CHAPTER I

INTRODUCTION

1.1 General

The Tertiary deposits in Thailand are found in isolated basins of limited extent. At present, sixty one basins have been identified and they are distributed throughout the country, including the areas in the Gulf of Thailand and the Andaman Sea (Figure 1.1a). The size of the basins varies from large regional tectonic basin to small intermontane basin. Some large basins consist of a connected set of sub-basins. Therefore, the number of basin including sub-basins should exceed sixty-one. Most of the Tertiary basins overly on the unconformity and are overlain by the unconsolidated deposits of Quaternary Period. These Tertiary basins differ from each other in many respects. The elevation of topographic ground-surface within the basin varies from below mean sea level in the Gulf, to slightly above the mean sea level at Krabi basin in the south, to 320 metres and 1,000 metres above the mean sea level at Mae Moh and Boluang basins in the north, respectively. These elevation differences are probably the result of subsequent tectonic movements. Some paleontological and palynological data of these basins indicate the age range from Upper Eocene to Pliocene (Table 1.1a). The tectonic setting of these basins are different ranging from full graben, half-graben to syncline.However, some similarities exist among these Tertiary basins, namely,basin shape, environment of deposition, etc. The elliptical shape of the basins are generally elongated following the regional strike of the

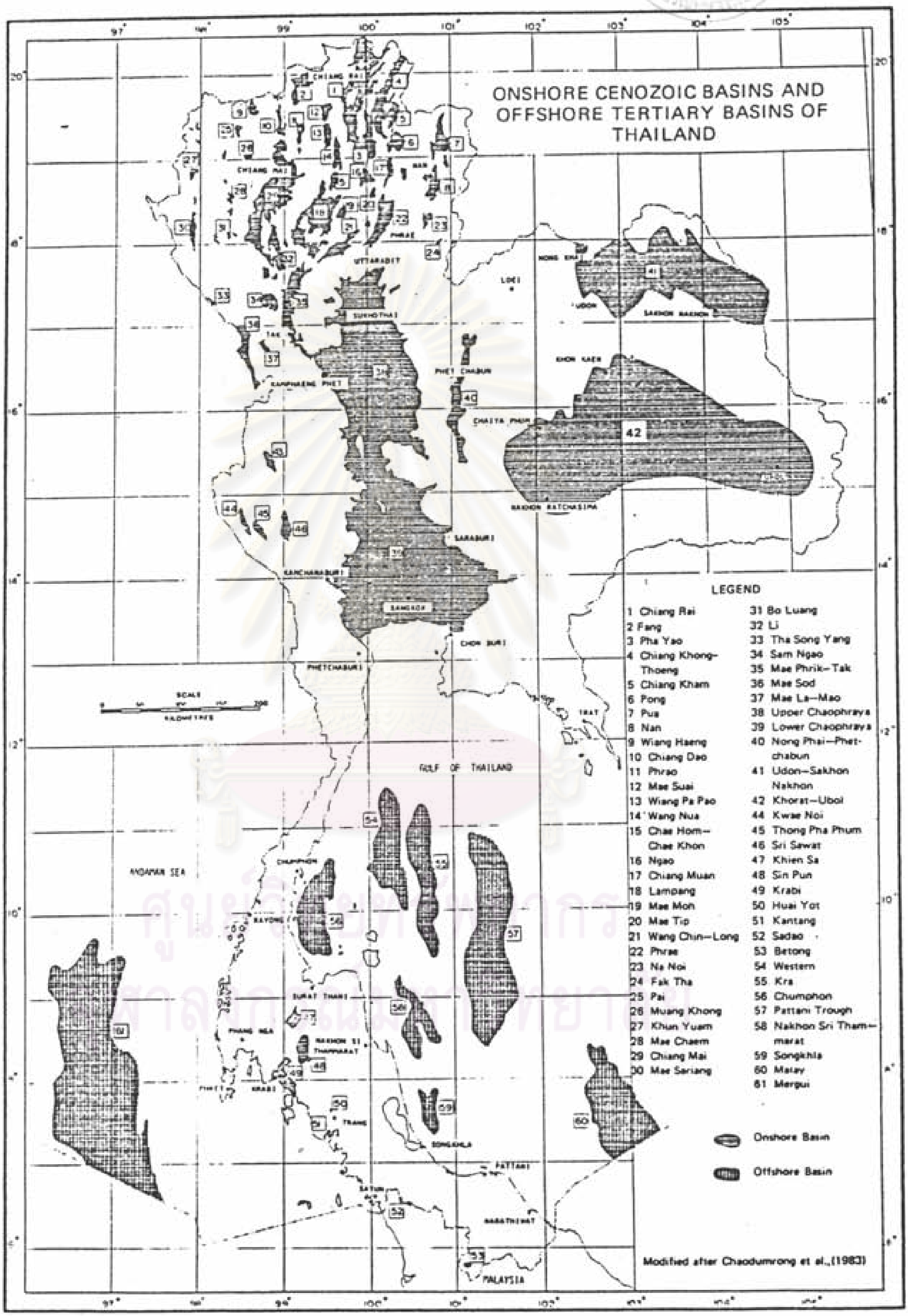


Fig. 1.1 a Onshore Cenozoic Basins and Offshore Tertiary Basins of Thailand.

Table 1.1a Summary of the ages of Tertiary basins (Basin numbers in brackets are referred to Fig. 1.1a) (after Chaodumrong et al., 1983).

Region	Basins		Ages	References
Northern Thailand	Mae Soon (Fang-2)		Oligocene-Pliocene	Buravas (1975)
	Lampang (18) (Mae Ta)		Miocene–Pliocene	Pariwatvorn (1962) Ingavat (1981)
	Mae Moh (19)		Miocene–Pliocene	von Koenigswald (1959), Buravas (1973), Ingavat (1981), Ginsburg (1983)
	Li (32)	Pa Kha	? U. Eocene–Miocene	Buravas (1973), Endo (1964, 1966), Ingavat (1981)
		Nam Long	Miocene	Ingavat (1982)
		Na Sai	Miocene	Ingavat (1983)
	Mae Sot (36)		Miocene-Pliocene	Brown et al. (1951), Endo and Fuji-yama (1965), Uyeno (1969), Buravas (1973)
	Phayao (3)		Miocene	Baum et al. (1970)
Peninsula	Krabi (49)		Paleocene–Miocene	Hedlund (1972) in Achalabhuti (1975)
	Klong Wai Lek (Krabi mine)		Miocene	Ingavat (1982)
Gulf of Thailand	Gulf of Thailand		? Oligocene–Pliocene	Achalabhuti (197), Woollands and Haw (1976), Paul and Lian (1975)
	Northern Malay (60)		Miocene–Pliocene	Woollands and Haw (1976)
Central Plain	Chao Phraya		? Oligocene–Pliocene	

older formations, varying from north-south to NNE/SSW directions. Paleontological evidences of the sediments within Tertiary basins, generally, indicate the non-marine or fresh-water depositional environment except those in the Gulf where there are evidences of marine influence in the Tertiary stratigraphic sequence.

It is noted that almost all of the Tertiary deposits are clastic sediments of fluviatile and lacustrine origins. Besides, the Tertiary deposits are mainly overlain by medium to coarse-grained terrigenous strata of Quaternary deposits. Due to the fact that the tectonic activity during Quaternary time has been relatively low, therefore almost all of the Tertiary deposits are not exposed. Any attempt to study the Tertiary deposits must be essentially based on the data and information obtained from borehole investigation.

Most geological investigations on Tertiary deposits have been motivated by the extraction of various types of mineral resources within these basins. These mineral resources include coal, petroleum, oil shale, and diatomite. At present, seven active coal-mines, ranging in coal rank from lignite to high volatile C bituminous, are located at Mae Moh, Mae Tip, Mae Tun, Li, and Krabi basins. Petroleum exploration and production programmes are actively carried outin several Tertiary basins in the Gulf of Thailand, Fang intermontane basin in the north, and Phitsanulok basin in the Central plain of Thailand. Oil shale deposits have been found in many intermontane basins in northern Thailand, notably, Mae Sot basin, Li basin, Chae Hom basin, and Lampang basin, etc. Diatomite deposits have been investigated in several sub-basins within Lampang basin. In addition, numerous exploration programmes have been planned and partly executed regarding the coal and petroleum resources in many on-shore and off-shore Tertiary basins.

Sedimentological studies of Tertiary deposits are therefore useful not only for the progress on knowledge of geology of Thailand, but also benefitial to the development geology of mineral industries. It is also noted that, geological contribution on Tertiary geology is extremely limited at present. This is basically due to the fact that almost all information and data on this matter are kept in confidential by law during active exploration phase. The deliberate contribution from this study is considered to be quite significant under the present circumstances.

Mae Moh basin has been selected for the present investigation under several reasonings. First, the Mae Moh basin has been geologically considered to be a classic Tertiary basin of intermontane type. Second, intensive exploration programmes, notably, drilling exploration, geophysical etc.have been undertaken so that sub-surface geological information are properly available. Third, the findings of the present study will be very useful in assisting the current coal development programmes of the Electricity Generating Authority of Thailand (EGAT.). Last, it is expected that the Mae Moh basin should contain the complete lithostratigraphy representing the intermontane type of basin which can be utilized as geological reference for exploration elsewhere.

1.2 The Study area

1.2.1 Location

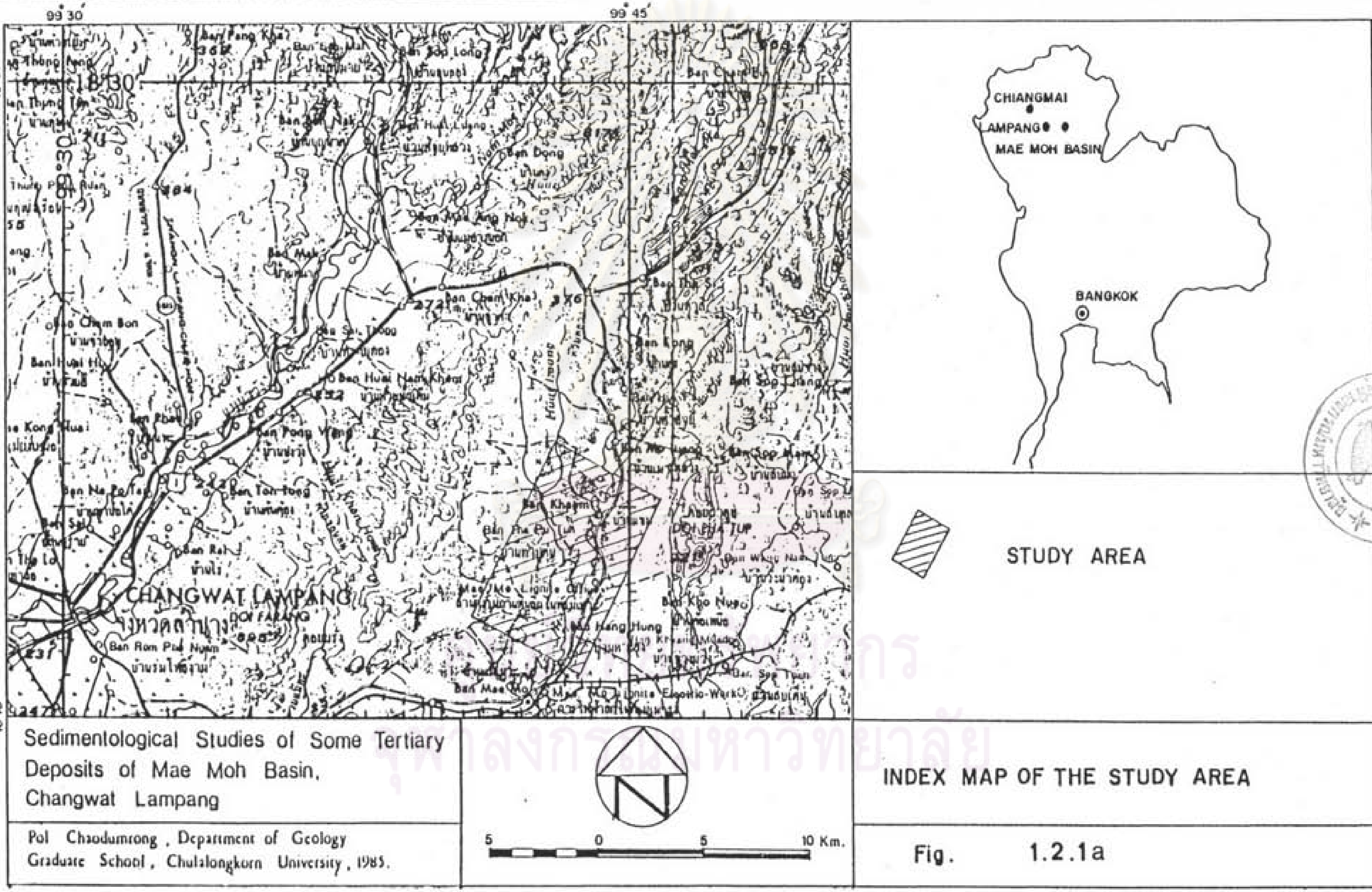
The Mae Moh basin is mainly confined to Amphoe Mae Moh, Changwat Lampang in the northern part of Thailand. The basin lies approximately between latitudes 18^{o} 16' to 18^{o} 25' and longitudes 99^{o} 34' to 99^{o} 46' . The shape of the basin is roughly triangular elongated in the NNE/SSW direction. The basin covers approximately 80 square kilometres, with the maximum width in the east-west direction of about 7 kilometres and maximum length in north-south direction of about 16 kilometres.

The study area is located in the southern half of the Mae Moh basin covering the total area of approximately 32 square kilometres, from latitudes 18^{o} 16' to 18^{o} 22' and longitudes 99^{o} 40' to 99^{o} 46'(Figure 1.2.1a).

1.2.2 Physiographic setting

The topography of Mae Moh basin is generally flat to slightly rolling with the average ground elevation of 320 metres above the mean sea level (Figures 1.2.1a and 1.2.2a). The basin is bounded by steep, rugged mountain range of pre-Tertiary rocks on the east and west, whereas the southern part of the basin is covered by a basalt trap of Pleistocene age.

The climate of the area is characterized by a definitely wet and dry season. The west or southwest monsoon starts from May to October. The dry season starts in late October and lasts until April. Cool weather prevails in the basin area during late December to February.The annual mean temperature of the area is 25^{o} C with mean maximum temperature of 37.6^{o} C in April and mean minimum temperature of 12.1^{o}C in January (1972-1976). A maximum wind speed of 120 kilometres per hour has been recorded at Lampang, but the average wind speed is generally low throughout the year. The mean annual rainfall is

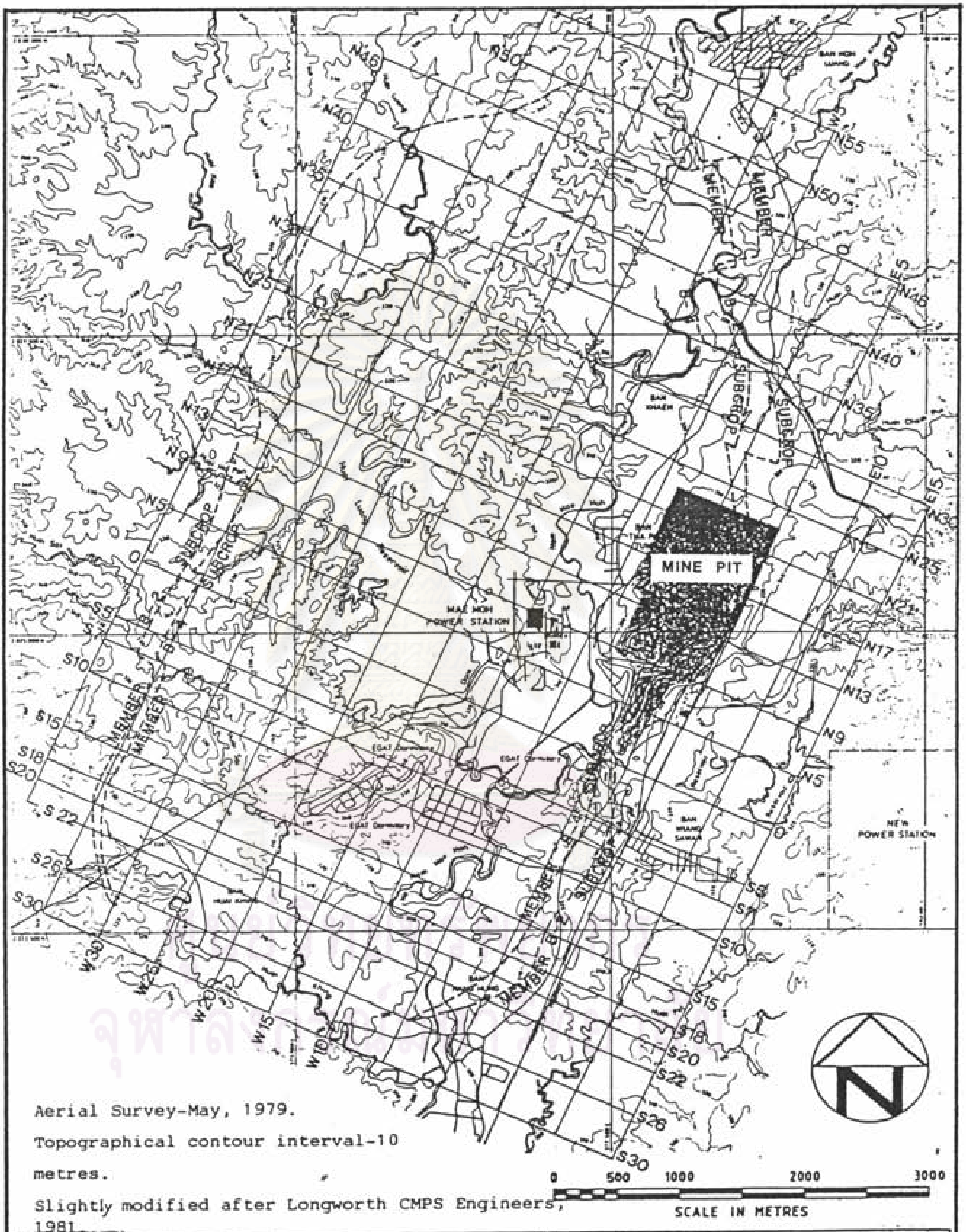


Sedimentological Studies of Some Tertiary Deposits of Mae Moh Basin, Changwat Lampang

Pol Chaodumrong, Department of Geology Graduate School, Chulalongkorn University, 1985.

INDEX MAP OF THE STUDY AREA

Fig. 1.2.1a



Aerial Survey-May, 1979.

Topographical contour interval-10 metres.

Slightly modified after Longworth CMPS Engineers, 1981.

Sedimentological Studies of Some Tertiary Deposits of Mae Moh Basin, Changwat Lampang.	**Topography and Mine Grid of the Study Area**
Pol Chaodumrong, Department of Geology Graduate School Chulalongkorn University, 1985.	Fig. 1.2.2a

1,212 millimetres with 85-95 percent of the annual rainfall occuring during the southwest monsoon. The variation of annual rainfall is in the range of 20 percent above and below normal.

1.2.3 Distribution of boreholes and seismic traverses

Up to present, there are altogether about 4,000 boreholes in the study area with mean density of approximately 100 boreholes per square kilometre. The depth of penetration of the borehole ranges from 60 to over 700 metres with average depth of about 150 metres below the present ground surface.

The characteristics of these boreholes can be classified into three main categories as follows,

a) Exploratory boreholes which can be further subdivided into

   a.1) open-holes with or without geophysical logs.

   a.2) touch coring holes, with geophysical logs

b) Geotechnical holes, with geophysical logs, and

c) Stratigraphic holes, with geophysical logs.

In addition, there are 72.61 line kilometres of shallow seismic reflection survey (The Mini-SOSIE technique) covering the whole basin in two main directions, namely NNE/SSW and NWW/SEE following the mine grid system.

1.3 Objectives

The study primarily aims at utilizing the borehole data supplemented by detailed laboratory analyses to define the sub-surface geology of Tertiary deposits of the Mae Moh basin in terms of litho-stratigraphy and sedimentary facies in particular. Additional attempts will be made to describe the origin of coal and to reconstruct the depositional environment of the coal-bearing sedimentary sequences of the Tertiary deposits within the basin.

1.4 General approach and study methodology

Generally, the first effort at interpretation of sediments are directed toward reconstruction of the environment of deposition at a particular time and place. Consideration of the basin where sediments are deposited as a whole provides a truly unified approach to the study of sediments. This study, so called "Basin Analysis", is simply the application of stratigraphy and sedimentology to be geological history of the basin. The approach to the sedimentary of the study field within a basin is to study its spatial arrangement. The vast amount of subsurface information now available makes possible what has come to be called "Lithofacies Analysis". The real situation in "Nature" is undoubtedly complex, but clearly lithofacies analysis is an attempt to analyse the arrangement of the basin fill and to utilize the pattern for predictive purposes.

In order to fullfill the objectives and scopes or the present study, five basic steps of approach have been proposed :

a) Review of the existing data and information

b) Field investigation and laboratory analyses

c) Data preparation and manipulation

d) Data analyses and evaluation

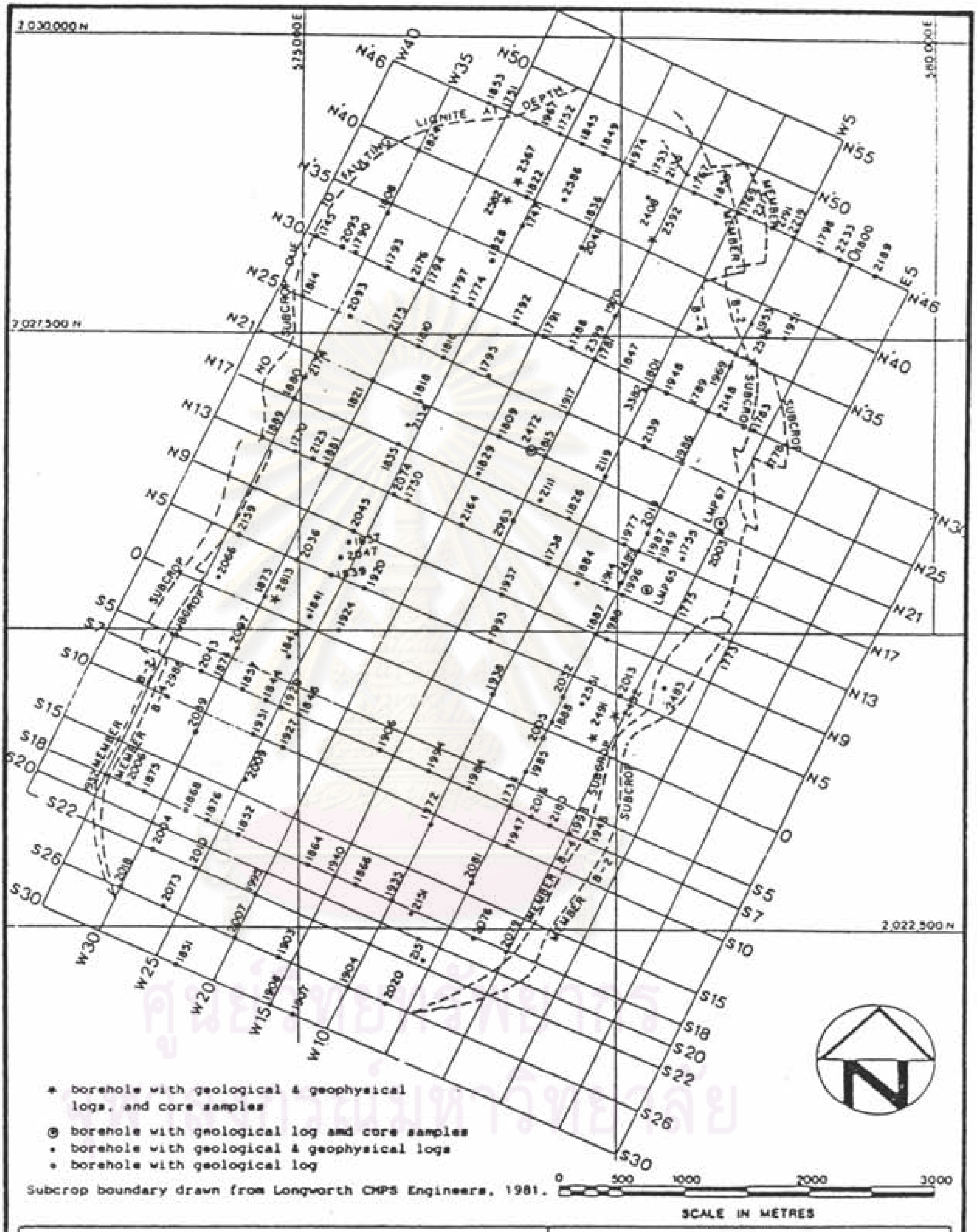
e) Interpretation and conclusion.

The review of existing data and information include the literature review of theories and related case studies, the review of geological setting of the area from previous investigation, and the review of available subsurface geology and geophysics of the study area. Particular emphasis has been given to the data and information on lithological logs obtained from 178 drill holes (Figure 1.4 a); geophysical logs of following parameters, namely, caliper, short and long density, resistivity, self-potential, gamma ray and neutron, and ground seismic reflection survey of about 33 line kilometres (Figure 1.4 b). The aforementioned subsurface geology and geophysics of the study area are exclusively obtained from the Electricity Generating Authority of Thailand (EGAT).

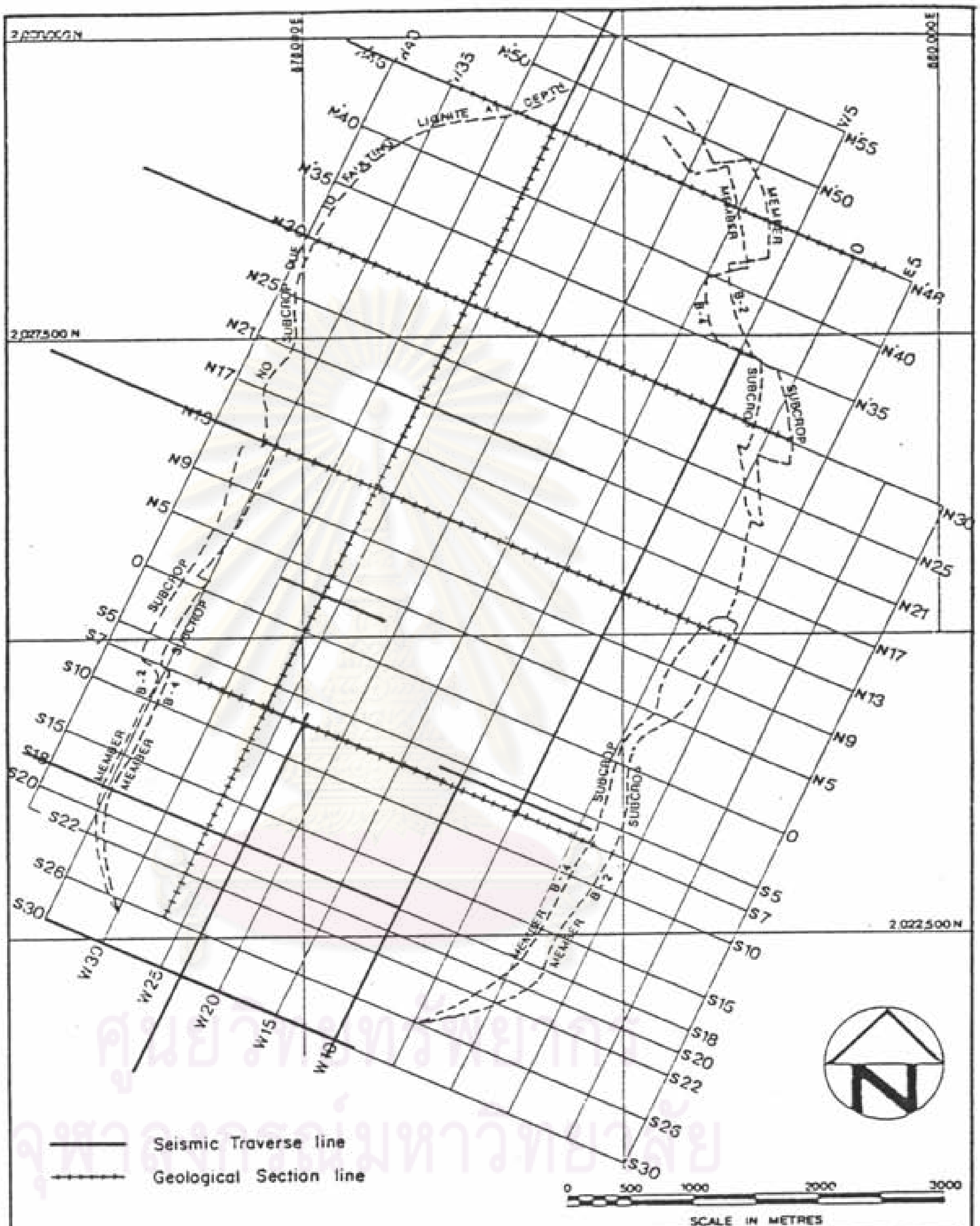
According to the selected boreholes that shown in figure 1.4a, four boreholes of these were reached the basement of marine Triassic rocks, Lampang Group. The boreholes in this study can be subdivided into 4 categories as follows. :

a) borehole with geological and geophysical logs, and core samples, total 7 boreholes
b) borehole with geological logs and core samples, total 3 boreholes
c) borehole with geological and geophysical logs, total 158 boreholes
d) borehole with geological log, total 10 boreholes.

It is against this background information, detailed field and laboratory studies have been subsequently formulated and carried out.



Sedimentological Studies of Some Tertiary Deposits of Mae Moh Basin, Changwat Lampang	Boreholes Location
Pol Chaodumrong, Department of Geology Graduate School, Chulalongkorn University, 1985.	Fig. 1.4a



Sedimentological Studies of Some Tertiary Deposits of Mae Moh Basin, Changwat Lampang	Seismic Traverse lines and Geological Section lines
Pol Chaodumrong, Department of Geology Graduate School, Chulalongkorn University, 1985.	Fig. 1.4 b

The detailed field investigation includes the examination and measuring of the geological sections in the active coal mine pit, and the sampling of geological materials. The geological samples obtained from the field sampling programme and drilling programme have been further analysed in the laboratory. The sedimentary structures have been studied from the polished core slab and rock slab, whereas the texture and composition have been studied by the petrographic method. Additional attempt, has been made to study the clay mineralogy using the X-ray diffractometer technique (Philips Generator, model 1730/10, nickle-filtered copper radiation at 30 KV and 25 MA, scanning speed 2^{o} 2θ per minute, rate metre 8, time constant 4 second, and multiplier 1).

The next stage, all the geological and geophysical data,information obtained from previous stages are prepared and manipulated in such a manner that they can be appropriately utilized for lithostratigraphic and facies analyses. Numerous graphic representations are finally prepared, notably, geological map, well location map, geological and/or geophysical drill chart, geological sections, structural contour map, isopach contour map, seismic basement profiles, and etc.

The data acquisition and data preparation employed in the present study have been summarized and presented in figure 1.4c.

Since the stratigraphic analysis is a prerequisite of the sedimentary basin analysis, because there is an obvious relationship between the characteristics of a given sedimentary environment and the sediments that accumulate there. Some adjacent environments show quite contrasting conditions and sediments; therefore, the rocks produced by such environments will be strikingly different. These

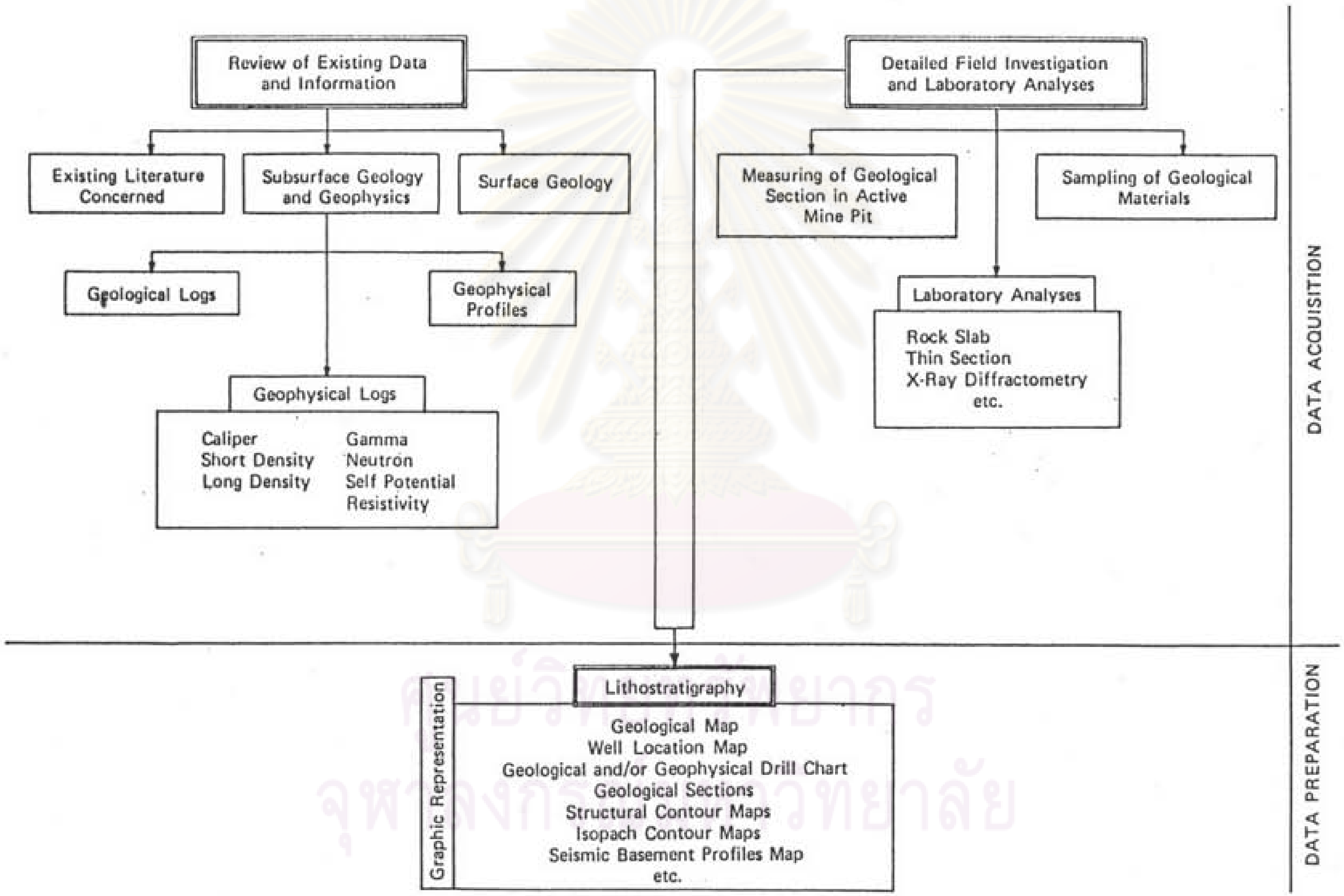


Fig. I.4 c Stages of data acquisition and data preparation in reconstruction of basinal analyses.

differences may be sufficent to warrant different designations as lithostratigraphic units. Thus adjacent lithostratigraphic units typically represent adjacent depositional environments.

In this study, an attempt has been made to establish the lithostratigraphy of sedimentary sequence within the Mae Moh basin requiring the classification and nomenclature of lithostratigraphic unit. The international Guide to Stratigraphic Classification, Terminology, and Usage and published in 1972 as Report No.7 of the International Subcommission on Stratigraphic Classification (Hedberg, 1976) has been used in organizing strata into units. The hierarchy of formal lithostratigraphic units includes group, formation, member, and bed. The definition of these units is based on observable criteria, and the extent of lithostratigraphic units is determined solely by the extent of their diagnostic features. All lithostratigraphic units receives their informal name at this stage.

A sedimentary facies should ideally be distinctive rock that from under certain conditions of sedimentation, reflecting a particular process or environment. Facies may be subdivided into subfacies or group into facies associations or assemblages (Reading, 1978). A sedimentary facies can be defined and distinguished from others by its geometry, lithology, sedimentary structure, fossils, and paleocurrent (Selley, 1978). Individual facies relationship according to Walther's Law of Facies (1894) is that "only those facies and facies-areas can be superimposed primarily which can be observed beside each other at the present time".

Facies are important because their recognition and analysis provide the basis for an environmental interpretation of stratigraphic units. The interpretation of the facies is to combine observations made on their spatial relations and internal characteristics (lithology and sedimentary structure) with comparative information obtained from modern environments and from other well studied stratigraphic units. The method, so-called "facies analysis or comparative sedimentology", which is the generalizations based on comparative studies of several similar modern and ancient examples or facies models are being used in the present study. It has been suggested by Walker (1976) that a good facies model has four functions, besides being a generalization of a number of real examples.

a) It can serve as NORM, with which any real example can be compared.
b) It can act as FRAMEWORK and GUIDE for future observations.
c) It can act as a PREDICTOR in new geological situations.
d) It can act as a basis for interpretation of the facies in terms of physical or chemical MECHANISMS.

In this study, the facies models previously developed by Selley (1976) and Walker (1976) have been used in the facies analyses. Besides, techniques of subsurface facies analysis by Selley (1978) is employed in the present investigation.

After the facies analysis has been carried out, the interpretation of ancient sedimentary sequences or the reconstruction of depositional environment is made. Basically, there are three stages of interpretation, namely, the formulation of initial working hypothesis, the development of a paleogeographical interpretation, and the realistic interpretation.

Finally, the geological evolution of the Tertiary deposit in Mae Moh basin has been synthesised and proposed. Emphasis is made on the coal formation within the sedimentary sequences.

The overall studies methodology and approach employed in this study are summarized and presented in Figures 1.4c and 1.4d.

1.5 Semi-quantitative analysis of relative abundance of clay minerals by X-ray diffractometer

Quantitative determination of minerals by X-ray diffraction in whole rock are very complicate. It involves the measurement of intensity of X-ray diffracted from that mineral and comparision with a calibrated standard. In this study a semi-quantitative determination of a relative abundance of clay minerals were determined. According to the corrected samples, clay minerals interpretation within "B Formation" of the Mae Moh Group are emphasised.

Different samples of the same pure mineral will produce X-ray peak of the same intensity or in another way, the same mineral in different samples will not produce the same intensity. So, the intensity of a mineral's characteristics of X-ray diffraction peak cannot be used directly as a measure of its abundance. The intensity of peak is affected by many factors including mineral percentage, matrix effect , composition variation and experimental variation (Cubitt, 1975). The percentage of minerals vary directly with peak intensity. The matrix effect are produced by absorption and reemission of X-ray by certain elements in the matrix. The composition variations are resulting from differences in the degree and nature of crystallinity of the particle in the matrix. The experimental variation can be ascribed in three

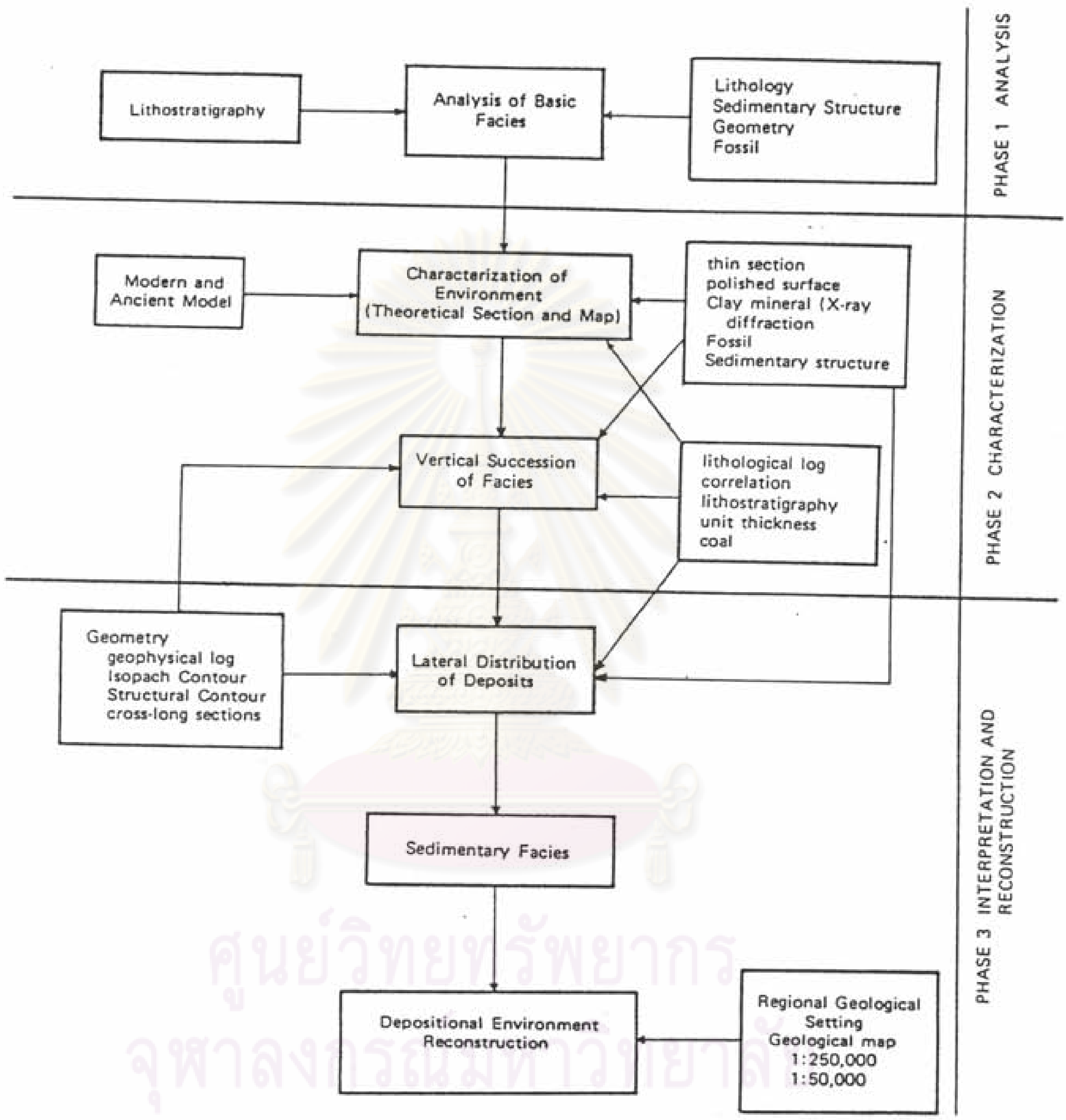


Fig. 1.4d Stages in the reconstruction of basinal deposits.

sources : 1) inhomogeneity within replicate, such as slide thickness; 2) differences between prepared replicates of sample; and 3) instrumental fluctuation.

A measurement of the basal peak area of that clay mineral and comparision with a method of Johns, Grim and Bradley (1954), and Weaver (1961) were used in this study. Figure 1.5a is an outline in semi-quantitative analysis of relative abundance of clay minerals in this study.

1.5.1 Sample preparation

1. Crush to break down the sample with jaw crusher
2. Quartering the sample with riffle
3. Grind the sample with dish mill into powder size (less than 2 micron), normally 2 minutes were used, then store in glass bottle.
4. Remove calcium carbonate with sodium acetate and acetic acid (pH 4.5-5.0)
5. Remove organic matter with hydrogen per-oxide.
6. Wash the sample with distilled water, then transfer to the centifuge tube.
7. Shake the centifuge tube, and centifuge it again.
8. Repeat steps 6 and 7 for 2-3 times
9. Smear of wet paste on glass-slide (Gibbs, 1965)

1.5.2 Chemical pretreatment

a) Removal of calcium carbonate

1. Place a suitable amount of sample into bottle of

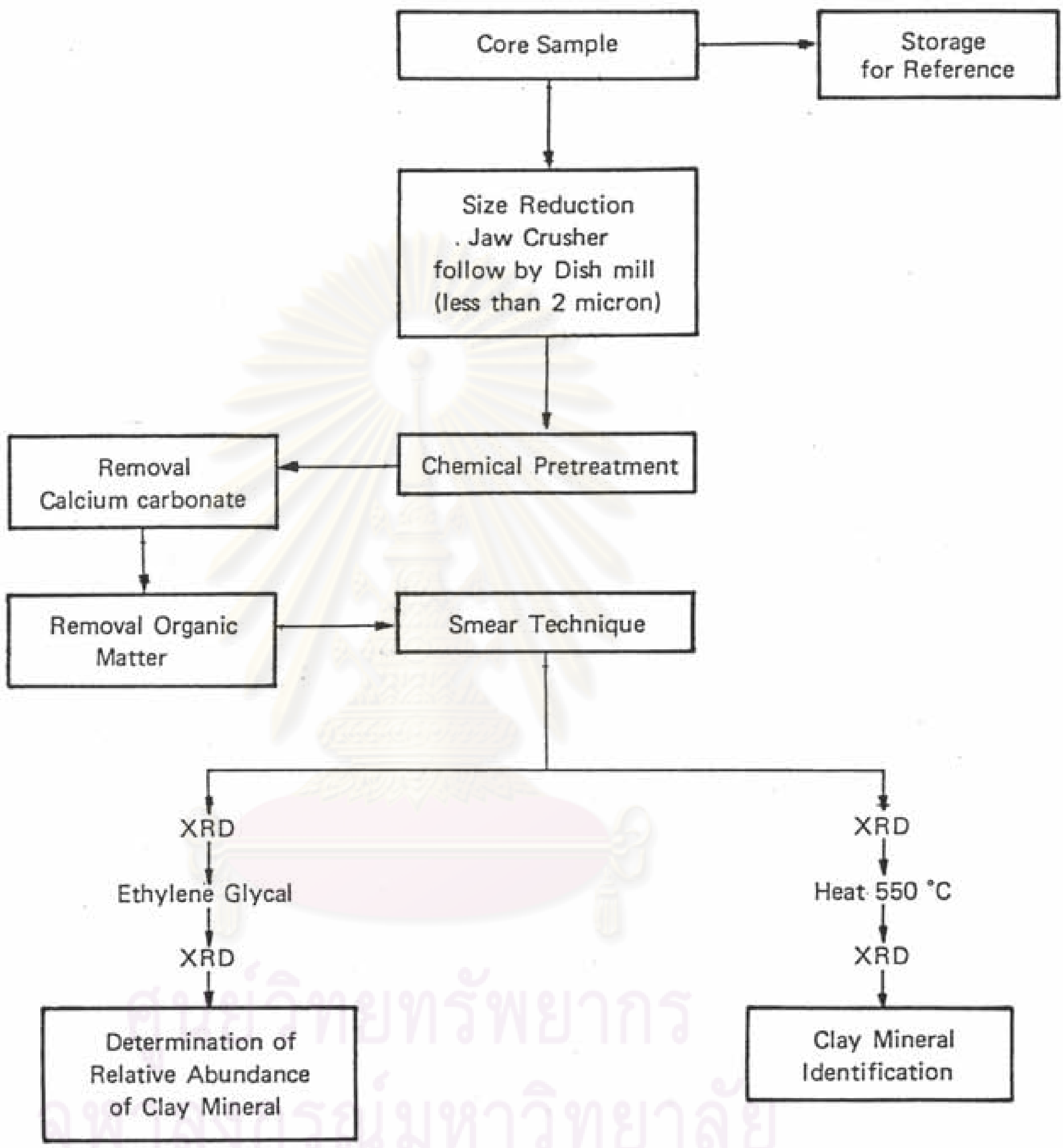


Fig. 1.5 a Flow chart illustrating the semi-quantitative determination of relative abundance of clay minerals.

sufficient height

2. Pour a suitable amount of sodium acetate buffer into the bottle (Sodium acetate, 1 N, 136 gm. per liter, adjusted to pH 4.5-5.0 with acetic acid).

3. Place the bottle on a boiling water bath to expedite dissolution. The bubbles of carbon dioxide should appear.

4. Stir sample 4-5 times per day until the bubble ceased. The sample are ready to remove organic matter.

b) <u>Removal of organic matter</u>

1. Pour the hydrogen peroxide, 30 % into the bottle.

2. Place the bottle on a water bath, the temperature should not excess 70^{o}c.

3. Digest the sample until frothing ceased. The sample should lose its dark color.

4. Wash the sample with distilled water.

5. Go to step 8 in 1.5.1

1.5.3 <u>Mineral identification</u>

Clay minerals have platy crystals. After the smear of wet paste on glass-slide technique (Gibbs,1965), the (001) crystal face will always lie parallel to the surface of the glass slide. When X-ray strikes the clay powder, the X-ray will strike the (001) crystal face and yield the (00ℓ) reflections and produces an X-ray pattern on the strip chart recording. Different incident angle (θ) on different types of clay minerals produces different (001) reflections. The first reflection is (001), the second is (002), the third is (003), and so on. From the angle of incidence for each reflection, a "d" value may be calculated by Bragg's Law, The "d" values are related as follow : (002) = 1/2 (001), (003) = 1/3 (001), (004) = 1/4 (001), and so on. The values in $d(A^{o})$ of the characteristic reflections of current clay minerals, after diagnostic treatment is shown in Table 1.5.3a and 1.5.3b.

X-ray diffractograms were obtained using Phillips generator (model 1730/10), nickle-filter and copper radiation generate at 30 kilovolts and 25 milliamperes, and scanning speed at 2^{o} (2θ) per minute, rate metre 8, time constant 4 second and multiplier 1.

1.5.4 <u>Clay mineral percentage calculation</u>

After getting the complete X-ray pattern, the (001) peak of each kind of clay mineral upon ethylene glycolation is used as their semi-quantitative determination of relative abundance. The method are as follows :

a) Draw the background curve under the basal peak of each clay mineral. For kaolinite, montmorillonite and illite the peak are 7 A^{o}, 17 A^{o} and 10 A^{o}, respectively (Table 1.5.3a).

b) Measure the peak area under the basal peak (001) using square grid pattern method.

c) For collection the intensity of peak area, divide the area by correction factor; the correction factor depends on the clay

Table1.5.3a Values in d(Å) of the characteristic reflections of the series (001) of current clay minerals, after various diagnostic treatments (after LUCAS, 1963). (N = natural, untreated sample EG = ethylene glycol 500 and 550 = heating treatments). (after Thorez, 1976)

		d-spacing in Å										
MINERAL	SYMBOL	7	8	9	10	11	12	13	14	15	16	17
Kaolinite	K	N EG										
Chlorite	C								N EG 500			
Swelling Chlorite	Cg								N 500		EG	
Illite	I				N EG 500							
Smectites (Montmorillonites)	M				500		N ⟵	⟶	⟶ N			EG
Vermiculite	V				500				N EG			
Palygorskite	PAL				N EG 500							
Sepiolite	SEP				500		N EG					

Table1.5.3b Values of the basal reflection, in d(Å), for the current clay minerals, after the classical identification essays (N = natural, untreated sample EG = ethylene glycol 500 = heating to 500°). (after Thorez, 1976)

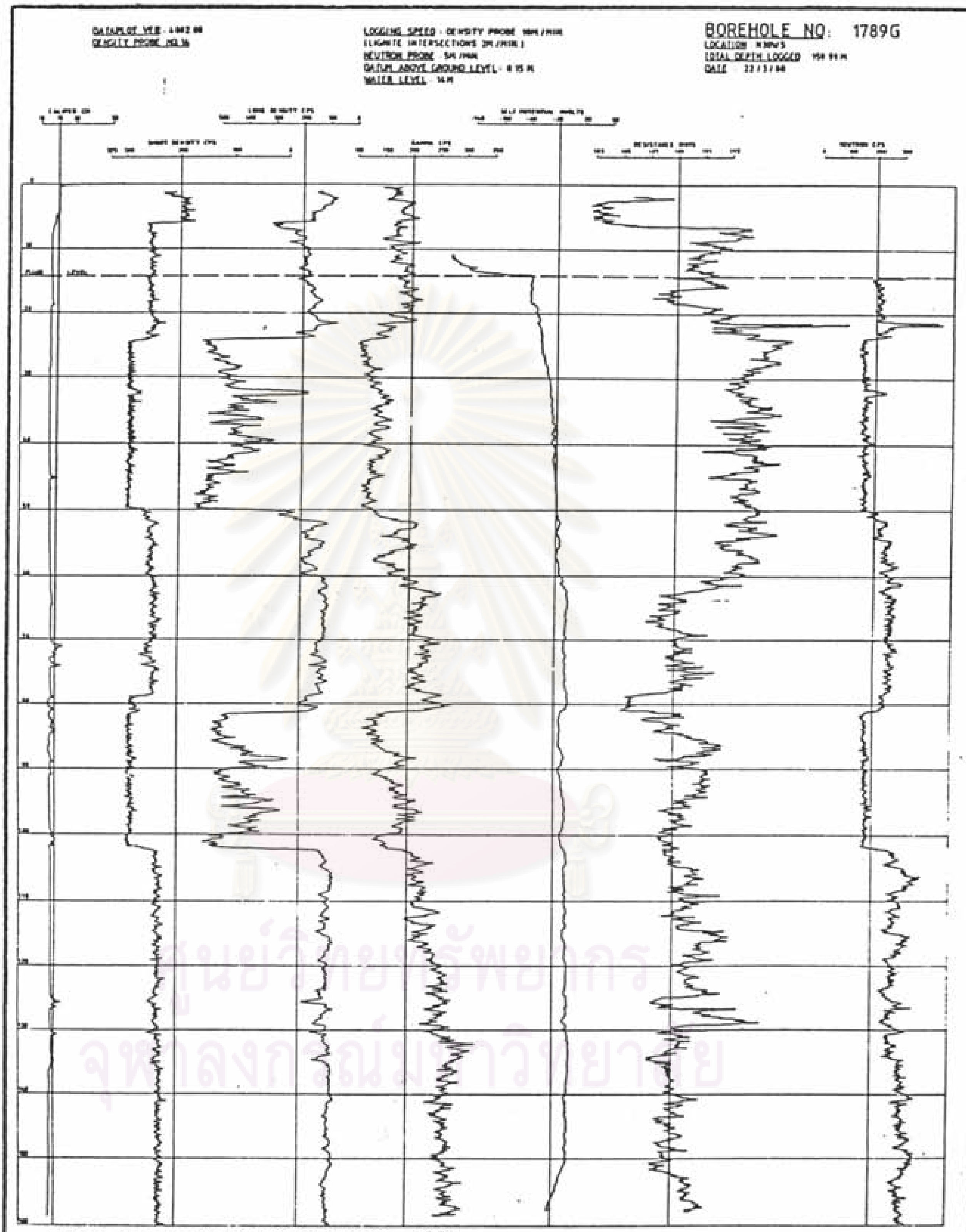
MINERAL	TREATMENTS	Values (in Å) of the characteristic reflections of simple clay minerals after different treatments. (001)	(002)	(003)	(004)	(005)
K	N	7.1	3.58	2.33		
	EG	no changes				
	500	disappearance of all the reflections				
I	N	10	5	3.3	2.5	
	EG	no changes				
	500	no changes				
M	N	15.4		5.1		3.05
	EG	17	3.5	5.7	4.2	3.4
	500	10		5		3.3
C	N	14	7	4.7	3.5	2.83
	EG	no changes				
	500	no changes or slight changes in the even orders				
	550	14	–	4.7	–	2.83
		(disappearance of the even orders)				
Cg	N	14	7-7.2	4.7	3.5	2.83
	EG	17	8.85	5.85		
	500	same reactions as for normal chlorites				
	550					
V (Mg-satured)	N	14	no changes			
	EG	14				
	500	10				

mineral. For montmorillonite, divided by 4; for illite, divided by 1 ; for kaolinite divide by 2.5.

d) The weighted peak areas of clay minerals present are summed, and the weighted peak area of each mineral times 100 and divided by the sum of peak area give the relative weight percentage of each clay mineral present in the sample.

1.6 Methods in geophysical log interpretation

Geophysical logging has been established for many years as an important technique in the coal exploration. This method provides a cheap, when compared to others, and quick method of obtaining accurate information concerning the depth, thickness and quality of coal in the borehole. In order to well understand the subsurface geology of the Mae Moh Tertiary basin, geophysical log is one of the most important parameters in geological subsurface interpretation. According to geophysical log which obtained from the Electricity Generating Authority of Thailand (EGAT.), two probes were used, namely, density probe and neutron probe. Density probe is consisting of sensors for borehole diameter (Caliper), short space density, and long space density; whereas neutron probe is consisting sensors for natural gamma, electrical self potential, electrical resistivity, and neutron. All the equipment is mounted permanently on the four-wheel-drive logging trucks. After the electrical signals are transmitted to a computer, they are converted and stored in a magnetic computer tape. Finally, these information is recorded in graphical form comprising seven separate traces on one sheet, normally plotted in the vertical scale of 1:200. Figure 1.6a shows typical



After Longworth CMPS Engineers, 1981

Sedimentological Studies of Some Tertiary Deposits of Mae Moh Basin, Changwat Lampang	Typical Geophysical borehole log
Pol Chaodumrong, Department of Geology Graduate School Chulalongkorn University, 1985.	Fig. 1.6a

geophysical logs. Most geophysical logs indicate changes in the physical properties of the rocks. According to the EGAT. drilling programmes, almost all of the drilled holes have penetrated only a few metres below the base of the lower coal seam (referred to as "B-2 Member" in this study). Combination of the logs are collectively useful in the interpretation of lithostratigraphy, structure, depth, and the geometry of the sedimentary facies of the Mae Moh basin.

The caliper probe is a tool for measuring a size and shape of borehole, it contains a thin steel arm which is spring loaded inside the probe. When the probe reaches the bottom of the hole the arm is opened is activated from the surface. As the probe is pulled up the arm rides against the side of the hole. The resultant geophysical output of this technique shows a profile of the borehole wall indicating the position of cavities.

The density tool is one of the most frequently run geophysical tools in coalfield. It is used qualitatively to identify the coal seam and to establish the seam correlation, and seam thickness.

The density probe contains a small radioactive source. For Mae Moh Project, the 125 m curie of caesium 137 is being used. The radioactive source is situated near the very bottom of the probe. Two X-ray detectors, one of these is spaced 16 cms. from the source is refered to as the short-space detector, and the other is 46 cms. from the source, and is refered to as the long space detector. As gamma rays are emitted from the radioactive source, they collide with electrons in the sidewall strata and are scattered back to the detector within the sonde in all directions. The back scatter is registered by the detectors and is dependent on the bulk density of the formation through which the probe passes. Most commercial density logs are reversed, so that radiation increases to the left, rather than the right as on natural-gamma and neutron logs. The purpose of this reversal is to illustrate porosity increase to the left, as on long-spaced neutron logs. Confusion can be eliminated by remembering that radiation recorded on density logs increases with increasing porosity. Lignite has very low density and the resulting response from the detectors is very high count per second or CPS.

The natural gamma ray log is very commonly employed in coal exploration and is the principal tool used for identification of litho-logy, and for the investigation of the depositional history of a stra-tigraphic sequence. General-scale gamma logs are perticularly useful for lithological correlation between drill-holes. The level of gamma radiation for each lithology is usually fairly consistent within a localized area (Hoffman et al.,1982).

The gamma probe consists of a scintillometer detector for measuring the naturally occuring gamma radiation in the rock strata and borehole. The radiation is a part of the energy released by cer-tain naturally occurring. Generally, clay minerals contained radio-active elements, namely, potassium-40, thorium, uranium. Consequently, the gamma probe responses most strongly to clay minerals, and the response decreases with decreasing content of clay minerals. Thus, coal and clean sandstone usually have the lowest amount of clay min-erals, the response from the gamma probe are also consequently low count per second. However, the response of signature of these two rock types, namely, coal and clean sandstone are quite similar; in order to differentiate these two lithologies, gamma log should be used in association with density, neutron or resistivity logs.

The neutron log measures the proportion of hydrogen atoms in the formation surrounding the borehole and indicate the amount of water or hydrocarbon materials. Neutron logs are not used for quantitative determination of coal porosity because hydrogen in the coal macerals cannot be distinguished from the hydrogen in pore-filling fluid. Machanically, it comprises of radioactive source which emits neutrons and a detector inside the probe for measuring the number of neutrons which are not absorbed by the hydrogen atoms either in the surrounding formation, or in the fluid in the borehole. As the probe passes through lignite seam which contains high water content or high porosity, the response from the neutron detector is therefore low. It is noted that the neutron signature in sandstone can be quite variable due to the effect of water content in sandstone of different porosity.

The resistivity and self-potential logs are referred to as electric logs because they indicate the electrical properties of the formation. Most coalfield strata, when perfectly dry, do not conduct electric current. The current actually flows through water-filled interstitial pore spaces. If the pore spaces are not interconnected, the current is inhibited and resistivity increases. However, clay minerals also conduct electric current by ion exchange. So, clay-bearing lithology will have low resistivity, even though the porosity and permeability are usually relatively low. The ion exchange effect is strongest for montmorillonite, intermediate for the illite group, and low for kaolinite (Hoffman et al., 1982).Lignite generally has a much higher electrical resistivity than shale and claystone. However, the resistivity of coal varies with rank because coal porosity and fluid content vary with rank. So, higher rank coal usually have higher resistivity. The self-potential log indicates the changing potential difference between the electrode on the probe and the ground electrode. The S.P. log cannot be generally used to identify lignite but often indicates zones where water is flowing into the borehole from surrounding formations.

The lithological boundaries which responsed on the geophysical logs is shown in Figure 1.6 b.

1.7 Previous investigations

In order to seek petroleum or coal for the railways' steam locomotives, Prince Kamphaengbej who was the Commissioner of the Royal State Railways had engaged an American geologist named Wallace M.Lee to investigate the mineral fuels then known in Thailand. The Mae Moh lignite deposit was first briefly described in a published report by Lee (1923, pp.17). According to Lee (1923), the lignite had previously been reported by M.Boyer during construction of the railroad from Bankkok to Chiangmai.

In order to compile the geology and mineral deposits of Thailand, a team of geologist from the Thai Department of Mineral Resource (formerly called the Royal Department of Mines) and the U.S. Geological Survey described the known geology and mineral deposits of Thailand. As a result of this investigation, the U.S.Geological Survey issued a report in 1951 in form of the Geological Survey Bulletin 984 (Brown et al.,1951) and the Royal Department of Mines in 1953 issued

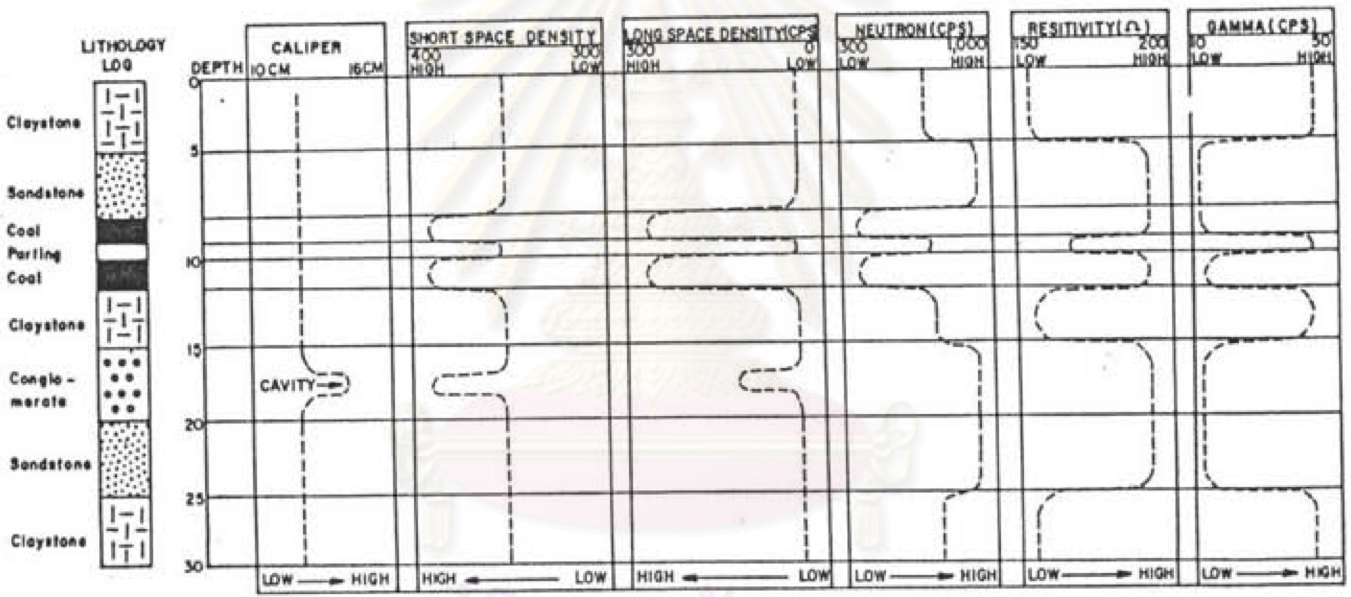


Fig. 1.6 b Theoretical model of geophysical borehole logging. (modified after Longworth – CMPS Engineers, 1981)

a report with the same material and illustrations as in the Geological Survey Bulletin 984 in form of Geological Survey Memoir I (Brown et al., 1953). According to Brown et al. (1953), there are altogether fourteen Tertiary basins, among these eight basin were in the peninsula and six intermontane basins were in the northern part of Thailand. They named the Krabi Series and the Mae Sot Series to represent Tertiary rocks in the southern and the northern part of Thailand, respectively. The difference between these series is that the Krabi Series contains some marine fossils. The Mae Sot Series is reported to be semiconsolidated fluviatile and lacustrine sediments. A brief discussion of the Mae Moh intermontane geology with lignite seam was also reported.

In 1954, the government of Australia sent a drilling engineer, C.Gloe, to help with further investigations of the Mae Moh lignite deposit as well as to plan and develop a suitable open-cast mine.Consequently, Gloe (1955) reported much valuable information on the geology of the area, notably, the distribution and nature of the lignite, including a lithostratigraphic classification and the development work at the mine.

In 1955 Pitakpaivan who studied the marine Triassic along the Mae Moh Valley, had devided the Triassic marine rocks into seven lithological units, four of which he named.

In 1957 and 1958, a team of geologists and engineers from Fried Krupp Rohstoffe of Essen,Germany, investigated the Mae Moh lignite deposit as a part of a survey of mineral products suitable for a steel industry in Thailand. They took large-sized samples of lignite, impurities, and interbeds to Germany for further study and analysis. Their unpublished report (Fried Krupp Rohstaffe Co., 1959) contains much valuable detailed information on the deposit, especially on the physical, chemical and the economic properties of the lignite.

Sithiprasasna (1959) on his attempt to carry out the stratigraphic position of know mastodon fossil, he reported occurrence of teeth of mastodon, fish remains, shells, turtle rib and back plate. According to Sithiprasasna (1959), two sets of stegolophodon teeth were discovered at two different spots referring to in this study as B 4.4 and B 4.5 Beds (the embrace of B-4 Member). In the same year, Von Koenigswald (1959) had identified the photographs of the teeth of mastoton from Mae Moh as related to Stegolophodon latidens but more primitive and most probably represented an ancestral form of that genus. He thus proposed the name Stegolophodon praelatidens n. sp. for that fossil remain. The age was concluded to be Lower to Middle Pliocene.

In 1964, Sundharovat proposed the hypothesis on the origin of the oil of probably non-marine origin. According to the hypothesis, the interrelationships among oil, oil shale and lignite were proposed and presented. Besides, a summary on the geology of the Fang, Mae Sot and Mae Moh basins have been discussed.

In the first detailed study, Gardner (1967) formally described a type section of the Mae Moh Tertiary rocks using data from outcrops and boreholes. He proposed the Mae Moh Formation including the name of lignite seams and claystone beds in alphabetical sequence similar to the sequence of Gloe (1955). In addition, other aspects, namely, the exploration and development plan, character of the lignite, processing and utilization were reported.

Piyasin (1971, 1972), in his compiled the geological map of Lampang Sheet in scale 1:250,000, named the Mae Mo Group for the Tertiary rock found in northern Thailand.

In order to increase the electricity capacity, numerous boreholes were drilled by EGAT, Gold (1979) estimated the total lignite reserve of 650 million tons. During 1979 - 1981, Longworth CMPS Engineers conducted a programme to assess the quantity and quality of lignite in the Mae Moh basin. According to this project, 72.6 line kilometres of high resolution seismic reflection survey, 454 boreholes totalling 98,250 meters were undertaken. Drilling exploration were carried out using the open-hole drilling method coupled with the geophysical borehole logging. As a result of this project, the reported of Longworth DMPS Enginers (1981) contained much valuable detailed information, especially on the quantity, quality and distribution of lignite, basinal structure and the future development plan.

Gibling and Ratanastien (1980) classified the Cenozoic sediments of Thailand into three facies associations. The sediments in the Mae Moh basin were classified as fine-terrigenous association. In addition, they studied the fossil assemblages in the mudstone, the mudstone unit of 6 metres thick, containing fish fragments in the lower part, with gastropods, fish and plant fragments in the upper part. The mudstone unit is overlain by coal. They reported such cyclicity is of regressive type, indicating the change of depositional environment from bodies of open water to swamps and peat bogs.

The nearly north-south trend and graben-form of the basin show a similarity to the structures in the northern Gulf of Thailand (Achalabhuti, 1974 ; Wollands and Haw, 1976), and the tensional tectonic regime suggests that the north Thailand basin and the central plain are the northward extenion of the Tertiary Gulf of Thailand intracratonic spreading basin (Bunopas, 1983). Vella (1983) proposed that the Mae Moh basin was formed by post - Middle to Late Miocene normal faulting, and the faulting took place after the deposition of the Miocene sediments, consistent with the late Cenozoic uplift of the mountains of Thailand inferred by Bunopas (1981).

Ratanasthien (1983) divided coal bearing Tertiary basins in Thailand on the basis of coal quality into 3 mode of environment as characterized by stratigraphic sequences. The Mae Moh basin is classified as lacustrine environment.

Ginsburg (1983) identified the new species of fossil collected from Mae Moh basin as Siamogale thailandica, Rhinocerotini indet. cf. Gaindatherium.. Two broken teeth of proboscidian were also collected and reported. He reported that one of this tooth is similar to the specimens examined by Von Koenigswald (1959). Besides, the mastodonts from Mae Moh was identified as Stegolophodon sp. Consequently, the Mae Moh lignite is believed to be the upper part of the Middle Miocene.

During 1983-1984, the EGAT. has concerned a project to evaluate the lignite reserve, basin geology, and to formulate the future development plan, etc. This project is called "Australian Development Assistant Bureau" (ADAB). Numerous boreholes were drilled including few stratigraphic boreholes which reached the basement rocks of Marine Triassic. The data and information which are obtained from the ADAB. project, revealed much valuable details on the basin stratigraphy and basin structure. This is considered to be the most essential input for the present study.

Comparative classification of Tertiary rocks of Thailand is shown in Table 1.7a

Table 1.7a A comparative classification of Tertiary rocks of Thailand (modified after Chaodumrong et al., 1983).

	Neogene		Palaeogene		
	Pliocene	Miocene	Oligocene	Eocene	Paleocene
Brown, et al., 1951	Krabi Series (South) Mae Sot Series (North)				
Javanaphet, 1969	Krabi Group				
	Mae Mo Formation		Li Formation		
Gardner, 1967	Mae Mo Fm.				
Piyasin, 1972 1975	Mae Mo Group				
Buravas, 1973	Mae Sot Fm.	Mae Mo Fm.	Li Fm.	Nam Pat Fm.	
Suensilpong, et al., (1978)	Krabi Group				
	Mae Mo Fm.	Li Fm.			
Others	Tertiary sequence or geographic names of each basin				
Present Study	Mae Moh Group		?		
	C Fm.	? B Fm. ? A Fm.	?		