CHAPTER I

INTRODUCTION

1.1 General

The Tertiary sediments of northern Thailand are found in isolated intermontane basins which vary in size from a few square kilometres to a few hundreds square kilometres (Figure 1.1.1). At present, 37 basins have been identified and they are distributed throughout the northern region. Some large basins, including Li basin, consist of a connected set of sub-basins. Most of Tertiary sediments overlie unconformably the pre-Tertiary rocks and are overlain by unconsolidated sediments of Quaternary Period. These Tertiary basins differ from each other in many respects. The elevation differences of present-day topographic ground-surface within the basin are probably the result of recent surface processes and subsequent tectonic movements. Some paleontological data of these basins indicate the age range from Eocene to Pliocene (Table 1.1.1).

The tectonic setting of Tertiary intermontane basins of northern Thailand are full grabens and/or half grabens, 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 older formations, varying from north-south to north/northeast-south/southwest directions. Paleontological evidences of the sediments within Tertiary basins of northern Thailand, generally, indicate the

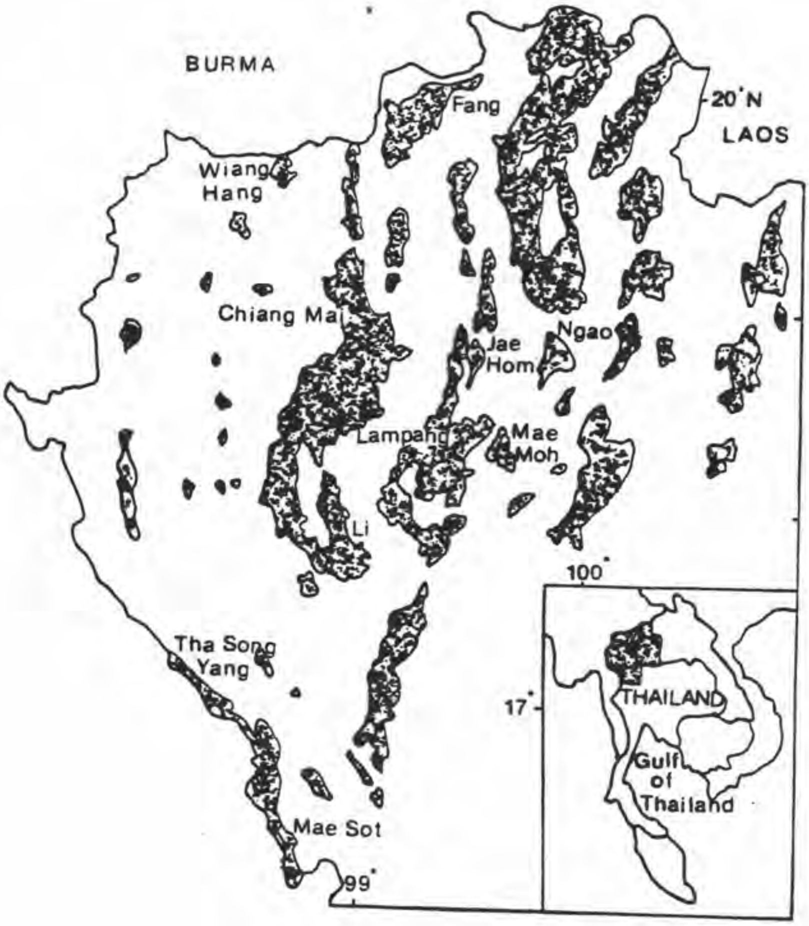

Figure 1.1.1 Major Cenozoic intermontane basins in northern Thailand (after Suchit Pitragool, 1980).

Table 1.1.1 Cenezoic intermontane basins of northern Thailand ; Location and Ages (Compiled from Somchat Boripatkosol, 1986).

Basin	District	Age
Boa Luang	Chiang Mai	Neogene
Chae Hom	Lampang	Miocene
Chae Kon	Lampang	Pliocene
Chiang Dao	Chiang Mai	Neogene
Chiang Kam	Chiang Rai	Neogene
Chiang Kong-Thoeng	Chiang Rai	Neogene
Chiang Mai	Chiang Mai Lamphun	Miocene-Pliocene
Chiang Muan	Chiang Rai	Miocene-Pliocene
Chiang Rai	Chiang Rai	Neogene
Fang	Chiang Mai	Oligocene
Khun Yuam	Mae Hong Son	Neogene
Lampang	Lampang	Miocene
Li	Lamphun	Eocene
Mae Cham	Chiang Mai	Miocene-Pliocene
Mae Chan	Chiang Rai	Neogene
Mae Jai	Payao	Neogene
Mae Lamao	Tak	Neogene
Mae Moh	Lampang	Miocene-Pliocene
Mae Sarieng	Mae Hong Son	Neogene
Mae Sod	Tak	Miocene-Pliocene
Mae Suai	Chiang Rai	Neogene
Mae Teep	Lampang	Miocene
Mae Tun	Tak	Miocene-Pliocene
Ngao	Lampang	Neogene
Om Koi	Chiang Mai	Neogene
Pai	Mae Hong Son	Neogene
Payao	Payao	Miocene
Phrae	Phrae	Miocene
Pong	Payao	Neogene
Prao	Chiang Mai	Neogene
Pua	Nan	Neogene
Sa-Iab		Miocene
Sam Ngao	Tak	Neogene
Serm Ngam	Lampang	Miocene
Tha Song Yang	Tak	Paleogene
Wang Nua	Lampang	Miocene
Wieng Haeng	Chiang Mai	Neogene

non-marine or fresh-water depositional environment. The Tertiary sediments are mostly clastic sediments of lacustrine and fluviatile facies interbedded with organic sediments and mainly overlain by medium- to coarse-grained terrigenous Quaternary deposits.

Due to the fact that the tectonic activity during Quaternary time has been relatively low, therefor almost all of the Tertiary sediments are not exposed. The study of Tertiary sediments must be essentially based on the data and information obtained from borehole investigation and geophysical exploration.

Most geological investigations on Tertiary sediments of northern Thailand are essentially motivated by the exploration extraction of various types of mineral resources within these basins. These mineral resources include coal, petroleum, oil shale, diatomaceous earth, plastic clay and groundwater. At present, active coal-mines are located at Mae Moh, Mae Tip, several localities in the Li basin, Mae Cham, Mae Lamao, Mae Tan and Mae Tuen. Petroleum exploration and production in northern Thailand is located at Fang basin and Phitsanulok basin. Oil shale deposits have been found in many intermontane basins, notably, Mae Sot basin, Li basin, Chae Hom basin and Lampang basin, etc.. Diatomaceous deposits have been investigated in several sub-basins within Lampang basin.

Amongst over 37 intermontane basins in northern Thailand, Li basin which in composed of several sub-basins is one of the important basins. This is basically due to the fact that Li basin is the coal-bearing basin which coal has been currently and partly exploited to meet the increasing domestic demand for energy.

Sedimentological studies of Tertiary sediments are therefor considered to be only for the progress on knowledge of Tertiary geology of Thailand, but also beneficial to the development geology of mineral industries. Li basin has been selected for the present investigation under several reasonings. First, the Li basin has been geologically considered to be an oldest Tertiary intermontane basin in Thailand. Second, numerous exploration programmes, notably, drilling exploration, borehole geophysics, etc. have been undertaken so that reasonable subsurface geological information are properly available. Third, the findings of the present study will be useful in assisting the current coal development programmes. Last, it is expected that the Li basin should contain the complete lithostratigraphy representing the intermontane type of basin and geological structures which can be utilized as geological reference for further exploration in neighbouring ambiguous area.

1.2 The Study Area

1.2.1 Location

The Li basin is mainly confined to the administrative boundary of Amphoe Li, Changwat Lamphun in the northern part of Thailand. The basin lies approximately between latitudes 17° 39' N to 17° 51' N and longitudes 98° 54' E to 99° 5' E. The shape of the basin is roughly elliptical elongated in the north/northwest-south/southeast direction. The basin covers approximately 270 square kilometres with the maximum width in the east-west direction of about 18 kilometres and maximum length in the north-south direction of about 21 kilometres.

The study area is mostly included in the administrative boundary of Amphoe Li, Changwat Lamphun (Figure 1.2.1.1). The eastern and southeastern parts of the basin is in the administrative boundary of Amphoe Thoen of Changwat Lamphang, whereas the southern part of the basin is in the administrative boundary of Amphoe Mae Prik of Changwat Lampang.

1.2.2 Physiographic Setting

The topography of Li basin is generally flat to slightly rolling with the average ground elevation 440 metres above the mean sea level. The basin is bounded by steep, rugged mountain range of pre-Tertiary rocks on three sides, namely, the east, the west and the southern parts of the basin. The average height of the mountains in any directions is about 750 metres above mean sea level. The highest peaks on the three sides are ; the mountain range near Huai Mae Van (1058 metres above mean sea level) in the east, the mountain range near Huai Pha Mun (1050 metres above mean sea level) in the south, and Khao Doi Ton mountain (1066 metres above mean sea level) in the western part of the area.

The climate of the area is characterized by a definitely wet and dry seasons. 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 climatic condition of the Li basin in terms of temperature and rainfall as deduced from the meteorological data of Changwat Lamphun is summarized and presented in Figure 1.2.2.1. The annual mean temperature of the area is $26^{o}C$ with mean maximum

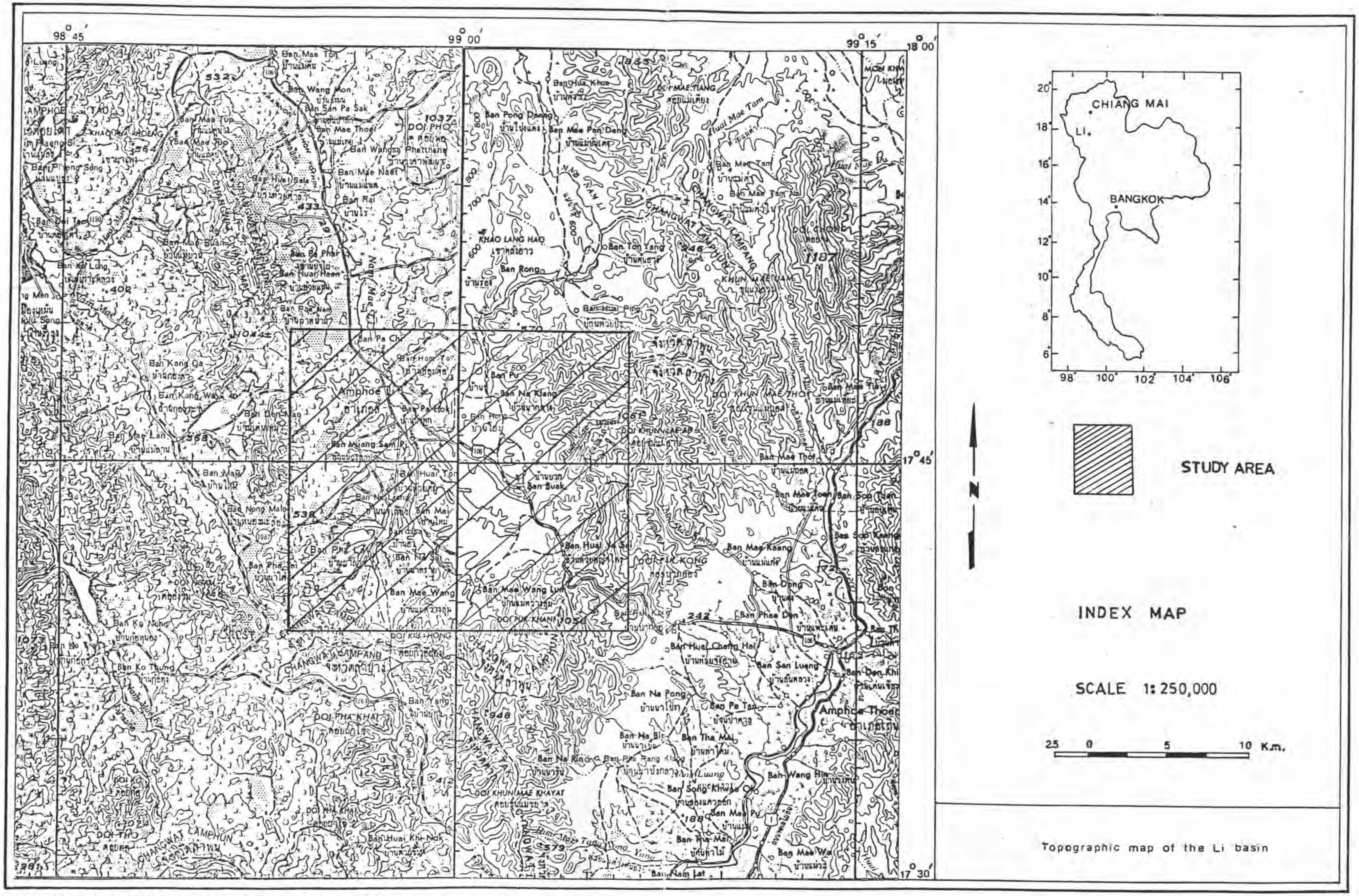

Figure 1.2.1.1 Topographic map of the Li basin.

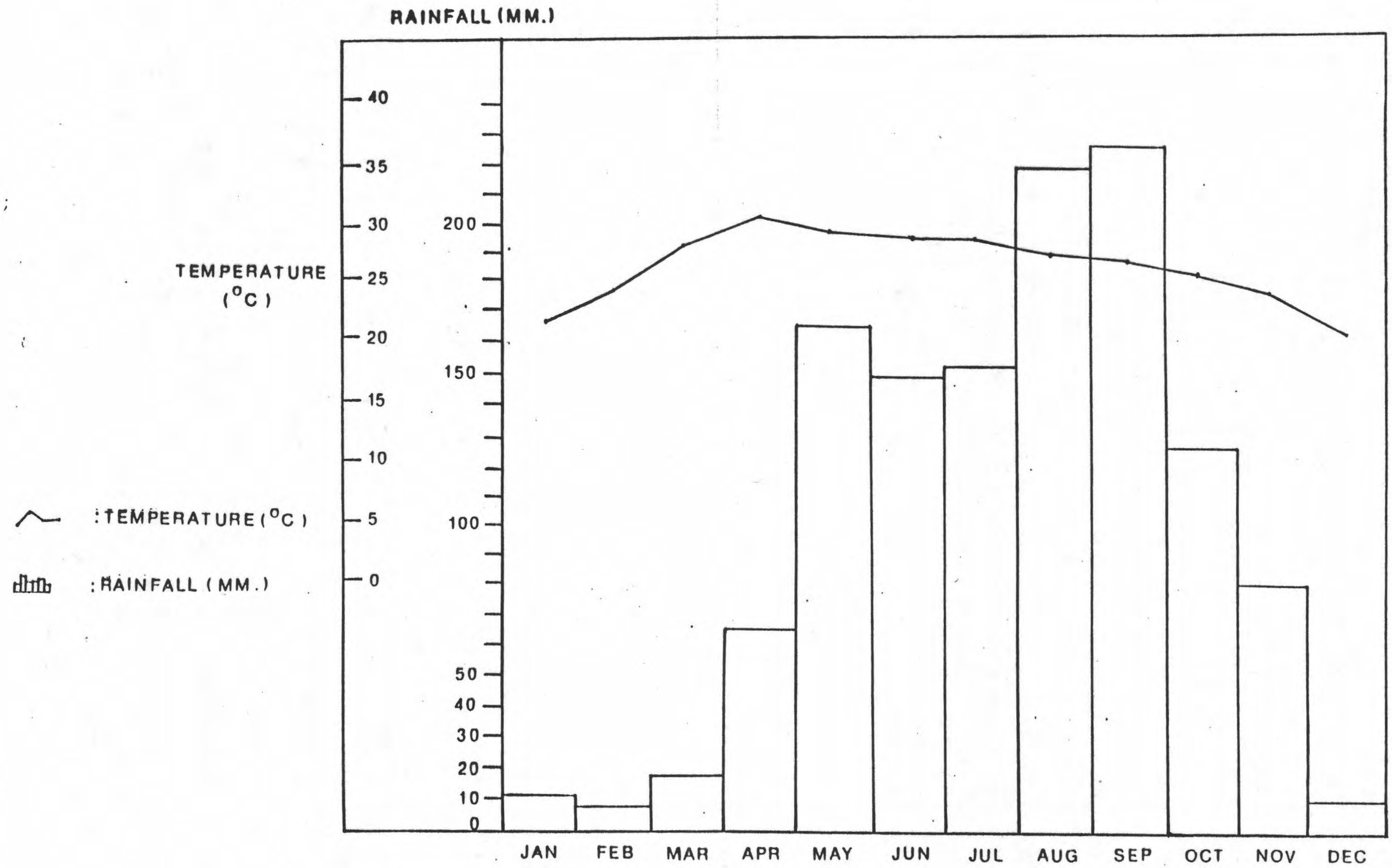

Figure 1.2.2.1 The mean monthly rainfall and temperature of Changwat Lamphun (1951 to 1980).

temperature of 30 ^{o}C in April and mean minimum temperature of 20 ^{o}C in December. The annual mean rainfall of the area is 102.75 mm. with mean maximum rainfall of 225 mm. in September and mean minimum rainfall of 8 mm. in February. The maximum relative humidity is approximately 93% and the minimum relative humidity is about 15%.

1.2.3 Distribution pattern of drill-holes

About fourty years of coalfield investigation and mining, boreholes have been drilled by Department of Mineral Resources, National Energy Administration and private companies in all sub - basins within the Li basin. Most of boreholes were drilled under the aim of coal resources exploration and exploitation. A small number of boreholes were drilled through the Tertiary sediments and stopped wherever the basements were reached. The boreholes were scatterred all over the basin with rather low density with random pattern in general. However, in the economic areas, the drilling holes were concentrated and designed in a grid system with varying grid-spacings.

Up to present, there are altogether about 616 boreholes in the study area with total length of approximately 47.56 kilometres. The depth of penetration of the borehole ranges from 1.65 to 454.00 metres with average depth of about 76.75 metres below the 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 without geophysical logs.

a.2) touch-coring holes with or without geophysical logs.

b) Geotechnical and hydrogeological holes with geophysical logs.

c) Full cored stratigraphic holes with or without geophysical logs.

Amongst these 616 drill-holes, only 313 drill-holes will be referred to in this study as primary drill-holes, whereas the rest are secondary drill-holes. The primary drill-holes are those with geological and geophysical data, penetrating through the most representative sedimentary sequence of the area concerned, and lacated at or near the geological section-lines under the present study. Therefore, the primary drill-holes are the main skeleton of the subsurface geological study of the Li basin. For secondary drill-holes, the data and information of these drill-holes are used to supplement the primary drill-holes in order to obtain a better and more complete configuration of the sediments in the basin.

Due to the fact that, the density of boreholes is not even throughtout the basin, the reliability of interpretation is therefore varies with the density of the drill-holes in each area. The distribution pattern of drill-holes within the Li basin is shown in Figure 1.2.3.1.

1.3 Objectives

The study primarily aims at utilizing the borehole data and the surface geological maps supplemented by detailed laboratory analyses to define the subsurface geology of Tertiary sediments of the Li basin in terms of lithostratigraphy, sedimentary facies, and

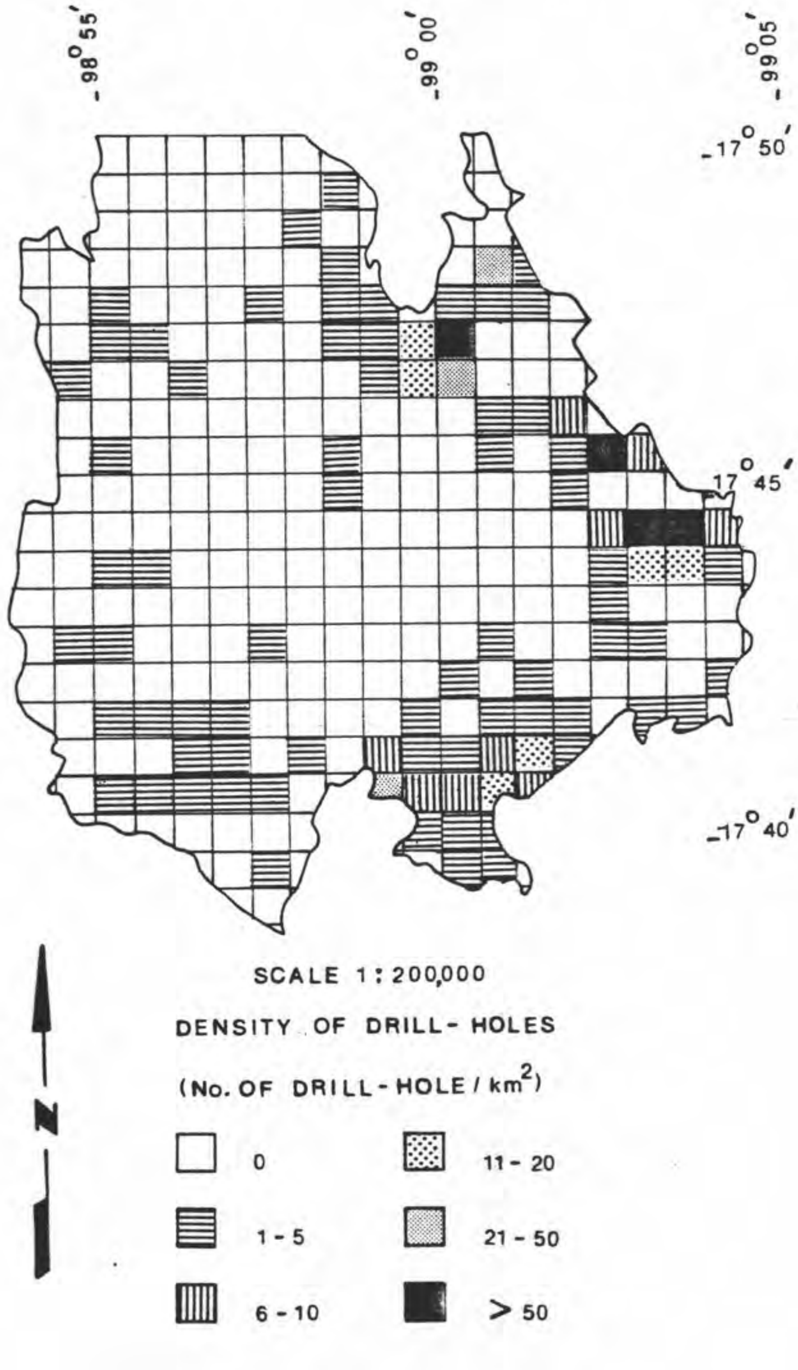

Figure 1.2.3.1. The density of drill-holes within the Li basin.

geological structures. Consequently, the overall geological history and geological processes concerned will be proposed to explain the existing geological deposits. 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 sediments within the basin.

1.4 Approach and Scope

Basically, the main goal of this study is to analyse the sedimentary facies of the intermontane basin. In order to achieve this, fundamental concept, scope and model of sedimentary facies have to be fully understood and defined to serve as the background of the study.

For the geologist working with ancient sedimentary rocks, a product of the depositional environment is a sedimentary facies. The term facies was introduced into geology by Nicholaus Steno in 1699. The modern usage of the term facies which concerned the aspect of a rock was introduced by Amand Gressly in 1838. Afterwards, the concept of sedimentary facies was defined by many geologists as Moore (1949), Teichert (1958), Selly (1970), Middleton (1973).

Due to the fact that every depositional system consists of numerous but limited depositional environments, the product of a depositional system comprised limited sedimentary facies which associated with each other. The relationships between these depositional environments in space and hence stratigraphic sequences developed through time as a result of transgression, regression, and lateral accretion, was first found by Johannes Walther in 1894 which well known as "Law of Correlation of Facies" or "Walther's Law". The facies sequence can be defined as stratigraphic sequence if it represents a rational arrangement of specific sedimentary facies of each specific depositional system (Middleton,1978).

The final facies sequence of a specific depositional system elsewhere is only local summaries (a local model), not general model for a specific depositional system, when compare them with each other and data from modern one is incorporated, the points in common between all of these comparison begin to assume a generality that can be termed a model. The facies model could be defined as a general summary arrangement of associated sedimentary facies of a specific depositional system (Walker,1984 ; Harper,1984).

The sedimentary facies analysis is approached in relation to sedimentary environment, geological setting, tectonics and climate. The distribution of facies is subjected to regularities, and the key to interpretation of sedimentary facies is to combine observation made on their spatial relationships, and internal characteristics with comparative information obtained from facies model.

Before going beyond to further step, some agreement should be made. This is, unfortunately, because the term facies has been used in many different ways. In this context, it has been used in interpretive or genetic mean. Another point which cannot be overlooked is to define a scale of facies. In this context a fairly broad facies subdivision, facies sequence, is used depending on the available data. Unfortunately, it appears that the available data are not good enough to subdivide facies into subfacies of Selly (1970) in more detail.

Basically, the main methodology employed in the present investigation is so - called lithostratigraphic analysis of sedimentary basin or basin analysis. This method has been developed to assist the exploration of most of the geological resources derived from and associated with sedimentary rocks. The work may include many components, amongst which the most important are stratigraphy, structure and sedimentology (Conybeare,1979 ; Jain & deFigueiredo, 1982 ; Miall,1984 ; Visher,1984).

The basin analysis requires the application of many methods and techniques designed to elucidate various aspects of the geological history of sedimentary layers within the basins. These methods may be direct, as in the case of surface geological mapping and the examination of subsurface drill core and cutting, or indirect, as in the case of geophysical surveys and petrophysical logging of drill-holes. They are concerned with lithology, fossil and mineral content, grain characteristics, physical and chemical properties, and the geometry of stratigraphic bodies of rocks.

In order to fulfill the objectives and scope of the present study, seven basic steps of approach have been proposed.

a) Review of the existing data and previous investigations.

b) Data acquisition, compilation and preliminary analyses.

c) Field observation and laboratory analyses.

d) Acquisition and compilation of subsurface geology.

e) Data analysis and interpretation.

f) Evaluation.

g) Conclusion and reporting.

Primarily, the review of existing data and previous investigations including the regional geological setting of northern Thailand, and geology of the Li basin are carried out to serve as a background of the study programme and to assist in identifying problems concerned. Special emphasis, however, has been given to the geological setting of the Li basin and existing subsurface data of the Li coalfield.

Within the over 270 square kilometres area of the Li basin, there are altogether five coal exploration and production areas, namely, Ban Pu, Ban Hong, Ban Mae Long, Ban Pa Kha and Ban Na Sai covering approximately 12, 15, 10, 8.5 and 14 square kilometres, respectively. With respect to the existing drill-holes data in these areas, there are 56 drill-holes in Ban Pu area, 109 drill-holes in Ban Hong area, 101 drill-holes in Ban Mae Long area, 189 drill-holes in Ban Pa Kha area, 99 drill-holes in Ban Na Sai area (Figure 1 4.1a, b, c, d and e) and 62 drill-holes in the external sub-basinal areas.

The total length of 616 coal exploration drillholes in the Li basin is approximately 47.56 kilometres. The drillholes data and information including geological as well as geophysical logs. The geophysical log data available are mainly the gamma, neutron, density and caliper.

In addition to the existing data and information on drilling exploration, borehole geophysics and subsurface geology, there are some information on the photogeological interpretation, petrographical properties of coal, characteristics of coal, coal

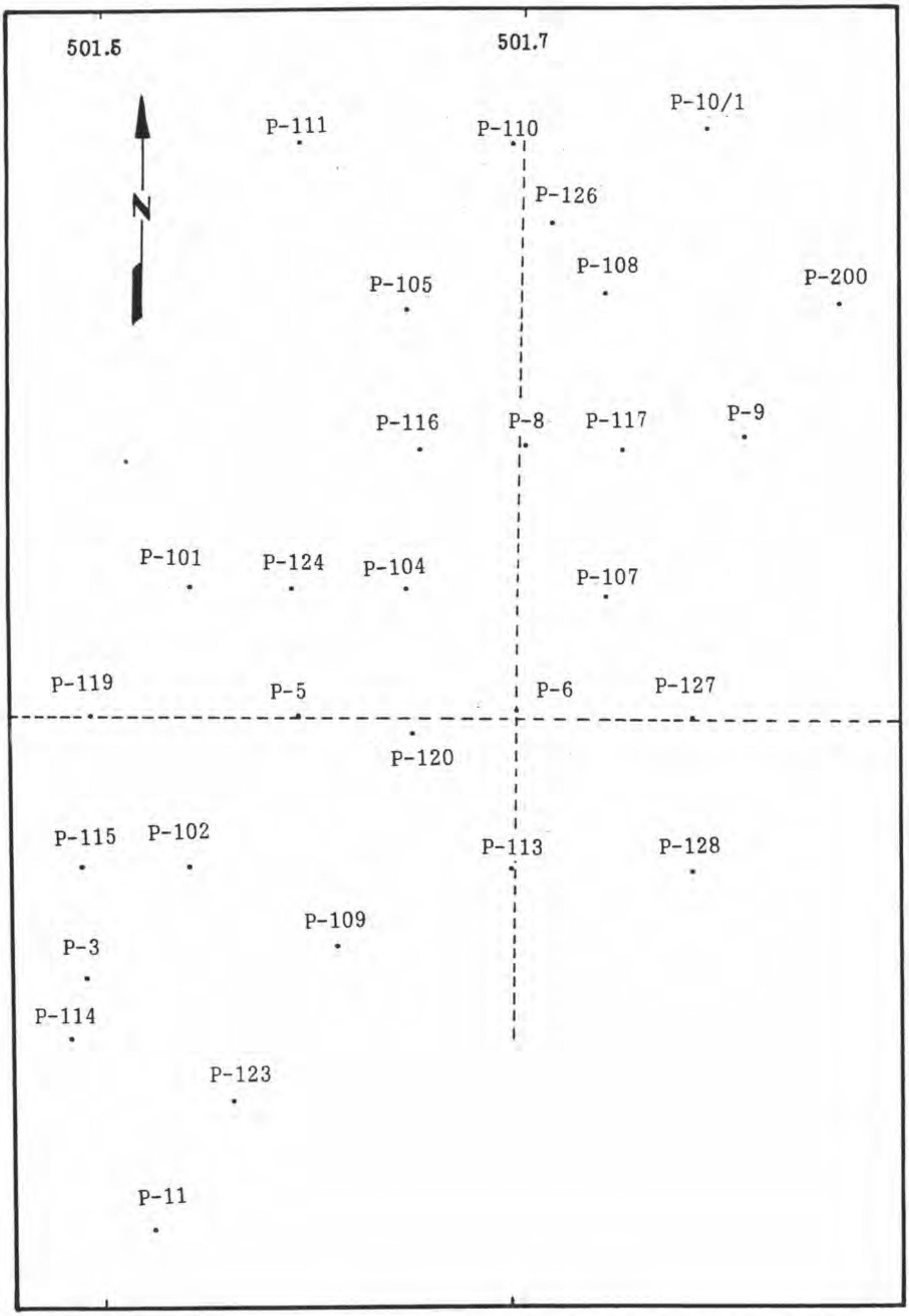

Figure 1.4.1.a Drill-holes location map of the Ban Pu sub-basin with lines of facies profile.

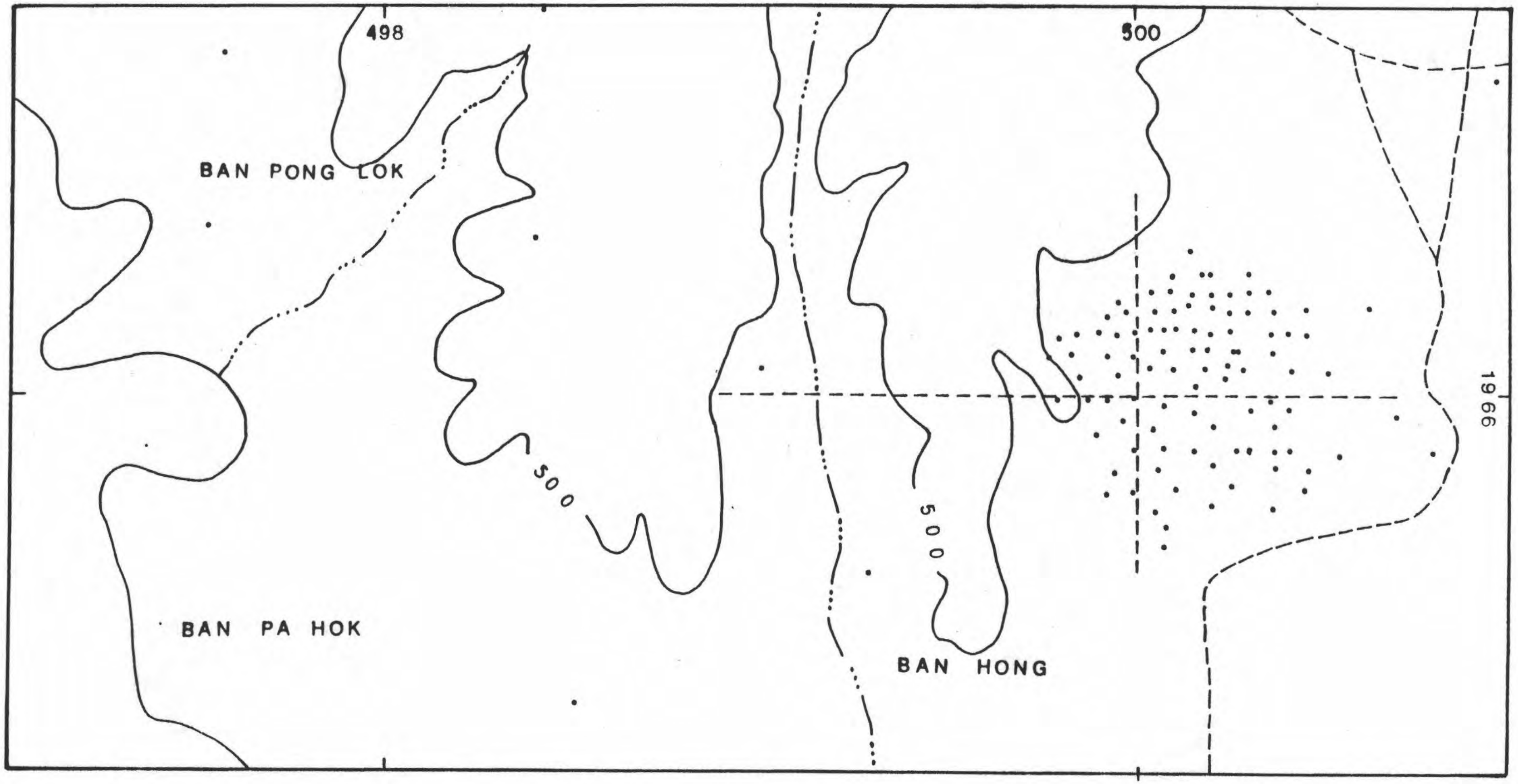

Figure 1.4.1.b Drill-holes location map of the Ban Hong sub-basin with lines of facies profile.

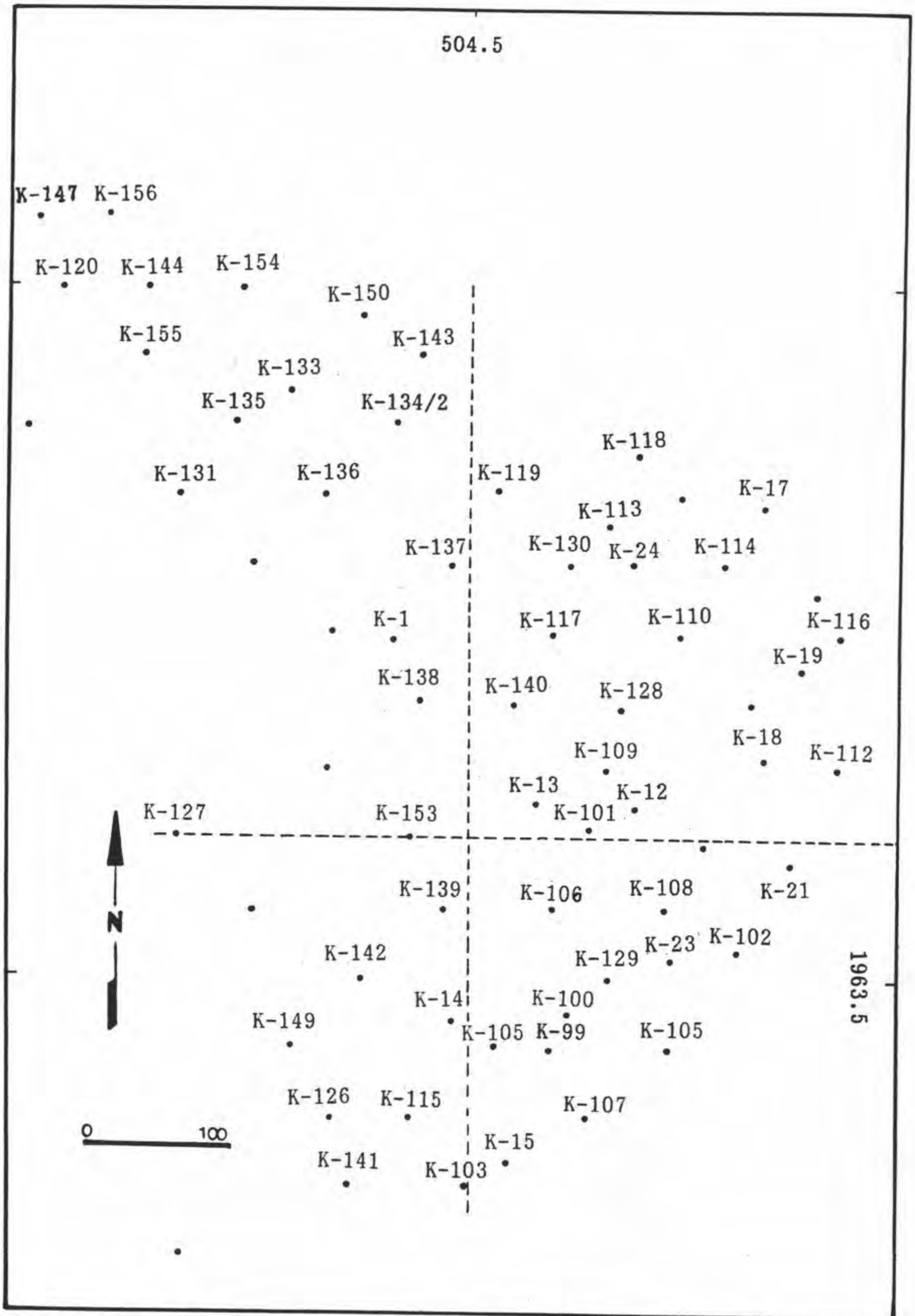

Figure 1.4.1.c Drill-holes location map of the Ban Mae Long sub-basin with lines of facies profile.

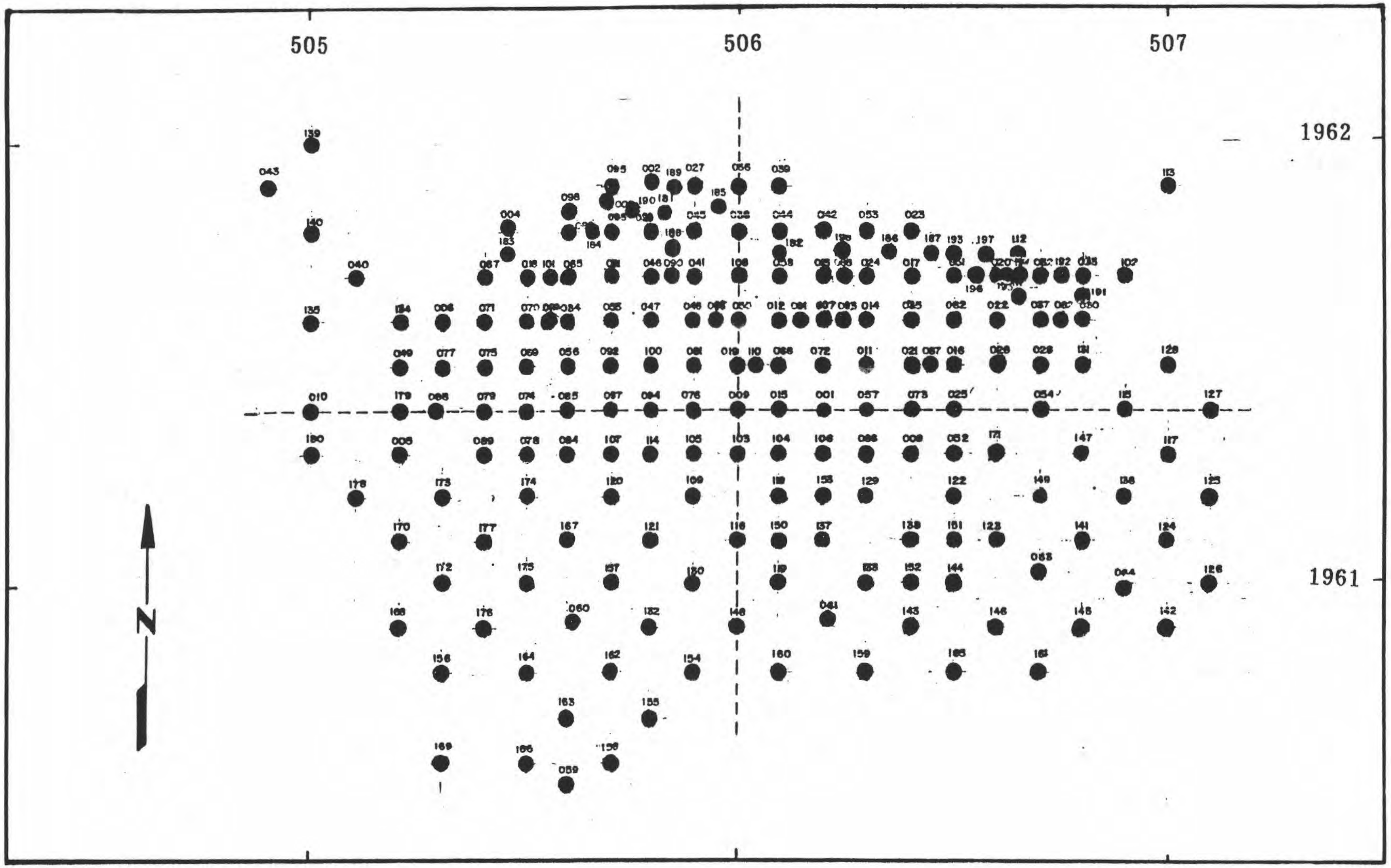

Figure 1.4.1.d Drill-holes location map of the Ban Pa Kha sub- basin with lines of facies profile.

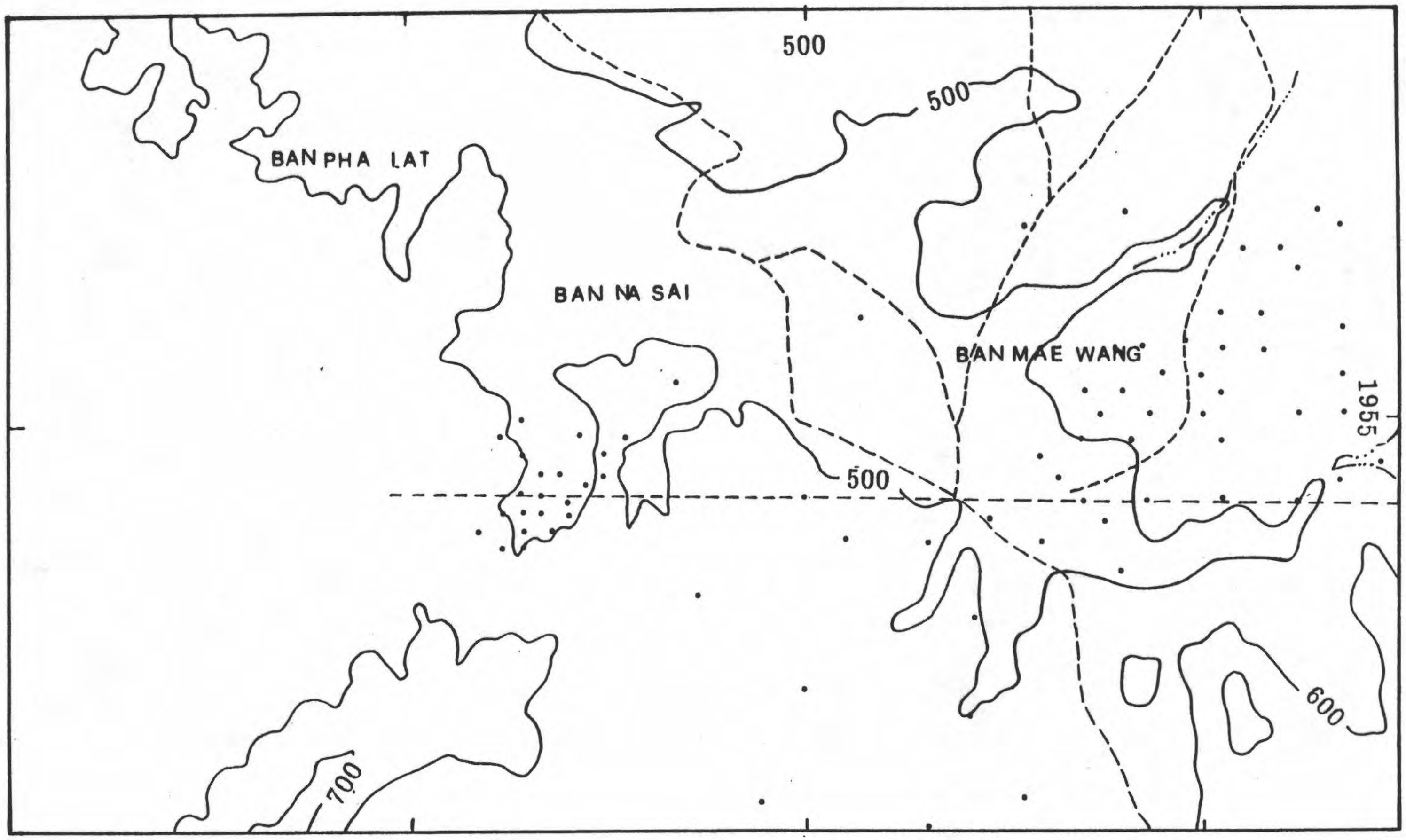

Figure 1.4.1.e Drill-holes location map of the Ban Na Sai-Ban Mae Wang sub-basin with lines of facies profile.

quality and coal resources of the Li coalfield available.

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 sedimentaryand facies analyses. Numerous graphic representations are finally prepared, notably, geological map, well location map, structural contour map, facies profile, etc..

It is against the compilation and analysis of previously outlined data, the present study programme has been accordingly designed and formulated. The scope of the study includes the following aspects, notably, the configuration of Cenozoic Li basin, the analysis of subsurface facies of the Upper Tertiary and Quaternary deposits, lithostratigraphy and structure of the basin - filled sediments, geological evolution of the basin, and coal geology,etc..

During the study programme, the field trips were conducted aiming at the acquisition of additional required data, observing the geology of the area, and collecting samples for laboratory study.

Finally, the geological evolution of the Tertiary deposits in the Li basin has been synthesized and proposed. Emphasis is made on the coal formation within the sedimentary sequences. The approach and techniques employed in the present study are summarized and presented in Figures 1.4.2 a and b.

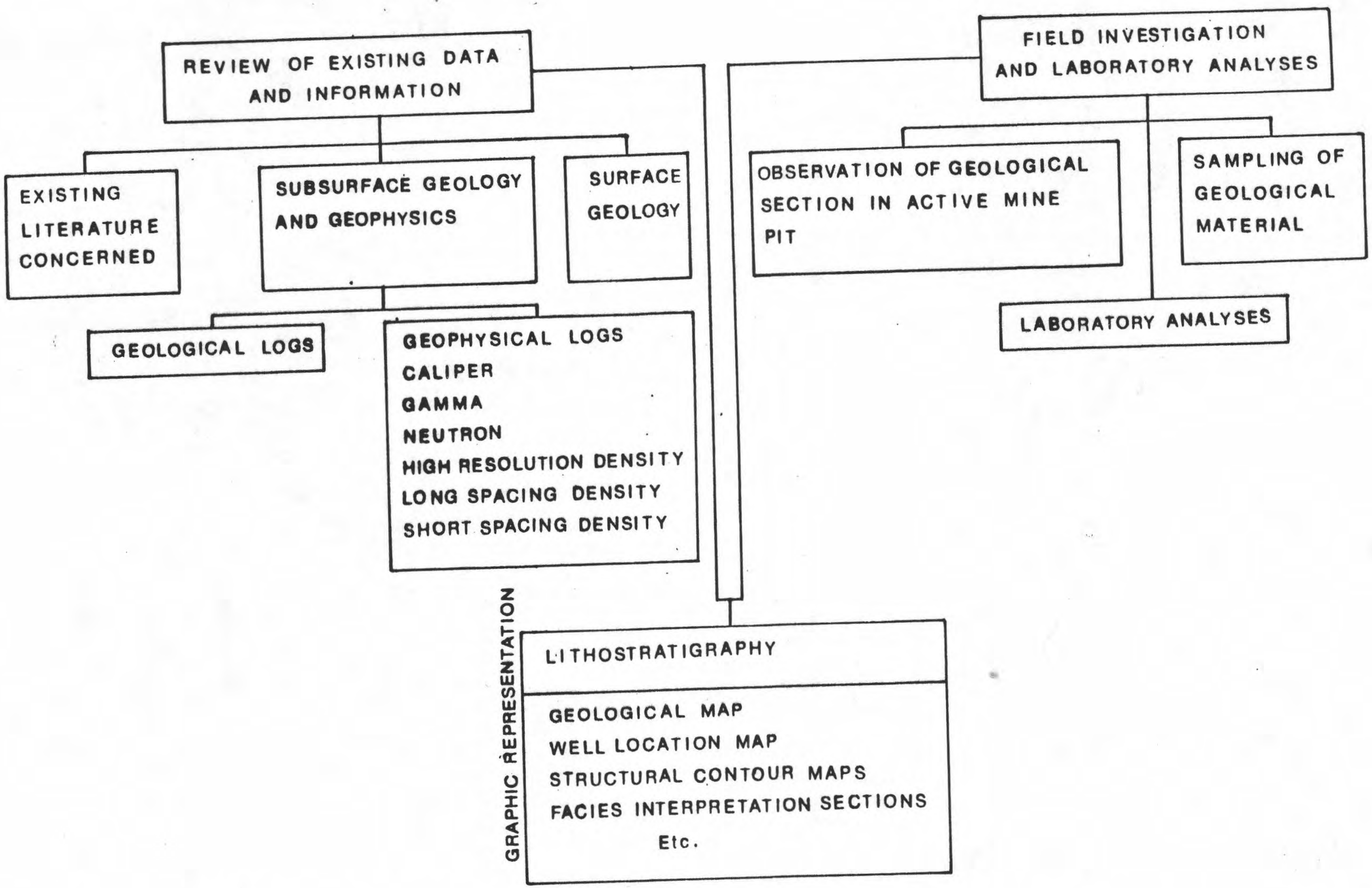

Figure 1.4.2.a Stages of data acquisition and data preparation in reconstruction of basin analysis.

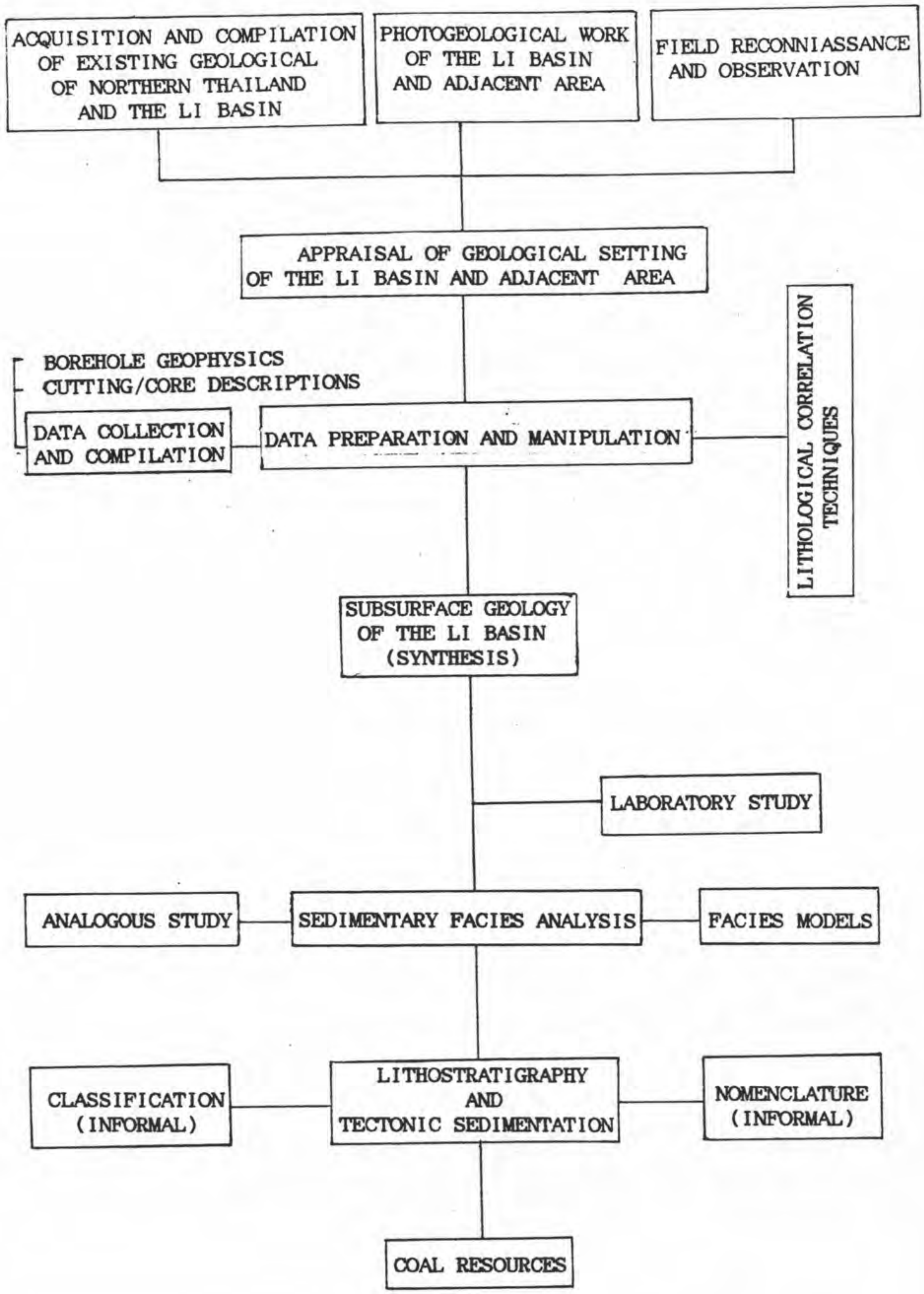

Figure 1.4.2.b Flow-chart illustrating the methodology and steps of work in the analysis of the Li basin.

1.5 Methodology

1.5.1 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 Li Tertiary basin, geophysical log is one of the most important parameters in geological subsurface interpretation. According to geophysical log obtained from the Ban Pu Coal Co.Ltd., two types of probes were used. The first type of probe is consisting of sensors for natural gamma, long spacing density and high resolution density. The second type of probe is consisting of density probe and neutron probe. Density probe is consisting of sensors for borehole diameter(Caliper), short spacing density and long spacing density; whereas neutron probe is consisting of sensors for natural gamma, electrical self potential, and neutron. The equipment with the second type of probe is mounted permanently on the logging truck whereas the first type of probe is used with the potable equipment. 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 geophysical form comprising seven separate traces on two sheets, normally plotted in the vertical scale of 1 : 100. Most geophysical logs indicate changes in the physical properties of the rocks. Combination of the logs are collectively useful in the interpretation of lithostratigraphy, structure, depth and the geometry of the sedimentary facies of the Li basin.

The caliper 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 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 which emit the gamma ray. The gamma ray 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, as on long spaced neutron logs. Confusion can be eliminated by remembering that radiation recorded on density logs increases with increasing porosity. Low rank coal 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 lithology and for the investigation of the depositional history of a stratigraphic sequence. General - scale gamma logs are particularly useful for lithological correlation between drillholes. The level of gamma radiation for each lithology is usually fairly consistent within a localized area.

The gamma probe consists of scintillometer detector for measuring the naturally occurring gamma radiation on the rock strata and borehole. The radiation is a part of the energy released by certain naturally occurring. The gamma probe responses most strongly to clay minerals. Thus coal and clean sandstone usually have the lowest amount of clay minerals, 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 differentiated 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 pore - filling fluid. Mechanically, 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 coal 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 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 self - potential log indicates the changing potential difference between the electrode on the probe and the ground electrode. The SP. log cannot be generally used to identify low rank coal but often indicates zones where water is flowing into the borehole from surrounding formations. According to the Ban Pu Coal Co.Ltd. geophysical logs, the SP. log was failed.

The geophysical log response to various lithologies is shown in Figure 1.5.1.1.

1.5.2 Coal Petrographic Method

In most coal seams, vertical zones or benches can be distinguished on the basis of gross differences in luster, texture, or fracture pattern. The variation in appearance can be traced to variations in depositional environment and different depositional environments led to the formation of different types of coal. Investigations of coal type based on megascopic appearance can yield information useful for seam correlation, for predicting minability and for predicting lateral changes in coal properties.

The microscopic examination and analysis of coal is the technique presently used to characterize coal type quantitatively. The petrographic properties of coals are described either by means of transmitted light or incident light microscopy. The components correspond approximately to microscopically discernible 1) vitrinite, 2) exinite or liptinite, 3) fusinite and 4) semifusinite.

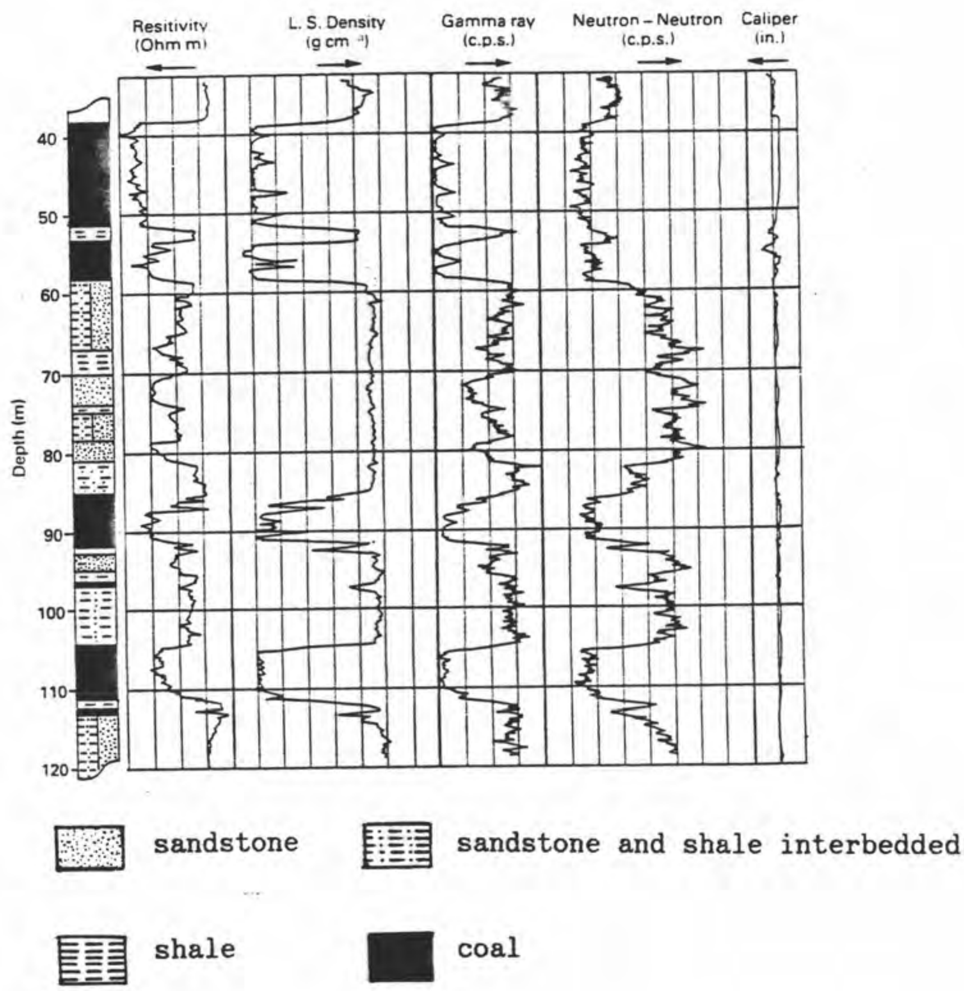

Figure 1.5.1.1 Geophysical logs in a typical borehole through coal-bearing strata (After Ward, 1984).

Detailed procedures for sample preparation and microscopic analysis of coal are describes in ASTM. Standards D 2796 - D2799. The topics of the methods are :

1) ASTM. Standards, 1988, Designation D 2796 - 88, Standard Definitions of Terms Relating to Lithologic Classes and Physical Component of Coal.

2) ASTM. Standards, 1988, Designation D 2797 - 85, Standard Method of Preparing Coal Samples for Microscopical Analysis by Reflected Light.

3) ASTM. Standards, 1988, Designation D 2798 - 85, Standard Method for Microscopical Determination of the Reflectance of the Organic Components in a Polished Specimen of Coal.

4) ASTM. Standards, 1988, Designation D 2799 - 86, Standard Method for Microscopical Determination of Volume Percent of Physical Components of Coal.

5) ASTM. Standards, 1988, Designation D 2013 - 86, Standard Method Preparing Coal Samples for Analysis.

Oriented blocks of coal can be polished and studied microscopically, and are often used in geological studies such as exploration and seam correlation. For evaluating a coal to be used in processing, however, a representative split of crushed coal is molded into a block with epoxy or polyester binder, after which the block is polished. Procedures for preparing samples for petrographic examination are described in ASTM. D 2797. A representative sample of air - dried coal is crushed to pass a No.4 (4.75 millimetres) screen, minimizing the production of fines in the process. About 250 gramme is rifted off and crushed to pass a No.20 (0.85 millimetres) sieve, intermittently screening off the material that will pass the screen and crushing the oversize in a mortar and pestle (stage crushing). About 10 gramme of the -20 mesh coal is mixed well with about 4 gramme of an epoxy resin to make a paste that is placed in a cylindrical mold of 1 inch I.D.(wall about 14 inch thick, height about 1 1/2 inch), the inside of which is coated with a release agent. Sliding - fit plugs seal the bottom and top, and a hydraulic press is used to compact the mass and expel air. The epoxy is allowed to cure, and the briquette is pressed from the mold. When the pellet is to be used in an automated microscope, the relative coal and binder volumes are carefully measured.

The briquettes are ground and polished on a rotary lap using water - slurried abrasives of successively finer particle size. Normally the final polish is made with submicron - sized alumina on a cloth - covering - lap. In a commonly employed technique an apparatus is used that holds six briquettes and rotates the briquettes as the lap is turned. When proceeding from one abrasive size to the next finer size, particular care should be exercised to remove all the coarser abrasive, lest residual particles leave scratches on the surface. A final wipe with a mild detergent solution on a cotton swab followed by a flush with distilled water will remove any last remaining abrasive particles. The finished surface should be plane and scratch - free, exposing polished cross sections of the individual coal grains.

A microscope with a vertical illuminator is employed to examine the polished surfaces. For analysis of maceral content requiring maximum resolving glass plate. However, for measurement of reflectance, a Berek prism is employed. For relatively low magnification, dry objectives are commonly used; however at higher magnification, oil immersion objectives are used, and special microscope, immersion oil is employed as a medium between the objective and the specimen.

The unpolished (bottom) surface of the briquette is mounted with a small piece of modeling clay on a glass or metal plate that fits the holding mechanism of the mechanical stage. The polished (top) surface is rendered parallel to the plate by pressing between two parallel platens, the clay serving the compensate for any nonparallelism of the top and bottom of the briquette.

After that, the coal microscopic study just begin on the concentration of component classification and properties of macerals, following the ASTM. Standards. The classification of the microscopic constituents into groups of similar properties in a given coal is shown in Table 1.5.2.1. The three maceral groups can be distinguished by different in gray levels or reflectivity as :

Liptinite = dark gray, low reflecting

Vitrinite = medium gray, medium reflecting; and

Inertinite = light gray to white, high reflecting.

Associations of macerals, the microlithotypes of coal, have been attributed environmental significance by a number of authors, namely, Karmasin,1952 ; Teichmuler and Thomson,1958 ; Teichmuler,1962; Hacquebard and others, 1967 ; Bustin and others, 1983 and others.

Table 1.5.2.1 The classification of the microscopic constituents into groups of similar properties in a given coal (After ASTM. Classification of Coal by Rank, 1988).

Maceral Group	Maceral
Vitrinite	vitrinite
Liptinite or Exinite	alginite
	cutinite
	resinite
	sporonite
Inertinite	fusinite
	inertodetrinite
	macrinite
	micrinite
	sclerotinite
	semifusinite

In the present study, subsurface geological and geophysical study is an essential part while coal petrography is a component part. Samples for coal petrographic study are designed to collect only in each seam of northern, southern, eastern and western portions of each sub - basins.

1.6 Previous Investigations

The preliminary geological investigation of Li basin was carried out by the Defense Energy Department, Ministry of Defense in 1960 when sub-bituminous coal and oil shale deposits have been found at Ban Pa Kha in Amphoe Li, Changwat Lamphun. The Department of Mines has continued to carry out the investigation since September 1961, aiming at evaluating of coal and oil shale reserves.

In 1960, it was reported that "crude oil" at Ban Na Sai had caught fire. However, after the investigation it was found that the fire was caused by spontaneous combustion of the coal outcrop. It is important to note that some coal outcrops at Ban Huai Dua and oil shale at Huai Mae Van, east of the Li-Thoen road were discovered during this investigation. In the same year, Sae V. Bhienphitaya and his co-workers had conducted the geological investigation and feasibility study on the coal and oil shale deposits at Ban Na Sai which is situated on the southern rim of the Li basin.

In 1961, the Defense Energy Department reported to the Prime Minister on the coal and oil shale resources of Amphoe Li, Changwat Lamphun, consequently, the cabinet had ordered the Department of Mines and Defense Energy Department to conduct the joint-investigation programme of the area. The Geological Survey Division, under the Non-metallic Project, had been assigned to carry out the oil and coal exploration in the area concerned. Phumval Komalarachun and his team had subsequently reported the oil shale at Tambol Dong Dum, coal at Tambol Li and Tambol Na Sai in Amphoe Li, Changwat Lamphun including the geological setting of the areas.

Later on, the geological investigation at Ban Mae Long was jointly conducted by the Department of Mines, National Energy Administration and Electricity Generating Authority of Thailand in 1962.

Sangas Bunopas (1962) reported the general geology of lignite and oil shale deposits at Ban Pa Kha. He discovered abundant plant fossils in the lower oil shale bed and shale which were subsequently identified by Endo in 1963 to be of Paleogene age which is the oldest known Tertiary onshore fossils in the Li basin.

In 1963, Aganit Suwanasing reported the discovery of petrified woods in the quartzite-gravel deposit at Ban Mae Pok , Tambol Mae Tuen of Amphoe Li, Changwat Lamphun.

In 1964, Endo identified five species of plant fossils collected from Ban Pa Kha in the Li basin as :

Alnus thaiensis (new species) ENDO

Sequoia langsdorfi HEER

Taxodium thaiensis (new species) ENDO

Sparganium thaiensis ENDO new species

Carpinus(?) sp.

The assemblage of these plants was considered by Endo to be Upper Eocene, and the climate in which it flourished was warm temperate and tropical.

In 1965, the first systematic geological survey was conducted in the area of Tambol Mae Tuen, and Tambol Li of Amphoe Li, Changwat Lamphun. Verasak Nakintarabordi gave the comprehensive geological report covering the quadrangle 47Q/CB24 (1:50,000 scale) of Ban Pa Phai. Besides, various economic mineral deposits of the area had been reported, notably, iron, manganese, fluorite, stibnite, galena, barite, cassiterite, and construction materials.

In 1966, Endo identified a new collection of plant remains from the Li basin as :

Glyptostrobus europaeus

Sequia langsdofii

Ficus eowightiana

Alnus thaiensis

Alnus thaiensis(?)

Fagus feroniae

Quercus lanceaefolia

Quercus cf. protoglauca

Salix? sp.

In 1969, Charal Achalabhuti, under Non-metallic Project of the Department of Mineral Resources, proposed the origin of Paleogene oil shale and gave the evaluation of 15 million metric tons reserve of sub -bituminous coal covering the areas of 1.2 square kilometres in the eastern portion of Ban Pa Kha area. He also commented on the feasibility study of lignite and oil shale in the basin particularly regarding the utilization of the lignite which was carried out in cooperation with the Krupp Rohstoffe of Germany, the Tobacco Experimental Station of Thailand Tobacco Monopoly and the State Railway of Thailand since April 1966.

In 1973, Thawat Japakasetr and others reported the geology and mineral resources in the neighbourhood of Li river. The mineral resources in the area include manganese, feldspar, barite, coal, oil shale, copper, iron, phosphate, fluorite, petrified wood, and gold.

In 1974, Charal Achalabhuti (Poothai) in his feasibility study of lignite and oil shale deposits at Amphoe Li, Changwat Lamphun, summarized the geology of Li basin. The relationships of lignite/ oil shale and Tertiary rocks with the local stratigraphic units were also defined.

In 1975, Sangas Piyasin proposed the lithostratigraphic nomenclature for Tertiary deposits in northern Thailand as Mae Mo Group.

In 1981, Braun and others, under German Geological Mission (GGM.) to Thailand in co-operation with the Geological Survey Division, Department of Mineral Resources, compiled the geological map of Amphoe Li (Sheet 6) in the 1:250,000 scale.

The nearly north-south trend of the longitudinal axes of almost all intermontane basins in northern Thailand including the Li basin and the graben-form of these basins show a similarity to the structures in the northern Gulf of Thailand (Charal Achalabhuti,1975;

Woolands and Haws, 1976). Besides, the tensional tectonic regime suggests that the northern Thailand basins and the central plain are the northward extension of the Tertiary Gulf of Thailand intracratonic spreading basin (Sangas Bunopas, 1983). Paleontological data from Li basin also show that the Li basin was formed during Early to Middle Miocene and the faulting took place after the deposition of the Miocene sediments, concurrent with the Late Cenozoic uplift of the mountains of Thailand inferred by Sangas Bunopas (1981).

Gibling and Benjavun Ratanasthien (1981) measured and described the sequence of strata in the eastern part of Ban Pa Kha Coal Mine. They recognized the fossil assemblages from base to top of the sequence of Ban Pa Kha strata as follows :

Woody plants predominate, uncommon

Burrow predominate

Encrusted plants predominate

Shelled arthopode, with bivalves, predominate

Gastropods predominate, and

Woody plants predominate, abundant.

The systematic vertical occurrence of fossil assemblages in the coal to mudstone transition suggests that they reflect progressive change in environment from swamp to shallow lake. The age of these fossil assemblages was considered to be Paleogene.

In 1981, Sathien Snansieng and Pol Chaodumrong recognized the abundant plant remains, mainly leaves, found in shale embedded in massive coal seam at Ban Pu Coal Mine, eastern Li basin.

In 1981,Yongyudh Ukakimapan collected fragments of bones at Ban Mae Long, western of Li basin, some of which resemble Legomericidae. Others are

Turtle plates

Snake vertebrate

Fish vertebrate

Fish remains (probably cat fish)

Fish jaws and teeth

In 1982, Pol Chaodumrong and others, under Tertiary Project of the Geological Survey Division, Department of Mineral Resources, studied the geology of Li basin and prepared a draft of 1:50,000 geological map with report of the basin. The depositional environment of Tertiary rocks in the area was described. In their report, various available drilling logs were used in the interpretation of environment of deposition of the Tertiary rocks in this area.

In 1982, Rucha Helmcke Ingavat identified the fossils collected by Yongyudh Ukakimapan in 1981 and assigned a Lower to Middle Miocene age.

In 1983, Sathien Snansieng and Somchat Boripatkosol collected fossils from the gastropod bed overlying coal strata at Ban Na Sai, southern rim of Li basin. The fossils were identified by Rucha Helmcke Ingavat in 1983 as Viviparus sp., Melanoides sp. others are fish fragments and dicotyledon leaves. They concluded that the age of the Tertiary sediments of the Li basin ranges from Paleogene (Upper Eocene) in the east to Neogene (Lower to Middle Miocene) in the west of the basin.

In the same year, Sathien Snansieng and others published the Tertiary Sedimentary Rocks of Thailand, including Li basin. The composite stratigraphy of the Cenozoic sediments in the Li basin is shown in Table 1.6.1.

A tree stump in growth position found in the massive coal seam at Ban Pu Coal Mine, eastern Li basin, indicated the autochthonous origin of the plants was recognizes by Pol Chaodumrong and others in 1983.

Benjavun Ratanasthien (1983) divided coal bearing Tertiary basins in Thailand on the basis of coal quality into 3 modes of environment as characterized by stratigraphic sequences. The Li basin is classified as swamp and lacustrine environment.

Benjavun Ratanasthien (1984) studied shales associated with coal deposits of Ban Pa Kha coal-bearing formation in Li basin and indicated the age of shale by the presence of Alnus pollen as Oligocene - Lower Miocene age.

Benjavun Ratanasthien and Kittisub Ruenwathanasirikul (1984) discussed the effect of the depositional environment on the coal quality and listed the affecting factors and purposed that the depositional environment of Ban Pa Kha coalfield was the mixing of forest swamp and lacustrine environment.

Ginsburg (1985, 1987) identified fossils from Mae Long, west of Li basin as the primitive primate (mammalia) of the Miocene age. The fossils are as follows :

Table 1.6.1 The composite stratigraphy of the Cenozoic sediments within the Li basin (After Sathien Snansieng and others, 1983).

Rock unit	Description	Thickness	Age
Alluvium Terrace	Unconsolidated gravel, sand, clay, laterite		Holocene - U.Pleistocene
Mae Taeng Formation	Semiconsolidated gravel bed, sand, silt	100+	L.Pleistocene
unconformity			
Mae Moh Formation (Na Sai Formation)	Sandstone, claystone (calcareous) marlstone (Viviparus bed) lignite mudstone	200+	Neogene (Pliocene - Miocene)
unconformity			
Li Formation (Pa Kha Formation)	Shale, oil shale lignite to sub-bituminous mudstone, sandstone lignite gray shale, carbonaceous shale claystone	150+	Paleogene (Oligocene - Eocene)
unconformity			
Basement	Mesozoic (Dark gray shale) Paleozoic (Quartzite, phyllite)		

Fauna

Stephanocemas

Anthemus thailandicus

Spanocricetodon khami

Kanisamys benjavuni

Atlantoxerus

Diatomys pliensis

Tarsus thailandica

Flora

Sparganium

Taxodium

Alnus

He also suggested that the flora of Li indicating a mild temperate and wet climate considering the low latitude of Li basin (just a little more than 17 ^{o}N) it would be situated in highlands about 1,500 metres high or more.

Pol Chaodumrong, Suwit Chiemton and Sathien Snansieng (1985), under Tertiary Research of Geological Survey Division, Department of Mineral Resources, studied geology of Amphoe Thoen (sheet 4844III, series L7017), including the southeastern part of Li basin. The draft of 1:50,000 geologic map has also been prepared.

In 1985, Sathien Snansieng and Niwat Maneekut gave an analysis of the Li basin and considered that the basin is the oldest Cenozoic basin of Thailand.

Somchat Boripatkosol, Niwat Maneekut and Sathien Snansieng (1985), under Tertiary Research of Geological Survey Division, Department of Mineral Resources, studied geology of Ban Puang (sheet 4844IV, series L7017), including the northeastern part of Li basin. The draft of 1:50,000 geologic map has also been prepared.

Pol Chaodumrong and Suwit Chiemton (1986), under Tertiary Research of Geological Survey Division, Department of Mineral Resources, studied geology of Ban Ko Thung (sheet 4744II, series L7017), including the southwestern part of Li basin. The draft of 1:50,000 geological map has also been prepared.

Somchat Boripatkosol (1986), under Tertiary Research of Geological Survey Division, Department of Mineral Resources, studied geology of Amphoe Li (sheet 4744 I, series L7017), including the northwestern part of Li basin. The draft of 1:50,000 geologic map has also been prepared.

Faunas age dating by Ginsburg (1988) at Amphoe Li, Changwat Lamphun were primitive primate (Mammalia) of Miocene age.

Manas Wattanasak (1989) studied the palynology of Mid - Tertiary intermontane basins in northern Thailand and divided into 2 zones (Figure 1.6.1). Flora from Li basin was recorded in SIAM - 1 zone. The correlation of hydrocarbon bearing strata resulted that Li coal seams is Late Oligocene in age.

Afterwards, in June 1990, he joins his palynological study of Mid - Tertiary intermontane basin in Thailand. The reference section of SIAM - 1 zone is in P-120 borehole between depths of 32.2 and 2.6 metres, Ban Pu Mine, Li basin. He noted that

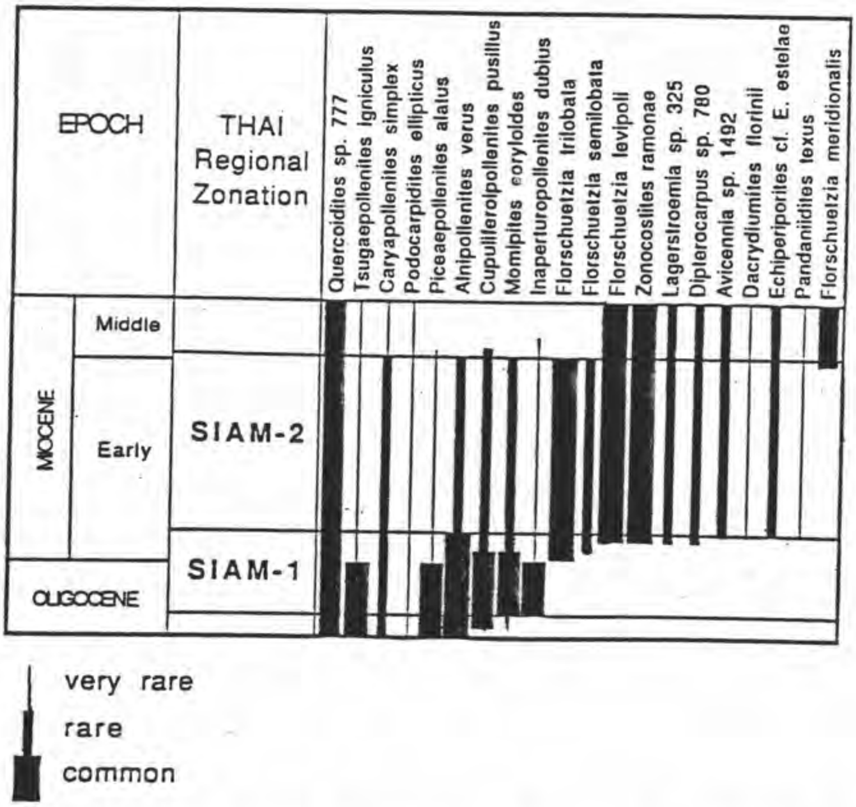

Figure 1.6.1 Mid-Tertiary stratigraphic ranges of selected pollen from Thailand (After Manas Wattanasak, 1990) .

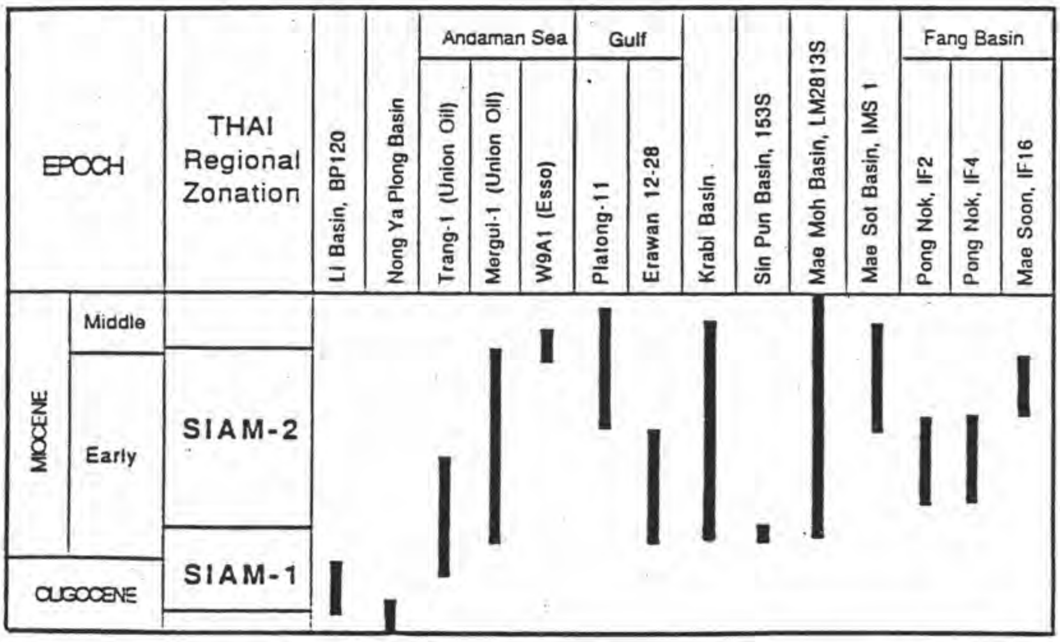

Figure 1.6.2 Palynology dating and correlation of Mid-Tertiary sequences from Thailand (After Manas Wattanasak, 1990) .

SIAM - 1 Zone is characterized by assemblages comprising high frequencies of Pinuspollenites sp. 1436, Piceaepollenites alatus, Tsugaepollenites igniculus, Inaperturopollenites dubius, Quercoidites sp.777, Alnipollenites verus, Cupuliferoipollenites pusillus and Momipites coryloides. Other commonly occurring species include : Faguspollenites sp.845, Florschuetzia trilobata, Ilexpollenites iliacus, Rhoipites cf. R. retiformis, Rhoipites sp.847, Polypodiisporites alienus and Laevigatosporites ovatus. Some rare species include : Monoporopollenites gramineoides, Tetracolporopollenites sapotoides, Caryapollenites simplex, Aceripollis sp.853, Polyatrio-pollenites stellatus and Podocarpidites ellipticus.

At this present moment of his research, he stated that SIAM - 1 Zone, including Li basin, is dated as Upper Oligocene to Lower Miocene. Palynological dating and correlation of Mid Tertiary sequence from Thailand is shown in Figure 1.6.2.

Comparative stratigraphic classification of Tertiary rocks of Thailand is shown in Table 1.6.2.

Table 1.6.2 A comparative classification of Tertiary rocks of Thailand (After Pol Chaodumrong and others, 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, 1969	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				