CHAPTER 4

MINERALOGY AND ORGANIC PETROLOGY

4.1 GENERAL CHARACTERISTICS

Petrographic characteristics of the lithologies and in particular that of the shales are described in detail in Chapter 2. Only a short summary of that follows below.

4.1.1 Description of hand specimens

In general, shales of the lowermost unit (Unit 1) are dark brown/brownish black coloured, in most cases distinctly laminated (Plate 4.1, Figure 1) and less tough than shales of the overlying units. They comprise mainly clay-sized grains. Laminations are distinctive due to compositional variation, in particular organic matter to mineral matter ratio. Stratification may range from a fraction of a millimeter to beds as thick as a few meters and mean couplet thickness for laminations may be as many as 20 mm. They commonly fracture in slabs along planar surfaces. Most of the shales from the overlying units are light gray (Unit 3) and medium light gray (upper part of Unit 2), and dark gray - brownish gray (lower part of Unit 2) sometimes with relatively much clay - silt sized fractions. Both laminated and non-laminated shales (Plate 4.1, Figure 2) may be present and laminations are mostly expressed in grain size variation with less obvious organic matter rich laminae. These shales are a little bit tougher and fall apart in conchoidal to subconchoidal fracture.

Sedimentary structures, other than laminations, in some shales may include : microfaults, contorted laminae, slickensides, intraformational breccia etc. Abundant plant fragments, rare leaf remains (?) along frac-
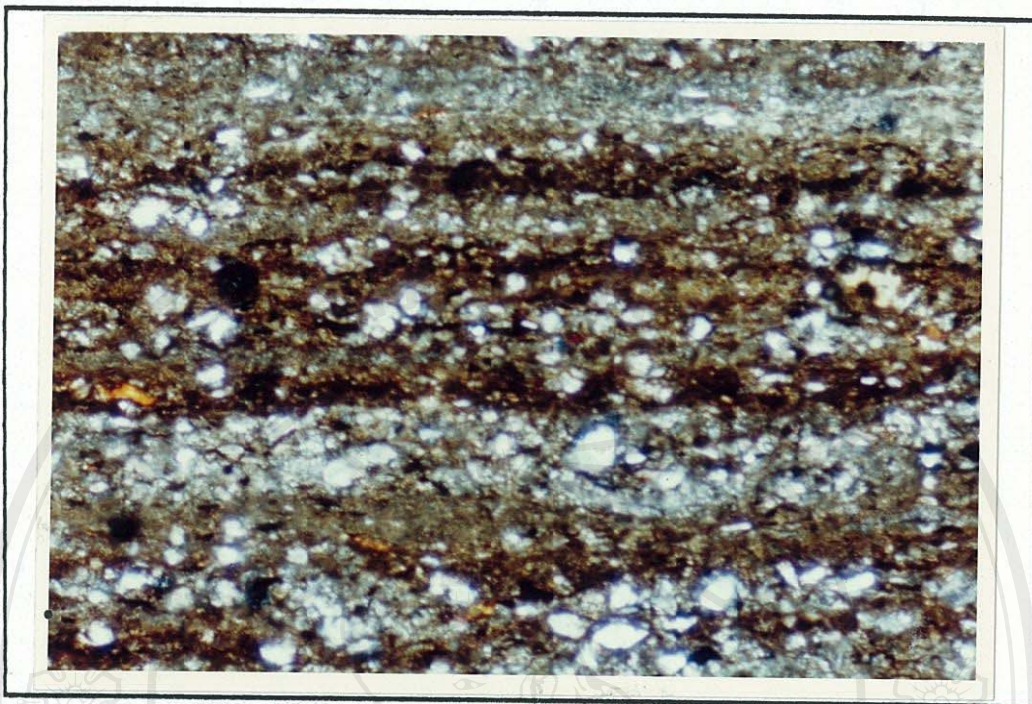
PLATE 4.1

Figure 1 Photomicrograph of distinctly laminated shale showing alternation of organic and mineral matter rich laminae from the lower lacustrine shale.
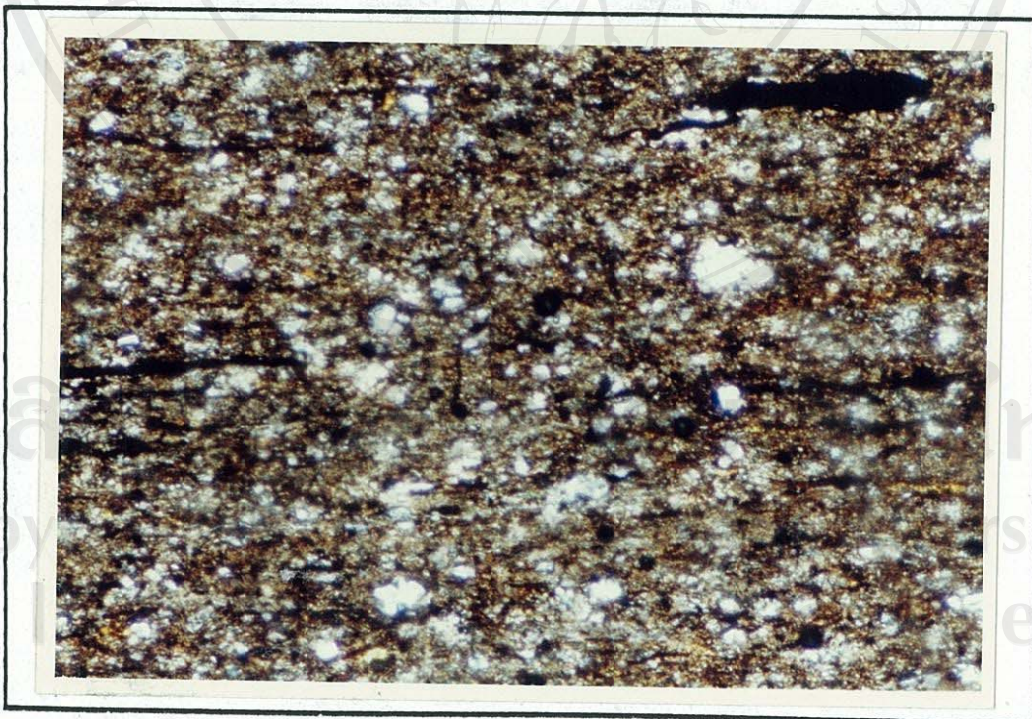

Figure 2 Photomicrograph of massive / microlaminated shale from the upper lacustrine facies.

tures or bedding planes and mottling after plant debris are seldom observed. Fossils of viviparous (gastropods) are reported from Pong Nok oil field from presumably equivalent strata to Unit 3.

4.1.2 Thin Section Study

A few sandstones were taken for mineralogical and textural studies from the fluvio-lacustrine and lacustrine facies. Texturally, most of the sandstones are fine-coarse grained and gray to dark gray coloured. Volumetrically, the most essential constituents of the sandstones are quartz (45-65 %) and rare rock fragments (Plate 4.2, Figure 1). Grains are subangular to subrounded with moderate to good sorting. The rock fragments may include chert, micaceous rocks, low grade metamorphic rocks (phyllite), and quartzite. Individual clast size may range between 0.25-1.75 mm-the maximum for some sandstones (Plate 4.2, Figure 2). Matrix is variable and may include, quartz, clay, mica, Fe Oxide with silica or simply iron oxide. Some discrete layers lying in between quartz rich layers look very much like slump structures. Most of the sandstones can be classified as quartz arenites.

4.2 X-RAY ANALYSIS (MINERALOGY)

Microscopic techniques which are successfully applied to coarse grained rocks have been less effective when applied to shales and claystones. What is known about shales is based upon chemical, thermal, X-ray and electron microscope studies. In this study, a few shale samples were analysed using X-ray diffraction techniques. From the X-ray
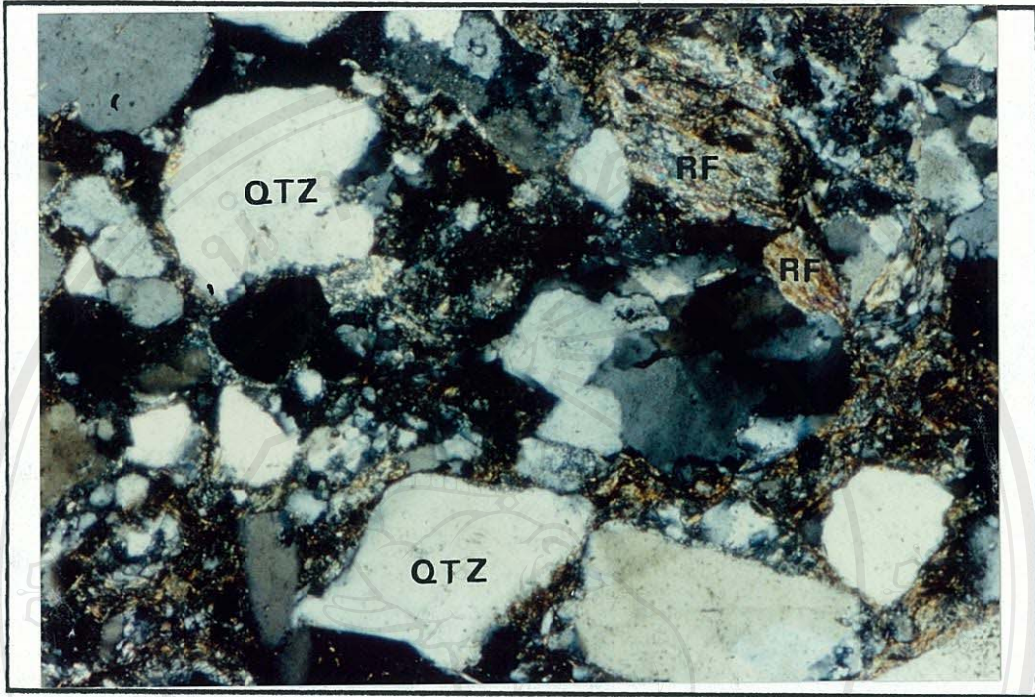
PLATE 4.2

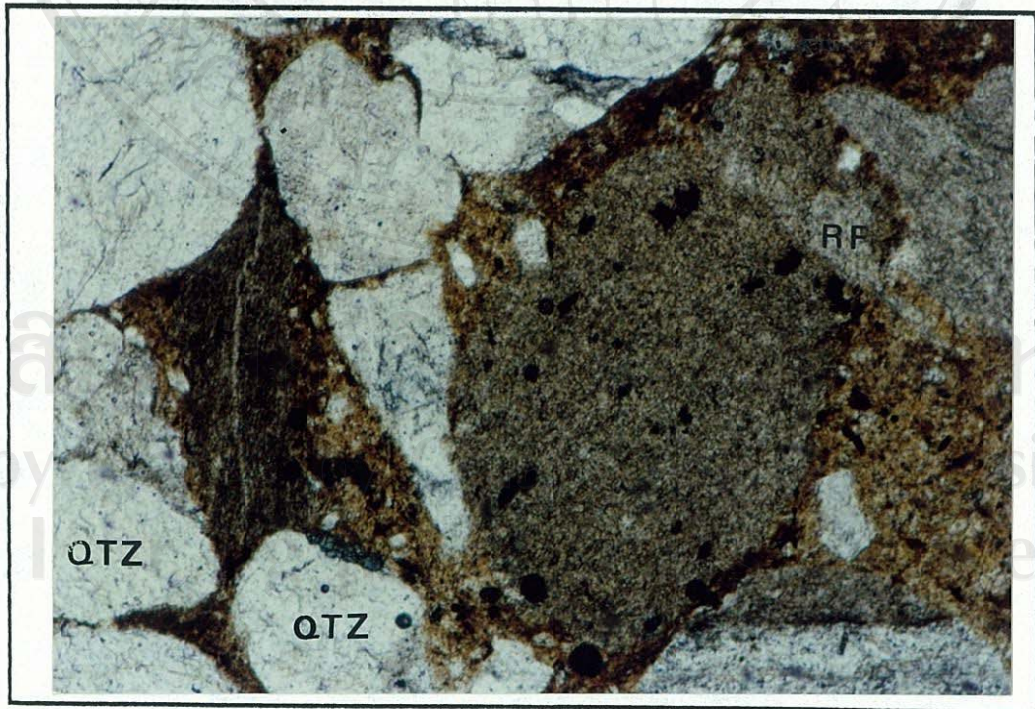Figure 1. Photomicrograph of sandstone from the lower lacustrine facies (mag. 400x)

Figure 2 Photomicrograph of conglomeratic sandstone from the fluvio - lacustrine facies (mag. 400x)

diffraction data, the bulk as well as the clay mineralogy were determined and the amount of the minerals semiquantitatively estimated. The data provided some information regarding the depositional environment, processes and provenance of the sediments.

4.2.1 Sample analysis

About 100 gm. of fresh samples were crushed and ground using a hammer puluveriser and shatter box. Subsamples for X-ray analysis were passed through a 230 mesh sieve. Throughly mixed and dry samples were then packed into alluminium holders as unoriented powder mounts and pressed with glass slide inorder to obtain a flat surface and a preferrential (001) orientation of layered minerals. An X-ray diffractometer with Ni-filtered CuKα radiation was used to obtain X-ray diffractograms. Runs were made at a scanning speed of one degree/minute (2θ) and a scanning distance ranging between 50°-60°. The position of each peak on a diffractogram is measured as an angle "2θ" and values can be read directly from the chart recordings. From these, for the first order reflections, the value of d-spacing can be found using standard tables. The d-spacing value for (001) plane is referred to as the basal spacing which is characteristics of the relevant mineral and may serve to identify it. For the identification, the d-spacing values obtained from the initial diffractrogram are compared with d-spacing values of known minerals on standard tables (Carrol, 1970).

4.2.2 Semiquatitative analysis

Following the identification of the minerals, the relative proportion in a sample can be approximated from the relative intensity of

Figure 4.1 XRD analysis of lowermost shale (Unit 1).

SAMPLE NO. 32

I = Illite
K = Kaolinite
CH = Chlorite
Pl = Plagioclase
Q = Quartz
Si = Siderite
Py = Pyrite

◇ = peak

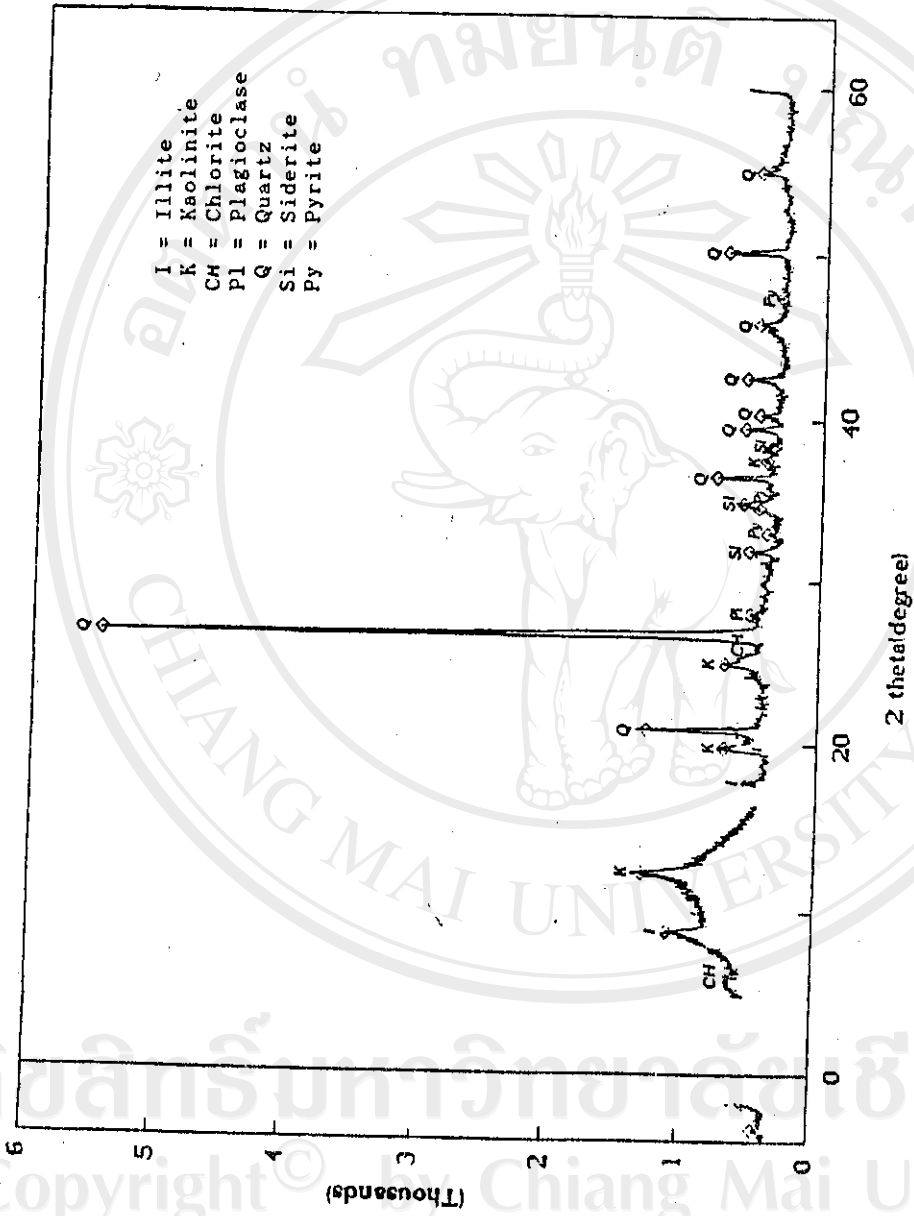Figure 4.2   XRD analysis of lowermost shale (Unit 1).

Figure 4.3 XRD analysis of a shale sample from the lower part of Unit 2.

SAMPLE NO. 15.2

Figure 4.4   XRD analysis of shale from the middle part of Unit 2.
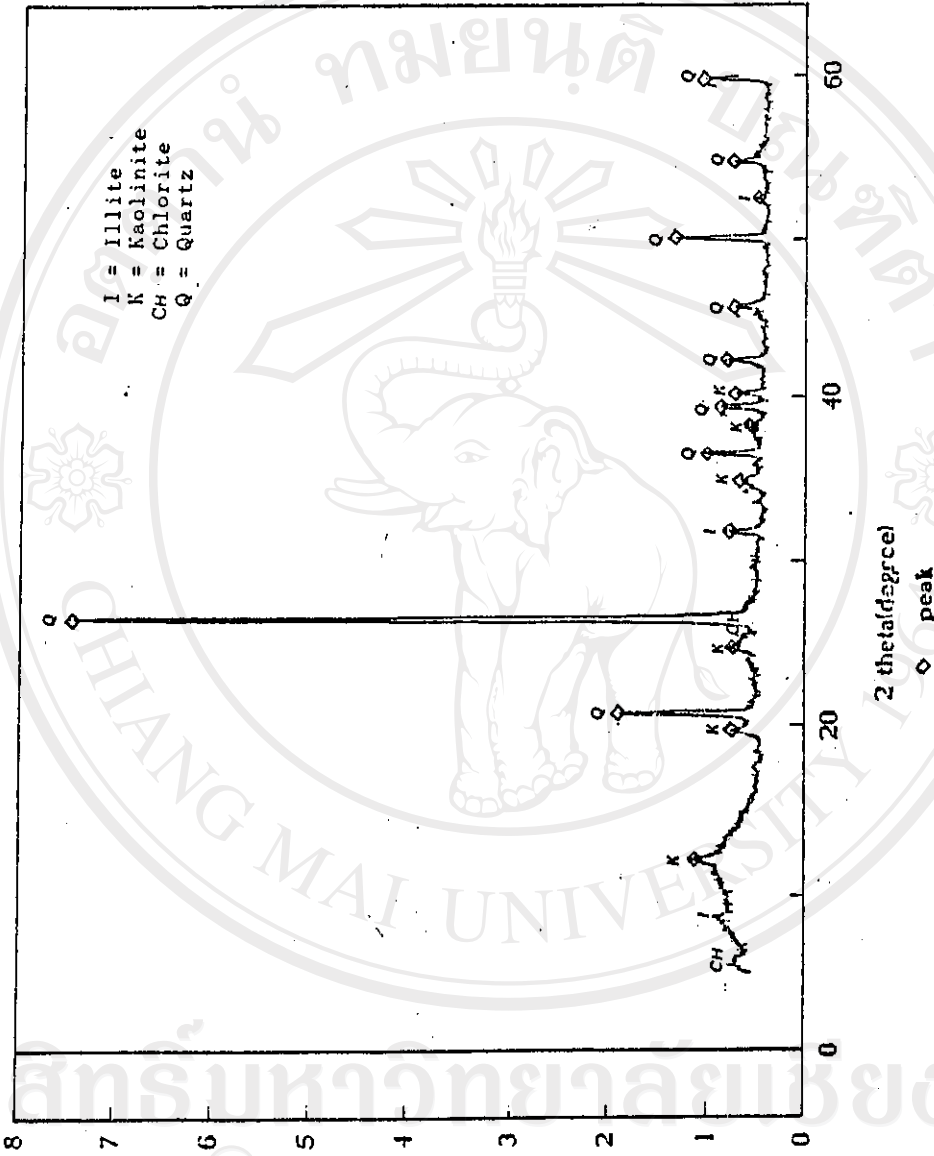
Figure 4.5 XRD analysis of shale from the lower part of Unit 3.

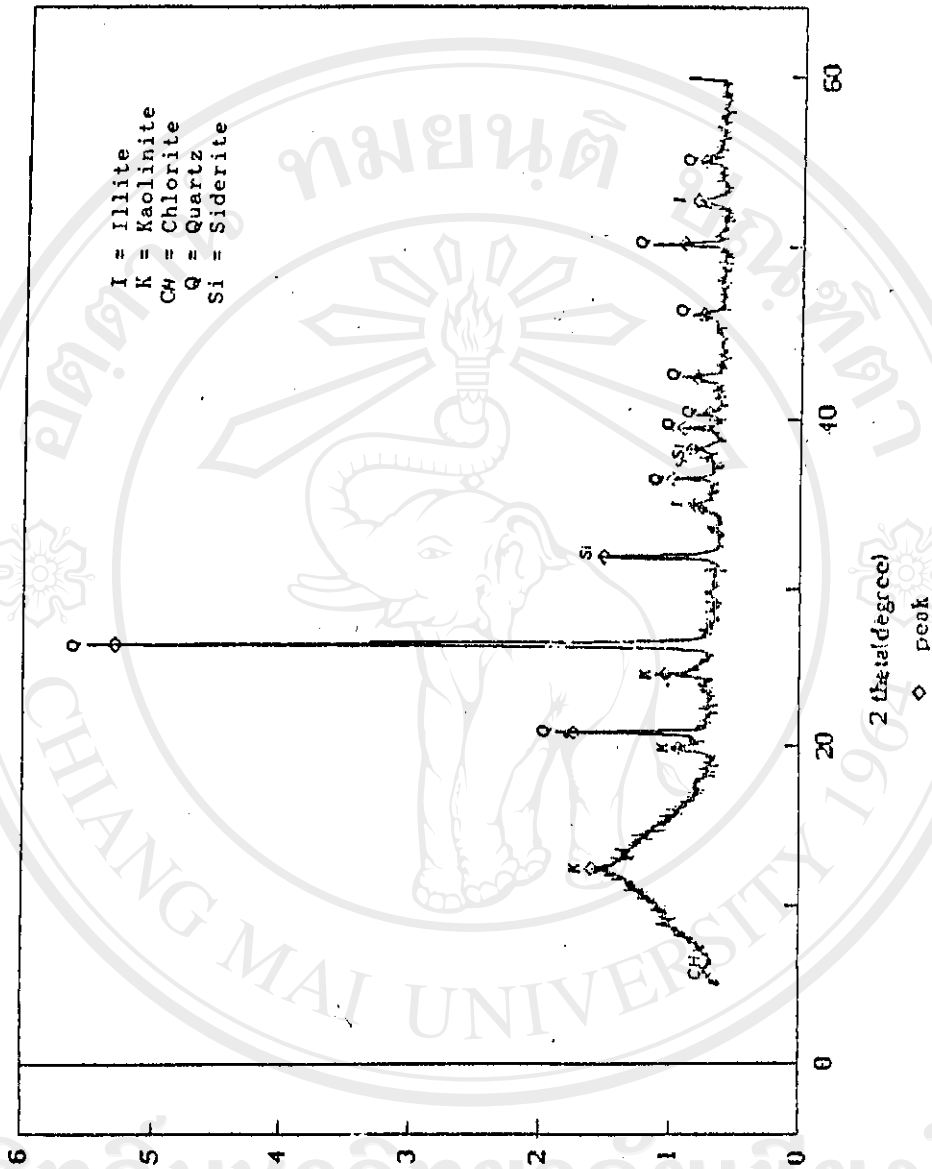Figure 4.6 XRD analysis of claystone from the upper part of Unit 3.

Table 4.1 Relative abundance of minerals of shales from IF 30 03S.

Depth (ft.)	Sample No.	Minerals identified	d-spacing (A°)	hkl	peak height	peak width	mass absorption coefficient CuKα	peak ratio	Relative abundance
4500-4524	38	Kaolinite	7.1522	001	1.3	0.2	30	0.004	7.71
		Quartz	3.3391	101	11.3	0.5	35	0.049	86.18
		Plagioclase	3.1911	002	0.4	0.3	52	0.002	2.06
		Pyrite	2.7061	200	0.3	0.4	200	0.0003	0.54
		Siderite	7.953	104	0.3	0.5	162	0.0004	0.82
		Illite	10.0226	002	0.7	0.2	44	0.002	2.69
4005-4074	32	Illite	10.0090	002	0.6	0.2	44	0.002	1.33
		Kaolinite	7.1646	001	1.0	1.5	30	0.025	24.38
		Quartz	3.3442	101	10.5	0.5	35	0.075	71.56
		Plagioclase	3.1945	002	0.2	0.4	52	0.0008	0.75
		Siderite	2.8014	104	0.2	0.3	162	0.0003	0.76
		Pyrite	1.6341	311	0.3	0.3	200	0.0002	0.22
3595	22	Quartz	3.3478	101	10	0.5	35	0.157	54.67
		Dolomite	2.8733	104	0.2	0.3	50	0.0006	0.22
		Illite	10.0795	002	0.7	0.2	44	0.002	0.56
		Kaolinite	3.5754	002	0.5	0.5	30	0.125	43.93
		Siderite	2.8012	104	0.2	0.3	162	0.0002	0.65
3102	15.2	Illite	10.3000	110	2.0	0.3	44	0.004	3.73
		Kaolinite	3.5920	002	0.7	0.5	30	0.006	6.38
		Quartz	3.3561	010	11.5	0.5	35	0.082	89.89
2759	11.1	Kaolinite	7.2592	001	0.7	0.7	30	0.008	10.49
		Quartz	3.3616	101	12	0.5	35	0.068	87.08
		Illite	4.5135	004	0.7	0.2	44	0.0016	2.04
		Pyrite	2.8148	200	0.6	0.2	200	0.0003	0.39
1934	5.1	Kaolinite	3.5968	002	1.0	0.2	30	0.003	3.90
		Quartz	3.3453	101	11	0.5	35	0.079	87.18
		Illite	2.5657	202	0.3	0.6	44	0.002	2.27
		Siderite	2.7980	104	200	0.3	162	0.0061	6.85

the peaks on an X-ray diffraction pattern and comparison of the half peak areas under the half peak is determined by multipyling the height of the highest intensity peak by the half width at the mid-point of the peak for each mineral. This is then divided by the mass absorption coeficients for CuK of individual minerals to correct the peak intensity. The relative abundance is determined based on the fact that the half peak area of every mineral identified in the sample is converted to 100 percent.

4.2.3 Interpretation of X-ray data

Typical diffraction traces for each of the samples are illustrated in Figures 4.1 to 4.6. Table 4.1 shows the semiquantitative percentages of the minerals identified and is calculated from the half peak areas and corrected by the mass absorption coefficient. Clay minerals in the samples are represented by abundant kaolinite, and illite is present in trace amounts. No significant variation was observed in clay mineralogy with depth except that kaolinite is at its maxima in the fluvio-lacustrine and lacustrine facies. Illite is fairly uniformly distributed throughout the section. Chlorite and calcite occur only in trace amount in some samples. The non clay mineral components in the samples are dominated by quartz (ranging between 54.64-89.89 %) and minor plagioclase feldspars (0.75-2.06 %). A few X-ray diffraction traces contain some peaks attributable to siderite, pyrite and dolomite.

4.3 ENVIRONMENT OF DEPOSITION

The minerals of sedimentary rocks should arouse an attention as indicators of the physico-chemical environment or of the change in the

environment of deposition. A great number of minerals in sedimentary rocks may serve as indicators of the condition of sedimentation, of the value of pH, salinity and partly of temperature. In particular, authigenic minerals are of great interest since they reflect the physico-chemical conditions of sedimentation, the diagnetic history of the sedimentary rocks etc. (Teodrovich, 1961). Similarily clay minerals present in argillaceous deposits at the time of deposition depend on the character of the source rocks and on the environment of the source area, although they may be altered in the depositional environment (Williams and others, 1985). Hence, authigenic and some clay minerals can give an insight into the depositional environment and the provenance of the sediments. In this study, authigenic minerals such as siderite, pyrite and dolomite and the kaolinite minerals are of great importance in this regard.

Authigenic dolomite in the samples could have formed during early dignesis and under low sulfate (Gibling and others, 1985) and is characteristics of an alkaline environment where pH is greater than 7.45 (Teodrovich, 1961) or could have precipitated from a stratified lake (Sherwood and others, 1984). Siderite is chiefly a syngenetic mineral (the period of diagnesis of sediments) and may occur as disseminated grains in argillaceous rocks. It forms in a weakly reducing to neutral and reducing environments and hence is an indicator of oxidizing to reducing conditions (Teodrovich, 1961). As discussed by Krauskopf (1978), siderite may also preciptate in quantity where the supply of ferrous iron is large or a reducing environment is maintained by abundant organic matter. Pyrite is

the principal iron-bearing mineral formed under strongly reducing conditions that may occur in restricted environments where organic matter accumulates and oxygen supply becomes depleted (Williams and others, 1985).

Kaolinite is generally of exogenetic surfacial origin, formed during, weathering of aluminosilicates in igneous, metamorphic and occassionally sedimentary rocks. It is normally derived from the surface weathering of acidic and intermediate igneous rocks and gneiss (Teodrovich, 1961) also commonly from basic rocks. Quick release of potassium and magnesium ions from acidic rocks, due to intensive weathering, leads to the formation of kaolinite. Similarily the removal of magnesium ions from a parent basic rock, owing to high rainfall and good drainage may results in kaolinite formation. It may also form authigenically in an acid environment or could preciptate from solutions circulating through sedimentary rocks.

According to Grim (1968), fluviatile environments are ideal sites for kaolinite deposition and William and others (1985) pointed out that kaolinite is more stable in fresh water than in marine environments because it occurs abundantly in non-marine rocks. Caroll (1970) suggested that kaolinite is generally more abundant in regions of tropical weathering than in temperate zones and occurs in detrital deposits derived from tropical weathering.

In summary, much of the detrital materials contained in the sediments could have been contributed from igneous, sedimentary and metamorphic rocks exposed in the proximity of the depositional site. Reducing conditions were estabilished through much of the deposition of the lower part of the

sedimentary succession as indicated by the presence of siderite and pyrite. Although under rare cases, or periodically, similar conditions might have prevailed in the upper part of the sequence.

4.4 ORGANIC PETROLOGY

4.4.1 Introduction

A suite of shale cores were studied using organic petrographic methods. Organic petrological methods can allow the determination of the organic matter composition, abundance and maturation level. The type and abundance of organic matter can be used to determine source potential. In combination with the maturation level, they are used to define the generative potential of a given source rock.

Organic petrographic characteristics of source rocks can be assessed in terms of quantitative and semiquantitative maceral analyses. Maceral analysis of source rocks is specially useful when oilproneness and maturation are to be determined. Macerals are the microscopic constituents of coals analogous to minerals in rocks. Organic matter in source rocks can be placed into one of the major maceral types : Exinite (liptinite), vitrinite and inertinite. Exinite type organic matter, owing to its sufficiently high hydrogen content, is considered to be excellent (alginite) or good (resinite, cutinite, sporinite) source material for oil; vitrinite, for example, has enormous potential for gas but little for oil;and inertinite is generally discounted as a source altogether, or at most as a source for gas only.

In this study, organic petrographic methods were employed in view of characterising the organic petrographic features as well as the maturity status of the organic matter. In addition, an attempt has been made to estabilish the organic matter distribution over the vertical section.

4.4.2 Organic Petrological method

For this study, each sample was prepared as a polished particulate block/grain mount following ASTM'S standard D-2797-85 (ASTM, 1989). Its organic matter content was determined microscopically by the point count technique. Oil immersion and incident light (both plane polarised white light, and blue light excitation) were used at 400 x magnification. The organic matter was classified in accordance with the recommendations of the international committee for coal petrology (ICCP, 1963; 1971; Table 4.2) with the modification and subdivision of the term alginite (Hutton and others, 1980; Cook and others, 1982). Lamalginite (Alginite B) refers to thin lamellar or filamentous alginite. Telalginite (Alginite A) refers to discrete colonial and unicellular algal bodies that are ellipsoidal or disc shaped. Optical studies in reflected light allowed the identification of vitrinite and inertinite groups, whereas, exinite macerals were identified using fluorescence mode microscopy. The identified macerals were photographed using oil immersion objectives and at a magnification of 400 x in reflected white light.

Table 4.2   Terminology, origin and optical properties of macerals
            (ICCP, 1963, 1971)

Maceral Group	Maceral Sub-Group	Maceral	Properties
Vitrinite (Humified tissue typically derived from lignin, cellulose and tannins origin)	Telovitrinite	Textinite Texto-ulminite Eu-ulminite Telocollinite	Reflectance range small and lying between those of liptinite and inertinite. Fluorescence moderate, weak or absent.
	Detrovitrinite	Attrinite Densinite Desmocollinite	
	Gelovitrinite	Corpogelinite Porigelinite Eugelinite	
Inertinite (Thermally or biochemically altered tissues origin)	Teloinertinite	Sclerotinite Semifusinite	Reflectance above that of vitrinite except at extremely high rank. Weak or no fluorescence.
	Detroinertinite	Fusinite Micrinite	
	Geloinertinite	Inertodetrinite Macrinite	
Liptinite (Sporopollenin, cutin, suberin, resins, waxes, oils, algal and phytoplankton origin).		Alginite Sporinite Cutinite Suberinite Resinite Fluorinite Exsudatinite Bituminite Liptodetrinite	Reflectance below that of vitrinite, except at high rank where reflectance becomes equal to or greater than that of vitrinite. Fluorescence distinct to intense.

4.4.3 Organic Petrological features (Results and discussion)

Volumetric composition of the samples studied is presented in Table 4.3. On handspecimen and microscopic scale, the lower lacustrine shales are distinctly laminated in which organic rich laminae alternate with mineral matter rich layers. These shales are distinguished by higher algal organic matter and higher plant exinite maceral input. Most of the exinite macerals consist of alginites and liptodetrinites, and resinite/bitumen are also ubiquitous. Lamalginite could be present but is not typically the dominant form. Rather, the bulk algal material occurs as telalginite and is referrable to forms related to *Botroyococcus* (Plate 4.3, Figure 1) and may sometimes constitute upto 20 % of a lamination. Telalginites occur as discrete entities having either elliptical or spherical shapes. Fluorescence color ranges from orange through dull orange to brownish orange. *Botroyococcus* related alginite is derived from planktonic green alga, commonly occuring in small and shallow fresh-water lakes.

A unique characteristics of the lower lacustrine shales is the complete absence of inertinite macerals except sclerotinite (Plate 4.3, Figure 2), which is of fungal origin. Inertinite macerals originate from oxidation as a result of microbial attack or fires (Bustin et al., 1985) and are not rare in source rocks. The relative scarcity of inertinites may have resulted from extensive reworking, greater communition and oxidation of inertinites prior to deposition.

In most cases, the *Botroyococcus* alginites are partially or wholly replaced by fine grained anhedral pyrite, non fluorescing quartz and clay

Table 4.3 Volumetric composition, fluorescence colours and intensity of exinite macerals of shale samples (Oil Well IF 30 03S).

Sample No. and depth (ft.)	Exinites (with fluorescence colours)				non fluorescing OM	Inorganic matters %	
	Lamalginite	Telalginite	Liptodetrinite	Bitumen/Resinite	Huminite/inertinite	Pyrite/other highly reflecting mineral metter	Clay/silt size mineral matter
15 (3181) UPFLF	rare	rare	2 (yo, my, mo)	3 non-fluorescing	12/3	rare-sparse	80
16* (3200-3250) UPFLF	rare	rare	3 (yo, my, mo)	3 non-fluorescing	16/3	rare-sparse	75
19 (3579) UPFLF	5 (myo, yo)	1 (mo, my)	10 (various mo, my, yo, myo)	4 (dbr, non fluorescing)	16/2	3	59
22 (3597) LPFLF	1	12 (mobr, my)	10 (mo, my, db)	4 (weak, dbr)	15/0	4	54
25 (3627) LLF	rare	rare-sparse (mdo, y, o)	2 (my, mo)	3 weak-non fluorescing	10/2	1	82
33 (4055) LLF	rare-sparse	3 (mdo, y, o)	4 (y, o, mdo)	3	15/0	sparse	75
38 (4505) LLF	1 (myo, o)	8 (mdo, do)	9 (my, mo, do)	3 do, dy, weak-non fluorescing	16/0	3	60

Table 4.3 Cont.

| Sample No. and depth (ft.) | Exinites (with fluorescence colours) | | | | non fluorescing OM | Inorganic matters % | |
	Lamalginite	Telalginite	Liptodetrinite	Bitumen/Resinite	Huminite/inertinite	Pyrite/other highly reflecting mineral metter	Clay/silt size mineral matter
40 (4523) LLF	1 (do, myo)	11 (mdo, do)	11 (do, my, mo)	4 weak-non fluorescing	12/0	4	57

Key Fluorescence intensities : m = medium; d = dull

Fluorescence colours : y = yellow; o = orange; b = brown

abundance : rare = < 0.5 %; sparse = 0.5-1 %

UPFLF = Upper part of fluvio-lacustrine facies

LPFLF = Lower part of fluvio-lacustrine facies

LLF   = Lower lacustrine facies

*   = Cutting sample

PLATE 4.3
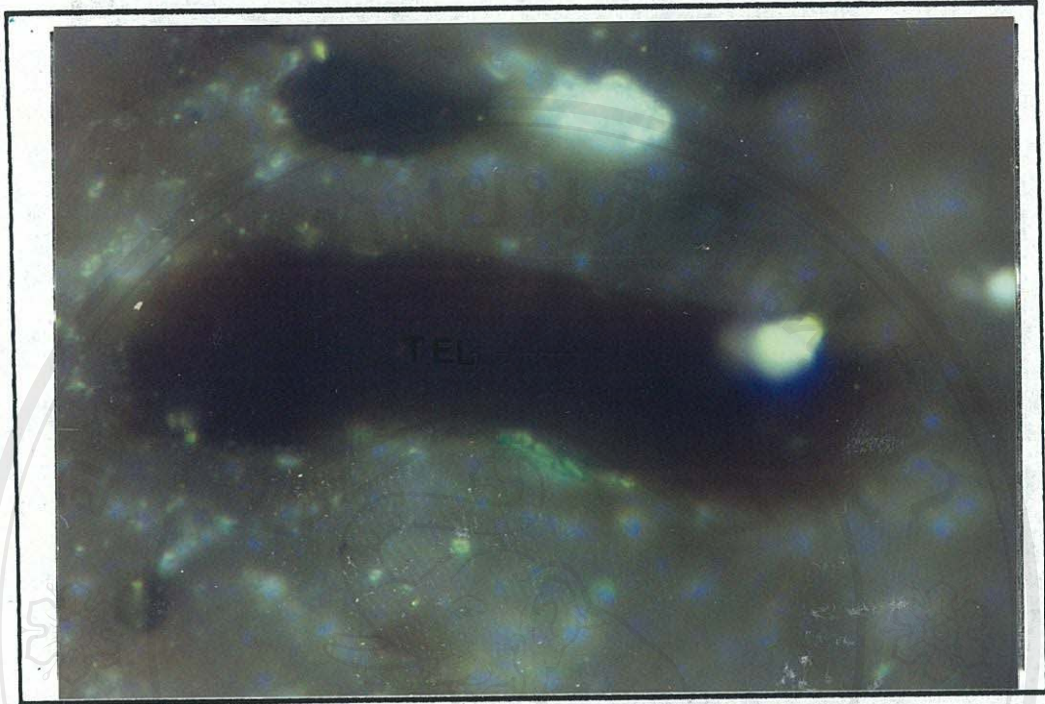
Figure 1. Lower lacustrine shale showing Botroyococcus related Telalginite (oil imm., mag. 400x)
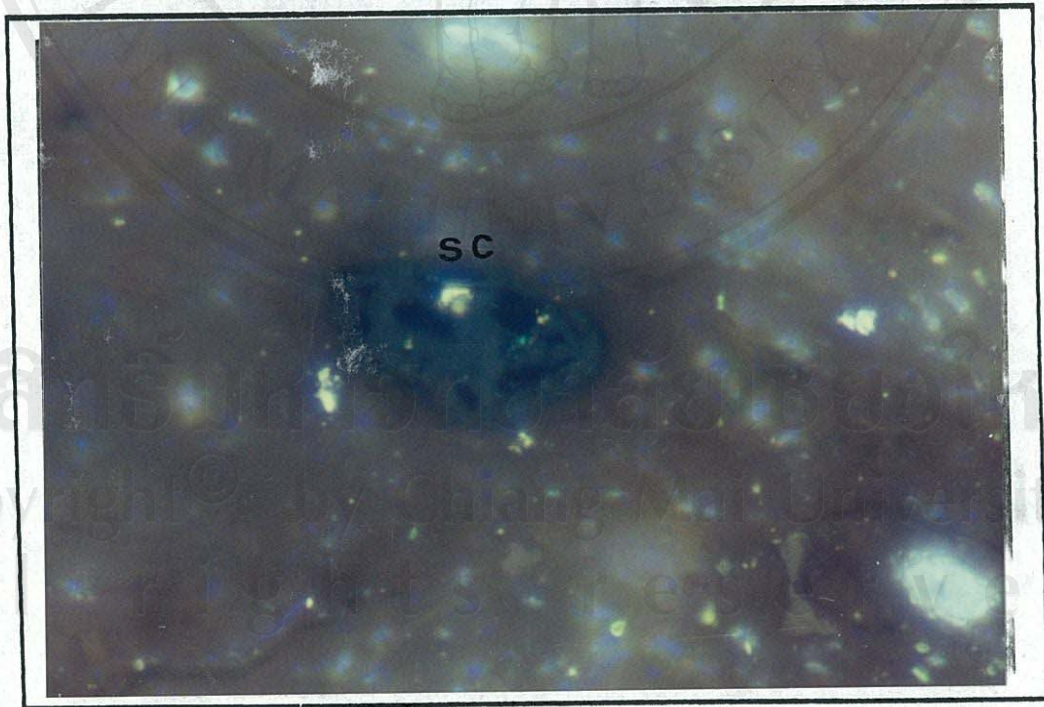
Figure 2 Sclerotinite in the lower lacustrine shale (oil imm., mag. 400x)

minerals (Plate 4.4, Figure 1). Where total replacement occurs, the alginites have a much reduced fluorescence intensity and granular texture. In most cases, the alginites may not be replaced (Plate 4.4, Figure 2).

Vitrinite is typically the most abundant maceral in the upper part of fluvio-lacustrine shales. Liptodetrinite, resinite/bitumen and lamalginite are present only in trace amounts. Inertinite is not also a major component, but may occur in form of inertodetrinite. Vitrinite occurs as small phytoclasts (Plate 4.5, Figure 1), laminae, lenses, disseminated fragments or stringers. The phytoclasts are probably derived from fragments of terrestrial higher plants whereas the stringers are possibly derived from fungal or other higher vascular plants. Inertodetrinite is common in the upper part of the fluvio-lacustrine shales (Plate 4.5, Figure 1). It is probably derived from fusinite, semifusinite or reworked vitrinite. Higher reflectances observed in some grains may suggest origin from charred plant remains. Communited lipinites which are invariably associated with the vitrinite could possibly refer to a detrital origin.

Lamalginite (Alginite B of Hutton et al., [1980] and renamed lamalginite by Cook et al., [1982]) is found in some samples and consists of filamentatous organic matter with filaments elongating parallel to bedding (Plate 4.5, Figure 2). They occur as continuous or discontinuous groups. Sections of lamalginite parallel to bedding show irregular forms. Under reflected white light some lamalginites occur as gray homogenous material but lack fluorescence. Fluorescence colors range from medium yellowish orange through medium yellow to medium/dull orange. Lamalginite is mainly derived from planktonic and perhaps from benthonic precursors.
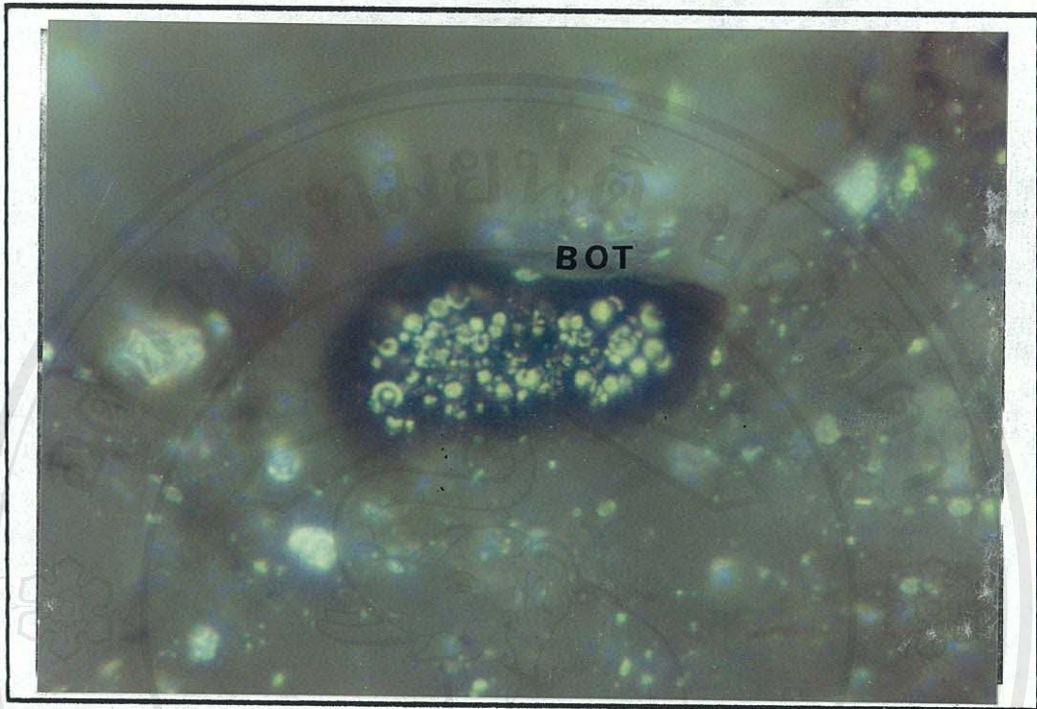
PLATE 4.4

Figure 1 Botroyococcus related Telalginite partially replaced by fine
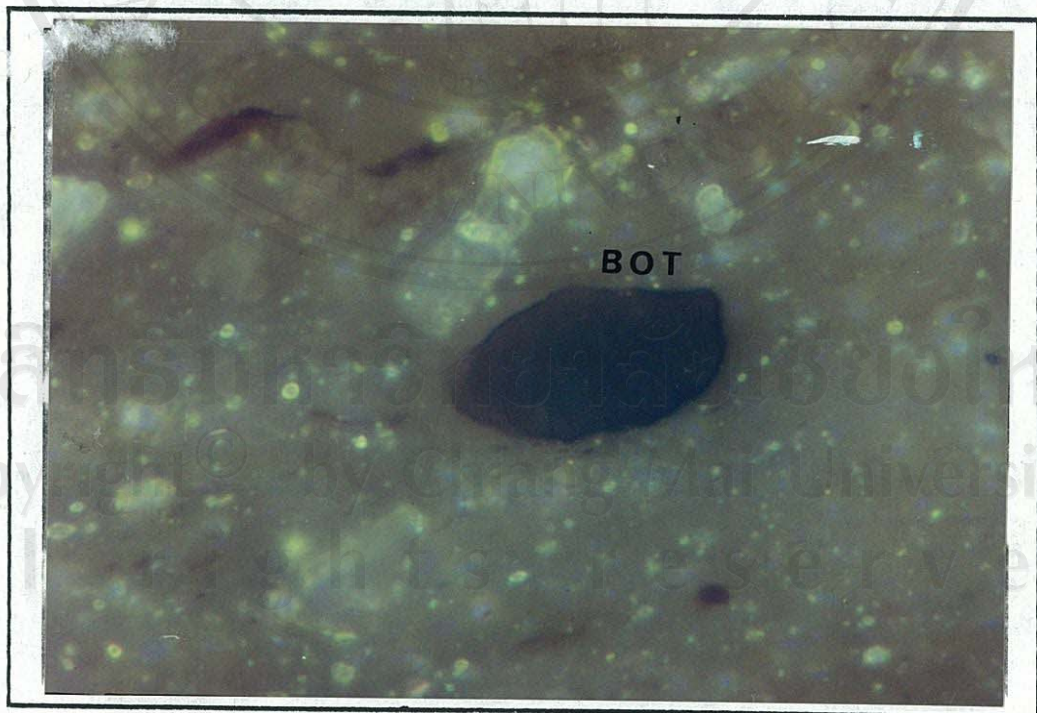aggregates of pyrite and mineral matter (oil imm., mag. 400x)

Figure 2 Botroyococcus related Telalginite from the lower lacustrine shales
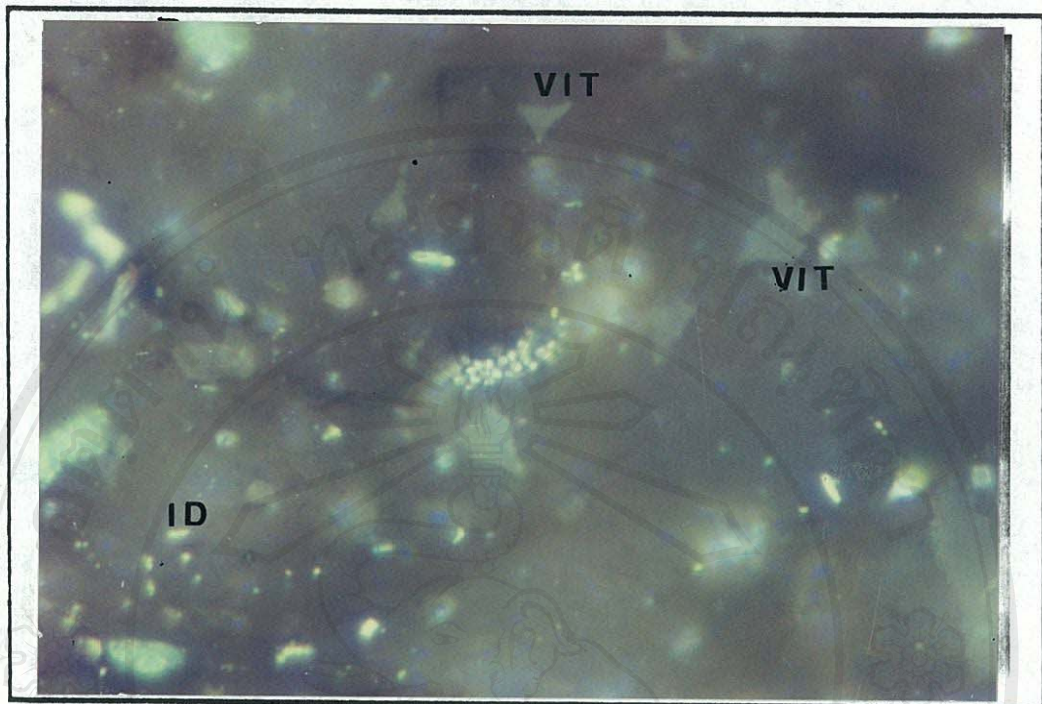(oil imm., mag. 400x)

PLATE 4.5

Figure 1 Common forms of vitrinite and fine aggregates of pyrite (oil imm.,
mag. 400x) from the upper part of the fluvio-lacustrine facies.
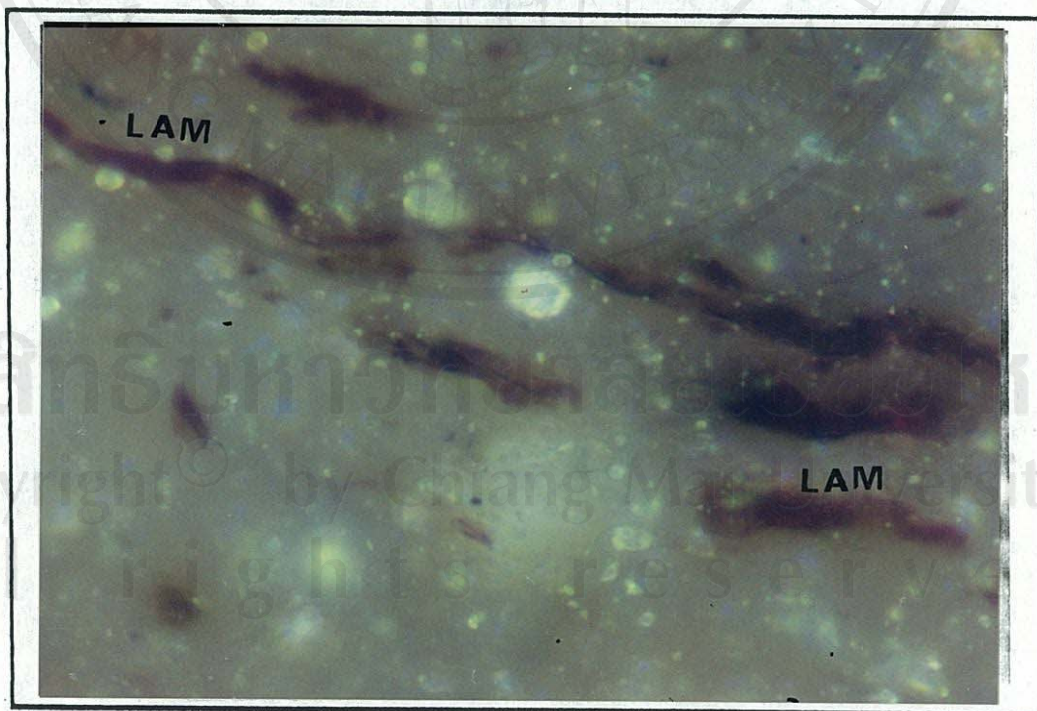Note also the sparse inertodetrinite.

Figure 2 Lamalginite running parallel to bedding plane (oil imm., mag. 400x)

Liptodetrinite (Plate 4.5, Figure 1) is ubiquitous in most samples and occurs as disseminations or concentrated in some laminae. It is found in abundance in the lower lacustrine shales and occurs in a variety of forms such as tiny flecks, grains, less commonly as rods or splinters. It fluoresces in dull orange, orange, and yellow colors with dull to moderate intensity. Most of the liptodetrinite is supposed to have originated from alginites, tiny pods of resinite/bitumen or fragmented remains of other exinites.

Bitumen/resinite, mostly non fluorescing, commonly occurs as isolated pods or irregularily shaped globules. It also forms thin, and anastomosing veins running parallel to bedding planes. It probably originates from fats, resins, and waxes extruded from organic matter or from migrated hydrocarbons.

Some samples with a brown to dark matrix show background fluorescence coming from within the groundmass after prolonged irradiation. This fluorescence may have its origin in the fine grained algal or other organic materials in the mineral groundmass or alternatively from H-rich exinites. Commonly, quartz and clay minerals as well as pyrite [anhedral and framboidal (Plate 4.5, Figure 2)] are intimately mixed with the organic and mineral groundmass.

In summarising, the petrographic entities recognised above appear to have been derived from a number of precursor materials such as higher plant liptinites (liptodetrinite, resinite/bitumen), algal organic matter (alginites) and terrestrial higher plant detritus (vitrinites and minor inertinites). The distribution of organic matter is such that there is a rela-
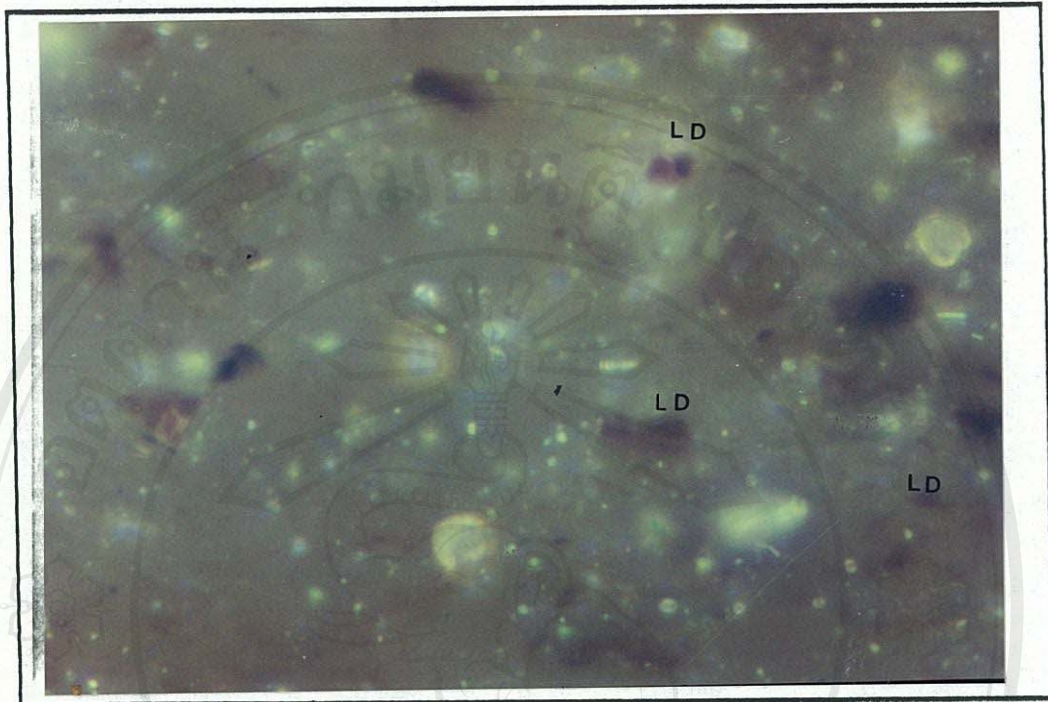
PLATE 4.6

Figure 1 Typical field of view showing abundant liptodetrinite from the lacustrine shales (oil imm., mag. 400x)
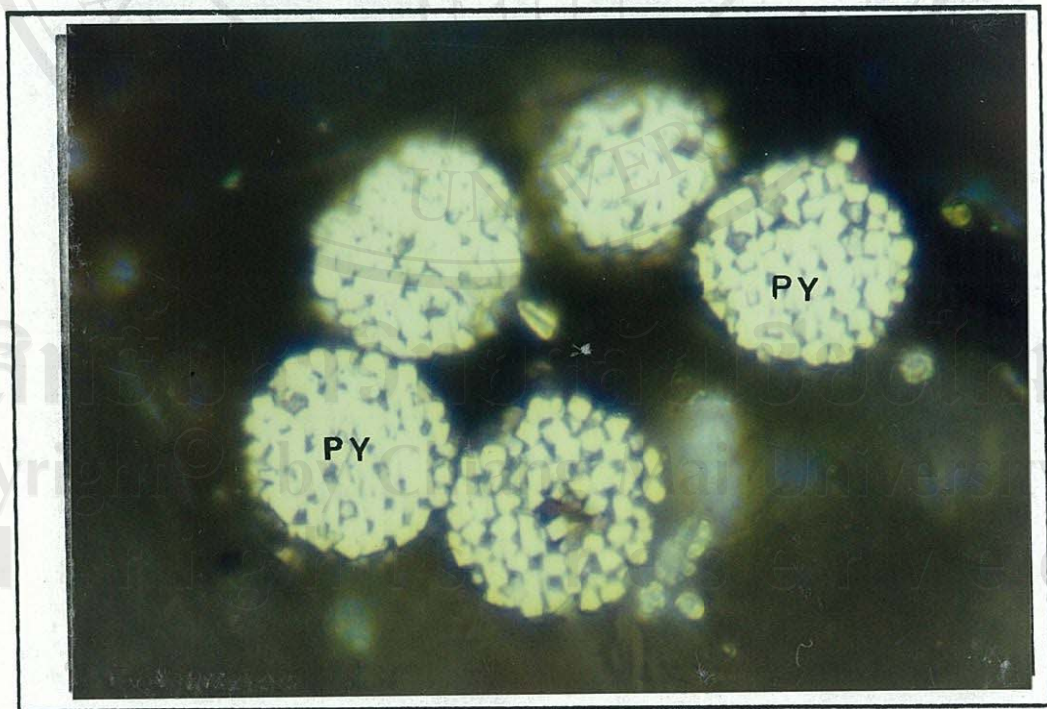

Figure 2 Framboids of pyrite (oil imm., mag. 400x) from the lower lacustrine shales.

tively higher input of algal organic matter in the lower lacustrine shales. The maceral composition of the upper part of the fluvio-lacustrine shales is consistent with a higher plant source; vitrinite is typically the most abundant maceral. Geochemical evidences (Chapter 6) also strongly argue for this assumption. Type II kerogen (which is of higher plant liptinite and algal origin), higher HI and TOC values typically characterise the lower lacustrine shales. Petrographic and geochemical evidences could perhaps suggest an increase towards a better source potential with depth, partly for the presence of relatively abundant liptinite macerals and type II kerogen, both of which are oil prone.

4.4.4 Thermal maturity

The amount of oil or gas formed from a source rock is not only a function of the type and abundance of organic matter contained in it but also depends on the maturity status of the organic matter. Examination in transmitted or reflected light with or without fluorescence provides different types of informations on the thermal evolution of the organic matter. The most commonly applied optical parameters are vitrinite reflectance and spore pollen colouration (Thermal alteration index). Data for this study are given on Table 4.4.

Vitrinite reflectance is based on the reflectance measurements of coal macerals. TAI has its base on progressive changes of color and/or structure of spores and pollens. As to vitrinite reflectance, there is no distinct limit for the oil window (Stach, 1985) but rather varies widely between 0.35 and 0.6 % Ro [Heroux et al. (1979)]. The oil and gas death lines are

Table 4.4 Spore colour index and vitrinite reflectance
data (after D.E.D., 1987).

SAMPLE DEPTH (ft.)	SPORE COLOUR INDEX (1-10)	VITRINITE REFLECTIVITY (Ro Oil av %)
1680-1720	3.5	0.40
2080-2120	3.5-4.0	0.73
2580-2620	4.0-4.5	0.42
3100-3140	4.0-4.5	0.45
3700-3740	3.5-4.0	0.47
4100-4140	4.0-4.5	0.47
4460-4500	4.5-5.0	0.48

better defined at values corresponding to 1.3-1.4 % and 2.5-3.5 % Rm, respectively. TAI is expressed according to a scale from 1-5. Oil source rock potential requires a TAI value between 2 and 3. The range from 2.5 to 3.0 encompasses the entire oil window.

The vitrinite reflectance values for the analysed samples range between 0.39-0.48 % Ro (Table 4.4). Based on these values, the shales could be evaluated as immature to marginally mature. However, it should be considered here that the rank of the shales might not be as low as that indicated by the vitrinite reflectance values. It is well estabilished that the presence of alginite can significantly lower vitrinite reflectance values (Hutton et al., 1980). This may probably be the case for the lower part of fluvio-lacustrine and lower lacustrine shales which contain abundant alginite macerals. A similar conclusion was reached by (D.E.D., 1987, Figure 4.7). According to that plot the maturity profile indicates an early mature stage. The spore color index values are given in Table 5.4. A plot of these data versus depth and the corresponding TAI of these data against depth and the corresponding TAI values (Figure 4.8) which vary from 2 to 2.5 indicate also an early mature stage of the organic matter.
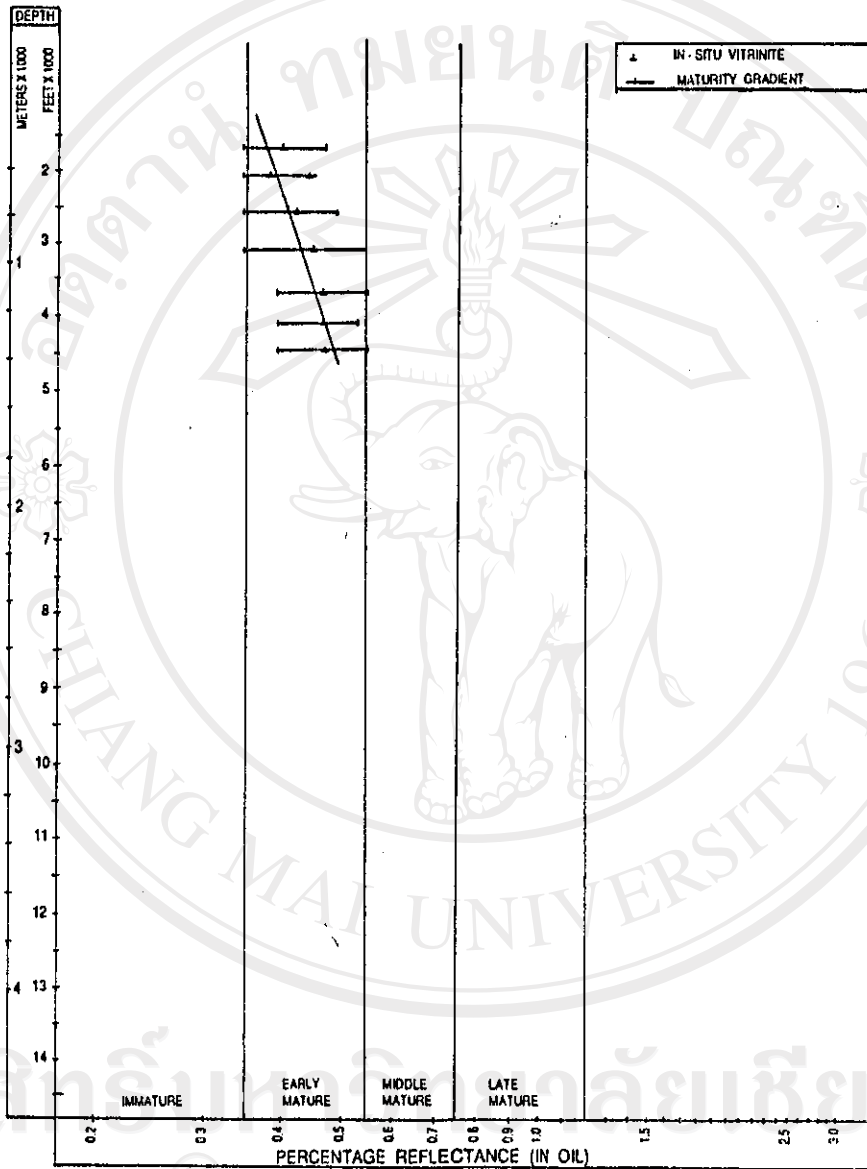
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FIGURE 47 VITRINITE REFLECTANCE AGAINST DEPTH (after D.E.D, 1987)

FIGURE 4.8 SPORE COLOR INDEX AGAINST DEPTH (after D.E.D, 1987)