether these horizons may be correlated or not. Could it be that the accuracy of the age dating concerned causes the difficulty in correlation?

UPPER PLEISTOCENE

The base of the Upper Pleistocene is placed at the beginning of isotope stage 5 (128 ka), indicating the start of the Last Interglacial Stage. There was a warm period at the onset of the Late Pleistocene followed by a cold one belonging to the Last Glacial.

In the seas around China, evidence for the warm period of isotope stage 5 in the early-Late Pleistocene may be found in borehole Xsh-1 of Xisha Island, in core V36-06-3 on the north slope of the South China Sea, in core QC_2 in the Yellow Sea, as well as in core Z14-6 in the Okinawa Trough (Yang, 1989). For example in core QC_2, transgressive bed H_{IV} was deposited in a warm period proved by spore-pollen analysis, and results of a trial oxygen isotopic analysis indicate that bed H_{IV} also belongs to stage 5. Both H_I and H_{IV} are prominent transgressive beds among eight transgressions and their microfossil assemblage shows a water depth of more than 50 m in its lower part (Lin, 1991). Ages of samples collected from its upper and lower parts and from the bottom are 88.7 ka, 101.3 ka and 134.5 ka respectively, dated by the ESR method, and agree with the age of 75 – 128 ka inferred originally. All data indicate that H_{IV} is a product of a marine transgression that occurred during the Last Interglacial.

During the Last Interglacial, regression dominated in the Yellow Sea. Only two rather small scale transgressions occurred in the period 75 ka to 11 ka BP. The first one has been dated at 60 to 50 ka BP and reached the present level of 50 m water depth in the Yellow Sea. Bed H_{III} formed at that time. The second transgression created bed H_{II}. It reached the present level of 50 m water depth at about 29 ka and 21 ka BP respectively, and deposited bed H_{II}. It was followed by a large scale regression during the Last Glacial Maximum at about 18 ka to 15 ka BP; the coast line receded to the present -80 m to -140 m line. The shelf of Eastern China became dry land and underwent weathering and erosion during that period.

The Upper Pleistocene in Chinese continental deposits is represented by the Sala Us Formation and the Malan Loess. The Sala Us Formation was deposited under warm climatic conditions in a fluviolacustrine environment containing grassland- mammalian fauna. The age of this formation is 200 ka at its bottom and 150 to 70 ka in beds 10 to 29 upwards (Zheng et al., 1991), and it can be correlated with paleosol S_1 in the Chinese loess area, the TL age of which is reported as 110 ka (Nishimura, 1984) or 110 to 130 ka (Zheng et al., 1991). Both formations were deposited during the Last Interglacial. After the Sala Us Formation, the Malan Loess (or Chengchuan Formation) was deposited in a cold, arid environment. Its age is 29.2 ka at bed 33 in its upper part and 65 ka at bed 30 at its bottom (Zheng et al., 1991). The Malan Loess corresponds to loess L_1 in the Luochuan section of Shaanxi, the age of which is 20-71 ka as dated by a series of TL samples (Li, 1980).

According to TL and ESR dating, Arkhipov regarded the horizon linked to the Kazatsevo transgression in Northern Siberia as the one formed in isotope stage 5, corresponding to a period of high sea level early in the Last Interglacial (Arkhipov, 1987). This horizon should be compared with the lower part of H_{IV} in the Yellow Sea. Horizons corresponding to the transgression that occurred during the Last Interglacial period in the region are: marine bed Mal1 in the Osaka Group of Japan, the transgressive beds in the Moc Hoa horizon of Viet Nam and in the Pradoeng Formation of Thailand, terrace deposits of the same period in Indonesia and in New Zealand, the Kainini Interglacial in West Land or the Hauriri, Inana and Rapanui horizons of stage 5 in Wanganui Terrace.

No exact age of transgressive bed H_{III} in core QC_2 has been established and it can therefore not be correlated accurately. Nevertheless, corresponding horizons may exist in East and Southeast Asia, as for example the Mal2 in the Osaka Group of Japan. The transgression of H_{II} has been widely established in Eastern China.

Loessic sediments have been found in strata of the late-Late Pleistocene to Early Holocene in Southeast Asian countries such as Viet Nam, Thailand and Malaysia. For instance in Viet Nam, the Thu Duc horizon consists of yellowish red or reddish yellow silty sand-clay with a thickness of 1-10 m (Hoang, 1989), and is correlated with the red yellow loess in Thailand, with the loam cover of fine grained layers in Malaysia and with the Red Earth of Myanmar (Hoang, 1991). Such loessic sediments, that were deposited late in the Last Glacial as a result of eolian sedimentation may well be correlated with the Malan Loess of China. They represent yet another marker horizon tor Late Pleistocene stratigraphic correlation in the region.

HOLOCENE

10 ka BP is taken as the beginning of the Holocene. That point in time coincides with the climatic transition to the Postglacial period, after the Last Glacial had undergone several climatic fluctuations and expired.

Subdivision and correlation of the Holocene is mainly based on the radiometric dating of ^{14}C. Climatic changes were accompanied by remarkable changes in the fauna but particularly in floral development. For example, on the basis of abundant sporo-pollen data in China, not only the lower boundary of the Holocene has been determined but the further subdivision of three parts of the Holocene was made possible as well. The Holocene can thus be better correlated with other areas (Yang, 1989a). Warm and rainy periods increased fluvial, lacustrine and alluvial sedimentation in the terrestrial facies of the Holocene. In the marine facies, along with the melting of the continental ice-sheet, the sea level was going up, leading to a universal, large scale transgression along the continental margin. Transgressive beds were formed, such as H_I in the Yellow Sea, the Jomon Transgression and Ma13 of the Osaka Group in Japan, the An Giang and U Minh horizons in Viet Nam and the Bangkok Clay in Thailand, etc. This transgression corresponds to the Flandrian transgression in Northwest Europe. In East and Southeast Asia the transgression has some common characteristics: sea levels began to rise rapidly from 10,000 to 8,000 years BP, and culminated about 7,000 to 5,000 years ago, reaching levels of up to 5 m above the present sea-level; from 6,000 to 4,000 years ago the sea receded gradually with minor fluctuations before reaching its current level.

An important event marked by a sudden decline in temperature took place in the Younger Dryas (11,000 to 10,300 years ago), just before the start of the Holocene. Corresponding horizons have been found in the shelf around China and in the ice-cores of the Qinghai-Tibet Plateau and the Sulu Sea. The phenomenon should be further studied in the region as it would provide an important marker horizon for Holocene correlation.

4. CONCLUSION AND DISCUSSION

1. The "Golden Spike" should be adopted as a rule or as one of the most important tools for Quaternary subdivision and correlation in the region of Asia and the Pacific. As a "Golden Spike", the first apparent disappearance (FAD) of *Globorotalia truncatulinoides* or the base of the Olduvai Subchron (1.9 Ma BP) is proposed as the lower boundary of the Quaternary in the region. This boundary can be recognized and applied very easily in the region, and furthermore, it is much closer to the 1.67 Ma recommended by the ICS than the boundary of 2.4 Ma BP.

2. Special emphasis should be put on geological events. Only after identifying those significant events that are widespread and interrelated, Quaternary correlation will become feasible on a regional or even a global scale. Regional events should be linked with global changes, for example tektite rains, pronounced marine transgressions, declines in temperature such as occurred in the Younger Dryas, as well as with biological events (evolution, migration, dispersal, etc.).

3. Age dating and magnetostratigraphic studies should be strengthened, and their accuracy improved. Their special significance lies in the fact, that these methods are effective and direct means to Quaternary subdivision and correlation.

4. Much attention should be paid to the study of marine transgressions. They are directly related to warm climatic periods although they are controlled by various factors. Marine transgressions that occurred during major warm periods are generally isochronous and widespread and represent additional major marker horizons for Quaternary correlation.

5. The isochronism between climatic cycles recorded in loess on the one hand and the deep sea record on the other has become a major basis for correlation in East and Southeast Asia. Tropical loessic sediments, weathered horizons and paleosols play important roles in reflecting climatic changes and therefore merit further study.

6. The study of micromammalian fossils should be strengthened. Because of their rapid evolution and dispersal during the Pliocene to Early Pleistocene, they can should play an important role in Quaternary correlation.

7. After evaluating known events with a view to their potential for regional correlation, a "time window" can be established in some detail for the Holocene and Upper Pleistocene, and at least approximately for the Middle and Early Pleistocene in the region.

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STRATIGRAPHIC SUBDIVISION AND CLIMATIC CHANGES IN THE LOESS PLATEAU OF MAINLAND CHINA AND THE CHINESE PROVINCE OF TAIWAN[1]

IUGS UNESCO IGCP 296

by

Armelle Billard[2]

Abstract

In Southeast Asia, Pleistocene climatic changes were mainly dependent upon fluctuations of the summer monsoon, the most complete record of which is found in the loess-palaeosol sequence of the Chinese Loess Plateau. This paper presents a comparison between this area and the northwestern part of the Chinese Province of Taiwan, a region which has been subjected to subtropical warm and humid climates in alternation with cooler and drier conditions. It is shown that further investigations are needed on the island in order to establish the conditions under which the red soils formed and the thick loam layers were deposited.

1. INTRODUCTION

Although the Quaternary stratigraphic sequences in the subtropical countries of Southeast Asia are, for the most part, incomplete and fragmentary, they reflect the occurrence of climatic cycles. These correspond to the alternation of periods of different warmth and humidity which have often been interpreted in terms of pluvials and interpluvials. The broad coincidence of interpluvials and glacials on the one hand, and pluvials and interglacials on the other, has been established in several parts of Southeast Asia, as reported by Šibrava (1993a.b). This interpretation was initially derived from comparison with the palaeoenvironmental conditions in Africa. Confirmation could well come from a comparison of the climatic and environmental changes found in these areas with the changes recorded in the sequence of the Loess Plateau in China, a sensitive margin which has been subjected to strong climatic contrasts since 2,4 million years ago (Liu, 1985). Because the resulting loess-palaeosol sequence has been exceptionally well preserved, it can be used as a reference for attempts toward correlations to be made in Asia.

2. THE LOESS-PALAEOSOL SEQUENCE OF THE LOESS PLATEAU IN RELATION TO THE PALAEOMONSOON

The loess-palaeosol sequence of the Loess Plateau (Figure 1) records long term variations in the Pleistocene climate (Liu, 1985; Kukla, 1987). It is considered to be the most complete and continuous palaeoclimatic and stratigraphic record so far known from the continents for the last 2,5 million years (Figure 2) and it has been correlated with the isotopic marine stages (Liu et al., 1985; Rutter et al., 1991). The Loess Plateau sequence is the result of an alternation of periods of loess accumulation associates with cold-dry climates with a winter monsoon dominance, and periods of pedogenesis during warm-humid climate with a summer monsoon dominance (An et al., 1991). It records the Pleistocene and Holocene variation of the northwestern wind stress (Liu et al., 1989) on the one hand, and the southeastern summer palaeomonsoon (An et al., 1991) on the other.

In addition to the periodicity of the cold-dry and warm-humid periods, the sequence found on the Loess Plateau records some irregularity in the amplitude of the cold stages as shown by the occurrence of

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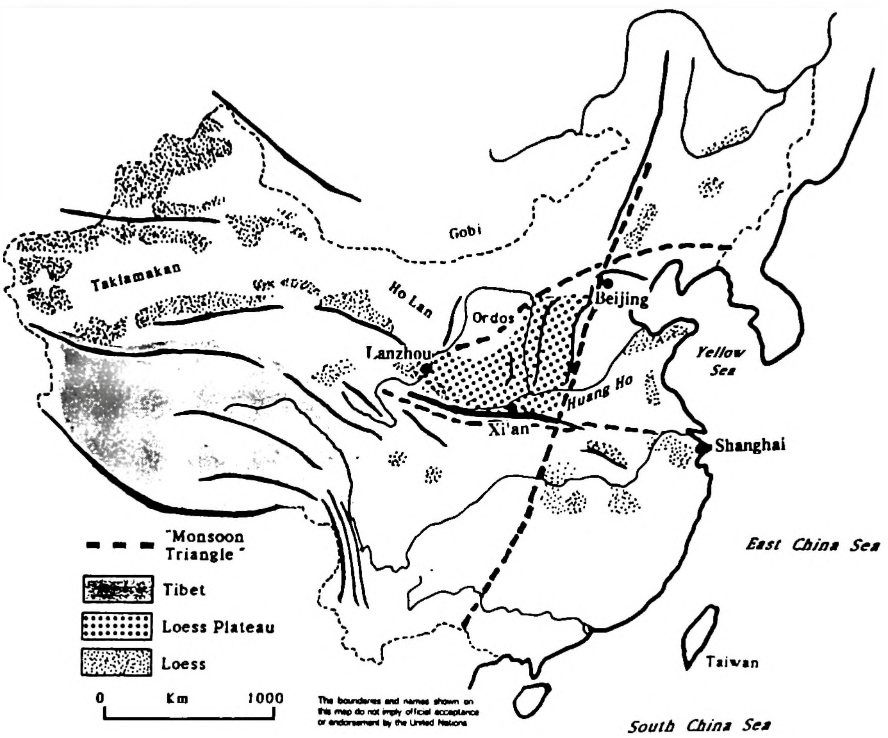
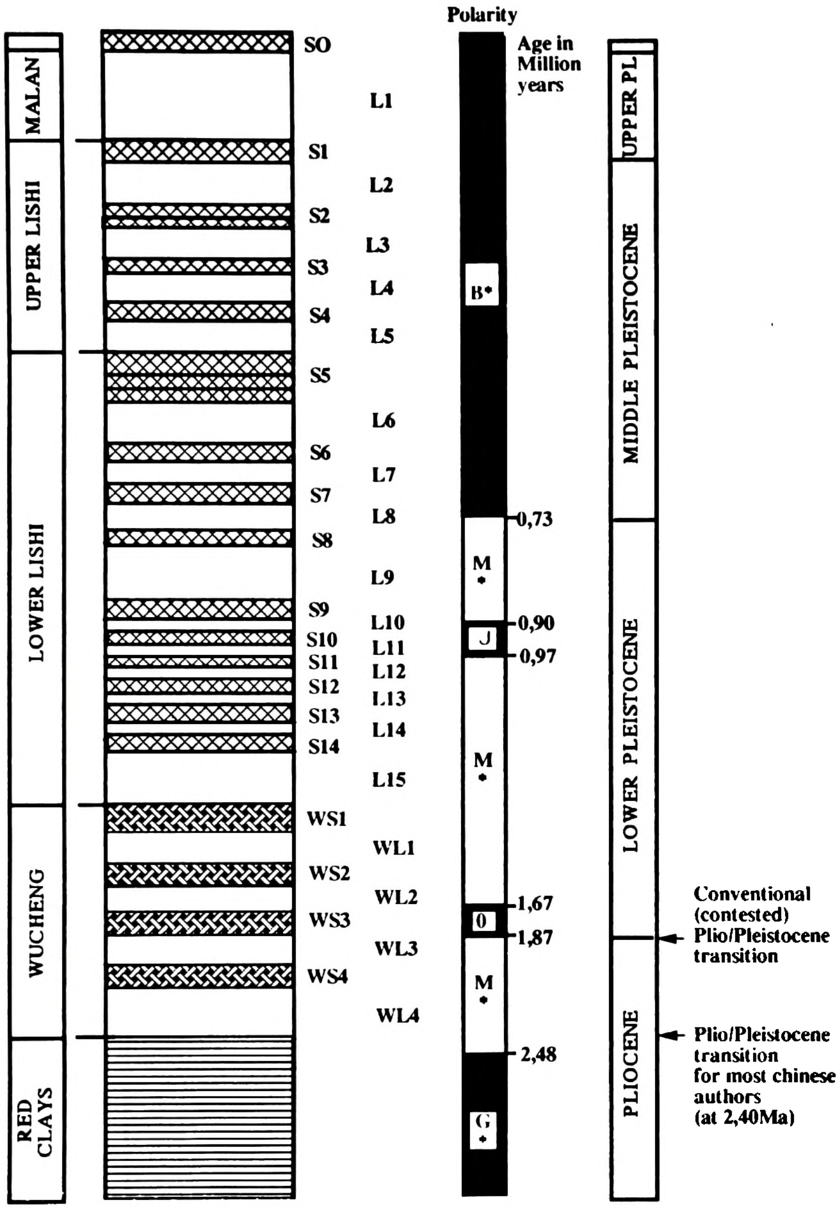


Figure 1. Location map showing main areas studied. The "monsoon triangle" of Li et al. (1988) is the region in which the limits of penetration of the moist southeastern monsoon overlap the area of the most concentrated dust falls derived from cold and dry northwestern winds

some major units of thick sandy loess (Liu, 1985; An et al., 1991). The irregular development of the palaeosols indicates that the amounts of rainfall and the temperatures of the humid and warm stages were also rather variable. The most spectacular examples is provided by the occurrence, in the Middle Pleistocene, of the palaeosol complex S5 and especially of palaeosol S5-1 which has been correlated with isotopic stage 13 (Liu et al., 1985).

The proposal (An et al., 1987) that the whole climatic episode represented by S5 is of global significance is worthy of careful consideration. As underlined by Kukla (1987), the isotopic stage 13 "barely reaches two-thirds of the isotopic values of the younger warm stages" so that S5 has no equivalent in the oceanic record. Neither is the significance of S5 reinforced by its correlation (proposed by An et al., 1987) with the "Mindel-Riss" or "Great Interglacial" of the Alps because this does not exist as such (Billard, 1993). This is demonstrated by the fact that no major pedogenesis, developed during this stage, is recorded in the other loessic sequences or in the other continental sequences of Eurasia. This so-called "Mindel-Riss Great Interglacial" is a theoretical concept based largely on the amalgamation into a single pedological unit of several red soils which developed during different successive interglacial stages from the Matuyama to the mid-Brunhes chron (Billard, 1993). A progressive change, recorded in the palaeosols and especially obvious from stages 13 to 9, expresses a shift towards cooler and drier climates during the interglacial stages in Europe. A similar evolution has been found in central Asia (Dodonov, 1979; 1986).

However, the specificity of the S5-1 palaeosol, interbedded in the Brunhes loess series of the Loess Plateau in China demonstrates the occurrence in this region of a climatic optimum during a Middle Pleistocene interglacial. Not being global, the S5 episode cannot be entirely the product of orbital forcing but must also reflect local influences which require closer investigation. the climatic optimum of Central China might be related to a slight shift in the extent of the summer paleomonsoon towards the north, driven by continental influences in Asia. Consequently, the question arises as to whether an equivalent variability in the climate of the humid and warm periods is also found in other regions of Southeast Asia, with an increase in the precipitation and temperature as reflected further North by theformation of S5 and more especially S5-1.



• B: Brunhes, M: Matuyama, J: Jaramillo, O: Olduvai, G: Gauss.

Figure 2. **The loess-palaeosol sequence in the Chinese Loess Plateau. Stratigraphic subdivisions for the Malan and Lishi loess are after Liu et al. (1985), and those for the Wucheng loess follow Kukla (1987). The post-glacial palaeosol (S_0) is found above the glacial loess (L_1), etc. The sandy loess units (L_9 and L_{15}) and the triple S_5 palaeosol have frequently been used as markers in the region**

More generally, the effects of the climatic and environmental cyclic variations, controlled by the astronomical forcing and recorded on the Loess Plateau, should also be found further South in the warmer and more humid areas of Southeast Asia. Although the stratigraphic sequences are incomplete and fragmentary in many of these areas, they clearly reflect the occurrence of climatic cycles (Šibrava, 1993a). These correspond to the alternation of periods of variable warmth and humidity which have been interpreted in terms of pluvials and interpluvials. A special attention should be given to the correlation of these climatic stages with the alternating periods of strengthening and weakening of the summer monsoon, the succession of which is recorded and exceptionally well preserved on the Loess Plateau.

3. NEW STRATIGRAPHIC OBSERVATIONS IN NORTHWEST TAIWAN, PROVINCE OF CHINA

What follows is a first attempt at a comparison of the stratigraphic sequence as observed in the northwest of the island of Taiwan, Province of China and that found on the Loess Plateau of China. In the words of Liew (1988) "In the foothills of northwestern and/or west central Taiwan, the early Pleistocene shallow marine sediments of the Cholon and Toukoshan Formations were continuously deposited till middle Pleistocene. These thick continuous Pleistocene sediments represent a unique geological setting of this young mountain belt". Additional original data used in this discussion were provided to the author by Dr. Liew Ping-Mei (pers. comm., 1991).

In the northwest of the island (Figure 3), Tomida (1972) showed that rivers running from east to west formed a large and composite alluvial deltaic fan at sea level, the coarse sediments of which are found interfingering with the shallow marine sediments (marls, sandstones and sands) of the Toukoshan Formation. The uplift of the area, in the Middle Pleistocene, caused the emergence of the area and the formation of tectonic blocks raised to different altitudes above sea level. A change in the river system followed, with incision of the streams aligned along a dominantly south to north direction, which resulted in a set of terraces, inset into the Toukoshan formation (Figure 4). this uplift has continued to the present time and affected the fluviatile terraces which are found to be tectonically disturbed in several locations.

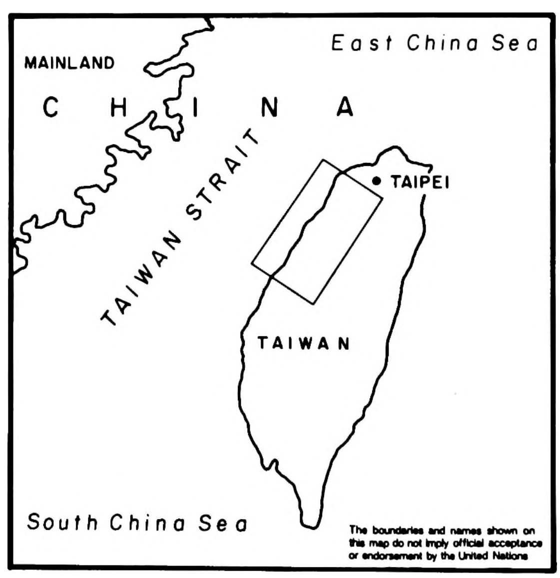


Figure 3. Location of the study area in northwestern Taiwan, Province of China

Red palaeosols classified as laterites (Tomida, 1972) are found in the upper part of the deltaic and fluviatile deposits. They show thicknesses and a degree of weathering which vary in relation to their age. The reconstitution of the palaeoclimatic variations is based on the results of comparative pollen analysis from different sections observed on the island of Taiwan (Liew, 1979, 1982, 1985, 1988: Chen & Liew, 1990), and preliminary observations of the pedological features.

In the northwest of the island, 25 to 50 km north-northwest of Taipei, the Wugukeng block (Figure 5) reaches 250 m above sea level. It consists of interdigitated shallow marine and deltaic sediments which correspond to the Tananwan formation. This one was first considered younger than the toukoshan formation and tentatively placed in the upper part of the Brunhes epoch (Liew, 1988). On the basis of new absolute dates however, the two formations are now considered to be contemporaneous. The lower part of the Tananwan formation overlies disturbed layers of Pliocene sandstone dated by nannofossils. The age of the Tananwan formation is provided by two age determinations based on different methods (Liew Ping-Mei, pers. comm., 1991):

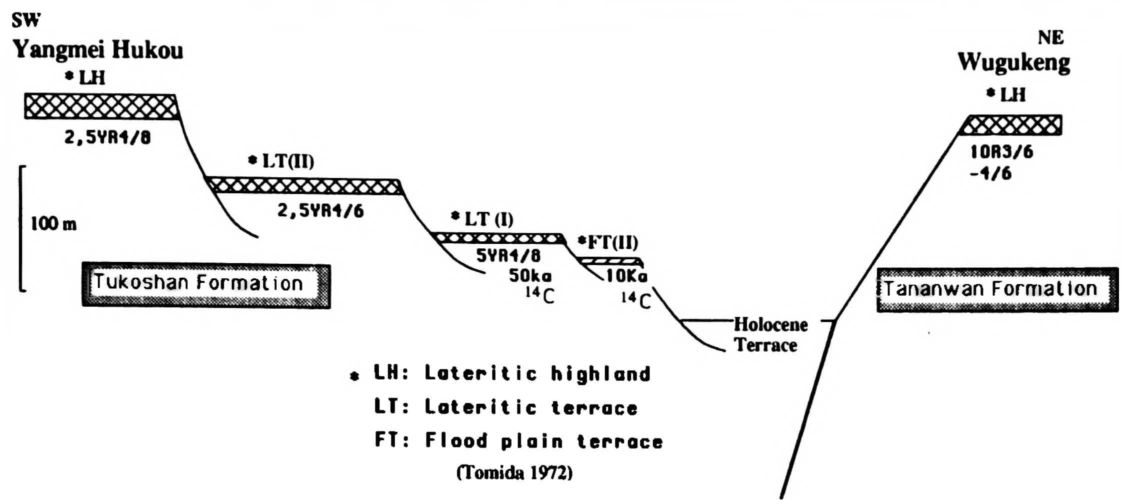


Figure 4. Schematic diagram showing the major landscape units in the study area in northwestern Taiwan, Province of China

- Fission-track analysis gives an age of 1 million years to volcanic rocks, sampled at about 80 m above sea-level, which cut across the coarse deltaic sediments;

- ESR (electron spin resonance) gives an age of 770,000 years (770 ka) to shallow marine sediments sampled at about 60 m above sea level.

These two types of dating methods thus clearly show that the Tananwan formation is older than previously assumed.

Palynological analysis carried out on shallow marine sediments provides evidence for an alternation of warm-humid and cool-drier periods considered as coeval with the interglacials and glacials found at moderate and high latitudes. Below 60 m above sea level (770 ka) at a level tentatively placed in the Jaramillo subchron, the sediment contains a palynological flora rich in Castanopsis, signifying a period with a warm and very humid climate. This periods is considered by the author to be the equivalent of an interglacial stage. As such it would be coeval with a Lower Pleistocene palaeosol, close to the Jaramillo, in the Loess Plateau record.

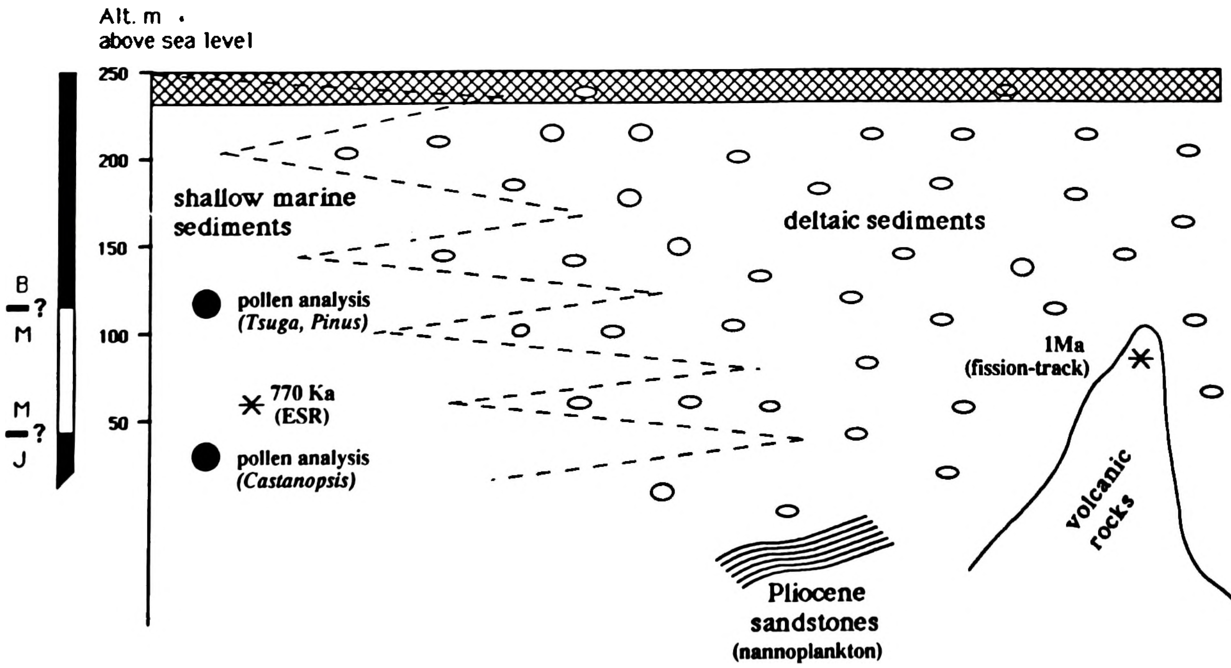


Figure 5. Schematic representation of the Wugukeng block, with tentative dating in the Tananwan Formation and underlying strata

Above 60 m above sea level (770 ka), the pollen content of the sediment, dominated by Tsuga and Pinus is indicative of a cool climate. The period represented by this stratum is considered by the author to be the equivalent of a glacial stage. Thus it should be regarded as coeval with the deposition of a loess unit on the Loess Plateau. It is tentatively correlated (by Liew Ping-Mei, pers. comm.) with isotopic marine stage 20 (hence L8 on the Loess Plateau), by assuming that the Brunhes-Matuyama boundary might be located at this level above the sediment, dated at 770 ka. However, no paleomagnetic measurements have yet been obtained for the whole thickness of these sediments, such data being limited to only the uppermost part of the sequence (more than 120 m above sea level) where positive values were found.

The deltaic sediments seen at Wugukeng are overlain by an 8 to 10 m thick loam, the origin of which requires further study. A sharp discontinuity can be observed between the coarse deltaic gravel and the loam. Both these units have been affected by a type of pedogenesis which resulted in a 20 to 30 m thick red palaeosol (19R 3/6 and 10R 4/6 in the upper horizons) classified as lateritic in the literature concerning the island (Tomida, 1972). The pedogenic features associated with the strong weathering of the materials affect the whole loam and the upper part of the deltaic sediments (Figure 5). Being exposed at the surface, the soil may have experienced continuous pedogenic processes since its initiation.

The interpretation of the origin of the loams is not clear and more investigations are needed in order to compare it with the weathered "loessic sediments" identified in the countries further south (Šibrava, 1993a). As a consequence of this, a question arises about the climatic succession recorded in the upper part of the Wugukeng section. As a first hypothesis, it may be assumed that the deposition of the loam took place under aquatic conditions either as a shallow marine sediment or as a flood loam. This was followed by pedogenesis occurring after the uplift and emergence of the Wugukeng block. This pedogenesis corresponds to at least one warm and humid climatic period, i.e. at least one interglacial stage.

If however, according to a second hypothesis, the loam proved to be an aeolian sediment, the climatic succession would become:

- one cool and dry period occurring after the uplift of the Wugukeng block, with deposition of an aeolian sediment on top of the gravel; and
- one warm and humid period of pedogenesis affecting both the aeolian sediment and the underlying deltaic gravel.

To the best of our knowledge to date, no single argument favours one hypothesis over the other.

A strongly developed red palaeosol also occurs on coarse deltaic sediments in the upper part of the Toukoshan Formation which makes up the uplifted block seen at Yangmei and Hokou at an altitude lower than Wugukeng. The pedological and weathering features are rather similar in these three profiles. The red horizons seem to be slightly thinner at Yangmei and Kukou, with matrix colour of 2,5 YR 4/8 to 5/8 in the upper 10 m, progressively passing into yellow (10 YR 7/6) below. At Hukou, the pedogenesis affects both the gravel and an overlying loam, 4 to 5 m thick, significantly thinner than at Wugukeng. Because of the textural contrast and the sharp contact between the gravel and the loam, the question arises again of the possible aeolian origin of the loam on the one hand, and the climato-stratigraphic succession on the other.

Palaeosols of a similar type, the thickness and degree of development of which progressively decrease with age, are found in the upper parts of the stepped fluviatile terraces inset into the Toukoshan Formation (Figure 4). At Longtang, on the LT (II) terrace, a red lessive palaeosol (colour 2,5 YR 4/6) has developed on a 4 to 5 m thick loam, the colour changing locally to 10R 4/8 at the very top of the underlying gravel into which the weathering continues by pipes. The lower LT (I) terrace is tentatively dated at 50 ka by ^{14}C using samples collected at a depth 60 m below the surface. The palaeosol observed in the Chiting profile becomes reddish (5 YR 4/8) on the loam, passing to strong brown (7,5 YR 5/6) at the top of the underlying gravel. On the FT (II) terrace dated at 10 ka by ^{14}C, the Holocene soil has a brown colour. The soil is hydromorphous on the Holocene terraces located 100 m below LT (I).

This stratigraphic sequence from the northwestern part of the island does not appear to be as complete as that in the Loess Plateau of the mainland. Nevertheless, a comparison of the climatic variations is possible. Because the Castanopsis flora is found in a part of the sequence tentatively placed within the Jaramillo, and because the formation of the strongly developed red palaeosols, classified as laterites, formed in the upper Matuyama and the lower Brunhes chrons, it is likely that the warmest and most humid climatic periods occurred in the Lower Pleistocene and at the beginning of the Middle Pleistocene. In contrast, no evidence has been found of a Middle Pleistocene climatic optimum equivalent to the period recorded by the palaeosol complex S5 on the Loess Plateau.

4. MAIN OBJECTIVES OF FUTURE STUDIES

More investigations are needed in order to improve our understanding of the origin of the loams overlying the gravels found on the island of Taiwan, Province of China. They may be aeolian deposits strongly transformed by pedogenesis, which should be compared with the loessic sediments found in Thailand (Sibrava, 1993b). However, such an interpretation cannot yet be confirmed for the northwestern part of the island. The development of the fossil soils found on the gravels and the loams, must be studied in relation to the palaeoclimatic and palaeoenvironmental conditions, and the shift of the climatic zones during the Quaternary.

In many areas of Southeast Asia, the stratigraphic sequences are incomplete and fragmentary. However, they reflect a succession of more humid and drier periods considered as pluvial and interpluvial stages (Sibrava, 1993a). These may correspond to the alternating periods of strengthening and weakening of the summer monsoon, an alternation clearly recorded in the Loess Plateau of China. Further work is clearly needed in order to test this hypothesis, as well as to improve our understanding of the environmental conditions under which the formation of the palaeosols and the aeolian sedimentation took place in Southeast Asia.

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SIGNIFICANCE OF PALYNOLOGY IN LATE QUATERNARY SEDIMENTS OF PENINSULAR MALAYSIA[1]

IUGS UNESCO

IGCP 296

by

Kamaludin[2] bin Hassan

Abstract

Palynology is indispensable to Quaternary geological investigations. This paper discusses the palynological interpretation applied to the environments of deposition of some of the Holocene sediments in Peninsular Malaysia. The significance of palynology in delineating the Quaternary stratigraphy is stressed, and a new unit for the Holocene is introduced: the Parit Buntar Member of the Gula Formation.

1. INTRODUCTION

Ever since the report by Haseldonckx (1977a), palynology has contributed much to the interpretation and reconstruction of the Quaternary sedimentary depositional environments in Peninsular Malaysia. In Southeast Asia, the study has been widely used, both to reconstruct vegetational history and as a tool in stratigraphic interpretation to distinguish the terrestrial from the marine sequence of the Tertiary. This is attributed largely to its extensive use in biostratigraphy for petroleum exploration in the region.

Interpretation of the Depositional Environment

Various sedimentary depositional environments are recognised from the palynological study conducted at Seberang Prai (Kamaludin, 1989). Mangrove and back mangrove conditions are well depicted with instances of open swamp and fluviatile influence as shown by borehole A13. Figure 1 shows the location of the study area while Figures 2 and 3 represent the pollen diagrams of boreholes A13 and L7.

Similar work in other parts of the Peninsula by Chow (1971) and Hillen (1986) further elucidate the palynological characteristics associated with littoral and sublittoral environments. Anderson and Muller (1975), Haseldonckx (1977b) and Morley (1981) investigated the peat swamp environments in Sarawak, Johore and Kalimantan respectively.

Six types of Quaternary depositional environments based on palynological and lithological characteristics are interpreted and classified as presented in Table 1.

Shallow marine offshore

Generally, the lithology of the sediment deposited under this condition is homogeneous and made up of clay, silt and sand. Shell and plant remains may be abundant or present in moderate amounts.

[1] *Paper contributed to IGCP 296 though presented earlier at the 1987 Annual Conference of the Geological Society of Malaysia, and included in this volume with permission of the Society.*

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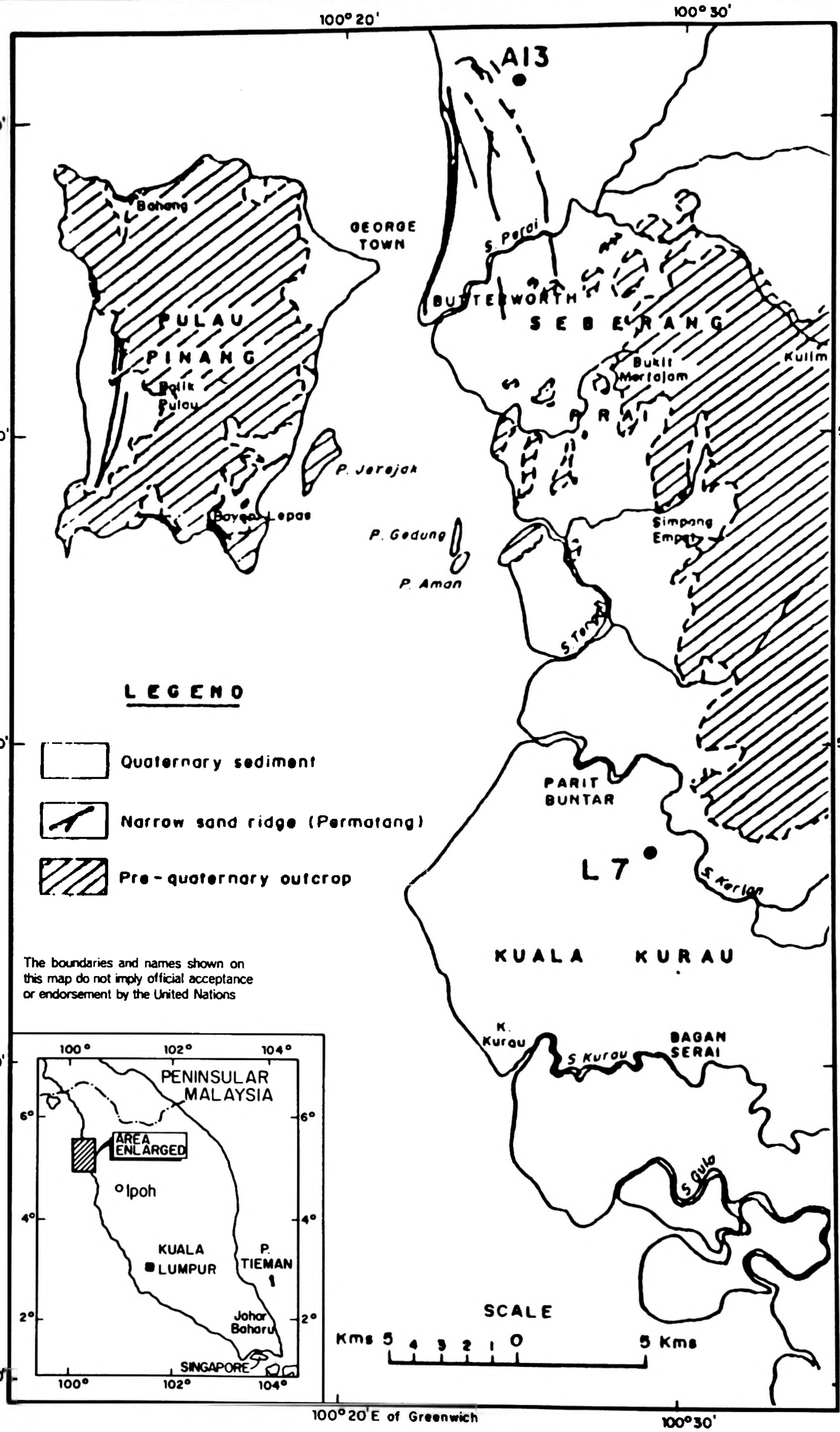

Figure 1. Location of boreholes A_{13} and L_7 in Seberang Prai, Penang, Malaysia

Palynological characteristics are shown by the moderate[3] amount of pollen grains dominated by mangrove species which constitute more than 40%, back mangrove type less than 15%, the other tree pollen generally less than 30%, while spores show poor values.

Deltaic, lagoonal and estuarine

The sediment normally consists of clay, silt and sand. Gravel is sometimes present. Thin layers of fine to coarse sand are frequently encountered. Small to moderate amounts of shell and plant remains may be present.

The pollen content is moderate to fairly rich. According to Hillen (1986), the sediment shows 40-60% mangrove species, 15-35% Palmae, high *Sonneratia* and spore values, and is moderately rich in mangrove species.

Mangrove

Clay and silt make up the sediment and occasionally peat (generally less than 2 metres) is encountered. Small to moderate amounts of plant remains and sometimes shell remains are present, while wrinkled plant structure could quite often be found.

A moderate to rich pollen content is common. Mangrove species constitute more than 60% and consist of *Rhizophora* (the major component), *Bruguiera*, *Sonneratia*, *Avicennia*, and *Acrostichum*. Palmae contribute generally less than 10%, while spores and indeterminate species display low values. Pollen diversity is often low to moderate.

Back mangrove

Clay, silt and often peat constitute the sediment. Sand is often present and gravel can be expected. Small amounts to abundant plant remains may be present. The sediment is frequently organic. In a thick peat sequence, the basal layer generally characterizes the sediment. Shell remains are absent.

The pollen content is moderate to rich and pollen diversity is fairly well represented in general. *Oncosperma*, other Palmae and often *Pandanus* are environmental indicators and normally show high values within their profile. Mangrove species especially *Rhizophora* are generally less than 40% and normally their pollen curve shows a decreasing trend. The spore value is low to moderate.

Freshwater swamp

Peat is basically the major component. Clay, silt, some sand and in places minor amounts of gravel are present. Shell remains are absent.

The sediment is moderately rich to rich in pollen and displays a wide range of pollen types. Mangrove and back mangrove pollen may be present but often in poor amounts. Some of the common pollen types include *Eugenia*, *Macaranga*, *Pandanus*, *Gramineae*, *Euphorbiaceae*, *Rubiaceae* and others. When present, riparian fringe species often show and increase in value. Spore values found may vary from moderate to high.

Peat swamps

As the name implies, peat forms the only component present. The thickness varies from less than a metre to more than 5 metres in different places and the top sequence is less compacted than the horizon below.

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[3] *The terminology used is subjective. A count of at least 200 grains per sample is required for a good interpretation. A suggested guide for the number of pollen grains counted per shade is listed here. (It should be noted that pollen content or amount and diversity of pollen in a sample are two separate entities). 1) absent (no pollen), 2) very poor (less than 10 grains), 3) poor (11 to 30 grains), 4) moderate (31 to 100 grains), 5) moderately rich (101 to 200 grains), 6) rich (more than 201 grains).*

Table 1. Classification of Late Quaternary depositional environments and the corresponding lithological and palynological characteristics

Depositional Environment	Lithology	Palynological Characteristics
Shallow marine offshore (including tidal flat)	clay, silt sand shell & plant remains	moderate pollen content mangrove species > 40% Palmae < 15% Other pollen types < 30% Pollen diversity low to moderate low spore value
Deltaic, lagoonal and estuarine	clay, silt sand rare gravel plant & some- time shell remains	moderate to rich pollen content mangrove species 40 to 60% high *Sonneratia* Palmae 15-35% moderately rich in species high spore value
Mangrove	clay, silt peat rare sand & gravel shell and plant remains	moderate to rich pollen content mangrove species > 40% *Rhizophora* > 50% Palmae < 10% pollen diversity low to moderate low spore value
Back mangrove	clay, silt sand, peat rare gravel plant remains	moderate to rich pollen content low mangrove species Rhizophora < 40% high Palmae., peak in the individual profile e.g. *Oncosperma, Phoenix, Nypa fruticans, Calamus* etc. high Pandanaceae pollen diversity moderate to high low to moderate spore value
Freshwater swamp	peat clay, silt sand rare gravel	moderately rich to rich pollen content absent or low mangrove species low Palmae common pollen types: *Eugenia, Macranga, Pandanus*, Gramineae, Euphorbiaceae, Rubiaceae, etc. pollen diversity high moderate to high spore value
Peat swamp	peat	Rich pollen content absent or very low mangrove and Palmae constituents common pollen types: *Stemonurus, Ilex, Campnosperma, Palaquium, Pandanus*, Rubiaceae, *Euphorniaceae*, etc. pollen diversity high low to moderate spore value

As far as palynological characteristics are concerned, this type of sediment is typically rich in pollen with a high diversity of pollen types. When present, mangrove and back mangrove species occur in small amounts. The common pollen types *include Stemonurus, Ilex, Campnosperma, Calophyllum, Eugenia, palaquium, Pandanus, Rubiaceae, Euphorbiaceae* and others. Spore values are often low to moderate. During peat development, individual species may predominate within the taxa.

2. STRATIGRAPHIC APPLICATION

The Quaternary stratigraphy of Malaysia has been defined according to lithologic criteria and is divided into various lithostratigraphic units (Suntharalingam 1983, Bosch 1986; Loh 1986. The Simpang and Kempadang Formations are interpreted as of Pleistocene age. The Holocene units are made up of the Gula and Beruas Formations in which four members are assigned to the former and one member to the latter respectively.

Until recently, any palynological investigations and interpretations carried out were from the lowland coastal areas ascribed to the Holocene units. The information gathered from the present study further updates an interpretation previously based solely on lithological characteristics. The environments of deposition interpreted would explain the various members in the two Holocene Formations.

In the Gula Formation the four members hitherto defined are:

1. Bagan Datoh Member
2. Teluk Intan Member
3. Port Weld Member
4. Matang Gelugor Member

The Bagan Datoh Member is interpreted from the pollen assemblages that define a shallow marine offshore environment. The Teluk Intan Member represents a deltaic lagoonal or estuarine environment. The Port Weld Member shows a typical mangrove deposit.

The Matang Gelugor Member is defined as a shallow marine coastal deposit. It is distinguished by the lithology. Sand (often coarse grained), gravel and shell remains, which constitute the deposit, are unsuitable for pollen analyses since pollen are generally absent or, even if present, their interpretation is not always reliable.

The Pengkalan Member of the Beruas Formation is explained as having been derived from the fresh water of a peat swamp environment.

From the palynological study in the Seberang Prai area (Kamaludin, in manuscript) and comparison made with other studies, it is found that back mangrove sediments are present from the drilling cores investigated. The sequence is described by Anderson and Muller (1975) and Haseldonckx (1977b) just below the peat layer, and in Hillen's (1986) diagram A it forms the transition zone, while in the Seberang Prai area it is shown in the pollen assemblage zones II and IX (Figures 2 and 3). In these studies Oncosperma show a distinctly high value within the corresponding profile.

This finding calls for an explanation, which is found in a separate sequence and a new unit within the Gula Formation. Consequently, this is introduced here as the Parit Buntar Member.

The Parit Buntar Member

The Parit Buntar Member constitutes a sequence of grey (7.5Y 5/1) to brownish black (10YR 2/2) clay, silt, with in places thin layers of sand and gravel, as well as peat deposited in the back mangrove environment. Its occurrence is widespread in the west coast of Peninsular Malaysia, often less than 3 metres thick, generally stratigraphically above the Port Weld Member. The type locality is at Parit Buntar and its vicinity.

Table 2 shows the various depositional environments as derived from the pollen assemblages for the Holocene and the corresponding stratigraphic units designated.

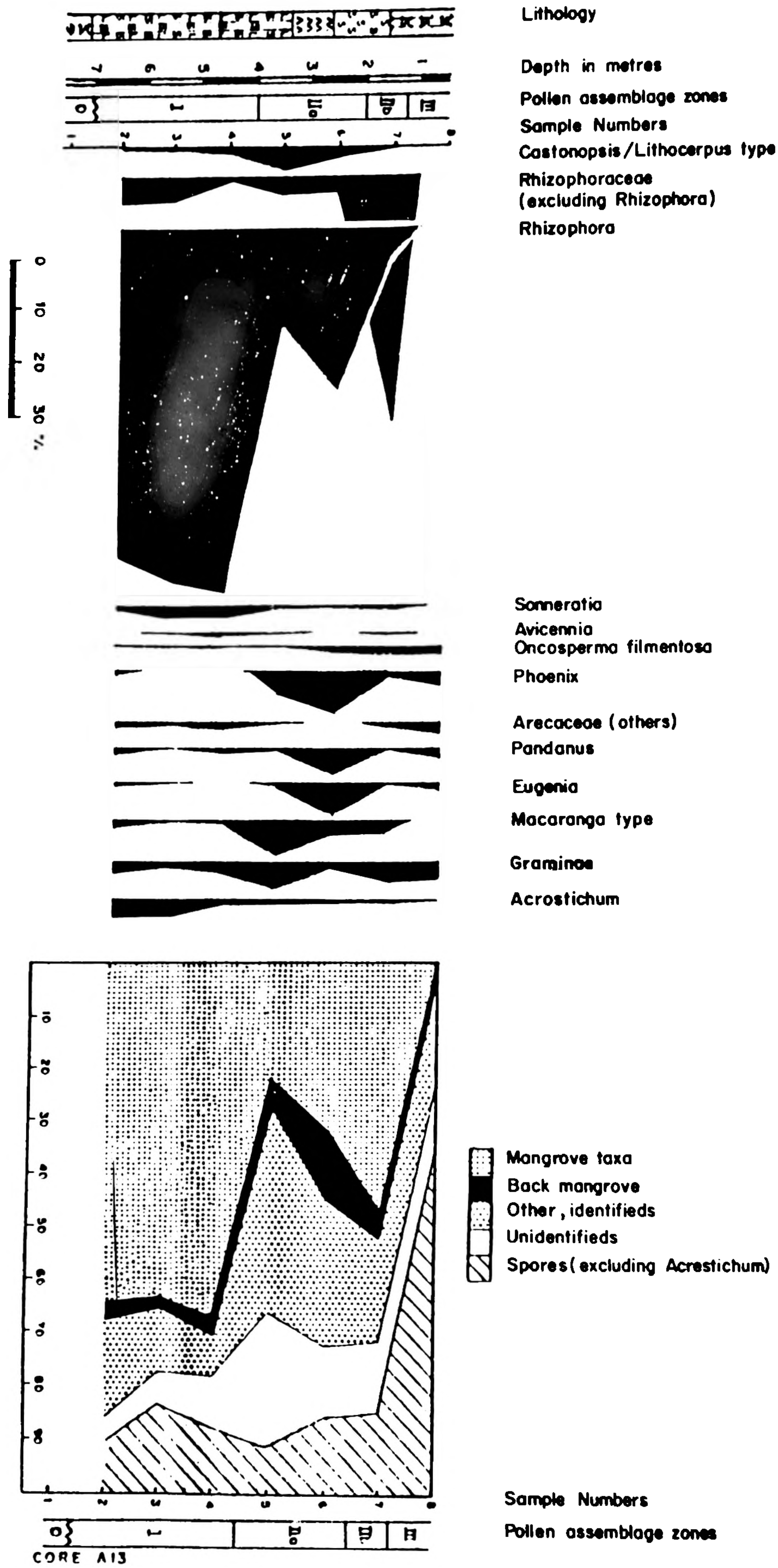

Figure 2. Pollen diagram from core A_{13}, Seberang Prai, Penang, Malaysia (after Kamaludin, 1989)

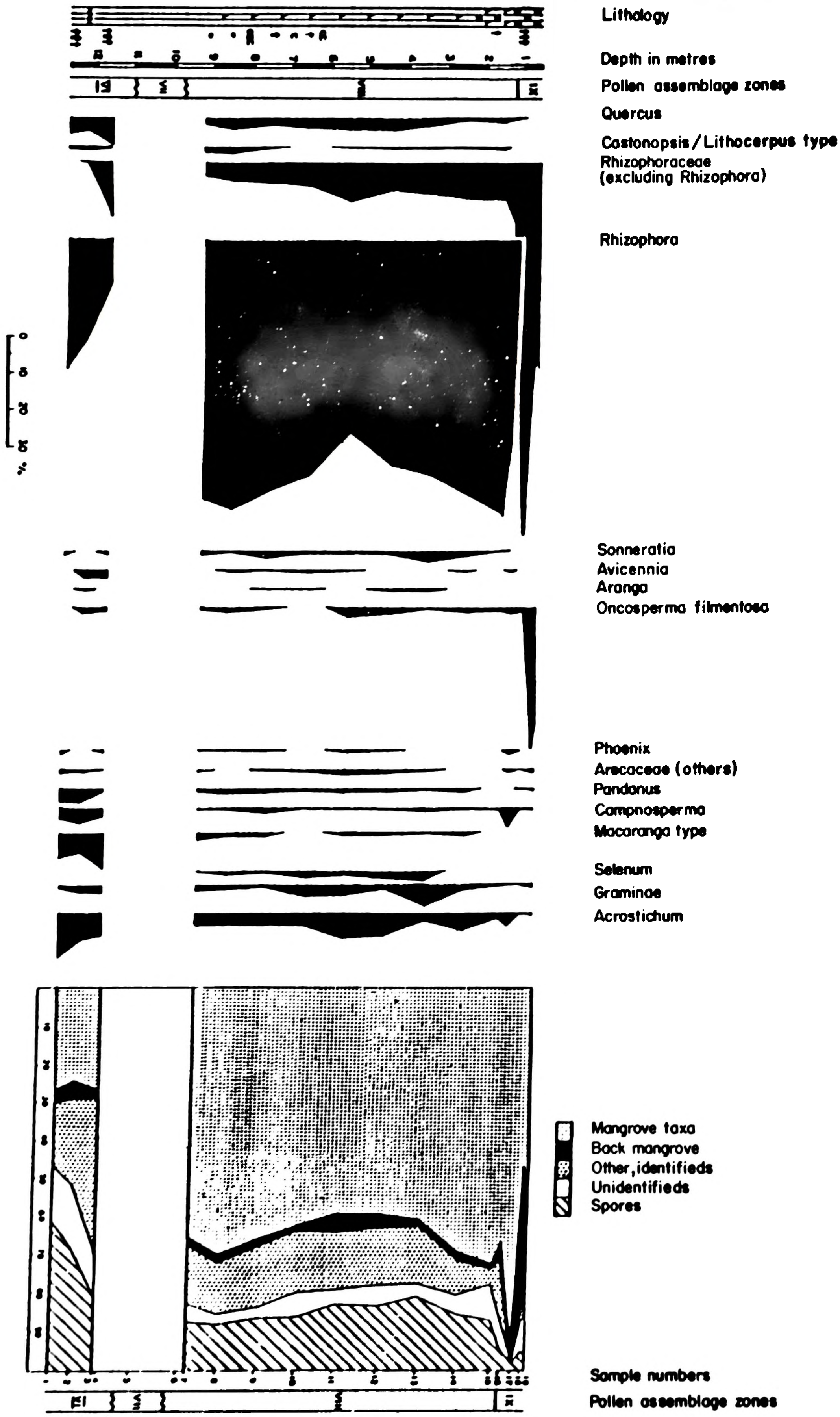

Figure 3. Pollen diagram from core L₇, Seberang Prai, Penang, Malaysia (after Kamaludin, 1989)

Table 2. Late Quaternary stratigraphy and the characteristic depositional environment

Quaternary Epoch	Formation	Member	Depositional environment
Holocene	Beruas	Pengkalan	freshwater/peat swamp
	Gula	Matang Gelugor	shallow marine coastal
		Parit Buntar	back mangrove
		Port Weld	mangrove
		Teluk Intan	deltaic/lagoonal/estuarine
		Bagan Datoh	shallow marine offshore

3. CONCLUSIONS

- As far as geological investigations of Late Quaternary sediments are concerned, it is emphasised that apart from lithology, palynological characteristics are also important in delineating the depositional environment. Whenever possible, such investigations should be supplemented with radiocarbon dating on representative samples.
- The introduction of the Parit Buntar Member in the Holocene units further updates the stratigraphy of the Quaternary.

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QUATERNARY DEPOSITS NEAR PANTAI REMIS, NORTHWEST PENINSULAR MALAYSIA, AND THE SIGNIFICANCE OF THE PLEISTOCENE-HOLOCENE UNCONFORMITY[1]

IUGS UNESCO

IGCP 296

by

Mazlan[2] bin Hj. Madon and Kamaludin[3] bin Hassan

Abstract

Quaternary deposits exposed in a tin mine near Pantai Remis, in the northwest of Peninsular Malaysia, consist of more than 17m of Pleistocene (with a ^{14}C age of more than 28,900 years) alluvial and estuarine deposits, overlain by about 3m of Holocene (less than 500 years old) transgressive marine sediments. The contact between the Pleistocene and Holocene at 1.5m below mean sea level is an erosional unconformity marked by a paleosol formed after a long period of subaerial exposure and weathering.

Radiometric data indicate that the unconformity represents a significant hiatus in the late Quaternary sedimentary record of at least 28,000 years, which is probably partly due to erosion of upper Pleistocene sediments. Published records of Quaternary sea levels show that Holocene sea level rose to within 2m below the present level between 7,000 and 6,000 years ago, but the data presented here indicate that the Pantai Remis area was never inundated until about 500 years ago. The occurrence of relatively older Pleistocene deposits (more than 28,900 years old) at only 1.5m below present sea level suggests that there has been relative uplift of the area during the late Pleistocene to early Holocene. The data indicate that relative sea level changes during the Quaternary may have been partly due to tectonics.

1. INTRODUCTION

An interesting aspect of Quaternary research in Southeast Asia is the recognition of sea level fluctuations relative to present-day mean sea level (see reviews by Haile, 1971 and Tjia, 1980, 1990). Sea level curves for the Quaternary (e.g. Geyh et al., 1979; Streif, 1979) are constructed using ^{14}C ages of samples ('shoreline indicators') which were collected at different elevations relative to mean sea level. The validity of these curves however, depends on the assumption that during the Quaternary tectonic movements were insignificant and that sea level fluctuations were entirely due to eustasy (Tjia et al., 1977, Geyh et al., 1979).

Some workers (e.g. Tjia, et al., 1977) suggested that tectonic movements did affect parts of Southeast Asia, including 'stable' Sundaland. Hence, it is important that any evidence for such movements, which could affect our interpretation of Quaternary sea level changes, be properly documented. This paper describes Quaternary deposits near Pantai Remis in northwestern Peninsular Malaysia, where a major late Pleistocene-Holocene unconformity occurs, interpreted to be due to uplift and erosion. The significance of this unconformity to Quaternary stratigraphy and sea level changes is discussed.

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2. GENERAL SETTING

The Quaternary deposits studied are exposed in an abandoned tin mine, near the village of Pantai Remis, Perak, in the northwest of Peninsular Malaysia (see Figure 1 in Kamaludin et al., this volume). The mine is located in a northward-trending Pleistocene river valley which is surrounded by granite hills. Preliminary surveys of the mine area were made in May and June 1989. Further field work in November 1989 involved detailed sedimentological description and the collection of samples along Profiles 1 and 2, which form a NNW-SSE transect across the mine pit (see Kamaludin et al., this volume). More than 150 samples were collected for grain size and heavy mineral analyses, fossil identification, and radiometric dating. Results of these analyses will be reported elsewhere. This paper discusses the interpretation of field observations made mainly along the northern and western faces of the mine pit, with supporting radiometric age data from Kamaludin et al. (this volume).

3. STRATIGRAPHY AND SEDIMENTOLOGY

Approximately 20m of Quaternary sediments was exposed and logged. The strata comprise two stratigraphic units (Figure 1): the lower unit is Pleistocene, with ^{14}C ages greater than 28,900 years, whereas the upper unit is Holocene (less than 500 years old). The boundary between these two units is a surface representing an erosional unconformity (Figure 1). The sedimentological characteristics of the sediments and the nature of the Pleistocene-Holocene unconformity are described below.

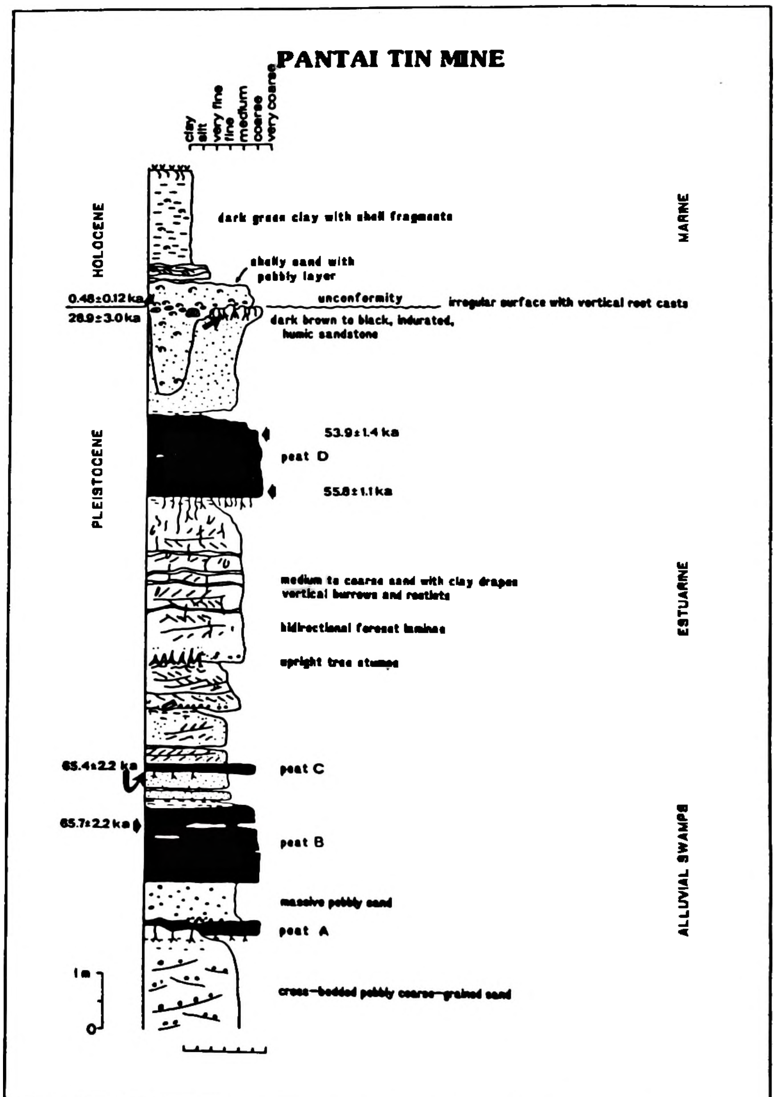

Figure 1. Summary of stratigraphy, lithology, and paleoenvironmental interpretation of Quaternary deposits in the Pantai Tin Mine, Malaysia

Pleistocene sequence

Description

The thickness of the Pleistocene sequence exposed is about 17m. At the base of the mine pit is a thick, cross-bedded, pebbly to very coarse-grained sand, which fines upward into clay with roots, and is overlain by a thin peat layer (Peat A, Figure 1). Overlying this peat is a massive pebbly-clayey sand, whose thickness varies laterally between 50 and 100cm (Figure 2). The sand shows basal scour features, and contains abundant organic matter and white feldspar grains (ca. 1cm across) which cause its spotted appearance.

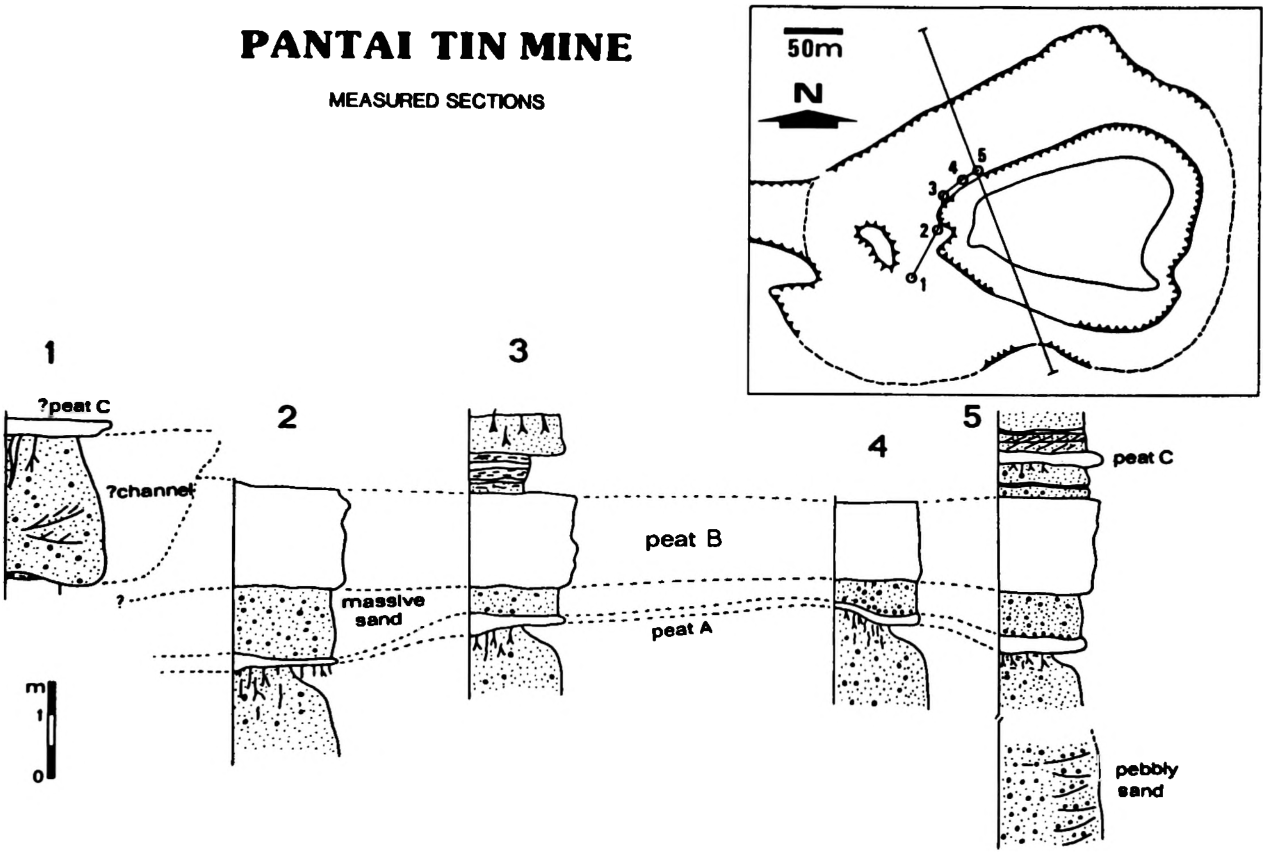

Figure 2. Lithological correlation of measured sections at selected locations shown on map (inset)

A 1.5m thick peat (Peat B, Figures 1, 2) overlies the massive sand. No root traces were found underneath peat B. The peat has a fabric strongly parallel to the bedding, with cm-thick lenses of clayey sand in its upper part, and contains very large wood fragments and tree trunks. Upward, the peat becomes clayey, and appears to pinch out or split laterally. At the southwestern corner of the mine pit (Site 1, Figure 2) peat B is absent, and is replaced (truncated?) by a channelized, upward-fining, pebbly sand with roots at its top.

The rest of the Pleistocene sequence consists of cross-laminated medium to coarse-grained sands with interbedded clay and peat (Figure 1). The sand has a relatively sharp base with upright tree stumps in places, and becomes more clayey upward with abundant clay drapes, burrows, and roots. Megaripples in the sand show opposing foreset laminae, indicative of bidirectional current flow. The cross-laminated sand is overlain by peat D (1.5m thick) near the top of the Pleistocene sequence (Figure 1). Roots occur underneath peat D.

Peat D is overlain by dark brown to black, humus-cemented, medium to coarse-grained sandstone which is resistant to weathering (Figure 3). This humic sandstone has an irregular top surface with relief exceeding 1 m. Numerous upright fossil roots, up to 10cm in diameter, occur directly beneath this surface. In places, large oysters (20 to 30cm across) are found attached to the surface.

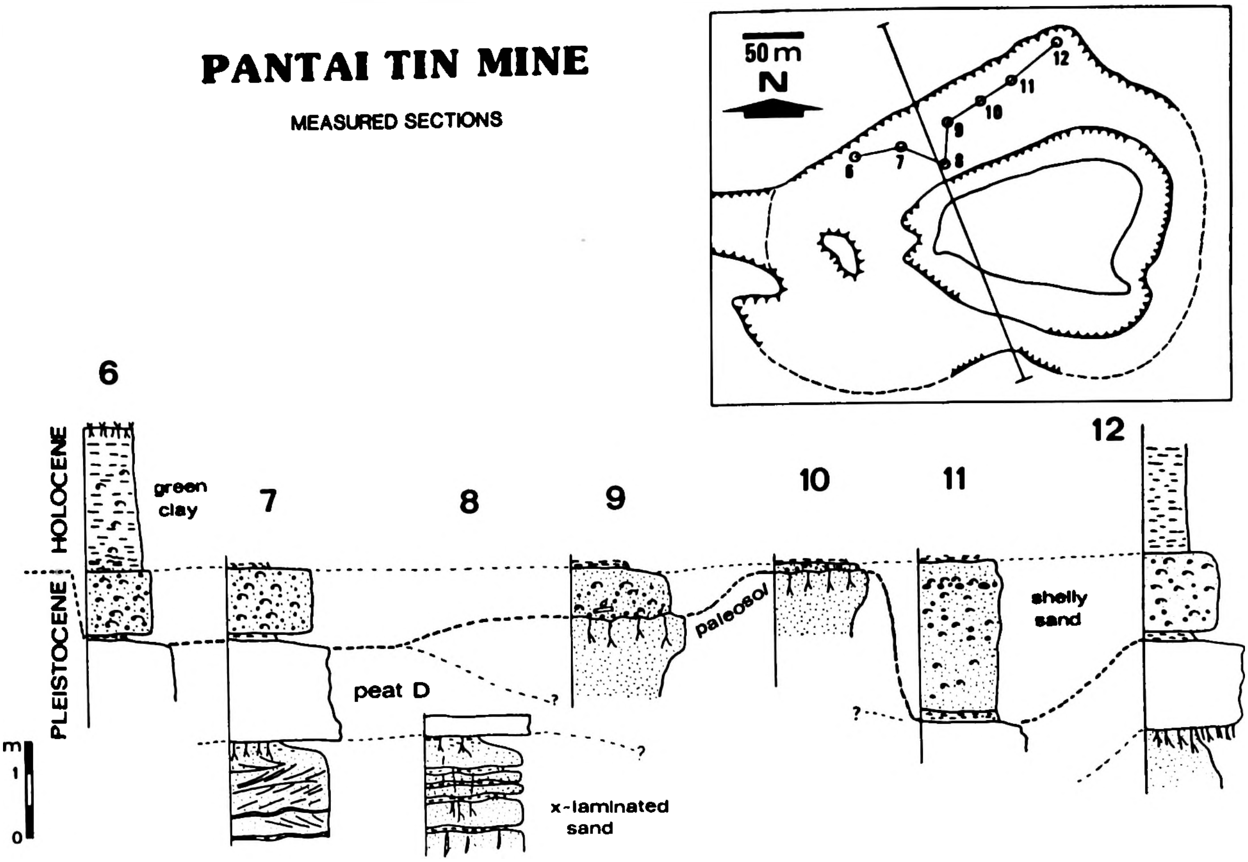

Figure 3. Correlation of measured sections showing the irregular nature of the Pleistocene-Holocene contact. Peat D generally overlies the humic sandstone (paleosol), but the relationship is unclear in places

Interpretation

The Pleistocene sequence is interpreted to represent two facies associations: alluvial and estuarine (Figure 1). The association of channelized sandbodies and peat layers, and the general absence of fossils, suggest that the sediments were deposited in a nonmarine alluvial to coastal plain environment. Coarse-grained pebbly sand at the base of the exposed sequence represents the lower part of the alluvial valley-fill derived from the underlying and surrounding granitic bedrock. This fluvial sediment has been the target for placer tin exploration.

The coarse-grained nature of the channel deposits suggest that deposition was initially by high-gradient streams. The peat layers (e.g. peat A) were formed in poorly-drained swamps formed on parts of the alluvial plain as a result of channel abandonment.

The massive sand overlying Peat A was deposited by rapid high-suspension flow and indicates rapid input of sediment onto the alluvial plain. This is evidenced by ungraded and poorly sorted nature of the sand, and the presence of scours at the base. Peat B is interpreted as having formed in a swamp environment where large amounts of plant material accumulated. The absence of roots and paleosol beneath Peat B suggests that much of the plant material, including the large tree trunks, is allochthonous.

The cross-laminated sand above the alluvial sediments (Figure 1) is interpreted as a tidally-influenced estuarine channel-fill deposit, based on the occurrence of bidirectional current indicators, finer grain size, better sorting, and less clay content. The sand was probably deposited during a relative rise in sea level, causing reworking, sorting, and winnowing of fluvial sands and deposition in an estuarine environment.

Vegetation might have developed on the banks of the estuary and in backswamps where thick accumulations of peat were formed (Peat D).

The humic sandstone is interpreted as a paleosol formed during a long period of subaerial exposure, and indicates a relative sea level drop. The irregular top of the paleosol, supported by radiometric age data, suggests that substantial erosion of Pleistocene sediments has taken place. The presence of large oysters which grew on this erosion surface suggests that the paleosol surface was in part a marine hardground formed during Holocene marine transgression in the area.

Holocene sequence

Description

The Holocene sequence, as measured in Profile 2 (Figure 2), is approximately 3m thick and consists of shelly sand at the base, passing upwards through flaser-bedded sand, into green shelly clay. The shelly sand abruptly overlies the Pleistocene humic sandstone, commonly infilling hollows and notches (Figure 3). Shells and rounded clasts of humic sandstone form a discrete layer in the sand. Pieces of man-made pottery were also found in this layer. In some places, upright tree trunks were found.

The green clay at the top of the unit contains foraminifera which indicate a nearshore marine environment.

Interpretation

The Holocene deposits are undoubtedly marine, as evidenced by the abundance of shells and foraminifers. They shelly sand was deposited over an irregular erosional surface following the Holocene marine transgression. Radiometric data from the shell layer suggest that the marine incursion in the area occurred only within the last 500 years, suggesting that the area had remained emergent throughout the late Pleistocene and early Holocene.

4. DISCUSSION

The nature of the Pleistocene-Holocene boundary in Sundaland

Published data show that there was a major drop in sea level in the late Pleistocene, which caused the emergence of the Sunda Shelf (e.g. Haile et al., 1963; Haile, 1969, 1971; Tjia, 1980). Hence, the Pleistocene-Holocene boundary should be represented by a major hiatus or erosional unconformity in most parts of Sundaland.

Pleistocene 'emergent' surfaces have been reported from many places around Peninsular Malaysia and on the Sunda shelf (Figure 4 shows some examples). These surfaces are interpreted as being due to a major drop in sea level during the last Pleistocene glaciation. For example, Aleva el al. (1973) reported a Pleistocene erosional unconformity 20 to 30m beneath the sea floor on the Sunda shelf. The unconformity is associated with red clays (indicating subaerial exposure) and is overlain by Holocene marine mud.

In the southern part of the Strait of Malacca, the BGR (1977) reported a subaerially weathered Pleistocene surface with roots, peat, and freshwater clays beneath Holocene sediments. Radiocarbon dates showed that this once-emergent surface persisted from 40,000 to 10,000 years ago. A similar surface was recorded in a seismic survey off the coast of Kedah (Ryall et al., 1977).

Off the east coast of Peninsular Malaysia, Biswas (1973) recognised a lateritized Pleistocene surface (dated 11,000 years), at 30m to 75m below present sea level, formed by subaerial weathering during the Pleistocene sea level lowstand. Bosch (1988, p. 80) reported a Pleistocene land surface marked by a yellow- and red-mottled soil at depths of 50m to 70m beneath Holocene deposits in north Kelantan.

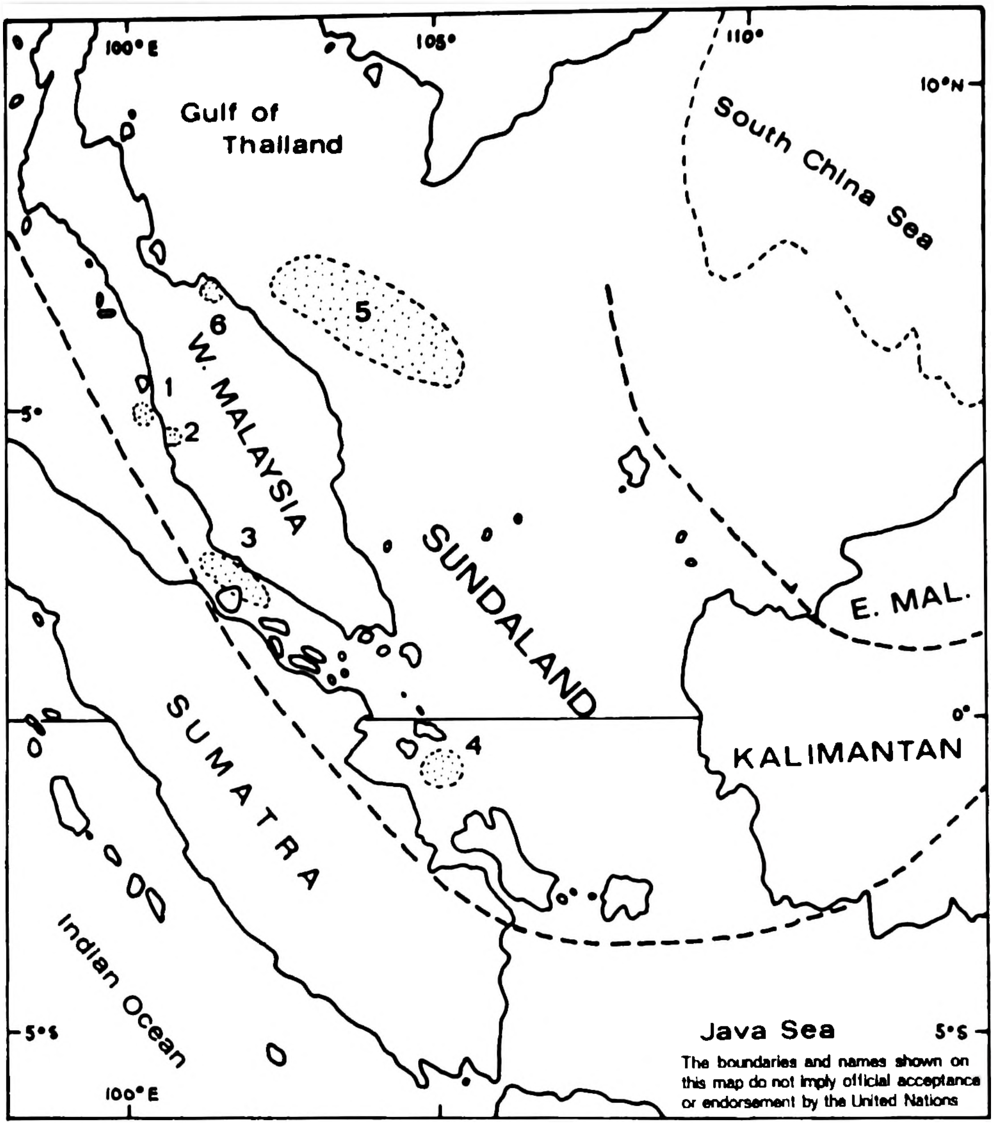

Figure 4. Approximate extent of Sundaland at low sea level during the Pleistocene, shown by dashed lines (modified after Tjia et al., 1977). Examples of reported Pleistocene emergent surfaces as mentioned in the text are numbered: 1. Offshore Kedah, 2. Pantai Remis, 3. Strait of Malacca, 4. Singkep, 5. Offshore Terengganu, 6. Northern Kelantan.

Other occurrences of Pleistocene emergent surfaces have been described earlier by Haile et al. (1963) and Haile (1971). All these reports, including the present study, are evidence that there must have been a relative drop in sea level in the late Pleistocene that caused a large part of Sundaland to be exposed to subaerial weathering. Thus, a significant hiatus in the late Pleistocene to Holocene sedimentary record should exist, particularly in the present coastal areas and on land where erosion and non-deposition must have occurred for a longer period. Consequently, more 'complete' stratigraphic data for the Quaternary should exist in the present offshore areas. Correlation of the Quaternary in the region using onshore data such as those from Pantai Remis will be constrained by the incompleteness of the stratigraphic record.

Implications for Quaternary tectonics and sea level changes

According to the Quaternary sea level curve constructed for the region (e.g. Geyh et al., 1979; Tjia, 1990), the Holocene sea level rose to within 2m below the present level between 7,000 and 6,000 years ago. The data from Pantai Remis, however, show that the Holocene sea level reached 1.5m below the present one only within the last 500 years. In the Pantai Remis section the Pleistocene surface (minimum age 28,9000 years) is only 1.5m below the present level, whereas according to the curve the sea level at that time was more than 30m below the present one. This suggests that the area may have been uplifted during the late Pleistocene to Holocene causing erosion of part of the upper Pleistocene. The rate of uplift must have been greater than the rate of sea level rise, for the area to have remained emergent until 5 years ago. The Pantai Remis data show that tectonics may have influenced relative fluctuations in sea level during the Quaternary.

5. CONCLUSIONS

Quaternary deposits exposed near Pantai Remis, in the northwest of Peninsular Malaysia, consist of Pleistocene nonmarine alluvial to estuarine sediments, overlain unconformably by Holocene transgressive marine sediments. The Pleistocene-Holocene unconformity represents a significant hiatus, of at least 28,000 years, in the late Pleistocene sedimentary record, suggesting that tectonic movements may have affected parts of Sundaland during this time. Hence, relative sea level changes during the Quaternary may be partly due to such movements, and should therefore be interpreted with caution.

Because a significant portion of the Pleistocene to Holocene sedimentary record is missing, the Pantai Remis section may not be suitable as a late Quaternary type section for Northwest Peninsular Malaysia.

6. ACKNOWLEDGEMENTS

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RADIOCARBON AND THERMOLUMINISCENCE DATING OF 'OLD ALLUVIUM' FROM A COASTAL SITE IN PERAK, MALAYSIA[1]

IUGS UNESCO IGCP 296

by

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Abstract

Exposures of 'Old Alluvium' in the Pantai and Sinar Manjung Mines in Perak, Peninsular Malaysia, reveal woody peat layers interbedded with angular sands and gravels. Eight samples taken from peat within the Pantai Mine were dated using accelerator mass spectrometry (AMS) radiocarbon dating, together with nearsurface shell samples. Five samples of quartz sand from the Pantai Mine and three samples of similar sand from the Sinar Manjung Mine were dated by thermoluminiscence (TL). While for several samples, both dating techniques were at the ends of their detection limits, results from the upper strata of the northwestern face of the Pantai Mine indicate agreement between the two independent dating techniques. The age of the Old Alluvium, known as the Simpang Formation in Perak, is confirmed as late Pleistocene at this site. The measured ages range from 28,000 years to 67,000 years BP, but the lower units at this site are older than this and appear to be beyond the range of either dating technique.

1. INTRODUCTION

The 'Old Alluvium' is a Quaternary alluvial formation which is widespread throughout Malaysia, Singapore and parts of Indonesia (Walker, 1956; Burton, 1964; Sivam, 1969; Stauffer, 1973; Gupta et al., 1987; Thorp et al., 1990). It forms a series of distinct terraces and terrace remnants, but the condition under which it has been deposited remain unclear. A major impediment to understanding the time frame involved in its deposition has been the lack of reliable techniques by which to determine its age.

Strictly, the 'Old Alluvium' as defined by Walker (1956), consists mainly of grey to brown sandy clay, with frequent horizontal sand and gravel laminae. The gravel contains clasts up to 15cm long. Stauffer (1973) summed up the Old Alluvium as essentially synonymous with the 'high-level alluvium' of Scrivenor (1924) and Rastall (1927), and with the 'Older Alluvium' of Burton (1964). It is a complex of unconsolidated sediments which include gravel, sand, silt and clay in all possible mixtures, together with peaty sediments, peat, and accumulations of partly lignified wood and logs. Works in offshore areas of the Strait of Malacca (Batchelor, 1979a; Emmel and Curay, 1982), the Indonesian tin islands (Aleva, 1973) and the South China Sea (Biswas, 1973), indicate the extension of similar deposits into what is known as Sunda Land. The Sunda Shelf areas, presently submerged, have been subaerially exposed probably many times throughout the Pleistocene. Batchelor (1979b) categorized the 'Old Alluvium' as the Older Sedimentary Cover forming the distal facies of an alluvial plain environment.

In Perak, the Old Alluvium which contains economically significant cassiterite deposits, has been mapped and renamed the Simpang Formation (Suntharalingam, 1980, 1987; Suntharalingam and Teoh,

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1985). It comprises a lower sand and gravel unit and an upper clay and silt unit. Suntharalingam (1987) has reported conventional radiocarbon (^{14}C) dates of between 31,000 and 42,000 years BP on samples of peat and wood from the Simpang Formation. These ages are close to the limit of conventional ^{14}C dating and could be regarded as minimum ages. Thorp et al. (1990) reported several finite ^{14}C ages in the range 50,000 to 55,000 years BP from similar deposits in western Kalimantan.

However, the presence of tektites in some terraces suggests a mid Pleistocene age, and the radiometric dates presently available do not rule out a much older age. Indeed Rose (1984) suggested that medium level terraces in the Melinau catchment of the Baram River in Sarawak might have been deposited during the Last Interglacial (around 120,000 years BP).

Exposures of the Old Alluvium (Simpang Formation) in the open-pit gravel-pump tin mines in the west coast of Perak, reveal angular sands and gravels interbedded with woody peat layers. Overlying the deposit, separated by an erosional unconformity, is the topmost layer consisting of fossiliferous beach sands and soft greenish grey shelf muds, which are generally referred to as marine clay. The excellent exposures of the mine allowed sampling of material for dating by two independent methods. Samples of wood and peat were selected for age determination by accelerator mass spectrometry (AMS) ^{14}C dating (at Nagoya University), while samples of sand-sized quartz by thermoluminiscence (TL) dating (at the University of Wollongong).

2. METHODS USED

Accelerator Mass Spectrometry Radiocarbon Dating (AMS ^{14}C)

Conventional ^{14}C dating enables estimation of age to a limit of about 40,000 years BP. It involves the accurate measurement of beta rays emitted during the decay of ^{14}C. Accelerator mass spectrometry (AMS) enables the detection of ^{14}C atoms directly in a sample with improved sensitivity. The method has an advantage over the conventional technique in that i) very small samples (only a few milligrams of carbon) are required, ii) the range of ^{14}C dating has been extended to around 60,000 years BP (Terasmae, 1984; Nakamura and Nakai, 1991), and iii) a shorter counting time is involved. Moreover, in principle, a higher accuracy is possible since many more ^{14}C counts are recorded (Rucklidge, 1984).

A Tandetron accelerator mass spectrometer at Nagoya University has been used to measure ^{14}C ages of geological and archaeological samples as well as ^{14}C concentrations of natural samples since 1983. The ^{14}C background level of the spectrometer has been estimated by measuring ^{14}C content of commercial graphite and mineral graphite from an ore deposit in Sri Lanka which are too old to contain ^{14}C (Nakamura and Nakai, 1991). Owing to the ^{14}C background, the ^{14}C date shows a younger value than the intrinsic age of the sample. The difference between the true age and the apparent ^{14}C date increases as the sample becomes older. The oldest age measurable with the Tandetron spectrometer for natural samples has been estimated at about 60,000 years BP (reliable measurable age limit), while estimates from dead graphite samples have given apparent ^{14}C ages ranging from 62,000 years BP to 72,000 years BP.

Measurement of the Carbon Isotope Ratio

About 100mg of the peat and wood samples were treated at 80°C for one day with 1.2N NaOH, followed by 1.2N HCl at 80°C for two hours to eliminate carbonate minerals. They were later rinsed with distilled water and dried. The samples were then sealed in pyrex ampules under vacuum and heated to 500°C for two hours (Nakai et al., 1984; Nakamura et al., 1985). The pyrolyzed samples were treated with 1.2N HCl at 80°C to eliminate residual carbonates, rinsed and dried; thus, pure charcoal was prepared.

The sample $^{14}C/^{13}C$ ratio, $\delta^{14}C(13)$, was measured for the prepared elemental carbon sample (in forms of carbon-silver mixture targets) by using the Tandetron accelerator mass spectrometer.

$$\delta^{14}C(13) \quad \frac{^{14}C/^{13}C \text{ sample}}{^{14}C/^{13}C \text{ standard}} \;.- 1 \times 1000\ (‰)$$

As a ^{14}C standard, charcoal prepared from wood of the 1840 through 1860 AD annual rings of a Japanese cypress tree (*Chamaecyparis obtusa*), which had its $^{14}C/^{13}C$ ratio calibrated to the 'modern' ^{14}C standard (0.95 times the activity of NBS SRM-4990 oxalic acid) was used. The ^{14}C age (T) is calculated by using the ^{14}C half life ($T_{1/2}$) of 5570 years.

$$T = - (T_{1/2}/0.693) \times \ln (1 + \delta^{14}C(13)/1000)$$

The carbon-isotopic mass fractionation was not corrected for this age determination. However, this correction is negligibly small compared with one sigma error for wood and peat samples.

Thermoluminiscence Dating

Certain crystalline minerals have the ability to store thermoluminiscence (TL) in the form of trapped electrons over long periods of time. The energy to raise these electrons to elevated energy levels is provided by radiation from trace amounts of long-lived radio isotopes of uranium, thorium and potassium. Cosmic radiation also plays a contributory role, as does the presence of Rb although to a much lesser extent. Sedimentary dating by this method requires that the TL-sensitive grains buried within the sediment are sufficiently exposed to solar radiation prior to deposition to release the vast majority of the geologically acquired thermoluminiscence. Following deposition, the TL energy once again begins to build up at a rate dependent upon the radiation flux delivered from within the host sediment. The time lapsed from the last exposure to sunlight is measured by determining the amount of TL energy acquired since deposition the palaeodose (P) and the rate at which this energy is provided the annual dose (AD).

$$\text{TL Age} = \frac{\text{Palaeodose (P)}}{\text{Annual Dose (AD)}}$$

Evaluation of the Palaeodose

The samples dated in this study have been analyzed using a combined form of the regenerative and the additive methods of TL dating fully described by Nanson et al. (1991). The technique utilizes the 90-125 micron quartz grain fraction extracted from the sample, by wet sieving, chemical cleansing and finally etching in hydrofluoric acid. A portion of the material so prepared is subjected to a prolonged period of intense irradiation under a laboratory ultra-violet lamp which serves to remove all but the so called "unbleachable TL" from the quartz grains. Aliquots of these grains are deposited as a monolayer upon a series of aluminium discs, which are then incrementally irradiated with a calibrated ^{90}Sr plaque source. Thus, upon measurement of the laboratory-induced thermoluminiscence, a growth curve relating TL and radiation received is constructed.

The thermoluminiscence accumulated since the time of deposition is determined by measuring the amount of energy stored in a number of quartz aliquots containing unbleached sample. This is converted into terms of absorbed radiation by reference to the TL growth curve previously constructed. A correction for the thermoluminiscence retained at the time of deposition, i.e., the TL 'starting point', is determined using a similarly prepared modern analogue sample. The removal of the geologically acquired thermoluminiscence requires considerable exposure to solar radiation during the transport phase which generally necessitates long transport distances under low energy conditions. Application of a correction determined from an underexposed surface sample will result in an erroneously low TL age. Generally this effect becomes less noticeable with increasing sample age, as the correction becomes a lesser proportion of the total TL signal. If no surface correction is applied, then the TL 'starting point' becomes that reached after exposure to the laboratory UV lamp. Since this level is unlikely to be attained under natural field conditions, an under-correction results and thus a maximum TL age is obtained.

Determination of the Annual Dose (AD)

In order to determine the amount of radiation energy received annually by the sample, it is necessary to measure the contents of U, Th and K. If an accurate age-determination is to be made, it is essential that the sediment immediately surrounding the sample is homogeneous to a radius of 30cm. If this is not the case, then the long-range gamma radiation dose measured from the sample will be in error. In this instance, the Rb content of the samples has been assumed but plays a negligible contributory role to the overall AD value. A cosmic contribution of 150 ± 50 μGy/yr has been assumed and the large associated tolerance is in turn reflected in the final TL ages computed. In this case, the cosmic contribution to the total AD is relatively small and the error introduced as a result correspondingly very low.

In the Wollongong laboratory, the specific activity of both the U and the Th decay chains is determined by means of a thick source alpha counting. This process requires that the sample is extremely finely ground to enable the detection of the short-range alpha particles emitted. Three to four grams of the sample are lightly pressed upon a 42mm ZnS scintillation screen within a sealed counting cell. After a period of 21 days, the alpha activity of the sample is measured using a photomultiplier system calibrated against an international geological standard having a similar matrix as that of the sample. The amount of K in the sample is determined by means of atomic emission spectroscopy, and finally, the AD is computed by taking into account the moderating effect of the environmental moisture content. Thus by means of the equation shown above, the TL age of the sample can be computed.

A full description of the theoretical considerations and associated mechanism is given by Aitken (1985) and laboratory procedures used here are as those described by Nanson et al. (1991).

3. THE STUDY AREA

Samples for TL dating were collected from two adjacent mine pits, the Pantai Mine and the Sinar Manjung Mine, but only from the former for AMS ^{14}C dating. In this study, emphasis is on the Pantai Mine.

The Pantai Mine is situated on the west coast of Perak state, about 4km southwest of the fishing town of Pantai Remis. The mine is located in a valley surrounded by the Triassic granite hills of Bukit Segari, and flanked by the mangrove-fringed shoreline of the Strait of Malacca (Figure 1). A reconnaissance survey was conducted in May and June 1989. In November 1989, detailed stratigraphic mapping, sampling and levelling were undertaken. Two stratigraphic sections, running north-northwest to south-southeast across the exposed face of the mine pit, profiles 1 and 2 (Figure 2), were described and surveyed. The level of sediment layers are given in meters from mean sea level (MSL).

The Sinar Manjung Mine, situated at the coast further west from the Pantai Mine (Figure 1), is a much larger and deeper open-cast mine by comparison (Figure 3). Towards the upper sequence of the mine's western wall, peat layers are also exposed, with the lowermost peat layer having a relatively similar base level as that shown in the Pantai Mine. In February 1991, when samples were collected for TL dating, the mine had not been surveyed to MSL. Thus the TL dates of samples from the Sinar Manjung Mine cannot be compared directly with those from the Pantai Mine. Levelling of the mine was completed in February 1992.

4. RESULTS OF AGE DATING

Tables 1 and 2 list the respective results of the AMS ^{14}C and TL dating of samples selected from the Pantai Mine. The TL dates shown represent ages which have not been corrected for residual surface TL. The surface sample collected for correction, came from a washout area close to the rim of the pit, and was not considered representative of the original sedimentation process. The TL ages measured have therefore been derived, by using the TL level attained following a prolonged exposure under a laboratory ultraviolet sunlamp (Philips MLU300W). Under natural conditions it is most unlikely that this level would have been reached, thus resulting in an overcorrection on the natural TL accumulated since sample deposition, and

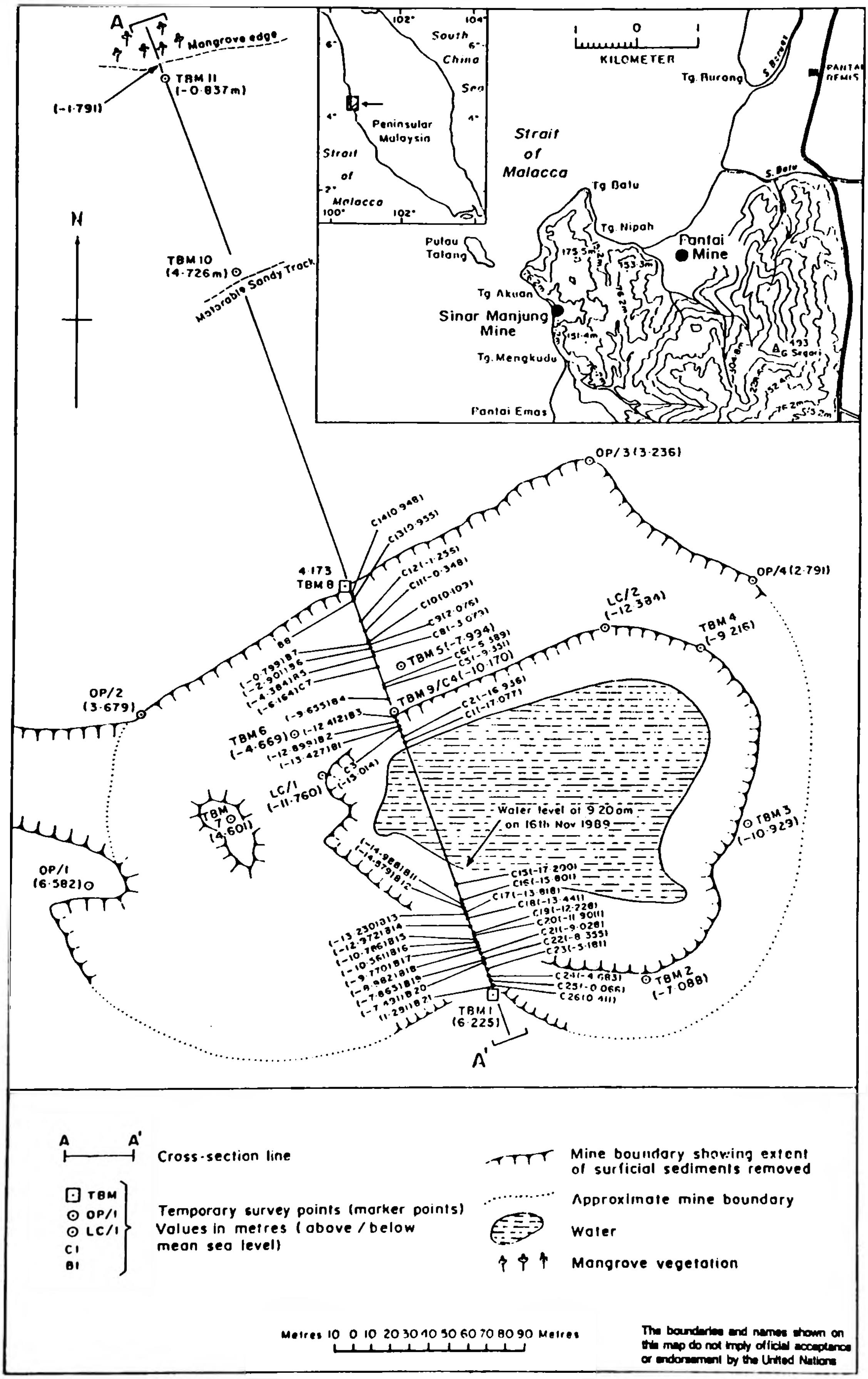


Figure 1. Locations of the study areas and plan view of the Pantai Mine, Perak, Malaysia

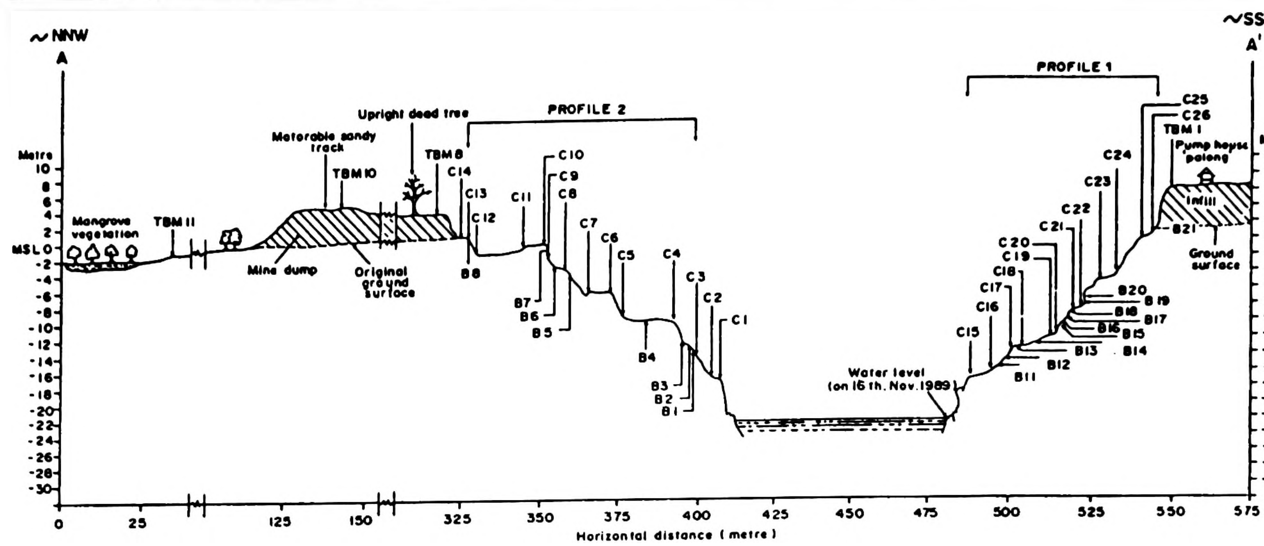


Figure 2. Cross-section along A-A' (approx. NNW-SSE) of the Pantai Mine, Perak, Malaysia

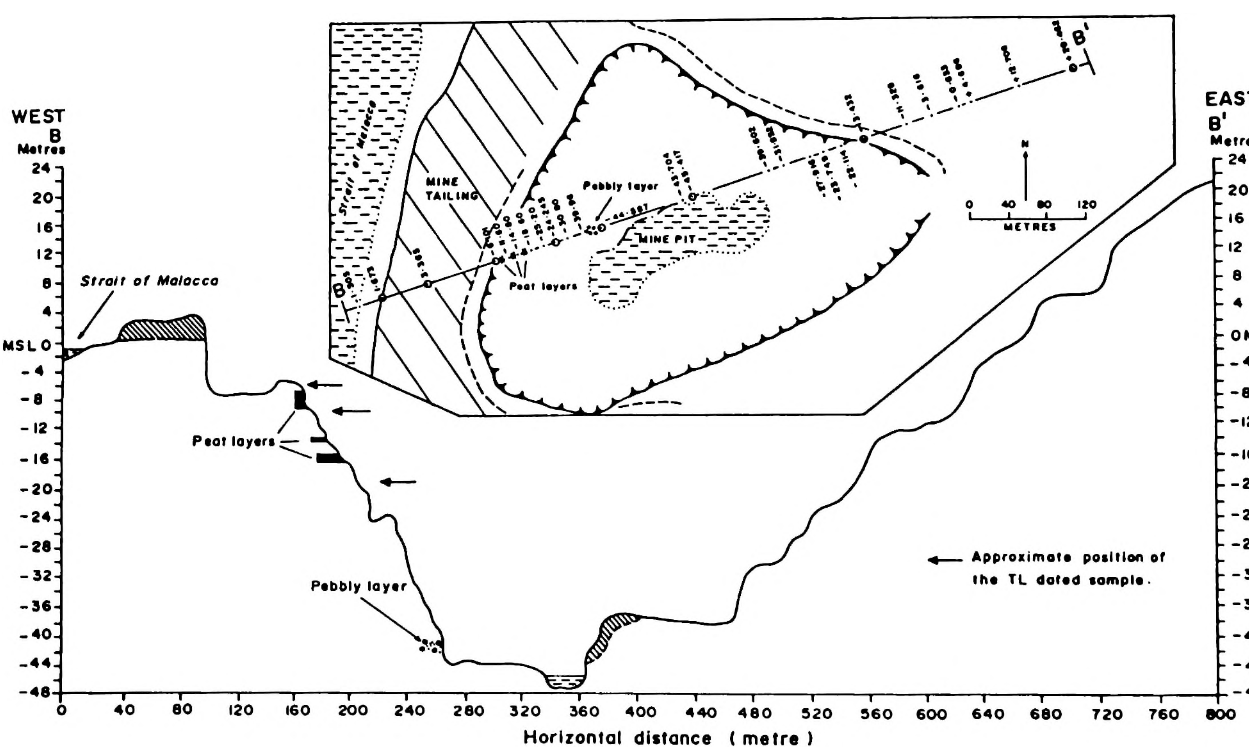


Figure 3. Plan and cross-section B-B' (approx. W-E) of the Sinar Manjung Mine, Perak, Malaysia

hence providing a maximum age value. From the good quality of the TL data (i.e. length of the TL temperature plateaux) this correction is thought to be small in this case and will become proportionally less significant anyhow with increasing sample age. This view is upheld by the general agreement between the ages derived using the two independent dating methods as well as the stratigraphic sequence of the TL data.

Profile 1 of the Pantai Mine

Figure 4 shows the lithological sequence of profile 1, and the corresponding results of the AMS ^{14}C and TL ages. The TL date of at least 55,800 ± 4,000 years BP from the sandy and clayey gravel layer at -8.2m and ^{14}C dates of $64,960^{+\infty}/_{-3600}$ years BP and $67,860^{+\infty}/_{-2150}$ years BP from the peat layers at -9.28m and -10.73m respectively, are in stratigraphic sequence. However, the ^{14}C dates yielded ages greater then the presumed measurable age limit. Considering the date as determined by the TL technique (at -8.2m) and the estimation from dead graphite samples for the Tandetron accelerator, the ages deduced for the two subsequent peat layers at -9.28m and -10.73m appear to be beyond the range of the AMS ^{14}C dating technique.

The TL age of at least 35,500 ± 3,900 years BP from the clay layer at -10.2m is low but represents a minimum age only. As shown in Table 2, relatively high U, Th and K activities are observed in the material. Under these circumstances, the radiation flux received brings about an early TL saturation beyond which the age of the sample cannot be determined by this method.

The base of the thickest peat layer in profile 1 at -14.60m below MSL is dated as 61,080$^{+\infty}/_{-2540}$ years BP. This value is stratigraphically inconsistent with those above it. Taking into account the measurable age limit of the ^{14}C dating, the apparent age indicates the larger degree of contemporary carbon contamination of sample C14-S7. Radiocarbon contamination during the sample preparation process may yield ^{14}C datings apparently younger than the true age of the material.

Profile 2 of the Pantai Mine

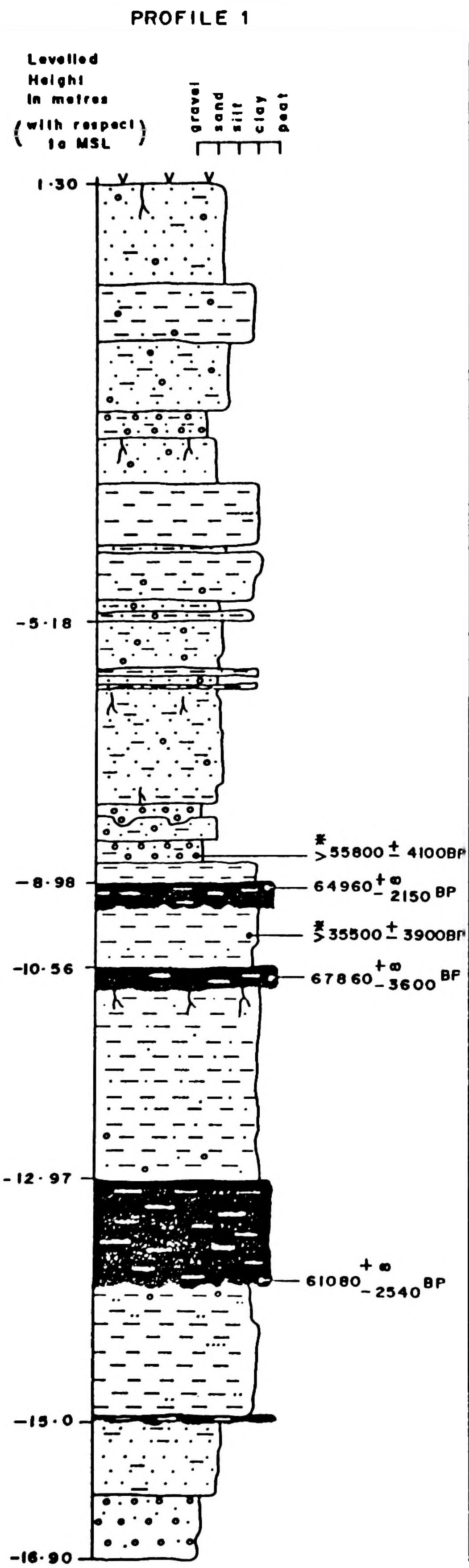
On profile 2, there is an unconformity at the top of the lithological sequence (Figure 5). The surface between -0.8m and -2.2m is very irregular, compacted, partially cemented, and in places entirely dissected and eroded. The sediments overlying this surface consists of clays interbedded with sandy gravel with abundant shells and shell fragments. A ^{14}C age of 480 ± 120 years BP based on shell material from this fossiliferous layer indicates that it is a relatively recent marine deposit. This is confirmed by the presence of pottery sherds. The clays and sandy gravels immediately below this surface have been dated using TL to 28,900 ±3,000 years BP at -1.6m and at least 37,700 ± 1,800 years BP at -2.3m.

Table 1. Radiocarbon dates from Pantai Mine, Pantai Remis, Perak.

Laboratory	*Material*	*Sample No.*	*Strati-graphic profile*	*Elevation (m M.S.L.)*	*Age[6] (years B.P.)*
NUTA-1 175	Peat	C14–S12	1	–9.28	64960 + ∞ -2150
NUTA-1203	Peat	C14–S10	1	–10.73	67860 + ∞ -3600
NUTA-1202	Peat	C14–S7	1	–14.60	61080 + ∞ -2540
NUTA-1386	Shell	C14–S5	2	–1.20	480 ± 120
NUTA-1167	Peat	P44	2	–3.07	53870 ± 1450
NUTA-1177	Peat	P36	2	–4.28	55810 ± 1140
NUTA-1158	Wood	C14–S4	2	–8.49	65450 ± ∞ -2230
NUTA-1236	Peat	P26	2	–10.71	65700 + ∞ -2230
NUTA-1235	Peat	P15	2	–12.35	65130 + ∞ -2420

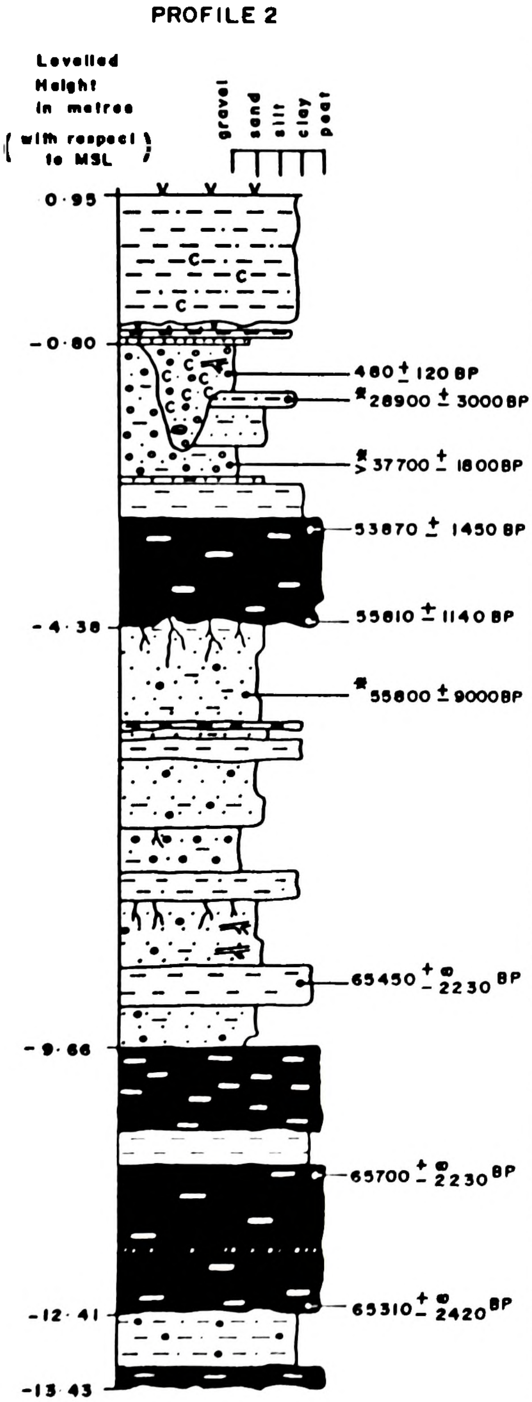
This first major peat layer has been subjected to AMS ^{14}C dating and yielded ages of 53,870 ± 1450 and 55,810 ± 1140 years BP at -3.07 m and -4.28 m respectively. A TL date of 55,800 ± 9,000 years BP has been determined on the clayey sand immediately below this, at -5.2m. The agreement between these dates, using different techniques and in different materials, is remarkable and leaves little doubt that these sediments were deposited around 55,000 years BP.

One sigma errors are shown. The upper errors are indicated as + ∞ for samples of ^{14}C dates greater than 60,000 years B.P. (the measurable limit of ^{14}C dating with a Tandetron AMS at Nagoya University), because true ages are probably older beyond the one sigma errors.

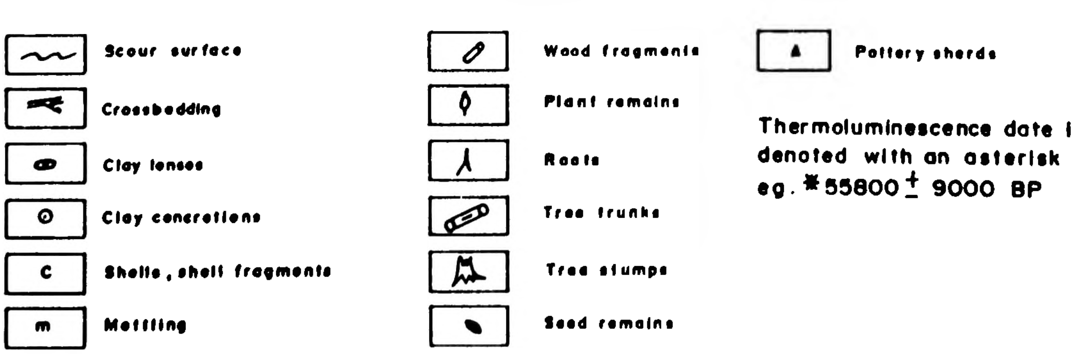


Sedimentary feature & Content	Description	Colour
m	Sand, slightly clayey, slightly gravelly mod. humic, rare amount of wood & roots Small amount of bright brown mottling along root gallery	brownish black grayish yellow
m	Clay slightly sandy and gravelly firm, mod. bright brown mottling	light gray
	Sand, v. clayey, slightly gravelly mod. humic, mod. amt. of plant & wood frag.	light gray
	Gravel, v. clayey, v. sandy; abund. plant & wood frag.	grayish yellow
	Sand, slightly gravelly mod. humic, small amt. of root remains	dull yellow orange
m	Clay; firm, small amt. of bright yellowish brown mottling, 5cm thick sand lens Sand; v. clayey	light gray light yellow
m	Clay, small amt. of bright yellowish brown mottl Clay, v-sandy, [illegible] gravelly	light gray
	Layers of sand and v-sandy clay resp.	d.y.o / l.gray
	Sand, v. clayey, slightly gravelly Bottom; v-gravelly	light gray
	Thin layers of sandy clay, sand and clay resp.	
	Sand, slightly to very clayey Top 25 cm clean sand In places rare gravel, small amount of clay concretions Bottom; thin layers of clay and organic material	light gray dull yellow orange grayish yellow
	Layers of sandy gravel and sl. clayey, sl. gravelly sand; channel-fill struct. & clay concretions	dull yellow orange
	Gravel, slightly clayey, v-sandy	light gray
	Clay, mod. humic, firm	dark grayish yellow
	Peat, mod. clayey	brown
	Clay, slightly humic, firm mod. amt. of disperse plant fragments Bottom; mod sandy, firm	light gray light yellow
	Peat, slightly clayey; trunk, stem, root etc.	dark reddish brown
	Clay, very sandy, slightly gravelly slightly humic, firm vertical & horizontal roots present Towards base; present of subangular to subrounded gravel (mostly qtz., some granite)	light gray to grayish yellow grayish yellow brown
	Peat, very clayey, mod sandy sand occurring in patches Base; wood resin present	yellowish gray to dark grayish yellow
	Clay, mod. sandy, slightly gravelly v-firm, sand & gravel in lenses rare amount of fine sand in lenses Small amount of medium sand in lenses Peat, mod. clayey, present of resin	light gray grayish white light gray to gray dark brown
	Sand, slightly to very silty, slightly to very clayey thin clay layers present, mod. wood, roots, black minerals	light gray to light olive gray
	Gravel, very sandy small amt. of clay concretions, ang. qtz. pebbles Bottom; slight. sandy, abund. clay conc., qtz. pebbles	grayish white

Figure 4. Lithological sequence (south wall) of the Pantai Mine



Sedimentary feature & Content	Description	Colour
	Clay, very silty Rare amt. of disperse shell, wood/plant frag (often referred as marine clay) Scour base	greenish gray
	Top - Interlayering of clay with sandy gravel Gravel, mod. to very sandy, abundant shell, clay lenses, wood frag., x - bedding	bright yellowish brown yellowish brown
	Clay, very sandy, lenses of gravel & shell frag Sand, mod. clayey, lenses of marine clay	light yellow
	Gravel, very sandy, slightly clayey clay conc., wood frag., gravel subangular	brownish black
	Sand, very clayey Clay, mod. humic	dull yellow orange light yellow & light gray
	Peat, mod. clayey Towards base; mod. clayey, slightly sandy scour base, sand in thin (1 to 3 cm) layers.	dark brown
	Sand, very clayey, very humic abundant vert. roots & wood frag. Middle; rare gravel, slightly silty Bottom; mod. clayey, slight amt. of plant frag.	yellowish brown grayish yellow light gray
	Interlayering of very humic clay with silty sand mod. amount of wood frag.	grayish yellow dull yellow orange
	Sand, slightly gravelly, slightly humic slight amount of wood remains Bottom; mod. clayey	dull yellowish brown dull yellowish orange
	Gravel, very sandy, slightly silty gravel subangular to subrounded, rare roots	dull yellowish orange
	Clay, slightly sandy, organic	dull yellow orange
	Sand, rare to slightly gravelly x - bedding, wood frag., vert. roots Bottom; slightly silty, x - bedding	dark brown & lightgray brownish black & dark grayish yellow
	Clay, v. peaty present of tree stumps, wood frag., bark, stem	grayish olive
	Sand, slightly clayey and gravelly, plant & wood Towards base; mod. gravelly	dull yellow orange
	Peat, very clayey Bottom; slightly clayey, scour base	brownish black
	Clay, very peaty	dark brown
	Peat, slightly clayey Tree trunks, stems etc. Occasionally presence of fine sand in lenses and thin (mm) layers Bottom; mod. clayey, scour base	brownish black
	Clay, very gravelly, mod. sandy some wood remains towards the top	gray
	Peat, slightly to mod. clayey	brownish black



Thermoluminescence date is denoted with an asterisk eg. *55800 ± 9000 BP

Figure 5. Lithological sequence (north wall) of the Pantai Mine

Lower in the profile, AMS ^{14}C ages of $65,450+\infty/_{2230}$ years BP on woody peat at -8.49 m, $65,700+\infty/_{2230}$ years BP on peat at -10.71 m, and $65,310+\infty/_{2420}$ years BP on peat at -12.35 m have been determined. Those ages also suggest that the lower peat strata are beyond the measurable age limit of the AMS ^{14}C technique.

Table 2. Thermoluminescene dates from Pantai Remis, Perak[7]

Lab. Code	*Profile*	*Elevation (m M.S.L.)*	*Plateau region (°C)*	*Analysis temp. (°C)*	*Paleo-dose (grays)*	*K Content (% by AES)*	*Moisture Content (% Wt)*	*U + Th spec. activity (Bq/kg)*	*Annual radiation (μ Gy/yr)*	*Tl Age ± 1 (yrs BP)*
W1113	2	-1.6	275–400	375	117±11	0.625	13.1	187	4056±67	28,900±3,000
W1114	2	-2.3	300–500	375	> 227±13	1.155	17.0	361	7351±64	> 37,700±1,800
W1115	2	-5.2	300–500	350	289±46	0.975	19.4	250	5165±63	55,800±9,000
W1116	1	-10.2	300–500	350	> 300±33	1,745	35.8	483	8458±54	> 35,500±3,900
W1117	1	-8.2	300–500	350	> 300±22	0.595	20.2	283	5381±62	> 55,800±4,100
W1216	SMM	-6	300–500	375	> 247±29	0.895	24.4	465	8311±60	> 29,700±3,500
W1217	SMM	-10	300–450	375	289±48	1,520	27.8	395	7475±58	38,600±6,500
W1218	SMM	-19	325–500	375	≥ 278±50	0.450	17.5	210	4119±64	≥67,600±12,100

SMM = Sinar Manjung Mine

The Sinar Manjung Mine Profile

TL ages have been determined on sandy alluvium samples which were collected from the south-southwest wall of the mine. In this wall, peat layers shown in Figure 3 were actually not exposed. As mentioned, the site has not been surveyed to MSL when samples were collected, but nevertheless the sampling positions were approximately estimated by comparing the level of the peat strata exposed in the western wall, and tentative correlation with profiles I and 2 of the Pantai Mine.

The TL dates found, of at least 29,700 ± 3,500 years BP at about -6m, of 38,600 ± 6,500 years BP at about -l0m and of at least 67,680 ± 12,100 years BP at around -19m, are presented in Table 2. They indicate a similar age range of the Old Alluvium as determined from profiles 1 and 2.

5. DISCUSSION

Good agreement was obtained between the AMS ^{14}C ages and the TL ages for Pantai Mine samples, as especially indicated in Profile 2. This illustrates that the upper strata of the Old Alluvium are late Pleistocene in age, while the lower strata were deposited more than 67,000 years ago, beyond the measurable limit of AMS ^{14}C dating. Even though the TL dating, in general, can offer a viable method of dating beyond this limit, the sediments at the Pantai Remis site are also found to be beyond the limit of the TL dating technique, owing to the TL saturation caused by relatively high annual radiation levels of the surrounding sediments.

Apart from dating, more than 130 samples were also collected from the Pantai Mine for other analyses such as grain size, heavy mineral, pollen and fossil identification. Preliminary findings from palynological analyses of the peat samples suggest that peat had accumulated in a series of marine transgressive and regressive phases. This important discovery will hopefully provide the insight necessary to explain and establish a glacial chronology, at least since the Riss-Würm Interglacial in this part of the world, ever since the work of Scrivenor (1949), Smit Sibinga (1953), and the evidence reported by Biswas (1973), Geyh et al. (1979), Emmel and Curray (1982), Tjia (1970, 1980), Aleva (1973), Batchelor (1979a, 1979b), Rose (1984), Thorp (1990), Gupta (1987) and others. Further palynological work is presently being undertaken with the collaboration of staff from the Institute of Petroleum Research of PETRONAS.

7 *Annual radiation values indicated assume cosmic contribution to be 150 μGray/year and a Rb content of 100 p.p.m. U + Th specific activity values were determined by means of calibrated thick source alpha counting and assume secular equilibrium. The TL ages indicated are not corrected for surface residual TL and therefore represent absolute maximum values.*

In addition, the basal peat in the Sinar Manjung Mine has been sampled for a palynological study aimed at achieving stratigraphic correlation with the Pantai Mine.

6. CONCLUSIONS

The Old Alluvium sequence of sandy clays, gravelly sands and interbedded peats exposed in the Pantai Mine represents late Pleistocene sediments, with some recent marine reworking and surface deposition. The Simpang Formation in Perak, and presumably much of the Old Alluvium in the region is thus Late Pleistocene in age, and possibly even older.

The maximum Holocene transgression of ca. 5000 years ago is depicted in neither of stratigraphic profiles 1 and 2 (Figures 4 and 5). This can be explained by the eroded and dissected unconformity at -0.8m to -2.2m in profile 2, indicating extensive erosion which had presumably removed sediments deposited during that period.

A remarkable correlation between AMS ^{14}C and TL dating has been demonstrated in this study. These two dating techniques, not previously used to date the Old Alluvium, indicate that the upper strata, at least in the vicinity of Pantai Remis, were deposited around 30,000 years ago. This lends support to some of the previous, conventional ^{14}C determinations from Malaysia and Indonesia. Although there have been distinct local changes in the environment of deposition at this site, marked by the alternation of sandy alluvium and woody peat, the dates obtained would indicate a relative continuity of conditions back to 67,000 years BP, and presumably beyond. Thermoluminiscence reached its saturation at this site because of the relatively high annual radiation dose, but nonetheless it obviously has wider potential if applied to the dating of sandy alluvium in the region.

7. ACKNOWLEDGEMENTS

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PALYNOLOGY OF LATE QUATERNARY SEDIMENTS FROM A COASTAL SITE IN PERAK, MALAYSIA[1]

IUGS UNESCO IGCP 296

by

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Abstract

Twenty eight samples of peat, clay and silty clay from a tin mine exposure near Pantai Remis, Perak, Malaysia, were palynologically analyzed. Six pollen zones and eight subzones were delineated based on the dominant floral components. Accelerator mass spectrometry (AMS), radiocarbon and thermoluminiscence dating on selected samples indicate late Pleistocene and older age. The occurrence of *Podocarpus imbricatus* pollen suggests that the deposit is not older than late Pliocene.

Fluctuation of the sea level during the late Pleistocene is believed to be the main factor that influenced the development of vegetation at the Pantai Remis area. The presence of mangrove peat at depth between 13.0 m and 14.0 m which overlies a freshwater *Pandanus* peat indicates the position of a former shoreline at Pantai Remis when the area was inundated sometimes during the Last Interglacial marine incursion. During this period of high sea level, the *Pandanus* swamp was probably being gradually replaced by mangrove vegetation. The mangrove sequence is regarded as equivalent to the Kempadang Formation.

A slight drop in sea level, some time during the Last Glacial Interstadial Stage probably caused a small, open alluvial swamp to be developed over the mangrove forest. This freshwater deposit may be the equivalent of the Simpang Formation.

As most sea level data previously acquired in this region are from the Holocene, the present study would represent a significant addition to our data base on the late Pleistocene.

1. INTRODUCTION

The strength of palynology as a tool in delineating depositional sedimentary environments in tropical coastal lowland areas may be attributed to the fact that most coastal plants are prolific pollen producers and therefore, their pollen are strongly represented in the sediments. Another factor is the sensitivity of the littoral flora to slight changes in salinity during rises or falls in sea level in response to the waning and waxing of glacial ice.

The Sunda Shelf, which includes the South China Sea and the Strait of Malacca, is a relatively shallow sea. Any change in the sea level will cause shorelines and their vegetation to shift. Pollen studies of the coastal lowlands and offshore areas have provided useful paleoenvironmental information for predicting the position of Quaternary shorelines (Biswas, 1973; Anderson and Muller, 1975; Chow, 1977; Haseldonckx, 1977a, b; Morley, 1981; Hillen, 1984, 1986; Ellison, 1989; Grindrod, 1988; Kamaludin, 1989; Somboon, 1990).

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The present study uses this knowledge base to interpret a sequence of Quaternary deposits exposed a tin mine near Pantai Remis, Perak. The sedimentology of these deposits have been described elsew (Mazlan and Kamaludin, 1991). This paper discusses the results of palynological analysis.

2. THE STUDY AREA

The mine is located about 4 km southwest of the fishing village of Pantai Remis, on the west coast Perak, Malaysia (Figure 1 of Kamaludin et al., this volume). This open-pit gravel-pump tin mine has abandoned and is now under water. The mine is surrounded by the Triassic granite hills of Bukit Seg Only to the north the mine faces a strip of mangrove shoreline.

3. METHOD OF STUDY

Sampling

Detailed stratigraphic mapping, sampling and levelling were carried out in November, 1989. Two north-northwest to south-southeast trending stratigraphic sections across the mine pit (Profiles 1 and 2) were described and measured (Figure 2 of Kamaludin et al., this volume).

Palynological analyses were done on 28 peat, clay and silty clay samples from Profile 1. A lithological description of the sediments from Profile 1 is shown elsewhere in this volume (Figure 4 of Kamaludin et al., this volume). The sampling interval ranges from 5 to 40 cm, depending on the lithology of the samples.

Laboratory Technique

Sample preparation took place at the Geological Survey Laboratory in Ipoh, Perak. About 1 to 2 cm^3 of each sample were processed for pollen grains and spores, according to the general procedure suggested by Faegri and Iversen (1975). During the preparation the samples were treated with 30 per cent hydrofluoric acid to dissolve silicate minerals and acetolysed to remove cellulosic material and humic acids.

To concentrate the pollen and spores, residues were gravity separated using a heavy liquid solution of bromoform-alcohol mixture (S.G.=2.0). The residues were stained using safranine to enhance the morphological features of the fossils before mounting them on slides with silicon oil (AK 2000). Silicon oil is used because the grains can be rotated by pressing a needle on the cover slip to make identification easier. Also the oil does not cause the pollen grains to swell.

The slides were studied under a transmitted light microscope at 400x magnification. When necessary, a more detailed examination was made at 1000x using an immersion oil objective. Whenever possible, a minimum of 200 pollen grains were counted for each slide. Pollen and spores were identified by comparing with a modern pollen collection and by the use of taxonomic keys and description in Huang (1972), Anderson and Muller (1975) and Chow (1972).

Data presentation

The pollen and spore counts are tabulated and displayed as a pollen diagram (Figure 1 – in pocke showing the variation in pollen percentage with depth. The percentages are based on the total sum pollen grains minus spores of ferns and algae. Spore percentages are also calculated, using the same poll sum. Thus, whenever spores outnumber the pollen count, their apparent percentage exceeds 100 per cent.

On the diagram, the pollen spectra are arranged according to the preferred habitat of their respecti parent plants. The most salt-tolerant community has been grouped under 'mangrove' and consists mainly the Rhizophoraceae (*Rhizophora* and *Bruguiera* species), *Sonneratia*, *Avicennia* and *Acanthus*. *Sonnera* *alba* and *Sonneratia caseolaris* are represented under one spectrum, as their presence is generally less than three per cent.

The 'back mangrove' pollen group contains the plant community with some degree of tolerance for freshwater influx. The next pollen spectra represent freshwater plants and undetermined pollen. Undetermined pollen comprise 'unknown' and 'unidentified' pollen. The former refer to pollen of which the botanical affinities are unknown, while the latter pollen are either broken, crumpled or hidden. A composite spectrum showing the variation between the mangrove, back mangrove and freshwater groups is also included.

The percentages of fern spores and freshwater algae (*Concentricysts*) also feature on the pollen diagram.

4. AGE DETERMINATION

Absolute ages were obtained from ^{14}C, using the accelerator mass spectrometry method, as well as the thermoluminiscence dating method. A detailed account of the dating is reported in Kamaludin et al. (this volume). The results, shown in Figure 2, indicate an absolute age ranging from 35,000 years BP to 68,000 years BP.

A single occurrence of *Podocarpus imbricatus* pollen grain from clay sample P64 indicates an age ranging from late Pliocene to Recent (Muller, 1966).

5. POLLEN ASSEMBLAGE ZONES

Six pollen assemblage zones and eight subzones have been recognized (Figure 4). The zones and subzones are interpreted as representing past vegetation and often correspond to lithological units.

Pandanus Zone (PZ) - Samples (P62, P62B)

Pandanus constitutes 80 per cent of the pollen in this zone whereas other pollen types like *Campnosperma* and *Macaranga/Mallotus* are less then three per cent.

Mangrove Zone I (MZI)

This zone is characterized by a low diversity in palynomorphs which is dominated by Rhizophoraceae. A low representation of undetermined pollen and spores is observed: four subzones are recognized:

Mangrove subzone I (MSI) - Samples (P64, P63)

This subzone is characterized by more than 70 per cent Rhizophoraceae pollen. Other pollen types include *Sonneratia*, *Avicennia*, *Acanthus*, *Oncosperma*, *Pandanus* and *Campnosperma*. Of special mention is the occurrence of a single grain of *Podocarpus imbricatus* pollen in sample P64.

Mangrove subzone II (MSII) - Samples (P66, P68, P69)

The palynomorph recovery from these samples is very poor, amounting to less than ten specimens per sample. Sample P66 yielded only four spores while sample P69 yielded only eight pollen. Seven pollen and two spores were recovered from sample P68. The highest pollen representation comes from Rhizophoraceae, *Sonneratia*, *Xylocarpus* and Sapotaceae/Meliaceae.

Mangrove subzone III (MSIII) – Samples (P71, P73)

Both samples are dominated by Rhizophoraceae (60 per cent). There is a low percentage of other pollen types which include *Sonneratia, Xylocarpus*, Sapotaceae/Meliaceae and *Combretocarpus*. A maximum representation of about eight per cent *Casuarina* pollen is recorded in this subzone.

Mangrove subzone IV (MSIV) – Samples (P75, P76, P77, P79)

About 80 per cent Rhizophoraceae pollen were recovered from this subzone. Other significant pollen are *Sonneratia, Lumnitzera*, Sapotaceae/Meliaceae and *Combretocarpus* and *Quercus* tp. A consistent occurrence of *Podocarpus polystachyus* is also observed.

Transition Zone I (TZI) – Samples (P80, P81)

This zone contains a wide range of pollen types, mainly Sapotaceae/Meliaceae (20 per cent), *Calophyllum* tp. (5 per cent), *Campnosperma* (8 per cent), Palmae (5 per cent), *Lithocarpus* tp (5 per cent), *Austrobuxus* (5 per cent) and single occurrences of *Oncosperma, Brownlowia, Barringtonia* and *Nypa*. A marked increase of undetermined pollen, monolete spores, trilete spores and *Concentricysts* is observed.

Transition Zone II (TZII) – Samples (P85)

The pollen assemblage in this zone is almost similar to that of the previous zone, but has no *Austrobuxus* pollen and shows a very prominent occurrence of *Clerodendrum inerme* pollen (40 per cent).

Freshwater Zone (FW)

The main feature is the high diversity of pollen. The zone is dominated mainly by pollen of freshwater plants and fern spores. The occurrence of undetermined pollen is consistently high throughout the zone. Four subzones were identified:

Freshwater Subzone I (FSI) – Samples (P86, P87)

This subzone has the highest representation of *Campnosperma* pollen (30 per cent). Other pollen types present in the subzone include *Pandanus, Combretocarpus, Calophyllum, Malastoma*, Myrtaceae, *Macaranga/Mallotus* and *Quercus*. Pollen of Sapotaceae/Meliaceae and spores are rare.

Freshwater Subzone II (FSII) – Samples (P88, P89, P90)

The main types of pollen in this subzone are Sapotaceae or Meliaceae, *Combretocarpus, Randia, Campnosperma, Stemonurus, Quercus* and Austrobuxus. Also, *Podocarpus polystachyus* pollen and the spores of *Lycopodium cernuum* have their strongest representation in this subzone.

Freshwater Subzone III (FSIII) – Samples (P91B, P91, P91T)

A strong representation of several types of pollen and spores can be observed in this subzone. This includes a peak in Sapotaceae/Meliaceae (60 per cent), *Combretocarpus* (10 per cent), *Altingia* (8 per cent), *Selaginella* and other monolete and trilete spores. Other important pollen types are *Brownlowia, Pandanus, Calophyllum* and *Campnosperma*.

Freshwater Subzone IV (FSIV) – Samples (P92, P93, P93T)

Despite a poor pollen recovery in sample P93T, a rich assemblage of spores was observed. Samples P92 and P93 yielded a wide variety of pollen including *Oncosperma, Pandanus, Calophyllum, Melastoma, Durio, Stemonurus*, Myrtaceae, *Macaranga/Mallotus* and *Flagellaria*. The pollen of Sapotaceae/

Meliaceae, *Combretocarpus* and *Campnosperma* show a drastic reduction. The freshwater algae, *Concentricysts* has the highest representation in this subzone.

Mangrove Zone II (MZII) – Sample (P107)

This is the uppermost sample analyzed. The assemblage is dominated by Rhizophoraceae pollen (65 per cent). Some undetermined pollen are also recorded.

6. INTERPRETATION

A summary of the pollen assemblage zones and their inferred past vegetation and depositional environment is given in Table 1. The zones are interpreted and evaluated chronologically, taking into consideration the lithology of the sediments.

Pandanus Zone

The preponderance of *Pandanus* pollen, a prolific pollen producer in this zone, indicates over-representation from a local source. The presence of a *Pandanus* swamp which shed pollen directly into the sediments resulted in the high abundance of *Pandanus* pollen in Zone PZ. *Pandanus* swamps occur extensively in present-day freshwater intertidal environments, such as that along the Pahang coast southward into Johor. *Pandanus* swamp fringes the Sedili river in a freshwater intertidal environment. The lowermost peat layer at Pantai Mine could have been deposited in a similar environment, possibly in an abandoned channel. The finding upward sequence observed at the base of the profile (see Fig. 4 in Kamaludin et al., this volume) suggests an abandoned tidal channel sequence.

Mangrove Zone I

The area around Pantai Remis was probably inundated by the sea following a rise in sea level. This resulted in the encroachment of the mangrove forest into the area. The sediment consists predominantly of clay which was formerly a mangrove mud deposited in brakish water. A river could have transported pollen of *Oncosperma*, *Pandanus*, *Campnosperma* and *Podocarpus imbricatus* from a distant inland source.

The clay of MSII is believed to have been deposited in an intertidal brackish environment which was similar to that of MSI. Sub-aerial exposure during its deposition is indicated by its grayish white color. This may cause the poor palynomorph recovery from this subzone.

The clay in MSIII was probably deposited in a slightly drier part of the mangrove zone. This is interpreted from the presence of back mangrove pollen *Sonneratia caseolaris*, *Xylocarpus* and Sapotaceae/ Meliaceae. The high representation of *Casuarina* pollen indicates that a beach could have developed near the site.

The development of a more advanced mangrove forest could have occurred in MSIV when the site was more frequently inundated by the sea. The river may have transported the hinterland pollen to the site. It is also important to note the presence of *P. polystachyus* type in this subzone. The pollen could have been produced by the coastal conifer *P. polystachyus* (Corner, 1951). This rule out the montane origin of a similar pollen type.

Table 1. Summary of pollen assemblage zones and their inferred paleoenvironment

ZONE	SUB ZONE	SAMPLE NUMBER	GROSS LITHO	DEPTH (meter)	MAIN PALYNOLOGICAL CHARACTERISTICS		DEPOSITIONAL ENVIRONMENT
MZ11		P107	G		. Rhizophoraceae (65%)		Mangrove swamp
	No data				Large sample gap		
FW	FS IV	P 93 T* P 93 P 92	P P P	−8.98	. Poor pollen recovery (P93T) . Oncosperma, Pandanus, Calophyllum, Melastoma, Durio, Stemonurus, Myrtaceae Macaranga/Mallotus, Flagellaria . Algae-Concentricyst . Spores-Monolete, Trilete	. High diversity . Mainly fresh-water pollen . High % of un-known, un-identified pollen . Abundant spores	Open alluvial swamp
	FS III	P 91 T* P 91 P 91 B	C C C		. Poor pollen recovery (P91T) . Sapotaceae/Meliaceae (60%) Combretocarpus (10%), Altingia (8%) . Brownlowia, Pandanus, Calophyllum, Campnosperma . Spores – Monolete, Trilete, Selaginella (Maximum)		Alluvial swamp
	FS II	P 90 P 89 P 88	C C C		. Sapotaceae/Meliaceae, Combretacarpus, Randia, Campnosperma, Stemonurus, Quercus, Austrobuxus . Podocarpus polystachyus . Spores – Lycopodium cemuum		Development of alluvial swamp
	FS I	P 87 P 86	P P	−10.56	. Campnosperma (30%) . Pandanus, Combretocarpus, Calophyllum, Melastoma, Myrtaceae, Macaranga/ Mallotus, Quercus		Transition to alluvial swamp or earliest phase of Anderson's peat swamp
TZ II		P 85	C		. Clerodendrum (40%) . Sapotaceae/Meliaceae, Combretocarpus, Randia, Campnosperma, Lithocarpus		Herbaceous swamp Slightly brackish
	No data				Sample gap		
TZ I		P 81 P 80	C P		. Sapotaceae – Meliaceae (20%) Calophyllum, Campnosperma (8%) Palmae, Lithocarpus, Austroluxus (5%) . Unknown, Unidentified pollen . Monolete, Trilete, Concentricyst	. High diversity . Mainly fresh-water pollen . Some back man-grove pollen	Fresh water swamp Fresh water intertidal Very slow salinity
MZ I	MS IV	P 79 P 77 P 76 P 75	P P P P	−12.97	. Rhizophoraceae (80%) . Sonneratia, Lumnitzera, Maliaceae, Quercus . Consistent P. polystachyus	. Low diversity . Mainly Rhizophoraceae . Low % of unknown, unidentified pollen . Some spore	Mangrove peat Brackish intertidal Salinity slightly increased compared with below
	MS III	P 73 P 71	P C		. Rhizophoraceae (60%) . Maximum Casuarina . Sonneratia, Xylocarpus, Sapotaceae/ Maliaceae, Combretocarpus		Back mangrove Brackish intertidal Marked salinity
	MS II	P 69* P 68* P 66*	C C C		. Poor recovery . Rhizophoraceae, Sonneratia, Xylocarpus, Sapotaceae/Meliaceae		Brackish intertidal
	MS I	P 64 P 63	C C		. Rhizophoraceae > 70% . Sonneratia, Avicennia, Acanthus, Oncosperma, Pandanus, Campnosperma . Podocarpus imbricatus		Mangrove mud Brackish intertidal Marked saline influence
PZ		P 62 P 62B	P P	−15.0	. Pandanus (80%)		Pandanus swamp Fresh water intertidal

LEGEND * Pollen recovery < 20 counts, G - Gravel, P - Peat, C- Clay

			Offshore Lumut Dindings (West Coast) (1)	Coastal Lowlands (2)	Kinta Valley (3)	South China Sea (East Coast) (4)
HOLOCENE		YOUNG ALLUVIUM	Younger Sedimentary Cover	Beruas Formation Gula Formation	Organic mud and peat Young Alluvium	↑
			DISCONFORMITY			
PLEISTOCENE	Late	YOUNG ALLUVIUM	Alluvial Complex			
			DISCONFORMITY			
PLEISTOCENE	Middle	T U	Transitional Unit	Kempadang Formation Simpang Formation	Old Alluvium	
			DISCONFORMITY			
PLEISTOCENE	Early	OLDER SEDIMENTARY COVER	Alluvial Plain Facies (Old Alluvium)	↓ ↓ ↓	? ?	Pilong Formation
PLIOCENE	Late	OLDER SEDIMENTARY COVER	Piedmont Fan Facies (Boulder beds/ Granite wash)	? ? ?	Boulder beds ? ?	
			DISCONFORMITY			
PLIOCENE	Early	S R	Sundaland Regolith			↓
	LATE MIOCENE	S R	↓			

Table 2. Late Cenozoic correlation chart, Peninsular Malaysia

Transition Zone I

A fall in sea level may have caused the mangrove forest to become smaller. The back mangrove and freshwater plants colonized the space left by the mangrove forest. During this time, the sea was probably near the site. This is indicated by the presence of important back mangrove species such as *Oncosperma, Brownlowia, Barringtonia* and *Nypa*. This sequence of events indicate a transition from a mangrove swamp to a freshwater swamp.

Transition Zone II

A brackish-influenced herbaceous swamp could have formed in TZII. This could be another transition zone similar to TZI. The only difference is in the high representation of *Clerodendrum* pollen. This pollen was probably derived from the coastal shrub *Clerodendrum inerme*.

Freshwater Zone

In this zone, various stages in the development of a freshwater swamp are observed. A fully developed peat swamp forest was not formed, probably due to constant input of mineral-rich water from a nearby river. The presence of the river is indicated by the occurrence of pollen from riparian plants such as *Pandanus, Pometia* and *Crudia*. However, the peat from Subzone FSI contains polien assemblages similar to Anderson's earliest peat swamp phase (Anderson and Muller, 1975; Morley, 1981). An open alluvial swamp was gradually developed in the subsequent subzones. This explains the presence of pollen and spores of *Macaranga/Mallotus, Lycopodium cernuum* and *Concentricysts*. The presence of back mangrove pollen in the alluvial swamp suggests that the sea was near this site. Therefore, a small alluvial swamp probably not more than 1 km in diameter could have formed (Anderson and Muller, 1975).

Mangrove Zone II

A rise in sea level could have caused another mangrove forest to be developed near the site. However, a final conclusion cannot be drawn due to incomplete data between Zones FW and MZII.

7. DISCUSSION

Stratigraphy

On the basis of age and depositional environment, various workers (Suntharalingam, 1983 and 1987; Suntharalingam and Teoh, 1985; Ghani, in manuscript; Bosch, 1986) have subdivided the Quaternary deposits of Peninsular Malaysia into four lithostratigraphic units, namely Simpang, Kempadang, Gula and Beruas Formations. The Simpang and Kempadang are terrestrial and marine (salt and brackish water) deposits respectively, and are Pleistocene. Gula and Beruas Formations are Holocene, and were deposited in marine and terrestrial environment respectively. These formations are equivalent to the classic 'Old Alluvium' and 'Young Alluvium' of Walker (1956). A correlation of the late Cenozoic sedimentary sequences for Peninsular Malaysia is shown in Table 2.

Kamaludin et al. (this volume) assigned late Pleistocene and older ages to the sediments at this site. The presence of *Podocarpus imbricatus* pollen in sample P64, which suggests an age older than that obtained from the AMS radiocarbon and thermoluminiscence dates. A similar finding of pollen from Old Alluvium in Kuala Lumpur area has been described by Mohammed Ayob (1970).

In the present study, the palynological assemblages for the interval between -12.97 m and -15 m (MZI Zone) suggest deposition in a mangrove swamp (Figure 2). The interval therefore, probably belongs to the Kempadang Formation. The formation was first defined in the Kuantan area (Ghani, in manuscript) and was later mapped in the Lumut area (Abdullah, in manuscript). It is the first marine Pleistocene deposit identified from boreholes in Kuantan and Lumut areas.

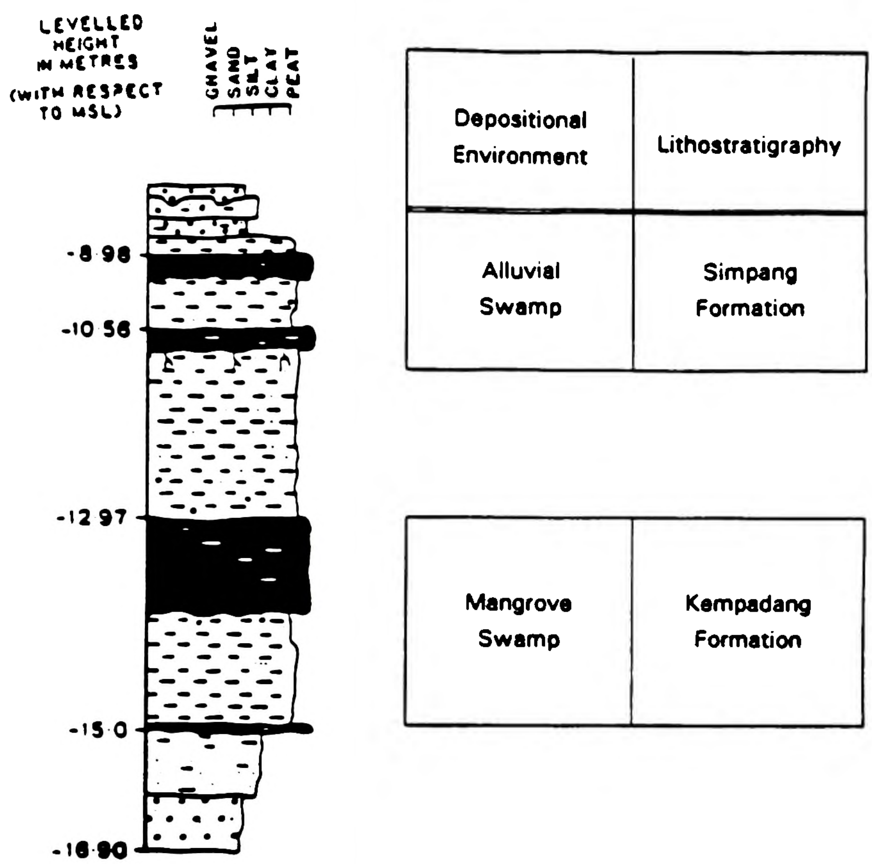

Figure 2. Pantai Tin Mine: Environment of deposition and its relation to Quaternary stratigraphy

The palynological assemblages between -8.5 m and -10.97 m (FW and TZII Zones) indicate that the sediments were deposited in an alluvial swamp. This interval probably represents the Simpang Formation.

Relationship With High Latitude Glacial Stages

The terms 'interglacials' and 'interstadials' are commonly used in the northwest of Europe to characterize intervals of ammeliorating climate in the Pleistocene (West, 1984). The interglacial refers to the temperate stage between cold stages, whereas the interstadial is the ammelioration phase within a cold stage. The relationship between these glacial stages, the generalized oxygen isotope curve (an indicator of paleotemperature of ocean water), and the Pantai Mine sedimentary sequence is shown in Figure 3.

The Kempadang Formation, which is a brackish water sequence, was probably deposited during high sea level in the Last Interglacial Stage.

The Simpang Formation in the Pantai Mine is an alluvial swamp sequence which was probably deposited near the coastline. Deposition during the interstadial of the Last Glacial Stage is a most likely interpretation.

Estimates of Former Sea Level

Streif (1979), Geyh (1979) and Tjia et al. (1977) presented some radiocarbon data of sediments from the Strait of Malacca. The first two authors highlighted the potential as well as the limitations of the data as indicators of former sea level. According to these authors, the presence of peats or organic-rich sequences, particularly of mangrove origin within or on top of coastal sequence provide insight on time-depth position of sea level. They also believed that mangroves are direct indicators of the tidal zone between mean neap and mean spring high (Figure 4).

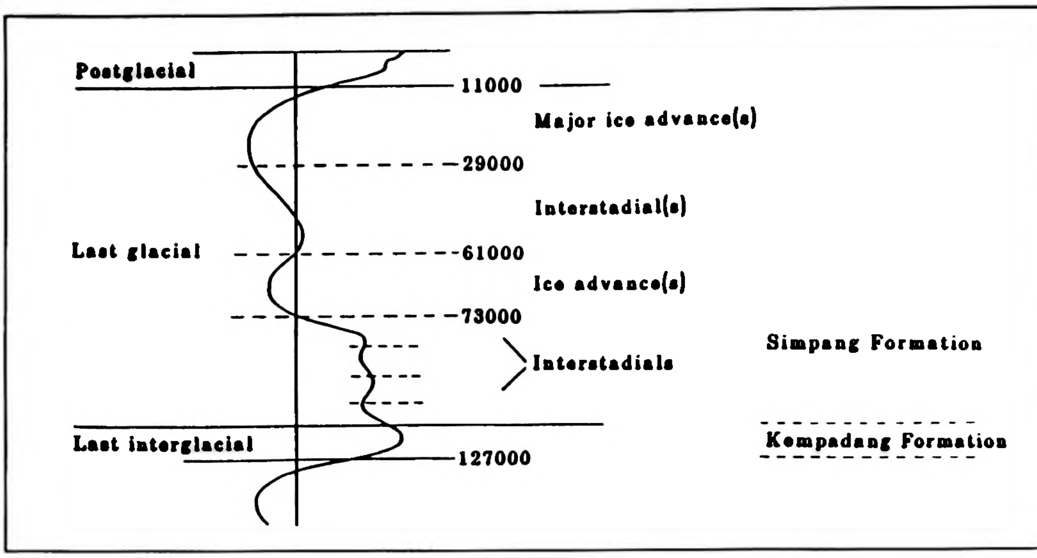

Figure 3. Relation of Simpang and Kepadang Formation with generalized oxygen isotope curve (after West, 1984)

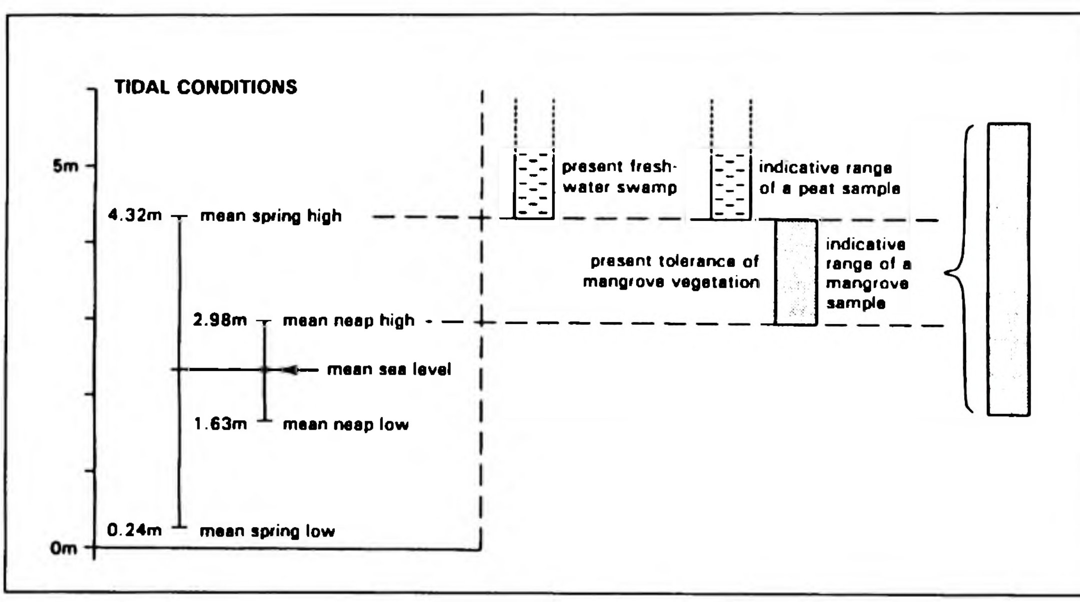

Figure 4. Ecological significance of vegetation and indicative range of samples (after Streif, 1979)

In this study the mangrove peat of the assumed Kempadang Formation is therefore indicative of the former shoreline position. Unfortunately the date obtained from the base of the mangrove peat i.e. 61,080 ± 2,540 years BP is beyond the measurable age limit of ^{14}C and is not in stratigraphic order with those above it (see Figure 4 of Kamaludin et al., this volume). Sibrava (1991) suggested that the Kempadang Formation was probably deposited as a marine deposit during the Last Interglacial Stage which is around 100,000 years BP. Taking into account 80 per cent compaction (Streif, 1979) of the lowermost Pandanus peat layer, the Kempadang peat was deposited probably about 0.375 m higher than the level presently measured at the mine exposure. It can be deduced that around 100,000 years BP the sea level was probably at -14 m near this site (Figure 5), assuming that this area was tectonically stable almost since the Tertiary (Tjia, 1980). This finding adds an important information regarding the late Pleistocene sea level, as most of the sea level data previously acquired in this area were from the younger deposits.

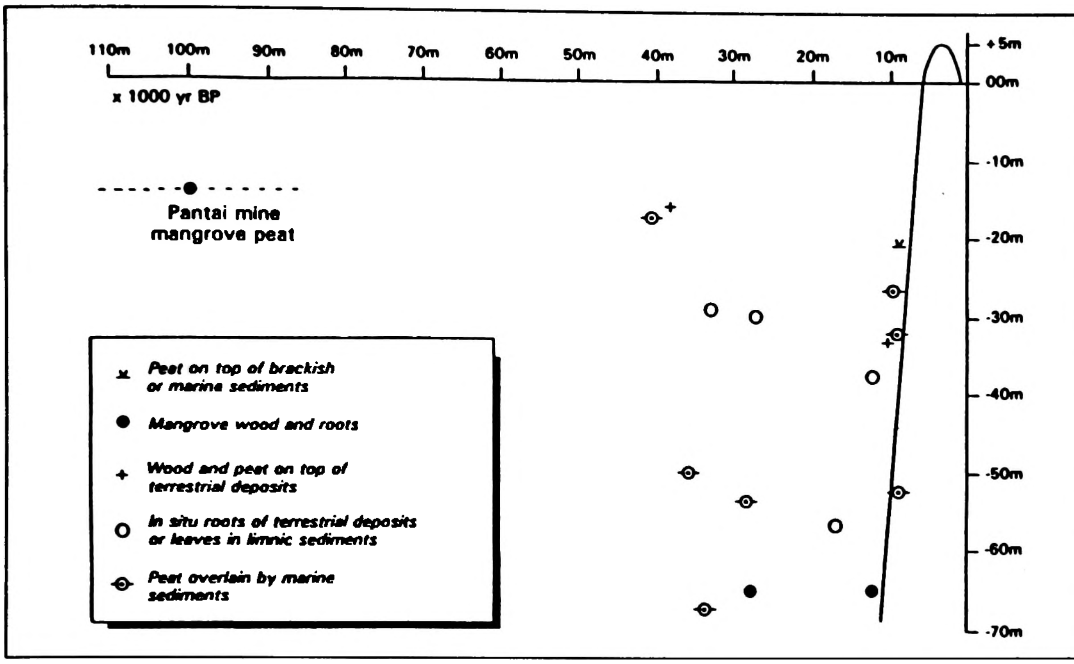

Figure 5. Data from Pantai Remis as compared to the sea level curve from the Strait of Malacca (after Geyh et. al., 1979)

8. CONCLUSIONS

Following a rise in sea level during the Last Interglacial, some 100,000 years ago, the area around Pantai Remis was probably slightly inundated. As a result, the *Pandanus* swamp which formerly occupied the abandoned freshwater channel was replaced by mangrove vegetation which tolerated brackish water conditions. A peak in the development of mangrove forest resulted in the accumulation of mangrove peat. This brackish water sequence is believed to belong to the Kempadang Formation.

As sea level fell slightly probably at some time during the Last Glacial Interstadial, the mangrove forest shifted seaward. A freshwater swamp gradually developed, beginning with a herb-dominated swamp at 68,000 years BP and finally into an open alluvial swamp some 55,000 years B.P. A peat swamp forest was never fully developed at the site because of close proximity to the sea. Furthermore, constant input of mineral-rich water into a swamp hindered the development of an advanced peat swamp. The extent of the alluvial swamp was estimated to be not more than 1 km across. This late Pleistocene freshwater sequence is regarded as belonging to the Simpang Formation.

9. ACKNOWLEDGEMENTS

Dr. R. J. Morley and Prof. H. D. Tjia contributed greatly with constructive ideas and their initiating of stimulating discussions. Colleagues at PRSS and GSM are much appreciated for their help in many aspects of this study. Special thanks to Ahmad Munif and Siti Sapurah for their effort in drawing the pollen diagram and nicely typing the manuscript. This paper is published with permission of the Directors of PETRONAS Research & Scientific Services and the Geological Survey of Malaysia.

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CORRELATION OF HOLOCENE SEA LEVEL CHANGES ALONG THE EAST COAST OF PENINSULAR THAILAND[1]

by

Virote Engkagul[2] and Paiboon Pramojanee[2]

IGCP 296

1. INTRODUCTION

The aim of this paper is to present an inventory of data collected during studies of Holocene transgressions that ocurred along the east coast of Peninsular Thailand, and to base the correlation of Holocene sea level changes in this area on this evidence. Results of ^{14}C dating carried out on each area of study are also discussed.

The study of Holocene sea level changes in Thailand started in the previous decade (1980-1990) in a cooperative effort involving the Department of Mineral Resources (DMR), the Department of Land Development, and a number of academic institutions in Thailand. This paper provides data available so far for the correlation of Holocene sea level changes in this region.

2. EVIDENCE OF HOLOCENE SEA LEVEL CHANGES ALONG THE EAST COAST OF PENINSULAR THAILAND

Holocene sea level changes have been studied along the east coast of Peninsular Thailand, in the areas of the lower Central Plain and the Southern Region of Thailand (from Prachuab Kirikhan to Narathiwat Province) as shown in Figure 1. The techniques used range from geomorphology through palynology and remote sensing to ^{14}C dating, used to estimate ages of peat and shells. See Table 1 at the end of this paper. The results of these studies are summarized as follows:

The Lower Central Plain

Nutalaya and Rau (1981) studied the causes of land subsidence in Bangkok. This investigation involved the study of subsurface sediments of Bangkok and its suburbs. Based on this study an isopach map of the marine clay in the Lower Central Plain was compiled (Figure 2). The age of the Bangkok embayment was estimated to be about 3000 to 5000 years BP. Thiramongkol (1984) also studied the geomorphology of the area (Figure 3). His study also dealt with Holocene eustatic sea level changes. ^{14}C dating in the area yielded ages of about 4,030 ± 120 to 744 ± 150 years BP, corresponding to a sea level at that time of about 2 to 3 m above present mean sea level (MSL).

Somboon (1988, 1990) studied the geomorphology of the Chao Phraya delta. The result of his investigation into the depositional environment and stratigraphic succession of this area is shown in Figure 4. From his ^{14}C data, the deposition of marine and brackish clays in the Lower Central Plain took place between 2,250 ± 140 to 7,800 ± 40 years BP. The marine transgression and regression in this area correspond to this period. The interpretation of the depositional environment (Figure 4) shows that the lowest strata of the succession consist of fluvial sediments. So during this period, the sea did not reach this level. These fluviatile sediments can be correlated with the stiff clay of the Late Pleistocene (Somboon, 1988). According to Nutalaya and Rau (1983) the ages of the stiff clay ranged from 14,700 ± 2,300 to 45,000 ± 6,900 years BP. For the upper layers, the depositional environment indicates a gradual change

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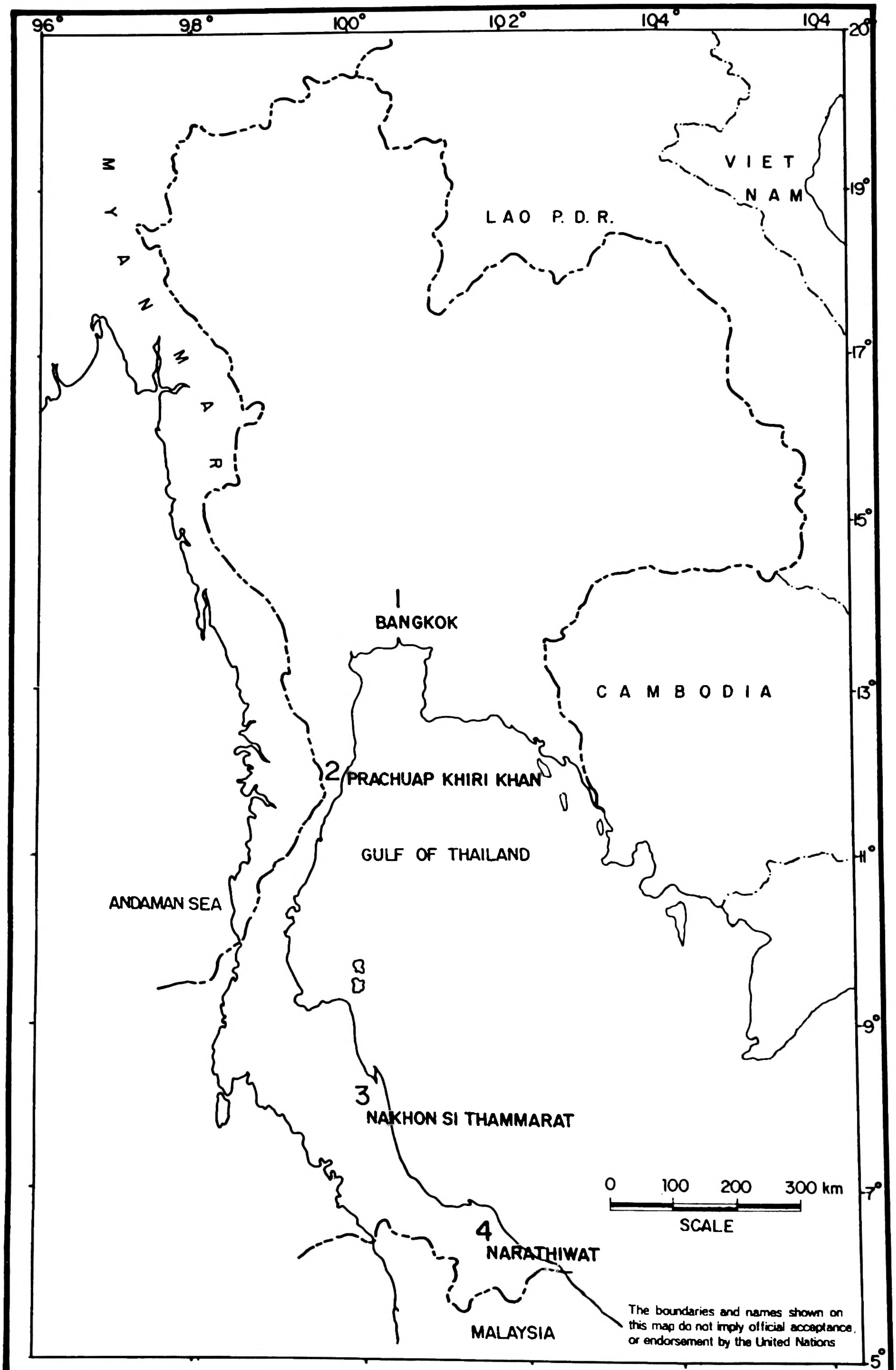

Figure 1. Locations of the study areas, Thailand

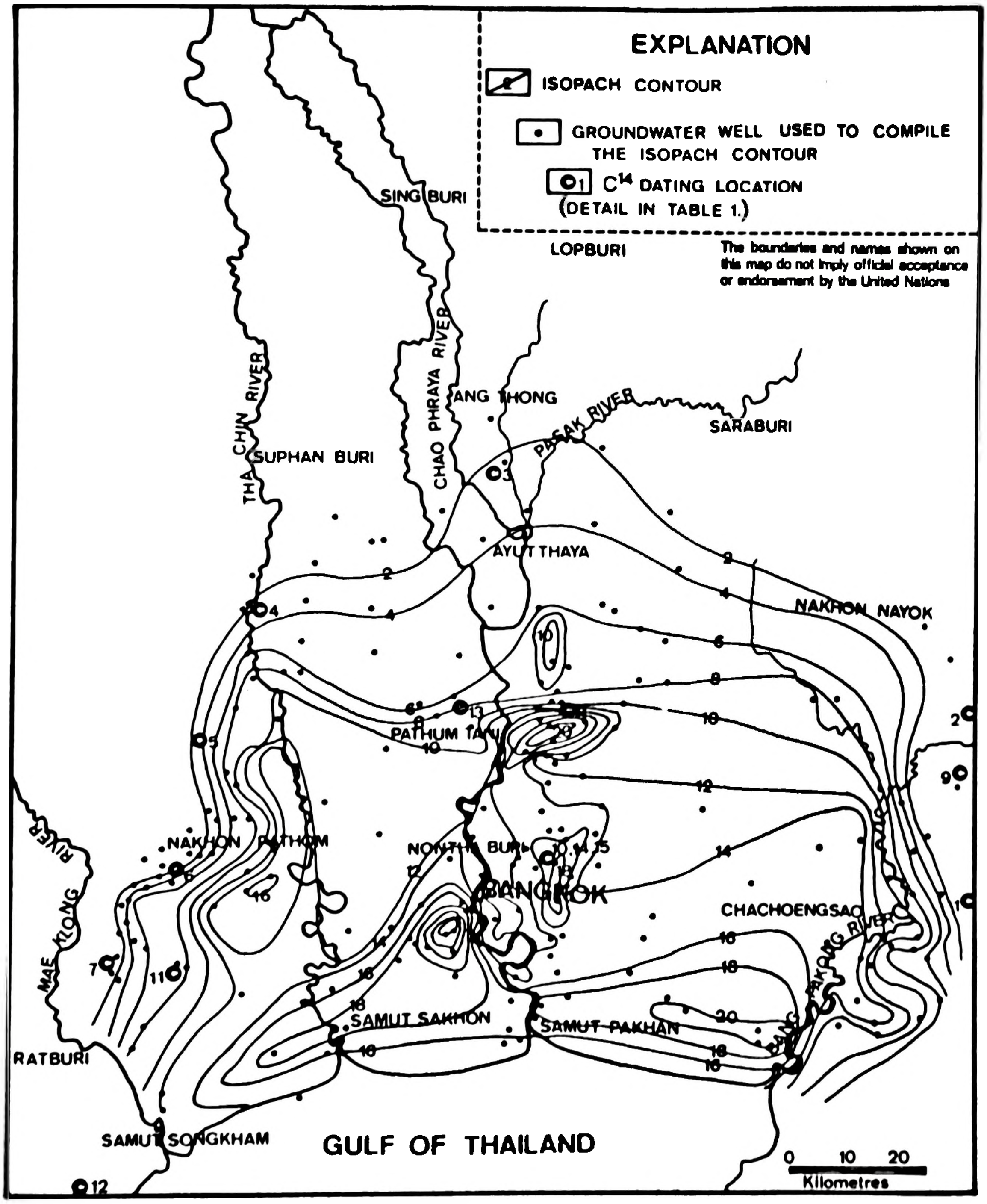

Figure 2. Isopach maps and locations of radiocarbon dating of the Bangkok marine clay (Nutalaya and Rau, 1981)

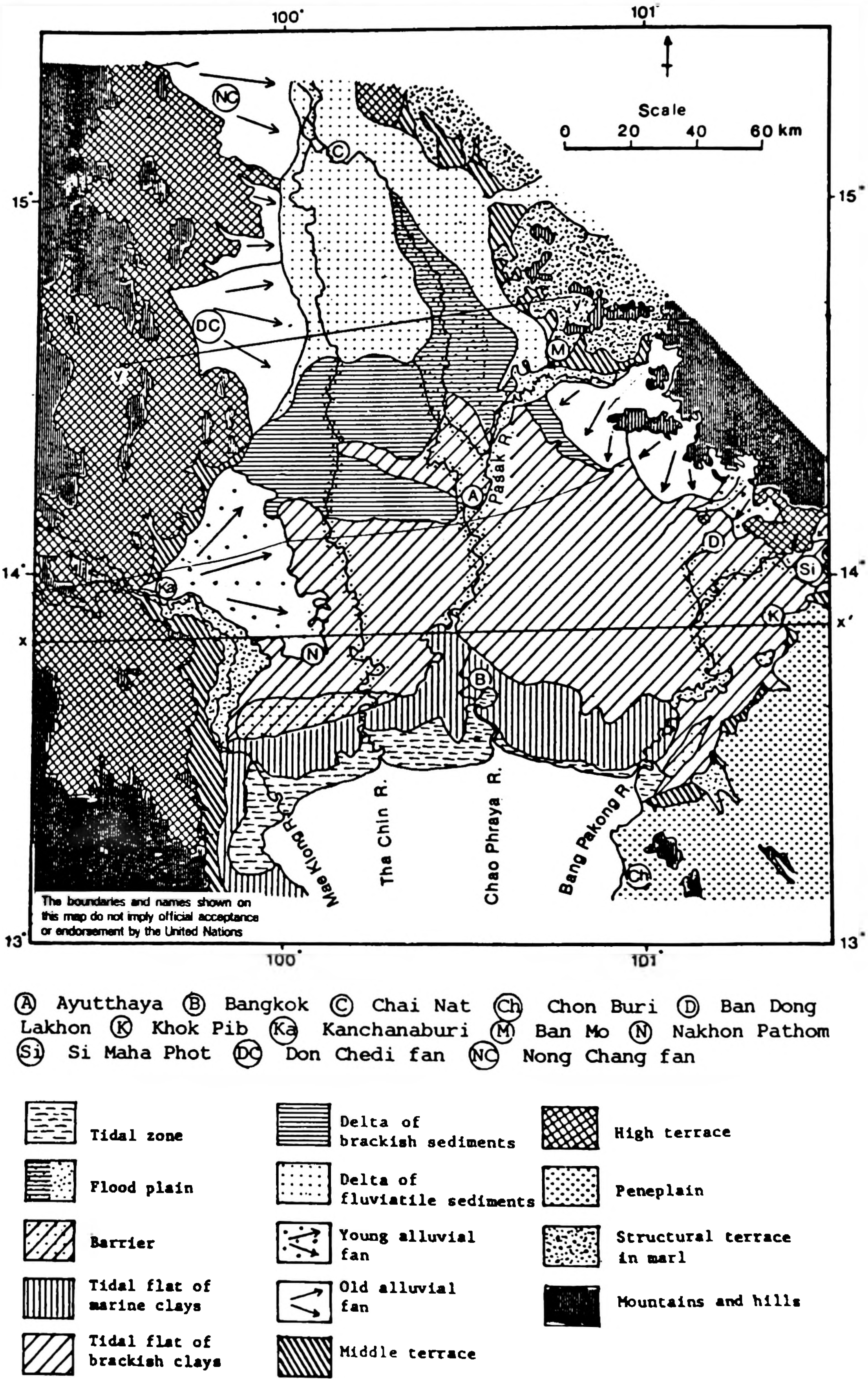

Figure 3. Geomorphological map of the lower central plain of Thailand (after Thiramongkol, 1984)

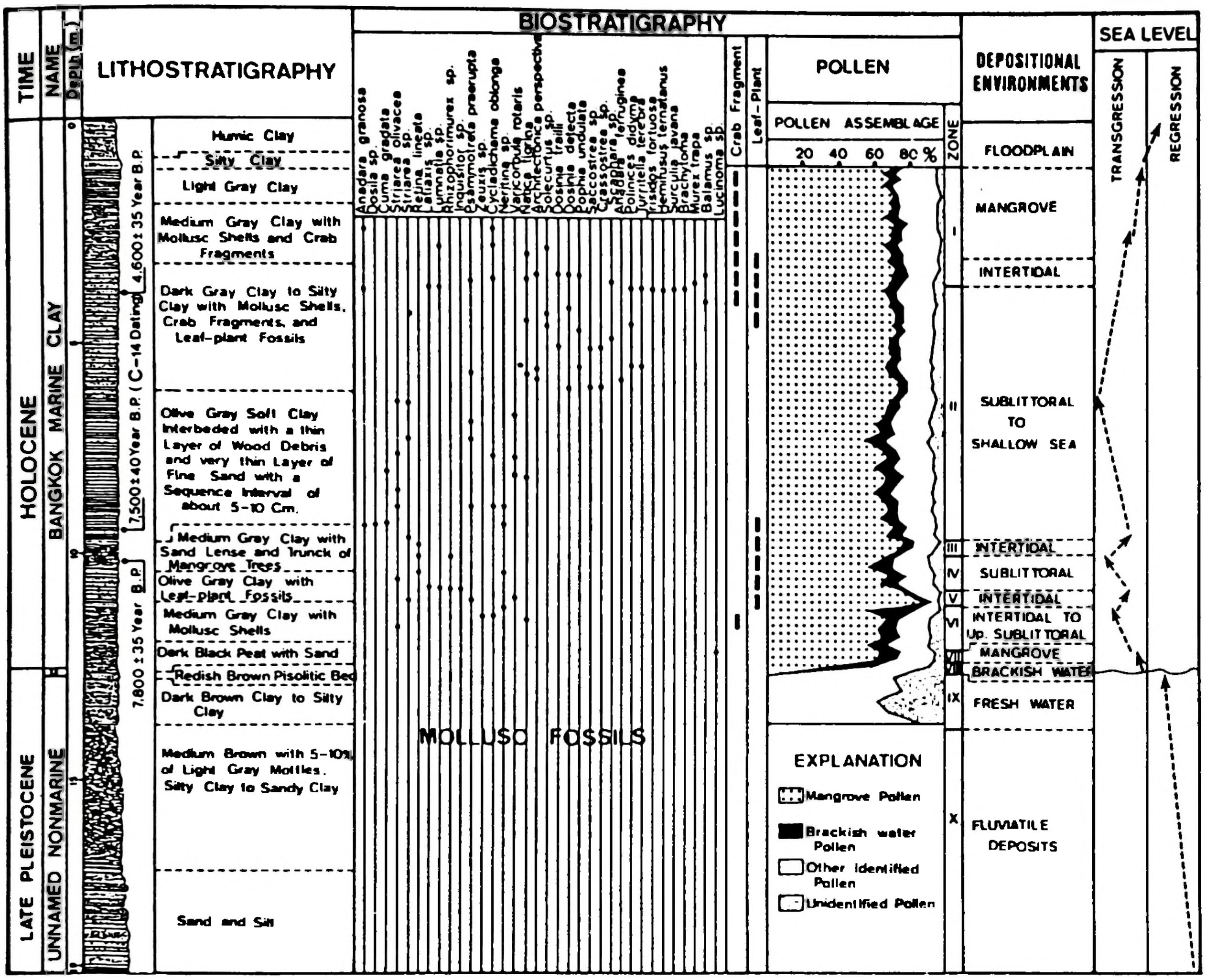

Figure 4. Stratigraphy and interpretation of the past environment of recent marine sediments in the lower central plain of Thailand (after Somboon, J.R.P., 1990)

from a fluviatile through a fresh water, brackish water, mangrove, intertidal, sublittoral to a shallow marine environment respectively. This indicates that from the late Pleistocene on, the sea was gradually transgressing. During the period of the highest sea level, characterized by a shallow marine environment, the sea reached the north of Ayuthaya Province (Figure 5). This event can be dated back to 5,600 years BP. Evidence from the depositional environment (which changed from marine via sublittoral and intertidal, to mangrove respectively), proves that after standing at this highest level, the sea gradually regressed until the present sea level was reached.

Prachuab Kirikhan Province

The study of the relationship between the ancient city sites and old shorelines in this area (Supajunya, pers. comm., 1991) led to the definition of two old shorelines in this area at 3.5 to 4m above present MSL (see also Supajunya, 1983). Another, lower level, can be observed at about 2m above present MSL. The ^{14}C data from this level should be available soon. However, oysters collected from Khao Chong Krachok, Prachuab Kirikhan Province, at an elevation of about 2 m above present MSL, were dated at 4,180 ± 160 years BP (Sinsakul, 1990) while those at an elevation of about 1 m above MSL yielded ages of 3,290 ± 125 years BP (Thiramongkol, 1984).

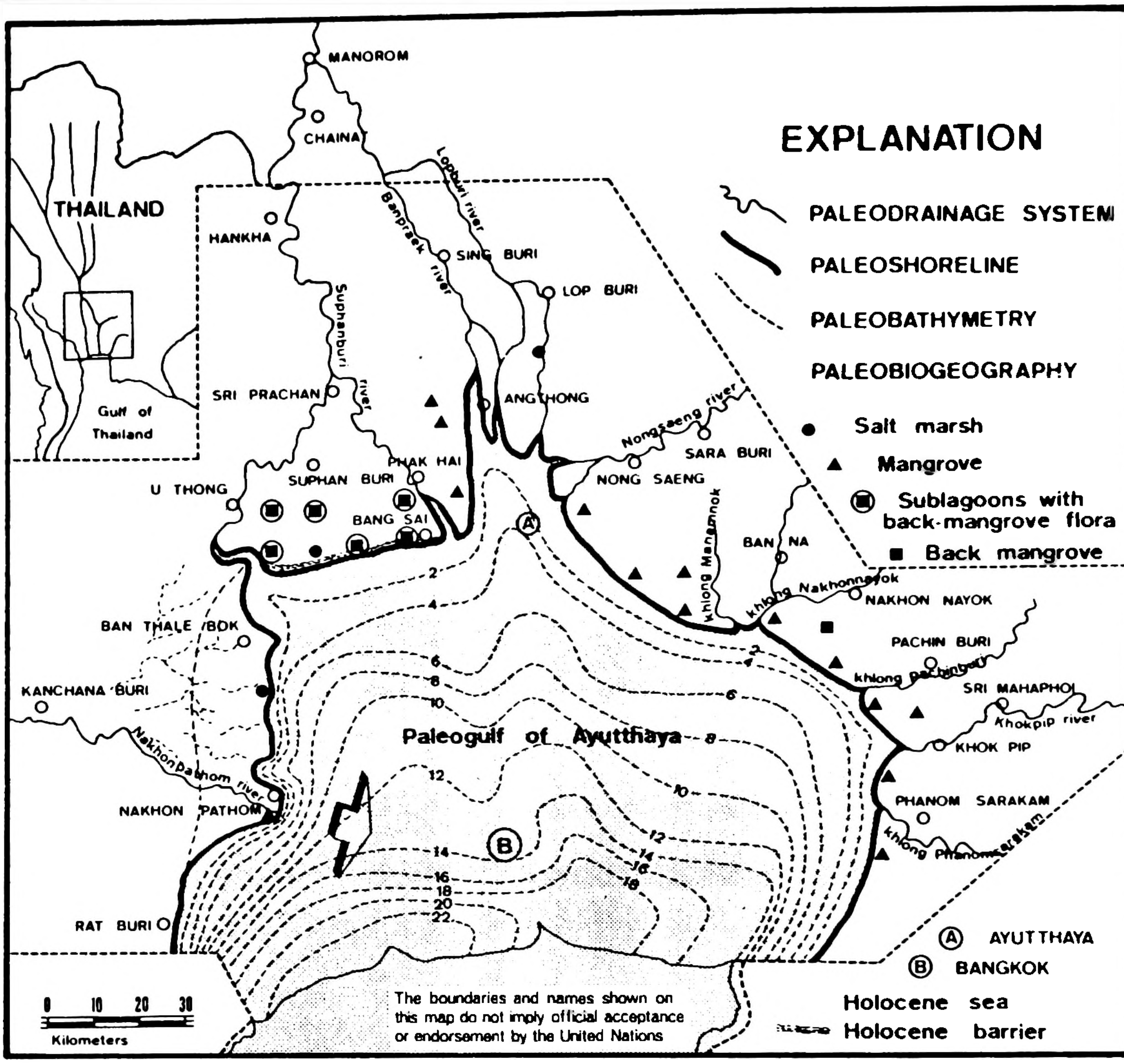

Figure 5. Paleogeographical map of the old coastal lowlands in lower central Thailand (after Somboon, J.R.P., 1990)

Nakorn Sithammarat, Song Khla Province

Abundant evidence shows that this area was influenced by marine processes. There are e.g. the remains of two large old beach ridges, almost parallel to the recent shoreline. They can be clearly seen on Landsat images. Marine sediments, peat and shell fragments were found in the former tidal plain between these two old shorelines and on the plain between the old beach ridge and the recent shoreline.

The area was studied by Pramojanee et al. (1984). The plain is underlain by marine and brackish clay of various thicknesses. In turn, the marine clay is underlain by the stiff clay. Evidence of a wave-cut notch can be found at Khao Daeng, Songkhla Province at an elevation of about 4.8m above present MSL, which represents the highest marine level established so far. Pramojanee et al. (1984) correlated this level with the 4.7m level of shell beds at Phang Nga province on the western coast of Peninsular Thailand, dated at 5,700 years BP. Pramojanee et al. (1984) therefore concluded that the highest level the sea ever reached was 4 to 5m above MSL, about 5,700 years ago. The transgressions and regressions of the Holocene period described by Pramojanee et al. (1984) are shown in Figure 6. Based on ^{14}C data of peat and shell samples from Peninsular Thailand, they attempted to construct a sea level curve by plotting ^{14}C age data versus local mean sea levels. This sea level curve is shown in Figure 7.

Time[1]	Sub division	Event
8500-		Beginning of Holocene transgression
8000-		Steady rise in sea level
7500-		
7000-	I	
6500-		
6000-		
5500-		Beginning of first regressive phase
5000-	IIa	Steady fall in sea level
4500-		Rise in sea level
	IIb	Drop in sea level[2]
4000-		
3500-	III	Stillstand
3000-		
2500-		Beginning of last regressive phase
	IV	
2000-		Present sea level
1500-		
1000-	V	Present sea level contitions
500-		
0-		

[1] In Radiocarbon years Before Present (yrs BP)

[2] Possible time of sea level fluctuation

Figure 6. Tentative Holocene chronology in Thailand (Pramojanee et. al., 1984)

To investigate the evolution of Song Khla Lake, the DMR studied many areas around the lake. Chaimanee and Tiyaparach (1983) explained the evolution of Song Khla Lake as follows: before middle Holocene, Song Khla Lake had an opening to the coast, but because of the regression of the sea around the middle Holocene, wave action produced a beach ridge known locally as the 'Song Khla Great Spit', closing off the sea, thus effecting the change from an open coast- to a lagoon environment. Based on ^{14}C age determinations of shells in this beach ridge, the latter has been dated at about 4860 ± 270 years BP. This puts the start of the development of Song Khla Lake around middle Holocene.

Narathiwat Province

Vijarnsorn and Liengsakul (1986) revealed that the Bacho swamp consists of 2 main peat layers, the lower one, at a depth of 2m, is about 3,956 ± 120 years old, while the 1m deep upper layer has been dated at about 2,400 to 3,000 years BP. For To Daeng Swamp, the lower layer is about 5,940 ± 100 to 6,700 ± 190 years old, while the upper one has been dated between 1080 ± 90 and 680 ± 85 years BP. These data represent summarized values from numerous age datings in this area. The thickness of the strata varies and peat sediments are underlain by a stiff clay. The authors concluded that the evolution of the peat swamps coincided with the marine transgression and regression which took place around 3,000 to 7,000 years ago.

3. DISCUSSION

Beginning with the late Pleistocene, the region of study was part of Sundaland and sea levels were about 100m to 200m below the present mean sea level (Tjia 1986, Biswas, 1973).

Basal peat indicates an early Holocene transgression; these peats represent the lowermost sections of marine Holocene sediments overlying late Pleistocene fluviatile sediments or stiff clay. ^{14}C age dating of these peats yielded ages of about 8,000 to 9,000 years BP (Sinsakul, 1990). Studies along the east coast of

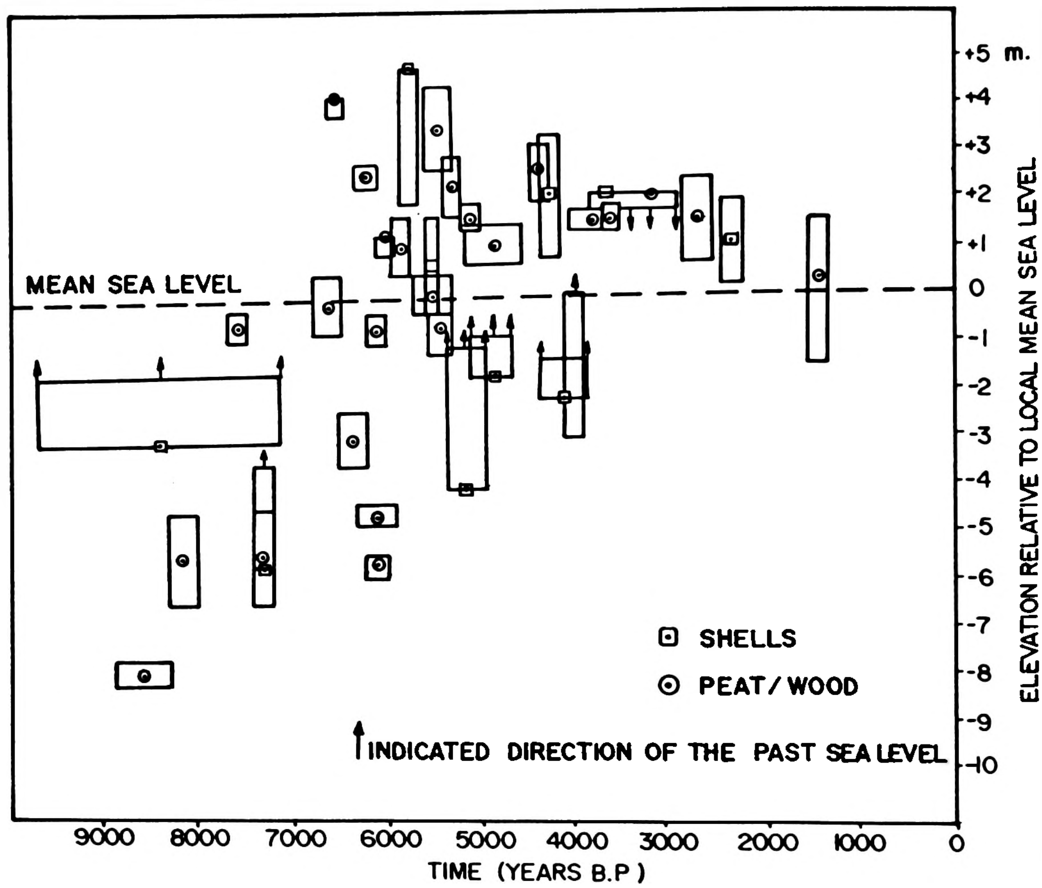

Figure 7. Holocene sea level curve (Pramojanee et al., 1984)

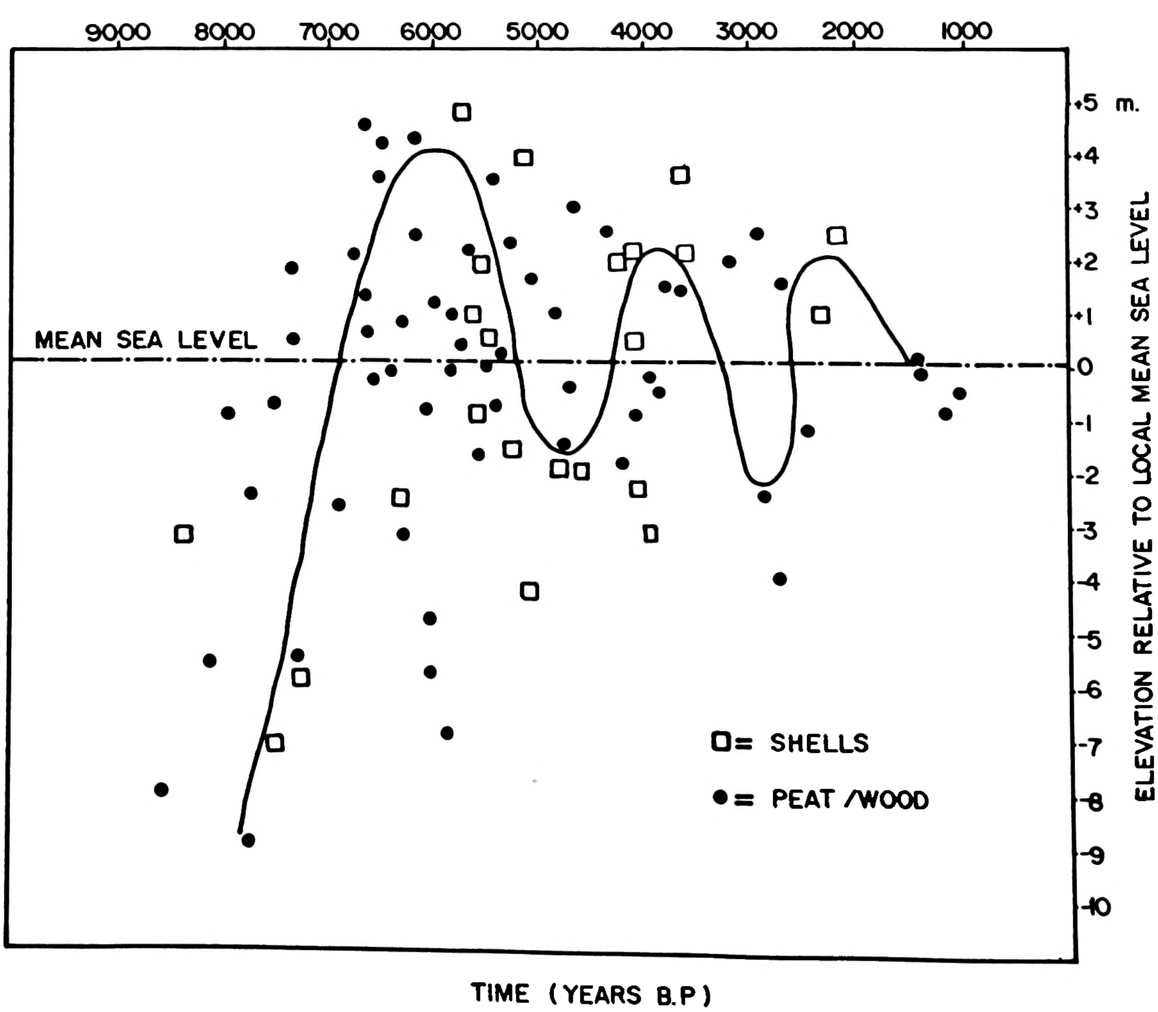

Figure 8. Holocene sea level curve (Sinsakul, 1990)

Peninsular Thailand produced early Holocene corresponding data as well (Pramojanee and Hastings, 1983, Somboon 1990, Pramojanee et al., 1984). The interpretation of depositional environments in the Lower Centra Plain indicates fluctuations of sea level, as well as a transgressional trend in the period from early to middle Holocene.

In his efforts to correlate the highest standing sea level, Somboon (1990) found that the present Lower Central Plain had been inundated when the highest Holocene sea level prevailed, i.e. about 5,600 years ago. Supajanya (pers. comm., 1991) mentioned that the highest sea level in Prachuab Kirikhan Province can be clearly recognized when interpreting remote sensing data. The highest old shoreline may be recognized at an elevation about 4.5 to 5m above MSL (based on the topographic map). This is in concordance with the evidence of the wave-cut notch at Khao Daeng, Songkhla Province, that was mentioned earlier (Pramojanee et al., 1984). In summary, it may be concluded that during the Holocene period the sea level along the east coast of Peninsular Thailand reached its maximum, i.e., about 4.5 to 5m above present MSL, about 6,500 to 5,500 years ago.

The highest standing sea level was followed by a regression, reflected in the change of depositional environment of marine sediments in the Lower Central Plain, from a shallow sea environment to a sublittoral and intertidal sedimentation respectively. So the sea level gradually dropped, although the diagram of depositional environments (Figure 4) showed a slight break in regression after 4,600 years BP. Observations from the southern region also indicatred regression as evidenced by peat and shell fragments from Chumporn to Nakorn Sithammarat Province. The ^{14}C dating of this biogenic material yielded ages of less than 5,000 years (Pramojanee et al., 1984 and Sinsakul, 1990), which corresponds to the age of the Great Songkhla Spit (about 4,860 ± 270 years BP) indicating a regression of the sea in this period (Chaimanee and Tiyaparach, 1983).

A new transgression is marked by a sea level standing at 2m above present MSL. In the Prachuab Kirikhan Province, Supajanya (pers. comm., 1991) recognized an old shoreline as well, at an elevation of about 2m above MSL. Radiocarbon dating was not included in his study, although some data are available on oyster ages from Khao Chong Krachol, Prachuab Kirikhan Province, based on samples collected from the marine standing level recognized at about 2m above MSL. These data indicate an age of about 4,180 ± 160 years BP. The dating of shells from the sea notch at 1m above MSL as observed in Prachuab Kirikhan Province, yielded an age of 3,290 ± 125 years BP (Thiramongkol, 1984). In the Lower Central Plain area, the plain +2m above MSL consists of marine sediments; the interpretation marine sediments (Figure 4) indicates that there was an regressionional interruption at about 4,600 years BP. This break might have been caused by a rise in sea level. Based on this evidence it may be concluded that after the sea level fall from the highest stand, there again occurred a transgression to a level of about 2m above MSL during the period between 4,000 and 5,000 years BP.

Pramojanee et al. (1984) believed that the period from about 4,000 to 3,000 years ago represented a phase of stagnation, but this idea had to be changed in view of the evidence from the more recent studies described. The study of peat swamps in Narathiwat Province (Vijarnson and Liengsakul, 1986 and unpublished data) as well as ^{14}C data from this area yield various peat ages ranging from 1,500 to 4,000 years BP. These data reflect a fluctuation of the sea level at a time comparable to that in the Lower Central Plain. Hence it may be interpreted that the sea level continued to fluctuate while falling to 2m below MSL about 3,000 years ago, and then rose again to 2.5m above MSL, as indicated by the ages of shell fragments from the Lower Central Plain (Somboon, 1990). Then from 3,500 to 2,500 years BP, the sea level along the east coast of Peninsular Thailand might have regressed to 2m above MSL and then again transgressed before finally falling to the present sea level. This regression may be derived from the minimum ages determined for the marine clay in the Lower Central Plain which is about 2,000 years BP. This would correspond to the ages of peat swamps in Narathiwat Province which are about 1,500 to 2,000 years old. Sinsakul (1990) subsequently concluded that the sea reached its present level about 1,500 years ago.

4. CONCLUSION

The fluctuations of the Holocene sea level are shown in Figure 8, the sea level curve for Thailand by Sinsakul (1990); this curve was developed from an earlier one (Figure 7) by Pramojanee et al. (1984), by using updated ^{14}C ages, plotted versus local mean sea levels (Sinsakul, pers. comm., 1991). After the Late Pleistocene, the sea level rose at the beginning of the Holocene. There were slight fluctuations, as shown by the interpretation of depositional environments, but overall the eustatic sea level rose. The highest standing sea level corresponds to the middle Holocene (6,500 to 5,500 years BP) at an elevation of about 4m to 5m above MSL. After this, the sea receded, but this regression was followed by a new transgression with shorelines at 2m above MSL. Marine sediments, corresponding to this level, in the Lower Central Plain and along the east coast of Peninsular Thailand, are 4,000 to 5,000 years old. For the period from 4,000 to 3,000 years BP, the ^{14}C data available from the Lower Central Plain as well as from the southern area, point to a fluctuation of the sea level. After the last transgression of the sea dated at about 3,500 to 2,500 years BP, the sea regressed and reached its present level about 1,500 years ago.

5. ACKNOWLEDGEMENTS

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Table 1. Some radiocarbon data of wood, peat and shell fragments, Thailand

Location	*Samples*	*Elevation (m.)*	*Depth (cm.)*	*C-14 age (yrs.BP)*	*Reference*
1. Lower Central Plain					
	wood	2	150	7,440±150	Somboon(1990)
	wood	5	330	6,760±140	
	wood	4	200	6,830±140	
	wood	3	240	6,680±140	
	wood	5	150	6,560±140	
	wood	2	200	6,490±135	
	wood	2	1100	7,800±40	
	shell	2.5	0	2,250±110	
	shell	2	300	5,600±35	
	shell	2	400	4,600±35	
	shell	2	900	7,500±35	
	peat	-	200	4,610±220	Engkagul (unpubl.)
	peat	-	410	7,770±350	
	peat	2	300-360	6,870±140	
	peat	-	200	5,240±1,700	
	shell	2	600-700	3,730±70	
	shell	-	350-400	8,470±170	
	shell	-	490	6,050±110	
	wood	-	80	5,560±740	
	peat	-	370	7,060±140	
	peat	-	470	7,290±110	
	peat	-	260-300	7,010±110	
	peat	5	250-320	7,210±180	
	peat	3	200-250	5,940±90	
	peat	-	370	7,060±140	
	peat	4	300-400	6,660±110	
	peat	17	550-600	7,180±160	
	peat	2	350	6,480±90	
	peat	3	420	5,850±160	
	peat	3	700	6,640±410	
	peat	10	250-270	7,580±130	
	peat	3	450-570	6,840±140	
2. Prachaub Kirikhan					
	shell	2	-	4,180±160	Sinsakul(1990)
	shell	1	-	3,290±125	Thiramongkol (1986)

Table 1. Some radiocarbon data of wood, peat and shell fragments, Thailand *(continued)*

Location	*Samples*	*Elevation (m.)*	*Depth (cm.)*	*C-14 age (yrs.BP)*	*Reference*
3. Nakorn Sri Thammarat - Song Khla					
	shell	-1.9--0.9		8,400±1300	Pramojanee
	shell	-4.5--1.9		7,340±80	et al. (1984)
	shell	+1.6--1.6		5,500±50	
	shell	-2.4--0.9		4,840±260	
	shell	+3.3-+0.7		4,250±80	
	shell	-3.0--1.4		4,100±260	
	shell	+2.0-+1.5		3,530±280	
	shell	+1.9-+0.1		2,350±70	
	peat	-8.1--7.8		8,600±300	
	peat	-5.5--5.7		6,100±100	
	peat	-4.4--4.8		6,100±190	
	peat	+0.8-+1.6		5,800±110	
	peat	+0.4--0.4		5,530±180	
	peat	-6.0--5.5		5,400±100	
	peat	-0.9--0.6		7,540±80	
	peat	-0.9-+0.9		6,600±150	
	peat	-3.4--1.2		6,380±140	
	peat	+2.3-+0.4		5,880±90	
	peat	+1.6-+0.6		5,400±90	
	peat	+3.1-+1.9		4,370±90	
4. Narathiwat					
	peat	-	400	5,940±100	Vijarnsorn
	peat	-	600	6,700±190	and
	peat	-	50	1,080±90	Liengsakul
	peat	-	200	3,950±120	(1986)
	peat	-	890	7,060±230	

CORRELATION OF HOLOCENE SEDIMENTS ALONG THE COASTAL PLAINS OF SUMATRA AND JAVA, INDONESIA AND COMPARISON WITH THAILAND AND MALAYSIA[1]

IGCP 296

by

Papay Suparan[2]

1. INTRODUCTION

Almost 30% of the land area of Indonesia is underlain by Quaternary deposits, of which those of Holocene age largely developed along the coastal area. Systematic investigations of Quaternary sediments was initiated in 1980 by the Geological Research and Development Center of Indonesia and focused on the mapping of coastal areas.

This paper is a first attempt at correlation of the Quaternary stratigraphy as found along the coast of Sumatra and Java; it represents a continuation of studies on Holocene deposits along the coast of Thailand and Peninsular Malaysia (Chaimanee at al., 1991). The study is expected to contribute to the understanding of marine transgressions during the Holocene period as well as to the understanding of sedimentation processes on the Sunda shelf. Figure 1 records the geographic positions of the various sections studied.

2. QUATERNARY STRATIGRAPHY AND CORRELATION

This correlation is based on the study of selected stratigraphic sections along the coast of Sumatra and Java islands and a comparison is made with results achieved in the correlation studies along the coastal plains of Thailand and Peninsular Malaysia (Chaimanee et al., 1991) Sermak Tiyapun and Phisit Dheeradilok, in Khon Kaen, 15-19 Oct. 1990. Lithostratigraphy and paleoenvironment of each section, including key marker horizons and their ^{14}C datings, were studied and analysed. The stratigraphic sequence was established on the basis of drilling, that intersected all sedimentary units deposited on the pre-Holocene substratum. Other remarkable marine, transitional and terrestrial facies were observed in the section and used as horizons for correlation of marine transgressive facies with those of coastal plains. The proposed stratigraphic correlation is as follows.

The Belawan section

The Belawan section is situated about 30km east of Medan. The sequence of strata encountered by drilling in Belawan (Figure 2: (B) D5) is subdivided into 6 sedimentary units. The pre-Holocene substratum consists of tuffaceous clay and greyish green, very firm and consolidated tuffaceous silt. Its upper boundary is characterized by an erosional surface which probably formed during the Pleistocene.

The lowest unit consists of paludal deposits of brown-black peat. The age of this unit has been determined at 9,690 ± 120 years BP. The second unit consists of clay with sparse shells and fish bones. It reflects a shallow marine environment. The third unit consists of nearshore deposits made up of clay, silt and alternating clay and silt layers, containing shells and plant remains. The fourth unit consists of peat, clay and fine sand, leaves and very thin horizontal and layers, which are interpreted as mangrove swamp deposits. The uppermost unit of the section consists of clay and silt; it is slightly mottled and contains some plant remains. It has been interpreted as a floodplain deposit.

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2 *Geological Division, Geological Research and Development Centre, Indonesia*

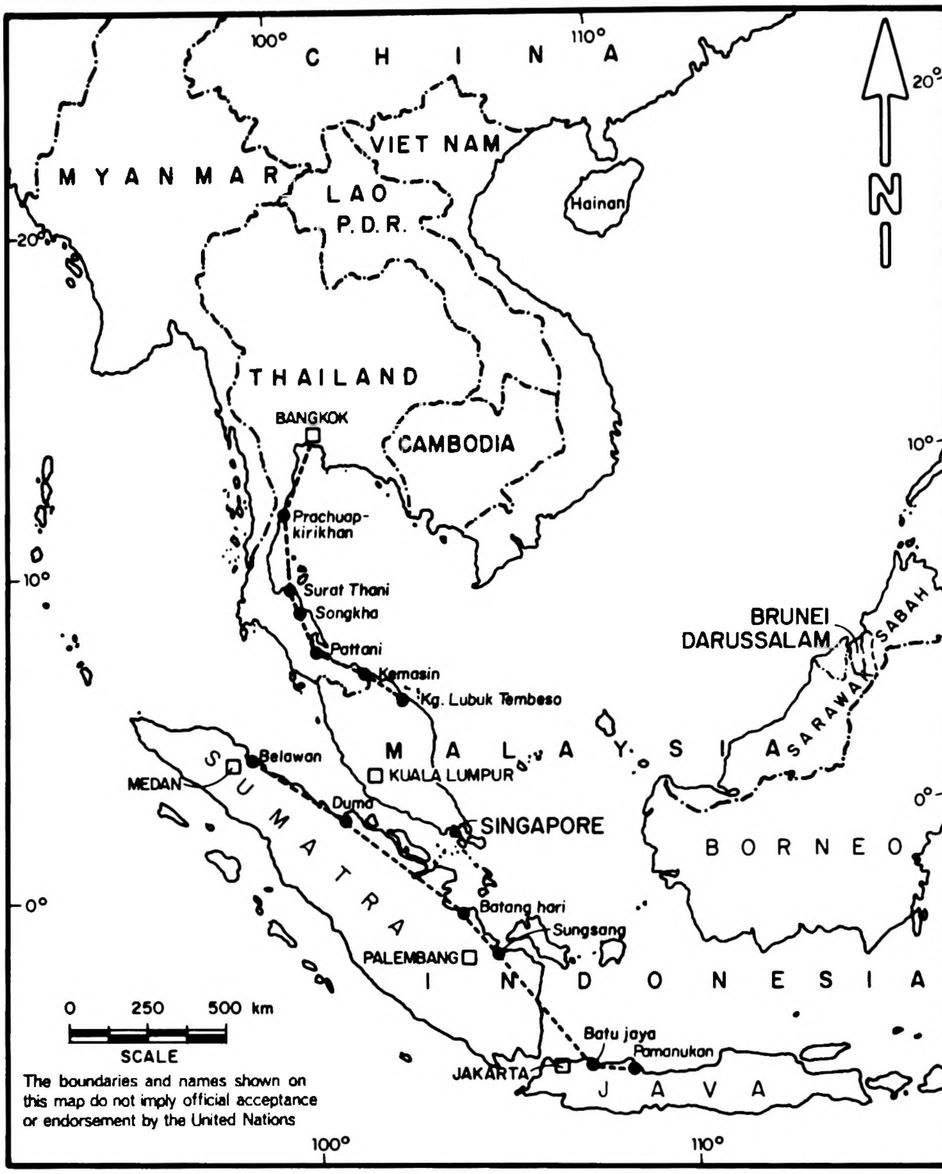

Figure 1. Location map of sections studied (Indonesia-Malaysia-Thailand)

In Figure 2 (B) A19, the section is divided into three sedimentary units overlying pre-Holocene deposits. The lowest unit consists of sandy clay, which is grey, very firm, slightly humic and contains some plant remains. This unit is dated at 6,920 ± 110 years BP and reflects a nearshore environment. The middle part of the section consists of sandy clay, peaty, humic clay with thin sandy layers. This unit is interpreted as a mangrove swamp deposit. The uppermost of these units consists of firm clay, with sand towards the bottom. It represents a flood plain deposit.

Section (B) A13 of Figure 2 is divided into four sedimentary units, the lowermost one consisting of very soft clay with some plant remains. This unit reflects shallow marine conditions. The second unit is a nearshore deposit characterized by grey, very soft clay containing 5 per cent sand, with small amounts of plant remains. The next unit consists of humic clay, with some peat layers and wood. This unit has been dated at 2,700 ± 180 years BP and reflects a mangrove swamp depositional environment. The uppermost of these units consists of mottled silty clay, with roots and other plant remains. This unit represents a floodplain deposit.

Section (B) B15 is divided into three sedimentary units. The lowermost of these consists of grey, soft, thinly layered clay, locally with small amounts of plant remains. It reflects shallow marine conditions. The middle unit is composed of sandy clay, which is partly humic and contains shell fragments. This unit reflects a nearshore depositional environment. The uppermost unit of this section was formed as part of a

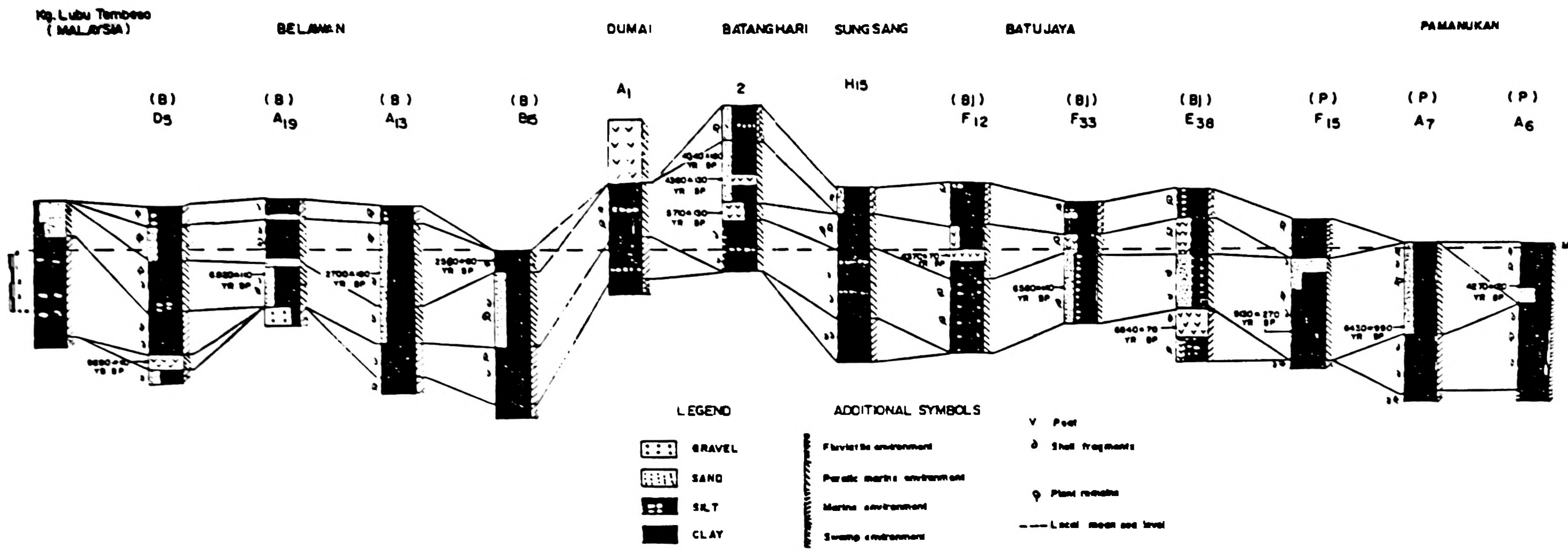

Figure 2. Stratigraphic correlation of Quaternary sediments along the coastal plains of Sumatra and Java

mangrove swamp deposit composed of humic clay, with thin peat layers, and small wood remains. The age of this unit has been determined as 2,590 ± 60 years BP.

The Dumai section

The Dumai section is located in the Province of Riau, about 400km southeast of Medan. It consists of three sedimentary units overlying the Minas Formation as the basement rock. The lowermost unit of this section consists of very soft clay, locally intercalated with thin layers of silt. This unit reflects shallow marine depositional conditions. The middle part of the section consists of humic clay, intercalated with silt. Some roots and leaves have been found near the bottom of this unit. It has been interpreted as a transitional environment of deposition. The uppermost of these units is a paludal deposit characterized by brown to black peat, with abundant leaves and other plant remains, among which are some pieces of wood.

The Batanghari section

The Batanghari section is located in the eastern part of Jambi, about 300km southeast of Dumai. It is divided into four sedimentary units. The lowermost of these consists of clay, silty clay, and alternating sand and silt, containing broken shells and is regarded as a tidal flat deposit. The second unit formed under mangrove swamp conditions and now consists of brown to blackish brown peat and peaty clay, with some wood relics and roots. The age of this unit has been determined at 5,710 ± 130 years BP (Sabiham, 1990). The third unit consists of clay, silty clay, sand and alternating layers of clay and silt, with some shell remains. It is considered to be a tidal flat deposit, dated at 4,360 ± 180 years BP (Sabiham, 1990). The uppermost unit of this section is a floodplain deposit composed of clay, sand and mottled silty clay and some plant remains, roots and wood relics.

The Sungsang section

The Sungsang section is located about 40km east of Palembang or about 500km southeast of Jambi. The representative sedimentary sequence in this area has been subdivided into four facies units covering the pre-Holocene substratum. The lowermost unit consists of sticky clay with some shell remains. It represents a shallow marine deposit. The second unit is composed of friable clay with intercalations of silt layers containing shell remains. It has been interpreted as a nearshore deposit. The third unit is characterized by silty clay with thin, humic, or slightly peaty layers, locally containing plant remains. It has been interpreted as a mangrove swamp deposit. The uppermost unit in this section represents a floodplain deposit consisting of sandy or silty, massive to soft clay.

The Batujaya section

The Batujaya section is situated about 20km east of Jakarta. Three sections have been selected in this area, viz. Batujaya (Bj) F12, F33 and E38. The (Bj) F12 section has been subdivided into three sedimentary units. The lowermost one consists of grey silt, with plant remains and very thinly laminated sandy intercalations towards the bottom. This unit reflects a shallow marine depositional environment. The middle part of this section consists of dark grey clay, with peat layers containing abundant wood remains. This unit has been interpreted as a mangrove swamp deposit, dated at 6,370 ± 70 years BP. The uppermost unit consists of slightly silty, firm clay, of a brown to light grey colour, with a varying degree of mottling, ranging from 5 per cent to 40 per cent. This unit represents a floodplain deposit.

The (Bj) F33 section is subdivided into three sedimentary units, the lowermost of which consists of clay, silt and interbedded sand. The silt is very clayey, slightly humic and has an olive-grey colour, while the greenish grey, rather loose sand contains some wood remains, dated at 6,580 ± years BP. This unit reflects a shallow marine depositional environment. The middle unit consists of soft, brownish black, slightly peaty and very humic clay, thought to be deposited under mangrove swamp conditions. The uppermost unit is a floodplain deposit characterized by slightly silty clay with predominantly orange mottling. Downward the clay becomes very sandy with a brown mottling and sparse black concretions.

At (Bj) E38, the section is subdivided into four sedimentary units. The lowermost one consists of reddish brown, very humic peat, with abundant wood and leave remains. The bottom part consists of slightly peaty and very humic silt. Age datings of peat and wood layer yielded 6,840 ± years BP. This unit reflects a shallow marine depositional environment. The second unit is composed of silt interbedded with sand of a dark grey to greenish grey color. Some shells and shell sherds as well as calcareous fragments are encountered as well. This unit is interpreted as a nearshore deposit. The third unit is a peaty sediment which consists of light grey silt with some plant remains of a humic, friable consistency. The abundance of wood and peat increases downward. This unit is interpreted as a marsh deposit. The uppermost unit in this section is a floodplain deposit characterized by a slightly silty and sandy, greyish brown firm clay, with an orange mottling and containing some roots and wood remains.

The Pamanukan section

The Pamanukan section is located about 40km east of the Batujaya section. Three sections have been selected from this area, viz. Pamanukan (P) F15, A7 and A6. The (P) F15 section is subdivided into three sedimentary units. The lowermost one of these, immediately overlying the pre-Holocene substratum, consists of slightly humic clay with small pieces of woods and organic matter towards the bottom, while the upper part consists of very sandy clay. This unit is interpreted as a nearshore deposit and has been dated at 9,120 ± 270 years BP. The second unit consists of clayey sand and is interpreted as a beachridge deposit. The uppermost unit consists of clay with some degree of mottling, and a firm consistency, and containing some manganese and iron concretions.

The (P) A7 section is subdivided into two sedimentary units which overly the pre-Holocene substratum. The lowermost unit consists of greenish grey clay, with pockets of sand towards the bottom. This unit reflects a shallow marine depositional environment. The second unit consists of slightly sandy clay, becoming less humic with depth, containing some shells and shell fragments. It is interpreted as a nearshore deposit and has been dated at 6,430 ± 990 years BP.

The (P) A6 section is subdivided into two sedimentary units. The first unit consists of very soft silty clay with some leaves and shell fragments. This unit reflects a shallow marine depositional environment. The topmost unit consists of humic clay with wood relics and plant remains; sandy layers are encountered as well. This unit has been dated at 4,270 ± 110 years BP and reflects mangrove-swampy conditions.

3. CONCLUSIONS

- Based on the study of depositional environments, all sections referred to can be correlated on the basis of both sedimentology and lithology.
- Pleistocene fluvial deposits or the pre-Holocene substratum are characterized in the profile by their stiffness, massiveness and content of mainly tuffaceous material.
- The ^{14}C age determinations carried out in the Belawan, Batanghari, Batujaya and Pamanukan areas reflect the evolution of the coastal plains, wherever the sea invaded the land.
- The presence of mangrove swamp deposits and peat layers indicates the fluctuation of the water level.
- The marine influence decreases upwards. This is probably caused by a high sedimentary influx from the upland areas as well as by the coastal rise during the late Quaternary (Tjia and Fujii, 1989).
- The correlation along the coastal plain of Thailand, Malaysia and Indonesia (Sumatra and Java) show that Holocene deposits were formed under rapid marine transgression and the sea retreated back during the very late Quaternary Period.

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NEW OBSERVATIONS ON THE LOESSIC SEDIMENTS OF TROPICAL ZONES IN THAILAND[1]

IUGS UNESCO IGCP

IGCP 296

by

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1. INTRODUCTION

Loessic sediments in tropical zones of Southeast Asia have been a subject of investigation, in particular during the last years. They have been studied in Viet Nam and Thailand, and have also been mentioned, without exact description, from Malaysia. The loessic deposits represent a part of eolian sedimentation in this climatic zone which is characterized also by eolian sands, described from Viet Nam from different stratigraphic positions. A brief review on eolian sediments in Thailand, Viet Nam and Malaysia and references to existing literature were given by Šibrava (1991); the loessic sediments in Viet Nam have been described in detail by Hoang (1989) and others. A comparison of loessic deposits of tropical zones in Southeast Asia with classical loesses in China, based mainly on their granulometric properties, was published earlier by Šibrava (1991). Granulometric analyses of samples taken in northeastern Thailand and Central Europe (central Moravia in the Czech Republic) revealed substantial differences in the composition and depositional environment of eolian sediments from these two climatic zones. It has been shown that Chinese loess displays a higher affinity to classical European loess and strongly differs from decalcified loessic sediments found in tropical zones of Southeast Asia.

In 1991 and 1992, the study of loessic sediments in Thailand continued jointly with the laboratories of the Institute of Geology, Geochemistry and Geophysics in Minsk (Belarus). New samples were taken in the surroundings of Prague (Czech Republic) to compare the loessic deposits in Thailand with typical loess laid down under the dry periglacial conditions of Central Europe.

Samples from both Thailand and the Czech Republic have been examined from petrographical, minera-logical, chemical and micromorphological points of view. The following laboratory equipment was used: scanning microscope Geols "GSM"-35 C, microprobe REM 100 U; the natural radioactivity was determined by USD-T instruments with crystal NaI (Tl) and technogenic radionucleides were examined by the analyzer AI-1024 and instrument BDBS-30M.

The results of new investigations are presented in the present text. Nevertheless, it has to be stated that these results must still be considered preliminary and that the final conclusion will require further studies based on substantially higher amounts of samples from different regions. Also some particular problems (origin of carbonates in Thai loessic sediments, geochemical processes like decarbonatization and others) must be further studied in detail.

1 *Paper presented at the IGCP 296 regional workshop held in Ho Chi Minh City from 13-15 December 1992*

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2. CHARACTERISTICS OF LOESSIC DEPOSITS IN SOUTHEAST ASIA AND THEIR COMPARISON WITH LOESSES OF MODERATE ZONES

Petrographical analysis

The samples of loessic deposits from the tropical zone in Thailand were taken in the northeastern part of the country, on the Khon Kaen Plateau near the Muadahorn Province. Thin sections revealed the irregular structure of the sediment. It predominantly consists of quartz grains of different sizes, mostly in the sandy fraction. Clayey and aleuritic cement and coating of grains represent about 20 per cent of total volume. Loessic deposits in Thailand are also characterized by their porosity with pores of different size and configuration. In the light fraction beside quartz, also feldspar and biotite may be observed. There is also an admixture of brown aggregates, probably composed of disintegrated biotite grains with small grains of quartz.

The grains of quartz, as observed in the scanning microscope, are mostly subangular in shape and show numerous shallow depressions (pock-marks) on their surface. These may be explained by intensive weathering under the influence of the temperature and precipitation of a tropical environment.

Heavy minerals represent only a small percentage of the rock composition. They are mostly represented by zircon, and by smaller amounts of rutile, leucoxene, and ilmenite. Other minerals like amphibole, tourmaline, disthene or staurolite are accessories. The grains of zircon and rutile also show isometric pock-marks on their surface, but generally less pronounced than those found on quartz. The effects of weathering have also been observed on the surface of loesses in the Czech Republic; nevertheless, they differ in their character and shape.

Clay minerals in Thai loessic sediments are represented mainly by kaolinite. Chemical analyses, both of loessic deposits in Thailand and of loess in the Czech Republic are given in Table 1.

Table 1. Chemical composition of loess and loessic sediments in Thailand and the Czech Republic (in mol %)

Elements	Thailand	Czech Republic
K	0.67	2.59
Ca	0.09	4.23
Fe	2.00	5.65
Si	75.91	66.63
P	0.01	0.14
Mg	0.76	2.36
Na	0.19	1.07
Al	19.71	11.84
Ti	0.53	1.14
S	0.00	0.01
Cl	0.00	0.00
Mn	0.00	0.07

Analysis: A. Komarovskij

Chemical analysis made it possible to establish small Ca contents in loessic sediments of Thailand; accessory calcite has also been found in a thin section of the sample taken in Northeast Thailand. This raises the questions of whether or not loessic deposits in Thailand were calcified at the time of their deposition and whether or not the processes of decalcification induced by climatic conditions did start after their deposition.

The content of trace elements in ppm or g/t is shown in Table 2.

Table 2. Trace element content in loess and loessic sediments in Thailand and the Czech Republic (in g/t = ppm)

Trace Elements	Thailand	Czech Republic
Ni	13	28
Co	7	14
Cr	11	50
V	40	90
Mn	60	400
Ti	950	4000
Zr	450	380
Cu	10	20
Pb	-	10

Analysis: I. Tereva

A higher concentration of zircon (550 g/t) corresponds to the mineralogical composition of the heavy fraction.

When compared to loessic sediments in Thailand, loesses from the surroundings of Prague (locality: Sedlec) in the Czech Republic are enriched in K, Ca, Fe as well as in the trace elements like Ti, Mn, V, Cr, Co, Ni and Cu. This may be explained by the fine-grained nature of the sediment as well as by the presence of Fe-aggregates, both of which are usually responsible for the concentration of trace elements. The substantially higher α- and β-radioactivity of loess deposits near Prague may be similarly explained (Table 3).

Table 3. Radioactivity of loess and loessic sediments in Thailand and the Czech Republic

Region	α-activity Ci/kg	β-activity imp./sec
Thailand	$3,50.10^{-9}$	0,13
Czech Republic	$1,32.10^{-8}$	0,70

Analysis: E. Loseva

This may be also indirectly confirmed by the examination on technogenic nucleides, where the results achieved, lead to conclusions on the presence of natural radioactivity and the absence of technogenic nucleides.

In comparison with loessic deposits in Thailand, those in the Czech Republic represent eolian sediments, laid down under dry, semiarid and arid climatic conditions. As such, they may be compared with the loesses in China deposited under similar conditions.

The analyses of samples from the Sedlec locality near Prague show that these loess covers represent carbonate deposits enriched in sandy and aleuritic material. Like those in Thailand, they show an irregular structure, but in contrast to the Thai loessic deposits, they contain an admixture of organic material. Quartz strongly prevails in their petrographic composition (about 80 per cent) and is mostly accompanied by feldspar (about 15 per cent), biotite and muscovite (about 5 per cent). Röntgenometric analysis established the presence of cristobalite and albite as well. In contrast with loessic deposits in Thailand, thin sections from Sedlec show a higher rounding of quartz grains – these are subrounded to rounded in shape. The grains are cemented by clayey-ferrous material with illite as principal clay mineral. Carbonates are represented by calcite in the form of grains of different shapes, sometimes angular and subangular, sometimes of the elongated "bacterial" type.

The grains of quartz are relatively well rounded, and have very small depressions (pock-marks) on their surface, but these are less pronounced if compared to those in Thailand. They may be explained rather by weathering than by eolian activity. The heavy fraction of the loesses sampled near Prague mostly consists of brown, white mottled or reddish colored aggregates. In the chemical composition Si and Fe prevails, with an admixture of K, Ca Ti, Mg, and very minor Mn content.

3. BASIC DIFFERENCES BETWEEN LOESSIC DEPOSITS OF TROPICAL ZONES IN THAILAND AND THOSE OF TEMPERATE ZONES, BASED ON COMPARATIVE PETROGRAPHICAL AND GEOCHEMICAL STUDIES

The loessic deposits in tropical and subtropical zones of Southeast Asia show a substantial difference from those in classical loess regions of temperate zones. As pointed out earlier (Šibrava 1991), they strongly differ from typical loesses as known from China and Europe in their granulometric and lithological compositions as well as in the sedimentation processes leading to their formation. New observations further confirmed these conclusions. The differences found both in petrographical and chemical composition may be explained by the different character of rocks in the source area of the loess sedimentation, by the different environmental conditions of loess deposition, character of loess transportation, geochemical processes of weathering and formation of secondary minerals, depending on climatic zones. Some of these elements are locally conditioned and may vary from place to place in both zones. Nevertheless the character of loessic deposits in Thailand indicates clearly a shorter transport of material than that in classical loess areas, caused probably by limited deflation areas and limited eolian activity in heavily vegetated areas. The loessic deposits in tropical areas of Southeast Asia have undergone complicated weathering processes under a tropical humid environment after their deposition, that probably led to their decalcification and that also attacked the minerals in the sediments with a much higher intensity than that of moderate zones.

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MEKONG TERRACE GRAVEL IN NAKHON PHANOM[1]

by

Sompob Wongsomsak[2]

IGCP 296

Abstract

Field evidence reveals three classical terraces: a high, a middle and a low terrace associated with the Mekong River. The high terrace-gravel is characterized by strongly weathered quartz granules and pebbles. The middle terrace-gravel is dominated by quartz, chert and extraneous black porphyritic volcanic rock-granules and pebbles in a white matrix. Finally, reworked quartz and rock-granules or -pebbles typify the low terrace-gravel that often shows cross-bedding. Lower, Middle and Upper Pleistocene are hypothetically assigned as the respective ages of the high, middle and low terraces.

1. INTRODUCTION

Nakhon Phanom, a province in the northeastern part of Thailand, is geologically situated in the "Sakhon Nakhon basin" of the Khorat Plateau. The field area closes to the northern rim of Phu Phan Range, between latitude 16°45'N to 17°15'N and longtitude 104°30'E to 104°49'E (Figure 1). Phu Phan, Khok Kurat and Maha Sarakham formation of Khorat Group have been mapped (Figure 2) in the area. Briefly, these are:

The Phu Phan formation, comprising mainly white sandstone and conglomeratic sandstone, of which quartz, chert, red siltstone and igneous rock pebbles are clast-composition, with shale interbedded. Cross-bedding is common in this formation, which is Lower to Middle Cretaceous of age. The Khok Kruat formation, Upper Cretaceous in age, is composed of gray, grayish-white and brown sandstone, siltstone, shale and lime-noduled conglomerate. The Maha Sarakham formation, Cretaceous to Tertiary in age, comprises red and brick-red mudstone, shale, siltstone, and fine-grained sandstone with rock salt in the lower part.

The study focused on the Mekong valley terrace-gravels; Mekong basin development, the geomorphogenetic classification of Quaternary deposits, the distribution of Mekong terrace-gravels and their age are all described below.

2. BASIN DEVELOPMENT

It is believed that collison of the Shan Thai and Indochina microplates in the Late Permian caused northwest-southeast trending strike-slip faults, such as the Me Ping Fault (Figure 3). These faults present under the Khorat Plateau gave rise to deposits of Triassic pre-Khorat sequences, targets for oil and gas prospecting, in a series of east-west or northwest-southeast trending basins. After that the subsidence along old deep-seated faults gave rise to the formation of a huge non-marine basin. The rapid subsidence that prevailed from the end of the Late Triassic through the Middle Jurassic was followed by a slower rate that lasted until the Middle Cretaceous. Periodic marine trangressions from the northwest are also noted in the Jurassic. After deposition of Middle Cretaceous redbeds, the Phu Phan anticlinorium and the edges of the Khorat Plateau were domed up and in doing so, created an evaporite pan. This was supposed to result from the collision of Western Myanmar and Southeast Asia from Late Cretaceous to Early Tertiary. From then

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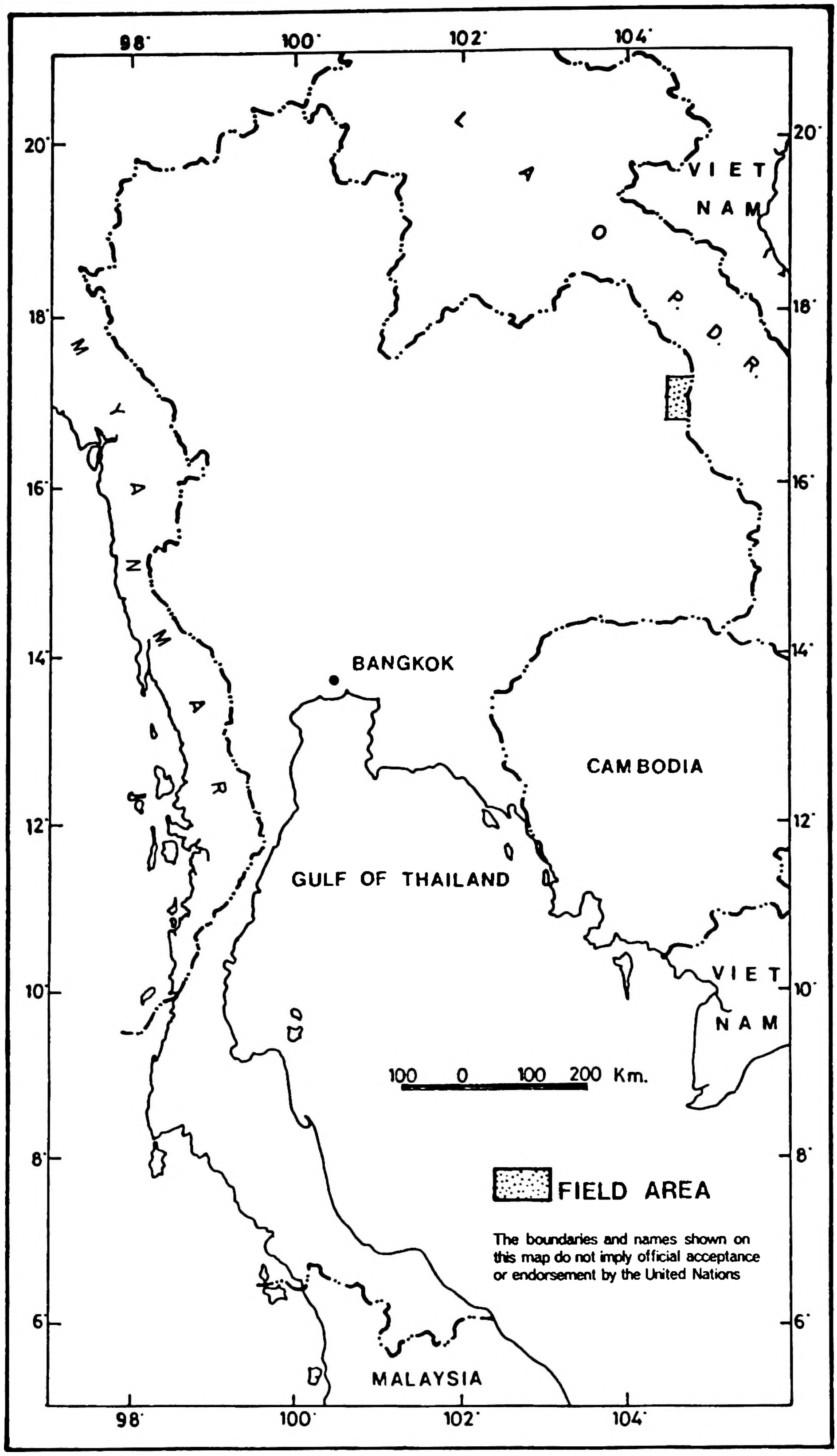

Figure 1. Index map of field area in the northeast of Thailand

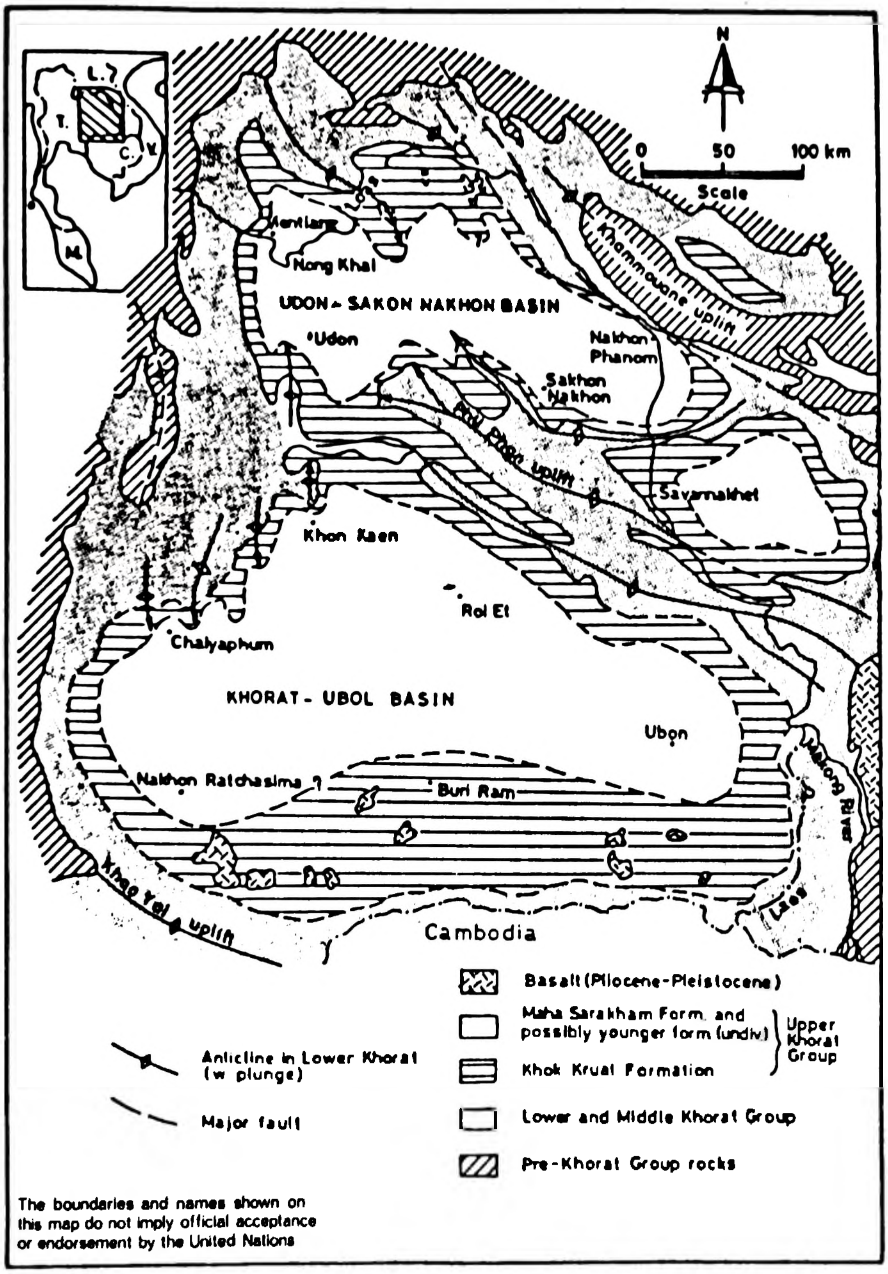

Figure 2. Generalized geological map of northeastern Thailand (modified after Wongsomsak, 1986)

on, the northward movement of the Indian craton and its progressive collision with South Asia caused the formation of Tertiary basins.

3. GEOMORPHOGENETIC CLASSIFICATION OF QUATERNARY DEPOSITS

Quaternary deposits in the area are rather thin, excepting the narrow belt of the Mekong flood plain. There are seven geomorphogenetic types of Quaternary deposits that are described below.

(i) High terrace deposits (Qth)

These represent the highest terrace of the Mekong River, dominated by strongly weathered quartz and rock-granules to coarse cobbles in a clayey sand matrix. Ferrugenous cement is common, particularly in the upper part, due to lateritization. The purplish red siltstone of Maha Sarakham formation occurs at the base and laterite at the top of the terrace gravel.

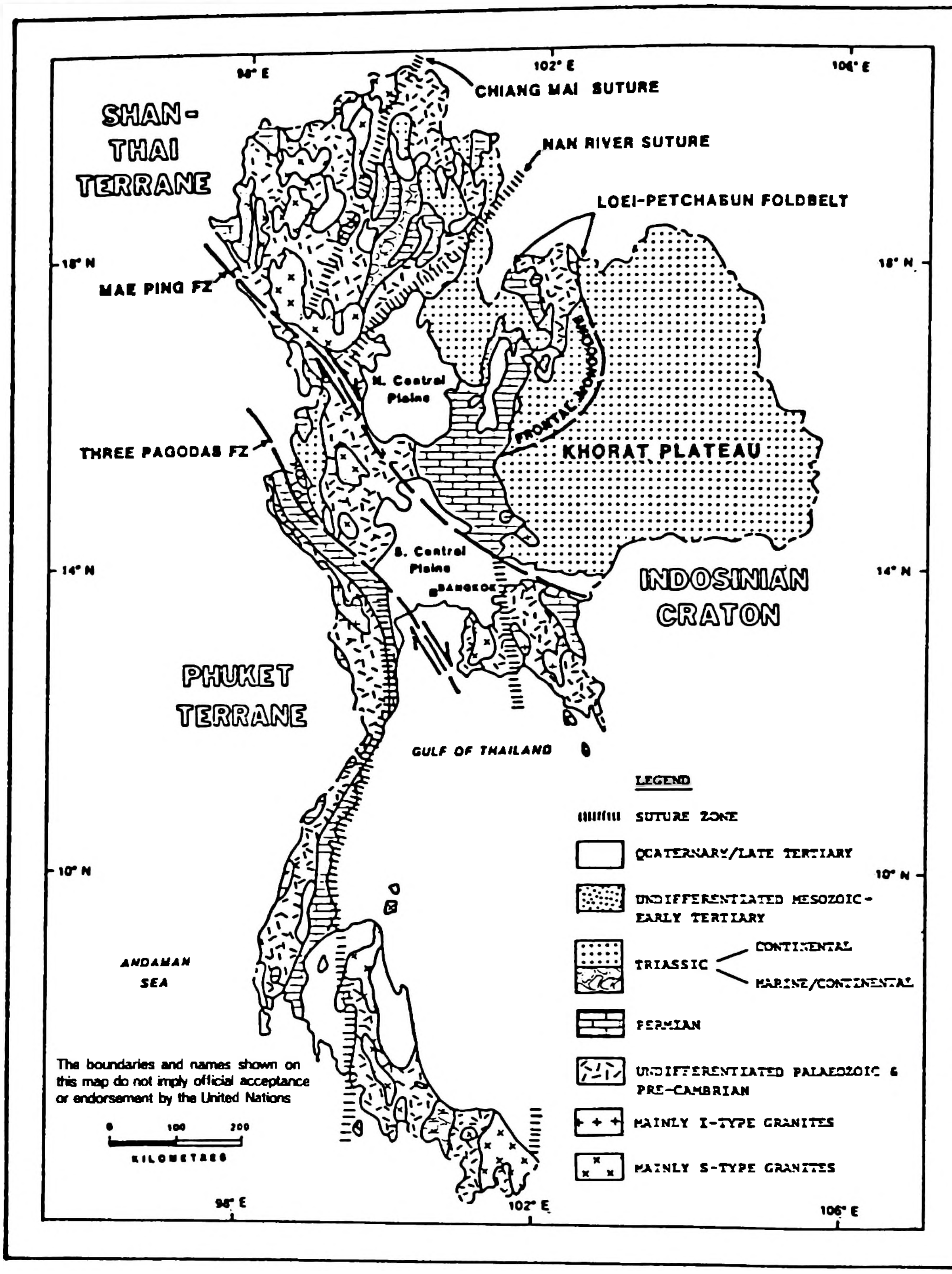

Figure 3. Simplified geological map of Thailand (modified after Cooper et al., 1989)

(ii) Middle terrace deposits (Qtm)

The middle terrace consists of poor sorted sediments containing subrounded quartz, chert and black porphyritic volcanic rock-granules and fine cobbles in a white, friable sandy to silty clay matrix. Laterite occurs locally on the top of the gravels, though plinthite is more common. Unfortunately, the base of the gravel sequence could not be observed.

(iii) Low terrace deposits (Qtl)

The low terrace level is just a few metres above the present flood plain. Its lithological composition is characterized by reworked quartz and gravels, with poorly sorted, subrounded, non-reworked quartz, chert and black porphyritic volcanic rock granules and fine cobbles in a pale brown to light yellow sandy clay or silty clay matrix. Locally, interbedded silty clay lenses are present. Cross-bedding is abundant. The gravel sequence is more than 7 metres thick.

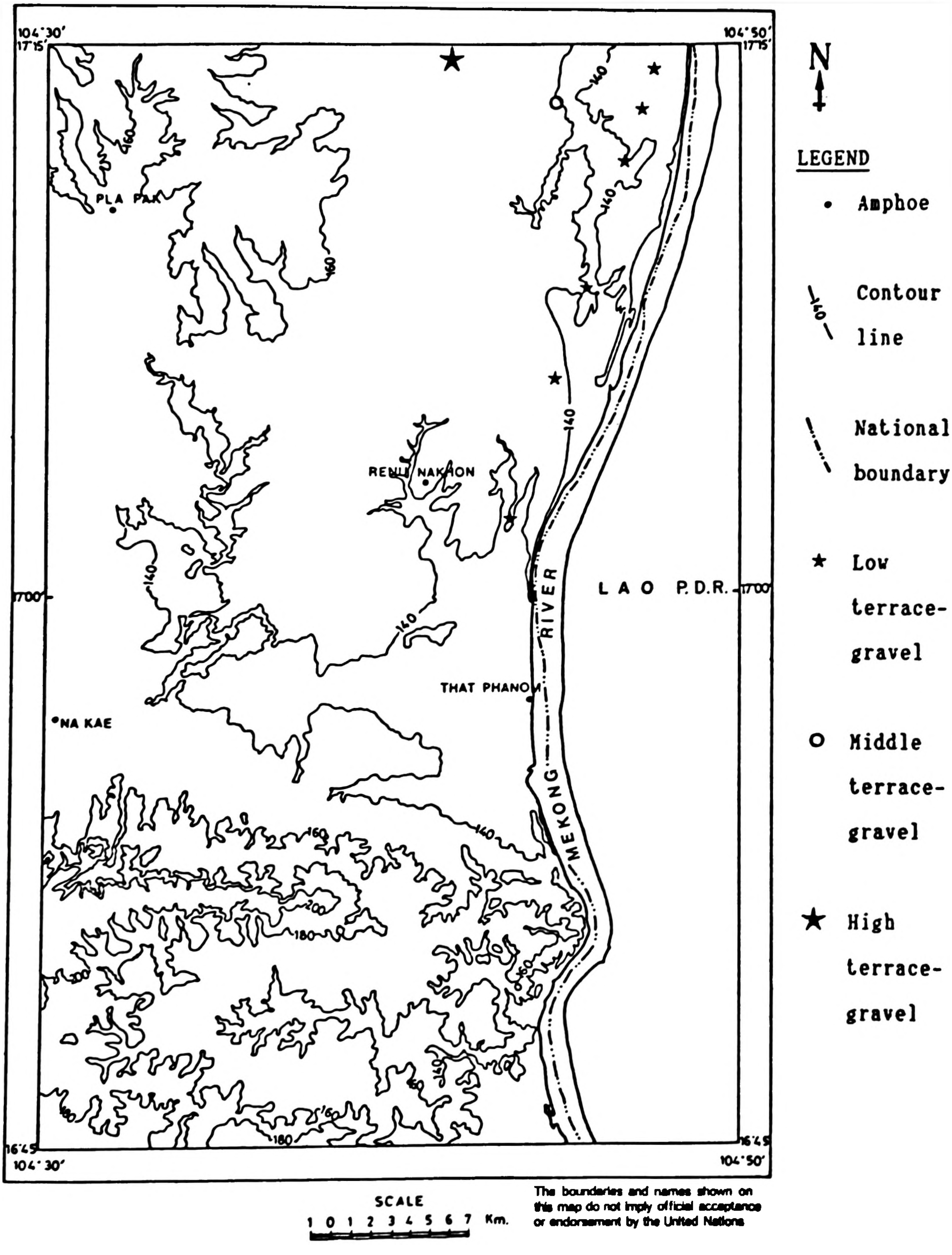

Figure 4. Locations of exposures of Mekong terrace gravel in the study area

(iv) Flood plain deposits (Qff)

This narrow belt is restricted to the Mekong flood plain that, geomorphologically, comprises a natural levee, a backswamp, ox-bow lakes, etc. Sediments therefore display a wide range of grain-sizes, going from clay, through silt and sand to gravel, coarsening downward, interrupted locally by peat or peaty sand or silty clay.

(v) Residual deposits (Qr)

These overlie the in-situ weathered bedrocks of Phu Phan, Khok Kruat and Maha Sarakham formations. Their granulometric composition varies widely from silt to sand to gravel, with the typical colours of fluviatile sediments. In addition, laterite and lateritic soils frequently overlie these sediments.

(vi) Slope wash deposits (Qsc)

These cover more than 60% of the surface area and consist of loose, angular to subangular silty sand and gravel, the sand being of a white to pale orange colour. Thicknesses vary from place to place, depending on paleo-topography and the influx of sediments.

(vii) Valley plain deposits (Qfv)

These are confined to narrow strips along the Mekong's tributaries. Normally, there are two different facies in which friable, brownish gray to brown sandy and silty clay prevail. The remainder consists of brittle, angular, poorly sorted, medium to coarse-grained, reddish brown to red sand. The thickness of this sequence is about 3 metres.

4. DISTRIBUTION OF MEKONG TERRACES

Figure 4 shows the exposures of Mekong valley terrace-gravel as found in the area. Those of high terrace-gravel are found about 12km from the present course of the Mekong river at Ban Don Daeng and Ban Phon Pa Wan, at more than 150m above mean sea level (MSL), i.e., 25m above the Mekong. This is only outcrop in the area, showing a terrace width of about 400m. The middle terrace-gravel also has only one outcrop, at Ban Khom Toei. This exposure occurs in an abandoned gravel pit, at an elevation of 142m to 145m above MSL, 7km from the present Mekong river, though only 17m above it. The low terrace-gravel is the only one that can be traced throughout the area. It follows a north-northeast to south-southwest direction and is found about 2 to 3km away from the present Mekong river. All outcrops at Ban Changom in the north and at Ban Phon Tha, Ban Kok Hai, Ban Na Thon Thung, Ban Khok Sawang and Ban Nong Yang Chin in the south are abandoned gravel pits.

The field evidence thus suggests that the extent of high and middle terrace-gravel is rather limited in the area. They are expected to occur further northward, however.

5. AGE ESTIMATES

Field data do not allow the determination of absolute ages of these terraces, although a relative age may be assigned to each of these terraces, using the degree of weathering as a main criterion, based on comments to that effect by former CCOP geologist Dr. J. Liebens (pers. comm.). Hence, the ages of the high, middle and low terraces have been set at Pleistocene, Middle Pleistocene and Upper Pleistocene respectively.

6. CONCLUSION

The study of Mekong terraces presented here has yielded basic field criteria for the distinction of terrace-gravels. Strongly weathered quartz pebbles and gravel in the high terrace, a white matrix in the middle terrace, and reworked quartz and rock gravels interbedded with 'non-river' gravel in their low terrace provide data for basic stratigraphic assignment. According to the degree of weathering, Lower Pleistocene, Middle Pleistocene and Upper Pleistocene ages are assigned to the high, middle and low terrace respectively.

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QUATERNARY LITHOSTRATIGRAPHY OF THE KOREAN PENINSULA[1]

IUGS UNESCO IGCP

IGCP 296

by

Lee Dong Young[2]

1. INTRODUCTION

The Korean peninsula is typically a mountainous region with steep slopes and rugged terrain. The peninsula is about 200km to 300km wide and 800km long, stretching southward from Manchuria. The western part of the mainland is characterized by the subdued relief of a small area of gently rolling hills and a large, shallow alluvial plain. These undulating hills are interconnected through inconspicuously elevated ridges, continuing inland and rising gently to the level of the mountains. A few big rivers with low stream gradients flow westward into the Yellow Sea. The Yellow Sea is a submerged margin of the Asian continent. It is a flat shallow basin with an average water depth of 44m reaching 103m in places. The coast is very irregular and features many islands, embayments and tidal flats.

The eastern coast, on the contrary, is more mountainous with many steep slopes. Valleys are deeply incised and short in length. The Taebacksan Mountain Range forms the backbone of the peninsula, its crests 20km to 30km from the east coast, running parallel to the coastline. This backbone slopes gently to the west but steeply to the east. Because of its narrow width in the east, a few mainly straight, short rivers flow into the East Sea. This coast is characterized by curvilinear, but steeply sloping headlands. A series of narrow coastal plains, fringed with sand and gravel beaches, occur only at and near the river mouths. The steeply incised narrow valleys near the coast are filled with alluvial gravel deposits, a result of the post-glacial sea level rise that drowned these valleys.

According to these physiographic characteristics of the Korean peninsula, the types of Quaternary sediments exposed on the mainland are grouped as follows:

for the Pleistocene:

* marine terraces and terrace deposits
* fluviatile terraces and terrace deposits
* soil deposits

for the Holocene:

* alluvium in the valley plain
* coastal deposits (peat and muds)

2. MARINE TERRACES AT THE COAST FROM POHANG TO ULSAN

Along the southeast coast of the Korean peninsula, step-like emergent terraces are developed on the gently inclined mountain slopes. They are stepped at different altitudes and disconnected from each other by poorly to well defined successive escarpments. These consecutive terraces are easily identified at five different altitudes along the coast from Pohang to Ulsan and further northwards up to Wolpo. The lst and the 2nd Terraces are characterized by horizontal flats with a mantle of terrace deposits. Higher ones such as the 4th and the 5th terraces are difficult to identify in many places because their escarpments have already been eroded, resulting in continuous, gently inclined slopes. The terrace deposits on these high surfaces are also seldom found. These terraces are grouped into two different types according to their origin. One type is represented by a wave-cut abraded terrace and the other by a wave-built constructional

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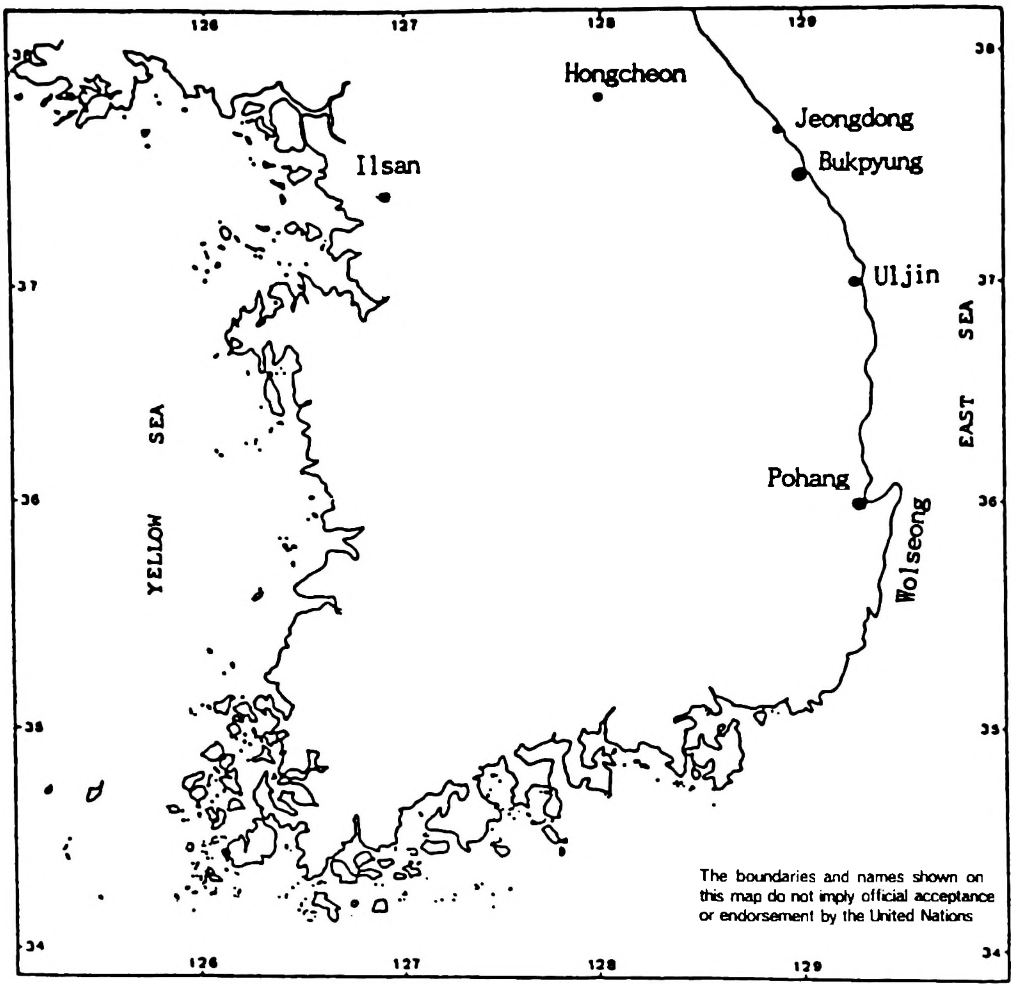


Figure 1. Locations of main Quaternary outcrops on the Korean peninsula

terrace. This genetic difference results from the type of local geology and the supply of clastic material to the coast by the fluviatile system. The abrasional terraces occur mainly north of Gampo and the constructional terraces are found from Gampo to Jeongja.

Kim, S.W. (1973) distinguished six terraces along the seaward mountain slope at every 20m interval of altitude from Pohang to Ulsan. Oh, G.H. (1977) and Jo, H.R. (1978) classified three more terraces. They attempted to correlate the ages of these terraces with classical Quaternary glacial cycles and to evaluate the tectonic stability of this area, mainly based on chronostratigraphy. There was however much discord between those studies, concerning elevation, nomenclature and chronostratigraphy of each terrace. Lee, D.Y. (1985) and Kim, J.Y. (1990) introduced another scheme of terrace morphostratigraphy in this area, extending their ages from Pliocene to Holocene (Table 1).

The 1st Terrace is well exposed at Yangnam, Napa, and Songha. All these areas show an elevated coastal strip at levels of +3m to +5m. The present beach in these areas consists of fine gravel and coarse sands, and extend up to the foreshore. It is unclear to limit the 1st Terrace in many places from the present foreshore deposits. However, the 1st Terrace is an almost horizontal flat, veneered by a mantle of coarse sand and gravel, which present waves or even storms cannot reach. Vertical exposures of these terrace deposits are rather scarce in these areas, because of the low level of the terrace. At Yangnam, the 3m thick terrace deposits are exposed along the stream. These deposits are made up of well-rounded gravel, coarsening upward. Concerning the age of this terrace, Kim S.W. (1973) mentioned the date of peat collected from the alluvial deposits at the level of +2.2m; this was 1,730 ± 100 years BP. But it is uncertain whether or not these alluvial deposits can correlated to the terrace deposits. Interpretations by Lee D.Y. (1985) on the basis of glacial isostasy and relative lithostratigraphy, suggest that the lst Terrace was formed around 5,000 years ago, when the sea level was slightly higher than at present.

Table 1. Previous studies on the marine terraces developed at the east coast of the Korean peninsula

CHRONOSTRATIGRAPHY	Pohang-Ulsan (Kim, 1973)	Gampo-Ulsan (Oh, 1977)	Pohang (Jo, 1978)	East coast (Lee, 1985)
Holocene	Jujeonri Tr. (3-7m)	Holocene Tr. (1-3m)		Songha Tr. (3-5m)
Last Glacial	Jeongjari Tr. (10-20m) Bang-eojin Tr. (30-40m) Hwajeongri Tr. (50-60m)	Sanhari Tr. (10-20m) Seakcheonri Tr. (30-50m)	Terrace III (10-20m) Terrace II (30-35m)	
Last Interglacial	Yeompori Tr. (70-80m) Bongwajae Tr. (90-100m)	Gampo Tr. (60-80m)	Terrace I (45-50m)	Na-a Tr. (10-15m)
Mid. Pleistocene				Wolseong Tr. (35-42m)
Low. Pleistocene				Eupcheon Tr. (50-60m)
Pliocene				Bonghwajae Tr. (75-90m)

The 2nd Terrace shows the most outstanding flat surface among the five successive terraces. Its extension is well marked by an abrupt break-in-slope at the front edge and by an escarpment sloping up to the 3rd Terrace along the backedge. The width of this terrace does not exceed 500m, but it is much more extensive parallel to the coast at levels of +10 to +15m. The 2nd Terrace deposits are found at Jeongja, Yangnam, Na-a and Mopo. All these areas are located along the coast south of Gampo. The most complete profiles were exposed at Mopo and Yangnam during artificial excavation. In these exposures, the coarse gravel layer constitutes the base of the terrace deposits, just overlying the abraded bedrock platform at a level of about +5m. Most of this gravel is well rounded but very poorly sorted, ranging from coarse sand to boulder size. This basal gravel layer is in turn overlain by well stratified coarse sands and fine pebble layers. Each layer dips seaward at an average of 9° to 10°, its dip increasing slightly upwards. All these gravel and sand deposits were jointly named the Na-a Formation. The slope deposits overlying the terrace deposits are not included in the Na-a Formation because they differ from the Na-a Formation in age and origin as well. Concerning the age of the Na-a Terrace, Kim, S.W. (1973) reported a ^{14}C age of 12,060 ± 600 years BP, based on charcoal fragments sampled from alluvial deposits at an elevation of +13m. Combining this altitude and the ^{14}C age, he inferred an age of the terrace at the level of 10 to 20m corresponding to Alleröd. On the contrary, the ^{14}C age of the clay layer overlying the terrace deposits turned out to be more than 52,000 years BP (Lee, D.Y., 1985). Also, the sea level during the formation of the Na-a Terrace must have stood much higher than at present. In this connection, the Na-a Terrace may be considered coeval with the Last Interglacial, most probably 125,000 years ago (Figures 2 and 3).

In the field, recognition of the 3rd Terrace is more difficult in comparison with lower terraces. The stepped front edge has been abraded downwards to a certain degree and the back edge is veneered by slope deposits, resulting in a gently inclined slope. The present configuration of the 3rd Terrace therefore shows a more inclined surface than the assumed original attitude, and the limit of its extension cannot easily be defined. At the coast from Guryongpo to Daebo, where Tertiary basalt is the main rock type, the 2nd Terrace gradually inclines down to the 2nd Terrace without showing any break-in-slope, whereas the back edge is clearly defined by an immediate rise of the slope to the mountain. While southward from Gampo,

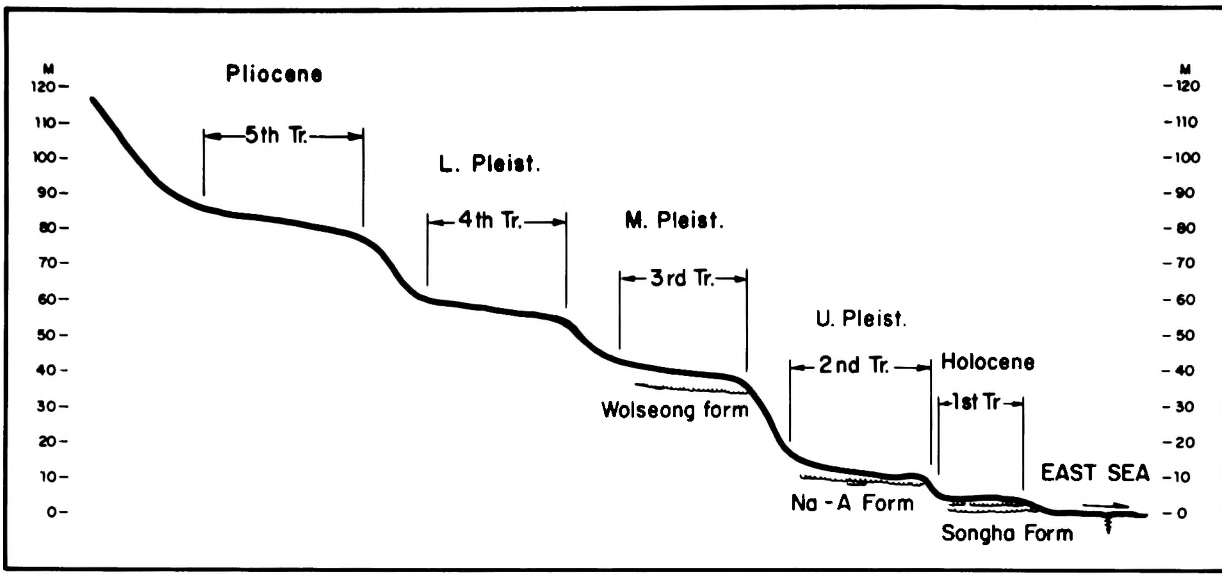


Figure 2. Schematic view of the idealized succession of terraces and their lithostratigraphic units

the 3rd Terrace is still well preserved with a relatively flat surface and terrace gravel deposits. The terrace deposits consist of fine gravel and coarse sand, similar to the 2nd Terrace deposits, except for the degree of weathering. These deposits are found at Eupcheon and Mopoat between +35 and +42m. No datable material has ever been found in the 3rd Terrace. However, magnetic polarity of the 3rd Terrace deposits turned out to be normal, corresponding to the Brunhes Epoch, i.e., younger than 0.73 million years. Also, the topographic position of the Early Pleistocene (Goedong Formation) is higher than the level of the 3rd Terrace. All this evidence suggests that the age of the 3rd Terrace is Middle Pleistocene.

Terraces higher than the 3rd Terrace have been subject to strong abrasion, resulting in a gently downward sloping surface. They have been intensely eroded along valley cuts and their surfaces are covered by superficial deposits of weathering products. Hence the only possible evidence identifying a terrace is the presence of rounded to subrounded, heterogeneous gravel in a matrix of yellowish red silty loam on a gently inclined surface. The dominant elevation and projected gradients however indicate the presence of terraces at an elevation of +50 to +60m (4th Terrace) and +75 to +90m (5th Terrace) respectively. The 4th Terrace along the coast can still be traced at very local areas. Among these are Eupcheon and Yangnam, where weathered gravel is scattered on the low gradient slope. The 5th Terrace is more difficult to recognize in the field. The presence of heterogeneous gravel on mountain slopes up to +90m may indicate such a high sea level stand. Remnants of such gravel are still found at Bongwhajae, Bong-gilri, Obalsan, etc.

The morphostratigraphy of all these terraces and the other Quaternary deposits are compared with their lithostratigraphy, magnetostratigraphy, topographic position of the deposits and the base-level changes as shown in Figure 4.

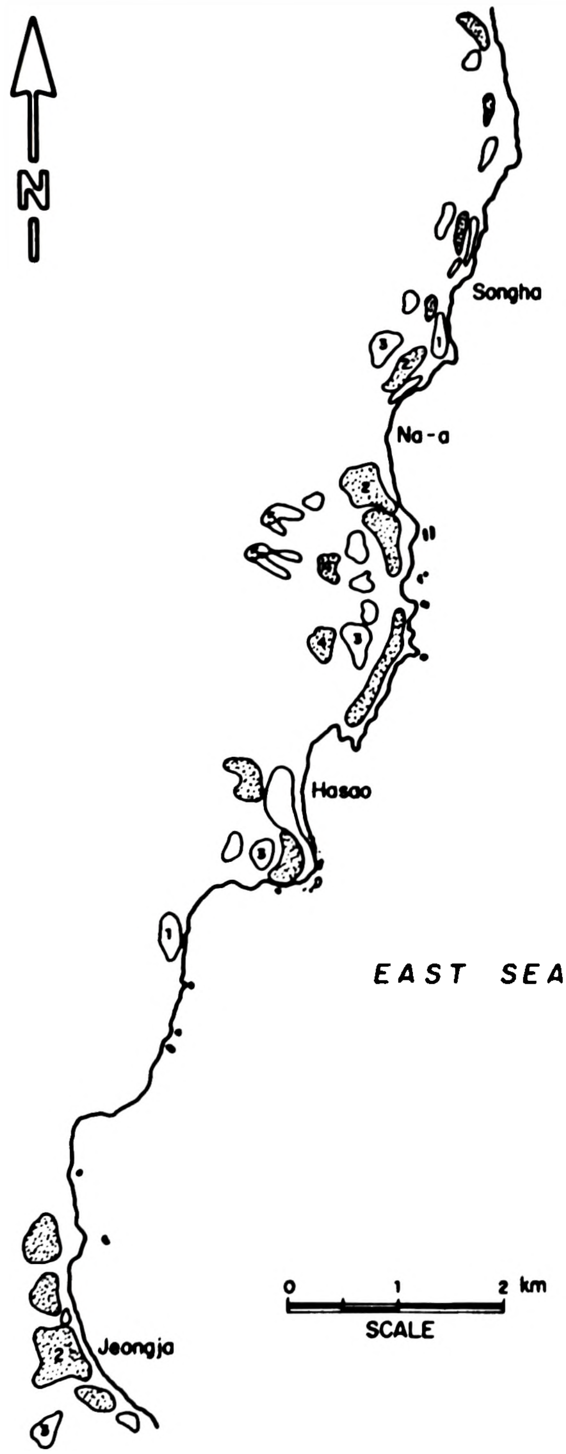


Figure 3. Outcrops of the successive marine terraces along the coast from Daebon to Jeongja. The numbers are in order of succession.

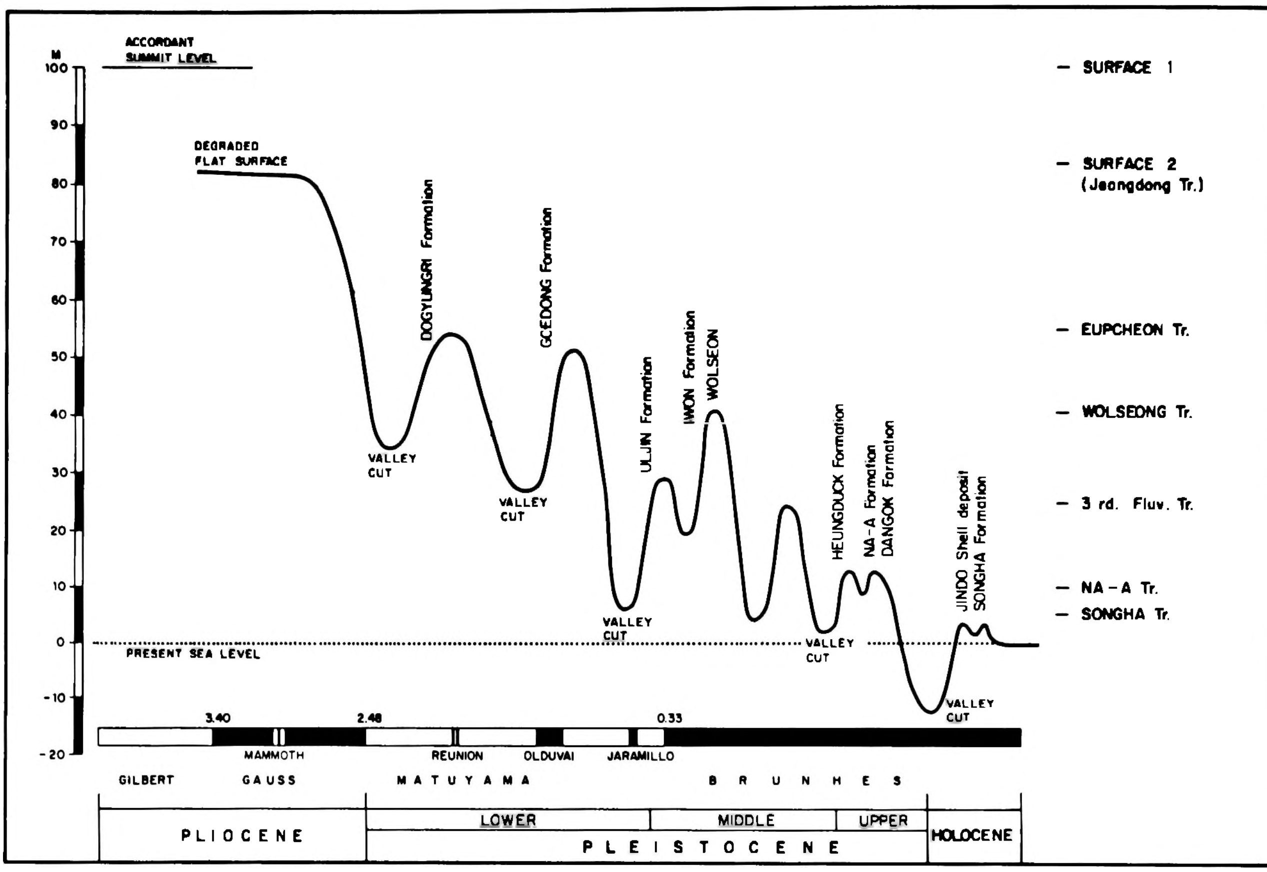


Figure 4. Base level fluctuations and stratigraphic units corresponding to each period of high stand of the base level, along the coast of the Korean peninsula, since the beginning of the Pleistocene.

3. MARINE TERRACES AT THE NORTHERN COAST OF POHANG

At the northern coast of Pohang, several step-like emergent terraces are developed on the gently inclined mountain slopes. They are stepped at three different altitudes and disconnected from each other by poorly to well defined escarpments. Jo, H.R. (1978) studied marine terraces at the coast of Yonghanri and identified three marine terraces as listed below:

Name	Altitude	Age
Terrace III	10-20m	Würm
Terrace II	30-35m	Würm
Terrace I	45-50m	Last Interglacial

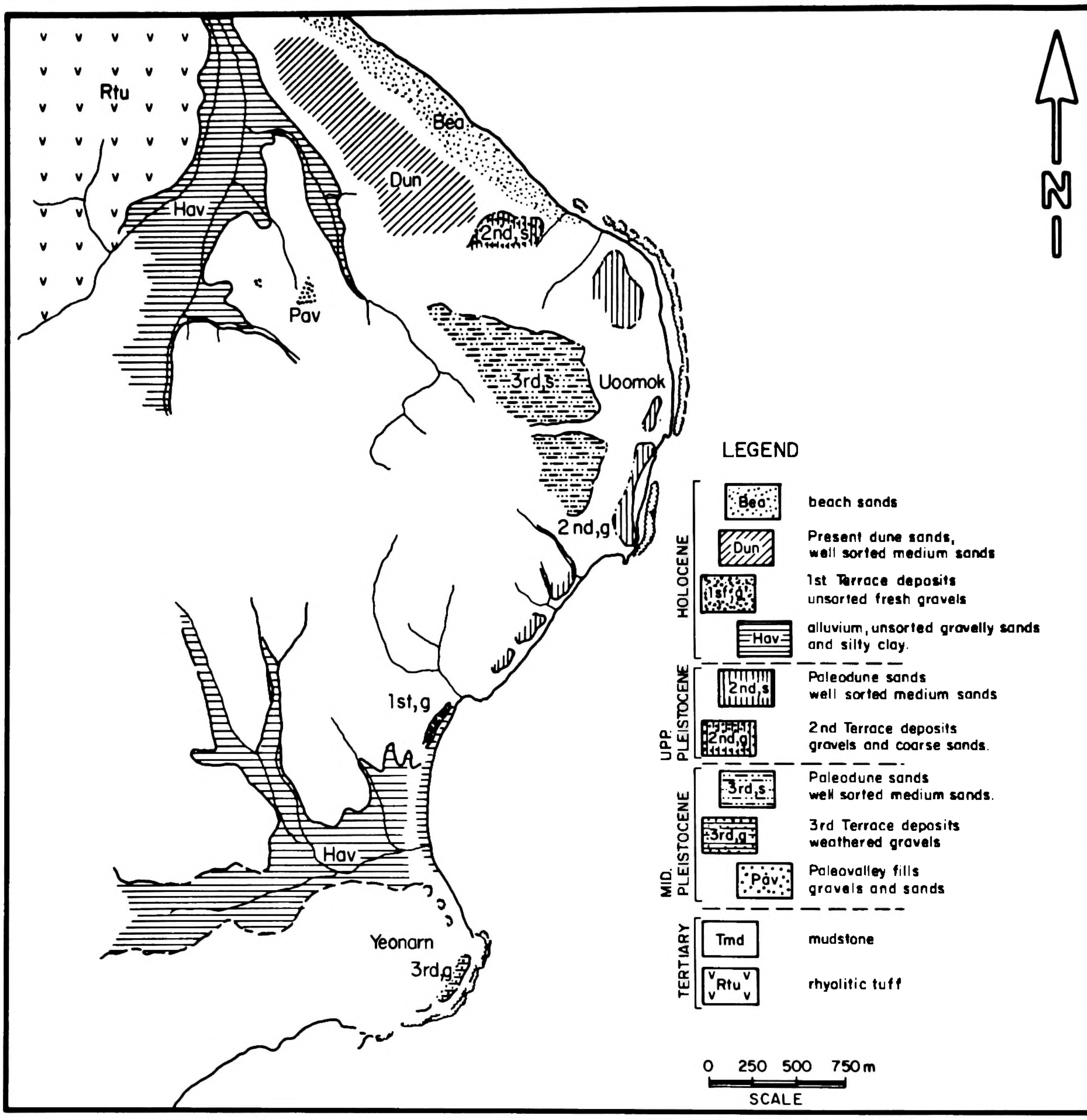
In this study, he inferred the age of these terraces, on the basis of topsoil colour and general geomorphological configurations. Lee et al. (1988) distinguished three different terraces in this same area (Figure 5). According to him, the lst Terrace is exposed at +3 to +5m and well rounded fresh gravel is covering the surface. The 2nd Terrace has a gently inclined flat surface at the level of +10 to +15m, its extent limited by front and back escarpments. The 3rd Terrace shows the most outstanding flat surface, paved with rounded gravel and overlain by well sorted, horizontally laminated yellowish brown sands. The basement of this area consists of whitish grey mudstone, representing the Duho Formation of Miocene age, although this area was previously known as the type locality of the Yeonam formation, which was considered the uppermost sequence of the Yeonil Series.

The Ist Terrace is confined to an elevated coastal strip at the level of +3 to +5m. The areal extent of this terrace is defined by an escarpment going up to the 2nd Terrace, and by beaches sloping down towards the sea. In the valley, this terrace incorporates Holocene valley fills, and between the valleys, it is often truncated by streams or creeks. Therefore, the best outcrops encountered at the corner of river mouths near the foothills of the mountains as shown at Dabble for example. The Ist Terrace deposits consist of gravel and sand similar to the present beach deposits. The 2nd Terrace is well developed along the coast from Jukcheondong to Uoomokdong at +10m to +15m. The terrace surface is quite flat, sloping gently seaward. The areal extent, with a maximum width of about 50m, is well marked by an abrupt break-in-slope at the front edge and by an escarpment sloping up to the 3rd Terrace along the back edge. The local basement of this area consists of whitish grey, semi-consolidated Miocene mudstone. The overlying terrace deposits consist of well rounded gravel and coarse sand. These deposits are about 2m thick and unconformably overlie the Tertiary substratum. They are roughly cross-stratified due to the platy fabric of the gravel and dip about 2 to 3 degrees seaward. Although no fossils have ever been found, this formation is interpreted as the result of littoral deposition. The 3rd Terrace has the most outstanding flat surface in this area. At Uoomokdong and Yonghandong coastal areas, the flat surface has its greatest extent, with a width of up to 250m, but the stepped front edge has been abraded to some degree while the back edge is covered by shallow slope deposits resulting in a gently inclined surface, though the most pronounced level of this terrace lies between +35m and +45m. At Yeonamdong, the terrace deposits consist of fine gravel and coarse sand, similar to the 2nd Terrace deposits, but at Uoomokdong, only well sorted fine sands are outcropped at the surface. These deposits are about 10m thick, and consist of light to brownish grey, horizontally stratified, fine sand, the origin of which was interpreted as eolian, on the basis of its grainsize distribution (Lee, et al. 1988).

4. FLUVIATILE TERRACES AT THE NAENGCHEON VALLEY

The Naengcheon valley is located at the southern part of Pohang with its main river flowing northwards, debouching sediments directly into the sea. The physiography of this valley is quite similar to that of others in the mountainous areas, as the valley is narrow but deep, filled with alluvium. The drainage pattern is dendritic in the upper reaches of the valley, changing downwards into a straight water course, with a few tributaries in the lower part. The geology of the upper part comprises granite or quartz porphyry of Cretaceous age, but the lower part features Tertiary mudstone. Due to these physiographic and lithologic characteristics, rock fragments are easily eroded from the Cretaceous outcrops in the upper reaches and transported downwards by fluviatile activity. Several successive terraces are present on both sides of the Naengcheon valley. Each terrace represents an extended flat surface and the altitude of this flat surface gently rises upvalley in accordance with the present stream gradient. The level of each terrace above the present river therefore remains quite constant along the valley. The first topographic observation of these terraces was recorded by Jo, H.R. (1978). He distinguished three different flat surfaces along the valley, viz. Surface 1 at about +15m, Surface 3 at +4 to +5m and Surface 2 in between these two surfaces. He further suggested the following respective ages of these surfaces: Surface 1 as belonging to the Würm Glacial, and Surfaces 2 and 3 either to the Würm Maximum or to any stable period of rising sea level during the Post Glacial. However, detailed airphoto interpretation, combined with field investigations by Lee D.Y. (1985) revealed 5 pronounced flat surfaces at different altitudes (Figure 6).

The Ist Terrace is developed at Induck and Cheongrim near the present coastal area. It has a stepped appearance with distinct flats bounded by bluffs standing 3 to 4m above the present channel floor. It is not clear whether or not to consider this level a vestige of a former surface, which the river has affected up to that level. The materials underneath the terrace consist of gravel and sand, which are very similar to the present nearby channel deposits. The surface is now used for agriculture, which may have disturbed the original surface to a certain extent. However, this surface is explained as a terrace on the basis of comparing the present base level along the coastal areas. In the drowned valleys, along the coast, the level of the alluvial plain generally reaches +2 to +4m, and channels are not deeply dissected. The bottom of the Naengcheon river is deeply eroded up to the present base level and the level of the horizontal surface stands at +4 to +5m, somewhat higher than the nearby alluvial plain. The present floods have been noticed as being confined mainly within the present channel floor. All these indications support the interpretation that the Ist Terrace is a vestige of the former valley floor, filled with streamflood gravel deposits.



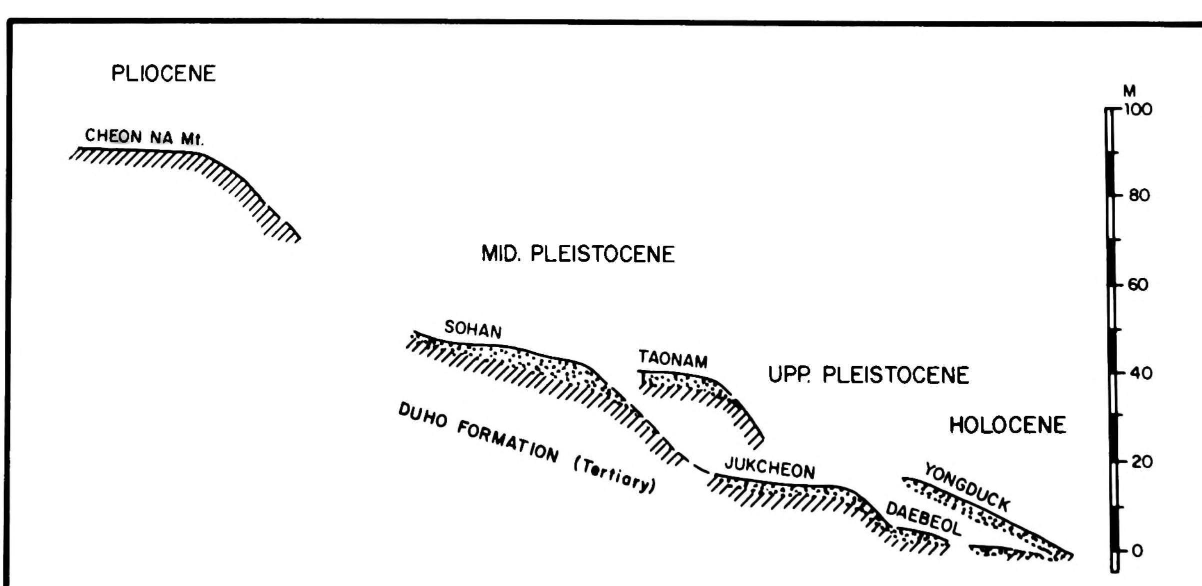


Figure 5. Quaternary outcrops and their topographic positions at the northern coast of Pohang, Korean peninsula.

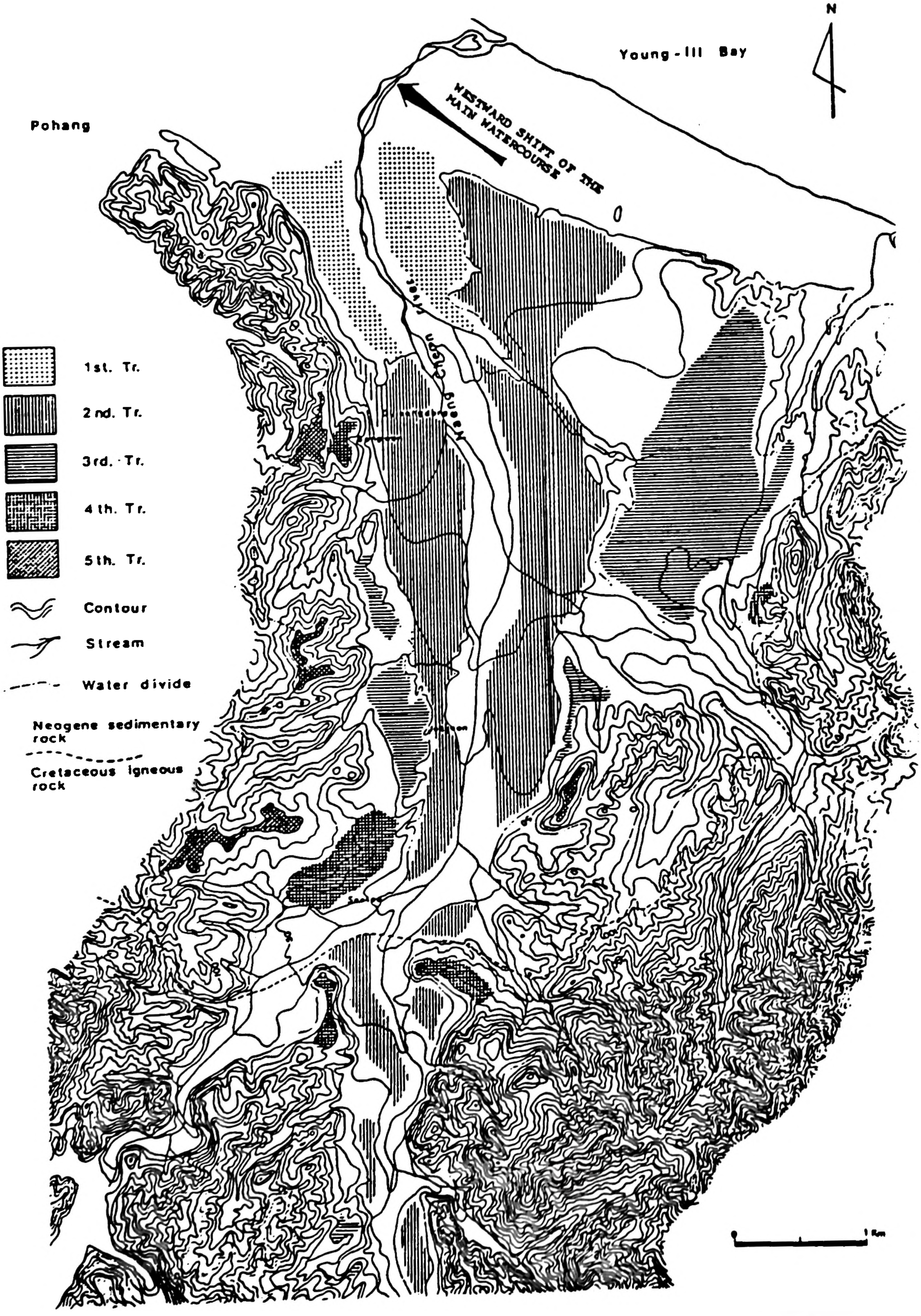


Figure 6. Distribution of terraces along the Naengcheon river valley.

The 2nd Terrace is continuous at the level of 10 to 12m above the channel bottom on both sides of the river. The Gujeongdong area has the largest flat surface, up to 700m in width. Its areal extent is confined by the present valley, but the terrace width increases downvalley. The back edge of the terrace is clearly defined by an abrupt break-in-slope down to the 3rd Terrace. The front edge abruptly dips down to the lst Terrace or to the channel floor. The terrace deposits, consisting mainly of gravel and sand, are often exposed along the bluffs.

The 3rd Terrace features the most outstanding flat surface, at 20m to m above the channel floor. The sudden changes in slope define the back and front of the terrace. They extend from close to the river to the rim of the mountains. In the upper region, the terrace is flatter and better preserved along the west side of the river than along the east side. In the lower region, the terrace slopes downwards very gently and remains wide along the eastside of the river. Terrace deposits of about 6m thick are well exposed at the bluffs near Jukjeon. They consist of rounded to subrounded gravel and very coarse sand. Boulders bigger than 10cm in size are occasionally intermixed. These unsorted gravel deposits are stream-flood deposits caused by abrupt high energetic floods. During such a flood, the narrow Naengcheon valley was instantly filled with gravelly deposits. The next deepening of the valley took place by subsequent lowering of the base level, thus forming the fluviatile terraces on both sides of the river.

The 4th Terrace stands about 10 to 15m above the 3rd Terrace and 40 to 45m higher than the present channel floor. The largest terrace is located at Saeteo. Its extent is confined to the areas near the foothills, just beyond the 3rd Terrace. However, several places along the valley still show remnants of the flat surface, mostly in the south, but most of them are partly obscured by slopewash from the side of the valley, accompanied by colluvium on the upper part of the terrace, and also by post-erosional activity that lowered its marginal surface. A profile across the terrace accordingly reveals a gently inclined surface. This terrace is not covered with gravel deposits, so the surface was highly vulnerable to erosion, particularly where on a semi-consolidated substratum.

The 5th Terrace is represented by a gently inclined flat surface along the western divide of the valley. Several summit surfaces are in accordance with each other at levels of around +80 to +90m and gently slope down, almost parallel to the current stream gradient. It is certain that the erosional activity has taken place along each side of the divide, so that only the linear vestige of the former surface is now traceable along several summits. It is not easy to infer the genetic origin of this surface. There are no remnants of paleosols or any alluvial deposits on it, so it could well be the mere result of slope denudation. This surface is not a local feature, however. At surroundings of the Pohang basin, as revealed by topographical profiles of the accordant summits, there is a flat surface through the accordant summits. The surface of the Neogene deposits has sometimes been lowered by erosional activity, while the vestige of the former surface has been preserved up to now. Hence, it is considered that the 5th Terrace indicates a former erosional base level developed near the coast (Figure 7).

5. SOIL DEPOSITS

Along the river valleys in the mountainous area, fluviatile terraces are seldom developed as explained in the previous chapter. A suitable topography for terrace development is found in valleys of which the widths are about 500 to 1000m, and where channels are flowing along the valley walls. At the back of terraces, the gentle slope changes into a steep mountain slope, along which soil deposits are easily transported from above, thus covering terrace deposits. These soil deposits mostly consist of sandy loam with few rock fragments, but they are structureless. Hence it is difficult to study these soil deposits in terms of stratigraphy.

Many archeological sites have recently been uncovered in the Korean peninsula, and detailed descriptions of each geological layer observed in archeological trenches have been made. Some of these trenches over fluviatile terraces intersected soil deposits. An example of these soil deposits can be seen at Cheongok, Seokjang Hongcheon and Daejin archeological sites, etc. There are quite some geological similarities in these trenches and a typical example is the Hongcheon site (Figure 8).

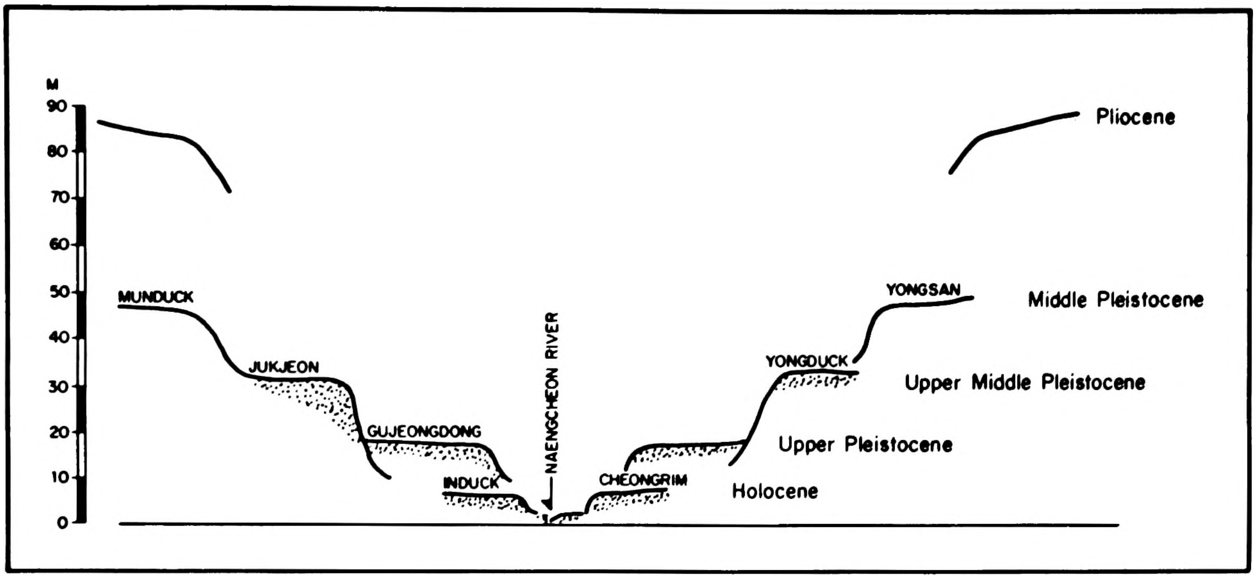


Figure 7. Topographic position and inferred age of fluviatile terraces developed at each side of the Naengcheon valley

The lower part of Hongcheon archeological trench corresponds to the upper part of the 2nd Terrace deposits. The soil deposits, consisting of fine sandy loam, directly overlie the terrace deposits. The lower part of these soil deposits is characterized by a reddish brown soil with a blocky structure and a high percentage of kaolinite. On top of this brown soil, fossil structures of soil wedges are vaguely visible. These fossil wedge soil structures are often found in the brown soil of central Korea. This brown soil is overlain by a brownish grey soil that reaches the present ground surface. A recent organic horizon has also developed on this uppermost horizon, while stone artefacts are found mostly in the central portion of these soil deposits. So far no datable materials from these soil deposits have been found, but we may assume the soil deposits to be younger than the age of the 2nd Terrace. The lower part of the soil deposits, represented by reddish brown soil, may be correlated with the Last Interglacial whereas the brown soil must have been formed during the Last Glacial, considering the age of soil wedge formations at the Last Glacial Maximum. The brownish grey soil from the ground surface to the soil wedge horizon should be Holocene. Such a stratigraphic framework of the soil deposits on the 2nd Terrace deposits still needs to be substantiated, if possible with absolute age dating.

6. THE HOLOCENE SEQUENCE

As the Korean peninsula is very mountainous, Holocene deposits are restricted to valley plains and coastal areas. In the valley plains, deposits are mostly alluvial gravel, directly overlying pre-Pleistocene. Towards the coast, these deposits change from gravelly valley fills into flood plain deposits, consisting of fine sandy clays. At the eastern coast, valley deposits are predominant and these occur right up to the coast due to the narrow, steep valleys. But at the western coast, the sediments of the Holocene sequence are very different because of low stream gradients. Going downstream, they gradually change from alluvial gravel to coastal deposits. At the coast, three different types of Holocene deposits have been found by drilling. These are tidal muds, peat and flood plain deposits. Among many outcrops, Ilsan is one of the best sites to observe a complete Holocene sequence. See Table 2.

Table 2. Holocene sequence at Ilsan area

Lithostratigraphy	Sedimentary environment	^{14}C Age
Saemal Form.	Flood plain	younger than 2400yrBP.
Gawaji peat Form.	Marsh	4720 ± 50 – 2460 ± 70yrBP.
Daehwa Form.	Tidal muds	older than 5170 ± 60yrBP.
Precambrian Gneiss	Metasedimentary rocks	

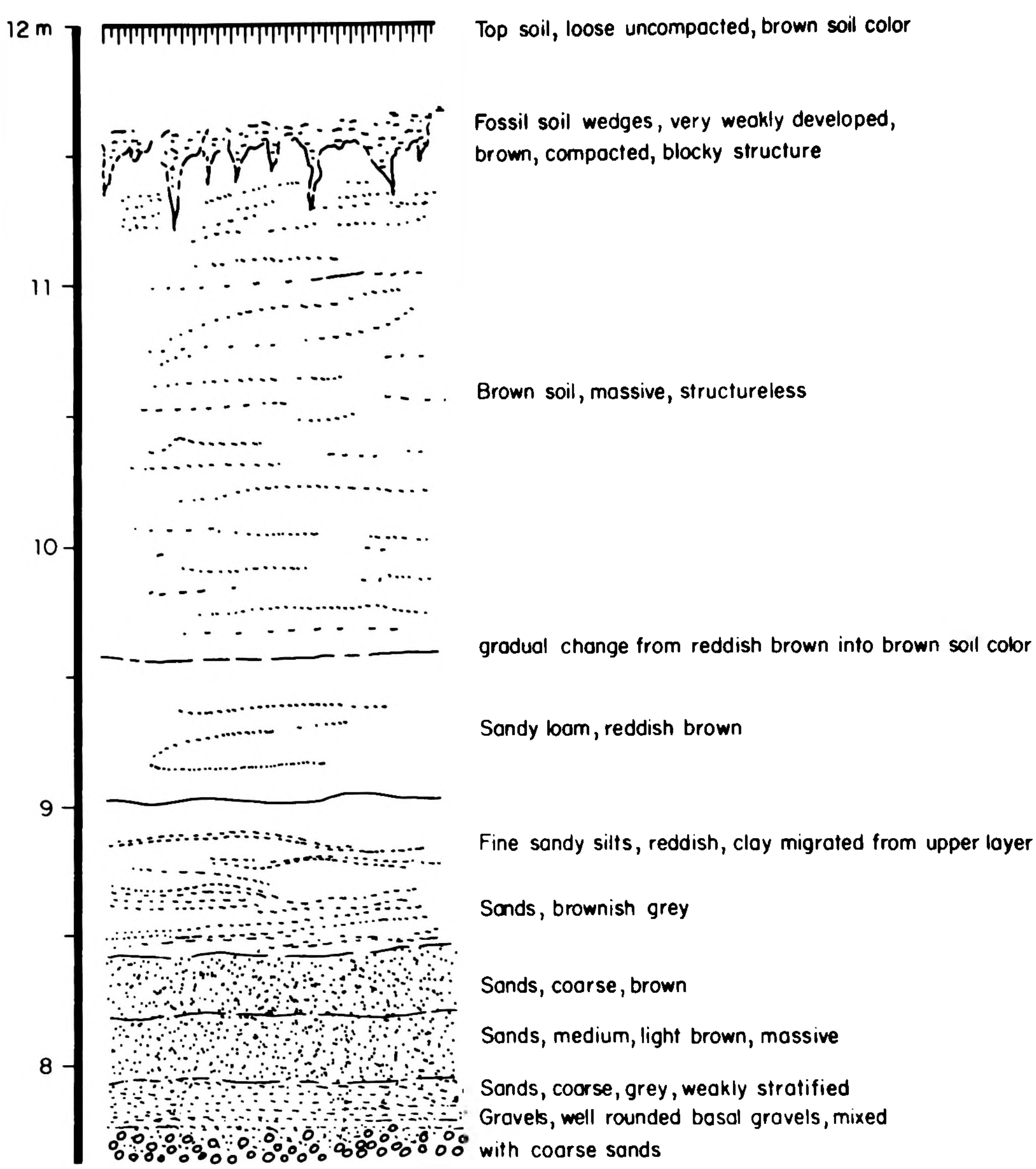


Figure 8. Geological layers at the Hongcheon archeological excavation site. The lower part represents the 2nd terrace deposits and the upper part represents soil deposits characterized by soil wedges.

Ilsan is at the west coast near Seoul. It is a very flat area, characterized by a broad alluvial plain. All around, small, gently undulating hills reach into the plain from the mountains. These low hills consist of gneiss, which is strongly weathered at the surface. The vertical extension of the Holocene sequence stretches from 20m below to 9m above the current mean sea level. Current tides reaches up to 9m, but it does not affect the present alluvial plain at Ilsan. The Holocene deposits in this area consist of ancient tidal muds near the bottom and flood plain deposits in the upper section. Peat layers are also found at the plain margin in the small, narrow valleys.

Tidal mud deposits

At Ilsan, the bedrock consists of Precambrian gneiss, directly underlying Holocene deposits. Consequently, there must be a great geological hiatus as the west coast has been relatively stable for a long time, experiencing mostly erosion. Holocene deposits are therefore not thick as compared to their areal extent. At the lowest part of the Holocene sequence, the tidal muds extend down to 20m below the ground surface. They are bluish grey, fine silty clay with many organic remains. Their ^{14}C ages exceed 5,170 ± 60 years BP. The results of this age determination correspond with the general nature of the Holocene transgression as it occurred near the coast of the Korean peninsula more than 5,000 years ago. Following this Holocene rise of the sea level, the tidal muds must have been formed around Ilsan.

Peat layer

Above the tidal mud deposits, peat is locally developed in the small marginal valleys. It consists of wood fragments and semi-decomposed plant leaves. This peat layer is topographically limited to the level between +5 and +8m above mean sea level in these valleys. Its thickness is less than 1½m. Wood fragments are still identifiable as oak or pine trees. According to the areal extent of this peat layer, a blackish, shallow lagoon must have existed to enable peat accumulation at the margin of the ancient tidal mud flats. It is also noted that the paleoclimate at the time of peat formation must have been much warmer than at present. The ^{14}C age determinations resulted in values ranging from 4,720 ± 50 years to 1,460 ± 50 years BP, indicating the time of the Holocene climatic maximum.

Flood plain deposits

As Ilsan is located near the Han river, mud deposits of flood origin are widespread over the alluvial plains. Their thickness varies depending on the distance from the present river. Their maximum thickness is about 5m near the river bank, thinning away towards the margin of the alluvial plain. It is brownish gray mud. The depositional structure is very massive with many organic burrows. Towards the coast, these mud deposits grade into tidal muds. The deposition of these mud deposits must have occurred in historic times, as they contain many human artefacts.

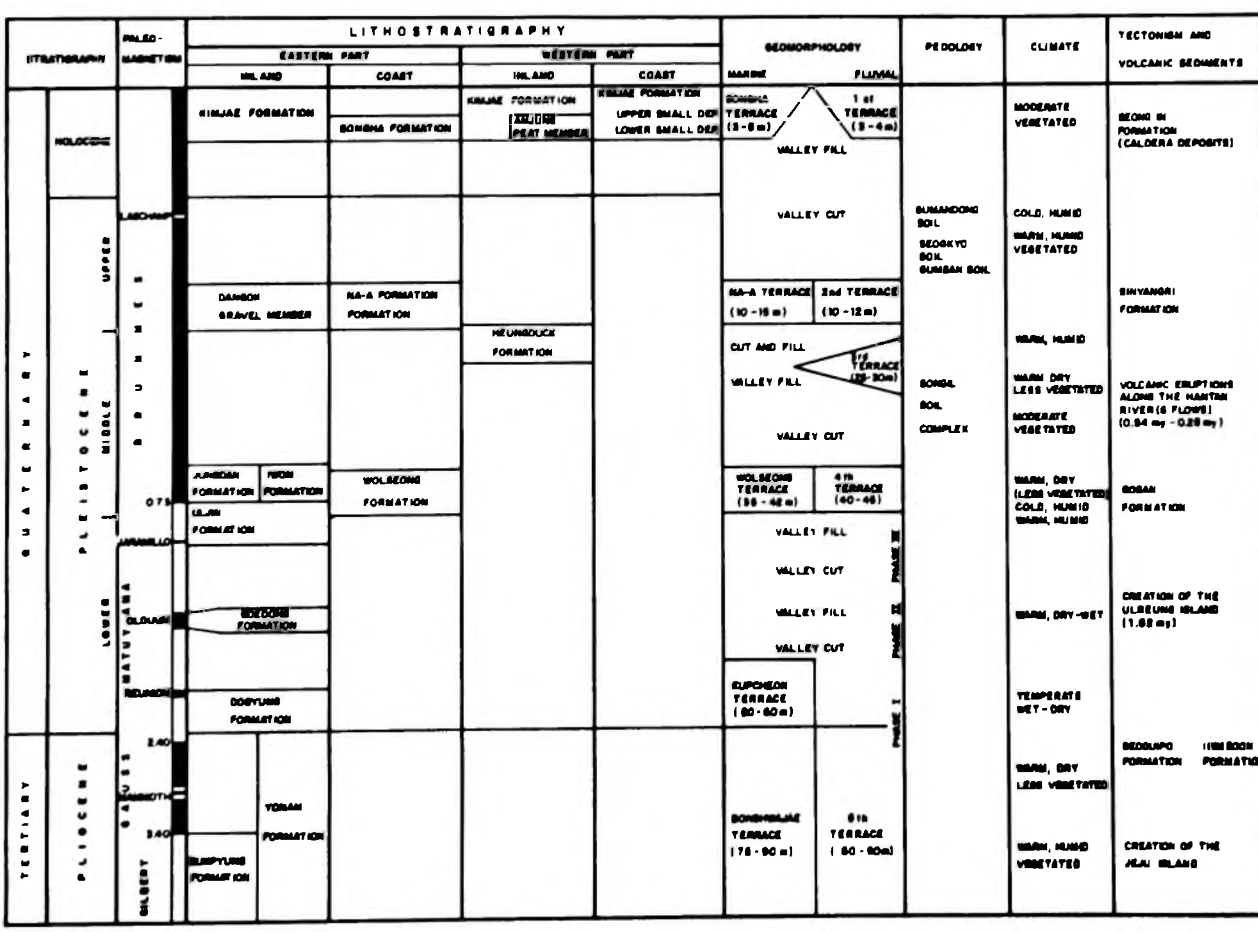


Figure 9. Quaternary stratigraphy of the Korean peninsula

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REVIEW OF QUATERNARY GEOLOGICAL STUDIES IN VIET NAM[1]

by

Nguyen Duc Tam[2]

1. INTRODUCTION

Quaternary geology becomes a more and more important branch of science and practice. It finds its application in many aspects of life, from identifying mineral resources for the industry, to construction activities and environmental protection. Now that the first 20 years of Quaternary geological study in Viet Nam have passed, it is time for a review, in order to draw conclusions and start a new period of Quaternary investigations.

To this end, a 4-year Quaternary geological mapping project was set up in 1990, to produce maps at a scale of 1:500,000 for the whole area of Viet Nam. This paper intends to review the Quaternary geological studies so far undertaken in Viet Nam, and to present the objectives of the 1:500,000 scale Quaternary mapping project (1991 - 1994) which represents the basis for further development of Quaternary research and its applications.

Before 1970, Quaternary geology had not been paid due attention. Quaternary research itself started in 1970 with the implementation the 1:200,000 scale geological mapping of the Hanoi sheet. To date, the coastal plain region has been mapped on this scale. In the mountainous regions, Quaternary research has been carried out in selected areas with placer deposits, producing maps of various larger scales (1:50,000; 1:25,000; 1:10,000 etc.). Other types of Quaternary geological work has mainly been related to construction activities, water supply and other purposes.

The result of the above-mentioned investigations led to the following knowledge of the Quaternary geology and history of Viet Nam.

2. QUATERNARY DEPOSITS IN THE COASTAL PLAIN REGION

In the Red River delta and the coastal plains of central Viet Nam, a preliminary Quaternary stratigraphic column has been established. It consist of two principal horizons: the Lower and Upper horizon.

The Lower horizon consists of continental coarse-grained sediments, with polymict pebbles, gravel and sand, while bearing thin layers of sandy fossiliferous clay in the coastal zone. Surrounding the plains are fragments of river terraces, with coarse-grained deposits, which are related to the horizon described above. This Lower horizon has been provisionally dated as Middle to Upper Pleistocene. Its thickness varies from 10 to 100 meters.

The Upper horizon is represented by fine-grained sediments, dated as Upper Pleistocene to Holocene in age. It comprises intercalated marine and continental formations with thicknesses varying between 10 and 80 meters.

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1 *Paper presented at the IGCP 296 regional workshop held in Ho Chi Minh City, Viet Nam from 13-15 December 1992*

2 *Institute of Geology and Mineral Resources, Hanoi, Viet Nam*

Continental suites are composed of gray sand to sandy clay, while each marine suite, as a rule, mainly consists of an underlying coastal swampy layer of a typical, dark grey silty clay (bearing abundant coastal zone fossils and remains of mangrove vegetation) and an overlying fine shallow marine clay with typical primary green and green grey colours, or secondary red-white one,s as a result of weathering. In some cases they are mixed with well sorted beach or coastal dune sands.

The main continental and marine sequences are dated as Upper Pleistocene, with only the uppermost marine suite being of Middle Holocene age.

On the coastal plains, exposures of the following main types of Quaternary deposits can be observed:

1. Coarse-grained deposits of the river terrace blocks.
2. Weakly weathered Upper Pleistocene marine and fluvio-marine sandy clay.
3. Upper Pleistocene and Holocene coastal dune deposits.
4. Middle and Upper Holocene beach, shallow sea and fluvio-marine deposits.
5. Coastal swampy deposits (in the actual mangrove swamps).
6. Holocene flood plain deposits.

In the Mekong River delta and adjacent areas, another sedimentary regime prevailed, with different types of Quaternary deposits. In the deeply subsided "West Nam Bo" (the large western part of the delta) mainly marine and fluvio-marine deposits were formed during the Pleistocene. At this time, in the "East Nam Bo" (the eastern part of the delta, which is the relatively uplifted block) mainly continental layers were deposited.

3. QUATERNARY DEPOSITS OF THE MOUNTAINOUS REGIONS

In the mountainous areas two principal types of Quaternary deposits exist: alluvial, river valley deposits and eluvial deposits.

Quaternary deposits in the river valleys

Along the river valleys, stream bed, flood plain and terrace deposits can be observed. Stream bed and lower flood plain deposits consist mainly of polymict pebbles, gravel and sand. The upper flood plain, as a rule, is composed of an underlying polymict gravel layer with a thickness of 1 to 5 m, overlying a sandy clay layer of 1 to 8 m thick. Along the river valleys, apart from the flood plain deposits, a rather complicated terrace system exists. In general, the first, the second and the third terraces are composed of rather thick (1 to 8 m) gravel overlain by clay layers. In the higher terraces, Quaternary deposits are limited to very small and thin fragments of coarse-grained layers.

The flood plains are Holocene in age. The deposits of the first terrace are dated as Upper Pleistocene ones. The sediments of higher terraces are attributed to an earlier period.

The eluvium and deluvium on bedrock

On the mountain slopes, a rather complicated system of eluvium and deluvium has developed, which could be divided into the following main types:

- The eluvium and deluvium on sedimentary and metamorphic rocks, composed of clay, sandy clay, sand or pebbles and gravel derived from underlying bedrock.
- The eluvium and deluvium on igneous rocks, composed of sand, gravel sand, gravel or clay related to the underlying bed rocks.

- The eluvium and deluvium on effusive rocks, consisting mainly of clay.
- The eluvium and deluvium overlying the Neogene-Quaternary basalt. This is represented by a special type of eluvium-deluvium, which consist of a red clay called "red soil", suitable for plantation of rubber, coffee, black pepper and other commercial crops.

The thickness of the eluvium-deluvium cover ranges from 1 to 40 m, depending on relief and bedrock characteristics. The age of the eluvium and deluvium is difficult to determine and remains a problem to be solved.

4. NEOGENE - QUATERNARY BASALTS

Olivine and tholeitic basalts are developed in the mountains, in the coastal plain as well as in the near-shore shallow sea areas. They form large plateaus as well as monadnocks and islands. Provisional dating assigns them to the Pliocene, Lower to Middle Pleistocene and Upper Pleistocene to Holocene group of phases, but further research and age-dating are needed.

5. MINERAL RESOURCES IN QUATERNARY DEPOSITS

Within the Quaternary deposits, mineral resources have been found both in coastal and mountainous areas:

In the coastal plain region

Clay, both for industrial purposes and construction is the most important and predominant type of mineral resource of this region. Along the coast, coastal placer deposits (mainly titaniferous) and glass sands are found. Peat represents yet another kind of mineral resource in the coastal plains.

In the mountainous region

This large region contains many important placer deposits. Most common are gold placers, which are found in nearly every valley. They are concentrated mainly in streams beds of flood plains and in the first, second and third terraces, which hold the major portion of the Quaternary valley deposits. Other important Quaternary deposits are the widespread tin placers. Apart from the above-mentioned environments, tin has been concentrated in large, deep karst and neotectonic depressions.

Besides industrial clays, sand and construction materials, the weathering crust contains some other materials, such as the bauxite developed in the weathering crust of Neogene-Quaternary basalts.

Ruby and sapphire deposits are associated with the weathering of metamorphic rocks and basalts. These precious stones, though of a lower quality, have been found in alluvial deposits as well.

6. IMPORTANCE OF AND PROSPECTS FOR QUATERNARY GEOLOGY

This review of Quaternary studies carried out in Viet Nam shows that the study of unconsolidated sediments, which often contain important reserves of mineral deposits, is of utmost importance. Quaternary deposits are closely related to people's everyday life. The most populated and important part of the country is the coastal plain region, with its concentration of towns, ports, industrial centres and cultivated lands. The problems of construction, water supply, agricultural development and environmental protection are concentrated here and their solutions closely depend on Quaternary geological work. For this exact reason, the 1991-1994 Quaternary geological mapping project has been established and is being implemented. The aim of this project is to collect and interpret the large amount of data existing on the Quaternary geology and mineral resources of Viet Nam and to correct and supplement the shortcomings of the previous stages of investigation. The following studies will be undertaken:

- Additional work into the subdivision of Quaternary sequences of the coastal plains.
- The replenishment and establishment of the marine and river terrace systems.
- The establishment and additional study of the transgression-regression cycles.
- Preliminary study of deluvial sediments and eluvial mantles in the mountain region.
- The paleogeographic reconstruction of the Quaternary period by using stable isotopes and other methods.

In this context it should be noted that this author is of the opinion that the large number of the "Vietnamese loess" exposures observed by Hoang Ngoc Ky are in fact those of weathered deluvium, weathered river terrace deposits and the upper part of the weathering crust of different kinds of bedrock.

- Additional neotectonic studies.
- Preliminary studies of coastal erosion.
- A study into the potential regularity of formation and distribution of mineral resources in Quaternary deposits.

The final output of the project consists of the 1:500,000 scale Quaternary geological map of the whole of Viet Nam, and will contain the results of the previous stage of investigation as well as form the basis for the next period of Quaternary studies and their application.

STRATIGRAPHIC CORRELATION OF QUATERNARY TRANSGRESSIONAL AND REGRESSIONAL DEPOSITS IN VIET NAM AND ADJACENT COUNTRIES[1]

IUGS UNESCO

IGCP 296

by

Hoang Ngoc Ky[2]

Abstract

Based on the results of Quaternary mapping on a scale of 1 : 200,000 in the whole the Viet Nam Plain, Quaternary deposits have been divided into alternating stratigraphical units of marine and terrestrial origin, respectively. In the Red River Plain in the north of Viet Nam, the formations Upper Thai Thuy, Vinh Phu and Hai Hung are of marine origin, while the formations Lower Thai Thuy, Ha Noi and Thai Ninh are of fluvial origin. In the Mekong Plain, in the southern part of Viet Nam, Ca Mau, Moc Hoa, An Giang and Uming Formations represent marine deposits, and Tieu Can, Hong Ngu, Thu Duc and Cuu Long formations are of fluvial, subaerial origin. Along the central coastal part of Viet Nam and the islands, marine deposits and terraces have been found at elevations of 40 to 70m and 15 to 25m above sea level. These formations are linked to the sea level changes during the Quaternary period. There were four marine transgressional and regressional phases, which have been named after eight Quaternary formations in the Mekong Plain of Viet Nam. They represent typical strata and phases suitable for a tentative correlation of Quaternary deposits in Viet Nam and other countries in Asia and the Pacific region.

1. INTRODUCTION

Deltaic and coastal plains constitute one third of Vietnamese territory. In each one, Quaternary deposits have been divided into formations according to their ages and the environment of their deposition. The results of these studies indicate that Quaternary formations related to sea level changes are linked to four transgressions and four regressions that occurred during the Quaternary Period. The Mekong Plain represents the largest fluvial plain, not only in Viet Nam, but in all Southeast Asian countries. Here, the Quaternary deposits are thicker that those in other areas. The Quaternary transgressions and regressions may serve as patterns for correlation of Quaternary deposits in Viet Nam with those in adjacent countries.

2. CORRELATION OF QUATERNARY STRATIGRAPHY IN VIET NAM WITH THAT IN ADJACENT COUNTRIES

The Quaternary coastal and deltaic plain formations of Viet Nam are related to sea level changes, as a change in sea level controls both sedimentary and erosional processes. The elevation of abrasive platforms, depositional terraces, wave-cut caverns on cliffs, lateritic crusts and fossil plants and oysters preserved in growth position are all useful indicators of the evolution of the sea level. The stratigraphic units of the Mekong Plain may be considered as a basis for correlation of Quaternary deposits in Viet Nam and adjacent areas.

The term "horizon" is used for a regional unit or a stratigraphic marker unit of formations which are linked by ages, but which bear different names. The following eight horizons exist in the region:

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1 *Paper presented at the IGCP 296 regional workshop held in Phuket, Thailand from 14-21 October 1991*

2 *Geological Survey of Viet Nam, 200 Ly Chinh Thang Street, 3rd District, Ho Chi Minh City, Viet Nam*

The Tieu Can horizon of the early Pleistocene regression

The Tieu Can regression evolved after the last Pliocene transgression. The sea level and shoreline were in the lowest position and far from the present one. The Tieu Can Formation does not contain marine fossils, but it bears abundant plant fragments.

In the Red River Plain, the lower part of the Thai Thuy Formation, which is of alluvial origin, is situated at 210 meters below sea level (Hoang Ngoc Ky et al., 1986). The Samut Prakan Formation is developed at the bottom of the lower central Bangkok Plain (Dheeradilok et al., 1986), and terrestrial deposits underlie transgressive bed HVII and bed HIX. Bed HVIII in the Bohai Sea and southern Yellow Sea of the Eastern China Shelf is linked to the Early to middle-Early Pleistocene Transgression (Lin Hemao, 1989, and Yang Zigeng, 1986), and belongs to the same horizon as the Tieu Can Formation.

Most of the formations of the onshore cover unconformably overlie the lateritic surface of marine or alluvial Pliocene deposits.

This regression is likely to have gradually exposed a large portion of the shelf of the South China Sea. It lasted from about Late Pliocene through Early to middle Early Pleistocene.

The Ca Mau horizon of the late Early Pleistocene transgression

The Ca Mau Formation, containing an abundance of fossil Foraminifera, was formed during this transgression (Hoang Ngoc Ky, 1989). It is located at an elevation of 40 to 70 meters above sea level. In the Red River Plain, the upper part of the Thai Thuy formation exists at a depth of 150 meters below sea level, while marine terraces at an elevation of 40 to 70 meters above sea level, distributed along the coastal plain of the central region and islands, which have all been affected by this transgression.

The sedimentary formations in onshore Viet Nam could be correlated with the Thon Buri Member of the Samut Prakan formation in the lower central plain of Thailand (Phisit Dheeradilok et al., 1986), and the transition bed VII (HVII) of the late Early Pleistocene in the southern Yellow Sea of the Eastern China Shelf (Lin Hemao et al., 1989, and Yang Zigeng, 1989).

Neotectonic movements may have been active up to the present time, causing much deformation of these shorelines and resulting in a vertical displacement of about 200 to 300 meters between the plain and offshore areas, uplifting the central region and islands.

The Tieu Can transgression gradually spread into the hinterland for about 20 to 50 kilometers from the present coast in late Early Pleistocene, before the tektite rain (700,000 to 800,000 years ago).

The Hong Ngu horizon of the Middle and early Late Pleistocene regression

The Hong Ngu Formation contains an abundance of plant fragments in its upper part, and is coarse-grained; it probably accumulated during a regression phase of large extent. The Ha Noi Formation in the Red River Plain of the northern region as well as coarse-grained gravel lying at the bottom of small plains in the central region are terrestrial deposits created coevally with the Hong Ngu Formation.

The estuaries and river deltas were probably lying further away, at distances of several hundred kilometers from the present coast, associated with a sea level standing several hundred meters below the present one. During the lowest sea level of this regression, most of the offshore islands and perhaps the Indonesian islands as well, were linked to continental Southeast Asia, forming a large peninsula. Radiocarbon dating of wood fragments in the upper formation gives about 35,000 to 45,000 years BP, which would indicate that this regression largely evolved towards the South China Sea during the middle to early Late Pleistocene.

The Phra Nakhon and Ping Formations occur in the central plain of Thailand (Dheeradilok et al., 1986), and a thick layer of transgressive beds HIII, HIV, HV, HVII in the Yellow Sea. Transgression beds M2F, M4F, M5F, M6F and M7F alternate with thick beds of terrestrial deposits in the Bohai Sea (Lin Hemao, 1989, Yang Zigeng, 1989), were probably created during this transgressive phase. Due to the small extent of this transgression, these beds did not develop onshore and stopped somewhere on the shelf of the South China Sea.

The Moc Hoa horizon of the middle Late Pleistocene transgression.

The Moc Hoa, Vinh Phu and Da Nang Formations, fine-grained and containing an abundance of fossil Foraminifera, are marine deposits covering a large area of plains or marine terraces, 5 to 10 meters above sea level. These formations exist around the deltaic plains of the Red and Mekong Rivers, while the depositional terraces occur at the foot of the hills along the coastline. Many plant remains are overlain by the clayey sand of this transgression, yielding radiocarbon ages of about 30,000 to 35,000 years BP.

These formations are unconformably overlain by Holocene deposits. The boundaries between them are marked by erosional or lateritic surfaces. The rising sea level had approached 10 to 25 meters a.s.l., with the shoreline reaching the foot of the hills.

The whitish clay occurring along the coastal zone of Peninsular Malaysian (Foo Khang Yee et al., 1976), the heavily mottled, light grey, stiff clay belonging to the Sanam Chai Formation (Chaimanee, 1986) as well as the sandy silty clay of the Phra Pradaeng Formation in the lower central plain of Thailand (Dheeradilok, 1987) are not continental deposits, but genetically similar to the Moc Hoa, Vinh Phu and Da Nang Formations in Viet Nam.

Marine transgressive bed HII in the Yellow Sea and bed M2F in the Bohai Sea of the Eastern China Shelf, representing nearshore deposits with radiocarbon ages of 24,600 ± 1,060, 28,000 ± 820 and 27,860 ± 820 years BP are considered coeval with the Moc Hoa Formation of the Late Pleistocene.

The Thu Duc loess horizon of the Late Pleistocene to Early Holocene regression

No regressive deposits have been observed in the hinterland. Erosional and weathering phenomena were found on the top surfaces of the Moc Hoa, Vinh Phu and Da Nang Formations at the base of young Holocene deposits at depths of 20 to 40 meters b.s.l. Channels and old rivers have cut through these marine deposits, down to more than 50 meters b.s.l.

In Viet Nam, radiocarbon dates of plants preserved in their growth position at 9 meters and 23 meters b.s.l. in the Red and Mekong Plains are 7,190 ± 85 and 8,200 ± 150 years BP (Hoang Ngoc Ky, 1986, 1989). The radiocarbon date of a wood fragment lying at 67 meters b.s.l. in an ESSO borehole in the Gulf of Thailand is 11,170 ± 150 years BP (Tjia, H.D. et al., 1976, Dheeradilok, 1989).

The sea level associated with this regression was probably lower than the present one. According to Nutalya et al., this regression occurred during the last glacial stage and the sea level dropped to 120 meters b.s.l.; many shelf seas such as the Gulf of Thailand or the Gulf of Tongking were dry land at the time. Malaysia and the Indonesian islands of Sumatra, Java and Kalimantan became an enlarged Southeast Asian peninsula (Verstappen, 1975). The additional dry land that thus existed during this regressive stage, formed a large region that supplied the source material for the Thu Duc Loess Formation of subaerial deposits in Viet Nam (Hoang Ngoc Ky, 1989, 1990).

The red yellow loess of the Khorat Plateau and Chiang Mai in Thailand (Boonsener, 1986, Dheeradilok, 1987, Nutalya, 1977), the fine-grained loam cover in the uplands of Malaysia (De Dapper, 1987), the Batambang grey earth in Cambodia, the Old Alluvial Clay and the red earth in the uplands and on the plateau of Myanmar (Chhibber, 1936), are eolian deposits according to the present author, and like the Thu Duc Loess Formation, have all been created during this stage.

At depths of 25 and 17 meters b.s.l. in boreholes on Xisha islands, sequences of eolian biocalcarenite (He Qixiang et al., 1976) probably deposited during the Late Pleistocene to the Holocene.

The radiocarbon dates of charcoal fragments in the upper part of the Thu Duc loess in southern Viet Nam and the yellow red loess in Thailand are 8,570 ± 40 and 8,190 ± 120 years BP in age, indicating that the regression evolved during the Late Pleistocene to the Early Holocene.

The An Giang horizon of the Early to Middle Holocene transgression (10,000 to 3,000 years BP)

Based on the results of morphological, stratigraphical and paleontological research and radiocarbon dating, we are allowed to link the An Giang Formation in the Mekong Plain to the Hai Hung in the north and the Tam Ky Formation in the centre of Viet Nam.

Depositional and erosive terraces extend along the coast onshore. Wave-cut caverns were found at 3 meters a.s.l. in the surrounding plains, shoreline and islands, representing marks determining the height of the sea level during the An Giang transgression.

Plant remains and oysters buried by the soft clay in the upper part of the An Giang Formation in the Mekong Plain were dated by the radiocarbon method, giving 8,200 ± 250 and 5,550 ± 80 years, while in the Red River Plain ages of 7,590 ± 85 and 4,150 ± 50 years BP were obtained. The radiocarbon dates of oyster shells found in wave-cut caverns of limestone at +3 meters a.s.l. is 3,100 ± 80 years BP.

The above-mentioned facts show that the sea level of the An Giang transgression rose slowly from the beginning of the Early Holocene, starting from approximately 80-120 meters b.s.l. 10,000 years ago to 1-2 meters b.s.l. at 5,000-6,000 years BP, but after that the sea level suddenly rose to 3 to 4 meters a.s.l., where it remained for a long period, i.e., until 3,000 years ago.

The soft clay of the Bangkok Clay Formation (Nutalya and Rau, 1981) yielding radiocarbon ages of 5,200 ± 350 years BP and 6,900 ± 90 years BP, the Krasaesin Formation of shallow marine deposits (Chaimanee, 1987) producing radiocarbon ages of 4,775 ± 10 and 6,900 ± 90 years BP in Thailand, the first marine terraces and lowlands of the coastal zones of Asian countries, the lower part of transgressive beds HI in the Yellow Sea and M1F in the Bohai Sea of coastal tidal flats and the near-shore marine deposits, with radiocarbon ages of 9,910 ± 100 and 10,340 ± 100 years BP, were all formed during this transgression.

The An Giang transgression is the equivalent of the Flandrian transgression, which evolved after the last glacial period, not only onshore and offshore of Viet Nam but in all coastal zones and continental shelves of Asia.

The Cuu Long horizon of the middle Late Holocene (about 3,000 to 2,000 years BP)

The Cuu Long Formation, the Thai Binh Formation and coastal lowlands were created during the regression of the middle Late Holocene. In the lowland, sandy dunes occur parallel to the present shoreline. Plant fragments and oyster shells are contained in alluvial deposits interlayered with the marine deposits of these formations. Absolute ages were determined as 2,600 ± 74 years BP, 2,500 ± 65 years BP and 2,400 ± 80 years BP. The sandy dunes represent an old shoreline developing continuously and gradually towards the present one. Old rivers channels reach down to 2-4 meters b.s.l., cutting through marine deposits that formed in the previous transgressive stage.

The data mentioned above allow us to conclude that during this regression the sea level fell suddenly, from 3-4 meters a.s.l. at 3,000 or 3,100 years BP, after which it declined slowly from 2 meters a.s.l. to 2 or 3 meters b.s.l. 2,000 years ago. At that time, the Cuu Long regression reached its lowest sea level, with shorelines far from the present one, many kilometers towards the South China Sea. The Songkhla Spit Formation of beach barriers and similar deposits on the eastern coast of Peninsular Thailand (Chaimanee, 1987) and the upper Bangkok Formation, the upper transgressive beds HI and MIF in the Eastern China Sea were all the result of this retrogression.

The Uminh horizon of the New (Late Holocene) transgression (2,000 BP to the present)

The Uminh Formation of this new transgression was investigated in the course of Quaternary mapping in the Mekong lower deltaic and coastal plains. It consists of dark clayey peat of swampy marine and swampy alluvial deposits occurring in the coastal zone and filling in old channels or ancient rivers.

Some places along the shoreline have been eroded by wave action; rock dams are being built there at present in order to protect the cultivated lowlands in populated areas from the adverse effects of collapse and erosion. The tides are encroaching not only upon the estuaries, causing high level of salinity, but also upon the coastal lowlands, creating lagoons, marshlands and mangrove forests, such as the Uminh peat mine, the Duyen Hai area or the Thao Muoi plain. These areas are gradually becoming acid sulphate soils. In the channels and old rivers peat has accumulated, dark grey clayey peat or, where mangrove is growing, forested lowlands are developing.

Radiocarbon data on plants preserved in their growth position at 1-3 meters below the present sea level indicate ages of 902 ± 64,916 ± 72 and 1,080 ± 60 years BP. A system of dikes and dams has been built over thousands of years along both banks of the river and along the coast to protect the population from floods and storms.

We may conclude that this new transgression evolved since 2,000 years BP with the sea gradually rising from 2-3 meters below to the present level.

The Thalac Luang Formation, consisting of silty, peaty to peat layers on the east coast of Peninsular Thailand (Chaimanee, 1987) and the marsh deposits forming in lowlands elsewhere were influenced by this new transgression.

3. DISCUSSION

This paper mentions the correlation of Quaternary deposits created from transgressions and regressions onshore in Viet Nam and Thailand and offshore in the East China Sea. The table of stratigraphical correlation of Quaternary deposits in Viet Nam with those in adjacent regions is considered a pattern linking Quaternary divisions based on transgression and regression.

As understood by the present author, Project 296 of the International Geological Correlation Programme aims to link Quaternary deposits of various genetic backgrounds, be they marine, terrestrial, subaerial, volcanic, or offshore, onshore, or from plateau regions. First, we select the stratotypes per region and from different origins, after which a correlation of stratigraphy should be established based on a particular genesis, e.g. loess (eolian) deposits, volcanic formations, terrestrial and marine deposits, etc. Although hard, the author believes these problems can be solved, leading to a successful conclusion of IGCP 296.

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QUATERNARY GEOLOGY OF THE PHANTHIET COASTAL PLAIN IN SOUTH-CENTRAL VIET NAM[1]

IGCP 296

by

Hoang[2] Ngoc Ky, Ngo[1] The Thai and Vu[1] Van Vinh

1. INTRODUCTION

The Phanthiet area represents a coastal plain in the southern part of central Viet Nam. Red sandy and white sandy dunes are characteristic of the Quaternary in this central region, and so are transgressive deposits exposed in deltaic plains and marine terraces. However, the origin and age of some Quaternary sediments are still the subject of discussion. The Quaternary sequence of the Phanthiet area may be subdivided into the following units.

2. MIDDLE-UPPER PLEISTOCENE (Q_{II-III})

Proluvial-alluvial deposits

These deposits consist mainly of pebbles, gravely sand intercalated with sandy or silty lenses. They are distributed in the bottom part of the plain sequence, and overlain by younger deposits. The thickness of these deposits is about 20 to 30 m.

3. UPPER PLEISTOCENE (Q_{III})

There are two units in the Late Pleistocene.

Marine deposits of the second terrace

These consist of the whitish sand and sandy gravel of the second marine terrace (known as the Cana second marine terrace) at an elevation of 10 to 25 m above present sea level, and exposed on the medium-level coastal plain, at an elevation of 10 to 20m. They are overlain by red and white sandy dunes of eolian origin. Marine deposits of the second terrace may be correlated with marine deposits of the Mochoa Formation, as discovered in the Mekong deltaic plain as well as in the second marine terrace along the coastal plain of Central Viet Nam. Their thickness varies from 10 to 15 m.

Marine-alluvial deposits

These consist of sandy silt and clayey to silty sand distributed in the upper part of river valleys formed in the uplands at 20 to 30 m above sea level. Their thickness varies from 5 to 10 m.

Both units of the Upper Pleistocene were laid down during the transgression; shells and corals in the Cana second marine terrace have radiocarbon ages of 18,500 ± 250 years BP (Saurin, 1963 – in Fontaine & Hoang, 1973).

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4. UPPER PLEISTOCENE-HOLOCENE (Q_{III-IV})

Phanthiet Red Sands Formation

This formation consists of sand (60-70 %), silt and clay (30-40 %) and is developed along the coastal plain, not only in Phanthiet, but also in Phanrang, Hamtan. Its width is 10 to 20 km and its length about one hundred km. This red sand forms red sandy dunes 100 to 200 m above the present sea level. Its thickness is about 80 to 100 m. The origin and age of the Phanthiet red sandy dunes are still the subject of discussion. Le Duc An (1981) described them as marine deposits of the middle Late Pleistocene. In the geological map of the 1 : 200,000 scale Phanthiet sheet, red sandy dunes are shown as marine-eolian deposits of the middle Late Pleistocene age, similar in age to the marine deposits of the inner plain with its red sandy dunes.

According to the present authors, the eolian deposits were not deposited coevally with the marine ones; they reflect different environments. Rather, they represent mixed eolian deposits resulting from both rolling and eolian sedimentation (Hoang Ngoc Ky, 1989, 1991). These red sand dunes could have been created during a regressive period of Late Pleistocene-Holocene, in a similar fashion as the loess on the Mekong plain.

5. LOWER MIDDLE HOLOCENE ($^{1-2}Q_{IV}$)

Two units may be distinguished here.

Marine deposits of the first terrace

These consist of sand and gravely sand that makes up the first terrace, at 3 to 5 m above sea level. The silty clay and silty sand forming the central plains of the Phanthiet and Phanri areas have an elevation of 2 to 3 m above sea level.

Marine-alluvial deposits

These consist of silty clay and sandy silt in the upper part of a small deltaic plain. Towards the upper part of Hamthuan and Songluy rivers, the alluvial deposits consist of sandy gravel and pebbles, forming the first river terrace at an elevation of 5 to 10 m above sea level. Thicknesses vary from 5 to 10 m.

Two units of early Middle Holocene could be correlated with marine sediments occurring in the Mekong area with red deltaic plains, and with marine deposits of the first terrace exposed along the coastal plains of Viet Nam's central region.

The radiocarbon age of coral and oyster shells in the Cana terrace is 4,500 ± 250 years BP.

6. MIDDLE UPPER HOLOCENE ($^{2-3}Q_{IV}$)

This consists mainly of white to grey medium-grained sand, forming high sandy dunes at elevations of 50m to 100 m above sea level. These white sands are distributed not only in the coastal plain of Phanthiet and Phanri but also along the coastal plain of the central region in Viet Nam. These sandy dunes lay parallel to each other as well as to the present coastline. The width of this white sandy dune complex is about 20 to 30 km and its length is several hundred km. The white sandy dunes are certainly of eolian origin, related to the rolling movement of marine medium-grained sand, exposed on a larger area during the regression in the middle Late Holocene. These sandy dunes are similar to those on the lower deltaic plains of the Mekong and the Red River. They could have been formed during the regression of the sea.

7. UPPER HOLOCENE ($^3Q_{IV}$)

Upper Holocene deposits are divided as follows:

Alluvial deposits

These consist of sand, gravel and sandy silt distributed in a narrow area along both banks of rivers.

Marine alluvial deposits

These consist of silty clay and sandy silt distributed in the lower estuarian area. The clay, silt of blackish dark colors may be observed in the marsh and swamps close to the coastline. Their thickness varies from about 2m to 4 m.

Marine deposits

These deposits consist of dark-gray sand containing heavy minerals and elements such as ilmenite, zircon, tin. They are exposed in some localities along the beaches of the Phanthiet, Phanri and Hamtan areas.

It is worth mentioning that the major part of the Phanthiet coastline has been and still is suffering strong erosion by wave action. Buildings, fields and dams are being destroyed day by day. The coastline is thus gradually being shifted inland. These facts are among the evidence that present sea levels are rising, and this 'new' transgression is developing all along the coastal zone of Viet Nam.

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SUBSURFACE FACIES ANALYSIS OF THE SAN ANTONIO GRABEN PLAIN, SOUTHWESTERN ZAMBALES, PHILIPPINES[1]

IGCP 296

by

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1. INTRODUCTION

Alluvial sediments, probably more than the other non-consolidated deposits, show sensitive responses to tectonic events. Their morphogenic and facies expressions often yield significant information about uplift and subsidence experienced. Alluvial sediments and sedimentary processes are dynamically and morphogenetically important because they provide a detailed if indirect key to tectonic activity (Miall 1981, Dickinson 1974). In fact, pulses of alluvial sedimentation commonly occur as a sequence of tectonic uplift. So much so that the scale of local facies variations (Bally and Snelson 1980) often entails an architectural morphogeny of basin fills with neotectonic affinities.

An alluvial-dominated morphogeny of the San Antonio graben plain in southwestern Zambales is postulated to have an intimate association with the listric reactivation of the San Antonio fracture zone. Basin-filling then ensued with the distributary depositional environments of the Santo Tomas river predominating. Sedimentation was dominated by fluvioclastics and minor near-shore facies.

Due to present constraints, i.e., insufficient deep bore profiles, poor well logs and the lack of an absolute stratigraphic Holocene record, this study concentrates only on morphogenetic interpretations and conceptual reconstructions of facies units.

2. STRUCTURAL FRAMEWORK

The study area is a graben plain situated between two massifs of the Zambales ophiolite complex: the Cabangan massif of mid-ocean ridge crustal material in the north, and the San Antonio massif with its island arc terrane in the south. According to Yumul et al. (1990), the graben plain is geostructurally bounded by the West Luzon shear in the west and the San Antonio fracture zone in the east, intimately associated with the active Mt. Pinatubo volcanic belt.

The San Antonio massif appears to consist of displaced terrane that was rifted from the Acoje block (Yumul et al., 1990) and translated southward, thus forming the San Antonio graben plain. The West Luzon shear could be responsible for this displacement. Yumul et al. further (1990) postulated that the island arc basement of the San Antonio massif has been separated from the Subic-Olongapo (MOR) crust by the Subic fault zone which is a splay of the San Antonio fracture zone.

There is a good possibility that Quaternary faults have made use of reactivated ancient fracture systems which thus juxtaposed the present ophiolitic terranes in the study area. These faults are best observed along the graben borders and mountain fronts. They may extend into the Holocene strata of the San Antonio graben fills. The significance of which is noticeable across the central part of the graben plain where there is an abrupt change in iso-thickness. To a large degree, the change entails cumulative differential movements across the boundaries of alluvial terranes which seems to have bifurcated into av

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splay near the surface into unconsolidated deposits, in a generally northwest direction. Proof of this bifurcation is found in the thickening or thinning of facies units and by the offset of the alluvial terranes in the downstream areas of the Santa Fe and Santo Tomas rivers. In most cases the thickening or thinning of facies is a manifestation of subsidiary extensional faulting within the basin.

Semi-circular or semi-ovate patterns of isopach lines are suggestive of subsidence contemporary within a major but localized range-front graben where the present Marella river is now flowing. If the isopach lines are superimposed on topographic elevation, and viewed in cross-section, using mean sea level as an arbitrary datum, structural affinities are very evident. Areas between Castillejos and San Marcelino disclose a probable change from slow to rapid subsidence during deposition of the San Antonio graben plain. Subsidence is at a maximum where isopach lines are most closely spaced. This zone seems to represent a tectonic hinge and is thought to move in conjunction with the tectonically active northwestern and northern fronts of the Magara ridge.

Consequently, local structural growth is most likely to occur along the promontories of Maubanban, Paete and Pimmayong mountains. A more or less circular northwestward motion of the basin shape is indicative of two events: (i) pulsatory tectonic activities of the graben shoulders and, (ii) progressive cessation of mountain uplift in the area.

3. FACIES UNITS

The term facies is used in many different ways in geology and can even mean different things to different people within the relatively restricted scope of sedimentology. The meaning of the term has changed over the years (Moore, 1949; Teichert, 1958; Weller, 1958; Krumbein and Sloss, 1963; Reading, 1978; Cant, 1978; Jackson II, 1978; Anderson, 1985). In this chapter, the term facies stands for a description or a classification of any body of sediment, followed by an interpretation if the processes and environments of deposition usually in terms of a facies model (Anderson, 1985 - p.32). Due to a lack of fine sizes, the study relies heavily on the interpretation and correlation of facies units which are derived from gravel and sand ratios. The focus is on changes of facies forms and stratigraphic sequences as structural manifestations of Quaternary movements.

Thirteen groundwater well logs are considered for this study. Each well log is processed with the percentages of gravel, sand, and silt/clay as primary end members. From these percentages the gravel ratio (CR) and sand ratio (SR) are derived. Both ratios act as guides for facies interpretation.

Within the limits of the ternary diagram that was compiled, SR (sand to silt/clay ratio) values 1/8, 1 and 8 are chosen as facies boundaries on the one hand and CR values 1/4, 1 and 4 (gravel ratios) on the other. Both ratios are then contoured as continuous functions. Further simplication is achieved by eliminating the 1/8-ratioline of the sand to silt/clay values (i.e. finer fractions are above 85%) and the 1/4-ratioline of the gravel values (i.e. a substantial proportion of gravel is 80%). At least six facies units are thus distinguished and indicated as A,B,C,D,E, and F.

Facies A: Gravel with minor sand and volcaniclastics

Facies A is intimately associated with the distal alluvial fan deposits. It is typified by groundwater well profile #12. This facies is placed within the 1/4 and 1 ratiolines which means that it contains a substantial proportion of gravel. It is notably widespread along the alluvial reaches of the Santo Tomas, Santa Fe and Marella rivers where the deposition of alluvial fans is prevalent. Their accretions are greatly influenced by the hydroclastic and volcaniclastic supply of an active Mt. Pinatubo.

This facies displays a generally fining-upward sequence. Elsewhere, Heward (1978) suggested that simple fining-upward sequences are the product of back-stepping of boundary faults; an event which is believed to be operative along the graben fault of Mt. Pimmayong. Moreover, a high gravel (CR) ratio of facies A is diagnostic of a sub-aerial facies (e.g. Bluck 1969).

Facies B: Medium to very coarse sand and clay with minor gravel and silt

Facies B appears the most widely deposited facies unit in the study area. This facies lies within the clastic limits of CR 1-8 and SR-1. The bulk of these sediments underlie large parts of the alluvial plains and intrabasinal areas of the graben plain. This facies is characterized by an abrupt funnel-shaped sequence, coarsening-upward. This funnel-shaped pattern derives from a progradation of a crevasse-splay into an interdistributary-deltaic complex (e.g. Cant 1984, Walker 1984). Typified by groundwater well profile #3, the sequence is evidently bimodal, which is marked by clay plus an underlying mixture of medium and very coarse sand. The bimodality of this facies sequence is associated with allocyclic vertical accretions outside the main channel (e.g. Santo Tomas river) which are the products of periodic uplifts. These uplifts are likely to be generated by recent tectonic rejuvenation of the graben borders and the San Antonio fracture zone.

Each mode of the sequence represents one cycle of catastrophic levee breaching. Witness to this catastrophic event is the basal abundance of organic remains. As reported by Rust (1971)from studies elsewhere, the relative abundance of organic remains in the basal part of a fluviatile sequence characterizes an accumulation zone atop older stable tracts where vegetation has a binding effect on silt and clay.

Facies C: Sand, silt, clay interlayers with admixture of minor gravel

A ternary plot of facies C demonstrates the best preservation of a restricted and channelized distributary environment. On the one hand, the environment tends to become dominated by coarse material towards the northwest, passing through the alluvial terrane of San Marcelino where gravel ratioline CR=1 dominates, and on the other hand it tends to become dominated by fines towards the southwest, passing through the areas of Castillejos where silt-clay ratioline SR=1 prevails. Based on the details of groundwater well profile #10, Facies – C displays spectacular stratal sets which basically entail lobe progradation/aggradation and channel fill. These stratal sets typify at least two sequences. Firstly, stratal set 1 indicates a thinning-coarsening upward sequence. Elsewhere, thinning sequences have been interpreted by Mutti and Ghibaudo (1972) to represent gradual infill and abandonment of channels. By contrast, the second sequence, comprising of stratal sets 2, 3, and 4 typifies a thickening/coarsening – upward pattern. This pattern manifests a shifting lobe-fringe environment (Walker and Mutti, 1973; Normark, 1978; Beeden, 1983).

In view of overall stratal thickness, a shelly accumulational base and the generally funnel-shaped coarsening upward patterns, facies C becomes a standard part of an environmental complex, i.e. (i) a prograding channelized submarine fan (Cant, 1984; Walker, 1984), and (ii) a delta-front platform (Allen, 1970; Barwis, 1982; Miall, 1984).

As reported by Heward (1978), Mack and Rasmussen (1984), an upward coarsening/thickening trend followed by a fining/thinning sequence in the study area translates the effects either of periodic tectonic uplift of the source area or of subsidence of the basin. But the spasmodic nature of movements along tectonically active zones (i.e. the San Antonio fracture zone or the Subic fault zone) allows depositional episodes to move toward equilibrium before renewed faulting occurs.

Facies D: Fine sand, locally with admixtures of silt and clay

Bounded by ratiolines CR=8 and SR=8, a rather allocyclic and deranged planform of facies D has developed a distinct elongation towards the southwest. The axis however tends to shift almost perpendicularly to a general northwest direction as it approaches the present coastal environment. Obviously, this shift is in harmony with the distal decay and distributive abandonment of surficial macroforms towards the same direction, which are postulated to be of tectonic importance.

Facies D is best described by the subsurface details of groundwater well profile #2. This shows a generally fining-upward sequence. Basically, such a fining-upward sequence results from lateral migration of a point bar. Elsewhere, similar sequences have been reported by Walker and Cant (1984), which developed from a spiralling flow through the meander loop, building laterally across the floodplain. Such a fining-upward sequence of facies D with gradational contacts is best manifested in channel fills (Williams and Rust, 1969; Reineck and Singh, 1975).

The size and shape of facies D evidently elongates colinear with the present flow of the Santo Tomas river. This feature becomes a standard part of floodplain topography. It secludes a basal, gravelly, coarse lag material that the Santo Tomas river system can only move at peak flood time. Above the lag material, sand is interpreted to have been deposited as bedload by a meandering system. Obviously, the sequence characterizes a mobile and flashy stream and appears to have been trenched. This trenching occurs due to two dominating conditions; (i) incision and erosion, and (ii) different levels of deposition at various flood stages.

Facies E: Fine to medium sand with clay layers and minor gravel

Putting the groundwater well profile into its areal context, facies E overlaps and juxtaposes with facies D. Its overall facies shape elucidates an amalgamation of several sandy cross-channel bar systems which form obliquely across the graben plain and the distributary system of facies D.

Based on vertical detail of groundwater well profiles, facies E provides two contrasting grainsize log patterns. Grainsize logs of well profile #5 generally fit a cylindrical thinning pattern. This pattern (e.g. Cant 1984, Walker 1984) implies a fluvial environment dominated by a stacking of many braided river channel sequences. Putnam (1982) has associated cylindrical log patterns with deep fluvial channel deposits.

The above situation is in contrast with the grainsize log pattern of well profile #6, where an irregular coarsening/thickening-upward sequence is followed by a fining/thinning pattern. Such a profile is ascribed to a distal alluvial fan propagation, resulting from the effects of rejuvenation wear-off (Mack and Rasmussen, 1984). An evident stratal alternation of clay materials in the sequence constitutes a separation of braided river channel fills which are a common depositional association with alluvial fans.

A feature worth noting from a ternary fence diagram constructed, is that facies E develops a downslope thinning towards coastal area in a generally northwest direction. This thinning phenomenon represents either a channel switching induced by distinct jumps in the downstream positions of formerly active debouchers of the Santo Tomas river, or a gradual lateral lobe shifting. Similar modes of fluviatile deposition have been studied in detail by Piper and Normark (1983), Kolla et al. (1984) and Graham and Bachman (1983).

Facies F: Gravelly sand with alternating quick sand and clay layers

Facies F is evidently sheltered along an active tract of the Pamatawan river. A striking alternation of quicksand in this facies highlights a condition of water saturation and unstable sediment distribution. Following studies by Lowe (1975), the presence of quicksand in this facies sequence suggests a depositional environment with rapid deposition of large amounts of sand from a fluidized flow. It further implies that the present site of the Pamatawan river experienced the passage of a turbidity current which normally keeps its sand load in suspension by fluid turbulence. As reported by Walker (1984), turbidity currents may pass through a stage of fluidized flow during the final few minutes of flow immediately before deposition.

Grainsize profiles of groundwater well #8 provides Facies – F with an irregular-mixed clean pattern. This pattern usually results from coarse-grained deep-water canyon fills where many individual channel-terrace units are superimposed: an environmental condition which is presently prevailing in both the Santo Tomas and the Pamatawan river valleys.

4. DISCUSSION AND INTERPRETATION

The location of the San Antonio graben plain is largely controlled by the stable massifs of the Zambales ophiolite complex. These massifs act as sediment sources and funnel major drainage systems (e.g. the Santo Tomas and Pamatawan rivers) into the graben plain. Three episodic phenomena are considered here to describe the evolution of the San Antonio graben plain. Their boundaries are based on geomorphogenetic deductions and lithofacies schemes.

Episode 1: First fluvial influx with dominant sedimentation of alluvial fans (facies A)

During this episode, sediment was supplied to the San Antonio graben plain from the northeast and east. In the northeast, this supply was effectuated by volcaniclastic sedimentation from Mt. Pinatubo which graded distally into an alluvial fan-dominated (facies A) depositional environment. Trends of facies profiles indicate that sediment was derived from progressively more distant source areas and transported through a network of channels (e.g. the Santo Tomas river) which penetrated far into the hinterland (e.g. Mt. Balitog). The material seems to have been supplied to the main channels throughout their length so that the alluvial fans are composed of material ranging from local to distant derivation. Compositions of the alluvial fan gravels are probably not representative of the source area due to selective decomposition of clasts during transport to the graben plain. But a distal fan progradation during Episode 1 is preserved by facies A with a simple fining-upward sequence. The sequence constitutes the beginning of major fluvial influxes into the San Antonio graben plain (Zone III). The influx is in response to the back-stepping of graben shoulders, specifically along the vicinities of the Simminoblon and Sindol hills, and to a possible volcanic rifting of the source area in Zone II.

Episode 2: Waning of first fluvial influx with dominant sedimentation of crevasse-splays (facies B) and channel fills (facies C)

Source area denudation and retreat continued during this episode. In the northeastern and eastern parts of the graben plain alluvial fans (facies A) continued to develop at the margin of upland areas. Source areas here were activated at a must faster pace than in northern part of the graben plain. The alluvial fans did not drain directly into a clayey-sandy floodplain (facies B) but instead appear to have led to a system of interdistributary river channels. This suggests a relatively fast rate of uplift of the periphery of the graben plain at this stage.

Approaching Zone III, the floodplain conditions of the southwestward interdistributary system were abruptly replaced by basinwide catastrophic levee breaching and crevasse-splay progradation. Next, the southwestward influx of sand (facies B) through low-sinuosity debouchures of the Santo Tomas river became fully established and prograded west- and northwestward across the San Antonio graben plain from the east. Another transitional braided system advanced from the southeast and notably drained towards the west.

Significantly, the northeasterly derived trunk river (i.e. the Santo Tomas river) underwent a radical change. The river began aggrading. From details of groundwater well profile #10, the drainage system fed out of the graben plain into the sea. The preservation of a very thick coarsening-upward sequence of sand, silt and clay interlayers (facies C) in association with the highly embayed promontories of the Magara ridge and the Saddle mountain suggests that subsidence occurred within the graben plain during this episode. At the beginning of this episode, a nascent fissure vent developed in the western part of the graben plain (Zone III).

As this episode proceeded, there was a waning in the fluvial influx from the north and southeast. Much of the graben plain was transformed into a silty-clayey floodplain dominated by overbank spills and localized shallow lakes (e.g. Lake Look) along graben shoulders. There was however a rapid influx of channel infills (facies C) along the deeply entrenched southwestward trunk line of the Santo Tomas river. The channel infilling was terminated by a northwestward swing of the laterally expansive terminal lobe-fringe environment. This constituted a nascent Pamatawan river at Zone III and river capture of the Marella river in Zone I.

Episode 3: Second fluvial influx with dominant associations of facies D, E and F

This episode witnessed a major change in the system of sedimentation from the southeast, east and south. Source area retreat continued and this was most marked in the southern perimeter of the graben plain where fault reactivation along the San Antonio fracture zone played the key role. The river system was dominated by distributary channels of low-sinuosity, which cut through a silty floodplain (facies B).

A sediment influx from the east and southeast was accompanied by a regional elevation of the water table within the San Antonio graben plain. This resulted in a stacking of transitional distributary channel deposits flanked by frequently flooded areas (facies E).

There was a shift in the debouchure pattern of the Santo Tomas river, so that the distributary system emanating from the confluence of the Marella river became redirected and contained towards the west and northwest upon entering the fault-line debouchure which effectuated the existence of the Santa Fe confluence and Simminoblon hill.

The preferential location of channel-dominated sequences (facies E and D) in belts parallel to graben borders may have been controlled by differential rejuvenations along neotectonic lines within the basement (e.g. the Subic fault zone and the San Antonio fracture zone). Their locations however, remained more stable than the graben shoulders so that extensive reworking of overbank deposits by low-sinuosity streams proceeded, resulting in domination of the preserved succession by channel deposits.

Preservation of facies F on the peripheral zone of the graben plain during this episode indicates a dramatic dual shift in the fall line and this zone now began to subside. This would have caused major drainage lines (i.e. the Santo Tomas and Pamatawan rivers) to be preferentially located in the areas of maximum subsidence. This consituted the containment of the Pamatawan river towards the south, following the San Antonio fracture zone and the Santo Tomas river towards the north, where the reactivation of the graben-fault effectuated the isolation of the Sindol and Simminoblon hills.

Meanwhile, a shallow wave-dominated barrier-beach strandplain advanced from the west oblique to the general east-west axis of the San Antonio graben plain. The first pulse was confined to the northwest (e.g. San Narciso town), while the second resulted in a southwestward drift of the shoreline, approaching the area of San Antonio town where the present Pamatawan river terminates.

Alluvial conditions within the San Antonio graben plain seem to have been terminated at the beginning of the Holocene and although there was still a terrigenous influx of sediment to the graben plain after this from the east, northeast and southeast, it was comparatively weak. The environmental changes which the graben plain endured during the closing stages of the Quaternary resulted from source area retreat, volcaniclastic sedimentation and base-level fall due to uplift. The latter eventually led to the widespread raised beaches.

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"Palynology of Late Quaternary Sediments from a Coastal Site in Perak, Malaysia"
Figure 1 - Pollen diagram, Pantai Tin Mine, Perak, Malaysia (selected species) - in pocket

Pollen Diagram, Pantai Tin Mine, Perak, Malaysia (selected species)

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