Chapter 4

Reconstruction of Past Geological Models

In the study area, the northeastern Gulf of Thailand which is a part of the Sunda shelf is mostly stable or very less tectonic movement through the Quaternary period (Sinsakul *et al.,* 1985 and Sinsakul, 1992; Tjia, 1986; Roy, 1989). Therefore, an important role to develop the Quaternary sequences underlying the Gulf is the eustatic sealevel changes.

Since eustatic sealevel has oscillated during the Quaternary, the coastal zone (nearshore and backshore) has repeatedly migrated forward and backward across the continental shelf and left a difficult-to-interpret record of erosional and depositional events. Terrestrial, estuarine and marine deposits all occur in complex arrangement in the vicinity of the coast (Roy, 1989).

An attempt has been made to analyse sealevel changes in the study area by comparison to published sealevel curve models of Quaternary period. On the local scale, however, it is not possible to obtain accurate dates for sequence age determination. In this study, therefore, it is appropriate to use sealevel curve models and available geological data to determine age of sequences comparatively.

Although, there are no dating data and palynological analyses to be used for age correlation between sequences on the profiles and on drill logs, the two widespread unconformities directly identified from seismic profiles can be correlated with the two major lowstands on the sealevel curves, as the major unconformities "A" and "B" in the study area (Figures 3.2, 3.3 and 3.4). They most likely represent the major middle and late Pleistocene marine regressions (Figures 3.16b and 3.17a).

Based on correlation of seismic records and drilling results, the past geological models through the Quaternary can be tentatively reconstructed, as discussed in the following sections.

4.1 Lithofacies Classification

"Lithofacies" is a general term used to describe particular sediment types that occur in specific depositional environments. The process of reliably identifying lithofacies in outcrop or in drillhole samples allows past depositional environments to be reconstructed. The spatial arrangement of lithofacies units and their relative ages make it possible to scheme the geological evolution of an area over time spans of millennia as the area responds to changes in sealevel, climate and other environmental factors. Three main environments of deposition recognized in the study area and their associated lithofacies units characterizing the various sub-environments are listed in Table 4.1.

Table 4.1 Lithofacies making up the main depositional elements of the study area

Depositional Environment	Lithofacies Units
1. Terrestrial	a. Regolith/Weathered bedrock b. Piedmont fan deposits (*floodplain, fluviatile channel, fresh water swamp)*
2. Estuarine	a. Tidal channel sands and muds
3. Marine	a. Nearshore sands and muds b. Shelf muds

4.1.1 Terrestrial Lithofacies

4.1.1.1 Regolith/Weathered Bedrock

The regolith generally refers to *in situ* weathering products and residual soils of tropical, and formerly tropical regions. It comprises all the weathered and pedologically altered material above rockhead, as seen in seismic profiles in Figures 3.9b-3.13b.

In the study area, there are only 84 holes intersected weathered *in situ* bedrock, including granite, schist, sandstone, siltstone and shale. Although the breakdown products of these rock types are variable in composition, the typical compositional and textural characteristics of sediments are very stiff or hardened clays with mottling and variable amounts of host rock fragments (Appendix C; Tables C8, C9, C12 and C14). In many cases, however, where holes were drilled in the flanks of drowned valleys, it is difficult to distinguish an *in situ* layer of disintegrated bedrocks from piedmont fans (alluvium and colluvium) (Appendix C; Figures C4, C8, C9 and C12_13).

4.1.1.2 Piedmont Fan Deposits

Piedmont fan deposits constitute the main terrestrial sediments encountered in all drillholes. The term "piedmont fan", following Batchelor (1979, 1984) and Roy (1989), used in this context includes floodplain, fluvial channel and fresh water swamp deposits (Appendix C).

- *Flood/Alluvial plain deposits* (Figures 3.6-3.14) are characterized by clayey sediments with variable amounts of sand but mostly less than 20 percent. The sediments are typically gray with reddish and yellowish brown mottles. Iron oxides and siderite nodules are commonly found (Appendix C; Tables C3-C5, C8-C9 and C12-C17).

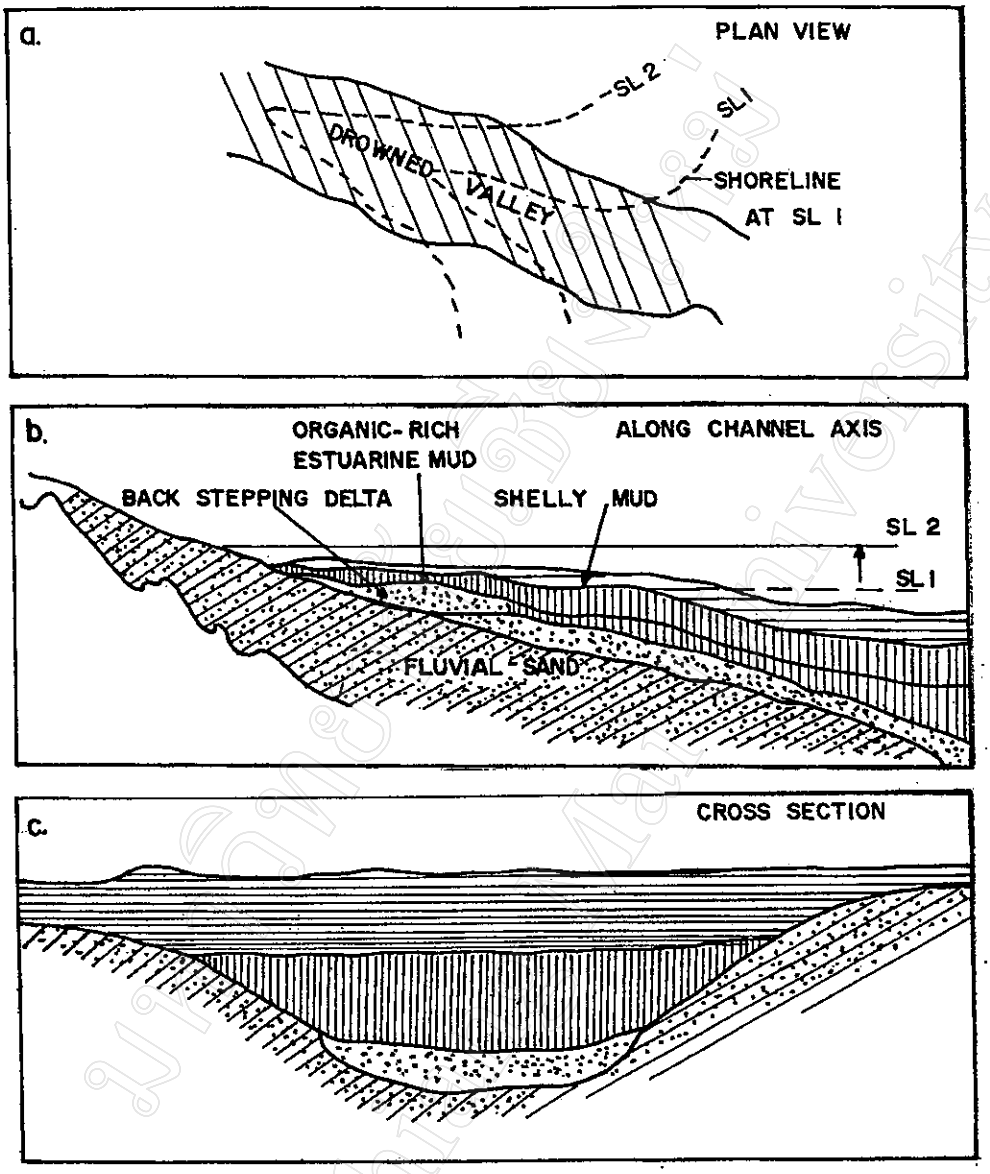
- *Fluvial channel deposits* (channel lags) (Figures 3.8b, 3.10b, 3.13b and 3.14b) are higher energy deposits than swamp counterparts described in the next section. Typically, sediments on channel beds are poorly sorted sands and gravels with small amount of clay and devoid of wood fragments (Appendix C; Tables C3, C5-C7, C10 and C15-C17). They are gray-brown in color and form fining up units with erosional bases and coarse lags that may represent individual flood events; scouring followed by deposition as flood flows wane, minor flood events cause surficial reworking and deposition of lens of clay and fine sand. Thick gravely sand strata commonly overlies just above bedrock in depression zones (Appendix C; Tables C3, C11 and C14 : see also corresponding figures).

- *Fresh water swamp* comprises organic-rich muds and peats. Without detailed palynological analyses, this sub-lithofacies remains questionable as estuarine muds also contain organic matter. Nevertheless, when considering the stratigraphic positions (from seismic records), it is found that the sediments were deposited in back swamps (typically far from the active channel fans) on the flood plain surface. The swamp environments represent the most stable and slowest changing parts of the flood plain.

4.1.2 Estuarine Lithofacies

The estuarine lithofacies is well developed in southern parts of sub-areas 1-C, 1-D and 1-E (Figures 3.6b, 3.7b and 3.8b). It is composed of gray-dark gray clays and sandy clays/clayey sands with (assumed) estuarine plant remains, but devoid of shell detritus. The absence of shell fragments was thought to be due to acidic conditions produced as the plant detritus decays.

In sub-areas 1-C and 1-D, several holes intersected sandy sediments underlying the estuarine clays (Appendix C; Tables C1, C3, C7, C9-C14 and C17). The sandy sediments are fluviatile in nature, but when considering the presence of plant remains and stratigraphic positions, they are deciphered as bay-head delta sands that accumulated in the heads of the drowned valleys. The absence of shell fragments in the sandy sediments was attributed to constantly reworking landward during marine incursions. Figure 4.1 exemplifies the mode of formation of the tidal delta sand facies.



(a) Idealized successive shorelines at different sealevel positions as marine transgression inundated an incised valley. (b) The fluvial sands were initially accumulated in the head of drowned valleys. These sand migrated landward as "backstepping bay-head deltas" as the valley was flooded by rising sealevel. Once water depth increased and turbulence level declined, organic rich muds settle from suspension. (c) Generalized stratigraphic section of the valley-fill sediments.

Figure 4.1 Illustration of an examplified mode of formation of estuarine sediment in a fluvial channel system drowned as sealevel rose (modified from Roy, 1989).

4.1.3 Marine Lithofacies

The marine lithofacies recognized in the study area is mud (see upper subsequence UC in Figures 3.6b-3.14b) with marine shells, fine organic matter and fine to medium sands (Appendix C). In sub-area 1-A, the amount of sand content increases shoreward. The sands derive from marine reworking of weathered granite and gneiss bedrocks nearby. The mud is originally terrigenous material. It is transported to the Gulf in suspension by the monsoon floods. Once it reaches the Gulf, the mud is dispersed by marine processes, and eventually deposited on the seabed in areas where turbulence levels are sufficiently low. In nearshore zones (water depths < 3 m; between line of breakers and high tide limit) the mud is not permanently preserved because of strong wave actions.

4.2 Quaternary Stratigraphic Development and Tentative Geochronology

According to Prадidtan and Dook (1992), the Gulf of Thailand began to form as a result of Late Cretaceous to early Tertiary subsidence, which emphasized the north-south tectonic trends and a series of pronounced depositional basin formed. Since the Tertiary, the coast and continental shelf have undergone slow subsidence but at a rate imperceptible over historic timespans. Despite eustatic fluctuations in sealevel and local tectonic movements, the coastline has migrated progressively northward. As a result, the perimeter of the Gulf is a zone of erosion and rework, producing relatively young sediments (except where it is cut by palaeo-river valleys), while the outer shelf is a depositional zone underlain by more than 500 m thick of terrestrial sediment.

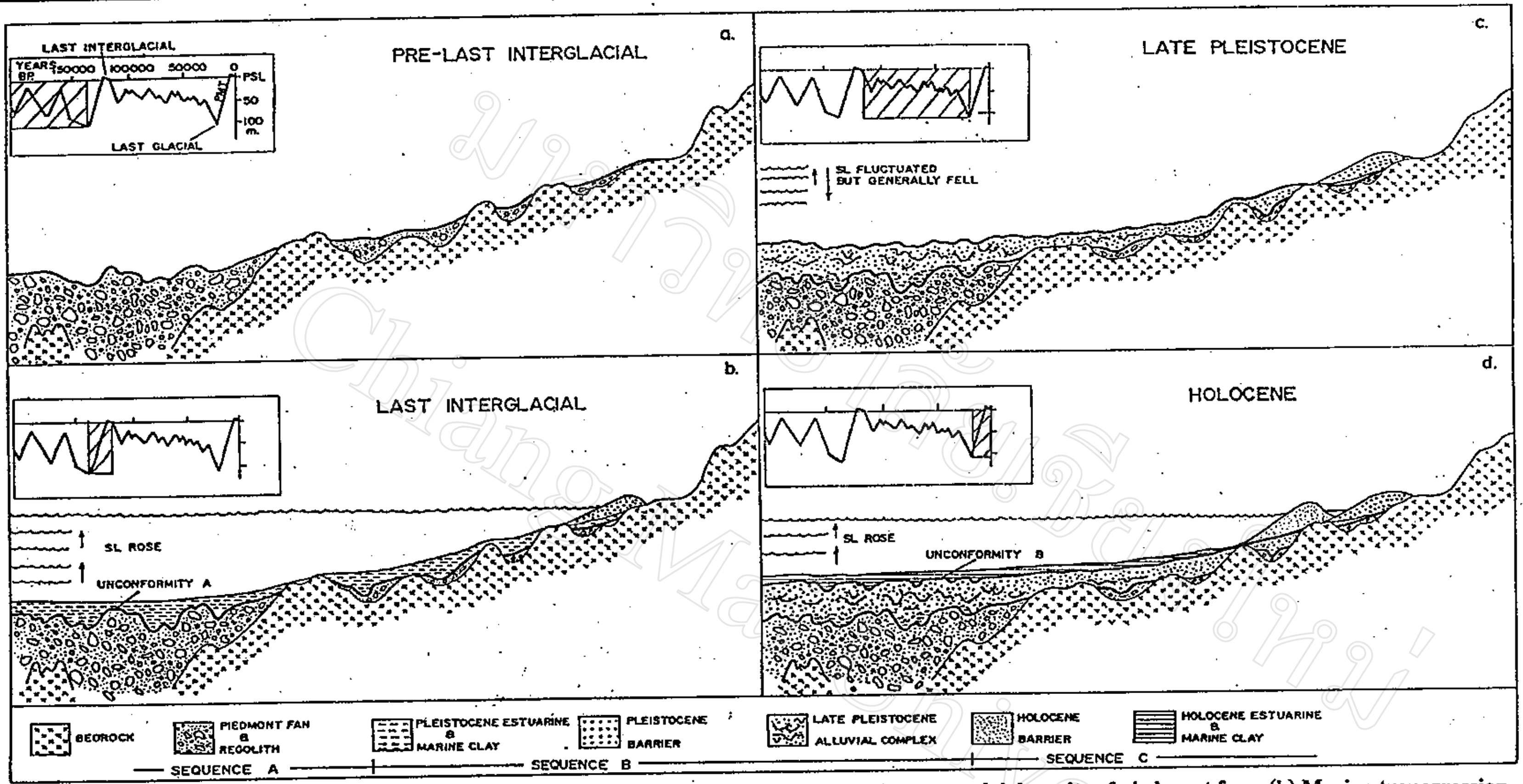
Existing data from offshore seismic profiling and drilling in the Area 1 reveal a complex assemblage of terrestrial, estuarine and marine sediments of presumably Quaternary age. The assemblage deposition (and erosion) of these sediments is intimately related to the glacio-eustatic changes in sealevel that have occurred many times over the last two million years. Three major stratigraphic sequences, however, can be identified, as shown in Table 4.2.

Sequence A : This sequence comprises the regolith and old piedmont fan deposits, old estuarine deposits (?) and old marine clay (?). The regolith/weathered bedrocks and old piedmont fans generally are defined as an initial depositional surface (Figures 3.8b-3.11b). In the flanks and axes of palaeo-valleys, the regolith sediments often grade upward into the piedmont fan deposits in which the disconformity of these two facies cannot be discerned in seismic profiles. Even in drillholes, it is very difficult to define the lithological break, as a reference of the sequence boundary, at the bottom of the sequence A. Hence, they are sometimes grouped as the lowest part of the sequence A overlying fresh bedrocks seen in the study area (Appendix C; Tables C8, C9, C12 and C14 : see also corresponding figures).

The sequence is interpreted to be deposited prior to the last interglacial (LIG; early late-Pleistocene, *c.*>125,000 years), when sealevel fluctuated (*c.* 10-150 m) below the present sealevel (Figure 4.2a). The Gulf at that time was dry and dominated by terrestrial environments. Old estuarine might be preserved somewhere in deep palaeo-valleys (>*c.* 50 m below the

Table 4.2 Summarized three major stratigraphic sequences in the study area, with estimated ages and relationships between lithology/lithofacies and seismic facies

DEPOSITIONAL SEQUENCE	LITHOFACIES	LITHOLOGY	SEISMIC PATTERNS	AGE ESTIMATES
SEQUENCE C	MARINE	Olive grey muds, sandy muds with shell fragments	parallel and subparallel patterns, weak to strong reflections, locally acoustically transparent pattern	HOLOCENE
	ESTUARINE	Estuarine clay, tidal delta sands with plant remains	parallel and subparallel, moderate to strong reflections, locally acoustically opaque zone	
SEQUENCE B	TERRESTRIAL			LATE PLEISTOCENE
	Complex alluvium			
	-flood plain	Lateritised alluvial clays with variable amounts of sands	subparallel with some speckled seismic signature to chaotic pattern	
	-fluvial channel	Sands and gravels with small amount of clays	more or less chaotic pattern, locally obliquely dipping fills; few subparallel fills	
	-fresh water swamp	Dark grey clays, mostly very homogeneous.	subparallel pattern, moderate to weak reflection, locally acoustically transparent pattern	
	ESTUARINE	Estuarine clay, tidal delta sands with plant remains	subparallel and acoustically transparent patterns	
SEQUENCE A	TERRESTRIAL			EARLY PLEISTOCENE
	-piedmont fan/ alluvium	Lateritised clays	chaotic pattern with some internal subparallel reflections or speckled features	
	weathered bedrock/regolith	Clays with hostrock fragments	chaotic pattern with a few speckled seismic signature	



(a) The Gulf of Thailand before the last interglacial peroid was a dry land and dominated by terrestrial deposits of piedmont fans. (b) Marine transgression high stand during the last interglacial resulted in the deposition of estuarine/ marine clays and sandy barriers. (c) Multi-phase of marine trangressions and regressions in the late Pleistocene led to deposition of terrestrial sediments rather than estuarine marine clay since the latter were highly mobilised and then reworked seaward during marine regressions. However, they might be preserved somewhere in deep valleys. (d) Postglacial marine transgression and stillstand have led to deposition of estuarine/ marine clays and barrier beaches.

Figure 4.2 Idealized Quaternary stratigraphic development in the Area 1, sealevel curve derived from SE Australian data (Thom and Roy, 1985) present sealevel) and blanket of old marine clay strata might also be preserved in the sequence on the top of old estuarine and further seaward. However, due to limitations of existing drilling techniques that cannot penetrate through sediments deeper than *c.* 50 m, it is questionable whether the old marine clay and old estuarine sediment were preserved.

Evidence suggested that the period of deposition of the sequence is its top surface which, on seismic profiles (Figures 3.2-3.4), is characterized by a strong reflector that possibly represents a surface of marine planation (prominent flat surface) during the last interglacial (LIG; some 125,000 years BP.), although minor incision is seen in places. Evidence of marine transgression and highstand during the LIG (Figure 4.2b) is the presence of inner sand barriers which stretch between Rayong and Chanthaburi and are located 1-10 km inland from the present coastline (Figure 4.3). These barriers are characterized by very fine to medium, clean, well sorted sand with an absence of shell detritus. The absence of shell fragments, due mainly to leaching by meteoric water, indicates a long period of surviving of the barriers and implies that the barriers formed during the highstand of sealevel, probably +*c.* 5 m higher than the present sealevel, in the LIG.

Sequence B : This sequence immediately overlies the sequence A. It is typically characterized by complex channel cut and fill patterns in the seismic records (Figures 3.3, 3.6b, 3.7b, 3.8b and 3.10b). The cut and fill pattern suggests deposition and erosion which are intimately linked to several glacial-interglacial cycles. The complex channel cut and fill patterns were strongly affected by numerous sealevel rising and falling. Evans *et al.* (1995)

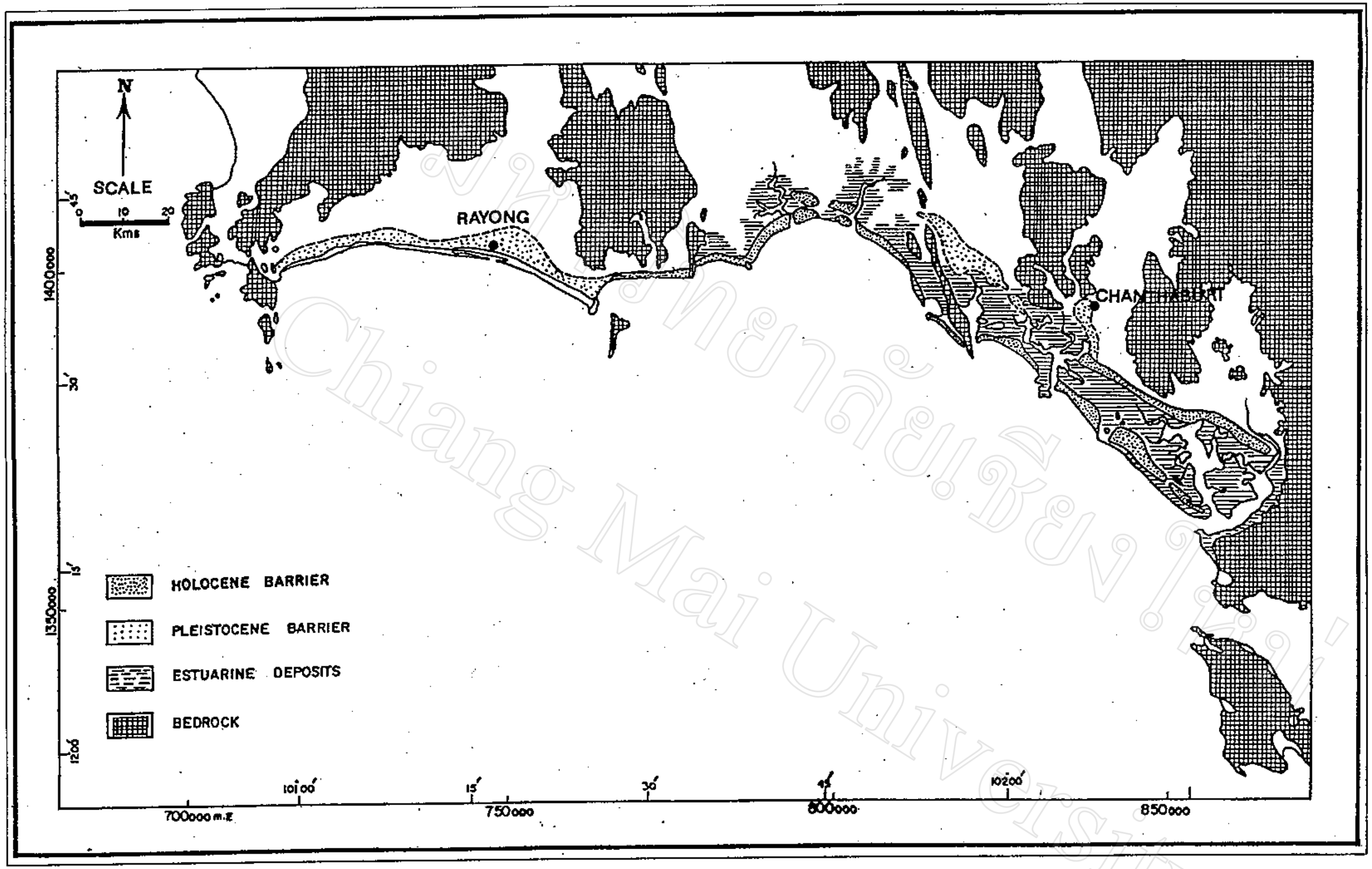


Figure 4.3 Distribution of barrier beaches and estuarine deposits in Rayong and Chanthaburi Provinces (after Roy, 1989)

and Roy (1989) indicated that the deviation of sealevel fluctuations maintained at a range from -10 to -80 m relative to the present sealevel after the last glacial (LG) through late Pleistocene. Drilling results reveal that the sediments of the sequence range from soft to stiff gray clay (often with reddish-yellowish brown mottles) through silt and fine sand to gravel (Appendix C). The complex assemblages of the sediments are interpreted to represent channel migration and erosion of floodplains. Typically, the upper part of the sequence contains iron oxides and siderite nodules (Appendix C) and it is likely compared with a hard ground surface with relatively strong reflections (Lallier, 1988). This characteristic together with stratigraphic position indicates that the deposits were subjected to subaerial conditions during the last glacial (LG : some 17,000 years BP.) period.

In sub-area 1-E, some channels are characterized by dark gray clays and fine-medium sands containing wood fragments. Whenever these sediments were encountered the overlying sediment is clay (Appendix C). The sediments, though devoid of shell detritus, are therefore deciphered as estuarine facies (intertidal channels) rather than fluvial facies. They were probably deposited under transgressive conditions as coastal valley systems were progressively drowned.

Fluvial channel facies, consisting of immature, poor sorting sands and gravels with small amount of clay but devoid of shell fragments, are mainly confined in deep valley incised in the lowermost sequence A. Locally, this facies intercalated with thin peaty clay layers (5-10 cm), suggesting frequent vertical sealevel oscillations.

On all counts, the deposits of the sequence B can be attributed to multiple phases of marine transgressions and regressions commenced *c.* 120,000 years ago after the last interglacial phase of high sealevels with warm temperature (Figures 3.17a and 4.2c). It was followed by slow cooling and generally falling sealevels culminating in the last glacial maxima *c.* 17,000 years BP. (Figure 4.2c) (Roy, 1989).

During phases of transgressions and highstands (interstadial), sandy barriers were developed; estuarine sediments were deposited in intertidal channel systems and overlain by marine muds, like the Holocene deposits as seen today. On the other hand, during phases of lower sealevel, whereas former land surface was incised, terrestrial sediments were spread out into the Gulf by rivers; marine muds as well as estuarine muds, due to their high mobility, were reworked and transported seaward. However, the estuarine muds may be preserved somewhere in deep palaeo-valleys since the gradient of the seabed in the Gulf is very low (*c.* 0.1-0.2 degree) (Offshore Mineral Exploration in the Gulf of Thailand Project, 1988a, 1988b, 1989a, 1989b; Roy 1989; Rasrikriengkri, 1985). The interstadial barrier sand bodies were translated landward (roll-over manner) or either destroyed, rather being drowned, when the subsequent Holocene rapid sealevel rise had taken place (Figure 4.2d).

Sequence C : This is the topmost sequence. It is likely deposited from about 10,000 years ago to the present. The sequence is distinctively distinguished into two subsequences on the profiles. The lower subsequence (LC), comprising organic-rich estuarine clays, is confined in valleys and is thought to be deposited during 10,000-6,000 years BP., when sealevel rose rapidly and inundated those valleys (Section 4.1). On the top of the lower subsequence, it is generally composed of marine muds with shell fragments and sands (particularly in nearshore zone). These sediments are believed to be deposited during highstand since late Holocene (Figure 4.2d). The thickness of the muds is not uniform. In sub-area 1-A, the muds form as a massive lens-like accumulation (mound shape) with thickness up to 20 m. This could be attributed to local variations in present-day depositional conditions, *i.e.* submarine current and tidal current.

The lower subsequence might be deposited during 10,000-6,000 years BP. It is mainly the transitional deposits consisting of estuarine and marine lithofacies. Before PMT the edge of the Gulf might be still dominated by the transition between estuarine and marine environments, then it was covered by sea water later when the rapid sealevel rise in late Holocene probably some 6,000 years ago. The deposits of the LC are mud and sandy mud of marine environment seaward. Evidence of Holocene sealevel changes in the coastal areas of Thailand was discussed in detailed by Sinsakul *et al.* (1985).

4.3 Lithofacies and Concentrations of Heavy Minerals

In this section, concentrations of placer deposits of economic heavy minerals and aggregates will be discussed in relation to their associated lithofacies and seismic facies patterns. The interpretation of high resolution of seismic profiles with the application of seismic stratigraphic concept enables to recognize and delineate the different lithofacies in the study area. Lithofacies related to seismic facies recognized on the profiles in the study is shown in Table 4.2. The seven main favorable lithofacies containing concentrations of heavy minerals, corundum, aggregates and other placer minerals were indicated by Ringis (1994), as summarized in Table 4.3. These seven main lithofacies are used as a guideline to determine seismic facies which would represent the lithofacies favorable to concentrations of heavy minerals and aggregates in the study area. In most cases, coarse-grained sediments (sand and gravel) are most likely deposited in relation to high energy depositional regime. Those may contain concentrations of heavy minerals, gold, corundum, diamond and aggregates. From the Table 4.3, it can then be assumed that the most prospective lithofacies are related to chaotic, chaotic and obliquely dipping fills, prograded oblique system and broad rise mound patterns, as shown in Figure 4.4. But it was found that in the study area sandy deposits generated subparallel pattern with relatively weak to moderate reflections.

Therefore, mapping the extents of sediment units which most likely contain accumulation of economic mineral deposits would be most essential to the offshore mineral exploration program. If there are sufficiently large volumes of the prospective sediment units and available source rocks of heavy minerals and aggregates, it would be beneficial to the offshore mineral development of the country in the future. Nonetheless, it also depends on an economically accessible depth and capability of appropriate today-mining technology.

As the results of the study, the sequence B is the most prospective sequence for deposits of heavy minerals, corundum and construction

Table 4.3 Summarized the seven main lithofacies likely favorable for accumulation of heavy minerals and aggregates (modified from Ringis, 1994)

Lithofacies	Seismic facies	Types of sediment	Depositional processes	Heavy mineral (HM) and aggregate accumulation
1.Terrestrial lithofacies				
1.1 residual deposits (regolith/weathered bedrock)	chaotic pattern with essentially no stratification	very poorly sorted grain size, varying from clay to gravel to large boulder at deeper levels	chemical weathering and machanical movement by elutriation, relatively very low energy of deposition	enrichment of dissiminated heavy minerals in the overlying residual sediments or weathered HM bearing rocks
1.2 colluvial/ piedmont fan deposit	chaotic pattern with probably some segment of sub horizontal stratification and development of minor channels	loose, poorly sorted, large percentage of coarse grained materials	downslope movement by surface runoff, sheet erosion, mass creep and slide, variable energy of depositonal regime such as intermittent sheet flood, creep and through fluvial process, relatively moderate to high energy of deposition	enrichment of HM and coarse sedment around the slope of steep hill by intermittent sheet flood and creep
1.3 alluvial/channel deposit (fluvial process)	exhibiting wide range of pattern from chaotic to obliquely dipping to acoustically transparent			
-proximal fan	more or less chaotic pattern	poorly sorted coarse grain channel fill (channel lag) with very small amount of clay	incised channel into bedrock or colluvium, poorly developed bedding, coarse grain deposited at the base of channel, relatively high energy of depositional regime	HM and aggregates deposited at base of channel, as channel lags
-distal braided stream	closely spaced obliquely dipping fill	mostly sandy sediment deposited as cross bedding and point bar in channels	moderately sorted coarse grained sediment deposited in braided/meandering stream, migrated channel	reworked residual and old piedmont fan; removing fine grained sediment; increasing HM concentration within coarse grained deposit
-distal flood plain/swamp/part of estuary	acoustically transparent (sometimes associated with acoustically opaques zone)	very fine grained alluvial plain, very fine sediment of overbank deposit and estuarine mud deposits or shallow marine sediments	very fine grained sediment fill in channel at relatively lowland during sealevel rise, bedding developed	very low HM content; less economic channel placer

Table 4.3 Summarized the seven main lithofacies likely favorable for accumulation of heavy minerals and aggregates (modified from Ringis, 1994) ; (continued)

Lithofacies	Seismic facies	Types of sediment	Depositional processes	Heavy mineral (HM) and aggregate accumulation
2.Marine lithofacies				
2.1 rivermouth/ inner shelf bar/ delta				
-rivermouth/inner shelf bar	broad rise with fainted oblique internal reflections	well sorted sandy sediment formed as a series of bars at rivermouth and nearshore blanket (lag deposit)	sandy sediment discharge into the shelf at rivermouth, formed as a series of bar by tidal current and wave action, relatively very high energy of deposition	locally high concentration of HM.; large volume of HM in large area of deposits
-delta	overlapping lense with sigmoidal internal reflections	well sorted sandy sediment formed as delta adjacent to rivermouth	large quantity of sediment discharged at rivermouth, most likely delta formed, variable energy of depositon from moderate to high energy of depositional regime	low concentration of HM; no report of mining in delta
2.2 beach/barrier system	a series of oblique, divergent seaward dipping reflection, often with irregular surface on the top of sediment bodies	very well sorted sandy sediments deposited as beach and barrier system during relatively stable sealevel for long period of time	a number of beach/barrier elements grading from one to another, exhibiting overlapping depositional surface dipping seaward with concave up shape, relatively high energy of deposition	ancient beach/ barrier system rich in deposit of light heavy minerals (ilmenite, rutile, zircon and monazite), gemstone and gold etc.
2.3 shelf lag deposits	not always possible to distinguish shelf lag on high resolution seismic profile	coarse grained, well sorted sediment left on the inner shelf after moving finer sediment seaward by current and wave action, mostly rest on an erosional surface	deposited as thin sheet of the reworked beach/barrier system during sealevel rise, relative very high energy of deposition	probably containing significant amount of enriched HM by reworking process during sealevel rise
2.4 shoreface lag deposit	chaotic reflection pattern with some seaward dipping reflection	very well sorted coarse grained sedment as lenses formed within the concave up shape at the shoreface	previous sediment units i.e. beach/barrier, residual, colluvium, piedmont fans and bedrocks eroded and reworked at shoreface by wave action, relatively very high energy depositional regime	quite rich concentration in coarse grained sediments; likely containing accumulation of HM

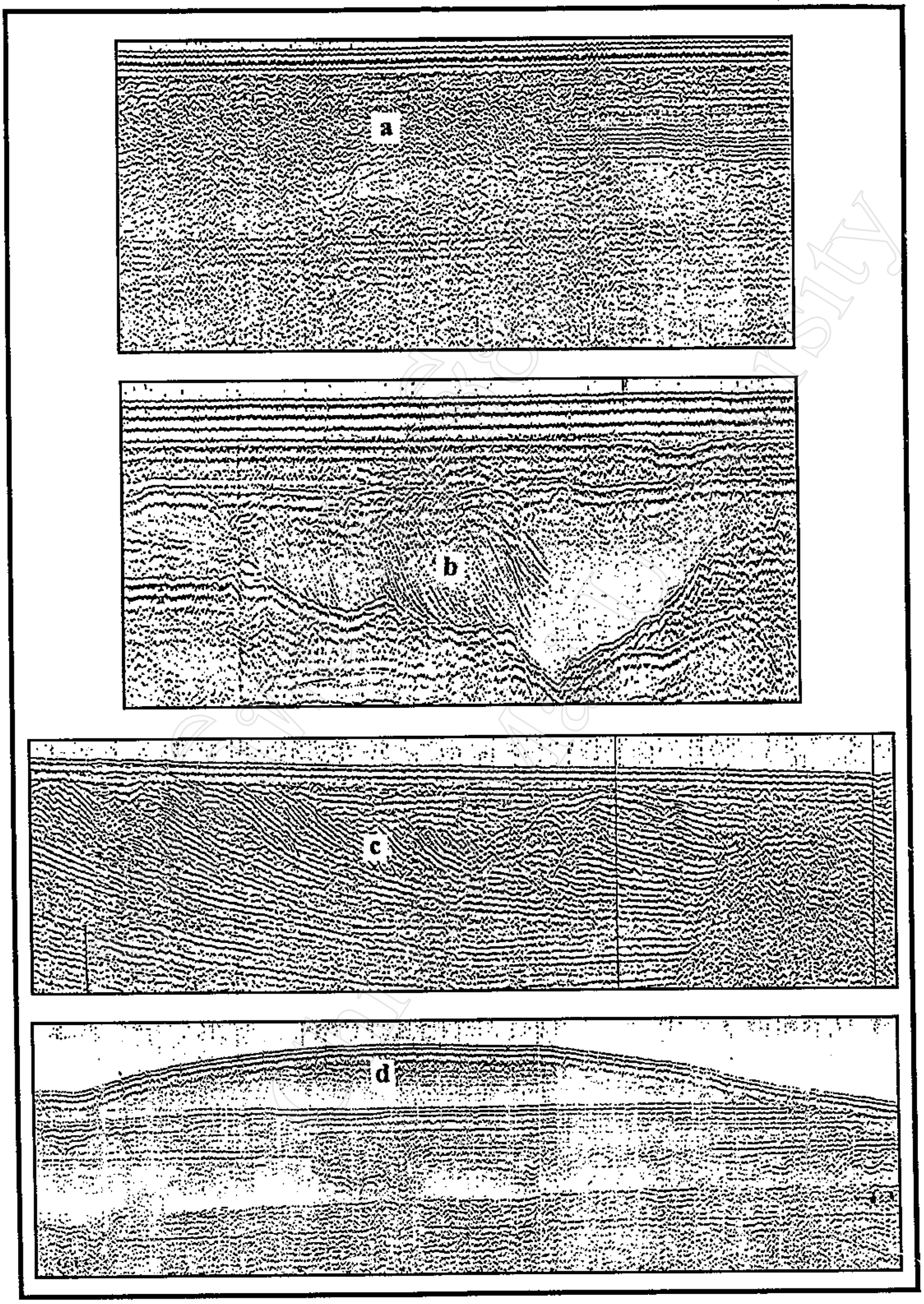


Figure 4.4 Seismic facies favorable for deposits of offshore placer minerals; including (a) chaotic, (b) chaotic and obliquely dipping fill, (c) prograded oblique system and (d) broad rise mound pattern

aggregates, particularly the part of terrestrial deposits where the most interesting seismic facies in the sequence are chaotic patterns, occasionally associated with few subparallel patterns. The chaotic pattern most likely represents sand and gravel deposits as fluvial channel fills within the sequence. Economic deposits of heavy minerals and corundum may be discovered in such channel fills. For example, deposits of corundum found in sub-area 1-E were mostly associated with chaotic patterns in fluvial channels (Appendix D).

A tentative map of distribution of dominant chaotic pattern within the sequence B is initially accomplished, as demonstrated in Figure 4.5. The map exemplifies the most likely favorable targets for further searches of offshore deposits of heavy minerals, corundum and aggregates in the study area. Thicknesses of the chaotic seismic facies range from 8 m to 15 m in sub-areas 1-A and 1-C, and 4 m to 12 m in sub-area 1-E. Those inferred coarse-grained deposits are still within economically accessible depth at present offshore mining technology, approximately from 10 m to 40 m below mean sealevel. However, detailed mapping of such patterns in Area 1 should be done afterward in particular interesting targets.

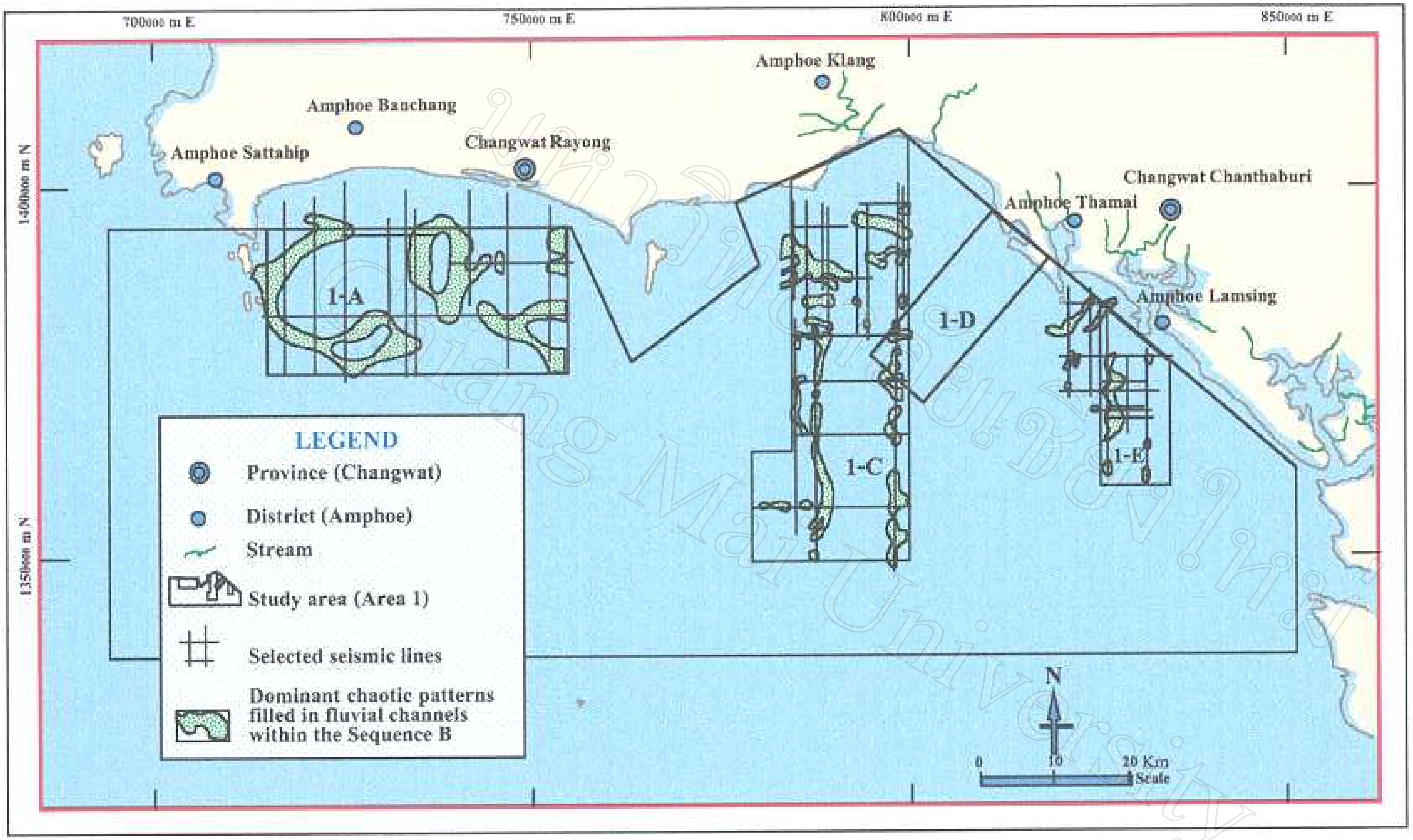


Figure 4.5 Map showing distribution of dominant chaotic seismic facies within the sequence B in the study area.