CHAPTER IV

COAL GEOLOGY AND CLAY MINERALOGY

4.1 Coal geology

Coal is a solid fossil fuel formed from plant derived organic remains plus some non-organic minerals. It is a heterogenous soft rock and composes of more than 50 percent by weight of organic matter. The oldest coal occurrences are the anthracite from the Jatulian of Finland, Precambrian coal from Kazakhstan, and some coal deposits in America (Bouska, 1981). The first large sources of plant matter giving rise to enormous coal reserves did not appear before the Carboniferous and in this system the first important coal deposits have been preserved. The Upper Carboniferous is the "bituminous-coal period". Gymnospermae dominated the plant kingdom from the Permian to the Cretaceous Period when the Anginospermae, which first appeared in Triassic time, underwent a rapid development (Diessel, 1982). They contain two groups, the Monocotyledons and the Dicotyledons. A large amount of coal also developed in the Tertiary and the greatest thickness is known from this period (Bouska, 1981).

The geological factors which determine the occurrence of coal deposits are:

a) basin development,
b) appearance of land plants in geological time,
c) accumulation and preservation of plant remains,
d) diagenesis, or surface or near-surface transformation of the coal remains, and

e) coalification under the action of mechanical stresses and temperatures.

Increased demands for energy in the face of diminishing supplies of readily available liquid hydrocarbons have turned the attention of energy industries to coal. Many characteristics of coal bands, namely, thickness continuity, quality, etc. can be attributed to the environments in which the peat beds accumulated and to the tectonic setting at and after the time of deposition. Therefore, a knowledge of depositional environments and tectonic influences should be in the exploration and development of economic coal bodies.

An attempt has, therefore, been made in the present study to focus some detailed study on the coal in the Tertiary sedimentary sequence of Mae Moh basin. The geology of coal in this study covers various aspects, namely, stratigraphic position and characteristics of coal seams, coal type, coal rank, and proposed coal depositional model. Details on each of the aforementioned aspects will be discussed as follows:

4.1.1 <u>Stratigraphic position and characteristies of coal seams</u>

The coal measures of the Mae Moh basin is characterized as B-Formation. It contains 2 major coal seams which have been economically exploited, 2 minor coal seams and one band. Besides, on the top of A-2 Member and locally within C-3 Member, coals are also present as minor coal seam or ligneous trace (Table 3.5.1a). The characteristics of each coal seam or band from bottom to top are as follows:

The lowermost minor coal seam is present on the top of the A-2 Member. This coal seam grades lithologically from coarse-grained clastic associations of the underlying strata to lignite band at the top. It comprises of alternating of thin band of low quality lignite and parting of calcareous silty claystone with intraformational conglomerate and lignite flake. Evidence from a few boreholes show that it is widely distributed in the study area with the thickness varies from a few centimetres to about 2 metres. Due to its small quantity and great depth, this seam shows little economic value at present.

The middle part of B-1 Member is characterized by another minor coal seam. Its stratigraphic position varies from 50 metres below the B-2 Member in the western part to about 100 metres in the eastern part of the study area. The thickness of lignite band is about 1-2 metres, and it commonly interbedswith thin bedded silty claystone, intraformational conglomerate with bioturbation and gastropods. Although it is widely distributed throughout the study area, it is considered to be of little economic value under the present circumstance.

The lower major coal seam is the B-2 Member which is further subdivided into 4 beds (see Chapter III). The area between mine-grids S7 and N'34, the coal seam is characterized by lignite with a few partings. Parting is highly calcareous, white to light gray claystone and appears as thin-to medium-bed as well as lenses. In this area, it is thinning westwardly with thickness varies from about 25-30 metres in the eastern margin to over 10 metres in the western margin. Beyond this area, the total thickness of the seam increases rapidly with increasing in number of the partings. In contrast, lignite is splitting and decreasing in both thickness and quality. In the study area, however, the degree of splitting in the northern area is relatively more apparent than in the southern area.

The upper part of B-3 Member is characterized by another one minor coal seam or band. It occurs a few metres below the upper limit of the B-3 Member and is well recognized in the northern and southern parts of the area with thickness less than a metre. In the western and eastern parts of the area, it appears as trace or only a few centimetres thick (Figure 3.3.3a).

The upper major coal seam is the B-4 Member which is further subdivided into 5 beds (see details in Chapter III). Between the mine-grid area S7 and N'34, the seam is of high quality with small amount of partings. Parting is characterized by highly calcareous, white to light gray claystone, and only locallizedly present as thick beds to lenses, such as, B4.2 and B4.4 Beds. This is probably due to the unstable depositional environment of the basin. In this area, the total thickness of the seam is generally greater than that of the B-2 Member. Similar to B-2 Member, it is thinning westwardly with thickness of about 30 metres in the eastern margin to 15 metres in the western margin. Beyond this area, each band of lignite decreases in both quality and thickness. In the far north and south areas only lignite on the top and bottom of the member are present. In contrast, the thickness of each parting increases rapidly. Consequently, the total thickness increases rapidly to the order of 40 and

80 metres in the northern and southern parts of the study area, respectively.

In the southern area, the B-4 Member is more intensively splitting than the B-2 Member whereas in the nothern area it is opposite. The similarity of both members is that in the far north and south areas the lignite appears only on the top and bottom of the member. However, the lignite of the B-4 Member is more persistent than the B-2 Member. In the north, trace of poor quality lignite of the B-4 Member persists northwardly to mine-grid N' 46 and continues a short distance into the northern sub-basin. In the south, the lignite of B-4 Member can be traced as far south as mine-grid S30 while lignite of the B-2 Member generally grades out and completely disappears at the mine-grid S26.

The another one minor coal seam is the B-6 Member. Generally, the lignite is characterized by poor quality and appears as thin to thick bands in the thick sequence of semiconsolidated highly calcareous of claystone, silty claystone, micrite beds and intraformational conglomerate. Totally 13 thin to thick bands of lignite are present in the western flank of the active mine-pit (Jariyabhum, 1983). The lignite bands are predominantly present only in the eastern and northern parts of the area. It is thinning or grade out westwardly and southwardly. Although, the lignite contains heavy amount of mineral matter, economic exploration of these lignite bands is possible using selective mining during the overburden removal operation.

4.1.2 Coal type

The lignite at the Mae Moh basin is characterized by dark brown to black, hard and brittle, moderately dull to dull luster, and hackly to earthy texture. It is considered to be attrital coal with some previtrain. It is humic coal or banded type (Fairbridge and Bourgeois, 1978) based on its characteristics and the original plant materials.

The micropetrographic structure of the lignite of B-4 Member was first described by the Fried, Krupp Rohstoffe Co. group (1959 in Gardner, 1967) as follows: "Examination under the microscope shows that the Mae Moh coal is extremely uniform also as regards to its texture. Except for its mineral intercalations the coal contains more than 95% of humus (vitritic) components which in contrast to other types of lignites are almost without exception finely detritic. Cell aggregates or even larger humus tissues are extremely rare, and woody tissues were not observed at all. Minute amounts of proto-bitumen mainly pollen and tiny fragments of fusinite as well as strongly reflecting fungus spores are embedded in this humus fine detritus which obviously is the decomposition product of stems, leafs, and roots of herbaceous plants. The pollen content varies slightly, and is larger in the coarse-sized portion of the total sample than in the finer fraction. It is probably not exceed 1% of the total coal except in rare instances, which means that it is not of any importance from a chemical-technological point of view. The resinite content (resins and waxes) is also a minimum. The so-called inert components fusinite and scleretinite occur also very seldom. Fusinite is sometimes slightly more abundant where clayey and calcareous inclusions exist. It appears to have been concentrated here by drifting. The paucity of scleretinite (strongly reflecting fungus spores and fungus sclerotia) is very conspicuous for a Tertiary lignite; which in Europe usually contains higher proportions of this component. The existing fungus spores are remarkably small and in the majority of cases belong to the two-cell teleutospores".

Ratanasthien and Reungwathanasirikul (1983) and Ratanasthien (1983 a) reported that the Q seam (B-2 Member) contains predominantly humic gel of huminite and gelinite in the lower part of the seam, whereas the middle part of the seam predominantly comprises of huminite with small amount of gelinite. This difference indicates that the depositional environment changed from deeper lake with floating plants to shallower lake with semi-aquatic plants. Petrographic study further reveals that traces of pyritizedly preserved semi-aquatic plants and framboidal pyrite distributed throughout the coal mass.

Spontaneous combustion easily occurs with Mae Moh lignite both at the stockpile and at the mine-face. Besides, it can not store for a long time even under cover because of its slacking property. The slacking property depends on quality of coal, high quality lignite tends to slack rapidly along subconcoidal and cubical fractures while low quality lignite containing more mineral matter content tends to slack rapidly as sheet - like form (Ratanasthien, 1983 a)

According to Stach et al. (1975) the spontaneous combustion caused by exothermal oxidation reactions. Some of these reactions are as follows:—"Spontaneous combustion of a coal can occur only when the quantity of heat released by oxidation is greater than the quantity of heat carried away during the same period of time. If this happens, the temperature of the coal rise; this, in turn, makes the rate of oxidation increase, this again leads to a rise in temperature and so on. . Where the circulation of air is insufficient, the temperature rise results from the poor heat conductivity of the coal. Vitrinite, regardless of rank, is always the maceral group most susceptible to spontaneous combustion. . Spontaneous combustion increases considerably with decreasing grain size. It was also enhanced by the sulphuric acid which forms by weathering of finely dispersed pyrite or pyritic concretions. . The seams or part of seams containing finely dispersed pyrite in high concentration (5-10%) are more inclined to spontaneous combustion than seams which are free of pyrite. . "

Ratanasthien (1983 b) reported the experimental work of spontaneous fire of Mae Moh Lignite stockpiles as follows: "the reactions starting by the accumulation of temperature in the stockpiles resulting from the sun, followed by the steam releasing causing the dehydration reaction which was effective mainly at the surface of the stockpiles, the oxidation, hydrolysis and hydration reactions inside the stockpiles gave rise to the increasing temperature from the heat of reactions, and led to the partial distillation of low-ignition temperature gases. Spontaneous fires occurred within 28 days mainly at the foot of the stockpiles or within 40 days inside the stockpiles. The rank of Mae Moh coals, the loss of moisture contents, the influence of low-ignition temperature gases, partial distilled by accumulating temperatures are thought to be the major causes of spontaneous ignition."

4.1.3 Coal rank

The categorization of coals by degree of metamorphism is known as rank classification. The changes in rank result mainly from the weight of overlying sedimentary rock, the heat produced by depth of burial, time, and structural deformation, all of which contribute to progressive compaction. Most rank classification systems are based on the following four changes that occur with increased metamorphism. These changes, as determined by laboratory tests, are: (1) decrease in the amount of volatile matter yielded during destructive distillation; (2) increase in heat value (calorific value) until the volatile matter content has decreased to between 14 and 22 percent, after which the heat value decrease also; (3) increase in carbon content; and (4) decrease in hydrogen content. In this study, the standard classification of coal by ranks (ASTM D 388-77) has been used. This classification is based on fixed carbon and calorific value (expressed in Btu/1b) calculated to the mineral-matter-free-basis. The high-rank coals are classified according to fixed carbon on the dry basis; the low-rank coal, such as of Mae Moh coal is classified according to calorific value on the moist basis.

In this study, the representative analyses of coal from boreholes scattering over main part of the study area have been selected for coal rank determination. The proximate analytical data are obtained from the EGAT. Analytical data of B-2 Member obtained from 21 boreholes totally 107 samples, and of B-4 Member obtained from 21 boreholes totally 145 samples have been evaluated. These data include heat value or calorific value, ash content and sulfur content. The calorific value of mineral matter free, on moist basis obtains from equation of Parr Formulas is as follows:

$$\text{Moist, Mn - free Btu} = \frac{\text{Btu} - 50S}{100 - (1.08A + 0.55S)} \times 100$$

Where

Mn = mineral matter

Btu = British thermal units per pound (calorific value)

A = percentage of ash, and

S = percentage of sulfur

The calculation of calorific value of 2 coal seams in the B-2 and B-4 Member have been carried out from 252 samples. The final evaluation reveals that the modal value of calorific value of the coal seam in both B-2 and B-4 Member fall within the range of lignite-A

(Figure 4.1.3a). However, some of them fall within the rank of sub-bituminous coal. For general name, coal of Mae Moh basin is concluded to be lignite. Generally, the lignite of B-2 Member shows higher calorific value and sulfur content than that of the B-4 Member. The lignite of Mae Moh basin exhibits a wide range of ash content, total moisture percentages as well as of calorific value. Longworth CMPS Engineers (1981) reported the lignite quality from their laboratory tests as : specific energy range from 14 to 24 MJ/kg (gross, dry basis, equal 6020 to 10320 Btu/lb on the same basis); the total moisture value range from 20 to 50 percent with an estimated basin average of about 38 percent; the mean value of sulfur content of K-seam (B-4 Member) is about 2.5 percent (dry basis) and Q-seam (B-2 Member) is about 4 percent (dry basis). However, the sulfur content of lignite in Mae Moh basin is relatively higher than limnic coals elsewhere. The abnormal higher sulfur content is caused by the calcium-rich depositional environment which is suited for the bacteria activity similar to brackish-marine environment (paralic coal). At present the sulfur is mainly contributed by the inorganic sulfur and free sulfur. Figure 4.1.3b shows crossplot of calorific value (dry basis) versus ash content (dry basis).

The lignite, as determined by ASTM rank classification, also shows relevant physical characteristics, namely, rapid slacking under ordinary atmospheric condition, brownish black streak, imparts a coffee-brown color to boiling potash solution, and yield a dark golden yellow solution upon leaching with nitric acid (Fried Krupp Rohstoffe Co., 1959 in Gardner, 1967).

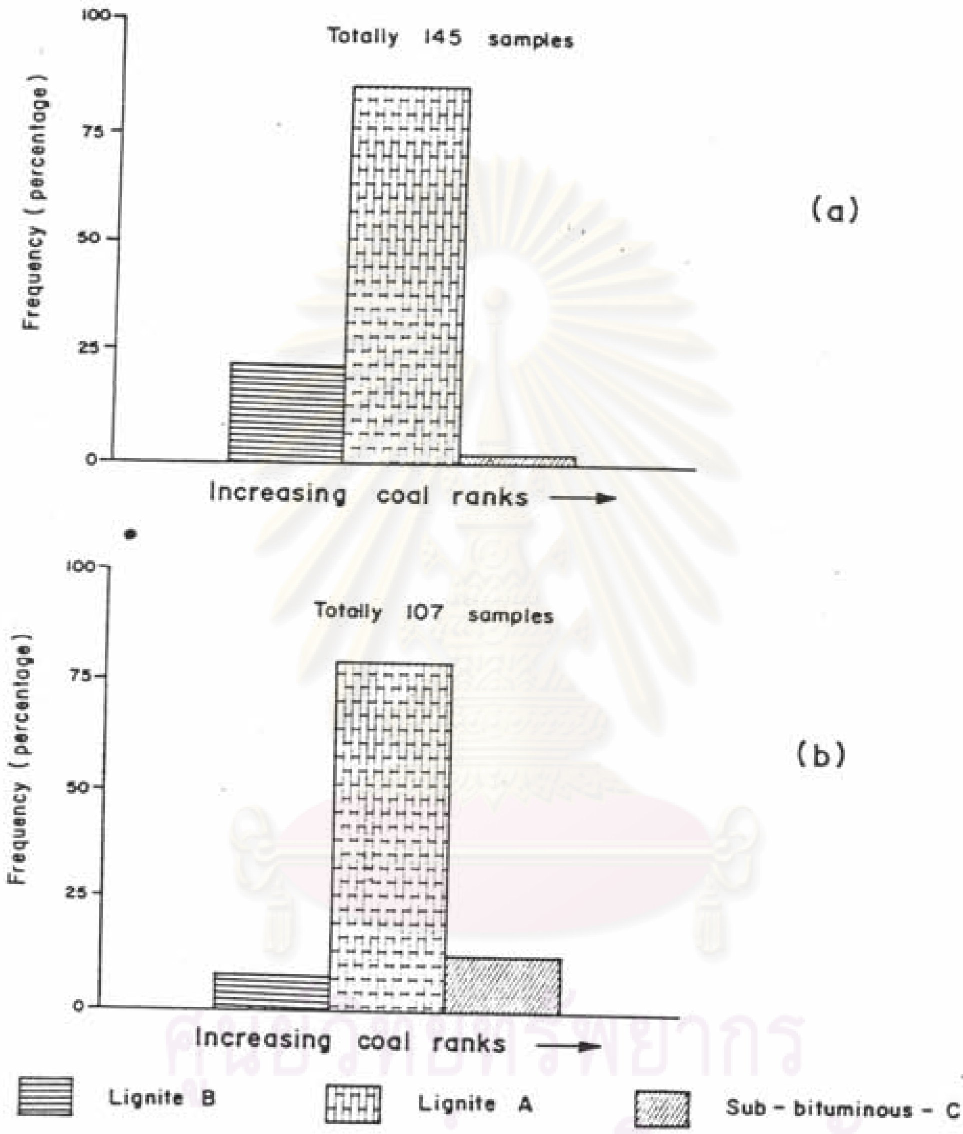

Fig. 4.1.3a Histogram showing calorific values of coal samples after Parr Formulas treatment.
(a) B-4 Member, (b) B-2 Member

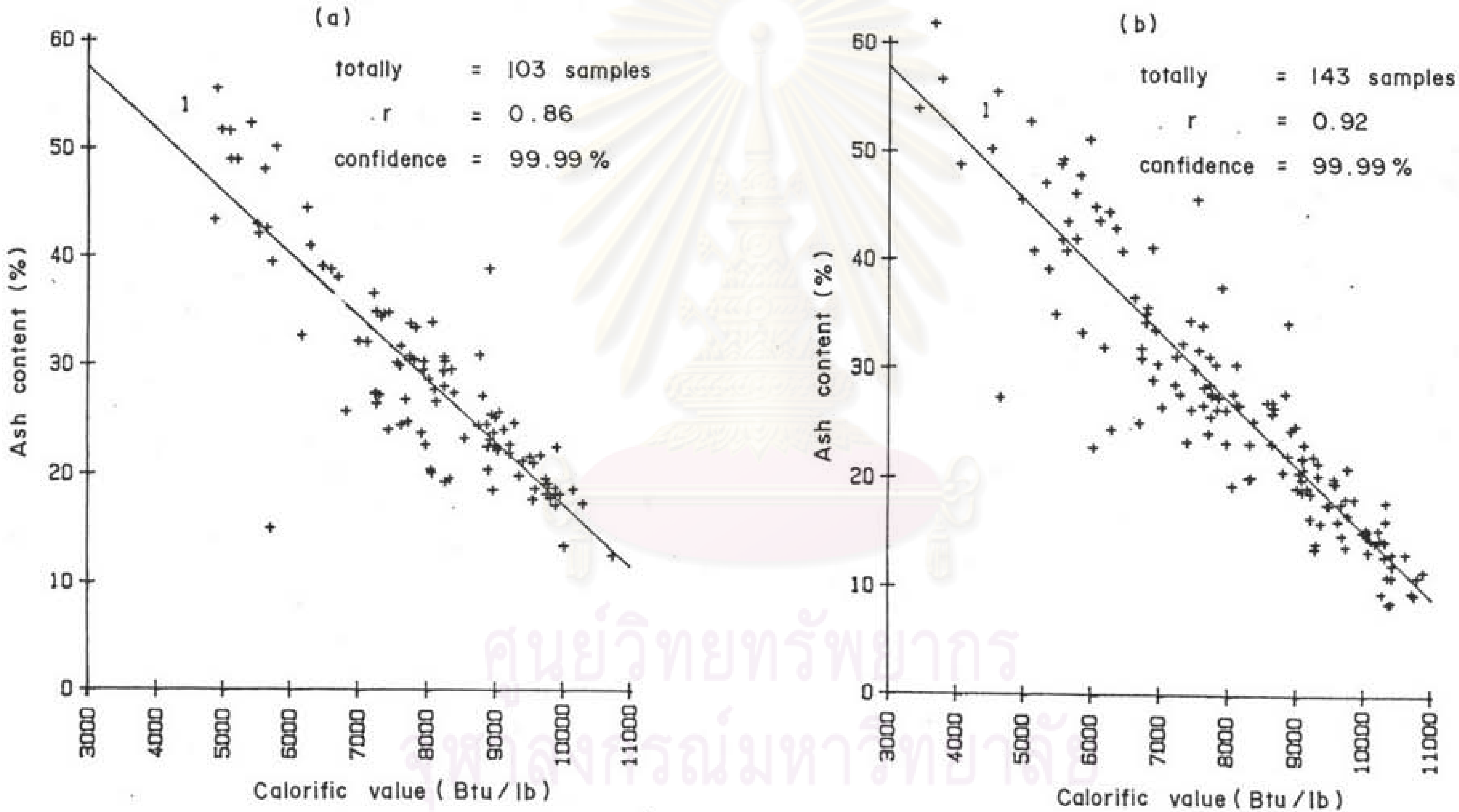

Figure 4.3.1b Crossplot between calorific value (dry basis) and ash (dry basis). (a) from lignite in the B-2 Member, (b) from lignite in the B-4 Member.

4.1.4 Proposed coal depositional model

The lignite deposit wihtin the Mae Moh intermontane basin is concluded to be a limnic coal. This means inland coal swamps or basins which never has any connection with the sea. Evidence of fossil records strongly supports the non-marine origin. This coal deposit usually shows a relatively limited number of seams with restricted areal extent, but individual seam is frequently very thick. The relatively thick coal deposit of limited areal extent also indicate the limnic origin.

Autochthonous coals develop from plants which after death form peat In Situ. The lignite in Mae Moh basin is concluded to be autochthonous coal. There are many evidences which support this conclusion, they are : wide distribution and rather uniform in thickness of individual seam, considerable thickness of lignite without parting interuption, gradational contact at the lower boundary. According to the hypothesis of allochthony, the coal seam should be stratified with alternations of coarse-and fine-grained material corresponding to the alternations of floods and low-water periods of river flowing into the lake. More over, the Mae Moh lignite seams especially B-2 and B-4 Members are covered by tens of metres of lacustrine claystone which are practically devoid of lignite seam (e.g. B-5 Member). In term of allochthony, it is difficult to see why the inflowing rivers, after having carried plant material into the lake for hundreds of years, suddenly stopped doing this and brought in only inorganic matter. However, evidence of abundant lignite flakes which are present close to lignite band is concluded to be hypautochthonous coal.

Due to the fact that the depositional environment of the B-Formation in the Mae Moh basin is the calcium-rich one. The parting and even within the lignite band itself contain considerable amount of primary calcareous substance. This calcareous substance appears as spot (nodule) and cement. The calcareous micro-nodule is believed to be syngenetic precipitation of lime (Fried. Krupp Rohstoffe Co., 1959 in Gardner, 1967). This calcium-rich would be the only explanation to why calcareous remnants of animal skeletons are well preserved. The coal-bearing sedimentary sequences elsewhere in the northern part of Thailand such as Mae Teep basin, Ban Pu sub-basin, Pha Kha sub-basin, etc. show evidence of the solutioning of calcareous skeletal material by humic acid of the peat.

In calcium-rich swamps, silica is also easily dissolved. However, the siliceous solution may be reprecipitated as a gel elsewhere in the swamp where the acidity is higher (Stach et al., 1975). The siliceous hard band within the B4.1 Bed occurs at the base of the coal seam (Figures 3.3.4. 1a and 3.3.4.1b). It is black, hard and very compacted, high carbonaceous matter content, detrital silt-sized quartz with siliceous cement and some quartz veinlet (Figures 3.3.4.1d and 3.3.4.1e) Due to the fact that the geochemistry of the depositional environment change from calcium-rich of B-3 Member to acid environment of B4.1 Bed. Therefore, the origin of this hard band is believed to be both clastic and chemical nature. The latter one is relatively more influential.

Coals, which were deposited in calcium-rich swamps, show similar properties to marine influenced coals (Stach et al.,1975). The calcium-rich waters must have been leached from the surrounding swamp areas as well as the basement rocks. The Mae Moh basin is bounded by limestone of Doi Chang and Doi Long Formations of Lampang Group. Besides, evidence from boreholes shows that the basement of the Mae Moh basin is partly underlain by Doi Chang Formation.Bacterial activity is accelerated in this environment, resulting in increased degradation of plant remains. Decomposition is especially severe in aerobic environment, even the very resistant part of plants is destroyed (Stach et al., 1975). This lies the reason why coal deposit of the Mae Moh basin always shows the characteristics of semi-aquatic plants. The other reason, the rate of plant growth is rapid and the life of semi-aquatic plants is rather short as compared with the woody plant. The latter requires a long time for their extremely growth, resulting inadequate of plant material to form thick coal deposit. Besides, there is no evidence of tree-trunk within the major coal seams of the Mae Moh basin.

As discussed in the preceeding, the lignite of Mae Moh basin is concluded to be mainly of autochthonous coal, plant materials are mainly of herbaceous and semi-aquatic types which had grown in calcium-rich marsh or swamp. In the case of thick coal band, the prolonged reducing coal-swamp environment coupled with the continuous subsidence of the depositional basin are believed to be the major controlling factors. This is the case for up to 3 metres thick of the B2.1, B2.4, B4.1 and B4.5 Beds. Considering the wide distribution of the lignite deposit, type of plant accumulation, and considerable thickness of lignite band, the lignite of Mae Moh basin originated in large marsh or swamp with plants of semi-aquatic and herbaceous widely distributed throughout the accumulation area. This semi-aquatic plants in general require a higher water table rather than the true swamp. Addition of water to the swamp should be fed by sluggish stream that carried only medium-to fine-grained sediment as indicated by a few medium-grained clastic rocks in the parting of the far northern and southern areas. Peat bogs of Mae Moh basin is considered to lowmoor bogs. The peat bogs must have a suitable subsiding rate which preserved the remaining plant materials in reducing environment. Because the rapid subsidence during sedimentation results generally in abrupt variation in coal-seam geometry, but favor lower sulfure and trace-element content whereas slower subsidence rates favor greater lateral continuity, but higher content of sulfur. If the subsidence rate is more slowly, plant materials should be rotted or decomposed results no plant matters were preserved. Ofcourse the whole basin must not have the same subsiding rate, indicates by the thickness of coal seams or bands and thickness of parting. The present eastern and southeastern margins with thickest coal seams or bands are the result of more suitable conditions for peat accumulation than the western margin. Gastropods and bioturbation commonly present in the partings indicate the shallow water environment. Besides, intraformational conglomerate is also common in the parting. It is believed that the intraformational conglomerate originated from reworked mud-crack, a chip of mud-crack was able to be redeposited faraway by the water buoyancy force even in calm aquatic environment. It is also indicated that some areas were exposed while the others submerged under the water. The presence of some lignite flakes lying parallel to the bedding plane within the parting also indicates some shifting of plant material within the basin.

Compaction ratio of peat to the lignite of Mae Moh basin has been measured from limestone inclusion within the B-4 Member in the active mine-pit. The finding, conformable with Gardner (1967) who measured the fragile gastropod shell embedded in the lignite and Longworth CMPS Engineers (1981), is about one-third to one-fourth. Coal seams in the eastern and southeastern margins with a few partings have the thickness of about 20 to 25 metres, indicating that the present coal seam have been compacted from the original thickness of 60-to 100 metres. Longworth CMPS Engineers (1981) concluded that the difference of present thickness between coal seam with few partings and coal seam with many parting in the northern and southern margins is due only to the differential compaction characteristics of organic and argillaceous materials.

4.2 Clay mineralogy

Semi-quantitative determination of the relative degree of abundance of clay minerals from B-Formation and pre-Tertiary rocks are based on peak areas on diffractogram of oriented samples. Altogether 43 samples have been analysed and evaluated, 41 of which are obtained from 7 representative boreholes scattering cover the main part of the areas except the southern part where no sample is available at the time of investigation. The others two are obtained from outcrop of Hong Hoi Formation and weathered rhyolite rock in the western part of the basin.

The brief characteristics of clay minerals obtained from the x-ray studies and relative degree of abundance of clay minerals are presented in the preceeding heading of 1.5 in Chapter I. Besides,all of clay mineral data with hand specimen description are shown in Table A-5.1 of Appendix 5. The clay peak characteristics of the X-ray diffractograms in the samples of untreated, ethylene glycol treatment and heating treatment are shown in Figures A-5.1 to A-5.4 of Appendix 5. The X-ray diffractograms of ethylene glycol treatment with respect to depth from LMP 65 are shown in Figure A-5.5 of Appendix 5. Qualitative determination of clay minerals of B-5 Member were previously carried out by Duangdeun (1978) and Tandicul (1983). The clay peak characteristics of the X-ray diffractograms in the present study are better defined than those previous works. The indistinctive peaks of the latter may be resulted from incomplete sample preparation, particularly with regard to carbonate and organic removal. Consequently, the montmorillonite is additionally reported in this study.

The illite is generally formed under condition of non-acid, potassium-rich, the rainfall and consequent leaching should be only moderate and intermittent. Kaolinite is characteristic of acid tropical soils where leaching is intensive, while montmorillonite is generally a product of intermediate leaching and weathering, and alkaline conditions.

4.2.1 Clay mineral associations

The major groups of clay minerals observed in this study are mainly of illite, kaolinite and montmorillonite. However, a trace of chlorite is also observed, but it is considered to be an unimportant constituent because it is present only in one sample in small amount (Figure A-5.3 of Appendix 5).

Illite, according to the weigh peak area percentage, is the most abundant clay mineral in all sample. Its 001 X-ray diffraction peak is moderately sharp to dull or blunt. Kaolinite is common clay mineral in the coal measures. It is well to moderate crystallized with its sharp 001-peak. Montmorillonite is found in B-5 Member. According to the crystallinity measurement method, the ratio v/p has been estimated. Where "p" is the height of the peak above background, and "p" is the depth of the "valley" on the low-angle side of the peak. Almost all of the v/p ratio of montmorillonite of B-5 Member samples indicate poor crystallinity.

4.2.2 <u>Relationship of clay minerals</u>

The identification and the semi-quantitative analyses of the major of clay mineral groups of altogether 43 samples from 7 representative boreholes and basement rocks reveal the following relationships:

a) In the fine-grained clastic rocks with three groups of clay mineral associations, namely, illite, kaolinite and montmorillonite, the relative kaolinite content varies inversely with the montnorillonite content. Therefore, the kaolinite shows antipathetic relationship with montmorillonite (Figure 4.2.2a).

b) The kaolinite content has a tendency to increase

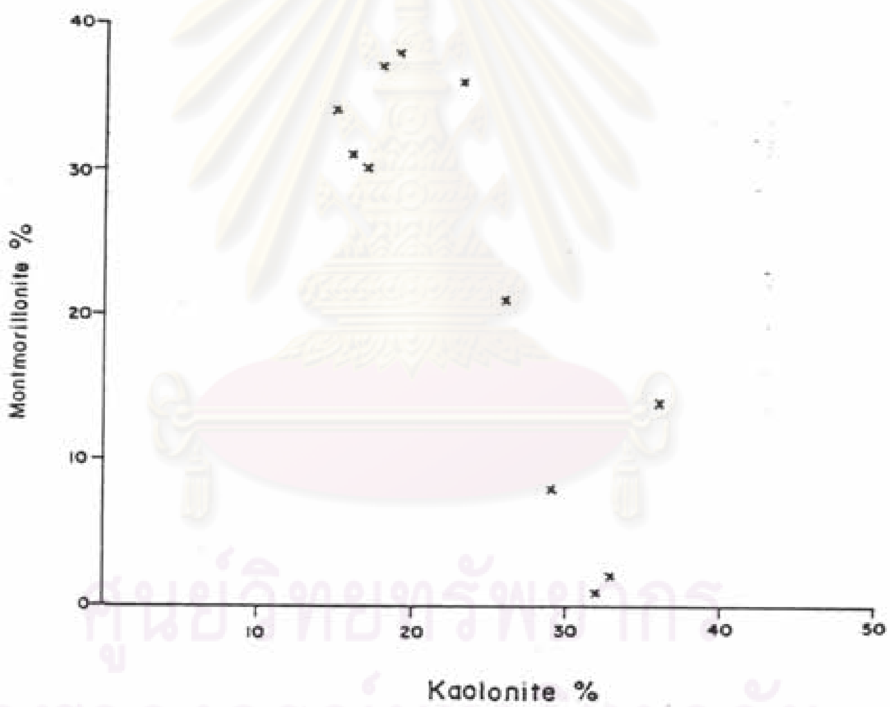

Fig. 4.2.2a Relationships between kaolinite and montmorillonite contents in fine-grained clastic rocks.

vertically towards the coal bands, especially within the coal seam (Figure 4.2.2b).

c) The clay mineral in the parting consist of illite and kaolinite of approximately equal proportion (Figure 4.2.2b , and Table A-5.1 in Appendix 5).

d) Considering the clay mineral suite of the fine-grained clastic rocks above and below the major coal seam (B-4 Member), the illite-kaolinite-montmorillonite suite is confined within the B-5 Member above the major coal seam, whereas the illite-kaolinite suite is confined within the B-3 and B-1 Member below the major coal seam of B-4 Member (Figures 4.2.2 b and 4.2.2 c).

e) Due to the limited clay mineral data of the basement rocks which are considered to be the potential source rocks of clay minerals in the basinal Tertiary sediments, the conclusion regarding the clay mineral relationships can not be drawn at this stage.

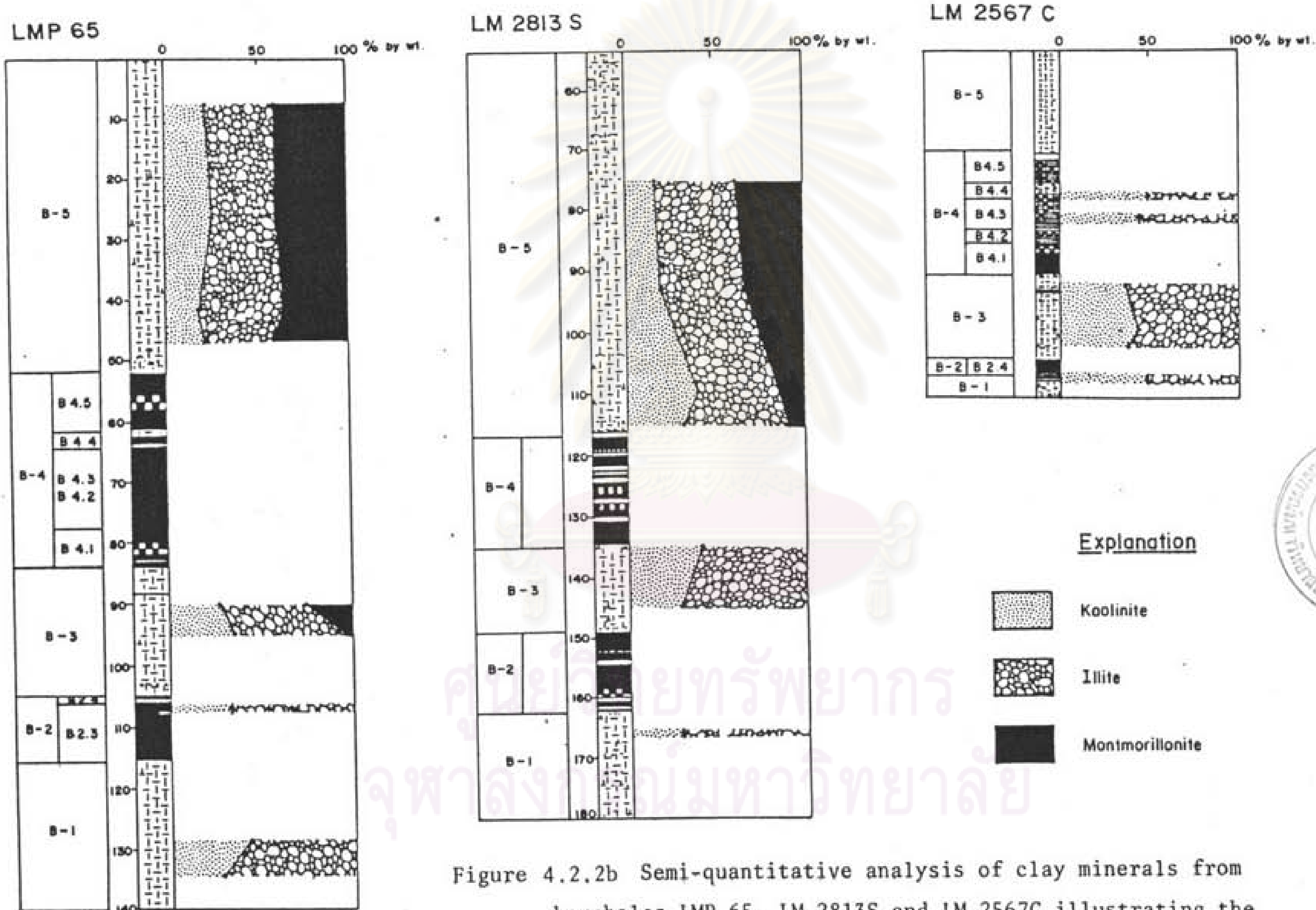

Figure 4.2.2b Semi-quantitative analysis of clay minerals from boreholes LMP 65, LM 2813S and LM 2567C illustrating the variation of kaolinite, illite and montmorillonite contents with respect to depth.

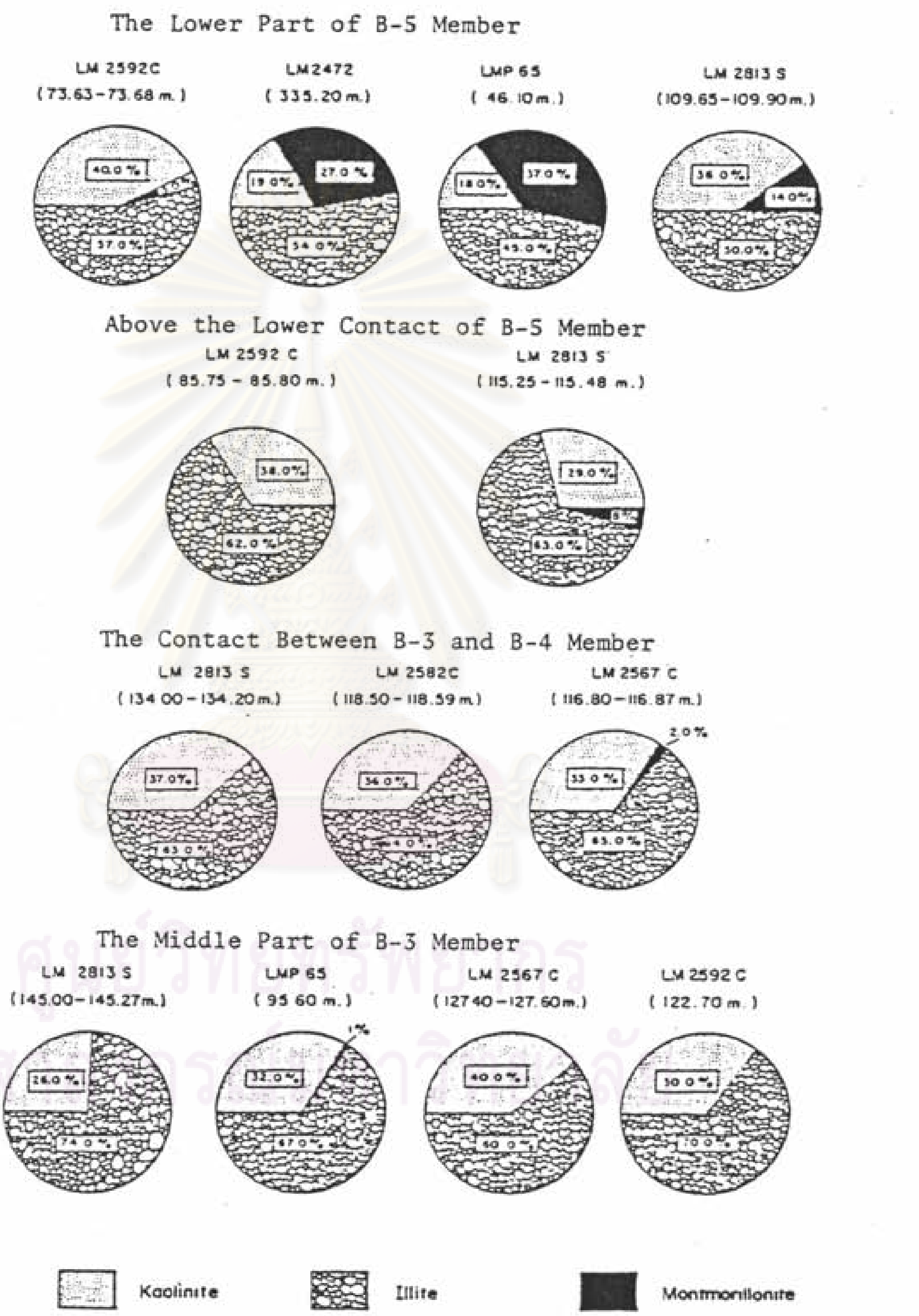

Figure 4.2.2.c Pie diagrammes illustrating the relative degree of abundance of clay minerals in both lateral and vertical variations.