CHAPTER 2

BASIN EVOLUTION OF THE NORTHERN PART OF THE WESTERN BASIN

General stratigraphy of Cenozoic basin in the Gulf of Thailand

The oldest Tertiary sedimentary rocks penetrated by the drill-hole in the Gulf of Thailand are Late Oligocene (after Chinbunchorn et.al.,1989) but older undrilled sections appear to be present in the deeper part of several basins. In addition , Eocene fossils have been identified only in the Krabi basin onshore peninsula Thailand.

General stratigraphy of Cenozoic basins in the Gulf of Thailand has been presented by several authors.

Woolands and Haw (1976) subdivided the Cenozoic stratigraphy in the Gulf of Thailand into three major sedimentary cycles (Fig.2.1 a). The lower most part is Cycle 1 (Oligocene - Early Miocene)is a regressive sequence of continental deposits. Cycle 1 was nowhere fully penetrated.It is a coarse basal unit resting unconformably on the Pre-

Northern part of the Gulf of Thailand

Cycle	Major Lithology	Environment	Age
III	sand, clay and coal	Inner Neritic, Coastal swamp	Quaternary
			Pliocene to Miocene
II	sand, clay, calcareous clay, mudstone and limestone	Fluvial to Deltaic/ Coastal swamp	
I	Sandstone and Conglomerate	Alluvial Fan	Early Tertiary

Southern part of the Gulf of Thailand

Cycle	Major Lithology	Environment	Age
III	clay with sand	Inner Neritic	Quaternary
	clay/mudstone interbedded with coal and sandstone	Coastal mangrove swamp	Pliocene to Mid-Miocene
II	Sandstone interbedded with shale and coal beds	Fluvial and Deltaic plain	Early-Mid Miocene
	abundant coal, shale and thin bedded sandstone	Coastal swamp and Tidal Influence	Early Tertiary
I	Sandstone, Siltstone and Shale / Mudstone	Channel and Flood-plain	

Figure 2.1 a Stratigraphy succession of the Gulf of Thailand.(after Woolands and Haw, 1976)

Tertiary basement. On the top of Cycle 1 is Cycle 2 (Early Miocene - Late Middle Miocene), which is a regressive sequence of deltaic coastal progradation into a brackish/marine environment. After the maximum regressive Cycle 1 and 2 , they are followed by a short marine transgressive phase , which is more widespread in the main basinal areas.However, this is only well documened for the end of Cycle 2, which is represented by a widespread regional unconformity in Late Middle Miocene.Overlying the unconformity is the Cycle 3 (Upper Late Middle Miocene - Recent). The Cycle 3 is a transgressive sequence of finer grained and deposited in lower energy environment than the two earlier cycles.

Achalabhuti (1981) has summarized the stratigraphy of Cenozoic basins in the Gulf of Thailand into five zones (Fig.2.1 b). Zone 1 and 2 but they have a little difference in time such as Zone 1 is Oligocene , Zone 2 is Lower - Middle Miocene. In the Cycle 3, he divided into three zones.

Chinbunchorn et. al. (1989) also subdivided the stratigraphy of Cenozoic basin in the Gulf of Thailand into 2 sequences, syn-rift and post-rift sequences. The syn-rift sequence consists of Lower, Middle and Upper units. The Lower unit (Late Oligocene - Lower Miocene) generally started with red brown claystone with minor coarse to fine lithic-sandstone of alluvial plain and

TIME STRATIGRAPHY	LITHO STRATIGRAPHY	FLORA ZONE	ENVIRONMENT	RESERVOIR
QUATERNARY	LIGHT GRAY TO GRAY-BROWN CLAYS, SILTY WITH LIGNITE INTER-BEDS	PODOCARPUS	MARINE	
PLIOCENE	LIGHT GRAY CLAYS WITH SANDS AND LIGNITE INTERBEDS	DACRYDIUM	COASTAL PLAIN	
LATE TO UPPER MIOCENE	GRAY CLAYSTONES AND SHALES WITH SANDSTONE, LIGNITE AND COAL INTERBEDS	FLORSCHUETZIA. MERIDIONALIS	FLUVIATILE	O
MIDDLE MIOCENE	VARIGATED SHALES WITH SANDSTONE AND COAL INTERBEDS	FLORSCHUETZIA LEVIPOLI		O
LOWER MIOCENE				
OLIGOCENE	RED, VARIGATED SHALE AND SILTSTONE AND COARSE LITHIC SANDSTONE LOCALLY DARK GREY SHALE WITH SANDSTONE INTERBEDS	FLORSCHUETZIA TRILOBATA	FLUVIATILE LOCALLY LACUSTRINE	

Figure 2.1 b The general stratigraphic section of the Gulf of Thailand. (After Achalabhuti, 1981)

lacustrine deposition. The Middle uniy (Lower Miocene - Middle Miocene) contains organic rich lacustrine claystone and shale. The Upper unit (Middle - Late Miocene) is generally composed of fluvial deposits. The post-rift sequence (Late Miocene - Recent), overlies unconformably the Upper syn-rift unit and consists of high energy fluviatile coarse sand and gravel with some interbeded varicoloured clay.

Polachan et. al.(1991) divided the stratigraphy of Cenozoic basins in the Gulf of Thailand into four units (Fig.2.1 C). Unit 1 and 4 are the same as Cycle 1 and 3, but in Cycle 2 is further divided into two units. He also proposed that the regional unconformity occurred during Late Miocene time rather Late Middle Miocene time due to the K/Ar radiometric age of basaltic lava flow in Phisanulolok basin 10.3 plus or minus 0.2 Ma. is considered more reliable than its age from a few diagnostic flora.

Stratigraphy of the northern part of the Western basin

The Pre-Tertiary of the northern part of the Western basin, which was drilled by well 6-1-C is dolomite. Dolomite are medium crystalline with a rhombohedral texture. Detailed thin- section analysis by Robertson (Singapore) Private Limited are as follow: No foraminifera were present and the carbonates are

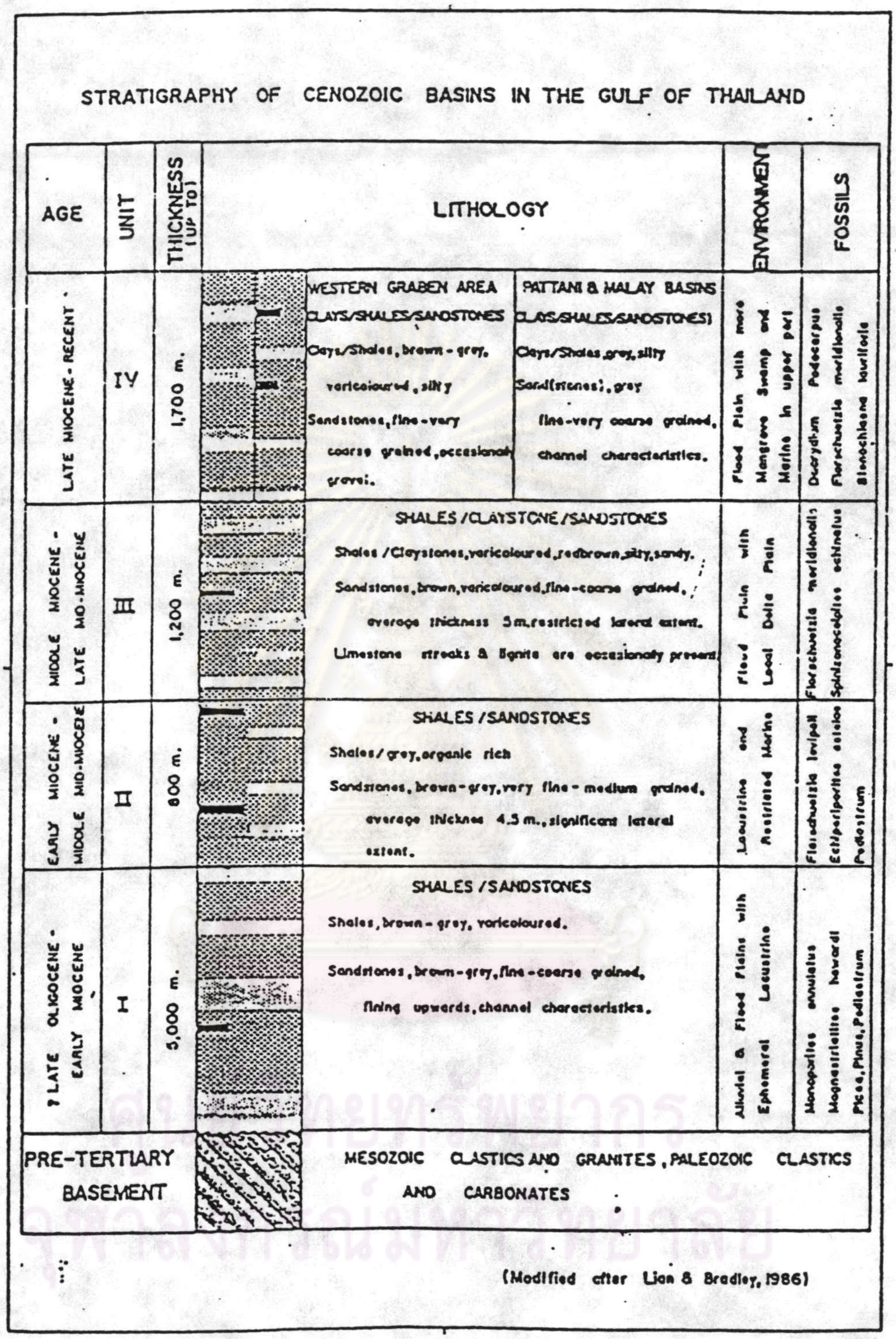

Figure 2.1 c The stratigraphic of Cenozoic basin in the Gulf of Thailand. (After Polachan et.al.,1991)

considered barren of fauna. Plant debris are low throughout, and no pollen grain is present.There is no faunal or floral evidence for the age of this interval. However, postulated a Mesozoic depositional basin in the Gulf of Thailand, based upon evidence from adjacent on-shore areas. The limestone sequence in the deepest part of this well may be part of such a depositional basin. It has however been assigned an indeterminate age, due to lack of palaeotological evidence.

The Cenozoic stratigraphy of the northern part of the Western basin can be divided into 4 units (Fig.2.2 a) . This unit was divided from the integration of geological data, geophysical logs ,seismic interpretation and palynology report.

1. Unit A (6,110-6,710 ft.)

Data from 6-1-C well reveals that the unit A is the lower sequence of Cenozoic rocks which overlies unconformably the Pre - Tertiary basement in this basin and is overlained by unit B. The thickness of this unit varies according to the shape of basin.

The lithology of this unit is massive, dence limestone ,which is occasionally white, pink, yellow to reddish white. Mainly microcrystalline to cryptocrystalline, often finely fractured (with hairline

GEOLOGICAL INFORMATION OF THE 6-1-C WELL

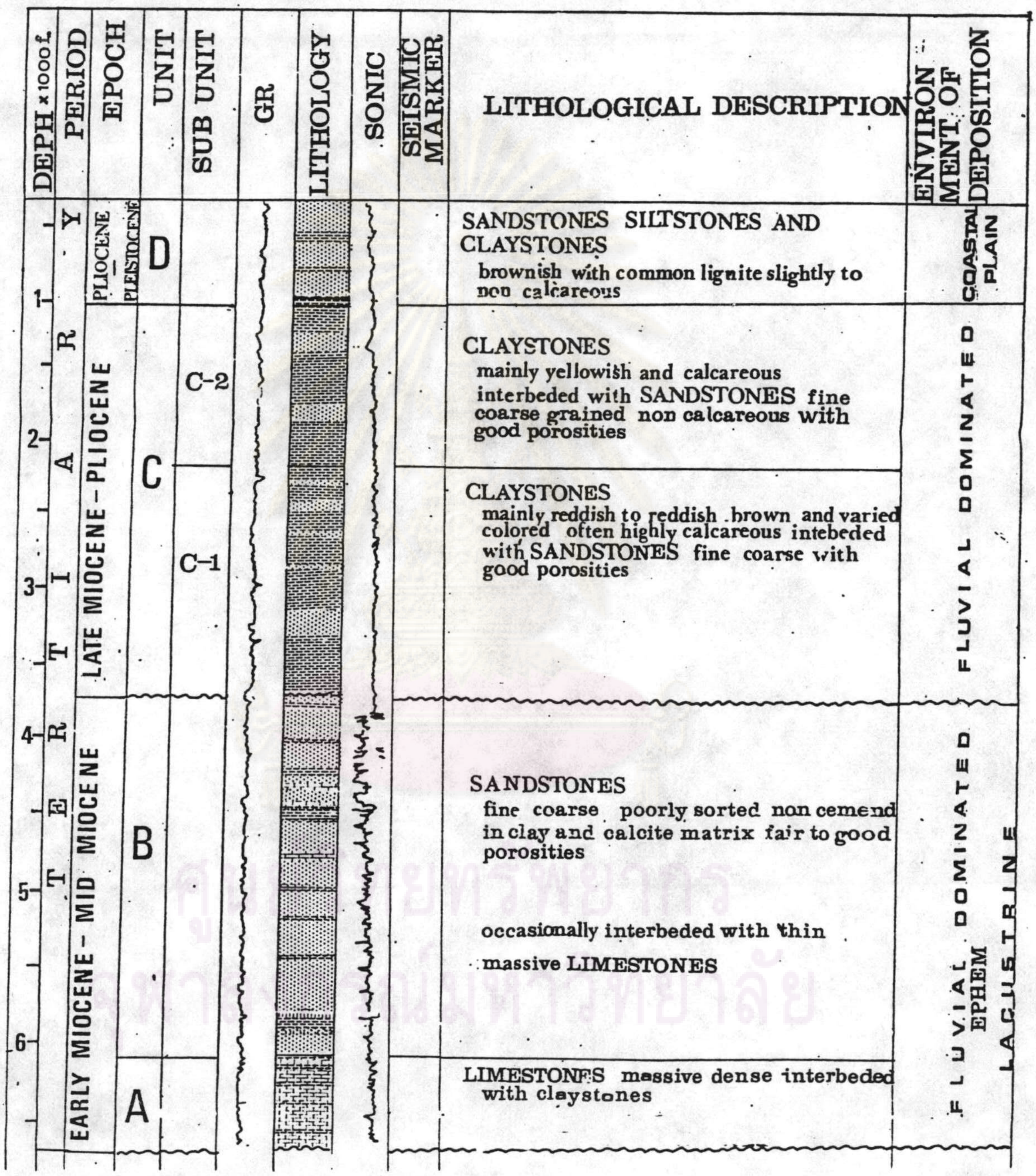

Figure 2.2 a The stratigraphy of the northern part of the Western basin.

fractures) filled with calcite micro veins. The limestone associate with claystone, silty claystone mainly reddish to reddish brown but also vari colored. These lithologies grade both vertically and laterally into the limestone facies. It is assumed that this section is approximately Early Miocene in age, and deposited in a lake or shallow - water lagoon , with the fluviatile environment. These sediments are assumed to have been derived mainly from carbonate source rocks exposed at that time on the western shelf. It is assumed, that there must have occurred during a major tectonic event in the source areas to cause such an abrupt change in unit A and unit B (after Keston,1976.).

<u>2.Unit B (3,700-6,110 ft.)</u>

The lithology consists predominantly of sandstones. These sandstones are interbedded with vari-coloured claystone mainly reddish brown and also often highly calcareous.

The lower boundary of this unit is quite sharp,and is marked by a thick, white, dense, limestone bed (at 6170 ft.). The limestone bed at 6110 - 6120 ft. is reddish in colour.

The age for this unit is interpreted to be Early to Middle Miocene and the environment of deposition is a fluviatile , rapidly changing including shallow, fresh - water lakes and lagoons inwhich the limestones accumulated (after Keston, 1976.).

No foraminifera and palynomorphs were recovered from this interval. Rare pollen grains and plant debris were recorded. The age of this interval is therefore indeterminate. The coarse red nature of the lithologies is probable responsible for the absence of palynomorphs. Because of the normal fault formed in the eastern area which close to Ko Kra ridge. Thus this fault might be caused the granitic talus that supply the coarse sediments. The depocenter of the basin may have been relatively close to eastern area. The eastern area (Kra Ridge) is presumably granitic basement, supply the bulk of coarse clastic sediment. To the west, presumably of palaeozoic sediments, supplying the bulk of the fine-grained and calcareous material.

In the lower part of this unit (below 4,400 ft.), these highly calcareous claystone grade into marls and massive, dense limestone, also vari colored which can clearly seen from density and sonic logs and mud log.

The limestones appear to be non-marine. No foraminifera were recored from the limestone.This unit has a good oil show between 3,850 - 6,100 ft. At the base of this unit is base on decreasing transit time in sonic log, due to increasing the denser rock.

From sonic log (Fig 2.2 a) show coarsening upward sequence that means in the lower part of this unit is low energy because of fresh water limestone appear in the lowerpart. Then the energy change to high fluviatile energy that sandstone appear.

3.Unit C (1,010-3,700 ft.)

This unit is difficult to divide from wire-line logs, because of the same environment as unit B. But on the basis of lithological characteristics it can be subdivides into 2 sub-units as follows:

(a) Sub-unit C-1 (2,160-3,700 ft.)

Comprises predominantly of reddish to reddish - brow claystone, with vari-coloured varieties (yellow/gray, purple/white) occurring as patches and/or pockets. It is interbeded with sandstones similar to those occurring in the upper unit. Most of these sandstone are still poorly compacted,with fair to good visible porosity.

The lower boundary of this unit is provisional placed as the base of the thick claystone bed and top of the predominantly sandstone section, however it could have been placed also at 3,740 ft. or 3,850 ft.

The side wall core samples at 3,740 ft. and 3,798 ft. are beginning to show signs of induration and tight compaction, hence the boundary could have been placed at 3,740 ft., and based on subsequent oil shows at 3,850 ft.

No gas or oil shows in this interval. The age of this interval is anticipated to be Late Miocene, and the depositional environment is fluviatile. No foraminifera was recovered from 'this interval. Through out 4 thin section plant debris densities are low to very low, and pollen and spore are rare. This is probably due to the red bed coloration and coarse sand lithology in the upper part of this interval.

(b) Sub-unit C-2 (1,010-2,160 ft.)

Comprises predominantly of yellowish claystone, massive, generally non-calcareous, interbedded with whitish to yellowish sandstone, fine to coarse grained, subangular to surrounded, in clay or calcareous matrix.

The upper boundary of this unit is relatively sharp, but the basal boundary appear transitional. Both boundaries are based on wire line log pattern. No gas or oil shows.

The age of this unit is anticipated to be Late Miocene and the environment of deposition is fluviatile

No microfossil was found. The lower baundary of this unit is base on a seismic sequence corresponding to the unconformity. No clear evidence from sonic and gamma ray because they are at the end of wireline log. Between 3,200-3500 ft.; the electric log signature shows fining upward sequence (Fig.2.2.3 a) which is interpreted to be the channel deposit followed by overbank fine-grained of high sinuosity channel generated by stream swinging from side to side across the flood plain on gentle slope.

4.Unit D (375-1,010 ft.)

This unit is composed of a series of interbedded gray to brownish sandstones, siltstone, and claystone with lignite and pyrite . The sandstone is fraible made up mainly of quartz, feldspars and lithic fragments, generally medium to coarse grained, subangular to surrounded. Between 930-970 ft.. the sandstone is generally slightly to non-calcareous, calcareous fossils are very rare, only few foraminifera are observed. No gas or oil shows.

The age of this section is anticipated to be Pliocene - Pleistocene. The environment of deposition is assumed to be brackish water coastal plain to deltaic in character.

The interval 600-1010 ft. yield shallow water

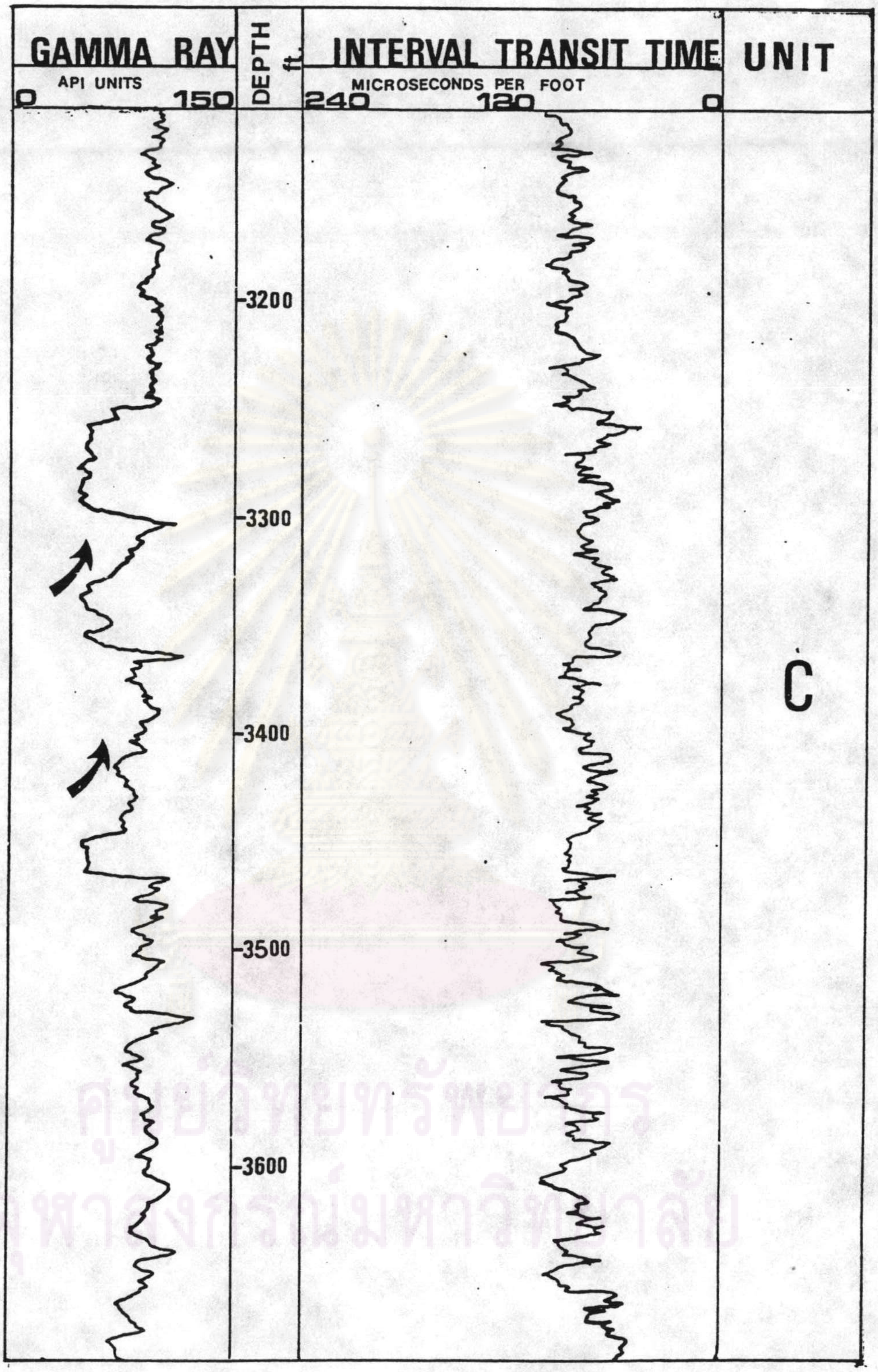

Figure 2.2.3 a The electric log signature shows fining upward sequence.

benthonic foraminifera, notably Ammonia bacciorii and Eliphidium sp. . Palynomorph are fairly abundant in the upper 600 ft., but the lower 300 ft. contains sparse floras. Two specimens of Dacrydium sp. were recorded, indicating a Pliocene age for this interval. Between 700-1,000 ft., the electric log signature shows coarsening upward (Fig.2.2.4 a). This is interpreted to be the progradation delta.

From seismic interpretation (Fig.2.2.4 b), the Tertiary basement reflector is the lowest marker indicating the lowest boundary of these Cenozoic sequences with the onlapping character of reflection to acoustic basement. The Tertiary basement map (time structural map) can see in Fig.2.2.4 c. The second marker shows onlapping and conforming with the top of the lowest sequence, and also shows onlapping to acoustic basement at the edge of basin. The time structural map is shown in Fig.2.2.4 d. The third marker is rather conform with the top of the second sequence. Generally, this marker is well known as the Middle Miocene Unconformity, which is regional unconformity in most of Tertiary basins in Thailand. This unconformity indicates the cessation of major rifting of most Tertiary basins and commonly marks by the die out of the faults which in turn have close relations with the development of Tertiary basins in Thailand.

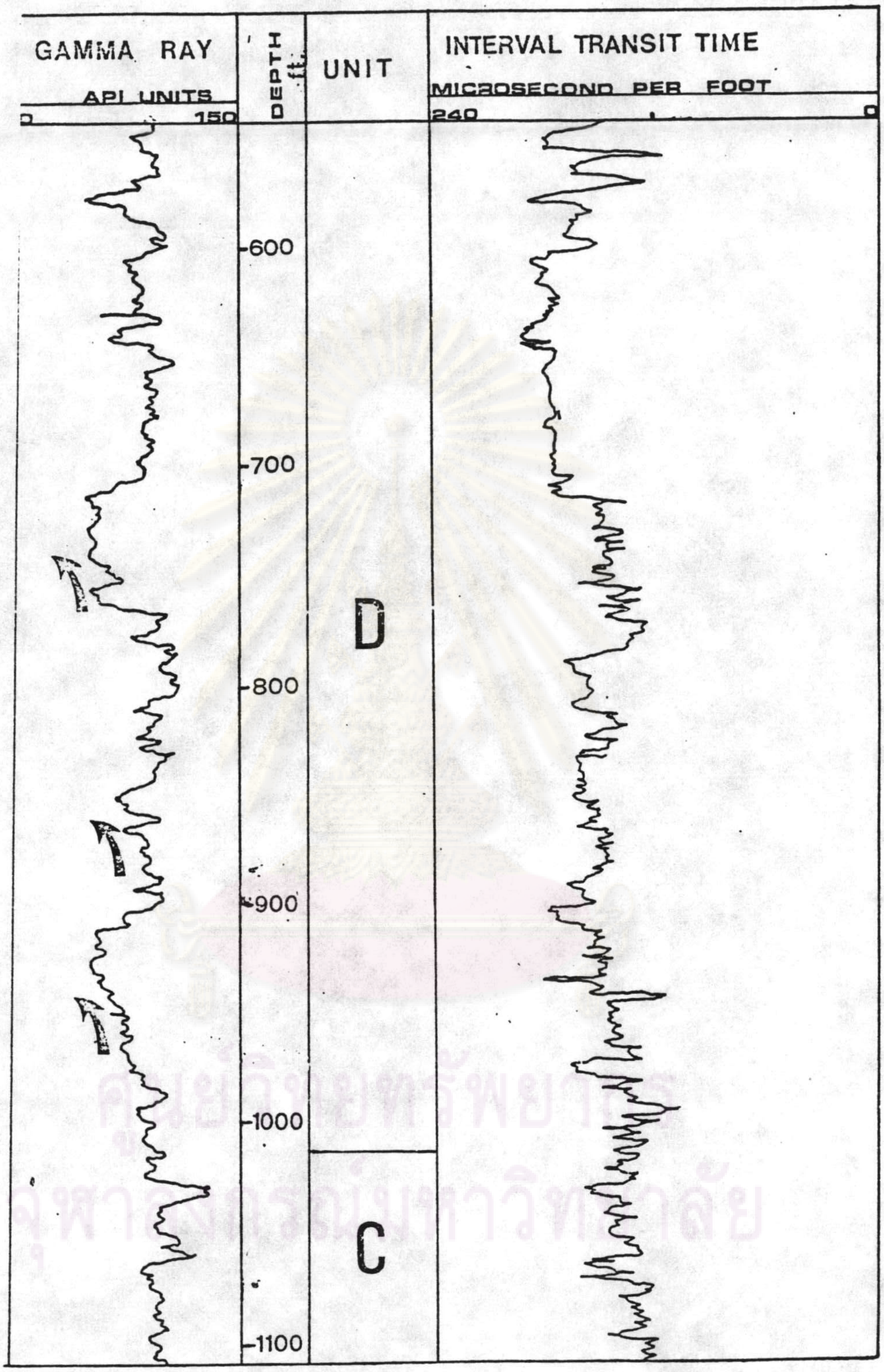

Figure 2.2.4 a The electric log signature shows coarsening upward sequence.

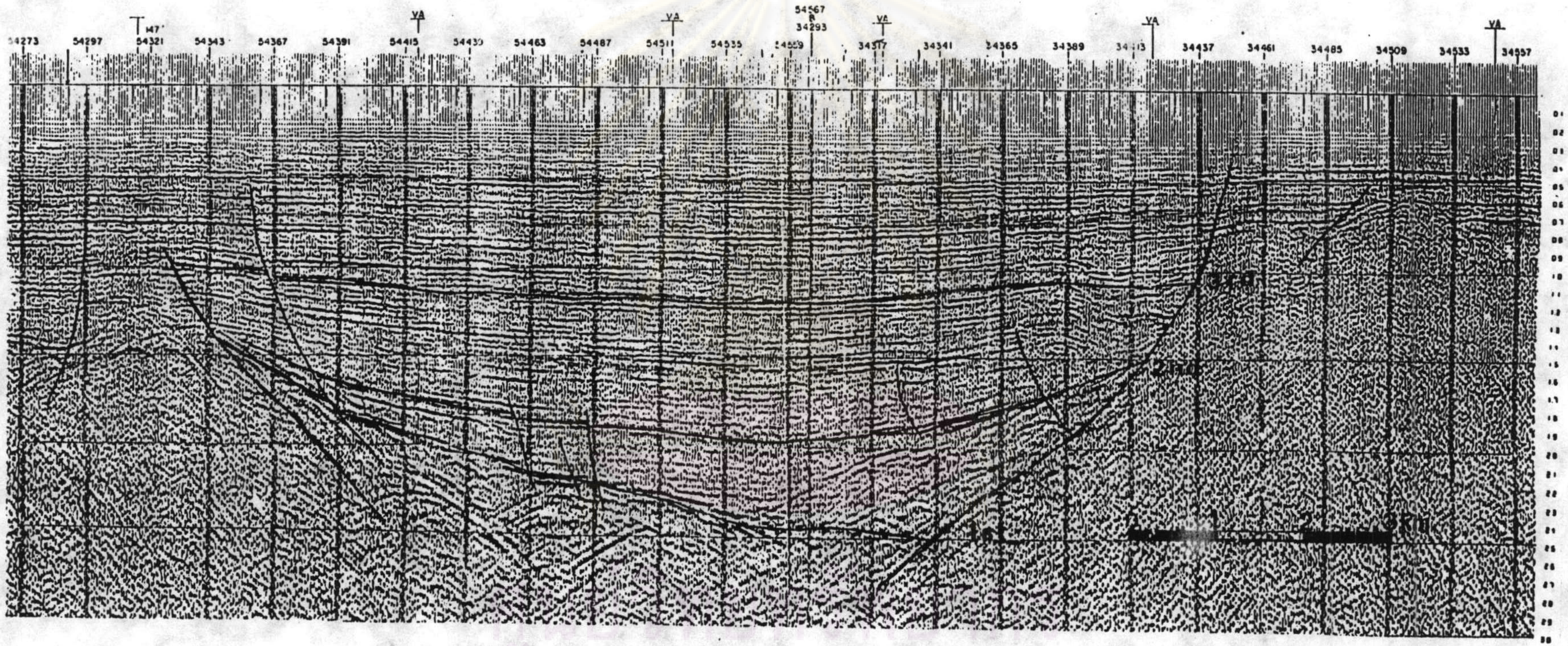

Figure 2.2.4 b The seismic section that shows three markers.

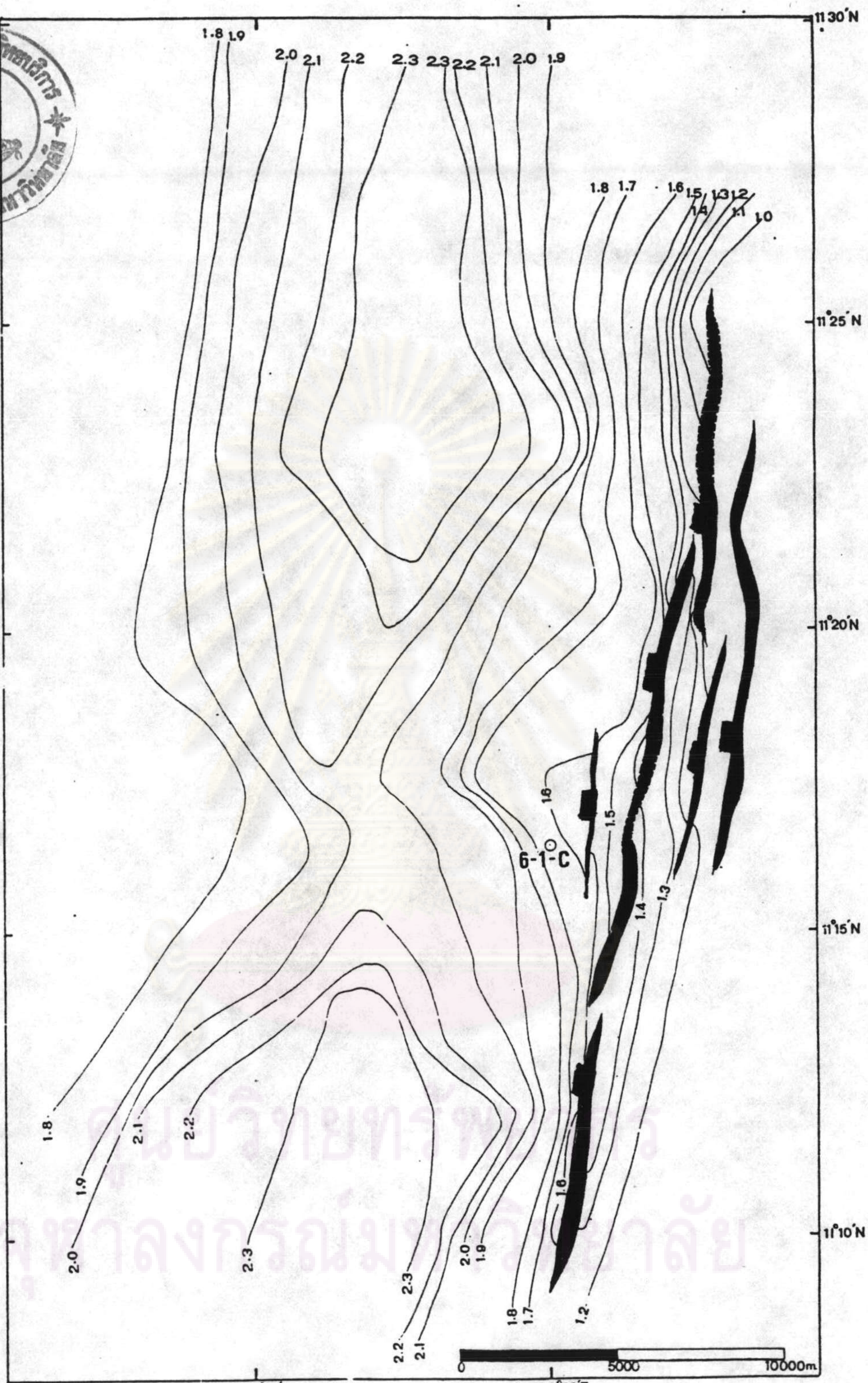

Figure 2.2.4 c The structural map of the basement of the northern part of the Western basin

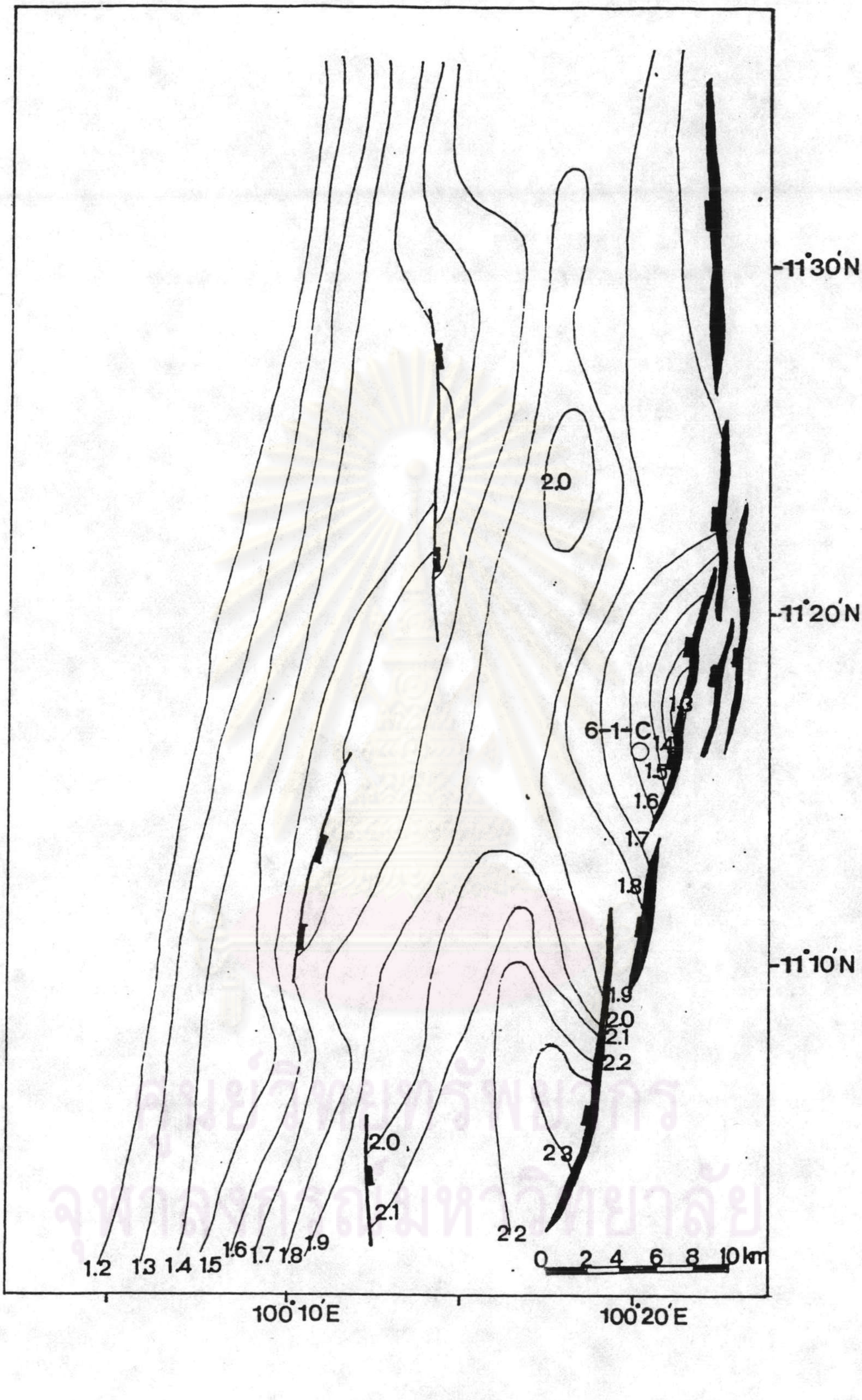

Figure 2.2.4 d The structural map of the Early Miocene age.

Heat flow analysis

This heat flow analysis is undertaken using the 6-1-C well log data (gamma ray and density logs). All the logging depths have been corrected to the sub-sea datum . The data has been read every 50 foot interval except the gamma ray data between the depth of 150-188 ft. the interval is 38 ft. due to the sub-sea extrapolation. The gamm ray data started from 188 ft. to 6,838 ft., but the density data started from 3,638 ft. to 6,838 ft. Vsh and porosity values have been calculated from the following formulas.

Vsh = (GRred-GRmin) / (GRmax-GRmin)

Vsh = Volume of shale

GRred = Gamma ray reading

GRmax = Maximum gamma ray reading

Porosity = (Dma-Dred) / (Dma-Df)

Dma = Matrix density, sand = 2.65, dolomite = 2.88

Dred = Reading density

Df = Fluid density (salt mud = 1.1 , Fresh mud= 1.0)

The thermal conductivity for each interval have been calculated by two equations .

1. First equation

$$(K) = (R_1/(K_1^{(1-0)}K_w^{0}) + R_2/(K_2^{(1-0)}K_w 0))^{-1}$$

(K) = Geometric mean thermal conductivity

R_1 = Volume of the first component, R1 = sand component = 1-Vsh

R_2 = Volume of second component , R2 = shale component = Vsh

K_1 = Thermal conductivity of sand matrix = 8 W/m°K, Dolomite =4.66 W/m° K

K_2 = Thermal conductivity of shale matrix=2 W/m°K

Kw = Thermal conductivity of water = 0.6 W/m°K

0 = Porosity

2. Second equation

The geothermal gradiant of the 6-1-C well is 2.31°F/100 ft. or 4.21113°C/100 m.. By means of this Geothermal gradient we can correct the thermal conductivity in the second equation as describe by the following relation:

$$(K_{mt}) = 358 \times (K_m - 1.84) \times ((1/273+t) - 1/(273+1200)) + 1.84$$

358 = Scale Factor

K_m = Thermal conductivity of matrix at 25°C for sand, shale, and dolomite

K_{mt}= Thermal conductivity after temperature correction

t = Temperature at each interval

1.84 = Thermal conductivity at 1200 °C

Finally, the average thermal conductivity ((K)) and heat flow (Q) of the 6-1-C well can be calculated by the following formulas.

$$((K)) = \frac{L}{\text{Sum } l_i/k_i}$$

((K)) = Average thermal conductivity

L = Total depth

l_i = Interval depth

k_i = Interval thermal conductivity

Q = ((K)) x Teperature gradient

Q = Heat flow

The result is shown in Figure 2.3 a and can conclude that

1. The thermal conductivities of the 6-1-C well are apparently controlled by the porosity rather than Vsh as shown in the graph of Vsh, k_i, and porosity versus depth. This might be correspond with the Unocal's report that the porosity in the Tertiary section of the Pattani basin are rapidly decreasing with depth.

2. The porosity in some interval might not be accurate due to cavings that will effect the depth of investigation of the tool.

Structural setting

Pollachan (1988) reviewed the tectonic framework of the Cenozoic basins in the Gulf of Thailand as it

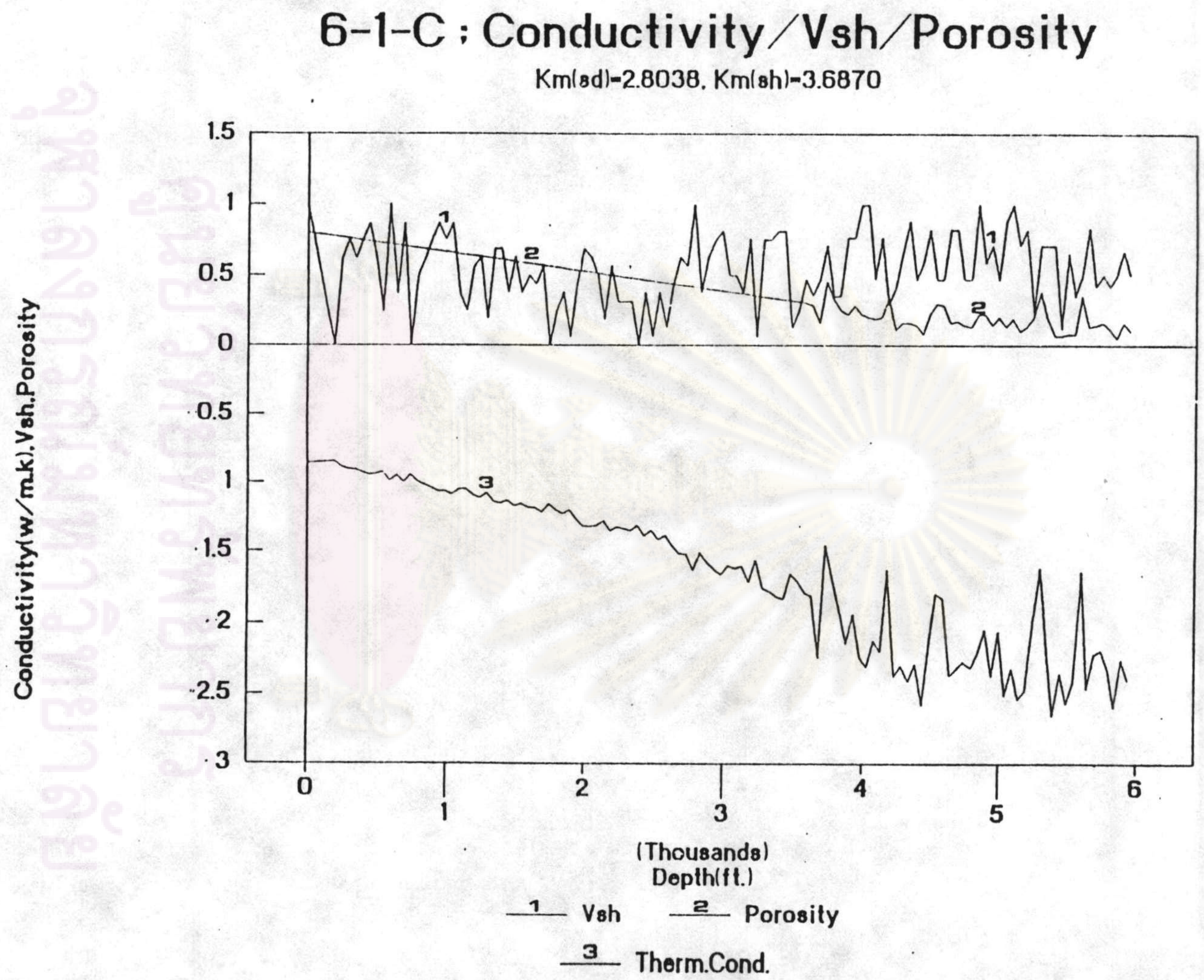

Figure 2.3 a The realation of Vsh, Ki and porosity versus depth of 6-1-C well

appears to lie near the intersection of the NE-SW Ranong Klong Marui and the NW-SE Three Pagodas strike-slip faults. During the Tertiary faults the Ranong-Klong Marui are conjugate left lateral strike - slip fault, which cut across the Thai - Malay Peninsula into the western part of the Gulf of Thailand. The Three Pagodas is the principle right lateral strike - slip fault, located at the east edge of the Gulf of Thailand Myanma. It represent a splay of the sagging fault in Mayanma and Northern tip extends from Mayanma across the Thai-Malay Peninsula, through the Gulf of Thailand. Based on structural relationships between the principal NW-SE right lateral strike-slip faults (Red River, Mae Ping, Three Pagodas and Sumatran) and the conjugate NE-SW left lateral strike-slip faults (Northern Thailand, Uttraradit, Ranong-Klong Marui) together with the evidence of clockwise rotation of crustal block, Polachan (1988) concluded that the N-S trendingCenozoic basin in Thailand develope dextral transtensional shear along the pre existing structure.

Polachan et.al., (1991) mentioned the large amount of left lateral offset along the NW-SE Three Pagodas fault as a result of the collision between the Shan-Thai and Indochina blocks during the late Permian to Middle Triassic. However, these faults changed the sense of movement from left to right lateral during the development of the Cenozoic Basins. Since the Oligocene, the right lateral displacement of these faults is only some tens of kilometres, which is not sufficient to destroy a relict of the previous left lateral offset.

Western basin is one of the Cenozoic basins, which is located in the Western intermontane graben area. It has developed as a combined result of the N-S extensional fault and the NW-SE Three Pagodas transcurrent fault zone. The precise timing of the opening of the basin is not clearly known.

The northern part of the Western basin is a half-graben basin which is bounded to the east and controlled by a major boundary fault to form narrow and elongate N-S trending basin. Interbasinnal high (buried) is present in this area. This basement high was probably caused by linking patterns of half grabens .

The seismic interpretation depicts hidden Tertiary basins with the major boundary fault on the west as shown in Figure 2.4 a. This may be represent the old weak zone of Pre - Tertiary.

<u>Evolution of the Northern part of the Western basin</u>

1. Oligocene to Early Miocene

During Oligocene time, the northern part of the

Fifure 2.4 a The seismic section shows the hidden Tertiary basin.

western basin developed as a small narrow basin associated with N-S extensional fault . Shallow lacustrine occurred in this period. The Depocenter of the basin was to the east. The fault talus caused by the N-S narmal fault that bounded the Ko Kra basin.

2. Early Miocene to Middle Miocene

During this period of time, the environment of deposition is shallow, fresh-water lake and lagoon in which the limestone accumulate of the unit A. The limeston might br derived mainly from the erosion of carbonate source rock exposed at that time od the western shelf and re-precipitated as secondary carbonate in a shallow, fresh water lahe and lagoon. During the Middle Miocene a change in tectonic and/or climatic condition took place with the cessation deposition of fluvio-lacustrine unit. Evidence from well(unit B) suggests rapid uplift and rapid supply of coarse terrigenous detritus in this period. In the northern part of the Western basin most of N-S extentional fault terminated at in the Middle Miocene. This unconformity may have been caused by chianging of regional stress regime due to a major realignment of plate movement. (Polachan et al.,1991)

3. Late Miocene to Pliocene

The unit C comprises interbeded fluvio-floodplain claystone and sandstone. The clastic sediments are thick and widespread through out the northern part of the Western basin. This basin during this period is mainly subsided and created more extensive basin.

4. Pliocene to Pleistocene

The evidence of marine transgression from the southern part of the Gulf of Thailand, ie, Patttani and Malay basins shows the timing of initial incursion of the sea in the Gulf as Eocene to Early Oligocene (Woolland and Haws,1976; Lian and Bradley, 1986). In the Upper Gulf area,a the depositional environment was shallow marine represented by the influence of marine transgression during the Late Pliocene to Holocene.

During Pliocene to Pleistocene in the northern part of the Western basin is referred to as the unit D. The unit D is accumulated under the shallow sea environment.

The northern part of the Western basin model

There are three main ideas about the development of the Tertiary basins in the Gulf of Thailand. The ideas are as follows; the first idea is defined during 1974 to 1987 by many geologists.They believe that the development of the Tertiary basins in the Gulf is the result of the plate motions in Southeast Asia during the Late Cretaceous to Early Tertiary. The activities of plates in Southeast Asia were closely related to the movements of India toward Asia, the sea-floor spreading, rifting and emplacement of granite in this region. Most of geologists defined these basins as the rift basin model. However, few geologists, such as Mitchell (1985) and Hutchison (1986) classified these basins as the back-arc basin model. The second idea is defined during 1986 to 1988. The second idea is believed that the Tertiary basins in the Gulf are the shear basin model or continental wrench basin model forming by the interaction of wrench faults. Finally, during 1987 to 1989 the third idea is originated by the combination of the first and second idea. In this idea, the development of the Tertiary basins in the Gulf are the result of the plate motion in Southeast Asia during the Early Cenozoic combined with the interactions of wrench faults in this region. These basins are classified as the rift/pull apart basin model.

The structural style of the northern part of the Western basin is dominated by mainly N-S to NNE to SSW fault. The basin is elongated in the N-S trend. The basin is approximately 6 kilometres wide and 11 kilometres long. The major N-S normal fault which controlled the basin lies on the east of the basin corresponding to the depocenter on the east. This fault is believed to be the effect of the collision of India with Urasia that make the N-S compression and cause the E-W extension. The result found the normal faults in this basin. The collision of India with Asia was the main cause of the reactivation of these transcurrent faults during the Early Tertiary. Afterward, the plate motion,a such as rifting and uplifting, were active during that time resulting in the changing sedimentation in this basin. The sedimentary facies associated with faulting were deposited during the same time of the basin forming.

The northern part of the Western basin is classified as intracratonic rift basin and as pull-apart basin. These basin resulted from the Eocene to Oligocene collision of the Indian plate with Eurasia and the subsequent extrusion and rotation of Indochina.