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Cenozoic basins of Thailand and their coal deposits: A preliminary report

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Abstract: Cenozoic deposits occur in many small intermontane basins, especially in northern Thailand; in the Chao Phraya basin; and offshore in the Gulf of Thailand. Basins are mainly fault-bounded graben and half graben, formed by reactivation of basement structures. Dips of strata are low but variable, related to local fault movements. Older Cenozoic strata in onshore basins are less than 3000 m thick, and have been dated as ?U. Eocene to L.–M. Pliocene. Strata in offshore basins have been drilled to more than 4000 m depth, with some wells reaching the Oligocene near T.D. A regional upwards facies change from mudstone and coal below to sandstone and mudstone above, locally unconformable, occurs in several northern basins. Pleistocene to Holocene sandstone and conglomerate lie unconformably above the Tertiary. Coal is abundant in the Tertiary, occurring as seams up to 35 m thick interbedded with massive mudstone (shallow lake or swamp deposits); minor carbonate, diatomite, gypsum and oil shale occur locally. Oil shale is common, associated with mudstone-carbonate and sandstone beds (moderate-depth lake deposits). Woody organic fragments occur rarely in coarse terrigenous sequences (fluvial deposits). Rank of coal (68 samples) ranges from lignite to high volatile C bituminous (4523–15,309 Btu/lb). Moisture averages 17.73 %, volatile matter 53.81 % (dry, mineral-free basis), and sulphur 3.70 % (high). All samples are non-agglomerating. Heating value is apparently higher and sulphur content lower in more westerly basins, probably because of local differences in tectonic and thermal history.

INTRODUCTION

Thailand contains many small intermontane basins and larger regional basins with Cenozoic sediments. Figure 1 shows major basins in northern Thailand. Cenozoic basins also occur offshore in the Gulf of Thailand. Geological data (mainly brief studies of surface outcrops) have been published for some basins; the history of research was summarised by Nutalaya (1975). Coal beds occur in nearly all basins, and in strata beneath the Gulf of Thailand. Major oil shale deposits are known in one basin and minor deposits in four others. Small amounts of petroleum are extracted from one basin, and natural gas is present in the Gulf of Thailand.

This report summarises data presently available on the geological setting of the basins, and on the characteristics of the coal deposits. Basins in northern Thailand are emphasised.

DISTRIBUTION AND BASIN TOPOGRAPHY

Natasilapa and Sucontanikorn (1979) listed 43 basins in northern Thailand which contain known Cenozoic deposits. Present-day surface areas of the basins range from 30 to 1400 km^2 (*ibid*, Table 3), averaging 295 km^2. The orientation of the basins follows the regional strike of the basement rocks, and they form flat-lying alluvial plains between the mountain ranges. Some large basins consist of a connected set of sub-basins, for example the Chiang Mai and Lampang basins. In central Thailand, the Chao Phraya basin covers a huge area (60,200 km^2), extending offshore into the Gulf of Thailand. In southern Thailand, eight small basins were discussed by Brown *et al.* (1951).

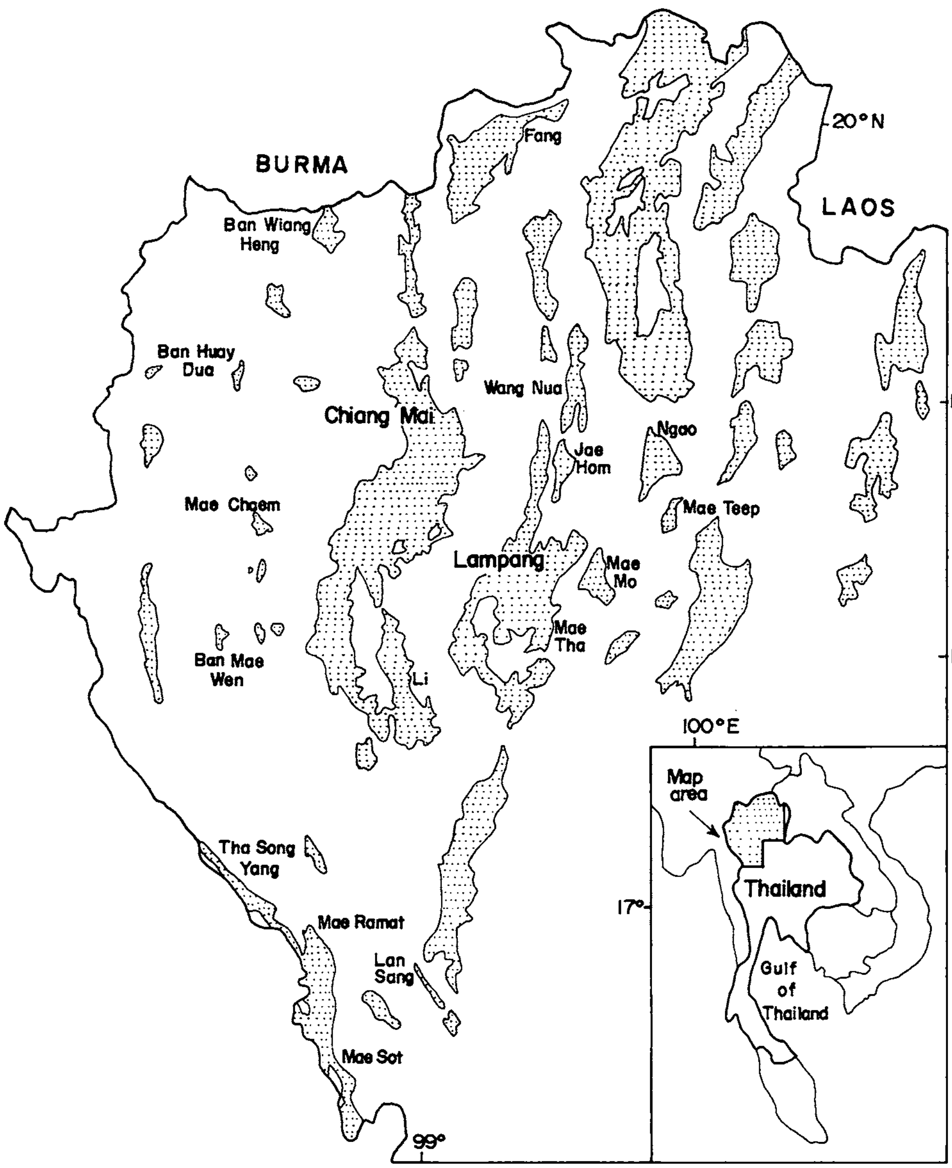

Fig. 1. Major Cenozoic basins in northern Thailand. Basins named are referred to in text. Data from Snansieng (1979) and S. Pitragool (unpublished).

The present-day surface elevation of the basins varies from just above sea-level at Krabi, southern Thailand (below sea-level in the Gulf) to 820 m above mean sea-level at Ban Huay Dua, Mae Hongson Province.

STRATIGRAPHY

Classification of the strata has proved difficult in view of the isolation of the basins and their differences in age and rock type. The Mae Sot Series and Krabi Series were named following reconnaissance study by Brown *et al.* (1951) for rocks in northern and southern Thailand respectively. In the first detailed study, Gardner (1967) formally described a type section of Cenozoic rocks using data from outcrop and boreholes in the vicinity of the Mae Mo mine. His Mae Mo Formation was later used for sequences in many adjacent basins (Mae Mo Group of Piyasin, 1972). Krabi Group has been used for all older Cenozoic sediments in Thailand (Javanaphet, 1969). More recently, a lower Mae Sot Formation has been separated from an upper Mae Fang Formation in several northern basins (Defense Energy Department, 1977, 1979; Piyasin, 1979), and more superficial alluvial sediments have been grouped as the Mae Teng Formation (Piyasin, 1972). Other terms used occasionally include the Nam Pat and Li Formations (older Cenozoic); the Chao Phya Formation (superficial alluvium) (Buravas, 1969); and the Ko Kha Formation (younger Cenozoic) (Defense Energy Department, 1977). Strata in the Gulf of Thailand have not yet been assigned formation names.

In this report, the sequences are referred to simply as "Cenozoic". Formation names are used occasionally, with quotation marks. Revision of the classification must await more detailed information. The superficial alluvial sediments, discussed by Takaya (1968), are not considered in detail here.

The thickness of strata in some basins is shown in Table 1. The greatest thickness is recorded in the Gulf of Thailand, and this figure may be less than half the full thickness of sediment present (Hamilton, 1979). Sequences on land are generally much less than 3000 m thick.

The Cenozoic strata rest unconformably on Mesozoic and older rocks. The stratigraphic sequence is similar in several of the larger northern basins (Table 2). A lowermost unit ("Mae Sot Formation") consists of dark mudstone, coal, sandstone and conglomerate. An overlying unit ("Mae Fang Formation") consists of sandstone, paler mudstone and conglomerate. An unconformity separates the two units in the Fang, Chiang Mai and Lampang basins (Piyasin, 1979). The third unit ("Mae Teng Formation") consists of conglomerate and sandstone. It forms superficial terrace deposits and includes alluvium of the modern river systems; basal contact is unconformable. The upper two units are often difficult to differentiate since their lithologies are similar and dip discordance is slight. In several smaller basins, a comparable sequence of strata occurs. In the Mae Chaem basin (Ukakimapan *et al.*, 1979) and the Ban Huay Dua basin (Gibling *et al.*, in prep.), mudstone-coal strata are overlain conformably by coarse terrigenous strata at least 100 m thick. In the Mae Mo basin (Gardner, 1967) and in the Ban Pa Ka (Li) basin, mudstone-coal strata are overlain with strong unconformity by coarse terrigenous strata containing laterite horizons locally.

TABLE 1.

THICKNESS OF STRATA IN SOME CENOZOIC BASINS OF THAILAND
(thickness values in brackets calculated from data reported in feet).

Basin	Max. Thickness	Type of Investigation	Reference
Chiang Mai	1254 m (4077′)	Drilling to basement (2 holes)	Piyasin, 1972, 1979
Lampang	1240 m (4033′)	Drilling to basement (3 holes)	Defense Energy Dept., 1977, 1978, Piyasin, 1979
Fang	2800 m	Seismic	Piyasin, 1979
Mae Sot	880 m (2854′)	Incomplete drilling (49 holes)	Mineral Fuels Division 1979
Mae Mo	937 m	Estimation from mine and drill data	Gardner, 1967
Chao Phraya	1846 m (6000′)	Incomplete drilling	Bunnag, 1959
Gulf of Thailand	3846 m (12,504′)	Incomplete drilling (41 holes)	Achalabhuti, 1975, Achalabuti and Oudom-Ugsorn, 1978

The few age determinations have been drawn from studies of plant remains, insects, gastropods, fish, land vertebrates, and pollen and spores. Age assignments for the lower mudstone-coal unit include Paleogene (possibly as old as U. Eocene) in the Ban Pa Ka (Li) basin (Endo, 1964; 1966); Oligocene-Miocene at 1860′ (572 m) depth in the Fang basin (Buravas, 1975); Miocene in the Payao basin (Baum *et al.*, 1970); and L.–M. Pliocene in the Mae Mo basin (von Koenigswald, 1959). It is evident that the successions vary widely in age, although most assemblages identified were taken from a limited stratigraphic interval and in no case has a complete section been dated. The

TABLE 2.

STRATIGRAPHY OF SOME CENOZOIC BASINS IN NORTHERN THAILAND.

Lithology	Fang Basin[1]	Chiang Mai Basin[2]	Lampang Basin[3]
Sandstone, comglomerate ("Mae Teng Fmn.")	5–67 m		54 m
		314–618 m	
Sandstone, mudstone conglomerate ("Mae Fang Fmn.")	306–419 m		628 m
Mudstone, coal, sandstone, conglomerate ("Mae Sot Fmn.")	380 m+	577–940 m	558 m+

1. Data from 18 holes (Defense Energy Department, 1979).
2. Data from 2 holes, uppermost unit ("Mae Teng Fmn.") est. 5–20 m (Piyasin, 1972).
3. Data from 1 hole (Defense Energy Department, 1978).

basal sediments in some basins could even be Mesozoic in age. Superficial gravels in the Chao Phraya basin have yielded bone material dated as M. Pleistocene (von Koenigswald, 1959). Strata of rather different facies in the Mae–Sot basin (see below) are dated as ?Miocene, Pliocene–Pleistocene (Brown *et al.*, 1951; Endo and Fujiyama, 1965; Mineral Fuels Division, 1978).

In the Gulf of Thailand, sedimentary sequences drilled range in age from Oligocene to Holocene, as indicated from studies of palynology (Achalabhuti, 1975). A notable unconformity occurs at 1000–4500′ (308–1385 m) depth (Achalabhuti, 1975; Hamilton, 1979). It is overlain by strata of Late Miocene age. This unconformity can be traced widely in the Sundaland area (Malaysia, Indonesia, Thailand) of southeast Asia, and has been dated as late Middle Miocene (Batchelor, 1979). It represents a major period of regression accompanied by subaerial sedimentation across the present-day continental shelf. With more data, it should prove possible to correlate strata in onshore basins of Thailand with those of the Gulf, and relate them to regional and global events.

SEDIMENTATION

Many sediment types occur in the Cenozoic basins. In strata underlying the superficial alluvium, three facies associations are recognised. The associations may be either of different ages or lateral facies equivalents locally. General data are taken from available reports, while detailed information is from outcrops examined by the authors. The sediments vary from consolidated to unconsolidated; rock (consolidated) terms are used in their description.

1) **Coarse terrigenous association**

Sediment types in approximate order of abundance are: sandstone, mudstone, conglomerate, coal. The sandstones are very fine- to very coarse-grained, and pebbly. At outcrops in the basin at Ban Huay Dua (Gibling *et al.*, in prep), they show horizontal lamination, small- to medium-scale cross-stratification, cross-cutting erosion surfaces, and graded bedding. The mudstones are thin, and reddish-brown, yellow or grey. The conglomerates tend to occur as thin beds with 20–40 cm clasts common; the clasts are both extrabasinal (granite and vein quartz) and intrabasinal (coal, oil shale, mudstone). Organic material is uncommon, consisting of thin coal beds, *in situ* tree stumps, logs, and small fragments of branches and leaves. No fauna has yet been recorded.

The data collectively suggest a fluvial origin for this association, with channel and overbank deposits. The organic material is mainly woody, resistant to degradation during active transport. Several basins contain basal conglomerates, with very coarse fragments. These may be coarse residual or fluvial deposits from the earliest stages of valley filling during uplift.

2) **Fine terrigenous association**

Sediment types in approximate order of abundance are: mudstone, coal, sandstone, oil shale, carbonate, diatomite, gypsum. This association has been studied in the Mae Mo, Ban Pa Ka (Li), Mae Teep and Ban Huay Dua basins.

The mudstones are massive (locally fissile) and up to 30 m thick. They are grey, blue, green, brown or red in colour. Some beds are calcareous. Included carbonaceous material comprises fragments of branches, leaves and seeds, rootlet beds, and thin coal beds. Fish and insect fragments, arthropods (?branchiopods) and gastropods are common. Turtle and mastodon fragments have been identified. The massive nature of many beds may reflect turbation by rootlets and other organisms.

The coal beds vary from a few cm to 35 m in thickness. At least four basins contain seams greater than 5 m thick, though most seams are between 0.5 and 2 m thick. Two 25–30 m beds of coal at the Mae Mo mine are quite uniform along strike for several km. In other basins, thinner beds of coal are lensoid, and some fill small topographic hollows in the underlying sediment. Rootlet beds underlie some coals. The coals contain pyrite, thin clay lenses, some recognizable woody fragments, and rare gastropods.

The oil shale occurs in beds quoted as up to 15 m thick. Some beds are high grade, but most are probably low grade, essentially carbonaceous mudstone. In several instances, for example at Ban Pa Ka (Li) and Mae Chaem, they directly overlie coal beds, to which they may be related by cyclic facies change during deposition or by diagenetic release and migration of oil from the coal beds during coalification. One bed contains abundant trace fossils (?*Planolites*) and was oxygenated at least temporarily during deposition.

Fine-grained carbonate occurs as unlaminated, thin-bedded units. Massive diatomite and thin beds of gypsum occur in some basins. The sandstones resemble those of the first facies association.

Cyclicity was observed at Mae Mo. A mudstone unit 6 m thick contains fish fragments below, with gastropods, and fish and plant fragments above, and is overlain by coal. Such cyclicity is of regressive type.

The data collectively suggest a shallow lacustrine environment of deposition, from bodies of open water to swamps and peat bogs. The fine terrigenous association is characterised by a relative abundance of fauna in all basins, in contrast to the other two associations. The abundant organic material was mainly non-woody in origin, and grew close to the site of deposition, as indicated by the common rootlet beds. There appears to be some geographic localisation of sediment types in northern Thailand. Mudstone and coal, locally with minor oil shale, occur in all basins. Carbonate beds have been reported only in four eastern basins—Ngao, Phrae, Sa Iap (Piyasin, 1972) and Mae Teep. Calcareous nodules a fraction of a mm in diameter also occur in coal beds at Mae Mo (Gardner, 1967). Diatomite has been reported in two adjacent basins further west (Lampang and Jae Hom; Piyasin, 1972), and gypsum in the Thung Ngam basin (Piyasin, 1972). This suggests that the basins formed interconnected groups during deposition, with distinctive chemical and biochemical conditions in each group. These three rock types have not been reported as yet from basins in the western highlands.

Strata in the south of Thailand show marine influence, unlike those in the north. Sediments in the Gulf of Thailand consist predominantly of mudstone, sandstone and minor coal. They have been interpreted as fluvial, coastal swamp and sublittoral deposits (Achalabhuti, 1975). The strata of Krabi contain calcareous, gypsiferous and bituminous units, and marine gastropods (Brown *et al.*, 1951; Poothai and Chana, 1969).

3) Fine terrigenous–Carbonate association

Sediments of this association are known presently only from the Mae Sot basin. Basic data is reported in Mineral Fuels Division (1978, 1979). Detailed information is from study of a 100 m section at outcrops near Ban Huay Kaloke, Amphoe Mae Sot, Cangwat Tak, in the upper part of the stratigraphic column.

Sediment types in approximate order of abundance in this area are: mudstone and/or carbonate; sandstone; oil shale; ?gypsum.

The mudstone and carbonate rocks occur as units up to several m thick. Clay-sized material predominates. Three types of unit are present:

(a) Well-stratified units consisting of carbonate (calcite and dolomite), quartz and feldspar, clay minerals, analcite, and carbonaceous material. Stratification scale varies from very thin laminated ("paper shale") to very thin bedded. The thin layers can be traced continuously across small outcrops. Soft-sediment deformation features such as microfaults, deformed laminae and clastic dykes are common. Colour is related to the content of organic matter, and ranges from yellow to grey-green or grey.

(b) Fissile mudstone, grey-green in colour.

(c) Massive carbonate, with mica and scattered quartz grains, and yellow-white to grey-green in colour.

Small-scale cross-stratification is very rare, and desiccation features were not observed in any units.

Sandstone occurs as distinct beds up to 60 cm but mainly 10–20 cm thick. Beds are fine- to coarse-grained, rarely pebbly. Colour is yellow-white. The beds are interlayered with mudstone and carbonate sediments. Significant features include flute casts, current crescents, and primary current lineation on the bases of beds, graded bedding, and megaripples (60 cm length, 7 cm amplitude) on upper surfaces.

Oil shale grades from grey-green organic-rich mudstone and carbonate (low grade) into black, pyritic, hard, massive to laminated rock (high grade). In this area, individual beds are up to 1.35 m thick; they occur in groups of 4 or 5 beds within an interval of about 15 m, groups being separated by about 45 m of mudstone, carbonate and sandstone. Individual beds can be traced for several km along strike with only minor splitting and thinning.

Gypsum is reported as bands and lenses in many parts of the basin. In the study area, thin (5 cm) beds of crystalline calcite display a texture of vertically-oriented prismatic crystals, suggesting that they replaced gypsum.

Very rare fauna comprises insect, fish and plant fragments.

Elsewhere in the basin, fossiliferous limestone (gastropod-rich) is reported to occur in the lower part of the section overlying basal sandstone and conglomerate. Coal beds crop out near Mae Ramat, associated with mudstones containing rootlets and gastropods.

The data collectively suggest a lacustrine environment of moderate depth and stratified at intervals. This is supported by the continuity of thin units, and the absence of desiccation features. Prevailing anaerobic conditions are indicated by the regular nature of lamination in many units (not bioturbated), the rarity of macrofossils (especially of benthonic organisms), and the abundance of organic matter. High salinity water was present at times, resulting in deposition of gypsum. The nature of the sandstone indicates periodic rapid transport of coarse sediment into deeper water, forming turbidites. Lateral facies changes involving all three associations may occur in the Mae Sot basin, but have not yet been identified.

TECTONICS

The tectonic history of Thailand has been briefly summarised by Suensilpong *et al.* (1978). The Cenozoic basins were initiated as a result of Cretaceous to Early Tertiary uplift. Cenozoic granites and volcanics occur. A tensional regime was operative from Oligocene to Quaternary times, with the development of graben both on land and offshore.

Many of the Cenozoic basins are probably fault-bounded (German Geological Mission, 1972), although evidence is commonly lacking. Hamilton (1979) reported that strata in nearshore parts of the Gulf of Thailand are broken by faults into horsts, graben and half graben, filled with Neogene sediments. The Lan Sang valley, Tak Province, studied in detail by Chantaramee (1979), shows a graben structure which probably originated either as a graben or a half graben in Upper Paleozoic times, and was reactivated with strong subsidence during the Cenozoic. In the Fang basin (Piyasin, 1979), a major fault system delineates the western margin of the basin, with strata dipping westwards and thickening to the west (half graben structure). A similar situation may occur in the Mae Mo basin, where Canozoic sediments are faulted to the west but are believed to lie unconformably on older rocks on the eastern margin (Gardner, 1967).

The marginal faults are commonly related to pre-existing basement structures, and most northern basins are oriented parallel to the regional structure. In the Gulf, growth faults unrelated to basement structures are present, and grew concurrently with sedimentation (Hamilton, 1979).

The strata in the northern basins strike roughly N–S, and dip gently at about 10–25 degrees. In some basins, dip direction is uniform, but in other basins, small-scale flexuring is apparent. Dip direction commonly is different in adjacent basins. It is concluded that structure within individual basins reflects local fault movements, although effects of regional tectonics (e.g. tilting) may be superimposed.

COAL DEPOSITS

1) Petrography

The coal is mainly banded, consisting of finely-interlayered vitrain and attrital coal. Impurities include clay layers and lenses, scattered detrital grains up to medium-sand size, pyrite, calcareous nodules and gastropod shells. Fracture is conchoidal to platy. Examination of Mae Mo coal under the microscope (Gardner, 1967) showed that finely detritic humic components form more than 95 % of the material; sclerotinite and resinite are rare, and pollen and fungal spores occur in small amounts. The coal was described as the decomposition product of stems, leaves and roots of herbaceous plants.

2) Quality

Data on the quality of the coal was compiled by Ratanasthien (1980, Table 7), who listed proximate and ultimate analyses for 35 separate samples from 14 basins. Analyses of 33 samples from the Mae Mo basin were reported by Gardner (1967, Table 4). Data must be considered preliminary since few results are available for some basins, some samples were taken from outcrop rather than drill core, and analysis was performed in different laboratories. Results of analysis of these 68 samples are summarised for each basin in Table 3.

Apparent rank of most coal samples, as indicated by heating value (American Society for Testing of Materials, 1977), is lignite or sub-bituminous, with some samples of high volatile C bituminous coal (4523–15,309 Btu/lb). Ash yield ranges from 2.24 % to 45.39 %, with most samples being true coals but 12 samples being of impure coal grade on the basis of mineral content (25–50 % ash). Sulphur content is high, averaging 3.7 %. Moisture content averages 17.73 %, and volatile matter averages 53.81 % on a moisture-free mineral-free basis. Samples are all non-agglomerating. Many show the property of slacking to powder when stored under atmospheric conditions.

The basins listed in Table 3 can be divided into three geographic groups (see Figs. 1 and 2):

(a) Basins at low elevation in the extreme west of Thailand.

(b) Basins at high elevation in the western ranges.

(c) Basins at low elevation in the east, around the Lampang basin.

The data suggest important differences between coal samples from basins in these three groups, especially between group (c) and the other two groups. The apparent rank of coal is higher in the west than the east, as indicated in the graph of heating value against fixed carbon % on a moisture-free basis (Fig. 2). Sulphur content varies widely, but tends to be lower in samples from the western basins (average 1.76 %, n = 10) than in those from the eastern basins (average 4.22 %, n = 55). These differences may result from several factors: nature of the original organic material and environment, e.g. related to elevation of basins during deposition; age of the deposits; and tectonic and thermal history of the basins. Since these trends in quality are of economic importance, their causes are under investigation by means of coal petrography, biostratigraphy, and structural studies. More representative sampling is also required to substantiate this observation.

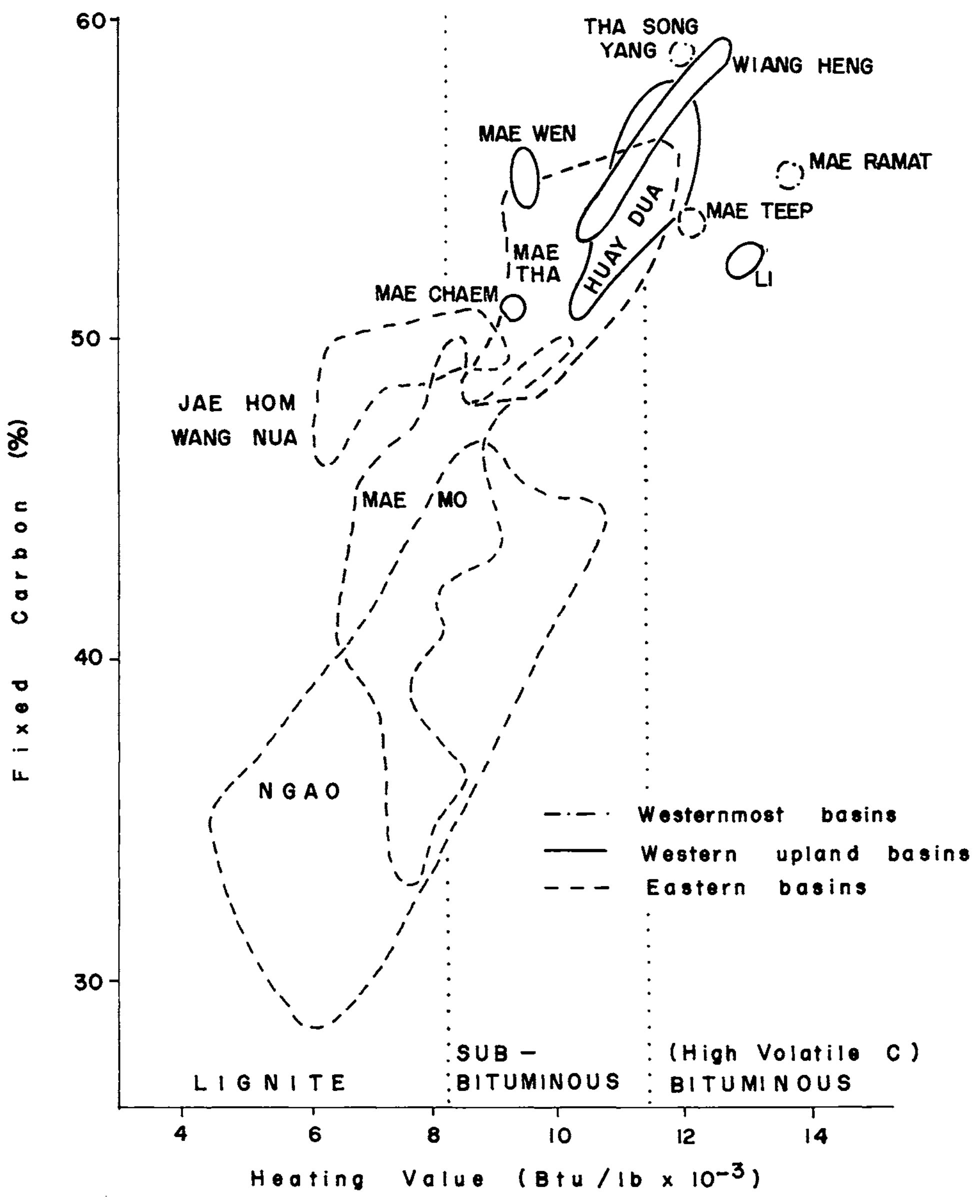

Fig. 2. Rank of coal in Cenozoic basins in northern Thailand. Heating value is on moist, mineral-free-matter basis: fixed carbon % is on dry, mineral-free-matter basis. Based on 68 analyses (data in Table 3).

TABLE 3.

COAL ANALYSES FROM NORTHERN THAILAND
Data (in percent) from Gardner (1967) and Ratanasthien (1980).

PROXIMATE ANALYSIS

Basin	No. of Analyses	Moisture		Ash		Dry, mineral-matter-free: Volatile Matter		Dry, mineral-matter-free: Fixed Carbon		Moist, m-m-f Heating Value (Btu/lb)	
		Range	Ave.	Range	Ave.	Range	Ave.	Range	Ave.	Range	Ave.
Eastern basins											
Jae Hom	6	11.3–23.1	16.9	14.3–38.4	26.5	49.2–53.6	50.9	46.4–50.8	49.1	6156–9007	7684
Wang Nua	1		28.8		21.1		51.3		48.7		6932
Mae Tha	7	7.8–22.8	14.5	5.8–45.4	18.9	44.4–51.5	49.1	48.5–55.7	50.9	8395–11,666	9674
Mae Teep	1		18.3		6.2		46.4		53.6		11,938
Ngao	7	21.0–28.0	24.3	17.4–43.9	27.3	53.8–71.3	59.6	28.7–46.2	40.4	4523–10,612	7688
Mae Mo	33	8.8–30.7	17.7	7.4–25.2	14.7	50.2–66.6	57.0	33.4–49.8	43.1	6450–9997	7792
Western basins											
Ban Pa Ka, Li	1		20.7		8.1		47.7		52.3		12,810
Ban Wiang Heng	2	19.7–22.1	20.9	3.9–14.5	9.2	41.0–46.7	43.8	53.5–59.0	56.2	10,334–12,470	11,402
Mae Chaem	2	10.8–15.8	13.3	8.8–41.8	25.3	49.1–74.0	61.6	26.0–50.9	38.4	9180–11,050	10,115
Ban Mae Wen	2	16.8–21.9	19.4	17.4–18.0	17.7	44.6–45.6	45.1	54.3–55.4	54.9	9290–9366	9328
Ban Huay Dua	4	10.5–17.4	14.8	2.2–11.1	6.8	42.4–49.3	45.4	50.7–57.8	54.6	10,211–11,835	11,176
Westernmost basins											
Tha Song Yang	1		11.0		8.9		41.3		58.7		11,883
Mae Ramat	1		4.8		12.8		45.1		54.9	13,525–15,309	—

Table 3 (*contd.*)

ULTIMATE ANALYSIS

Basin	No. of Analyses	Carbon		Hydrogen		Oxygen		Nitrogen		Sulphur*	
		Range	Ave.	Range	Ave.	Range	Ave.	Range	Ave.	Range	Ave.
Eastern basins											
Jae Hom	6	31.9 46.8	38.3	2.4 7.2	3.7	5.1 25.4	17.1	0.9 1.5	1.3	2.9 9.4	5.2
Wang Nua	1		40.1		5.5		9.6		0.9		1.3
Mae Tha	5	41.0–64.7	51.0	4.2–7.9	5.7	16.3–19.7	18.3	1.0–2.3	1.9	1.0–8.0	3.0
Mae Teep	1		63.8		6.9		18.9		2.0		6.5
Ngao	7	26.1–52.8	39.6	1.8–6.1	3.6	5.5–18.7	12.3	0.9–1.7	1.3	6.2–12.4	9.2
Mae Mo	1		70.7		5.0		18.2		2.3	1.4 4.5	3.0
Western basins											
Ban Pa Ka, Li		67.5		5.0		18.6		0.7		4.0	
Ban Wiang Heng	2	49.4–72.1	60.8	4.0–4.7	4.4	15.7–26.1	20.9	1.6–1.8	1.7	0.7–2.0	1.3
Mae Chaem	1		62.1		5.4		18.4		1.9	0.8–1.8	1.3
Ban Mae Wen	—		—		—		—		—	1.1–4.8	3.0
Ban Huay Dua	2	54.5–58.2	56.4	5.3–6.5	6.0	23.6 32.3	27.9	0.6 2.4	1.5	0.5 2.3	0.8
Westernmost basins											
Tha Song Yang	1		63.4		5.5		15.8		1.3		4.3
Mae Ramat										0.5 0.6	

*No. of analyses as for proximate analysis.

3) **Mining and industrial use**

The coal deposits can be divided into three groups as regards their suitability for production and use. Major factors include resistance to transportation, heating value, and resistance to slacking on storage. Sulphur content is high in all basins, a major disadvantage for industry. The groups show some geographic localisation.

Group I coals are of highest quality. They vary from dark brown to black in colour, and show fine banding of vitrain and attrital coal. They are hard, with conchoidal to subconchoidal fracture, and are resistant during long-distance transportation. Heating values are high, from sub-bituminous to high volatile C bituminous rank (8395–12,810 Btu/lb). Samples can be stored under cover for at least one year without slacking. The basins of Mae Tha, Mae Teep, Ban Pa Ka (Li), Ban Wiang Heng, and Ban Huay Dua (western and eastern basins) contain coals of this group.

Group II coals are of intermediate quality. They resembly those of Group I, but are only moderately hard and may show splintery fracture. Heating values are high, from sub-bituminous to high volatile C bituminous rank (9180–15,309 Btu/lb). On storage under cover for more than about six months, they slack into fragments and eventually powder, and develop white crystals between the coal layers. The basins of Mae Chaem, Tha Song Yang and Mae Ramat (western basins) contain such coals, and some samples from Jae Hom (eastern basin) belong to this group.

Group III coals are of lowest quality. They vary from brown to brownish-black in colour and tend to contain much attrital coal. They are brittle with splintery fracture, and are not resistant during long-distance transportation. Heating values are low, from lignite to sub-bituminous rank (4523–10,612 Btu/lb). On storage under cover, they slack rapidly into fragments and develop white crystals between the coal layers. They also show spontaneous combustion on storage. The basins of Jae Hom, Wang Nua, Ngao and Mae Mo (all in the east) belong to this group, and contain large reserves.

Coal accounted for only 1.9% of energy used in Thailand in 1977 (Achalabhuti, 1979). Total production in 1978 was quoted as 638,942 metric tons (Snansieng, 1979). At present only five deposits have active mines:

(a) Mae Mo, Lampang Province. This is the biggest mine in northern Thailand, with an estimated 112 million metric tons of workable reserves (Gardner, 1967).

(b) Ban Pa Ka (Li), Lampoon Province. Reserves are estimated at 15 million metric tons, of which 8.7 million tons can be mined opencast (German Geological Mission, 1972).

(c) Ban Pu (Li), Lampoon Province. Workable reserves are 5 million metric tons (German Geological Mission, 1972).

(d) Mae Teep, Ngao, Lampang Province. Reserves in this basin are not known.

(e) Ban Pu Dam, Krabi Province. Proven reserves are 13.5 million metric tons (Natasilapa and Sucontanikorn, 1979). This is the only active mine in southern Thailand.

Production problems include remoteness of some deposits and long distance for transportation, and thinness of coal units and moderate angles of dip in some small basins (high overburden ratio). Most of the low quality coal (Group III) is currently used immediately for electricity generation at the mining site, avoiding problems associated with transport and storage. In 1979, there were two generating plants of 75 MW at Mae Mo, and three plants of 20 MW at Krabi. Higher quality coal (Group I) is mined in smaller amounts and transported for use in tobacco curing, noodle factories, lime kilns, cement plants, hotels and crematoria. High sulphur content, high volatile and moisture content, and non-agglomerating properties presently hamper attempts at more specialised use such as for coke manufacture and smelting.

CONCLUSIONS

(1) Cenozoic strata of Thailand occupy many small intermontane basins in upland areas, and extensive low-level plains. The smaller basins are mainly fault-bounded graben and half graben, formed by reactivation of basement structures. Orientation and degree of deformation of the strata reflect local fault movements.

(2) Strata in onshore basins are up to about 3000 m thick, and from ?U. Eocene to L.–M. Pliocene in age. Complex coarse terrigenous units of Pleistocene age form a thin superficial sheet. In several northern basins, an unconformity separates predominantly mudstone-coal strata below from predominantly sandstone-mudstone strata above. With further work, the stratigraphic sequences may be correlated with those of offshore basins, and hence related to eustatic or tectonic events on regional and global scales.

(3) Organic material occurs uncommonly in coarse terrigenous facies (fluvial) as woody fragments. It is abundant in fine terrigenous facies (shallow lakes or swamps) as coal seams up to 35 m thick and as minor oil shale. Organic material is common in fine terrigenous-carbonate facies (moderate-depth lakes) as oil shale beds up to a few m thick. Coal and oil shale thus show lateral facies relationship.

(4) Coal beds range from lignite to high volatile C bituminous rank. Heating value is apparently higher and sulphur content lower in western upland basins in northern Thailand. Important factors for industrial evaluation include also resistance to slacking on storage and to transportation, agglomerating properties, and moisture and volatile contents.

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REFERENCES CITED

ACHALABHUTI, C., 1975. *Petroleum geology of the Gulf of Thailand.* Econ. Geol. Bull. 7. Dept. of Mineral Resources, Bangkok, 53 p.

————, 1979. Natural energy for relieving energy shortages in Thailand. *In Geol. Soc. of Thailand Special Paper*, Year 2522, p. 1–17 (in Thai).

———— and OUDOM-UGSORN, P., 1978. Petroleum potential in the Gulf of Thailand. *J. Geol. Soc. Thailand*, 3: Pl-17.

AMERICAN SOCIETY OF TESTING AND MATERIALS, 1977. *Classification of coals by rank.* Paper D388-77, Philadelphia, Pa. U.S.A., 5 p.

BATCHELOR, B.C., 1979. Discontinuously rising Late Cainozoic eustatic sea-levels, with special reference to Sundaland, Southeast Asia. *Geol. en Mijnbouw* 58: 1–20.

BAUM, F., BRAUN, E.V., HAHN, L., HESS, A., KOCH, K.E., KRUSE, G., QUARCH, H., and SIEBENHÜNER, M. and OTHERS, 1970. On the geology of northern Thailand. *Beih. Geol. Jahrb.*, Heft 102: 1–24.

BROWN, G.F., BURAVAS, S., CHARALJAVANAPHET, J., JALICHANDRA, N., JOHNSTON, W.D., SRESTHAPUTRA, V. and TAYLOR, G.C., 1951. Geological reconnaissance of the mineral deposits of Thailand. *U.S. Geol. Surv. Bull.* 984, 183 pp.

BUNNAG, D., 1959. Geophysical prospecting in the Chao Phraya basin. Thailand. *In Proceedings of the Symposium on the Development of Petroleum Resources of Asia and the Far East.* United Nations/ECAFE. Mineral Resources Development Series 10: 216–217.

BURAVAS, S., 1969. *Succession of rocks in Fang and Chiangmai areas.* Defense Energy Department, Ministry of Defense, Unpubl. report (in Thai).

————, 1975. Age of the Mae Soon oil field of Fang basin, Chiang Mai province. *Dept. Geol. Sci. Univ. Chiang Mai Spec. Publ.* 1, v. 2: 61–66.

CHANTARAMEE, S., 1979. *Structural evolution of the Lan Sang valley: a Cenozoic basin.* Dept. Geol. Sci. Univ. Chiang Mai Open File Report 7909–03, 14 pp.

DEFENSE ENERGY DEPARTMENT, 1977. *Geology and drilling report of petroleum drill hole IL-2(14), Lampang basin project, Lampang.* Division of Exploration and Production, D.E.D., Chotana Rd., Chiang Mai, 17 pp. (in Thai).

————, 1978. *Geological report of petroleum drill hole IL-3(15), Lampang basin project, Lampang.* Division of Exploration and Production, D.E.D, Petchaburi Rd., Bangkok, 8 pp. (in Thai).

————, 1979. *Report on exploration drilling of the Mae Soon oil field, Fang basin.* Division of Exploration and Production, D.E.D., Petchaburi Rd., Bangkok, 70 pp. (in Thai).

ENDO, S., 1964. Some older Tertiary plants from northern Thailand. *Geol. Palaeont. Southeast Asia*, Tokyo Univ. Press 1: 113–115.

————, 1966. A supplementary note on the Paleogene Li flora in northern Thailand. *Geol. Palaeont. Southeast Asia*, Tokyo Univ. Press 3: 165–169.

ENDO, S., and FUJIYAMA, I., 1965. Some late Mesozoic and late Tertiary plants and a fossil insect from Thailand. *Geol. Palaeont. Southeast Asia*, Tokyo Univ. Press 2: 301–307.

GARDNER, L.S., 1967. *The Mae Mo lignite deposit in northwestern Thailand.* Thai Dept. Mineral Resources, Rept. Invest. 12, 72 pp.

GIBLING, M.R., SUCHARITPORNCHAIKUL, O., SUPERTIPANISH, S. and UKAKIMAPAN, Y., in prep. *Stratigraphy and sedimentation of the Cenozoic coal-bearing rocks at Ban Huay Dua, Mae Hongson province, Thailand.*

GERMAN GEOLOGICAL MISSION, 1972. *Final Report.* Geol. Surv., Federal Republic Germany, Hannover, 94 pp.

HAMILTON, W., 1979. *Tectonics of the Indonesian region.* U.S. Geol. Surv. Prof. Pap. 1078, 345 pp.

JAVANAPHET, J.C., 1969. *Geological map of Thailand*, scale 1:1,000,000. Thai Dept. Mineral Resources, Bangkok.

MINERAL FUELS DIVISION, 1978. *Report on oil shale exploration, Amphoe Mae Sot, Tak province.* Thai Dept. Mineral Resources, Bangkok, unpubl. report, 32 pp. (in Thai).

———, 1979. Oil shale exploration, Amphoe Mae Sot, Tak province, *In Geol. Soc. Thailand Special Paper*, Year 2522, p. 45–60 (in Thai).

NATASILAPA, S. and SUCONTANIKORN, B., 1979. Lignite. *In "Engineering, Agriculture, Energy"*, Annual Conf. Royal Eng. Soc. Thailand, 2521–2, Section 5, 26 pp. (in Thai).

NUTALAYA, P., 1975. Cenozoic rocks (of Thailand). *Dept. Geol. Sci. Univ. Chiang Mai Spec. Publ.* 1, v. 1: 129–142.

PIYASIN, S., 1972. *Geology of Lampang sheet NE 47–7, Scale 1:250,000.* Thai Dept. Mineral Resources, Rept. Invest. 14, 98 pp. (in Thai, English abstract).

———, 1979. Petroleum exploration in the north. *In Geol. Soc. Thailand Special Paper*, Year 2522, p. 18–24 (in Thai).

POOTHAL, C. and CHANA, A., 1969. Geology of mineral fuels in Thailand, Part I. *Thai Dept. Mineral Resources, Min. Res. Gazette* 14: 72–84.

RATANASTHIEN, B., 1980. *Research report: Improving the quality of lignite for use in home industries. Part I: Quality of lignite in northern Thailand.* Unpubl. report, National Research Council, 80 pp. (in Thai).

SNANSIENG, S., 1979. Exploration and use of lignite in the north. *In Geol. Soc. Thailand Special Paper*, Year 2522, p. 25–38 (in Thai).

SUENSILPONG, S., BURTON, C.K., MANTAJIT, N. and WORKMAN, D.R., 1978. Geological evolution and igneous activity of Thailand and adjacent areas. *Episodes*, 1978 No. 3, 12–18.

TAKAYA, Y., 1968. Quaternary outcrops in the central plain of Thailand. *In Center for Southeast Asian Studies, Univ. Kyoto, Rep. Research Southeast Asia, Nat. Sci. Ser.* N-3, 7–68.

UKAKIMAPAN, Y. and SUPERTIPANISH, S., 1979. Lignite deposits of the Ban Na Hong Tertiary basin, Amphoe Mae Chaem, Chiang Mai province. *In Geol. Soc. Thailand Special Paper*. Year 2522, p. 39–44 (in Thai).

VON KOENIGSWALD, G.H.R., 1959. A mastodon and other fossil mammals from Thailand. *Thai Dept. Mineral Resources, Rept. Invest.* 2: 25–28.