Geol. Soc. Malaysia, Bulletin 16, December 1983, pp. 99–116

Geology of the Bangkok Clay

Jon L. Rau[1]
Prinya Nutalaya[2]

Abstract: The southern part of the Central Plain in Thailand is blanketed with a two part sequence here termed the Bangkok Clay. The lower part is a mixture of brown stiff clay, silt and sand which is interpreted as a deltaic-alluvial plain sequence. It is heterogeneous and cut by numerous channels reflecting drainage across the plain in Late Pleistocene and Holocene (?) time. The lower clay is separated from the upper deposit, a soft gray silty clay, by an erosional unconformity marked by paleosols and buried valleys. The upper clay is much softer and more homogeneous covering about 14,000 square kilometers of the lower Plain. It contains marine fossils which suggest it was deposited in from 20 to 50 meters of water. The deposit may be the result of the Flandrian transgression of Holocene time. Its environment of deposition is inferred to be a delta front (slope) where periodic slumping occurred. The upper 2–4 meters of the soft clay is weathered and altered to a mottled reddish grey crust. This soft clay emerged from the Holocene sea approximately 3,000 B.P.

INTRODUCTION

The southern Central Plain of Thailand supports the largest rice growing area in Southeast Asia, covering about 14,000 square kilometers. The surface of the Plain is blanketed with a soft marine clay that is so highly compressible that it causes major problems in Bangkok, a city of five million. The clay compresses under the load of major structures, road and railway embankments, and requires soil engineers to use special piling or to foot piles in a deeper horizon. Furthermore intensive pumping of ground water in Bangkok has resulted in the dewatering of sand aquifers immediately beneath the clay. The result is that pore pressure is reduced in the clay as water drains out of it and it compresses rapidly. At the present time the rate of compression is so rapid that most of the city of Bangkok will be at or below sea level in 10 to 20 years. Field instruments indicate a rate of compression of the upper 50 m section of 3 to 4 cm/year, corresponding to a rate of decline in the piezometric surface of from 3 to 4 meters per year.

The purpose of this paper is to briefly describe the geology of the clay and consider its environment of deposition. This information is necessary to consider the possibility of recharging the aquifers beneath the city of Bangkok so as to stabilize its surface and reduce the threat of prolonged flooding during the monsoon season, when drainage within the city is already inefficient because of the very low slope.

PREVIOUS WORK

The first worker to focus major attention on the soft clay at the surface of the lower Central Plain was Cox (1968; 1970). Although his papers focused on geotechnical

[1]Department of Geological Sciences, The University of British Columbia, Vancouver, B.C., Canada
[2]Division of Geotechnical and Transportation Engineering, Asian Institute of Technology, Bangkok, Thailand

properties and problems of siting buildings, roads, airports and harbours on marine clays, they also discussed the environment of deposition of the soft clay. The following major points were made by Cox (1968) in his discussion of the origin of the soft clay.

1. Its lithology is grey, soft, silty clay.
2. Its thickness varies from 10 to 30 meters at the Gulf Coast, but thins to zero inland.
3. The clay is derived from material brought down by the rivers of the Central Plain.
4. The sea in which the soft clay was deposited transgressed over the Central Plain about 8,000 to 4,000 years ago.
5. A deltaic plain was built into the sea after the transgression.
6. During the emergence the clay was alternately wet and dry during tidal cycles.
7. Terrestrial sediments were gradually deposited over the top of the clay and the surface of the plain was built above sea level.
8. Consolidation of the clay began as sediments were deposited over the top of it.
9. The surface subsided to an elevation of from 0.5 to 3.0 meters above mean sea level.
10. Sea water was trapped in the pores of the clay.
11. Seasonal flooding leached some of the salt from the upper part of the clay.
12. A weathered crust developed as the surface of the clay was alternately wet and dry.
13. The depth of weathering extends to a depth of from 6 to 8 meters but is shallower toward the Gulf.

NATURE OF THE BANGKOK CLAY

The term Bangkok Clay has been used in several ways but the most frequent usage is as follows. Moh *et al.* (1969) divided it into three units:

i. weathered clay
ii. soft clay
iii. stiff clay

The term stiff clay is used by geotechnical enginners to refer to the difference in the shear strength of the soft clay and the clay beneath it. Buried laterites and a dissected surface at the top of the stiff clay clearly indicate that it is separated from the overlying soft clay by an unconformity. The stiff clay is now known to be several tens of thousands of years older than the soft clay. The weathered clay of Moh *et al.* (1969) is simply the uppermost meter or two of the Bangkok Clay.

The unit beneath the weathered clay or crust is typically a soft olive grey or medium to dark grey clay. It locally contains fragments of shells and decayed plant remains. Sand lenses and silt are in places interbedded or interlaminated with the clay. Carbonate concretions (calcrete), apparently are absent from the soft clay though they have been reported from the underlying stiff clay. Thin beds of peat and organic detritus are common in some areas. The shells in the soft clay are similar to marine bivalves and gastropods living on the floor of the Gulf of Thailand and in deep harbour areas such as Hong Kong. The salt content is unusually high. The base of the soft clay rests on a dissected surface cut deeply into the underlying stiff clay. Laterally, the soft clay grades in places into clean, well-sorted fine sands, some of which represent beach deposits. The most abundant clay mineral in the Bangkok Clay is kaolinite, with illite and montmorillonite of lesser importance (Petersen, 1977). The approximate percentage of kaolinite in the soft clay ranges from 47 to 64 %, illite from 10 to 20 %, and montmorillonite from 20 to 43 %. The silt and sand fraction consists of the minerals quartz and feldspar with small amounts of heavy minerals.

The stiff clay is generally lighter coloured, commonly light brown to brown mottled yellow and buff. It is sandier than the soft clay and is more commonly found in a medium to coarse sand channel facies. On the other hand it less commonly contains either shells or organic detritus in the form of peat or humus. The silt content ranges from 17 to 35 % and the sand from 0 to 100 %. The top of the stiff clay is weathered zone and may be represented by paleosols or laterites. The sharp colour change at the base of the soft clay is readily apparent in cores and drill cuttings.

UNCONFORMITY BETWEEN SOFT AND STIFF CLAY

There is abundant evidence that the stiff clay was dissected by streams prior to the deposition of the soft clay. This is especially evident in the Bangkok area, where abundant data are available on the thickness of the soft clay (Figure 1). This erosion is shown by the presence of broad, shallow valleys carved into the stiff clay in the vicinity of the Gulf of Thailand and narrow, deeper valleys cut into the clay further north, near Ayutthaya.

Eide (1968, 1977) studied the soft clay on the Nakhon Sawan Highway between km 51.8 (10 km north of the campus of the Asian Institute of Technology) and Ayutthaya. Over a distance of 20 km, soft clay occurs at the surface and ranges from 5 to 15 meters in thickness. Over most of this distance the thickness of the soft clay is only 5 meters, but thicker sections occur in buried valleys that range in width from 50 to 100 m (Eide, 1977). These valleys predate the soft clay and indicate that the erosion surface that developed on the stiff clay in the Ayutthaya area was already entrenched to a depth of at least 10 m by streams before the marine transgression deposited the Bangkok soft clay.

Support for this entrenchment cycle is also provided by data from the rail line that parallels the Nakhon Sawan Highway, where thicker sections of the soft clay are found in buried valleys. Eide (1977) was able to plot data from both the rail line and the highway so as to reveal the path of the river that cut the valley (Figure 2). If one

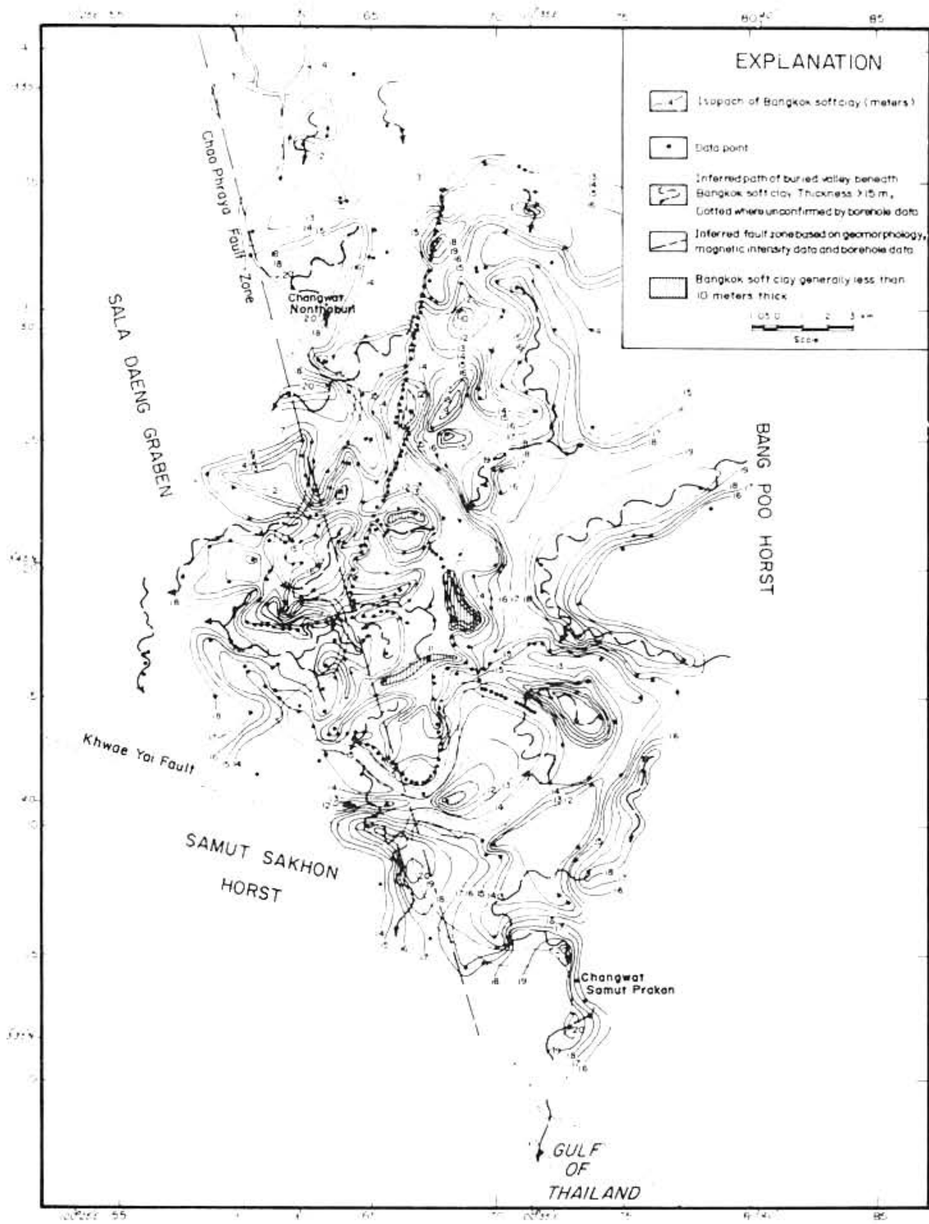


Fig. 1. Isopach map of the soft clay in the Bangkok area.

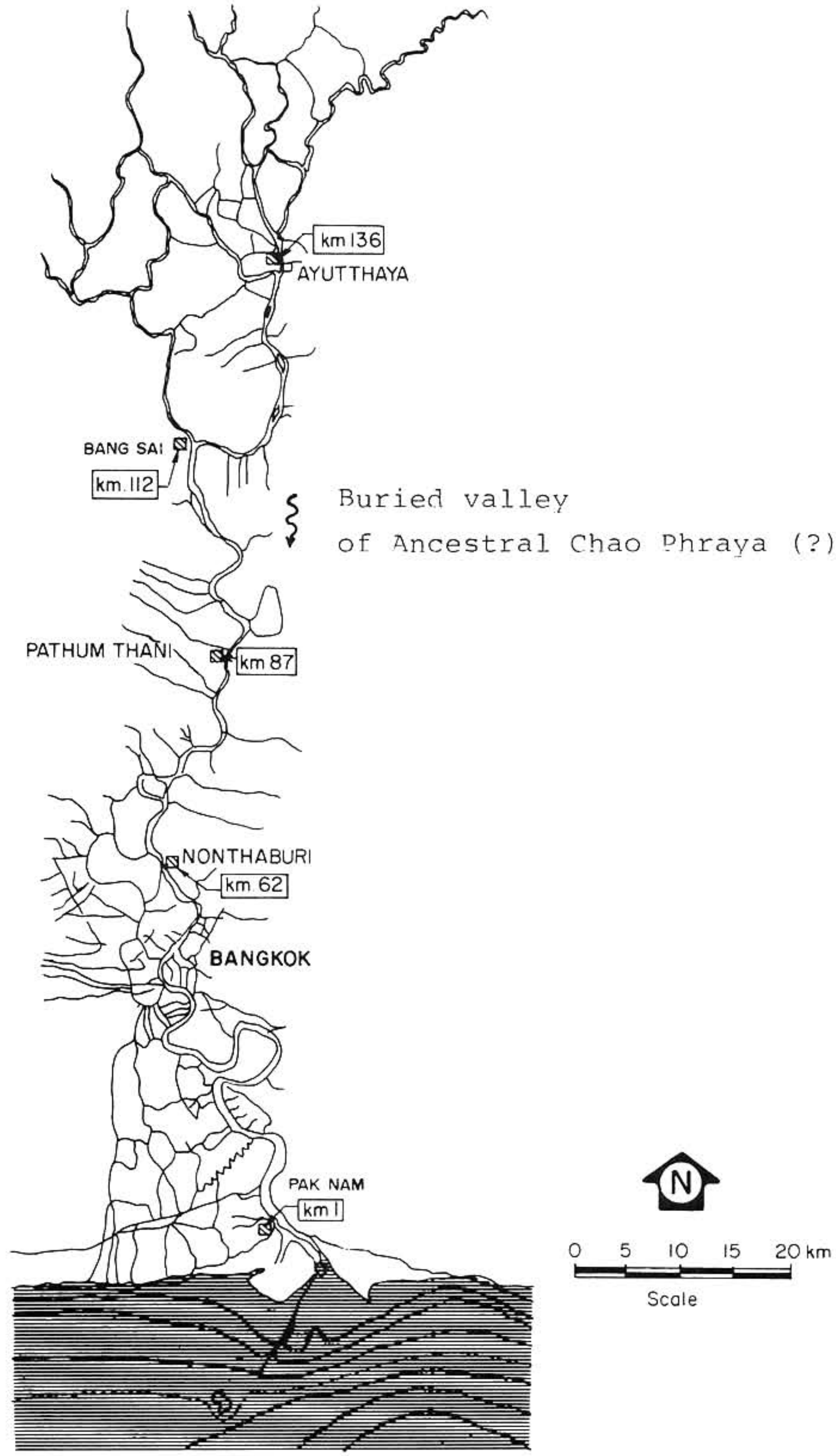


Fig. 2. Location of the buried valley on the Nakhon Sawan Highway about 52 kilometers north of Bangkok.

assumes that all the thick sections are related to the valley of a single river, presumed to be the ancestor of the Chao Phraya River, the pattern is one of a meandering stream which is more sinuous than the present Chao Phraya.

Eide (1977) constructed a longitudinal cross section of the subsurface along the Nakhon Sawan Highway (km 53—km 72), showing the valleys as "V" shaped. Such valleys probably developed during an entrenchment event following the deposition of the soft clay. Such an event could either be related to regional uplift or to an increase in the discharge of the ancestral Chao Phraya. No channel deposits were reported on the floor of the valleys of the unconformity.

Holmberg (1978) studied the geotechnical properties of the Bangkok soft clay on the Nakhon Sawan Highway at kilometer 53 near Bang Pa In. Geotechnical properties enable the base of the clay to be recognized at a depth of 4.0 m below msl over most of this area. The top of the soft clay is 2 m above msl over most of this area. The valleys that are cut into the stiff clay are 23 m deep here. They are filled with soft clay but some fine sand with plant remains is present in the basal 6 meters. In most buried valleys no sand or gravel is present.

In summary, the topography on the top of the stiff clay in the Nakhon Sawan-Bangkok area was in a youthful stage at the time of the deposition of the soft clay unit. The surface was dissected but the valleys were neither deep nor wide. The interstream areas were broad and flat. The valleys meander even more sinuously than the present Chao Phraya but lack flood plains suggesting that the entrenchment cycle was halted abruptly at the time of the marine incursion that resulted in the deposition of the soft clay.

THE UNCONFORMITY NEAR THE GULF OF THAILAND

Near the Gulf of Thailand some data on the base of the soft clay is available from the construction of the Bangkok-Siracha Highway, which crosses the Bang Pakong River at kilometer 50 and then closely follows the present coastline south. Eide (1977) shows a maximum relief of 11 m on the eroded surface at the top of the stiff clay. A 7 km wide buried valley, asymmetrical in profile, has been cut into the stiff clay 30 km southeast of Bangkok. The erosion surface there slopes toward kilometer 30 on the Bangkok-Siracha Highway from both directions. This large buried valley may have been the ancestral Bang Pakong River, and dates from a Pleistocene pluvial interval. It is clear that the profiles of the buried valleys in the southern part of the Central Plain are totally unlike those of the Nakhon Sawan Highway section. The Bangkok-Siracha buried valleys are cut into a more maturely eroded surface with few flat-topped summits occuring between major valleys. The southern valleys are not sharply defined as they are in the Nakhon Sawan area, and lack the nearly vertical walls seen there. Locally, relief on individual buried valleys ranges from 2 to 6 meters. The valleys are less deeply entrenched in the south because they are closer to base level. In the north the floor of the largest and deepest valley lies approximately 23 m below present sea level while several other valleys near Nakhon Sawan lie from 15 to 21 m below sea level (km 53—km 72). The valleys along the south coast would have been the first to be affected by a rising sea level and river downcutting would have been terminated earlier there than in the north.

In conclusion, there is irrefutable geological evidence that the stiff clay was exposed to subaerial erosion for several tens of thousands of years. During this time it was scoured and dissected by streams flowing to the ancestral Gulf of Thailand but no great thickness of sediment was removed. The mineralogy, colour and texture of the top of the stiff clay all suggest that it has been weathered prior to the deposition of the soft clay. Cox (1968) suggested that the surface of the stiff clay had been eroded to a depth of 15 m to explain the fact that it is overconsolidated. Eide (1967) and Moh *et al.* (1969) rejected the evidence for surface erosion and explained the overconsolidation of the stiff clay by attributing it to dessication and weathering rather than to preloading. The presence of the buried valleys in both the north and south of the lower Central Plain tend to lend credence to the interpretation of Cox (1968), but the amount of sediment stripped from the top of the stiff clay is unknown at this time.

AGE

Indirect evidence indicates that the most recent marine transgression into the Bangkok Plain occurred during Holocene time. The dating of this marine invasion is important as it marks the beginning of the deposition of the upper part or soft clay of the Bangkok Clay and succeeds the deposition of the stiff clay. According to Biswas (1973) the last rise in sea level in the Gulf of Thailand occurred after 11,170 ($\pm$ 150) years B.P. This date is the radiocarbon age of wood found beneath a laterite presently 68 meters below sea level in the Gulf of Thailand. The wood is a mangrove swamp deposit 1.5 m below the sea floor, 200 km east of Kuala Trengganu, Malaysia. The data suggest that there was a sea level rise of almost 70 m in the last 11,000 years, although tectonic subsidence is a possible alternative.

Haile (1971) found evidence for higher sea-level stands in Peninsular Malaysia of + 6 m above present sea level in Middle Holocene time. At this level he found extensive beaches suggesting that a still stand was maintained for some time. Radiocarbon dates on sea-cave deposits in Perlis, on the west coast of West Malaysia, are dated as 5,200 ($\pm$ 200) yrs B.P. Clam shells on Natuna Island on the Sunda Shelf have been dated at about the same age, and they are found + 0.4m above present sea level.

The average recovery of sea level since the end of the Wurm glaciation is about 1 m in 100 yrs if the data of Biswas (1973) and Haile (1971) are used to determine the rate of sea level rise (Sawamura and Laming, 1974). On the other hand, it is unusual to find subsidence rates in Tertiary basins exceeding one m in 10,000 years. Therefore it is considered there is good evidence for a eustatic rise in sea level in the Gulf of Thailand from 70 m below msl 11,700 yrs B.P. to about + 6 m above sea level, 5,200 yrs B.P.

In order to determine the age of the soft upper unit of the Bangkok Clay, eleven radiocarbon dates were obtained from shells in the clay deposits near the surface of the plain. Ten of these were obtained from the stiff clay underlying the soft clay and one was taken from the soft clay. The material dated from the soft clay consisted of bivalves similar to those found on the floor of the Gulf of Thailand today. The date obtained on the soft clay at a depth of 15.5 to 16 m was 710 (±280) years B.P. This deposit is about 10 kilometers south of Samut Prakan, at the mouth of the Chao Phraya River. The shells were collected from near the base of the soft clay. Their age should represent the beginning of the marine incursion into the Central Plain which resulted in the deposition of the soft clay. It is difficult to reconcile such a young date with other data that suggest the transgression began near the beginning of the Holocene and culminated in Middle Holocene time. The base of the clay should be about 6,000–10,000 years old. It is possible, but unlikely, that the sea transgressed from the latitude of Kuala Trengganu, Malaysia, to the northern edge of the Gulf of Thailand in 10,250 years and then covered the rest of the plain and regressed from it in less than 710 years. The base of the clay would be required to subside 15–16 m in less than 710 years, because the underlying deposit is non-marine and the soft clay was deposited in at least 20 m of water. Therefore, the 710 year old date for the base of the soft clay is rejected.

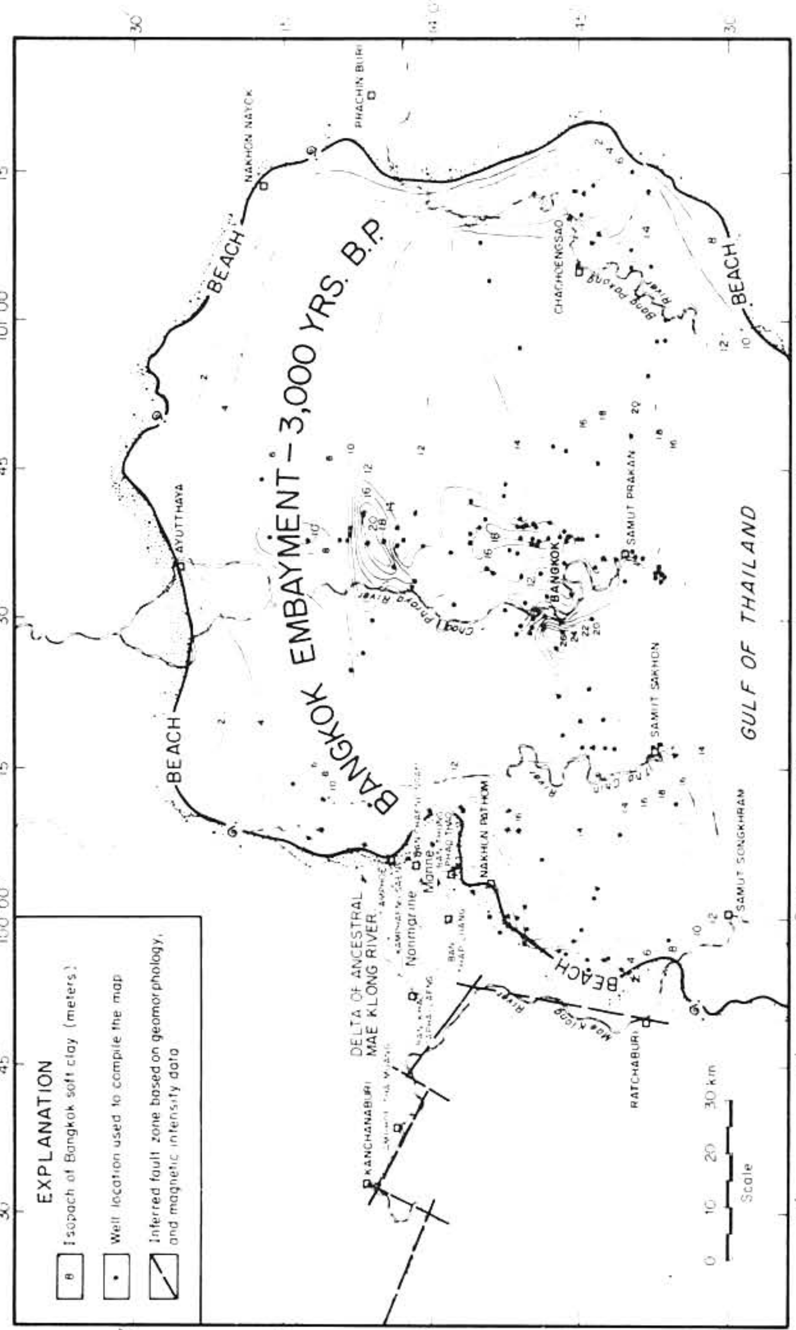
The other ten dates were obtained from the stiff clay, a non-marine deposit, and range from 14,700 to 45,000 B.P. These data support the interpretation that requires the shoreline to be well south of the latitude of the lower Central Plain prior to 11,000 yrs B.P. (Biswas, 1973). The material dated from the stiff clay consists of limestone nodules or concretions (calcrete) that probably developed at or near the water table in an environment typical of many places where they are forming in the Central Plain today. Data from Biswas (1973) placing the sea level in the Gulf of Thailand 70 m below its present level at 11,170 (±150) years B.P. seem to further limit the age of the soft clay to less than about 10,000 years B.P. as even a rapid transgression would take no less than 1,000 years to reach the coast of Thailand.

THICKNESS

The soft clay unit of the Bangkok Clay covers an area of approximately 13,800 square kilometers to an average depth of 15 meters. It ranges in thickness from 0 to 27 meters. The exact limits of the Bangkok Clay are difficult to determine. The boundary determined from all available borehole data, water well logs, and field work is shown in Figure 3. The inland margin of this transgression is not marked by prominent beaches or shell beds. In the future more data from boreholes will enable the extent of the clay to be mapped with greater accuracy. The present map should be considered a good approximation of its distribution and thickness (Figure 3).

BEACHES

The attention of the authors was focussed on the elevation of from +3 to +6 m because of the discovery of prominent beaches at this altitude in both Vietnam and Malaysia (Haile, 1971). A probable former beach was discovered just east of Ayutthaya at Ban Sai where a well-sorted medium grained sand occurs about +3 m above msl (Figure 4). Unfortunately, in spite of a thorough search there is little evidence of other beach deposits at this elevation. Whether this is due to paucity of sand or subsequent burial of beach deposits by prograding deltaic sediments is difficult to say. There is no question about the fact that the flat plain that begins at Ayutthaya is masked by the soft clay and that north of the plain is covered with sand. Below Ayutthaya the plain lies at an elevation of about +2 m and north of it at from +5 to +16 m above msl. Yet, there is no well developed beach at the edge of the clay.



Isopach Map of Bangkok Soft Clay

Fig. 3. Isopach map of the soft clay in the lower Central Plain of Thailand.

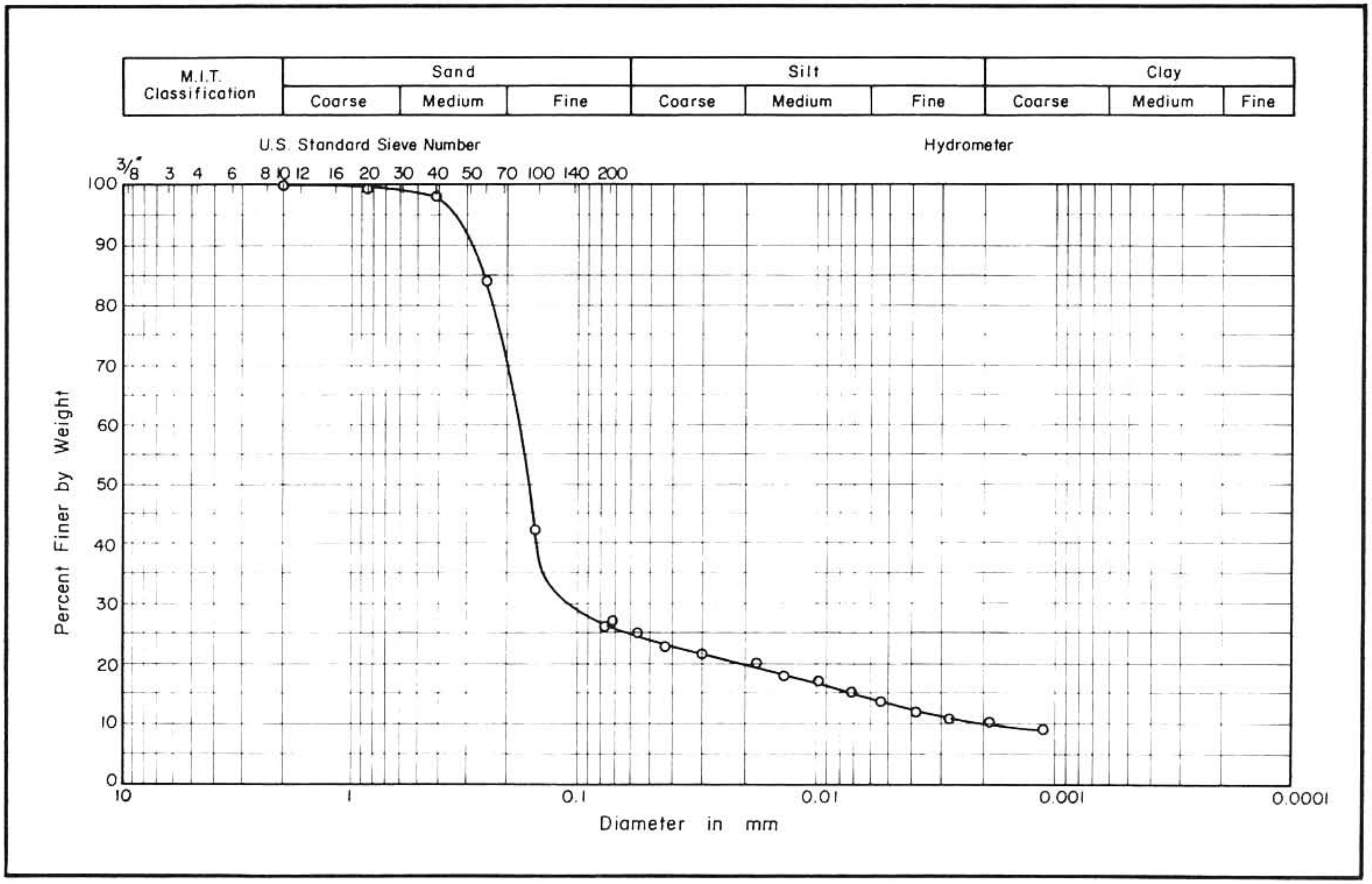


Fig. 4 Graphical representation of the size frequency analysis of a beach sand near Ayutthaya.

The surface of the plain has been only slightly modified by riverine processes since the retreat of the last transgression less than 1,500 years ago. In many places beach sands of the Middle Holocene transgression were buried by advancing deltaic deposits dumped onto the surface of the plain by streams disgorging from the mountains along its western border.

Examination of 1:50,000 topographic maps and borehole data, sparse though they may be, confirm that the 3 to 7 m altitude is the approximate limit of the Bangkok Clay. Landsat imagery also shows a dramatic change in the drainage pattern and density at this boundary (Figure 5). Just how long the sea remained in this embayment is unknown, but historical data show that present-day cities like Nakhon Pathom, Ayutthaya and Nakhon Nayok are located on the edge of the soft clay deposit and have been for more than 1,500 years (Schmidt, n.d.).

One puzzling piece of information is the historical report that places Lop Buri, the old capital of the Mon Empire, located 50 km north of Ayutthaya, on the sea about 1,500 years ago (Schmidt, n.d.). If this report were to be true, the shoreline at Ayutthaya, located by borehole data and the beach deposit, is much too far south. Perhaps at that time Lop Buri was a port on a river leading to the sea rather than being located directly on the coast. Today, Bangkok occupies a similar location on the Chao Phraya River some 35 kilometers from the sea.

ENVIRONMENT OF DEPOSITION

Soft Clay

The soft clay covers an area that is about 45 kilometers wide, extending northward from the Gulf inland to Ayutthaya, 90 km to the north. This is an area of roughly 14,000 square kilometers. The isopach map reveals that it is not a uniformly thick deposit, but varies over short distances, reflecting the uneven surface upon which it was deposited. It is thicker in the Bangkok area and along the north-south trending Chao Phraya fault zone (Figure 6). This may indicate that these faults were active in Holocene time. It thins to less than 10 m in an east-west trending belt 35 km wide just south of Ayutthaya. The nearly north-south trending eastern and western margins of the embayment may reflect the normal faulting that parallels the regional structural grain. Several deltas have been built into the Bangkok embayment, and these have not been fully deciphered, but the two most notable are the Chao Phraya in the vicinity of Ayutthaya, where the clay contains much more sand, and the Mae Nam Klong delta on the west, in the vicinity of Nakhon Pathom (Figure 3).

The following criteria were used to establish the environment of deposition of the soft clay:

1. It is uniformly deposited as a blanket over a broad area, the lower Central Plain.

2. Bedding is rare, and in most places the unit is a single massive homogeneous grey silty clay although it does contain fine sand laminae and grades into a clean basal sand in some areas.

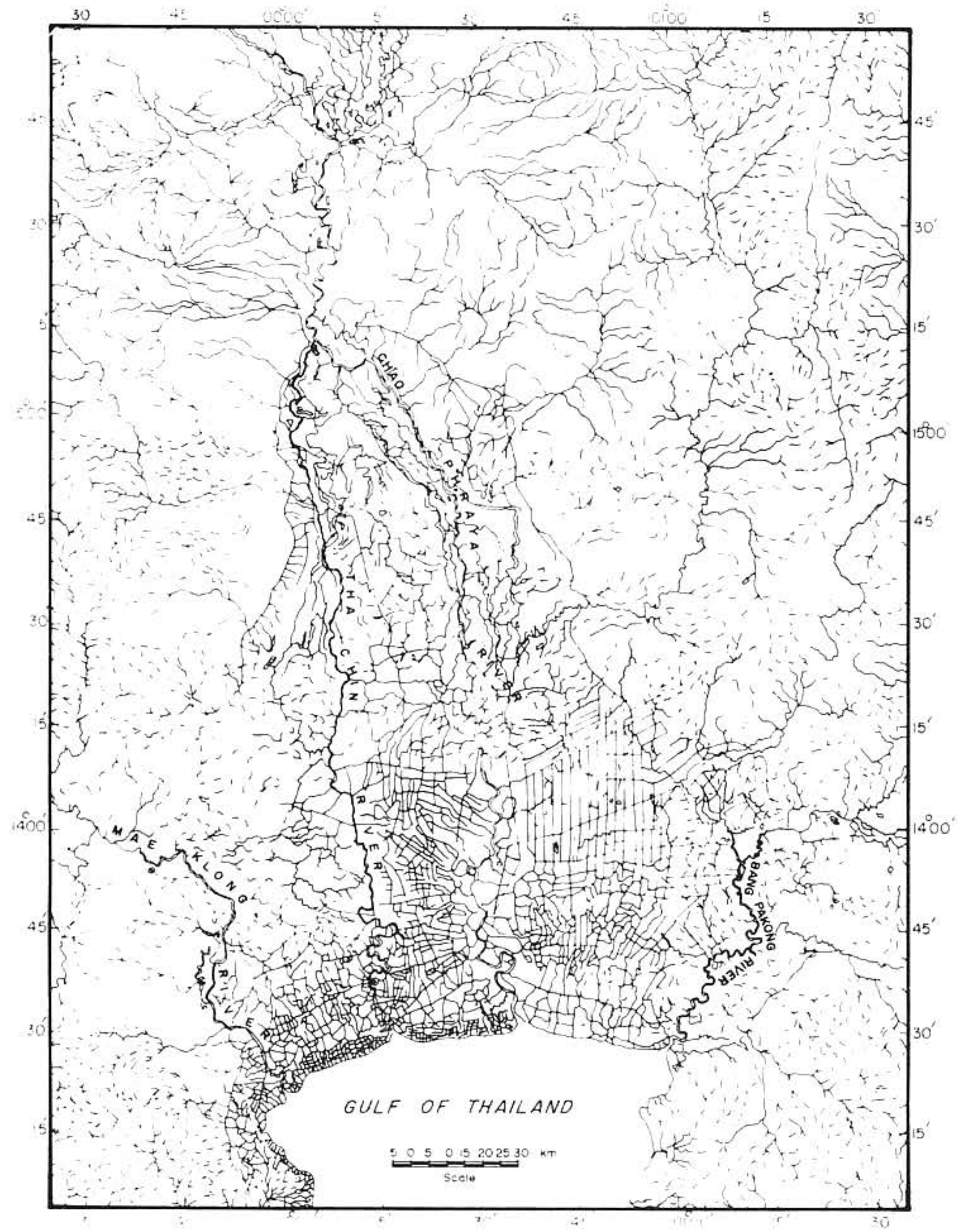


Fig. 5. Drainage map of the Central Plain of Thailand based on a Landsat image.

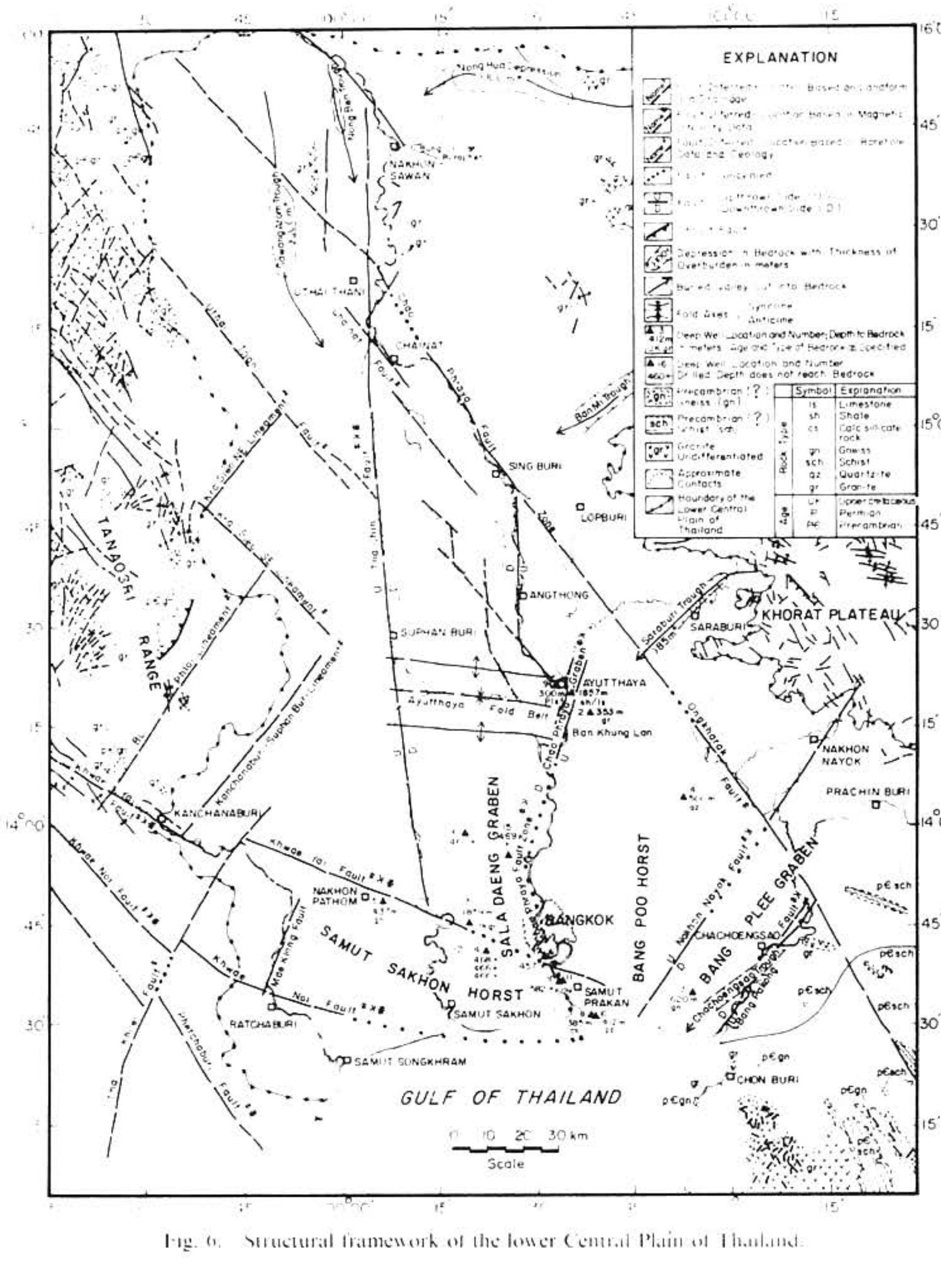


Fig. 6. Structural framework of the lower Central Plain of Thailand.

3. The deposit contains shells, including nearly perfect specimens of the fragile *Murex*, a gastropod with numerous spines that would be broken if the shell was deposited in shallow water.

4. Organic detritus is abundant in some areas, and deposits of decayed "plant" material have been logged by some drillers.

5. The deposit contains abundant slickensides (oral communication, Dr. Peter Brenner, July 15, 1980).

6. The clay may contain well sorted sands around its margin. Fine grained sands are also commonly reported in borehole logs near the Gulf Coast.

7. The salt content of the soft clay ranges from 50 ppm near the top to 9,000 ppm in the middle but the average concentration is about 3,000 ppm (Asian Institute of Technology, 1978).

8. The clay is draped over bedrock highs and lows of its basal unconformity as a ubiquitous deposit that is not restricted to well defined channels.

9. It overlies a plain that is marginal to the sea, and apparently extends continuously beneath the sea into the Bight of Bangkok.

10. It is found in an area that is so flat and so low that only a slight rise in present sea level would flood it all the way to Ayutthaya.

All indications are that the soft clay is a marine deposit. It bears all the hallmarks of having been deposited in quiet water because of the absence of shell hash, flaser bedding and intercalations of sand and gravel. Therefore, it is presumed to have been deposited on the delta front, where only fine silts and clays would settle out near the mouth of the numerous rivers entering the Bangkok embayment in Middle Holocene time.

Deposits of clay and silt which come to rest on the delta front frequently slump or slip down that surface because of their high water content and the slope angle (Rich, 1950). Such slips could create the slickensides that are commonly found within the clay (oral communication, R.P. Brenner, July 15, 1980). The most important single corroborating evidence of the environment of deposition of the soft clay comes from the occurrence within it of the gastropod *Murex unidentatus* Sowerby. A perfectly preserved shell of this species was identified by Dr. Emily H. Vokes of Tulane University (written communication, February 12, 1981). The shell was recovered from the soft clay at a depth of 9.35 m at Chulalongkorn University in central Bangkok. This species is commonly taken by fishermen in the Hong Kong area from depths ranging from 20 to 55 meters. Two records of collections of *Murex unidentatus* Sowerby from the Hong Kong area have been reported. One collection was from a depth of 20 to 24 m and the other was from 55 meters. The *Murex* group of gastropods is normally found in waters at a depth of about 50 m (written communication, E.H. Vokes, February 12, 1981).

Therefore, the Bangkok soft clay is interpreted as a delta front deposit laid down at a depth of from 20 to 50 m. The question that now remains is whether sea level was 20 to 50 m higher than it is now or whether the Bangkok Plain has been elevated 20 to 50 m in the last few thousand years.

These questions cannot be answered without a good deal more research on the geomorphology of the Central Plain and more detailed mapping of its ancient beaches and terraces.

The date of the marine transgression that covered the lower Central Plain with from 20 to 50 m of water may be correlated with the Flandarin transgression of Europe.

Fairbridge (1961) indicates that the Holocene is marked by the "tremendous Flandarin marine transgression, so that stratigraphically it is a distinct stage." Fairbridge cites the work of Dubois (1924, 1930) on the importance of the Flandarian transgression on Holocene coastal deposits throughout the world.

Radiocarbon dates indicate that the marine transgression innundating the Central Plain and resulting in the deposition of the soft clay began no earlier than 14,700 yrs B.P., the youngest date obtained from the underlying stiff clay. Data from Malaysia indicate that this transgression reached +6 m by no later than 5,200 ($\pm$200) years B.P. (Haile, 1971). At the height of this trangression there is some evidence for beach development at Ayutthaya where a remarkably well sorted sand is found at an elevation of from +3 to +5 m at Sena (Figure 7). According to Fairbridge (1961), in Europe a 3–5 m terrace is well developed and represents a Middle Holocene (5,000 years B.P.) submergence that is the culmination of the universal climatic and oceanic warming that began in the middle of the Holocene. Therefore, the +3 to +5 m beach found in the Central Plain is interpreted here to be the result of the Climatic Optimum which falls between 6,000 and 4,6000 B.P. in Europe (Fairbridge, 1961).

Stiff Clay

The area underlain by the Bangkok stiff clay occupies more than 14,000 square kilometers of the Central Plain. Its full extent is unknown because it is blanketed by younger deposits near the mountain front and by the Bangkok soft clay in the lower Central Plain. Throughout this large area the composition and thickness of this clay is generally variable, and in this respect it is quite different from the soft clay. The most important textural variant from the geological point of view is the percentage of silt and sand. The silt may vary from 17 to 35 percent and sand from 0 to 100 percent. Silt and sand occur as beds or laminae representing times of increased discharge or current activity within estuaries and tidal creeks.

The authors' conception of the environment of deposition of the stiff clay is one of a tidal flat-deltaic plain that gradually subsided in Late Pleistocene time, resulting in a deposit ranging from 1 to 24 m in thickness. This interpretation is in sharp contrast to the environment inferred for the soft clay which is considered to be a delta front deposit.

The coastal plain on which the stiff clay was deposited received sediment from rivers entering from the east, north and west. The major eastern river was the Prachin Buri

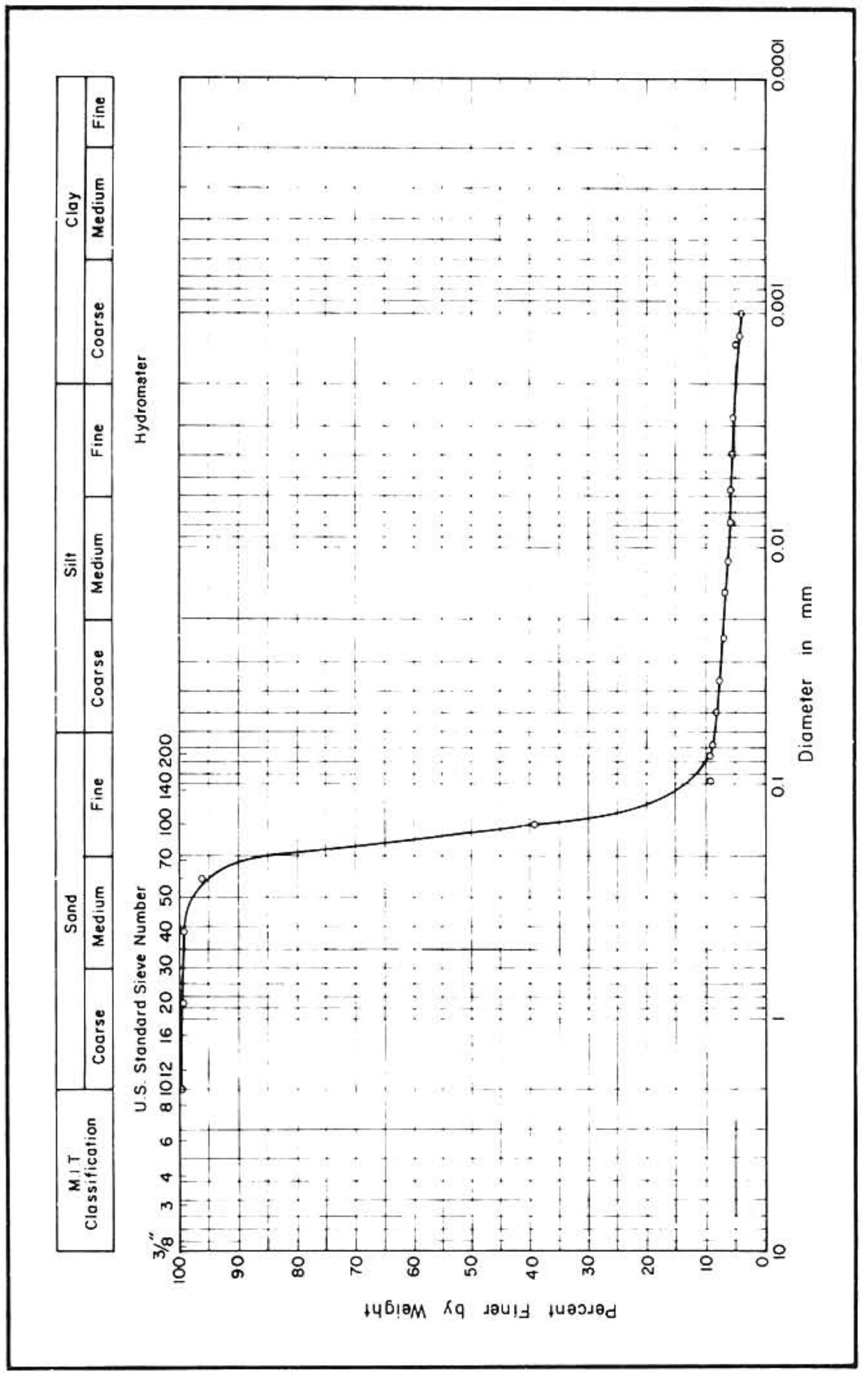


Fig. 7. Size frequency analysis of a beach sand east of Ayutthaya near Sena.

whilst the western ones include the Mae Nam Klong and the Tha Chin. Entering the head of the bay on the northeast was the Pa Sak and feeding directly into the centre of the bay were the ancestral Chao Phraya and Lop Buri Rivers. The coarse loads of these rivers were deposited soon after they reached their base level, the Central Plain, and as a result each developed a fan complex where they first entered the coastal plain whilst those rivers that persisted across the coastal plain fan complex developed bird's foot deltas in the Bangkok embayment.

In conclusion, the environment of deposition of the Bangkok stiff clay is interpreted to have been a vast alluvial plain that gradually subsided over the period from 45,000 to 10,000 yrs B.P. The resulting deposit ranges from 1 to 24 m in thickness, and is now from 10 to 18 m below mean sea level. Inasmuch as the stiff clay is now buried, subsidence of at least 20 to 40 m has occurred since its deposition. Some of the coarse debris fed to the Central Plain during this time was trapped behind the Nakhon Sawan arch, an east-west trending structural high through which the river has cut a narrows north of Uthai Thani. This topographic barrier has slowed the force of the monsoon floods across the southern half of the plain throughout Holocene time. Thus mostly fine sediments reached the lower basin during the deposition of both the soft and stiff clay.

CONCLUSION

The Bangkok Clay is a complex consisting of two deposits, a basal stiff clay and an upper soft clay. A prominent unconformity marks the boundary betwen the two clays. The basal clay is interpreted as a mostly non-marine deposit originating from the merger of a complex of fans and deltas built by streams entering the embayment from the east, north and west. The upper clay is lithologically less complex, consisting of mostly silty clay containing a well developed molluscan fauna. The ecology of the molluscs as well as geologic evidence suggests the clay is a front (slope) delta deposit and was laid down in water ranging from 20 to 50 m in depth.

REFERENCES

ASIAN INSTITUTE OF TECHNOLOGY (AIT), 1978. History, Theoretical Considerations, Field Instrumentation, and Laboratory Testing Program. *Investigation of Land Subsidence Caused by Deep Well Pumping in the Bangkok Area*, Phase 1, Progress Report, Bangkok, 104 p.

BISWAS, B., 1973. Quaternary changes in sea-level in the South China Sea. *Geological Society of Malaysia Bulletin*, No. 6 pp. 229–256.

COX, J.B., 1968. A review of the engineering characteristics of the recent marine clays in southeast Asia, *Asian Institute of Technology Research Report* 6, Bangkok.

COX, J.B., 1970. Shear strength characteristics of the recent marine clays in southeast Asia. *Journal of the Southeast Asian Society of Soil Engineering*, Vol. 1, pp. 1–28.

DUBOIS, G., 1924. Recherches sur les terrains Quaternaires du nord de las France. *Memoirs of the Societe Geologie Nord*, Vol. 8, No. 1.

DUBOIS, G., 1968. Un tableau de l'Europe Flandrienne, *Societe Geologic France, Livre Jubilaire*, Vol. 1, pp. 263–277.

EIDE, O., 1968. Geotechnical problems with soft Bangkok clay on the Nakhon Sawan Highway Project. *Norwegian Geotechnical Institute*, Publication 78.

EIDE, O., 1977. Exploration, sampling and in-situ testing of soft clay in the Bangkok area. *Geotechnical Aspects of Soft Clays, Proceedings of Conference*, Asian Institute of Technology, Bangkok, pp. 359–374.

FAIRBRIDGE, R.W., 1961. Eustatic changes in sea level. *Physics and Chemistry of the Earth*, Vol. 4, Pergamon Press, New York pp. 99–185.

HAILE, N.S., 1971. Quaternary shorelines in West Malaysia and adjacent parts of the Sunda Shelf. *Quaternaria*, Vol. XV, pp. 333–343.

HOLMBERG, SOREN, 1979. Bridge approaches on soft clay supported by embankment piles. *Geotechnical Engineering*, Vol. 10, p. 77–89.

MOH, Z.C., NELSON, J.D. and BRAND, E.W., 1969. Strength and deformation behaviour of Bangkok Clay. *Proceedings of the Seventh International Conference on Soil Mechanics*, Vol. 1, Mexico, City, 287 p.

PETERSEN, L., 1977. Mineralogical composition of the clay fraction of some soils in the Central Plain of Thailand, *Proceedings of Fifth Southeast Asian Conference on Soil Engineering*, Bangkok.

RICH, J.L., 1950. Flow markings, groovings and intrastratal crumplings as criteria for recognition of slope deposits, with illustrations from Silurian rocks of Wales, *American Association of Petroleum Geologists Bulletin*, Vol. 34, No. 4, pp. 717–741.

SAWAMURA, K., and LAMING, D.J.C., 1974. Sea-floor valleys in the Gulf of Thailand and Quaternary sea-level changes. *Committee on Co-ordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas (CCOP) Newsletter*, Vol. 1, No. 4, pp. 23–27.

SCHMIDT, K.O., (n.d.). *Thailand (Siam) mit Stadfuherer Bangkok*. 4th Edition, Mai's Weltfuhrer No. 1, Buchenhain, Vok und Heimat.

Manuscript received 29 Aug 1981.