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On the Quaternary deposits of Thailand

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Abstract: The Quaternary alluvial and coastal plains in Thailand covered approximately forty percent of the whole area of the country. These deposits are principal areas for the production of rice, the staple food of the country. The capital and major cities are mainly located on these Quaternary sedimentary plains. The Quaternary deposits are also of importance for economic mineral exploration, construction materials, groundwater, for evaluation of land use and rural development planning and also for coastal development projects. A complete stratigraphic sequence of Quaternary age probably developed in the Central Plain and these sedimentary formations can be classified into four distinct categories based on their histories, lithology, morphology, fauna and depositional environments. These are the fluviatile environment, the coastal environment, aeolian deposits and laterite. Block-faulting appear to be controlled by tectonic movements which affected also the changes in base level and erosional processes. These were followed by infilling of Quaternary alluvial sediments into the larger valley basin systems. Changes in climate and environmental processes were involved during these tectonic movements. Aeolian activity possibly occurred during the glacial period which coincided with drier conditions in this region. Weathering in humid tropical climate is generally responsible for laterization. The marine transgression-regression during Late Pleistocene-Holocene is also acceptable according to the available evidences. Quaternary stratigraphy of Thailand is in an embryonic state of development therefore it seems most desirable that attempts to set up local time stratigraphic classifications based on various types of lithogenetic sequences be continued in a variety of geographic areas. Before a valid Quaternary stratigraphy of Thailand can be established, more detail studies together with accurate absolute age determinations are needed.

INTRODUCTION

Quaternary sediments are extensively developed in Central lowland of the Chao Phraya Plain. They are also developed in the intermontane basins of the four principal river valleys and their tributaries in the northern part of Thailand as well as in the wide and broad of the two main river systems in the Khorat Plateau, northeastern Thailand. Both marine and continental deposits are extensively developed bordering along the coastal lines of the Gulf of Thailand and in the west coast of the Thai peninsula. Some experiences on aeolian sediments suggested there were loessial deposits developed in the Khorat Plateau region and in the western parts of its border. There is presence of hard-pan lateritized layers in various part of the country especially in higher terraces. A number of fauna and plant remains have been discovered from Pleistocene and Holocene sediments as well as fossil shells of marine environment found in the coastal deposits. C^{14} determination for absolute age palynological studies for the Northeastern parts of Thailand are in progress. C^{14} dating has so far yielded ages back to 13,000 yrs BP (P. Hastings personal communications). These studies may contribute some information to the argument concerning tropical climates during full glacial events. Evidences from archaeological sites of Prehistoric man show their development and the change of cultures are significant information in relationship to the Quaternary deposits in this region. Tectonic and structural controls involving the development of the present morphological features of the basins and the Central Plain as well as the

activity of basaltic flow overlying the gravel bed involved during the Quaternary time are also available evidences.

According to their Quaternary histories, mainly based on lithological and morphological aspects including evidences of fauna, the Quaternary sediments can be classified into four distinct categories (Fig. 1):

1. Fluviatile environment
2. Coastal environment
3. Aeolian deposits
4. Laterite

QUATERNARY GEOLOGICAL FORMATION

FLUVIATILE ENVIRONMENT

The development of this sedimentary system appears to have been affected mainly by rainfall during the Quaternary time. The fluviatile deposits are extensively developed throughout the country. Some areas have been affected by block faulting and by effusive basaltic flow. This system can be discussed in three different regions.

The fluviatile deposits of intermontane basins in northern, western Thailand and eastern margin of the Central Plain.

In the northern region, the fluviatile deposits have been developed in the four main river valley basins and in their tributaries namely, Ping, Wang, Yom and Nan, lying from the west to the east of the region respectively. These rivers are drained in subparallel direction from north to south. In the western region, the Mae Moei river basin, forming the border line between Thailand and Burma, drains from the southeast towards the northwest which is opposite to the Kwae Noi and Kwae Yai river valleys, while the tributaries of the Mae Klong river drain from the northwest to the southeast. To the eastern margin of the Central Plain, the Pa Sak river valley developed north-south along the narrow, elongated Petchabun basin. These intermontane basins are infilled with sequences of clastic sediments of gravel, sand, silt and clay since the Quaternary time (Brown *et al.*, 1951). They must have been involved with the development of block faulting which consists of horsts and grabens forming discontinuous, narrow mountain ranges and intervening basins. Consequently, thick deposits of fluviatile sediments are found extensively in the basins. The remarkable gravel beds comprise mainly gravel of pebble size with sand, silt and clay generally found at high terraces which are obviously located along the edge of the basins. The outcrops of these gravel beds can be observed from the excavated faces of roadcuts, for example, the outcrop at Mae Taeng District, north of Chiangmai Province, and the distinct semiconsolidated gravel bed which consists of pebbles and gravels with sand and clay matrix forming higher terrace at the level of 60 to 70 metres above the present flood plain of the Ping river. This gravel bed has been defined as Mae Taeng formation (Piyasin, 1972). The fluviatile sediments in Mae Taeng District, northern Thailand are made up of six facies units which accumulated during the Quaternary time. They are meander belt sand and silt, natural levee sand and silt, low terrace sand high terrace silt and sand. A remarkable gravel bed and lateritised layer are found in the high terrace

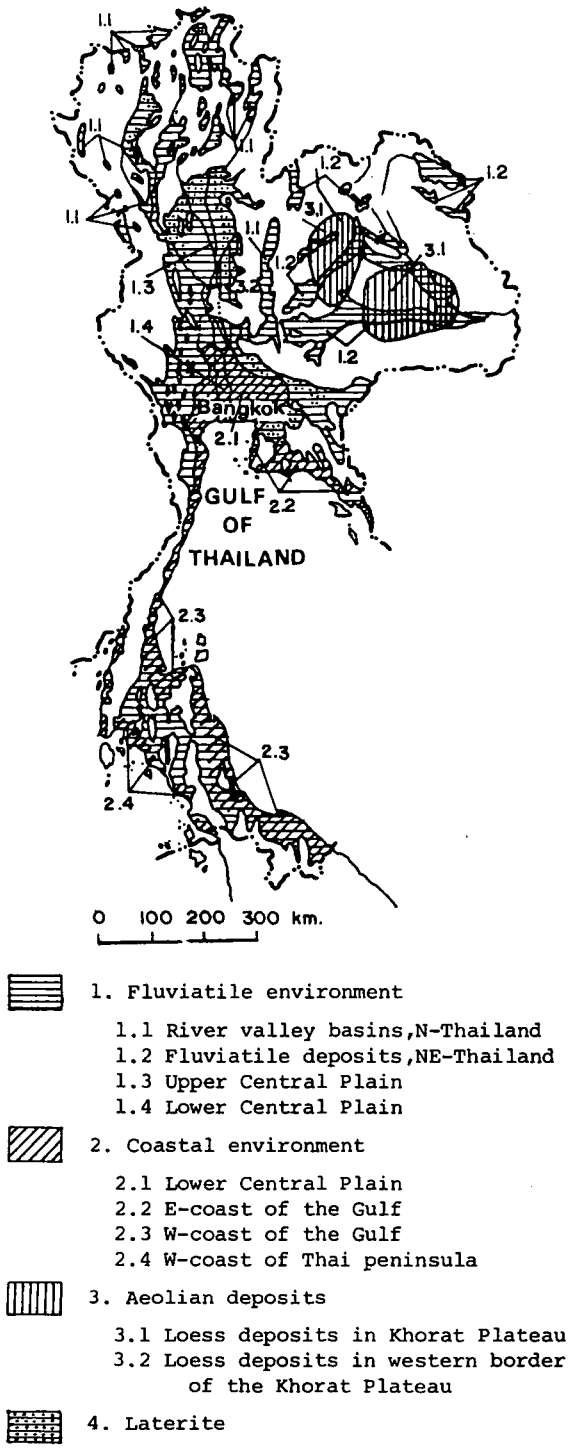

Fig. 1. Sketch map showing the distribution of Quaternary deposits of Thailand.

unit which is considered to be the oldest mapped unit in this area (Kaewyana & Tiyapairach 1982). The unconsolidated sedimentary deposts of Ban Luang Muang Kong and Ban Muang Kud, two small intermontane basins in northern Thailand, were described as resulting from the fluviatile environment and their geomorphological evolution were assumed to be influenced by tectonic movements during Tertiary and Quaternary in association with Pleistocene climatic changes (Thiramongkol, 1983).

A gravel bed of approximately 45 metre thick was found adjacent to Chom Thong District, southwest of Chiangmai Province. The extensive gravel deposits accumulated in the Khun Youm river valley basin and can be observed also along road cuts.

Exposures of fluviatile sediments, 15 to 20 metres thick, consist largely of gravel, sand and small amounts of silt and clay outcropping along the higher terraces in the Nan river valley basin. These deposits can be observed in several places at Na Noi District, Nan Province, northern Thailand.

In the Yom river valley, the thick gravel bed of higher terrace at a distance of about 15 kilometres is exposed to the east of Phrae province.

The gravel bed of higher terraces at the eastern rim of Mae Moh sub-basin, east of Lam Pang province, was overlain by basaltic flow (Fig. 2). The basaltic rock in this area has been dated (Barr & McDonald, 1978) and the age appear to be about 0.69 to 0.95 Ma.

During the second Quaternary geology training-workshop held by the Department of Mineral Resources in co-operation with CCOP, Quaternary geologists carried out their field training in the area south of Lampang basin. The results of study suggested that there were five phases of sedimentary deposits and volcanic activity involved during the Quaternary time. The first phase was characterized by coarse sediments overlying Tertiary sediments. The second phase was indicated by thick laterite formation. Then, the formation of terraces at several levels took place during the third phase followed by deep erosion forming deep valleys and contemporaneously the basaltic flow took place. In the fourth phase that followed, the valleys were filled up with fluviatile coarse clastic and then covered by clayey and silty deposits but no distinct laterite formed in this clastic formation. The last phase of Recent deposits are characterized by alluvial deposits and the rivers slightly cut into the valley fills (Second Quaternary Geology Training Workshop Report, DMR, 1981).

From the study of some properties of soil and substrata in the Lampang basin, Hattori (1983), concluded that the soil on Terrace III were derived from younger deposits than those of the underlying. A recent additional study on mineralogical and chemical properties on soil on high terraces in the Chiangmai and Lampang basins had been carried out and a profile of Quaternary deposits consisting of flood plain, Terrace I, Terrace II, Terrace IIIa, IIIb, IIIc and Hill or Peneplain was defined emphasizing that the soil situated on Terrace III is a young soil. This is by considering the parent materials of these soils are mixtures of the gravel layer of the Terrace III and the colluvial deposits of the soil materials from the hill behind (Hattori, 1983). However, this study has not clearly defined the stratigraphic position of the gravel bed in

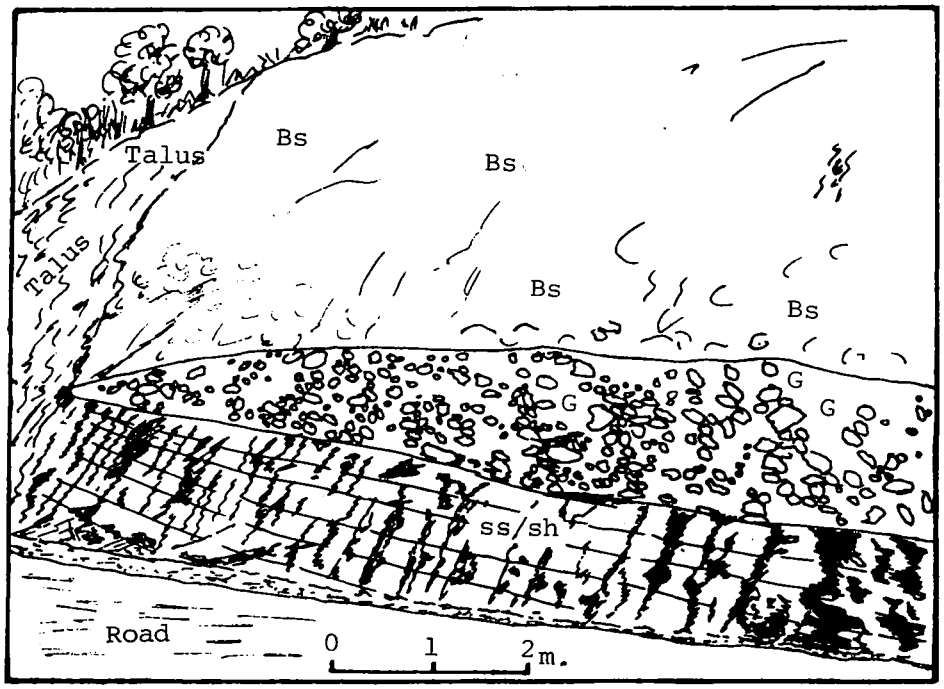

Fig. 2. A sketch of the outcrop of basaltic flow overlies on the Pleistocene (?) gravel bed which again overlies on the semi-consolidated sandstone and shale of Tertiary beds, east of Mae Moh basin, Lampang Province. Bs = Basalt, G = Gravel bed, ss/sh = sandstone/shale.

relationship to other formations even to the three subdivisions of Terrace III itself and the age of the formation has also not yet been determined.

The fluviatile deposits in the Khorat Plateau, northeastern Thailand

The fluviatile deposits extensively developed in the Khorat Plateau consist of two broad, flat and gently sloped landforms, namely, the Khorat basin and the Sakon Nakhon basin. They are separated by a NW-SE Phu Phan range. The Mun and Chi rivers that flow from the west and northwest respectively to the east join into one before confluencing with Mae Khong river. The Sakon Nakhon basin is drained by Mae Nam Songkram and its tributaries in the northern portion of the Khorat Plateau.

The extensive alluvial plain with 150 metres thick of Quaternary sediments was infilled in the Tung Kala Ronghai which is located in the central part of the Khorat basin. This deposit developed as the result of tectonically controlled changes in base level which caused the incision below the present land surface in the valley areas, with subsequent filling in of the larger valley system with alluvial sediments. Their stratigraphic sequences were classified into six units:- alluvial sediments of unknown composition, lower non organic sand, organic sand, non organic sand, clay and sand of meander belt unit (Loffler, *et al.*, 1983) (Fig. 3). Wood samples from organic sand unit

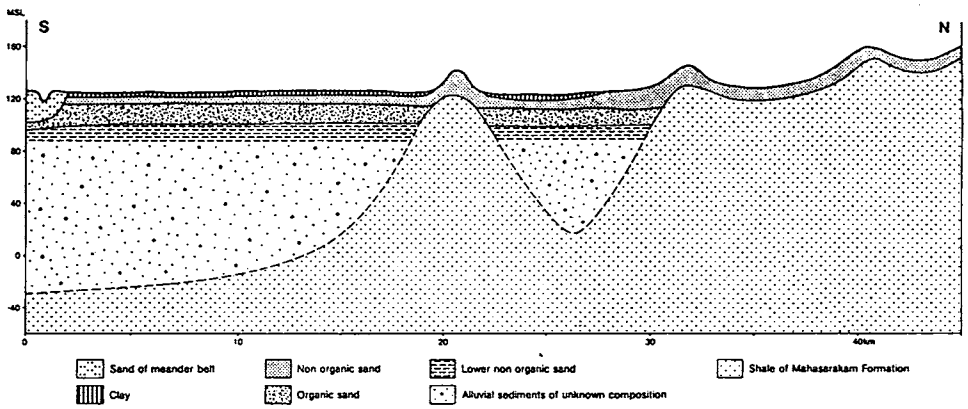

Fig. 3. Idealized stratigraphic cross section across Tung Kula Ronghai (after Loffler and others, 1983).

have been dated by C^{14} method and gave between 43,000 and 20,000 years B.P. Loffler *et al.* (1983), suggested that the uplands and slopes in northeastern Thailand are essentially erosional in origin, as was also pointed out by Michael (1982) and the climatic changes also influenced the landform development in this region which formerly was interpreted as largely alluvial in origin and having developed as a series of depositional and erosional events (Moorman, 1964).

The surficial deposits of Quaternary sediments around the town of Khon Kaen which is located in the northern part of the Chi river comprise fluviatile deposits, aeolian deposits, residual and colluvial deposits (Boonsaner, 1977; Boonsaner and Tanssanasorn, 1983). According to Dheeradilok *et al.*, (1983), the lowest sequences of fluviatile coarse sediments were infilled into a small, narrow valley of the late Cretaceous Mahasarakham formation between Amphoe Ban Phai and Amphoe Chonnabot during the early Quaternary time. Subsequently, the sediments were indicated by erosional and depositional facies.

The discovery of archaeological sites at Ban Chieng, 54 km. south of Udon Ratchathani province, suggested the late Neolithic inhabitants had settled along Mae Namsongkhram river basin during the Holocene time. These prehistoric sites are presently located on the middle terraces of this river basin. Dating by means of thermoluminescence method suggest the oldest time period at Ban Chieng was $4,630 \pm 520$ years (Charoenwongsa, 1973).

The fluviatile deposits in the Central Plain of Thailand

The first general outline of Quaternary deposits in Thailand, especially, the Central Plain was described by Brown *et al.* (1951). Three types of deposits, namely; terrace deposits, alluvium and laterite were noted and the age of Quaternary deposits had been determined based mainly on a hippopotamus skull and leg bones, a buffalo skull and an elephant tooth recovered at Nakhon Sawan province. These fauna

TABLE 1

PROVISIONAL CORRELATION CHART OF QUATERNARY DEPOSITS IN CENTRAL THAILAND (AFTER ALEKSEEV AND TAKAYA, 1967).

Chrono Stratigraphic Units			Index	Surveyed Areas						
				Northern Basin	Nakhon Sawan Area	Southern Basin (Bangkok Plain)	Easthern Margin Area	Mae Klong Drainage		
								Mae Klong Basin	Kwae Yai Valley	Kwae Noi Valley
QUATERNARY	HOLOCENE		Q_4	Alluvium of Flood Plain with "Sawankalok earthernware"	Loamy or sandy Alluvium of Flood Plain	Soft blue sandy clay, silt and fine sand	Alluvium of Flood Plain	Alluvium of Flood Plain	Loamy or sandy Alluvium of Flood Plain	Alluvium of Flood Plain
				Loamy alluvium of Terrace I	Loamy alluvium of Terrace I		Black soil	Loamy alluvium of Terrace I	Loamy alluvium of Terrace I	Loamy alluvium of Terrace I (Pebble – tools on Terrace II)
	PLEISTOCENE	UPPER	Q_3	Alluvium of Terrace II with pisolitic concretions	Clayey deposits of Terrace II with pisolitic concretions	Firm gray and brown plastic clay		Clayey deposits with pisolitic concretions	Surface of Terrace II	Gravel of Terrace III
				weathering of (surface of Terrace III	weathering of (surface of Terrace III	(sand)		(weathering)	(weathering)	(weathering)
		MIDDLE	Q_2	Sandy alluvium of Terrace III	Sandy alluvium of Terrace III with remains of Hippopotamus, Stegodon and Bubalus	Stiff red and gray clay with laterite		Loosely cemented sand, clay and gravel with calcareous concretions	Alluvium of Terrace III	Terrace — like surface
							Loose calcareous non-stratified sediments	(erosion)	Laterized alluvium of Terrace IV (erosion)	
		LOWER	Q_1	Thin laterites developed upon remnants of Peneplains		coarse sand		Clay with carcareous concretions	Peneplanation(?) and weathering	
NEOGENE	PLIOCENE	UPPER	N_2^2							

suggested the deposits appear to the Late Pleistocene to Recent in age. Alekseev and Takaya (1966–1967), made first attempts at establishing the Upper Cenozoic stratigraphy of the Central Plain based mainly on morphological expressions of the deposits and fauna. The stratigraphic correlations were also made throughout the Central Plain (Table 1). Four principle stratigraphic units had been defined as follows: The Lower Pleistocene (Q_1) is characterized by the remnants of peneplain and weathering surface with laterite formation. The Middle Pleistocene (Q_2) is defined by sandy alluvium of Terrace III and based on animal remains of Hippopotamus, Stegodon and Bubalus. The Upper Pleistocene (Q_3) is developed by alluvium of Terrace II with the formation of pisolite concretions. The Holocene (Q_4) is characterized by loamy alluvium of Terrace I including floodplain which contains "Sawankalok earthenware".

A tentative stratigraphy of Quarternary deposits in the Central Plain was also proposed by Takaya (1968). This was classified into floodplain, four different terraces and low-level and high-level peneplains. The classification of these formations was based mainly on morphology of surficial deposits which may be differentiated by the presence or absence of lateritization.

From the studies on the alteration of clay minerals found in the deposits, Hattori (1969, 1972) suggested that the clay mineral assemblage is consistent with the degree of weathering of the deposits and is closely related to the stratigraphic sequence. Consequently a formation of the former stratigraphic sequence which had been established by Takaya (1968), was modified.

The study of more than 2000 groundwater wells in Bangkok Metropolis by Piancharoen and Chuamthaisong (1978) pointed out that the thick sequence of sediments overlying the basement complex in the Chao Phraya basin are unconsolidated and semi-consolidated sediments ranging in age from Tertiary to Quaternary. At least three major breaks of deposits were recognized and each break could be also subdivided into minor horizons. The topmost formation is of marine, soft to stiff, dark-gray to black clay, known as "Bangkok Clay" with the thickness ranging from 20–30 metres. Underlying the Bangkok Clay to the first break at the depth of about 1000 metres are two sequences of medium to coarse sand and gravel layers with minor clay lenses. These are separated by a district clay bed. A typical thick sand and gravel bed of very coarse grained sediments is found at the lowest part. Carbonized wood is always found in this particular horizon. The presence of wood remains or peat within the formation might be a key for correlation to other Pleistocene beds in other parts of the country (Buravas, 1969). The second break found at 250 metres depth in the northern part of Bangkok gradually increases in depth to 400 metres near the Gulf. The sediments at a depth of 100 to 400 metres appear to have more or less the same characteristics as the overlying formation. Based on fresh water and locally brackish to salty water contents in the formation and the distinct break at a depth of 350 to 400 metres suggest that the whole deposit was probably accumulated under subaerated fluviatile environments during the Lower-Middle Pleistocene period (Piancharoen & Chuamthaisong, 1978). Beneath the second break, the deposits consist mostly of well sorted medium to coarse sand with occasional gravel. These deposits might be correspond to the sedimentary facies of shaly sand, dark shale and red bed deposits in the fluviatile-fluomarine environments penetrating the Gulf of Thailand and were deposited when the sea transgressed in Pliocene (Woollands & Haw, 1976).

COASTAL ENVIRONMENT

Many evidences suggest that the occurrence of widespread marine and continental deposits developed in the Lower Central Plain and along the extensive coastal zones for a distance of 1,840 km bordering the Gulf of Thailand and 865 km along the west coast of the Thai peninsula. They probably took place during the Late Pleistocene to Holocene time.

The recent study on the cause and effects of subsidence in Bangkok Metropolis by Nutalaya & Rau (1981), reported that the Chao Phraya basin had been continuously filled throughout the Quaternary time. After the fault-block mountains developed in this region as horsts and grabens with rhombohedral shapes forming discontinuous, narrow mountains ranges, the intervening basins of buried clastic sediments consist of alluvial sand and gravels interbedded with floodplain silts and clays grading seaward into deltaic and marine clays. The basement topography has a relief of more than 1800 metres between poorly consolidated rocks of Palaeozoic and Mesozoic age constituting the floor of the Chao Phraya basin. Following the Pliocene and

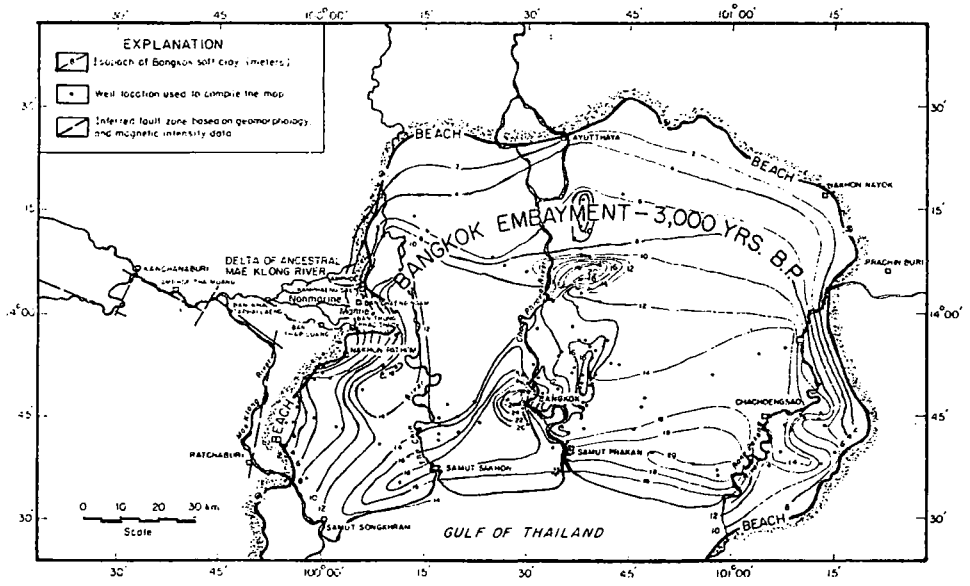

Fig. 4. Isopach map of the Bangkok Clay, showing the Holocene Bangkok Embayment (after Nutalaya and Rau, 1981).

Pleistocene infilling, the development of alluvial fans and sediments occurred around the edge of the basin. Finally, the sea invaded and transgressed over the Central Plain beyond Uthai Thani in the Late (?) Pleistocene, receding during the period from about 45,000 to 14,000 years ago, and making its last trangression over the Central Plain as far as Ayuthaya from 11,000 to 3000 years ago (Fig. 4). They also pointed out that the Bangkok Clay is the most important unit in the stratigraphic sequence from the point of view of land subsidence in the Bangkok area.

The upper most sequence marine muddy Bangkok Clay was excavated into a large pit to use as filling soil for housing development which is located about 15 km at the northeast corner of Bangkok Metropolis. Its stratigraphy and fauna have been studied by Dheeradilok, Chaimani, Piccoli & Robba (forthcoming). Preliminary results indicated that fossil shells and shell fragments occur at the level of 6 to 7 metres depth from the present ground surface containing molluscs of various genera. Some species of these molluscs have been determined: *Cuma lacera, Murex trapa, Anadara antiquata, Placuna placenta, Docinia penicillata, Azorinus abbreviatus, Barnea patula;* determination of the other shells are in progress. Tree remains was identified as *Xylocarpus* sp., a black mangrove tree and dated at $4{,}840 \pm 310$ years BP. Bioturbations and plant roots replaced by limonite are found underlying the shell bed from the level of 7 to 11 metres depth. Below the dark gray clay at 15.50 metres depth the formation starts to change into sand with increasing sand content downward towards the bottom of the pit.

C^{14} age dating of two peat samples gave 5200 ± 350 years and 5800 ± 180 years

and one shell sample gave 6300 ± 240 years. These suggest that the last event of transgression of the sea over the Central Plain took place 5000 years ago, which was probably contemporanous with the occurrence of fossil giant oysters found at Amphoe Lat Lum Kaew giving the C^{14} age of 5500 ± 50 years BP (Ingavat, Chonglakmani, Piccoli & Robba, forthcoming).

Two deltaic plains: the old delta that occupied the upper portion in the north and the young delta that developed in the south were recognized from the result of the study on landforms in the Lower Central Plain (Takaya & Thiramongkol, 1982). This appears to be supported by two Quaternary brackish clay beds found in the lower reaches of the Chao Phraya river (Takaya, 1971) and some properties of brackish sediments in this area were also studied by Hattori (1972).

A comparative study of the Mekong delta based on satellite imagery resulted in a geomorphological map of Chao Phraya delta of scale 1:1,000,000 showing the distribution of geomorphological units (Mekong Secretariat, 1980). This study also pointed out that the deltaic area occupied mainly the southern part of the Central Plain whereas the fluviatile deltaic sedimentation occurred upstream from the marine and brackish facies and the consequence of the regression was a drop in the base level of the rivers which formed their new floodplains at a slightly lower level, thus creating fluvial terraces within the deltaic formulations.

Ancient shorelines at three different levels, above the present sea level, were interpreted from landsat imageries, topographic maps, and aerial photographs by Supajanya (1980). They are presumed to be the regression shorelines of the Quaternary period, not earlier than Upper Pleistocene.

The study on recent sediments in view of transportation along the present shorelines in the Gulf of Thailand by interpretation of Landsat imageries and field evidences suggest accretions of coastal plains developed during the Holocene (Dheeradilok, 1980).

The investigations of Quaternary deposits along the coastal zones have been mapped by the Quaternary geology units of the Department of Mineral Resources in the Rayong area of the east coast (Sinsakul, *et al.*, 1982; Kaewyana, forthcoming), in Laem Chabang area of Chonburi (Dherradilok, *et al.*, 1982), in Hat Yai area (Wongsomsak *et al.*, 1982), in Songkhla province (Tiyapairach & Chaimani, 1983) (Fig. 5) and in the area of tidal-deposits of Phang Nga bay, southern Thailand (Sinsakul and Jongkanjanasoontorn,, 1984) (Fig. 6). Some reports of the investigations of these areas together with maps of scale 1:50,000 and profiles have been produced.

Recent study on geomorphology and palynology in relationship to sea level changes in Chanthaburi, eastern coast of Thailand interpreted two sea level changes, the older dated at $16,200 \pm 1,320$ years BP represents the beginning of the sea's regression during the last glacial event, Late Pleistocene, and the younger of $8,400 \pm 1,300$ years BP., is the start of the Holocene trangression in eastern Thailand (Hasting & Pramojanee, 1983).

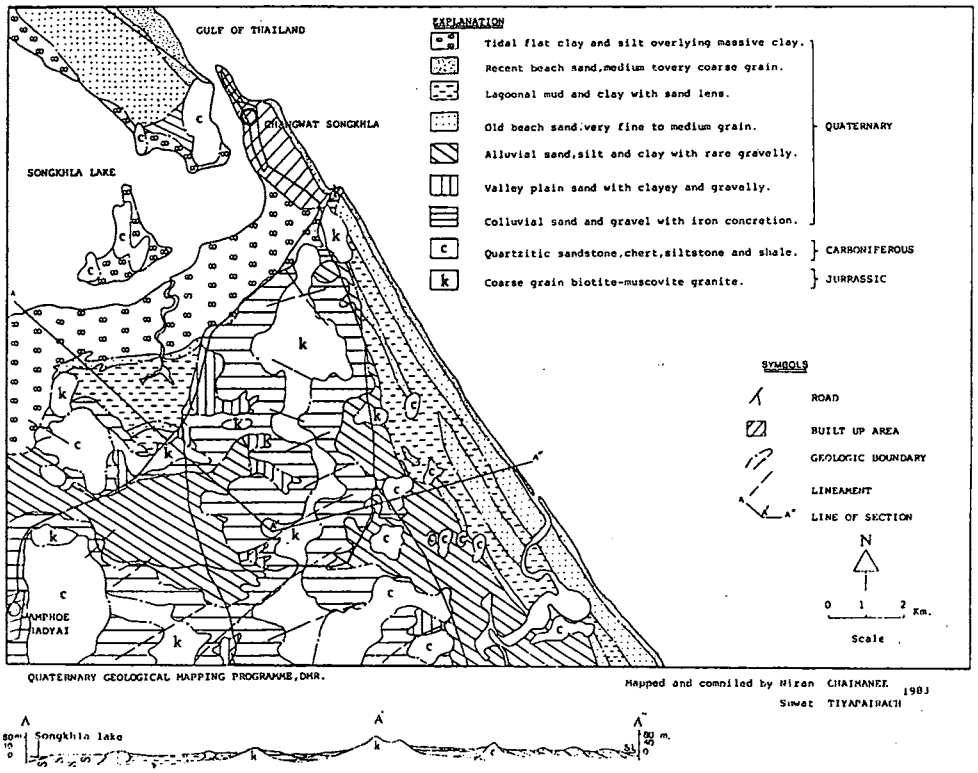

Fig. 5. Quaternary geological map of Changwat Songkhla, southern Thailand.

Coastal deposits in the area south of Nakhon Sri Thammarat province, southern Thailand was investigated by Kaewyana & Kruse (1981). They reported that the sediments are of muddy coast type with only two-, widely-spaced ancient beach-ridges. The open coast deposits contain more plant remains of Holocene age. The inshore deposits which represent the high tidal flat deposits can be distinguished among themselves by either an increase in amount of plant remains or by a sudden decrease in grain size, which in the open coast area is accompanied by a more or less diffuse layer enriched in sand. In the west and south of the investigated area, the deeper part of the deposits show a progradational sequence with a eustatic, peat layer overlying an older land surface with a palaeosol of the Late Pleistocene-Holocene. The upper part of the deposits reflects the regression of the sea (Kaewyana & Kruse, 1981).

A recent study of coastal sediments in eastern Peninsular Thailand (Pramojanee *et al.* 1986) indicated that the Holocene transgression began there about 8,500 yrs BP. A stillstand occurred between 5,000–4,000 yrs BP, with the regression and subsequent shoreline progradation beginning after this. Sea levels are thought to have been no higher than +6 m relative to the present sea level. Correlation between the east and west coasts is now being done.

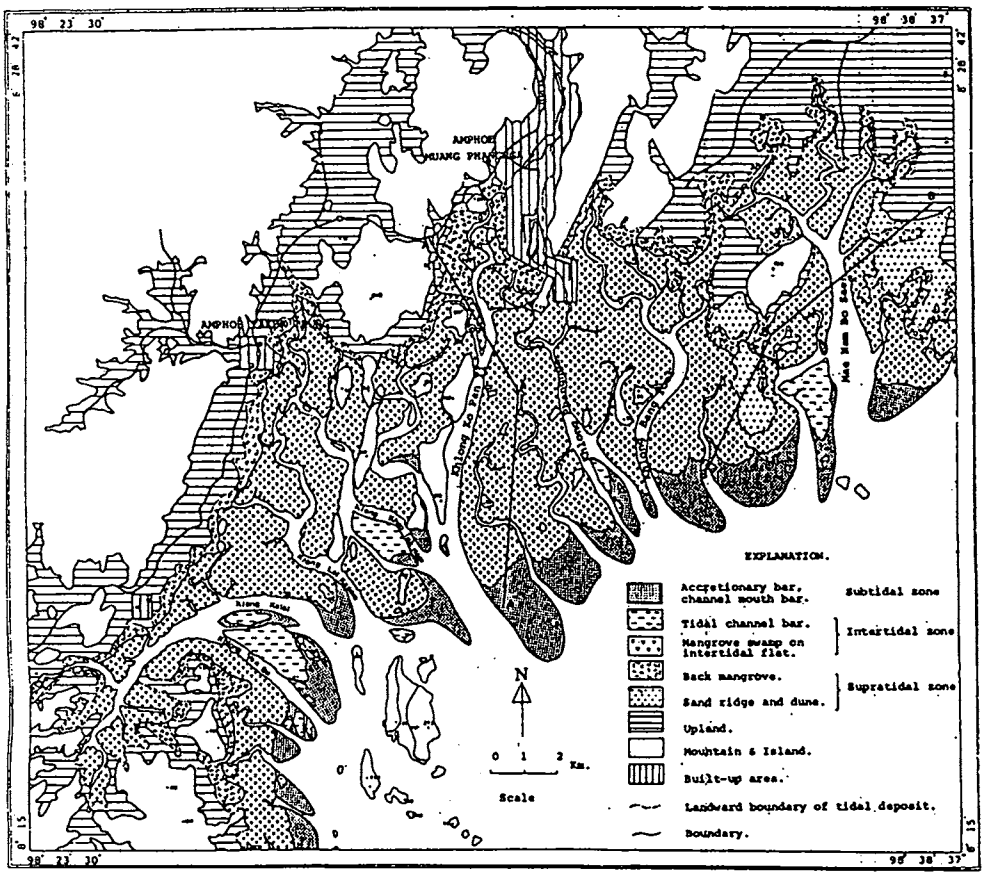

Fig. 6. Map of generalized morphology and depositional environment in Phangnga Bay (Sinsakul & Jongkanjanasoontorn, 1983).

One item of controversy still unresolved is the sea level during the late Pleistocene interstaidail, the Denekamp. Evidence from outside Thailand (Geyh, 1979) indicates low sea levels (< -20) while evidence from Thailand suggests sea levels very near the present level (Kruse, 1982; Pramojanee *et al.*, 1986; Sinsakul and Jongkanjanasoontorn, 1984). Further study is indicated.

AEOLIAN DEPOSITS

Nutalaya and Selvakumar (1980) suggested that during the Interglacial and sub-Recent periods several localities appear to have development of loessial deposits as evidenced by the expression of landform and sediments in the Khorat Plateau and the Khorat apron. Loessial deposits with stratigraphic position found at terraces around the town of Khon Kaen were studied by Boonsaner (1977). The study on Landsat imageries and aerial photographs suggested that the remarkable landform of loessial deposits appear to have been developed in the area west of Ubol Ratchathani province,

northeastern Thailand (Supajanya, 1982, personal communication). Nutalaya and Selvakumar (1980) noted that the aeolian deposits are also found in the adjacent to Nan river nearby Pisanulok province which is located in the eastern part of Upper Central Plain. He pointed out that the bahada landform is noticeable in Khok Samrong–Lob Buri–Sara Buri and these loesses partially to completely cover and obliterated the pre-existing landforms and thus make it more difficult to unravel the sequence of landform development.

Tuckson et al. (1982) on the generalized stratigraphy at Suwannaphum, northeastern Thailand, suggested that the deeper layers underlying a mixed lacustrine-alluvial deposits in the Mun river basin have a degree of sorting consistent with an aeolian origin, but which could be due to a well sorted source.

The geomorphological development of the Tung Kula Ronghai and its surrounding was studied by Loffler *et al.* (1983) with the aid of surface and subsurface information. It is shown that the present landscape developed as the result of tectonically controlled changes in base level causing incision well below the present land surface in valley areas followed by filling in of the larger valley systems with alluvial sediments. Superimposed onto these tectonically controlled processes were changes in climate and environmental processes with alternating drier and more humid phases and this was reflected in the different character of the sediments. Aeolian activity during the glacial period has been responsible for masking much of the erosional landscape with a blanket of sand. They pointed out that the pronounced dryness of the north-eastern Thailand was explained by the extensive land area during glacial low sea level stands.

A deposit in Udonthani Province thought to be aeolian in origin was dated to $6{,}620 \pm 150$ yrs BP (P. Hasting (DLD), personal communication). It is still unclear whether this sediment (Yasothon soil was aeolian in origin or had developed through local wash as believed by Michael (1982).

LATERITE

Geographically, Thailand is situated in a tropical region, and laterite is a known product of weathering in humid tropical climate. It is extensively developed throughout the country, particularly, in higher terraces along the edge of the Central Plain, in the higher terraces of the river valley basins in northern Thailand, in the Khorat Plateau and in southern Thailand. The lateritized formation is one of important units of the Quaternary deposits in this region as first suggested by Brown *et al.* (1951).

Alekseev & Takaya (1966–1967) noted that laterite widely developed on the remnant of peneplains and in high terraces which was considered to be the oldest formation of Plio-Pleistocene age in the proposed Quaternary stratigraphy of the Central Plain.

According to the classification of Quaternary formations defined by Mekong Secretariat (1980), on the result of the comparative study of the Mekong Delta, the sub-division, ancient alluvial deposits and recent alluvial deposits is based on the

presence or absence of "lateritization". Ancient Pleistocene and Plio-Pleistocene alluvia include the lateritized layers, and are separated from recent Holocene alluvia by a clear stratigraphic contact showing signs of prolonged emergence and hardened erosion surfaces.

The laterite is cut into blocks of any desirable dimensions or shape to produce construction material. The lateritic concretion or pisolite is supplied as raw material for producing portland cement or road pavement. Many archaeological sites of ruinous temples in Thailand were built from laterite-blocks during the historical time.

DISCUSSIONS ON QUATERNARY STRATIGRAPHY

Quaternary deposits have been investigated by many geologists in different regions in Thailand recently. Physiographic expression and morphology of the surficial deposits were often used as a basis for stratigraphic division and classification. Attempts on basing the divisions on rock-stratigraphic, time-stratigraphic and geologic-climate units have been made. However, correlations of stratigraphic units by position in sequences that record similar climatic depositional cycles still need distinctive time markets or other means of determining age equivalence to demonstrate contemporaneity between units of the sequences being compared. Only few stratigraphic parallel marker units are known in Thailand. Being preserved only very locally, basalt flow and tektite both dated as approximately 0.7 m.y., limit their utility for long distance correlation. The palaeosol found underlying the marine sediments at many places along the coastal areas might be another good time-stratigraphic marker. Data about absolute or direct dating such as isotopic dating and palaeomagnetic are very few in Thailand. Many more age determinations are needed to make the correlations and chronologies of Quaternary sequences in Thailand more perfect than they are now. Some studies of Quaternary fossils have been made in different areas.

TABLE 2

TENTATIVE STRATIGRAPHY OF THE CENTRAL PLAIN (AFTER TAKAYA, 1968).

Area / Stratigraphical unit		Northern basin	Nakhon Sawan area	Southern basin	Calcareous deposits
Holocene		Floodplain (sandy)	Floodplain (sandy)	Deltaic plain (clayey)	Floodplain (sandy)
		Terace I	Terrace I	Deltaic plain	Terrace I
		Formation I (loamy)	Formation I (clayey)	Formation I (clayey)	Formation I (clayey)
Pleistocene	Last glaciation	Terrace II	Terrace II	Terrace II	Terrace II
		Formation II (clayey)	Formation II (clayey)	Formation II (clayey)	Formation II (clayey)
	Penultimate glaciation	Terrace III	Terrace III		
		Formation III (sandy)	Formation III (sandy)	?	
	Antepenultimate glaciation	Terrace IV (?)	Terrace IV (?)		
		Formation IV (sandy)	Formation IV (sandy)		Calcareous deposits
		Low-level peneplain	Low-level peneplain		
Plio-cene	?	High-level peneplain	High-level peneplain		

The problems of climatic change might be resolved as the knowledge of palaeontologic evidence improves. Based on various means of time-stratigraphic correlation only few tentative Quaternary stratigraphy have been proposed. Tentative Quaternary stratigraphy of the Central Plain of Thailand proposed by Alekseev & Takaya (1966–1967) and by Takaya (1968) are given here (Table 1 & 2).

Of all Alekseev & Takaya's distinguished units only the age of floodplain deposits are known. Correlation of Terrace III deposits with mammalian fossil-bearing sediments dated as Middle Pleistocene at Dechatiwongse bridge, Nakhon Sawan province is doubtful. Since Quaternary climatic changes were recurrent and cyclic, correlations of terraces in different areas are based on parallel sequence risk being merely homotaxial. Moreover, Takaya's correlation of Quaternary sequences in the Central Plain of Thailand with the glacial sequences is arbitrary. To be a valid Quaternary stratigraphy these proposed tentative stratigraphy have to be improved. Hasting and Leingsakul (1983) studied Quaternary pollen and other signs of climatic change at some places in Thailand and with the aid of C^{14} datings they proposed a tentative chronology in relationships of climatic changes during Late Quaternary in Thailand as follows:-

RADIOCARBON DATING LOCATIONS IN THAILAND.

Site	Age*	Climate change**
2a) TKR	34,000 – 20,000	D- W- D
2b) Tha Mai	16,200 ± 1,320	W- D
3) Bangkok	17,000 – 14,700	D
4) Offshore— Nararhiwat	11,170 ± 400	D- W
5) Tha Ma	8,400 ± 1,300	D- W
6) Bangkok	5,200 ± 350	D- W
7) Chiengmai	4,300 ± 160	D- W
8) Narathiwat	3,780 ± 250	D- W

*Age in years BP
**D = Dry climate, W = Wet climate

PROPOSED CHRONOLOGY OF LATE QUATERNARY CLIMATIC CHANGE IN THAILAND.

Age*		Possible Climate
60,000		Dry and cool
30,000		Wet and warm
20,000		Dry and cool
	Pleistocene	
11,000*	Holocene	Wet and warm

*Age in years BP
**Change at C.4,000 for highland areas.

SUMMARY AND REMARKS

The study on Quaternary deposits in Thai sedimentary plains at the present stage can be classified into four distinct units depending on their mode of occurrences as the following:-

1. Fluviatile deposits of river valleys systems in the north, west and eastern mountainous areas: in the lowland and around the edge of the Central Plain; in southern Thai peninsula and in the broad river valley basins of the Khorat Plateau of northeastern Thailand.

2. Coastal deposits are extensively developed in the Central Plain. In so far the evidences suggest that the sea involved and transgressed over the Central Plain beyond Uthai Thani in the Late Pleistocene receding during the period from about 45,000 to 14,000 years ago, and making its last transgression over the Central Plain as far as Ayuthaya from 11,000 to 3,000 years ago. The definite indications of the present marine sediments are found along the coastal zones bordering along the Gulf of Thailand and in the west coast of Thai peninsula.

3. Aeolian deposits especially loesses appear to be developed in the northeastern Thailand and in the areas adjacent to the western border of the Khorat Plateau whereby the different character of sediment deposits so far observed are reflected in the climatic changes of alternating drier and more humid phases.

4. Laterite formation, a product of weathering in humid tropial climate, generally occurred on older and higher terraces of the sedimentary basins in Thailand. According to bibliographical data the sub-division of the Quaternary formations into ancient alluvial Plio-Pleistocene deposits and recent alluvial Holocene deposits is based on the presence or absence of laterization.

Evidences of block-faulting are involved with infilling of alluvial sediments in the larger valley basin systems. These appear to have been controlled by tectonic movements which also affected the changes in base level during the Quaternary time. Superimposed onto these tectonically controlled processes were changes in climatic and environmental processes with alternating drier and more humid phases and this is reflected in the different character of sediments. The marine transgressions and regression during Late Pleistocene–Holocene are also definite indications. The evidence of effusive basaltic flow overlying the gravel bed deposits occurring in northern Thailand suggest the result of tectonic movement during Quaternary time.

In conclusion it can be said that the Quaternary stratigraphy of Thailand at the present is in an early stage of development. It seems most desirable that attempts be continued to set up local time stratigraphic classification based on various types of lithogenetic sequences in a wide variety of geographic areas. A compilation of all information from a number of localities will provide a chronology of high probable accuracy. More detail studies of Quaternary deposits together with absolute age determinations are needed before the valid Quaternary stratigraphy of Thailand can be established.

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