CHAPTER 3

SUBSURFACE GEOLOGY OF OIL WELL IF 30 03S

3.1 GENERAL

The sedimentation and tectonic evolutions of the basin were discussed at length by Settakul, (1985) and Khantaprab and Kaewsaeng (1987), but only a brief resume of those information will be given before discussing the subsurface geology of borehole IF 30 03S.

The Fang Basin is an intracratonic basin initiated during late Cretaceous or Paleogene on an eroded Paleozoic or Mesozoic substratum. The sedimentary sequence records a history of an initial isostatic subsidence followed by a thick sedimentary infill (Dutescu and Enanche, 1980).

Early phases of sedimentation in the basin were presumably restricted to tilted fault block depressions in the northwestern and western margins of the basin. Alluvial fans, fluvial and locally ephemeral lake sediments were deposited during this period.

During early to middle Miocene, extensive paleolakes were developed, owing to the reactivation of pre-existing faults, and culuminated in wide-spread depressions in which liminic conditions were quickly established. Thick sequences of find-medium grained sediments, presumably of fluvio-lacustrine origin, appeared during this phase. These apparently thicken to the west with the fluvial detritus being delivered from the east.

Major tectonic and climatic changes during upper Miocene eventually led to the abrupt disappearance of the paleolake. Not only was this phase marked by the disappearance of the lake, but also by a transition from dominantly reducing environment into one of oxidizing type. Much of the sedimentation characterising this period is high energy fluvial facies (medium-coarse grained clastics). Locally, ephemeral lacustrine sediments are also well developed throughout the basin. A late Miocene unconformity separates these strata from the underlying sediments.

High-low energy fluvial deposits (terrace gravels and flood plain sediments), associated with the present day river patterns, form the main surfacial deposits.

3.2 LITHOLOGIC SEQUENCE

A broad subdivision of the lithologic succession of IF 30 03S included in descending order the Mae Fang and the Mae Sot Formations, with a further subdivision of the latter into upper and lower members.

In the present study, six broad units, designated 1-6, were identified. The study relied mainly on subsurface data in form of geophysical logs, drill cutting and cores. Description of cutting and cores provided much of the information regarding the lithologies of the stratigraphic section. Using logs sandstone and shale thicknesses were determined. Extended descriptions on each of these units is given below and the subsurface lithological sequence of the borehole is illustrated in Figure 3.1.

3.2.1 Unit 1

This unit is approximately 854 ft. thick and is defined by a rather uniform lithology, predominantly of shales. Occassionally interbedded sandstones and siltstones occur in the vertical sequence. Rapid

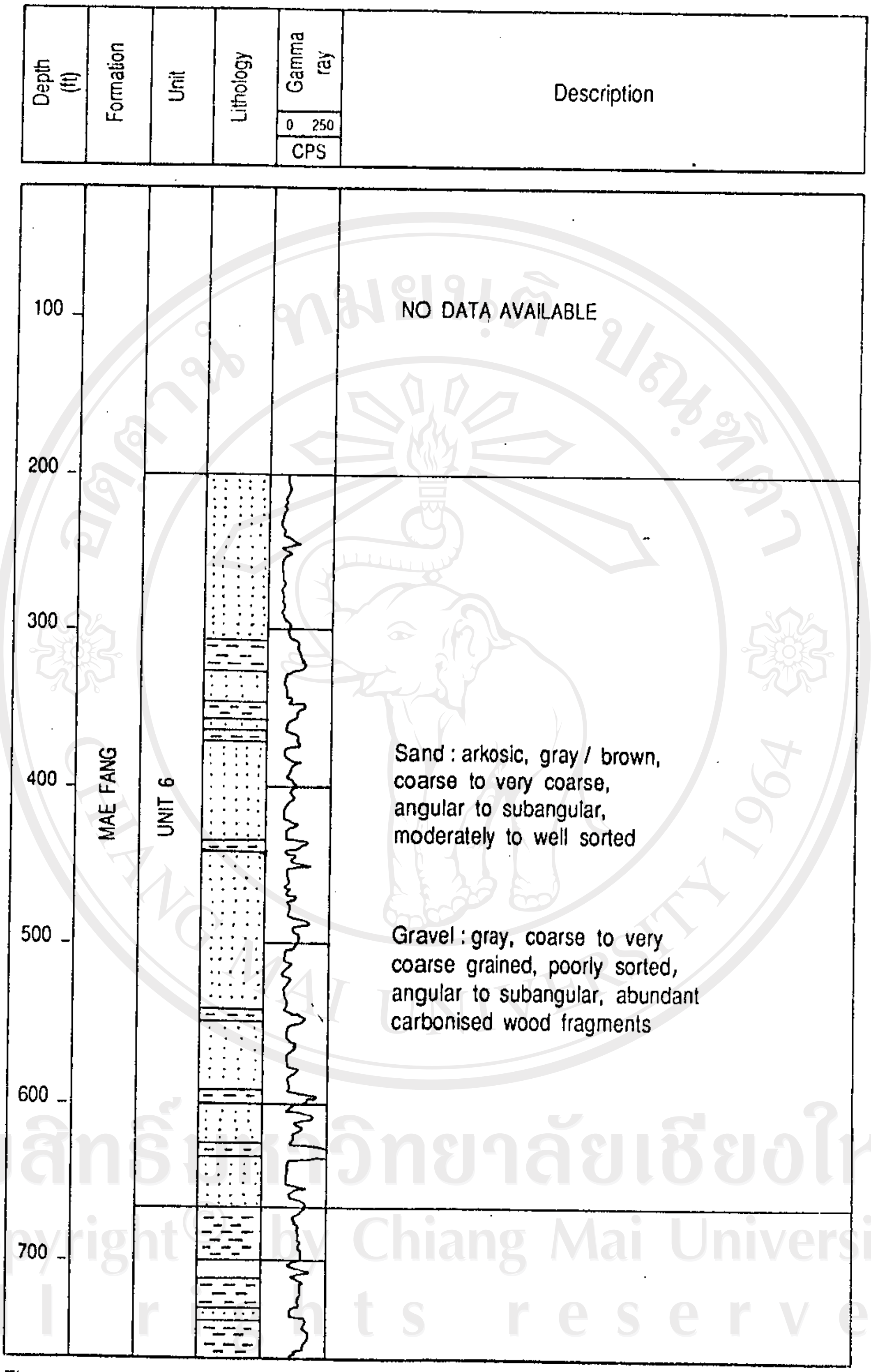


Figure 3.1 The subsurface lithological sequence of Oil Well IF 30 03S interpreted from gamma-ray geophysical log

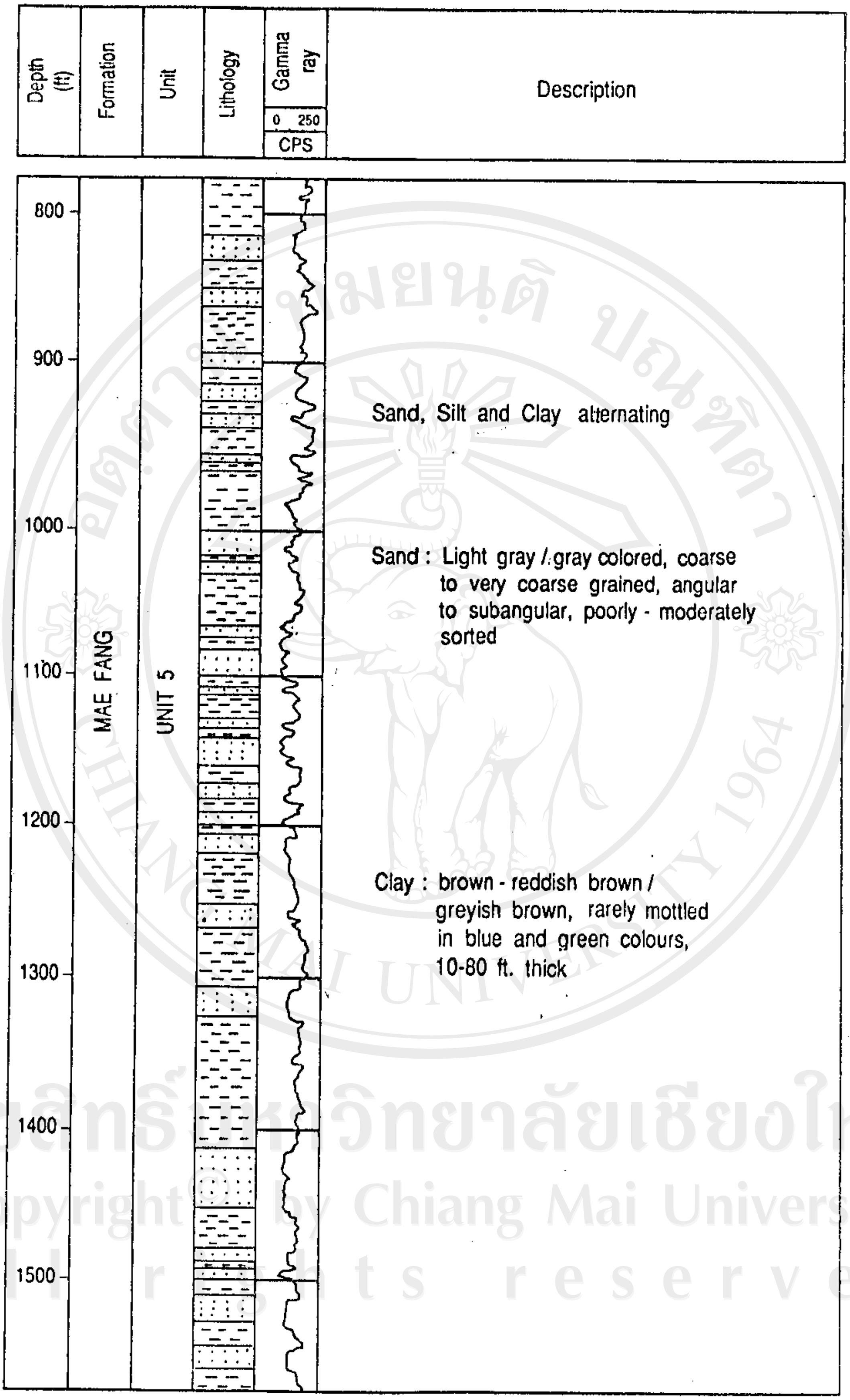
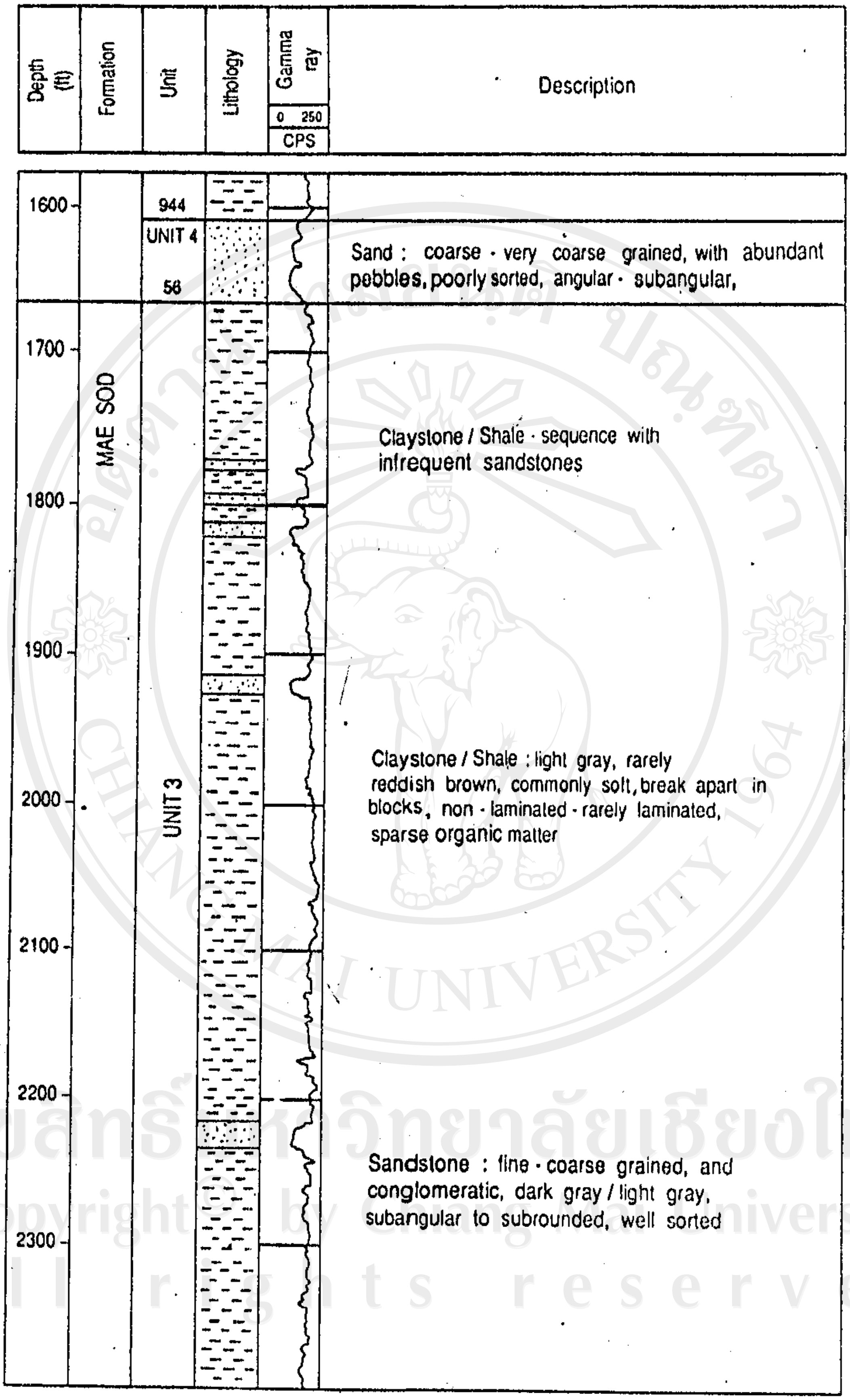


Figure 3.1 cont



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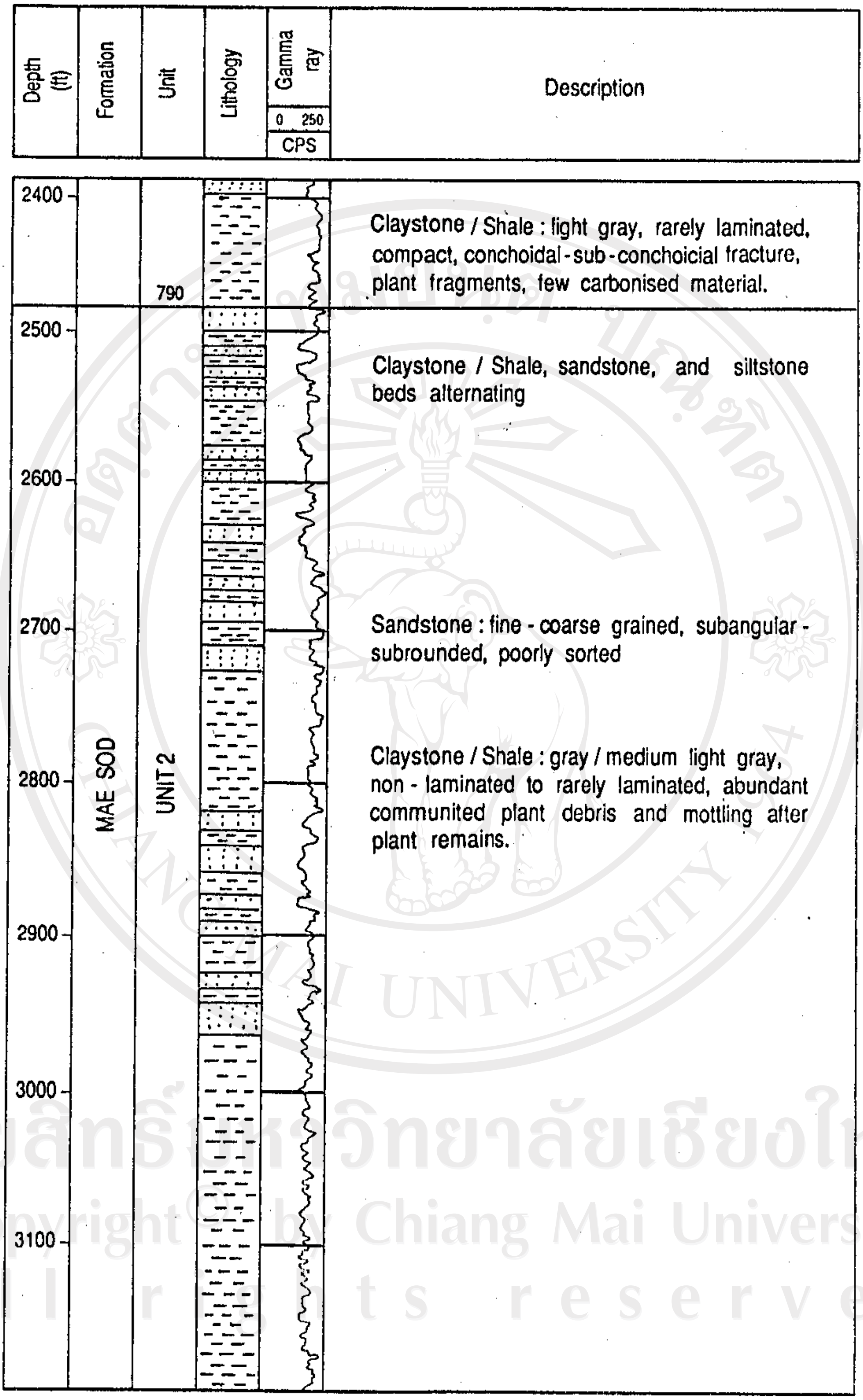

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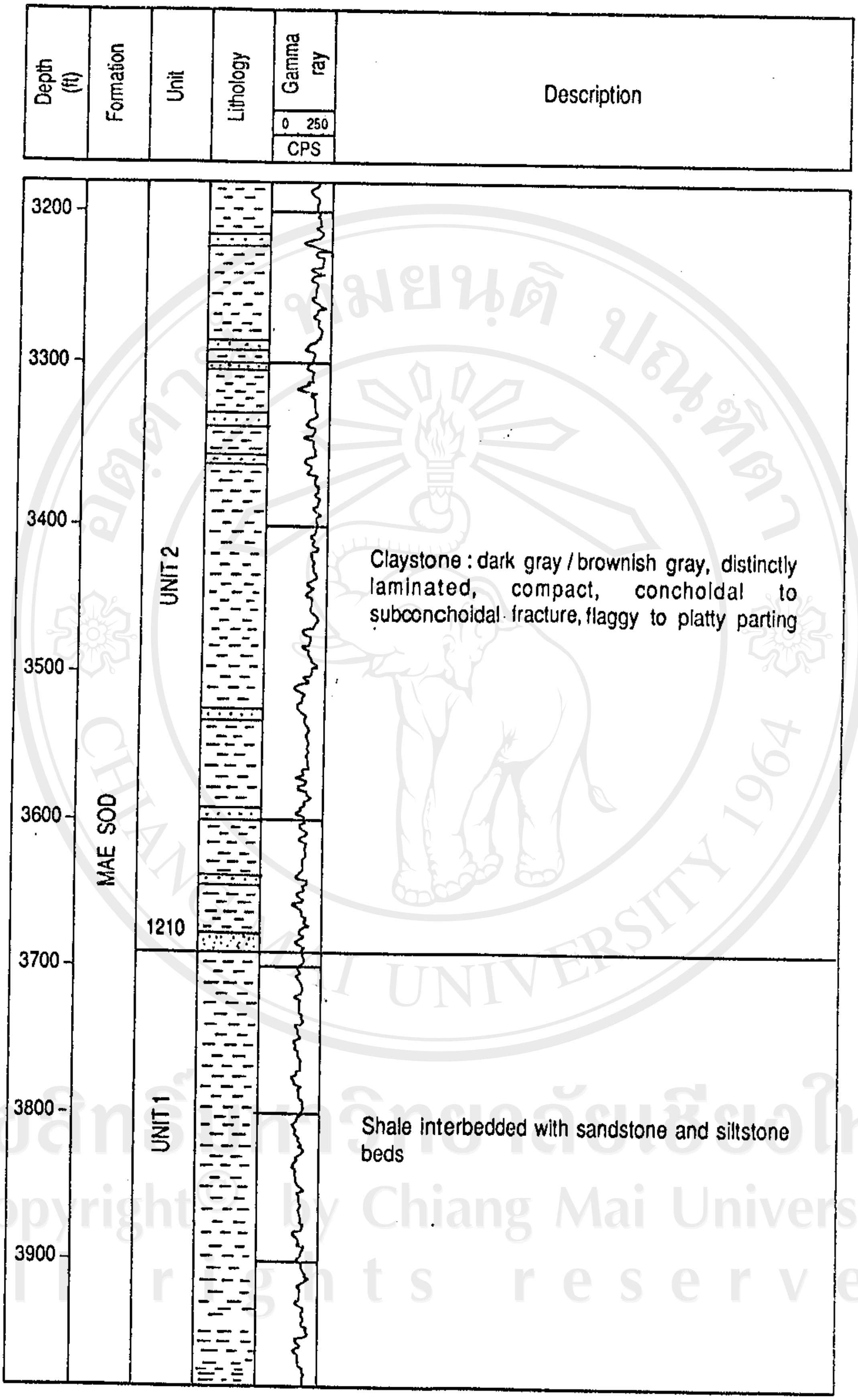

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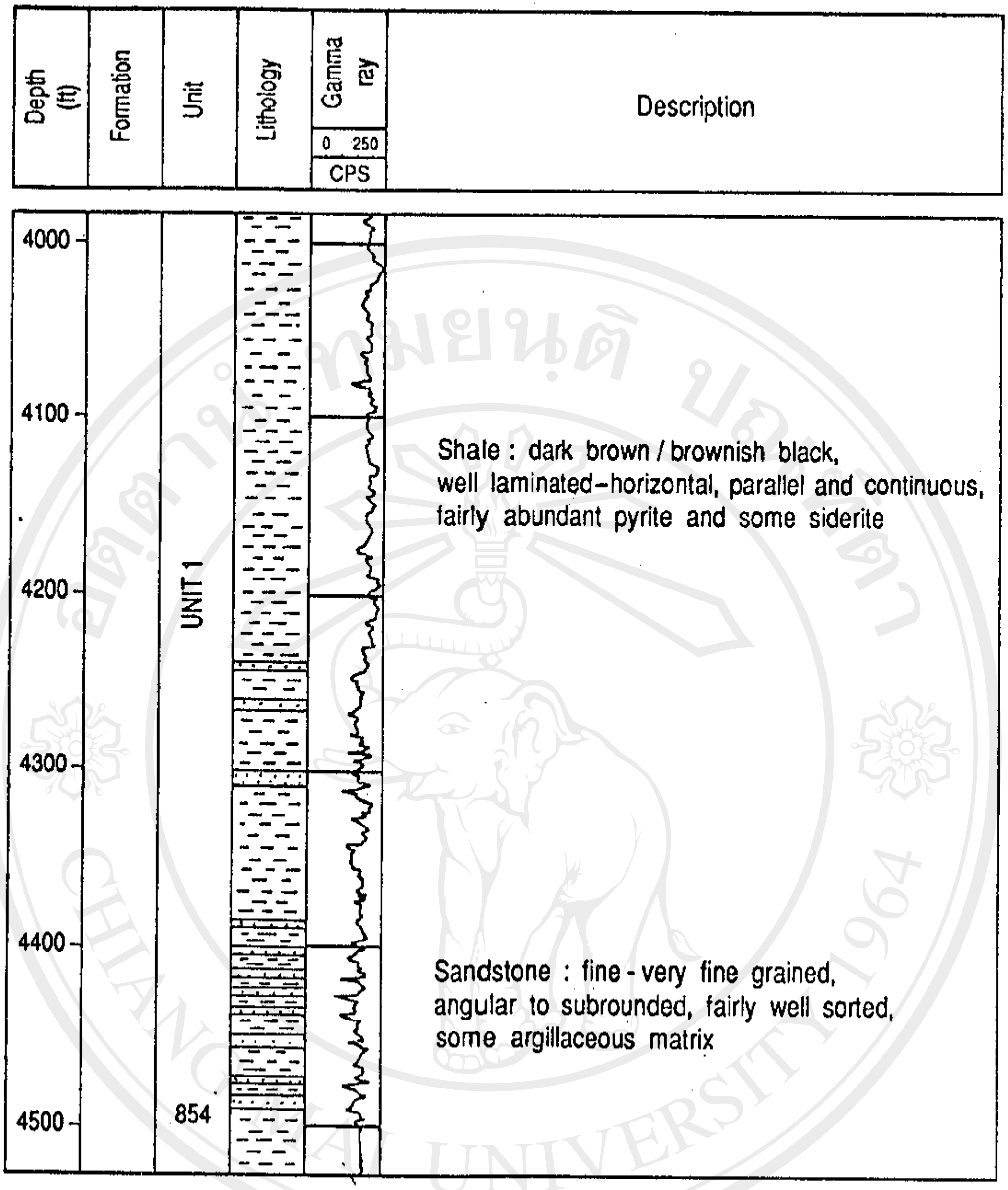
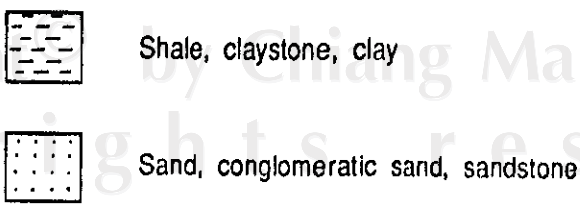

Depth (ft)
Formation
Unit
Lithology
Gamma ray
0 250
CPS
Description
4000
4100
4200
4300
4400
4500
UNIT 1
854
Shale : dark brown / brownish black, well laminated-horizontal, parallel and continuous, fairly abundant pyrite and some siderite
Sandstone : fine - very fine grained, angular to subrounded, fairly well sorted, some argillaceous matrix


Shale, claystone, clay
Sand, conglomeratic sand, sandstone

lithological changes occur vertically between the shales, sandstones and siltstones, particularily in the lowermost part of the section.

Most of the shales of this unit are exceptional in having distinct laminations and fairly well abundant pyrite. This is specially true of the shales from the lowermost part of the sequence. Wherever they are laminated, organic rich layers alternate with organic poor layers, commonly forming distinct couplets. Couplet thickness varies between 15 and 20 mm. In the organic poor laminae, silt sized quartz, feldspars as well as clay minerals assume greater importance. In all cases, the laminae are horizontal, parallel, and continuous. Irregular wavy parting may also occur. Current generated sedimentary structures are absent as these are erosional features. Further, there is no evidence of disturbance of bedding due to burrowing indicating an apparent absence of benthonic life.

Dark brown and brownish black colours characterise most of the shales, presumably referring to abundant organic matter input into the sediments and the unoxidized state of the organic matter contained. However, in many cases, light gray shales having little or no organic matter and abundant silt sized fractions may be associated. Some laminated organic poor shales may show distinct paler laminae which are much thicker than the associated organic-rich laminae.

Toughness of the shales appears to have been related to the organic matter and silt fraction contents. The style of fracturing is related to the presence or absence laminations. Laminated shales usually cleave along planar surfaces and are commonly fissil to platty. Massive shales, on the other hand, fall apart in irregular surfaces with flaggy to slabby partings. Tough sandstones, siltstones and some silty shales fracture conchoidally and tend to show granular texture on broken surfaces.

Frequently interbedded with the shales, fine to very fine grained sandstones grading up into siltstones occur. The sand grains are angular to subrounded and fairly well sorted with some argillaceous matrix. Rarely, the sandstones and siltstones show parallel laminations or a single set of cross-laminae which are crudely defined. Contorted bedding, slickensides, rarely breccia and clay clasts are among rare features preserved in the shales.

3.2.2 Unit 2

Unit 2 is a 1210 ft thick claystone-shale-sandstone-siltstone sequence. Shales are particularily restricted to the lowermost part and are separated by coarser clastics. They grade into an overlying upward fining sequence composed of sandstone, siltstone and shale through a transitional zone of sandstones and siltstones.

The majority of the shales in the lowermost part are dark gray to brownish gray colored and compact with conchoidal to subconchoidal fracture and flaggy or platty parting. They are distinctly laminated but adjacent laminae reveal only slight variations in color. Thin sections show alternation of paler and darker organic rich laminae. Pyrite and siderite are also ubiquitous.

Higher up in the succession, compact, mostly nonlaminated to rarely laminated, gray/medium light gray shales are common. Wherever laminations occur, they are mainly defined by grain size variation. Abundant silt sized fractions seem to have been introduced, as a result, most of the shales are silty. Occassionally silty layers alternate with clay laminae. Organic matter rich layers are ubiquitous but are not as abundant as they are in the lowermost sequence. Textural variations in the laminae may as much represent segregation of particles by differential settling or by differential rates of sediment supply.

Sandstone beds upto 45 ft thick, are interbedded within the shales. Grain size ranges upto coarse sand, with minor pebbles and basal lags of granule size. Grains are mostly subangular to subrounded and poorly sorted. The sandstones locally contain substantial amount of argillaceous matrix. Minerallogically, they are predominated by abundant quartz, and minor plagioclase feldspars as well as lithic fragments. In most cases, the sandstones are said to be characterised by strong oil show and two important pay zones (sands "G" and "H") are restricted to this part of the sequence (D.E.D., 1987).

The shales may display few structures other than laminations. Compactional as well as deformational structures such as convolute bedding, microfaults and slickensides may as well be preserved. Soft sediment structures such as convolute bedding may as much represent high rates of sedimentation and downslope movements. Microfaults, on the other hand, are related to compaction of the sediment during lithifaction. Abundant communited plant debris along bedding planes and sometimes mottling after plant remains are also common features. Rarely, few layers of intraformational breccia upto 10 cm thick and having individual clasts upto 3 cm in diameter are found in association with the shales. These are attributed to late stage post-depositional deformations mainly arising from the dewatering of colloidal mud. Sedimentary structures in the sandstones may include parallel and low-angled cross-laminations on a small scale.

3.2.3 Unit 3

This is distinctly characterised by considerably thick fine grained terregenous clastic sediments. Claystone/shale is the dominant lithology. Some thin sandstones are somewhat erratically distributed within the sequence and are of minor volumetric significance. The sandstone beds are seldom more than 15 ft. thick. The overall thickness of the unit is estimated to be 790 ft.

The sediments of this unit, for most part, are unlaminated. However, some silty claystones could be laminated almost invariably with faint color banding of gray and reddish-brown layers. Organic matter tends to be sparse, as a result the shales/claystones are generally light gray and sometimes reddish brown coloured. Some organic rich claystones could be either light brown or brownish coloured and may contain abundant pyrite and siderite. The organic material may include abundant finely divided plant fragments and few carbonized plant material along fractures and bedding planes.

Higher in the sucession, the claystones are light gray, commonly soft, friable and break apart in blocks. It seems that they had been subjected to prolonged exposure of weathering prior to the sedimentation of unit 4. Lower in the succession, the claystone/shale strata are compact and are characterised by planar to subplanar fractures. Here, internal laminations may not be easily discernible in hand-specimen, although they could be very distinct under the microscope. Rarely in some silty shales (lower part), siltstone and fine sandstone laminae together with compressed plant debris form poorly to well defined submillimeter-centimeter thick parallel graded laminations and also small scale cross-laminations. Minor soft sediment structures such as wavy stratifications are locally present.

Sandstones of this unit are mostly well sorted with some argillaceous matrix. They are fine-coarse grained and color ranges between dark gray and light gray. Sand grains are mainly subangular to subrounded and are essentially composed of quartz, feldspars and rare lithic fragments. Rarely, they are cross-laminated and locally have experienced some soft sediment deformations. Few thick sandstone beds referred to as sands D, E and F (D.E.D., 1987) are reported from this unit. They are thinnly bedded and texturally coarse to conglomeratic.

Fossils of *Vivaparous* sp. (gastropods) were reported from presumably equivalent shale facies of the Pong Nok sub-basin (Settakul, 1984; Khanthaprab and Kaewsaeng, 1987).

3.2.4 Unit 4

Litho-unit 4 is composed almost exclusively of very poorly sorted, coarse to very coarse grained sands with abundant pebbles. The sand grains are angular to subangular. Very thin layers of fine grained sands and muds are intercalated in the uppermost part of the unit. Bulk thickness of this unit is about 56 ft. The unit lies uncomformably on unit 3 of the Mae Sot Formation.

3.2.5 Unit 5

This unit consists of a series of alternating sand and clay strata, of which some part occurs in upward fining sequence. The overall thickness is 944 ft.

The sandstones of this unit are fine to very coarse grained and light gray coloured. Grains are angular to sub-angular, mostly well sorted with considerable argillaceous matrix. The associated clays vary in thickness between 10 and 80 ft., and are brown-reddish brown/grayish brown colored and rarely mottled in blue and green colors.

Fining upward sequences, contained in the unit, commence with medium to coarse sand and grade up into fine sand, and eventually into silts and clays (sandy clays) at the top.

3.2.6 Unit 6

This is the uppermost part of the lithologic sequence, typically represented by a 470 ft. thick predominantly sand associated with gravely sediments. Clays are volumetrically insignificant and occur as thin packages never exceeding 15 ft. Log patterns after gamma ray curves never show vertical variation in grain size, instead, the sands sometimes show abrupt upper and basal contacts.

The sands are light gray to gray colored, commonly coarse to very coarse grained with some granules. Grains are mostly angular to subangular and are not well sorted. The gravely sediments are also gray colored, coarse to very coarse grained, essentially angular, poorly sorted with some argillaceous matrix. Minerallogically, the sands are mainly composed of quartz, with rare feldspar grains and lithic fragments. Abundant carbonised wood fragments are well preserved and could be as long as a few centimeters (5-6 cm).

3.3 FACIES SEQUENCES AND DEPOSITIONAL ENVIRONMENTS

Basically, one of the goals of this study is to estabilish the depositional environment and sedimentary facies. These were achieved through the integration of several basic sedimentological and stratigraphic facts.

A sedimentary facies as Selly (1970) and Reading (1978) put it is a deposit evolving out of a specific depositional environment and has characteristics which can be defined using certain attributes of the rock body. Such attributes could include, color, bedding, composition, texture, fossils and sedimentary structures.

One common method for determining environments of deposition for ancient rocks is to compare the lithologic sequence with specified depositional models which have been previously generated from the study of modern environments. A facies model is an idealised simplification set up to aid our understanding of the complex phenomena, and processes involved during sedimentations and in the interpretation of facies distribution. In short, it is a summary of the depositional environment and its products.

Lateral and vertical facies variations are well apparent in the basin. The underlying controlling factors which largely governed the formation of facies and their distribution are considered to be intermittent tectonic subsidence (on localised and regional scales), climatic controls, relatively low sediment supply etc. (Khantaprab and Kaewsaeng, 1987; Prадidtan, 1989).

The sedimentary succession of borehole IF 30 03S consists of a wide range of lithologies with complex facies relationships where quite varied depositional environments are involved. The facies models used in this study include that of Miall (1978) for braided fluvial facies; Allen (1964) for meandering fluvial facies; Visher (1965), Kukal (1971), and Picard and High (1972) for lacustrine facies.

Six facies states are recognised. These include in ascending order the 1) Lower lacustrine facies 2) Fluvio-lacustrine facies 3) Upper lacustrine facies 4) Lower braided fluvial facies 5) Meandering river, channel margin and floodplain association 6) Upper braided fluvial facies. Description of each of these and the interpreted depositional environments are given below.

3.3.1 Lower lacustrine Facies

This facies represents unit 1, which is characterised by thick shale interbedded with thin siltstones and sandstones. The gamma ray log is characterised by an irregular shale line pattern.

Most of the shales show well defined and continuous laminae. There is little or no disturbance of bedding due to burrowing and current generated structures are altogether absent. Lithologic and sedimentological evidences as well as the log response suggest that deposition of the sediments occurred presumably in a lake environment and under extremely slow rate.

The lake was largely anoxic, although at intervals or periodically oxic conditions might have prevailed. Distinct laminations, abundant pyrite and siderite as well as locally well preserved alginite (*Botroyococcus* related, see Chapter 4) are some supportive evidences. Further the lake was stratified as *Botroyococcus* related alginite occurs in small, stratified fresh-water lakes (Sherwood et al., 1984). Stratification of the lake led to the differentiation of the water column into a fresh, persistently aerated upper part and an intermittently oxygen depleted, stagnant, and anoxic lower part. As a result organic ooze (plant detritus), settling very slowly from suspension in the static water column, alternated seasonally with silt and clay to produce the well laminated organic rich shales. Strongly reducing bottom conditions were very hostile to bottom dwelling organisms as a result the sediments were left non-bioturbated. The majority of the organic poor layers were perhaps deposited under aerobic conditions near the surface, where stratification was less developed. Aerobic conditions prevented much of the organic matter from accumulating. Poor organic matter preservation may also be enhanced by such factors as high temperature, high salinity conditions, poor water circulation, periodic lake dryness etc. The presence of thin sandstones interbedded with the claystone/shale strata indicate periodic influx of fluvial clastics into the lake.

Primary structures such as parallel, continuous and horizontal bedding indicate deposition on a flat surface such as a lake bottom and owe their origin to episodic suspension in still water. Massive nature of some shale/claystones could result from continuous and rapid sedimentation from suspension. Compactional and deformational structures such as slickensides are produced from shrinkage either by subacqueous synersis or subaerial drying (Potter and others, 1980). Some clay clasts in the siltstones are indicative of local erosion and deposition of cohesive clays. Small scale breccia within the shales are also thought to have been related to synersis.

Unit 1 is interpreted as to represent a lacustrine facies deposited in a fresh-water, perennial lake under anoxic conditions. The overall depositional system could fit well into the lacustrine deposi-tional models suggested by Picard and High (1972); and Kukal (1971).

3.3.2 Fluvio-Lacustrine Facies

This association is a mixture of sandstone, shale, siltstone. Fining upward sequences with sharp basal contacts were also noted on gamma ray logs. The gamma ray log curve sometimes shows a series of bell shaped patterns alternating with low lying and regular shale line patterns.

This facies was deposited under a variety of depositional conditions ranging from quite water slow suspension fall out (lower part of the sequence) to a relatively high energy fluvial condition (upper part). The complex interbeddding of the lithologies suggests quite varied depositional environments involved and deversified origins of deposition.

Shale/claystone strata representing the lowermost part were deposited under similar conditions to those responsible for the underlying lacustrine facies (unit 1). They are interpreted as suspension deposits under largely quite water conditions in a lake environment. Complete gradation of colours from dark gray to light gray and medium light gray suggest that sedimentation rates were at first slow but increased with time. This is also reflected in the degree of lamination and organic matter preservation over the section. Laminated and organic rich shales are mainly restricted to the lower most part. Relatively abundant organic matter, considerable pyrite and siderite (in the lower part) and the well preserved fine laminations indicate an anaerobic bottom due to stratified water column during the early periods of the lake's history.

This lacustrine facies grades up into a series of fining upward sequences interpreted as representing a fluvial facies deposited in a meandering river setting. Composite channel deposits and possibly related overbank/levee accumulations are supposed to make up the fining upward sequences. The transitional siltstone/sandstone horizon could possibly be related to a silting up phase of the lake at which point the predominant depositional setting changed from lacustrine to fluviatile. Frequent association of the lacustrine facies with the fluvial clastics could perhaps imply a marginal lacustrine situation of the environment.

Considered overall, therefore, the sequence is concluded to be a fluvio-lacustrine facies. This interpretation is made by comparison with the lacustrine depositional models reviewed by Picard and High (1972), and the meandering fluviatile model of Allen (1964).

3.3.3 Upper Lacustrine Facies

This facies represents Unit 3 which is dominated by relatively thick fine-grained terrigenous clastics consisting of shale, siltstone and sandstones. The associated sandy horizons are quantitatively insignificant. Gamma ray log curve, which is represented by an irregular shale line pattern, also shows the fine grained nature of the unit.

The abundance of fine grained sediments, massive to diffused laminae, the general absence of current-generated sedimentary features and the geophysical log signiture altogether attest to deposition under low energy condition, presumably in a lake environment. Paucity of pyrite in much of the section, the sparse organic matter contained, and also the light gray and rarely the reddish-brown coloured shales are thought to warrant sedimentation in a predominantly shallow and oxidising condition. Fossils of vivaparous are interpreted as reflecting a fresh water condition of sedimentation. All the data gathered are, therefore, consistent with a shallow oxygenated lake facies (Galloway and Hobday, 1983). The preservation of some organic rich layers with abudant pyrite could possibly be attributed to a reducing condition within the shallow substrate in which particularily organic rich layers persisted beneath a constantly oxygenated lake bed (Galloway and Hobday, 1983). The relatively thin and by far the less represented sandstones could indicate that the lake was periodically subjected to fluvial influx.

This interpretation is comparable to the lacustrine depositional models discussed by Picard and High (1972); Kukal (1971); Galloway and Hobday (1983).

3.3.4 Lower Braided Fluvial Facies

Deposits of Unit 4 are typically composed of texturally and mineralogically immature, poorly sorted sands and gravels with the exclusion of fine-grained overbank silts and clays. Futhermore, log response after the gamma ray curve reveals a general absence of textural fining upward trend and is specifically characterised by cylinderical patterns.

These apparently imply to sedimentation in a relatively high energy fluvial setting. Fluvial sedimentation appears to have been related to the braided river depositional models comparable to the Donjek, South Saskatchawan or Platte types of Miall (1978), primarily owing to the high sand to shale ratio.

Unit 4 is therefore a braided fluviatile facies which was deposited under relatively high gradient, straight to slightly sinous multiple channels and a shallow river where medium-coarse sands were transported in bed loads.

3.3.5 Meandering Fluviatile Facies

This facies represents unit 5 which comprises of thinnly interbedded clays, silts and fine-coarse sand. Occassionally some clayey strata are thick enough. Few upward fining profiles are separated by finer clastics (clay and silt).

Deposition of that part of the unit in fining upward sequences is interpreted as to have occurred in meandering river environment, with the coarse to medium sands representing channel deposits in meanders formed as a result of lateral accretion on point bars. Thinnly interbedded sequences of fine sand and clays (sandy clays) are interpreted as representing channel margin facies in overbank environments and characterise vertical accretion deposits accumulating as a result of the fall in the level of turbulence in overbank floods escaping from channels. The finer sediments such as the thick clays could have formed during relatively quiescent periods further out in flood plain areas. Alternatively, the latter could be interpreted as deposits of small, shallow and short-lived flood plain lakes. Lakes commonly develop on flood plains by either channel abandonment or by subsidence below the water table.

3.3.6 Upper Braided Fluviatile Facies

Unit 6 is represented by this facies and is typically defined by a thick sand dominant unit. The sands are sometimes interbedded with and grade vertically into gravels and thin clays. The sands are texturally as well as minerallogically immature. They are medium-coarse grained and poorly sorted with distinct angular grains. The gamma ray log is characterised by a series of cylinderical patterns, some parts of which have abrupt upper and lower contacts.

The coarse overall texture, poorly developed fining upward profiles, the quantitativly minor clays and the gamma ray log pattern collectively suggest deposition in a high energy fluviatile complex. The strata document sedimentation in a braided bed-load fluvial channels somewhere at a distal situation to the source. Such an environment is distinctly different from that of a coarse grained braided system where gravels and coarse sand are predominant and are commonly found at a proximal situation.

Hence the overall facies is interpreted as representing a sandy braided fluviatile system comparable to the South Saskatchewan River type (Cant and Walker, 1976). Fluvial sedimentation is envisaged to have taken place under relatively steep gradient and in a wide, straight to slightly sinous multiple channel type. The associated clays could represent the highest elevations in the braided system, such as crests of bars. Large pieces of carbonised wood fragments common in the sands were probably incorporated during high discharge (flood) events when vegetated bars were eroded. Similar braided river deposits are also reviewed by Miall (1978).

The subsurface sedimentary facies and depositional environments of borehole IF 30 03S are illustrated in Figure 3.2.

Depth (ft.)	Gamma ray	Description	Facies	Depositional environment
400		Arkosic sand , in part gravely, brownish, coarse-very coarse, angular - subrounded, mostly well sorted, abundant carbonised wood fragments UNIT 6	Upper braided fluviatile	Braided river of the South Saskatchwan type
800 1200 1600		Sand and clay alternating and thick clay Sand : fine - very fine, angular - subangular, mostly well sorted Clay : brown - redddish brown, rarely mottled in blue to greenish color UNIT 5	Meandering fluviatile, channel margin, and interchannel flood plain association	Meandering river, over bank and flood plain environments
		Sand, coarse-very coarse with granules, poorly sorted UNIT 4	Lower Braided fluvial	Braided River
2000 2400		Shale/Claystone and minor sandstone Shale : Light gray, unlaminated to rarely laminated Sandstone : fine-very coarse grained, angular-sub-angular, mostly poorly sorted UNIT 3	Upper Lacustrine	Shallow, mainly oxic, fresh-water lake
2800 3200 3600		Shale / claystone and sandstone in fining upward sequences Shale : light gray-medium light gray, mostly unlaminated, occass-ionally silty Shale : dark gray-brownish gray, distinctly laminated UNIT 2	Meandering fluviatile Lacustrine Fluvio-lacustrine	Marginal fresh-water lake largely influenced by meandering river
4000 4400		Shale interbedded with thin siltstone and sandstone Shale : Dark brown, brownish black, mostly well laminated, locally with abundant pyrite UNIT 1	Lower Lacustrine	Predominantly anoxic lake

Figure 3.2 Subsurface sedimentary facies and depositional environments of Oil Well IF 30 03S