DEPOSITIONAL ENVIRONMENT AND PETROLEUM SOURCE ROCK POTENTIAL IN MAE TEEP BASIN, LAMPANG PROVINCE

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สภาพแวดล้อมการสะสมตัวและศักยภาพของหินต้นกำเนิดปิโตรเลียม ในแอ่งแม่ตีบ จังหวัดลำปาง

นางสาวปิยะธิดา แสงทอง

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรดุษฎีบัณฑิต
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Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy.

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ปิยะธิดา แสงทอง : สภาพแวดล้อมการสะสมตัวและศักยภาพของหินต้นกำเนิดปิโตรเลียมในแอ่งแม่ตีบ จังหวัดลำปาง (DEPOSITIONAL ENVIRONMENT AND PETROLEUM SOURCE ROCK POTENTIAL IN MAE TEEP BASIN, LAMPANG PROVINCE) อาจารย์ที่ปรึกษา : ผู้ช่วยศาสตราจารย์ ดร. อัมพรรค์ วรรณโกมล, 275 หน้า.

วัตถุประสงค์หลักสองประการของการศึกษาครั้งนี้ คือ 1) เพื่อระบุศักยภาพของหินต้นกำเนิดปิโตรเลียมในแอ่งแม่ตีบโดยใช้การวิเคราะห์ทางธรณีเคมีและเทคนิคศิลาวรรณาวิทยาในอินทรีย์วัตถุ และ 2) เพื่อประเมินสภาพแวดล้อมการสะสมตัวและลักษณะของหินต้นกำเนิดปิโตรเลียมที่มีศักยภาพในแอ่งแม่ตีบ ตัวอย่างจำนวน 44 ตัวอย่าง จากเหมืองถ่านหินแม่ตีบ ถูกรวบรวมจากชั้นหินอินทรีย์หลัก 3 ชั้น จากหน้าเหมืองปัจจุบันในแนวตั้ง ประกอบด้วย ตัวอย่างหินน้ำมัน 14 ตัวอย่าง ตัวอย่างถ่านหิน 26 ตัวอย่าง และตัวอย่างลีโอนาร์ไดต์ 4 ตัวอย่าง ตัวอย่างเหล่านี้ถูกนำมาวิเคราะห์ด้วยวิธีการทางศิลาวรรณาและทางธรณีเคมีเพื่อการตีความถึงสภาพแวดล้อมของการสะสมตัวและศักยภาพด้านปิโตรเลียม ผลการศึกษาทางด้านศิลาวรรณาแสดงมาเซอรัลหลักเป็น ลิบติไนต์และวิตทริไนต์ซึ่งบ่งชี้ให้เห็นว่าสภาพแวดล้อมของการสะสมตัวจากด้านล่างขึ้นไปด้านบนของชั้นหินที่ทำการศึกษามีการเปลี่ยนแปลงจากที่ลุ่มน้ำขังตื้นๆไปเป็นป่าน้ำขังที่มีต้นไม้ใหญ่และเปลี่ยนไปเป็นทะเลสาบน้ำลึกและนิ่ง ผลการวิเคราะห์ทางธรณีเคมีแสดงค่าเฉลี่ยของปริมาณเถ้า 57.28 wt.% ปริมาณสารระเหยเฉลี่ย 28.45 wt.% ปริมาณธาตุคาร์บอนคงที่เฉลี่ย 14.28 wt.% ปริมาณธาตุคาร์บอนเฉลี่ย 23.44 wt.% และปริมาณธาตุไฮโดรเจนเฉลี่ย 3.17 wt.% ผลจากการวิเคราะห์ไพโรไลซิสแสดงค่าปริมาณของธาตุคาร์บอนโดยรวมทั้งหมด (TOC) มีค่าเฉลี่ยเป็น 23.04 wt.% ค่า S1 เฉลี่ย 1.47 mg/g ค่า S2 เฉลี่ย 53 mg/g ค่า S3 เฉลี่ย 5.57 mg/g และมีค่าอุณหภูมิสูงสุด (T_{max}) อยู่ช่วงระหว่าง 422 และ 434 องศาเซลเซียส ค่าศักยภาพการให้สารกำเนิดปิโตรเลียม (S1+S2) ของตัวอย่างที่นำมาศึกษามีค่าค่อนข้างสูงมาก (22.13 ถึง 72.12 mg/g) ซึ่งบ่งชี้ถึงการเป็นหินต้นกำเนิดปิโตรเลียมที่ดีมาก อย่างไรก็ตามระดับขั้นภาวะการได้ที่อันเนื่องมาจากความร้อนของตัวอย่างที่นำมาศึกษาที่ได้จากการวิเคราะห์การสะท้อนแสงของวิตทริไนต์นั้นมีค่าระหว่าง 0.31 และ 0.50 % Ro ซึ่งบ่งชี้ถึงระดับขั้นภาวะการได้ที่อันเนื่องมาจากความร้อนที่อยู่ในช่วงระดับขั้นภาวะก่อนการได้ที่ถึงระดับขั้นภาวะการได้ที่เริ่มต้น

สาขาวิชา <u>เทคโนโลยีธรณี</u> ลายมือชื่อนักศึกษา.....ปิยะธิดา แสงทอง.....

ปีการศึกษา 2561 ลายมือชื่ออาจารย์ที่ปรึกษา.....

ลายมือชื่ออาจารย์ที่ปรึกษาร่วม.....

PIYATIDA SANGTONG : DEPOSITIONAL ENVIRONMENT AND PETROLEUM SOURCE ROCK POTENTIAL IN MAE TEEP BASIN, LAMPANG PROVINCE. THESIS ADVISOR : ASST. PROF. AKKHAPUN WANNAKOMOL, Ph.D., 275 PP.

PETROLEUM POTENTIAL SOURCE ROCK/PROXIMATE AND ULTIMATE ANALYSIS/ORGANIC PETROLOGY/DEPOSITIONAL ENVIRONMENT/ MAE TEEP BASIN

Two main objectives of this study are: 1) to identify potential petroleum source rocks in Mae Teep basin using geochemical analysis and organic petrography techniques, and 2) to assess depositional environment and characteristics of potential petroleum source rocks in Mae Teep basin. Total of 44 samples from Mae Teep coal mine were collected in vertical succession from the present mining face. They were from 3 main organic units, including 14 oil shale, 26 coal and 4 leonardite samples. Petrological and geochemical analyses of samples were undertaken to interpret their depositional environments and petroleum potentiality. Petrology study shows that macerals in these samples are mainly liptinite and vitrinite which indicate that depositional environments of the studied succession changed from shallow swamp, forested swamp to a deep and stagnant lacustrine, as from the bottom to the top respectively. Geochemical analyses show an average of 57.28 wt.% ash, 28.45 wt.% volatile matter, 14.28 wt.% fixed carbon, 23.44 wt.% carbon and 3.17 wt.% hydrogen. Pyrolysis analyses show an average of 23.04 wt.% TOC, 1.47 mg/g of S1, 53 mg/g of S2, 5.57 mg/g of S3, and T_{max} ranges between 422 ºC and 434 ºC. The genetic potential (S1+S2) of the studied samples are very high and vary from 22.13 to 72.12 mg/g which indicates their excellent source

rock potentiality. However, thermal maturation determined by vitrinite reflectance of the studied samples ranges between 0.31 and 0.50 %Ro, indicating the immature to early mature stage.

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CHAPTER I

INTRODUCTION

Most of petroleum production in Thailand has been obtained from Tertiary basins. They occur both onshore and offshore (Chaodumrong *et al*., 1983). The main petroleum producing areas in 4 geological terrains of Thailand are Gulf of Thailand, onshore Northern and Central, onshore Northeastern (Khorat basin) and Mergui basin of Andaman Sea (DMF, 2007) (Figure 1.1) and especially in northern Thailand there are more than 40 basins (Polachan *et al*., 1991).

Tertiary basin occurred during Oligocene to Early Miocene (approximately 19 to 31 Ma), with unconformities occurred during the Upper Oligocene/Lower Miocene boundary (~24.5 Ma) and the Lower/Middle Miocene boundary (~17 Ma) (Ratanasthien, 2002). The basins developed during this age have been recognized as Cenozoic rift basins. They are very important resources for their deposited oil shales and coals throughout northern Thailand. Many of these northern Thailand basins have already generated petroleum such as Sirikit and Fang oil field. However, there are many of these basins which are uplifted and exposed their content of coals and oil shales association such as Wiang Haeng, Mae Chaem (Na Hong) in Ching Mai province, Ban Pa Kha, Li, Mae Than and Mae Teep in Lampang province, Mae Tun and Mae Lamao in Tak province. A well-known oil shale area is Mae Sot basin in Tak province (Morley and Racey 2011; Ratanasthien 2011).

1.1 Study Area

The Mae Teep basin is one of the uplift basins which exposed Tertiary oil shales and coals. It was interested in this study because of its organic deposits were clearly seen and there was not many information of these organic successions have been studied in details. The information of depositional environments of this basin could be an important key to other burial oil fields in northern Thailand.

Mae Teep basin is located about 80 kilometers northeast of Lampang city, Ngao district, Lampang province (Figure 1.2). The basin trends north-northeast – south-southwest direction and it is situated between the Ngao and Phrae basin. The valley of the basin has flat-rolling topography with the elevation of 220 – 280 m. msl. and the surrounding mountains rise to nearly 1200 m. msl. The northeastward along the basin is Mae Nam Tip stream which flows into the Mae Nam Ngao at the northern end of the basin. The study area is coal mined by the Suntitranon Co., Ltd. The mine area is 300 x 1,600 square meters. It is located on the 1:50,000 topography map, Ban Pa Dange L 7017 sheet 5046 III, bounded by the grid lines 2058000 N to 2055500 N and 606000 E to 609000 E of the UTM coordinate system of zone 48 N (WGS84 datum).

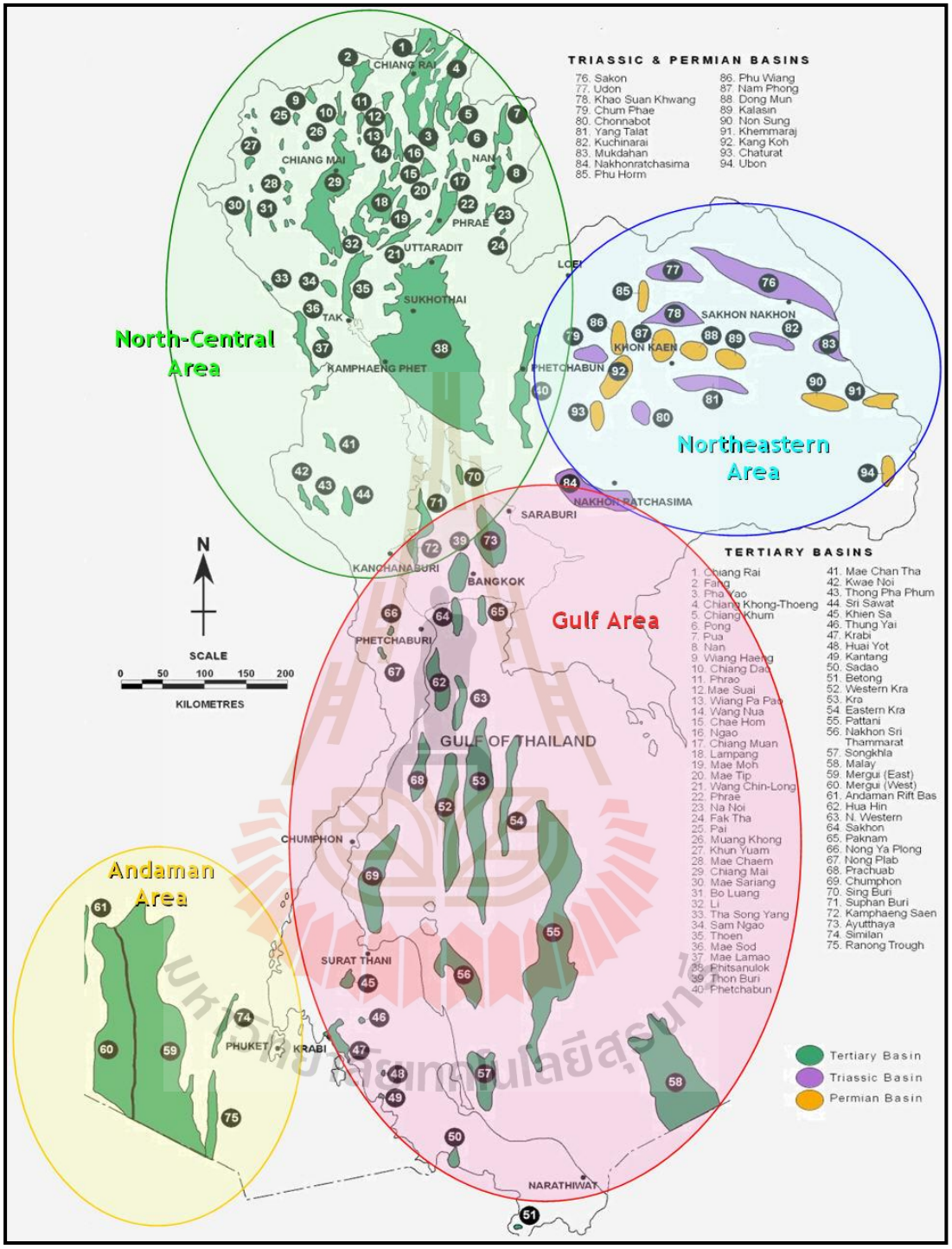


Figure 1.1 Four petroleum provinces in Thailand; the North and Central, the Northeastern, the Gulf and the Andaman areas (after DMF, 2007).

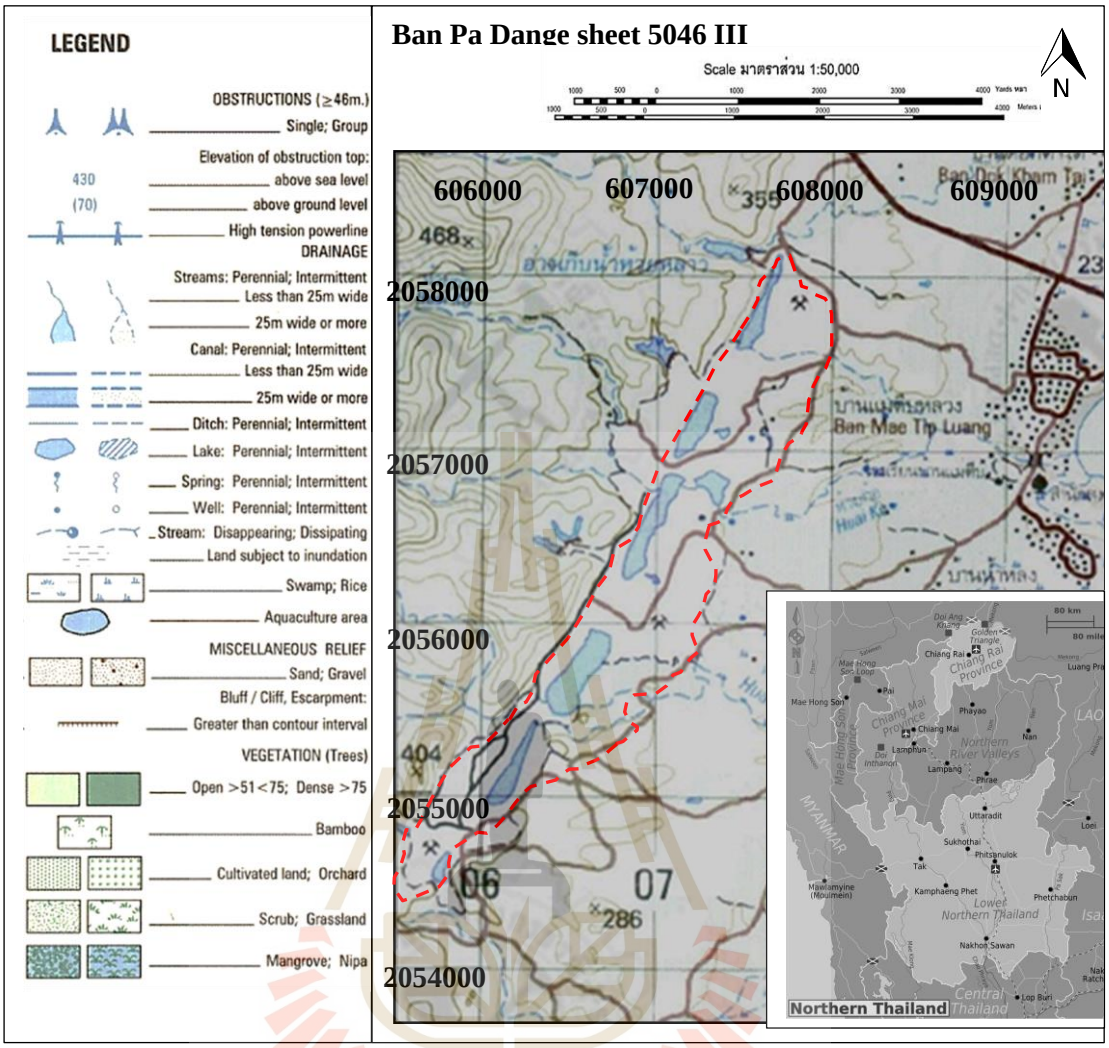


Figure 1.2 The location of the study area on map Ban Pa Dange, Map sheet 5046 III scale 1:50,000, Map Index L7018 (modified after The Royal Thai Survey Department, 1999).

1.2 Research Objectives

The two main objectives of this study are to identify the potential of petroleum source rocks by geochemical and organic petrology techniques, and to study the depositional environment and characteristics of potential petroleum source rocks in Mae Teep deposit.

1.3 Limitations and Scope of works

The study had been scoped only in the Mae Teep coal field of Sintitranon Ltd. in Mae Teep basin. Rock samples were prepared at Rock and Fluid Laboratory of Suranaree University of Technology, Nakhon Ratchasima province, Thailand. Geochemical analysis in this study were conducted by proximate and ultimate analysis according to the ASTM standard methods. Heating values of samples were examined at chemical lab testing unit of EGAT' Mae Moh coal mine, Lampang Province. Maceral types of samples were studied by petrography analysis at the Department of Geological Sciences, Chiang Mai University, Thailand. Pyrolysis analysis, including TOC and vitrinite reflectance (Ro), were conducted by Energy Resources Consulting Pty Ltd in Australia.

1.4 Expected Result

A better understanding in geology, stratigraphy, depositional environment of organic sedimentary rocks, and characteristics of potential source rocks in Mae Teep basin are the expected results of this study. In addition, results from this study could be applied to other petroleum potential basins in Thailand where have the similar depositional environments.

1.5 Research Methodology

The research methodology conducted is this study are showed in Figure 1.3, including literature review, field surveys, geochemical analysis, study of maceral types, quality and thermal maturity of the possible source rocks, the organic matter and source rock quality evaluation and study of the depositional environment of Mae Teep basin, respectively.

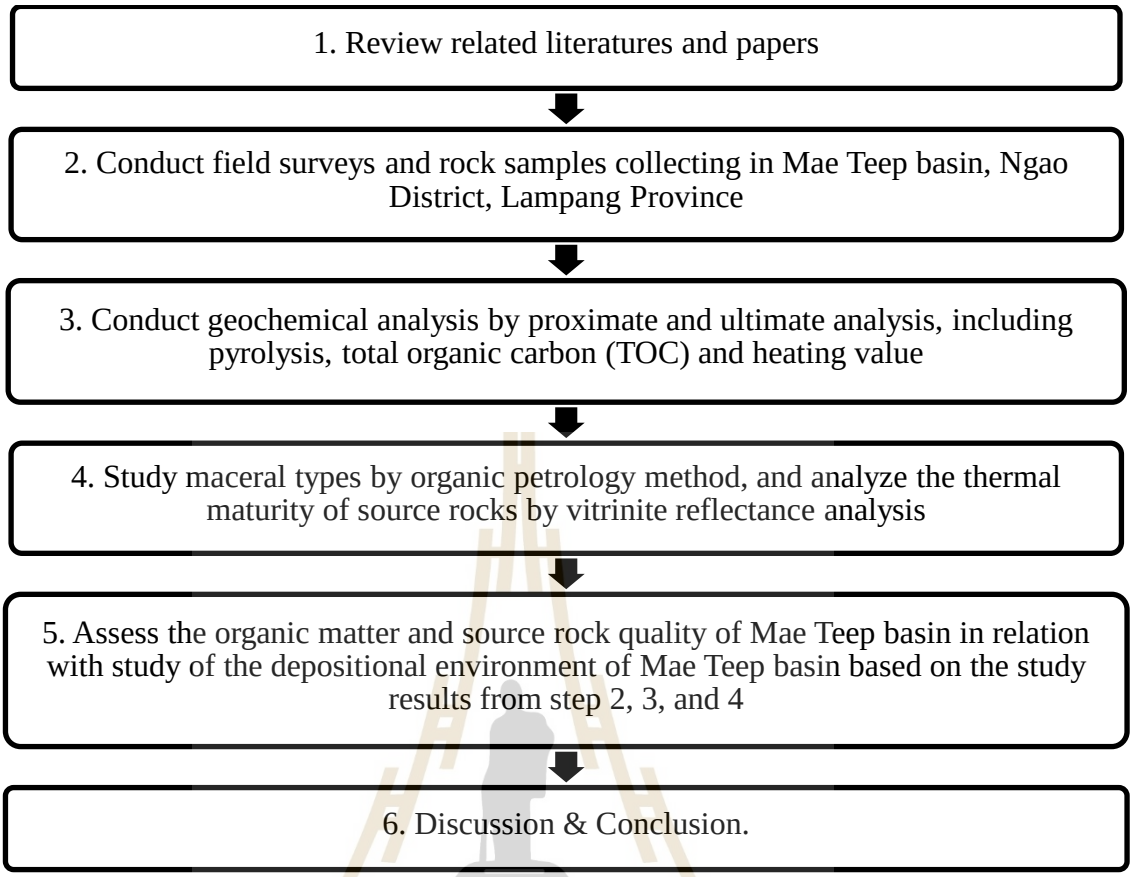


Figure 1.3 Flowchart showing research strategies and activities in this study.

1.6 Thesis contents

This thesis is divided into five chapters: Chapter I contains the research objectives and details of the study area, research methodology and scope of works that will be followed. Chapter II reviews the previous works, techniques and methodology for depositional environment of petroleum source rock evaluation, maceral classification and interpretation of petroleum potential. Chapter III describes methodology used in this study in detail, including fieldwork, sampling method, geochemical and petrographic analysis. Chapter IV presents results of the study and discussions in 2 topics: 1) the depositional environment and maceral character related to geochemical composition and 2) the evolution and thermal maturation of Mae Teep

deposits. Chapter V concludes and summarized results of the study and gives same recommendations for the future study.

CHAPTER II

LITERATURE REVIEW

This chapter presents the summary of the reviewed literatures that related to this study, including 1) Petroleum and coals in Tertiary basins of Thailand, 2) Mae Teep basin, 3) source rock classification and 4) petroleum source rocks evaluation respectively.

2.1 Petroleum and coal in Tertiary basins of Thailand

The main petroleum province of Thailand can be classified as follows: (1) Gulf of Thailand, (2) Onshore Northern and Central, (3) Onshore Northeastern (Khorat basin) and (4) Mergui basin, Andaman Sea (DMF, 2007). Gulf of Thailand is the main area for oil, gas and condensate production. The Northern and Central is the main area for oil exploration and development. The current production of gas, oil and condensate has been from 19 producing gas fields (18 offshore and 1 onshore) and 22 oil fields (19 onshore and 3 offshore).

From the economic important, the knowledge of hydrocarbon source rocks is recognized in Tertiary basins occur onshore and offshore, more than any other stratigraphic age (Polachan et al.,1980). They are generally associated with rift basins formed in extensional, transtensional or strike – slip settings. Morley and Racey (2011) mentioned that Tertiary basin unlike from main area petroleum geology of Thailand. In Northern and Central Thailand have 42 intermontane basins varying in size from a few kilometers to over 150 km. (Polachan and Satayark, 1989; Uttamo et al.,2003).

There is marked variation among the onshore basins in the timing of rifting and deposition. In general, basin formation and deposition occurred earlier in the western onshore basins (Late Oligocene – Early Miocene) and later in the eastern basins (Early to Middle Miocene). Moreover, there is often marked variation in basin-fill between the basins, although it is all alluvial-fluvial-lacustrine (Polachan et.al, 1991; Morley et al., 2001). The basins fall into two types: (1) smaller, intermontane basins in the Western Highlands, associated Mae Ping and Three Pagodas faults and (2) larger extensional basins located beneath the flat Central Plain region (Gibling, Ukakimaphan and Stisuk, 1985; O'Leary and Hill, 1989).

Burri (1989) summarized the petroleum potential of onshore basins of Thailand as follows;

1) Basin with a thick organic-rich lacustrine fill, Central and Northern Thailand. Source rocks in these basins have generally reached the oil window at depths of 1.4 - 3 km.

2) Basins dominated by alluvial deposits generally lack petroleum source rocks. Even if potential source rocks are present, the total sediment thickness may be too thin to have permitted hydrocarbon generation. These basins are considered unprospective such as Sing Buri and Ayutthaya basins.

3) Basins dominated by swamp deposits with thick lignite, for example, the Mae Moh and Li basins near the Lampang Basin in Northern Thailand, generally have a limited sediment thickness. The main factor downgrading the prospective of these basins are the lack of thermally mature source rocks.

Burri (1989) and Racey (2011) concluded that depositional environment of Tertiary basins in Thailand are mainly lacustrine, alluvial and swamp. The lacustrine

basins are located in Northern and Central Thailand and they are generally reached the oil window. Basins dominated by swamp deposit with thick coal are mostly found in Northern Thailand. They have a limited sediment thickness and the main factor downgrading the prospectively of these basins is the lack of thermally mature source rocks.

Onshore Tertiary basins having yielded significant hydrocarbon discoveries are Fang basin, Phisanulok basin, Phetchabun basin, Wichian Buri sub-basin and Suphan Buri/Kamphaeng Saen basin. The main petroleum and source rock associations are common in North Thailand. The largest petroleum potential in Chiang Mai province was found in Fang (Sethakul 1984; Burri 1989; Pradidtan 1989; Songtham, 2003). The similar other basins are Wiang Haeng and Mae Chaem (Na Hong) basin in Chiang Mai province, Ban Pa Kha, Li, Mae Than and Mae Teep basin in Lampang province, Mae Tun and Mae Lamao basin in Tak province (Morley and Racey, 2011; Ratanasthien, 2011).

However, most of onshore intermontane Tertiary basins in Thailand have been explored for coal resources, e.g. Chae Khon, Mae Chaem, Chiang Mai, Ngao, Lampang, Mae Tha, Mae Than, Mae Moh, Mae Teep, Li, Chae Hom, Wiang Haeng and Fang basins (Ratanasthien, 2011). There is only one coal deposit with oil shale is Khian Sa Basin in Surat Thani province (Morley and Racey, 2011). Mae Moh basin is the largest productive coal mine in Lampang provinces and Southeast Asia. The other Tertiary basins in the provinces are Wang Nua, Jae Kon, Jae Hom, Nago, Mae Teep, Mae Tha, Mae Than, and Serm Ngarm basin. In 2008 only four mines were in operation in Mae Moh, Mae Teep and Mae Than basin (Ratanasthien, 2011).

Racey (2011) described onshore Tertiary basins of Northern Thailand as follows;

Fang Basin is in the northernmost Thailand, occupies an area of 670 km^2. The basin is divided by strike-slip faults into 3 sub-basins. The Miocene – Pliocene lacustrine sediments are main exploration target, with sediment in the main organic-rich shales and lignite and reservoir quality sandstone. The discovery was encountered a combined structural/stratigraphic trap with production from coarse fluvial-lacustrine sandstone of the inferred Mae Sot Formation, sourced and sealed by lacustrine shales of similar age.

Mae Sot Basin covers 700 km^2 in Northwestern Thailand extend westwards into Myanmar. No oil and gas have been discovered yet in this basin, but it had been estimated 18 billion tons of oil shale (Chaodumrong et al., 1983). The average total organic carbon (TOC) contents in the oil shale is 20% and reach peaks of 63%, while vitrinite reflectance at the surface is around 0.4%Ro (Gibling et.al., 1985).

Ratanasthien et al. (1992) presented the results of proximate and ultimate analysis of coal fields in Lamphun province. The coal samples were collected from Ban Pu, Ban Hong, Na Klang, Ban Pa Kha, Mae Long Bok and Na Sai coal field. The proximate results indicated 14 – 47 % moisture, 25 – 49 % volatile matter, 2.2 – 25 % ash, and 16 – 41 % fixed carbon. The ultimate results indicated 29 – 65% of carbon, .8 – 6.7% of hydrogen, 0.24 – 1.28 % of nitrogen, and 0.27 – 5.6 % of sulphur.

Petersen et al. (2006) investigated Thai oil shales and coals and his study results are showed in Table 2.1 and 2.2. Results of his study indicated that Thai oil shales were deposited in freshwater to brackish. They have total organic carbon (TOC) range from 371 to 44.18 wt.%. H/C ratios range from 0.80 to 0.90 which is corresponded to Type

III kerogen. HI values range from 50 to 300 mg HC/g TOC and this is indicated a potential for oil/gas generation. Furthermore, the study of organic petrographic of the oil shales found that they were dominated by liptinite maceral. Most of the Li, Na Hong and Mae Lamao oil shale contain lamaginite. They are thermally immature (0.11 to 0.28 %Ro). Vitrinite reflectance values of most of Thai coals range from 0.38 to 0.47 %Ro, except the coal of Fang basin which has 0.59 %Ro. The oil window is estimated at 0.82 (Suphan Buri basin) to 0.98 %Ro (Fang basin).

Table 2.1 Source rock data of coal (Peterson et al., 2006)

Basin	**Moisture**	**Ash**	**C**	**H**	**N**	**S**	**O**	**H/C**	**O/C**
	%	% (dry)	% (d.a.f)					Atomic ratio	
Fang	1.25	48.75	70.22	4.67	1.81	6.71	16.59	0.80	0.18
Li	11.04	2.66	77.12	5.12	1.40	0.44	15.92	0.80	0.16
Mae Lamao	12.77	21.33	70.84	5.54	2.38	1.79	19.45	0.94	0.21
Mae Ramat	15.50	7.04	68.02	4.67	2.01	1.79	19.36	0.81	0.21
Na Hong	9.87	8.76	69.36	5.20	1.61	5.94	23.24	0.90	0.25
Wiang Haeng	5.70	20.90	70.65	6.45	1.93	0.58	18.70	1.10	0.20

Table 2.2 Source rock data of oil shale (Peterson et al., 2006)

Basin	**Moisture**	**Ash**	**C**	**H**	**N**	**S**	**O**	**H/C**	**O/C**
	%	% (dry)	% (d.a.f)					Atomic ratio	
Li	2.33	52.73	60.73	7.64	1.40	16.94	26.6	1.53	0.175
Mae	3.83	89.34	40.86	9.80	3.71	8.94	36.71	2.90	0.68
Lamao	2.75	54.38	66.32	8.72	1.81	1.82	21.33	1.57	0.25
Mae Sot Na Hong	3.12	50.25	59.32	7.46	1.88	7.49	23.86	1.51	0.305

Ratanasthien (1997) studied algae type of oil source rock in northern Thailand and also classified them into alginite maceral consisting of telalginite and lamaginite. The telaginite consists of *Botroyococcus* brownie, *Botryococcus* sp., *Pila* sp. and

Reinschia. Lamaginite is long shape algae and it is used to indicate depositional environment changing from lacustrine to temperate forested swamp.

Ratanasthien (1999) studied oil source rock in fang oil field, northern Thailand, using petrography study. Results of the study indicated that the lower part of Tertiary deposits succession contains only alginite A (*Botryococcus* sp.). The association of *Botryococcus braunii*, *Pila* algae, thick walled alginite B were found in the middle part of the studied sediment succession. The upper part of the studied sediment succession is dominated by alginite B with *Botryococcus*-related *Pila* algae, *Reinshia* and ferns. In Mae Sot basin, *Reinshia* is dominant in the northern part where as lamalginite is dominant in the south. Therefore, these evidences suggest the changes in depositional environments during Tertiary in northern Thailand.

2.2 Mae Teep basin

Coal in Mae Teep basin was first observed by Piyasin (1972). He found coal beds intercalated with shale along the Nam Mae Teep river. Their age is not known but they are presumed to be Tertiary by comparison with coal bearing strata elsewhere in Northern Thailand (Gibling and Ratanasthien, 1980; Gibling, Ukakimaphan and Srisuk, 1988; Ratanasthien, 1992).

The Mineral Fuels Division, Department of Mineral Resources (DMR) (1980) explored and drilled some exploration wells and found the Mae Teep basin trended north – south direction. The sedimentary strata on the western margin of the basin strike N10º – 30ºE and dip eastwards at about 20º - 40º, with minor faulting and surrounded by Permian-Triassic rocks.

The northern part of Mae Teep basin comprises Jurassic sandstone interbedded with shale and conglomerate (DMR, 1994) (Figure 2.1). The southern part of the basin comprises upper Triassic shale, sandstone, siltstone, mudstone, conglomerate, and limestone. The western part of the basin is bounded by the Triassic Pha Daeng

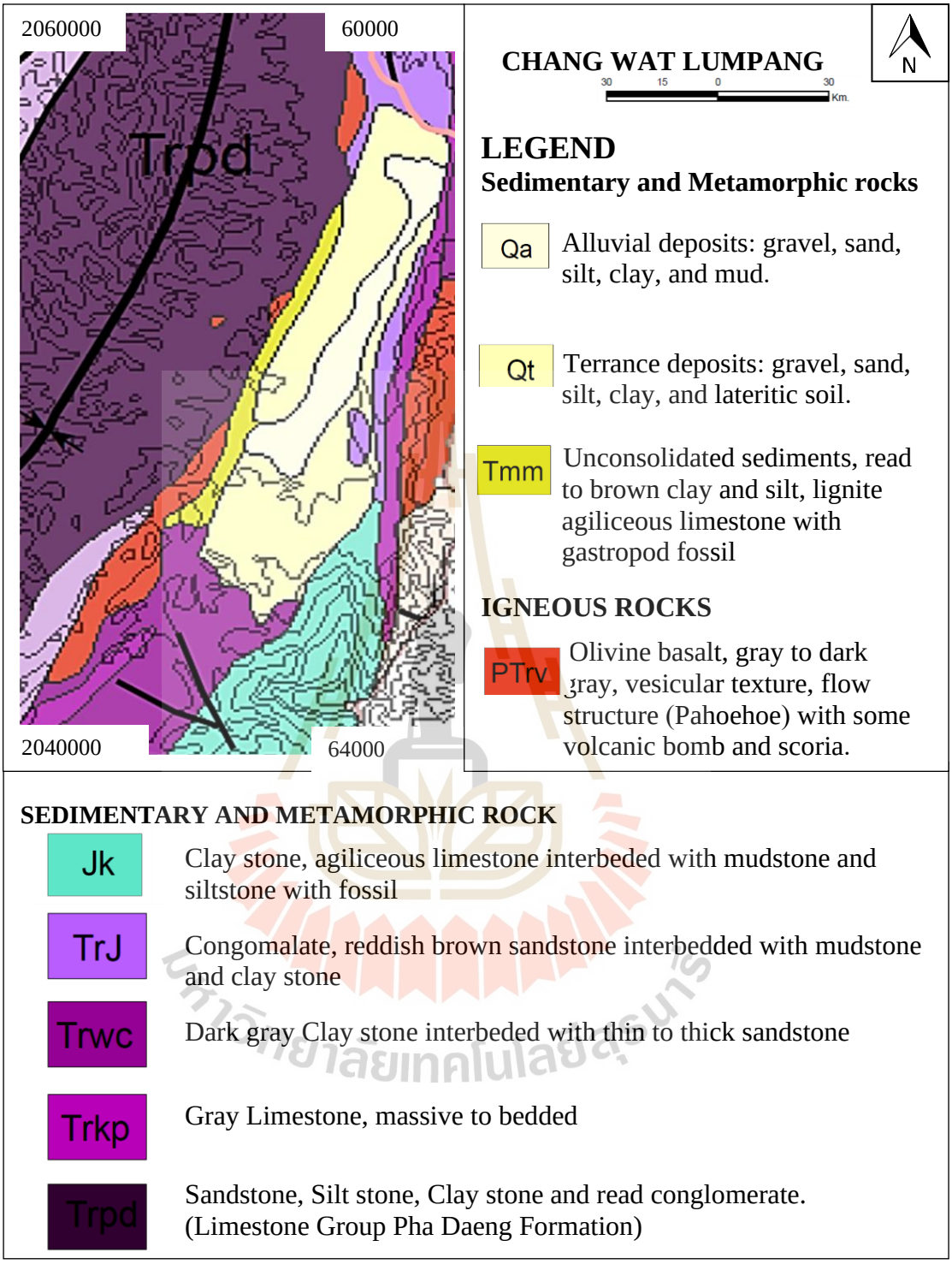


Figure 2.1 Geological map of Mae Teep basin and surrounding area (modified after DMR, 1994; Charoenprawat et al., 1994)

Formation, consisting of sandstone, siltstone, conglomerate, and shale. The basement rock of Mae Teep basin is related to limestone of upper Permian - Triassic and bounded to the east of the basin. The volcanic rocks of Triassic-Permian exposed in the western part of the basin along the north to south (Piyasin, 1957; Chaodumrong et. al., 2002)‥ The descriptions of rocks in the vicinity of Mae Teep basin are shown in Table 2.3.

Table 2.3 The rocks boundary around Mae Teep basin divided by age (Chaodumrong et. al., 2002).

Age	Units
Quaternary	Alluvial deposits: gravel, sand, silt, clay, and mud.
	Terrace deposits: gravel, sand, silt, clay, and lateritic soil.
Erosional Surface	
Tertiary	Interbedded claystone, sandstone, mudstone, diatomite, and shale with fossil leaves, stems, bone of fish, and *Viviparus* sp.
Unconformity	
Jurassic	Sandstone, purplish brown, fine-grained, calcareous, interbedded with shale, reddish brown, limestone nodules; shale, gray, intercalated with sandstone, fine-grained; and conglomerate.
Triassic	**Upper Triassic** divided into 2 units are 1) limestone, gray, massive to bedded; shale and sandstone, gray to greenish gray; with fossil *Cassianella* sp. and brachiopods, and 2) shale and sandstone, gray to greenish gray; siltstone; mudstone; conglomerate; and limestone; with fossils *Halobia* sp., *Cassianella* sp., *Liostrea* sp., *Unionites* sp., and bivalves.
	Middle to Upper Triassic: Pha Daeng Formation of Lampang group (Piyasin, 1975) consists of sandstone, red to reddish brown, cross-bedded; siltstone, conglomerate and shale.
Unconformity	
Permo-Triassic	**Igneous rocks;** Olivine basalt, gray to dark gray, vesicular texture, flow structure (Pahoehoe) with some volcanic bomb and scoria.
Permian	Limestone interbedded black shale, gray sandstone, dark gray mudstone and gray limestone with chert nodules; intercalated with fossiliferous limestone and mudstone, abundant fossils of *Paleofusulinasinensis* (Sheng) and common *Colaniella* cf. *lepida* (Wang). Assemblage with fragments of crinoid stems, bivalves, and blue algae coated by oncolith.

According to the study of Ratanasthien (2011) Mae Teep Tertiary sediments have a total thickness approximately 100 m and can be divided into three units described in ascending order as follows;

1) Underburden

This unit consists mainly of gray claystone in the upper part and white to gray gravelly sandy claystone in the lower part. It is up to c. 50 m. thick.

2) Main Coal Seam

The lower part of unit consists of coal interbedded with carbonaceous shale. The coal is hard, dense and black in color. The middle part consists of coal and sheeted coal interbedded with carbonaceous mudstone, and the upper part consists of coal interbedded with oil shale. The thickness of unit is 30 m. The coal is hard, dense and black and its rank ranges from sub-bituminous to high-volatile bituminous C.

3) Overburden

The lower part of this unit is dark-gray to black oil shale with a thickness of 5 – 7 m. The upper part of the unit consists mostly of black shale and claystone with a thickness of 25 m. Beds of hard, dense, brown sandy mudstone, 15 – 20 cm. thick, occur in places.

Ratanasthien (1989) studied the stratigraphic unit of sediments in Mae Teep basin. Results of the study indicated that Mae Teep basin consists of 6 stratigraphic units in ascending order as topsoil unit, claystone, shale and conglomerate unit, oil shale unit, coal unit, claystone, shale, sandstone and conglomeratic sandstone unit and basement unit. The total thickness of the studied succession is about 91 m.

Petersen et al. (2006) reported that the Mae Teep coal field has TOC between 40 – 58 wt.% TOC. The maceral compositions are corpohuminite, densinite, suberinite

(Su) and exsudatinite (Ex) in association with suberinite. Study results indicated that maceral types are mainly of huminite (80 – 82%) and liptinite (18 – 19%) and some of inertinite group (less than 1%). The average vitrinite reflectance is 0.425 %Ro. This is indicated the thermally immature source.

The results of proximate and ultimate analysis of Mae Teep coal and oil shale samples from the study of DMR (1981), Enrich Consultants (2005) and Ratanasthien (2011) are compared and showed in Table 2.4

Table 2.4 The results proximate and ultimate analysis of Mae Teep coal and oil shale samples.

Authors / Methods		**DMR, 1981**	**Enrich Consultants, 2005**		**Ratanasthien, 2011**
		As-determined	As-determined	Dry basis	As-determined
Proximate analysis	Moisture	26.22 – 8.57	25.55	-	13.7 – 23.3
	Volatile Matter	41.78 – 28.79	31.20	41.91*	21.8 – 36.4
	Ash	38.07 – 4.27	11.91	15.97*	8.16 – 39.7
	Fixed carbon	54.58 – 20.77	31.33	42.12*	23.8 – 30.8
Ultimate analysis	Carbon	-	-	-	17.7 – 58.9
	Hydrogen	-	-	-	5.39 – 8.58
	Nitrogen	-	-	-	0.61 – 2.24
	Sulfur	7.96 – 0.54	1.02	1.37*	0.92– 1.94

2.3 Source rocks classification and environment deposition

In petroleum geology, source rocks are fine-grained sedimentary deposited with organic materials and generating hydrocarbons (Law, 1999). The geological history shows main groups of biomass possible organic contribution to sediments in time with marine and non-marine are mostly of algae which were found since Precambrian to Paleozoic and Cenozoic with the adding of land plants which

commencing mostly in Cenozoic (Tappan and Loeblich, 1970). The accumulation modes of organic material can be divided into 4 modes; sea water, brackish water, fresh water and on land (Stopes and Wheeler, 1918). They are many researchers studied in hydrological environments such as Cohen et al., 1989; Petersen and Nielsen, 1995; Roberts and McCabe, 1992; Sebag et al., 2006a; 2006b; Staub, 1991 and Wang et al., 2011.

The relationship among organic-rich rock, known precursors, rock types and environment of depositional can be illustrated as showed in Figure 2.2 (Hutton, 1982; Hurron, 1987; Sykes, 2001)

Four swamp types can be distinguished on the basis of plant communities: 1) open-water areas with water plants (in part submerged), 2) open reed swamps, frequently with sedges, 3) forest swamps, and 4) moss swamps (Stach, 1975).

Brook et al. (1987) and many authors (Durand and Paratte, 1983; Hunt, 1991; Thomas, 1982) distinguished source rocks in difference type. The characteristic of source rocks are based on amount and type of organic matters and their physical and chemical composition. The component of organic matter in petroleum source rocks are presented in form of maceral types. The classification of maceral components is established by the International Committee for Coal and Organic Petrology (ICCP, 1998, 2001 and Sýkorová et al., 2005). A similar system is also used in a rank-based international classification of hard coal and brown coal. The macerals can be divided into three groups which are vitrinite/huminite, liptinite/Exinite and inertinite.

The kerogen evolution presents the stage of burial of source rocks. The kerogen is classified into three basic types (Type I, II and III) based on carbon, hydrogen and oxygen ratio (Tissot and Welte, 1978; Selley, 1985). Van Krevelen

(1993) developed a simple diagram for kerogen type classification based on H/C and O/C atomic ratios. The successive evolutions are corresponded to composition and they can be indicated principal generated products in three stages of maturity; diagenesis, catagenesis and metagensis. The amount of petroleum generated and expelled from source rock increases as the increasing of hydrogen to carbon ratio (H/C) of the organic matter (Hunt, 1996).

Tissot and Welte (1984) modified Van Krevelen diagram to utilize pyrolysis parameters (oil yield, kerogen yield and CO_2 and CO product) and total organic carbon (TOC). The hydrogen content of kerogen is the controlling factor for oil and gas yields from the primary hydrocarbon-generating reactions. The modified van Krevelen diagram classifies kerogen type into four types, I, II, III and IV, based on the different amounts of hydrogen to carbon and oxygen atom.

Maceral types correspond to the fraction of organic matter in sedimentary rocks in term of kerogen. The maceral characteristics are related to the kerogen type which is determined by hydrocarbon parameters: oil yield (S1), kerogen yield (S2), amount of (S3) and Total Organic Carbon (TOC). This refers to the petroleum expelled as show in Table 2.5.

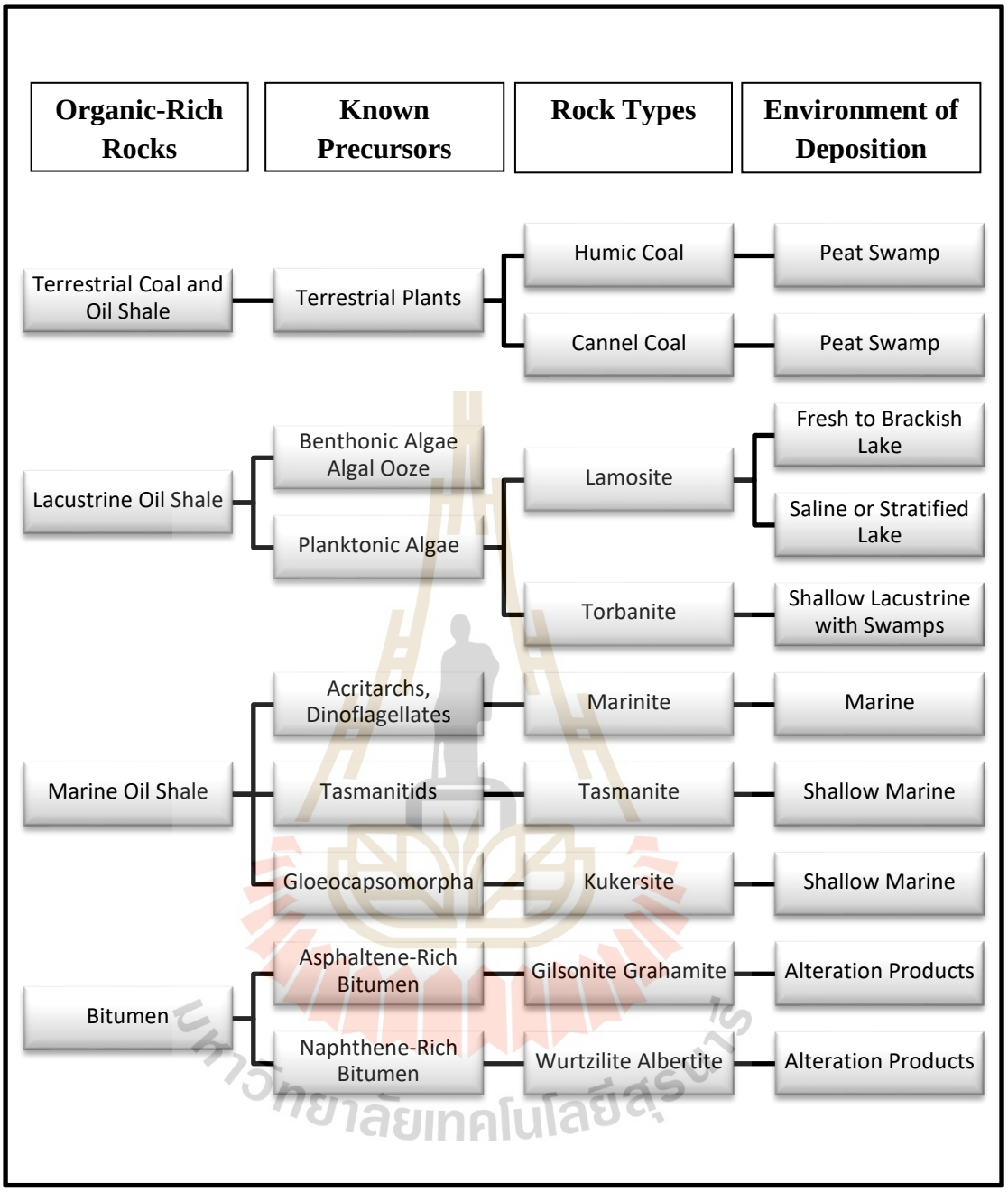


Figure 2.2 Relationship among organic-rich rock, known precursors, rock types and environment of depositional (modified after Hutton, 1982)

Table 2.5 Relationship among kerogen, maceral types, hydrocarbon index (HI), S2 to S3 ratio, and petroleum product expelled at maturity (modified after Peters and Cassa, 1994).

Kerogen type	Kerogen Composition (Marceral)	Hydrogen Index (HI)	S2/S3	Main Product
I	Amorphous/Alginate	>600	>15	Oil
II	Exinite	300 – 600	10 – 15	Oil
II/III	Exinite/Vitrinite	200 – 300	5 – 10	Mixed oil and gas
III	Vitrinite	50 – 200	1 – 5	Gas
IV	Inertinite	< 50	< 1	Gas

Pasley (1991), Jones (1987) and Tyson (1995) defined organic facies by geochemical, and optical data (microscopy). They integrated the organic petrography and organic geochemistry data not only to improve the better understanding of the occurrence of oil source rocks, but also to use it as a prediction tool. The seven organic facies defined by Jones (1987) are A, AB, B, BC, C, CD and D as presented in Table 2.6.

Petroleum source rock potential is directly related to its volume, organic richness and thermal maturity (Isaksen et. al., 1998). The potential of source rock is applied to a rock contains sufficient organic matter of suitable chemical composition to generate and expel hydrocarbons via biogenic or thermal processes (Miles, 1994). This is applied irrespective of whether its organic matter is mature or immature (Durand, 1993; Belaid et al., 2010).

The type of petroleum source rocks potential can be divided into four major categories: potential, effective, relic effective and spent source rock (Jeffrey, 1993;

Law, 1999; Ronald, Wikins and George, 2002). Each type refers to the stage of thermal maturity (immature, mature, and over/post mature)**.**

Table 2.6 The relationship among palynofacies, geochemical and environment factors (after Jone, 1987; Tyson, 1995).

Organic Facies	**A**	**AB**	**B**	**BC**	**C**	**CD**	**D**
Palynofacies characteristics							
% AOM of kerogen	Dominant			Mod	Usually low/absent		
AOM matrix fluorescence	Highest		Mod-weak		Weak	Usually absent	
% prasinophytes of plankton	Highest	Mod	Rare	Usually very rare			
% phytoclasts of kerogen	Low (dilution)		Mod	Usually dominant			
Opaque: translucent phytoclasts	Often high			Usually low		increases	
Geochemical characteristics (for immature sediments)							
Hydrogen Index (HI)	≥ 850	≥ 650	≥ 400	≥ 250	≥ 125	50 – 125	≤ 50
Kerogen type	I	I/II	II	II/III	III	III/IV	IV
TOC %	5 – 20+	3 – 10+		3 – 3+	≤ 3	< 0.5	
Environment factors							
Proximal-distal trend	Distal			Proximal		Distal	
Oxygen regime	Anoxic	Anoxic-dysoxic			Oxic		Very Oxic
Sediment accumulation rate	Low	Varies		High		Mod	Low

*AOM = Algal Organic Matter

Dow (1977) reported the petroleum generative windows which related to temperature as the oil generation (oil window) at 50 – 150 ºC and the gas generation (gas windows) at 150 – 200 ºC. This is depended on how quickly the source rock is heated. Generally, the onset of oil generation is also correlated with vitrinite reflectance of 0.5-0.6%Ro and the termination of oil generation with vitrinite reflectance of 0.85-

1.1%Ro. The onset of gas generation (gas window) is typically associated with values of 1.0-1.3%Ro and terminated around 3.0% Ro.

Cook and Kantsler (1982) modified the source rocks maturation range chart by elevated temperature associated with physic-chemical coalification and hydrocarbon generation. The maturity range is corresponded to hydrogen content (kerogen type).

2.4 Petroleum source rock evaluation and maturity

According to Law (1999) source rocks are referred to the stage of thermal maturity (Immature, Mature, and Over/Postmature). The potential of petroleum source rocks are usually assessed both in term of quantity and quality. Quantity and quality are commonly assessed by a measure of the total organic carbon (TOC), kerogen types contained in source rock, prevalence of hydrocarbons can be measured by ultimate analysis and elemental compositions, including the hydrogen and carbon ratio. They are related to the quantity of oil and gas windows of each kerogen type with temperature and depth.

There are many methods to identify oil and gas generation potential, thermal maturity and the organic matter type (Tissot and Welte, 1978). This part presents two of petroleum source rock evaluation methods, geochemical analysis and petrographic analysis.

2.4.1 Geochemical analysis

Most geochemical studies of source rocks belongs to one of the following types: elemental analysis, oxidation, hydrogenolysis and pyrolysis (Hutton, 1982). The determination for proximate and ultimate analyses follow the guide line of American Standards for Testing of Materials [ASTM]. The chemical classification of

source rocks is based on chemical properties and elemental composition of organic rocks. The most commonly employed systems of methods are:

- ASTM D3302/D3302M for total moisture and instrumental procedures (ASTM, 2011d)
- ASTM D5142-09 for proximate analysis of the analysis sample of coal and coke by instrumental procedures (ASTM, 2010)
- ASTM D7582 for proximate analysis of coal and coke by Macro Thermogravimetric analysis (ASTM, 2011e) and used percentages of C, H and O to plot the composition of coal
- ASTM D2013/D2013M-1 and Practice D346-04 for preparing coal samples for analysis (ASTM, 2011c).

The total organic carbon method is used to determine the concentration of total organic carbon in sediments or in soil samples and inorganics are removed by digestion in hydrochloric solution (McKee and Goodwin, 1923; Lewis and McConchie, 1937).

The classification of organic matter based on H/C and O/C atomic ratios (Van Krevelen, 1993). Exponents of the modified Van Krevelen diagrams recognize up to 4 types of kerogen; Type I, Type II, Type III and Type IV (Tissot and Welte, 1978; Durand, 1993). Type I is aliphatic kerogen with high initial H/C (1.5) and low initial O/C (1.0). Type II has relatively high H/C and low O/C. Type III kerogen is H/C 1 and O/C 0.2 to 0.3, derived from terrestrial plant. Type IV kerogen corresponds with inertinite. Type I, II and III are plotted in the same zone as alginate, higher plant exinite and vitrinite in coal on the van Krevelen diagram (Tissot and Welte, 1978).

Van Krevelen (1950) mapped the natural pathways of the major groups of coals (sapropelic and humic) as they thermally mature by using elemental analysis data on a plot of H/C vs. O/C (Figure 2.3). The various macerals of coal follow distinct pathways with distinct changes in H/C and O/C as they thermally mature (but all with decreasing H/C and O/C). Van Krevelen's work laid the foundation for the geochemical assessment of kerogens. However, as coals are terrestrial in origin, the thermal evolutionary pathway of marine macerals is still unknown.

The introduction to organic geochemistry by Killops (2005) and the biomarker guide by Peters, Walters and Moldowan (2005) indicated that the thermal maturation pathways of petroleum source rocks are approach specifically to kerogen that they contain. Tissot plotted data for kerogens that were falling on trend line (Figure 2.4). The labeled trend lines were foundation of the kerogen classification scheme that most geochemists use today with Type I kerogens being of lacustrine origin, Type II of marine origin, and Type III of terrestrial origin.

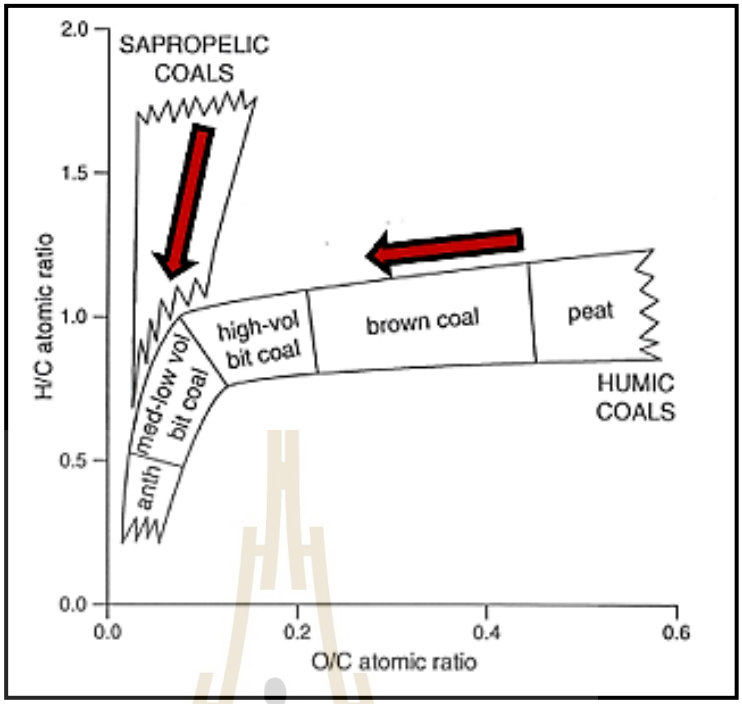


Figure 2.3 Van Krevelen diagram showing the evolutionary trends of dominant coal types (Van Kervelen, 1950).

Type I kerogen is the rarest of the three types and usually forms in oxygen-deficient, relatively fine-grained, shallow-water environments, with abundant freshwater algae (e.g. lagoons and lakes).

Type II kerogen can potentially be formed in a variety of environments, but generally in marine settings where the major source of organic matter is autochthonous phytoplankton from the water column.

Type III kerogen is formed from vascular plants and often contains identifiable plant debris, thus proximity to land is mandatory.

The major difference between what Tissot developed in the 1970's and what we use today is that we no longer use the hydrogen, carbon, and oxygen elemental composition of kerogen (which is required to achieve the H/C and O/C ratios plotted

on the van Krevelen diagram), instead we use the Hydrogen Index (HI) and Oxygen Index (OI) achieved through Rock-Eval Pyrolysis as developed (Figure 2.4).

Based on methods developed during the early 20th century for coal science, kerogens (and thus petroleum source rocks) are most commonly typed based on their relative abundance of hydrogen, carbon, and oxygen. Traditionally, the amount of H, C and O were determined via elemental analysis (ultimate analysis) of chemically purified kerogen and plotted in terms of H/C and O/C on a van Krevelen diagram. Since the late 1970, Rock-Eval pyrolysis has been used to determine the HI and OI of source rock kerogens which are proxies for the H/C and O/C, respectively. The results HI vs OI are then plotted on the modified Van Krevelen diagram. The beauty of Rock-Eval is that it's cheap, fast, and does not require the lengthy, hazardous, expensive procedure of chemically purifying the kerogen from the source rock prior to analysis. The work by Van Krevelen, Tissot, and Espitalie have resulted in the lumping of kerogen into three main groups, Type I (lacustrine), Type II (marine), and Type III (terrestrial). Moreover, kerogen type can be classified into 4 types based on palynology and chemical composition related to maceral type (Mendonca Filho et al., 2012) (Table 2.7).

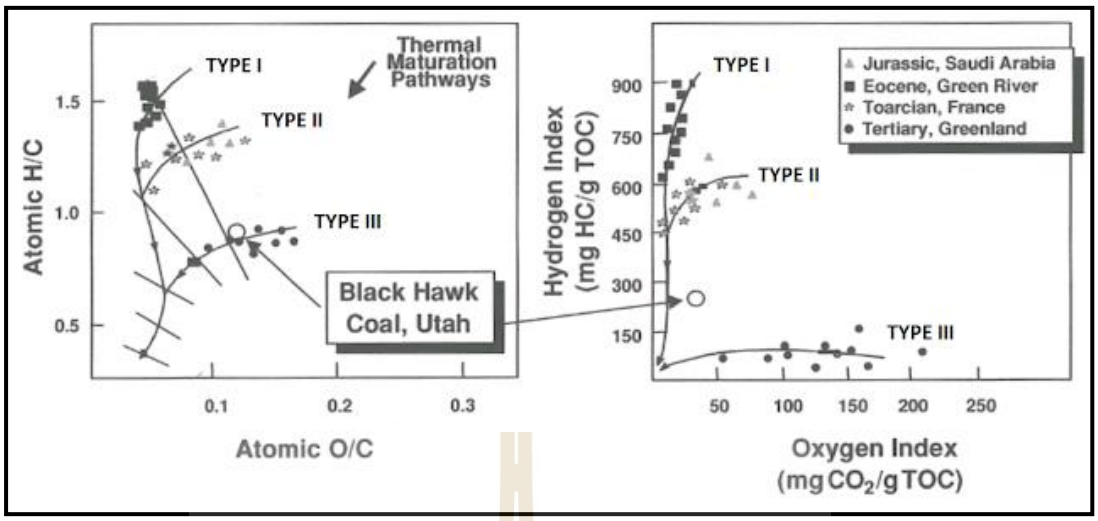


Figure 2.4 Van Krevelen diagram (left) showing thermal maturation trends of the different kerogen types on a plot of H/C vs. O/C. The modified Van Krevelen diagram (right) showing the same kerogen as that on the left, but analyzed using rock-Eval pyrolysis and plotted in terms of Hydrogen Index and Oxygen Index (Peters et al., 2005).

Table 2.7 The main type and evolution paths of kerogen occurred in difference type of palynology. (Mendonca Filho et al., 2012)

Palynology	**Algal**	**Amorphous**	**Herbaceous**	**Woody**	**Coaly**
Macerals	Liptinite (Exinite)			Vitrinite	Inertinite
Evolutionary Pathway	Type I or II		Type II	Type III	Type IV
H/C	1.7 – 0.3		1.4 – 0.3	1.0 – 0.3	0.45 – 0.3
O/C	0.1 – 0.02		0.2 – 0.02	0.4 – 0.02	0.3 – 0.02
Hydrogen Index	900 – 50		600 – 50	200 – 50	< 50
Source Material	Lacustrine and Marine		Terrestrial	Terrestrial	Terrestrial and Recycled
Hydrocarbons Generated	Mostly Oil		Oil and Gas	Mostly Gas	Very little gas

2.4.2 Petrographic analysis

The basis of organic petrography is optical microscopy that includes reflected and transmitted light, fluorescence and polarized light analysis of the organic matter in a broad sense. Maceral are microscopical organic entities derived from terrestrial, lacustrine and marine plant remains and modified by deposition processes, early diagenesis and subsequent thermal evolution. There are three maceral groups: huminite/vitrinite, liptinite/exinite and inertinite (Teichmuller, 1975; Teichmuller and Durand, 1983). Over the last two decades the International Committee for Coal and Organic Petrology (ICCP) has defined the description of maceral and revised their nomenclature (Suarez-Ruiz et al., 2012). Macerals classification based on ICCP (1995 and 2001) and Australian Standard (AS) (1986) and ASTM (1996) are compared and presented in Table 2.8.

The microscical determination of polished surfaces of vitrinite and other macerals can be measured their light reflectance in both the mean maximum and mean random reflectance. The vitrinite reflectance is determined by the percentage of incident light reflected from the surface (%R_o) based on vitrinite particles measured in an individual grain (Tissot et al., 1987).

According to vitrinite determination was became a skilled operation to both distinguish maceral of autochthonous and allochthonous vitrinite. It was the autochthonous or primary vitrinite that measurements should be made on and the values were derived from primary vitrinite that should be recorded. False values of maturity will result if unsuitable particles are measured (Matchette-Downes, 2009).

Table 2.8 Classification of maceral based on International Committee for Coal and Organic Petrology (ICCP) (after ICCP, 1995 and 2001; Stracher, Prakash and Ellina V. Sokol, 2012)

Maceral Group	**Maceral Subgroup**	**Maceral (ICCP, 1995)**	**Maceral (AS 3856, 1986)**	**Maceral (ASTM D2799, 1996)**
Vitrinite	Telovitrinite	Telinite Collotelinite	Textinite* Texto-Ulminite* Eu-Ulminite* Telocollinite	Vitrinite
	Detrovitrinite	Vitrodetrinite Collodetrinite	Attrinite* Densinite* Desmocollinite	
	Gelovitrinite	Gelinite Corpogelinite	Corpogelinite Porigelinite* Eugelinite	
Liptinite			Sporinite Cutinite Resinite Liptodetrinite Alginite Suberinite Fluorinite Exsudatinite Bituminite	Sporinite Cutinite Resinite Alginite
Inertinite	Telo-Inertinite		Fusinite Semifusinite Sclerotinite	Fusinite Semifusinite Sclerotinite
	Detro-Inertinite		Inertodetrinite Micrinite	Inertodetrinite Micrinite
	Gelo-Inertinite		Macrinite	Macrinite

*Maceral mostly in Tertiary basin

Levine (1993) compiled to report the evolution of coal as source rock and reservoir rock for oil and gas that the term maturation is commonly used synonymously with coalification. However, maturation is a broader term that refers more accurately to the complete set of compositional changes influencing sedimentary organic matter (OM) during burial, some of which occur in the near- surface

environment prior to and/or after diagenesis. The importance of this distinction lies in the fact that the various organic micro constituents in a single coal, having all experienced the same digenetic history, are technically of the same rank, but may exhibit widely varying degrees of compositional maturity. Inertinite macerals, for example, are compositionally mature even at low rank, having many of the same characteristics as vitrinite at much higher rank. As a consequence of coal being comprised of a mixture of materials of differing maturities, rank determination can be problematical for coals having unusual petrographic composition. For example, volatile matter yields of inertinite-rich Gondwana coals are abnormally low at low rank, giving them the appearance of a higher rank coal as compared with vitrinite-rich Euro-American Carboniferous age coals; or vitrinite reflectance of some alginite-rich coals can be suppressed at moderate rank, giving them the appearance of lower rank coals. Both of these examples are relevant to the present paper, as they specifically relate to the generation and partial retention of molecular hydrocarbons in coal.

CHAPTER III

METHODOLOGY

Research methodology in this study can be divided into 3 main parts; fieldwork, sampling methods and sample analysis (Figure 3.1). Fieldwork had been conducted to study geology and litho-stratigraphic units of the study area. The organic sediments sampling comprises samples collecting and preservation, samples description, and samples preparation for analyses. Geochemical analysis in this study comprises proximate analysis, ultimate analysis, heating value and pyrolysis analyses. Petrographic analysis comprises maceral identification and vitrinite reflectance measurement. Details of each work step are described as follows.

3.1 Fieldwork

Fieldwork is an important part of geological investigation as it provides many of data of environment conditions and petroleum potential source rocks of the studied organic sediments.

In this study fieldworks had been conducted during 15-17 June 2015 and 3-6 October 2015 at the studied sediment succession in the vicinity of Mae Teep coal mine, especially at mine-front. The objectives of this fieldworks are: 1) to study the lithology and stratigraphy of the studied sediment succession, and 2) to collect organic sediment samples for geochemical analysis and petrography study in laboratory. During conducting fieldwork, the necessary information including thickness of each rock layer, rock type, and location of rock sample are noted in field-note (Figure 3.2).

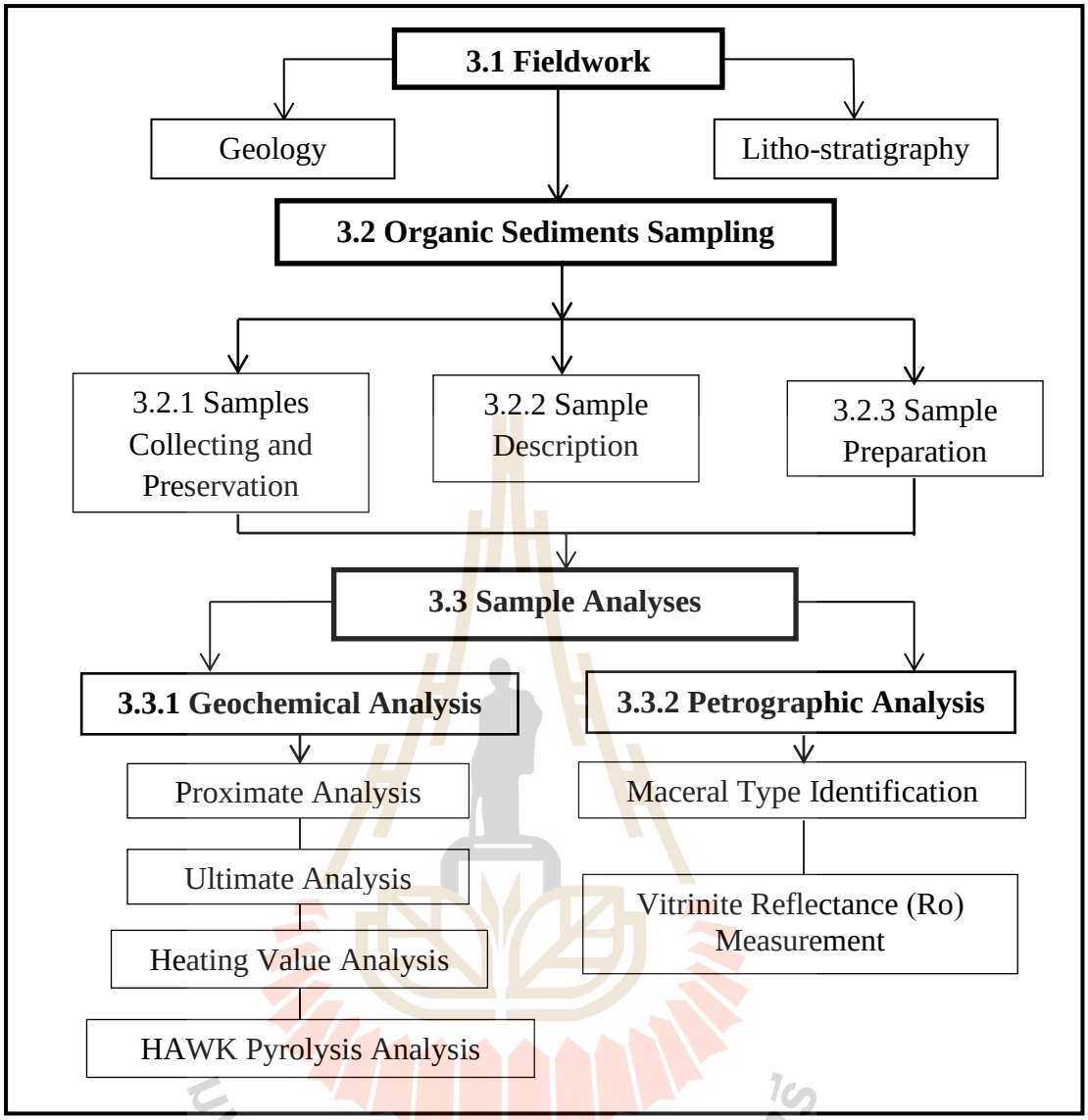


Figure 3.1 Steps of work and methodologies conducted and used in this study.

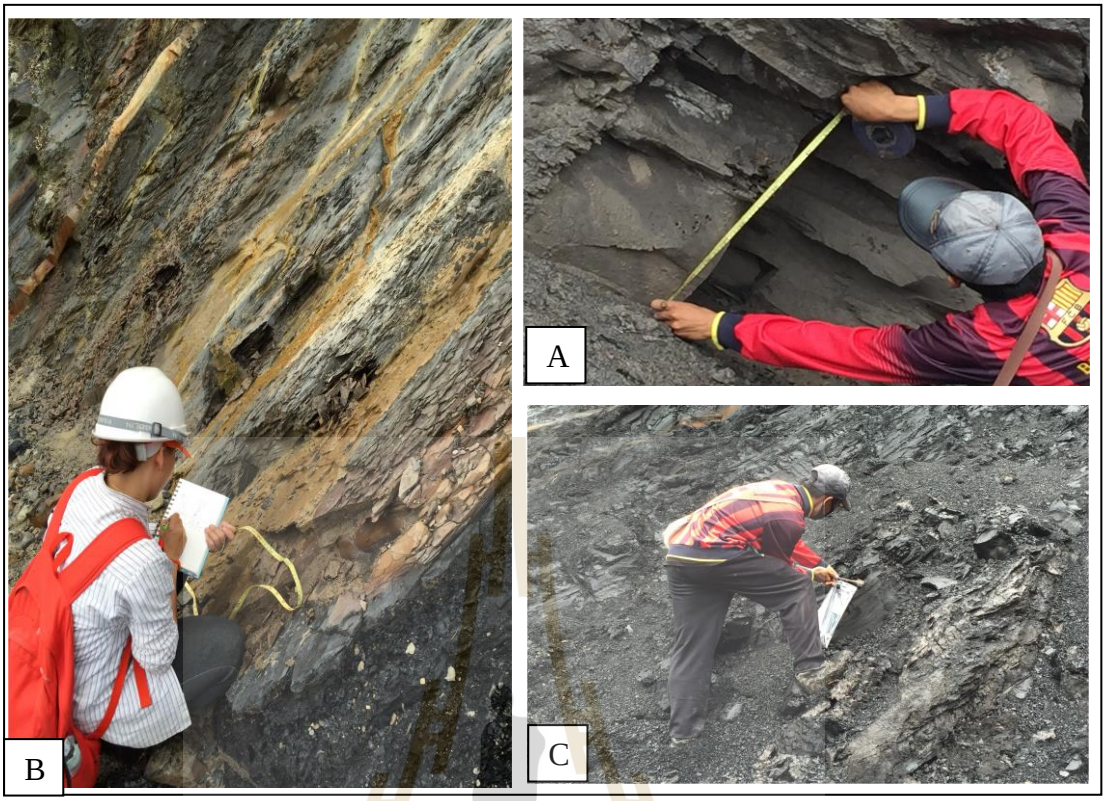


Figure 3.2 Fieldwork activities: measuring thickness of each layer by measuring tape (A), note taking everything on field note book (B), samples collecting (C).

3.2 Organic sediments sampling

Organic sediments sampling in this study comprises 3 main parts; sample collecting and preservation, sample description, and sample preparation. Details of each part are given as follows.

3.2.1 Samples collecting and preservation

Sample collecting and sample preservation from contamination are importance for laboratory work. Fresh rock samples about 5 kg from each sampling point were collected following the ASTM D 4596 – 09 standard (ASTM, 2011b) and stored in plastic bags.

3.2.2 Sample preparation

All of samples required air drying before feeding properly through the crushing, washing and dividing equipment. The air-dried samples were prepared following standard practice for preparing coal samples for geochemical analysis of ASTM D2013/D2013M-11 and Practice D346 – 04. The samples were air dried for 1-3 days to remove free moisture and were then crushed into the size less than 4.75 mm (4 mesh). After that, the samples were split into 8 parts by a dividing equipment machine, and then they were grinded to size smaller than 2.36 mm (8 mesh). Some of samples was ovened at 40℃ for 18 hours. Each sample was weighted before and after ovened. The lost weight of samples after ovened was recognized as the free moisture. Samples were then grinded to smaller than 1 mm (20 mesh) for vitrinite reflectance analysis and the rest were grinded to smaller than 250 μm (60 mesh) and 62 μm (250 mesh) for geochemical analysis. Steps of samples preparation are showed graphically in Figure 3.3.

Oil shale and other hard rock samples were prepared for microscopic analysis by cutting as polished rock slab specimens. The slabs were cut perpendiculars and parallel to the bedding plane approximately 2 cm wide, 3 cm long and 1.5 cm thick. Coal, clays, soft or brittle rock samples were grinded to smaller than 4 mm (20 mesh) to make resin mounting polished specimens. The mounting polished specimens were made up by mixing liquid epoxy resin with hardener and pour over the samples in molds for 12 hours. Next step, molded and slap samples were polished on the glass plate with aluminum oxide size No. 200, 400, 600 and 1000 with water as a lubricant. After that they were polished with 1-5 microns chrome oxide and 0.005 microns γ-alumina on the rolling table over the polishing pad or chamois cloth.

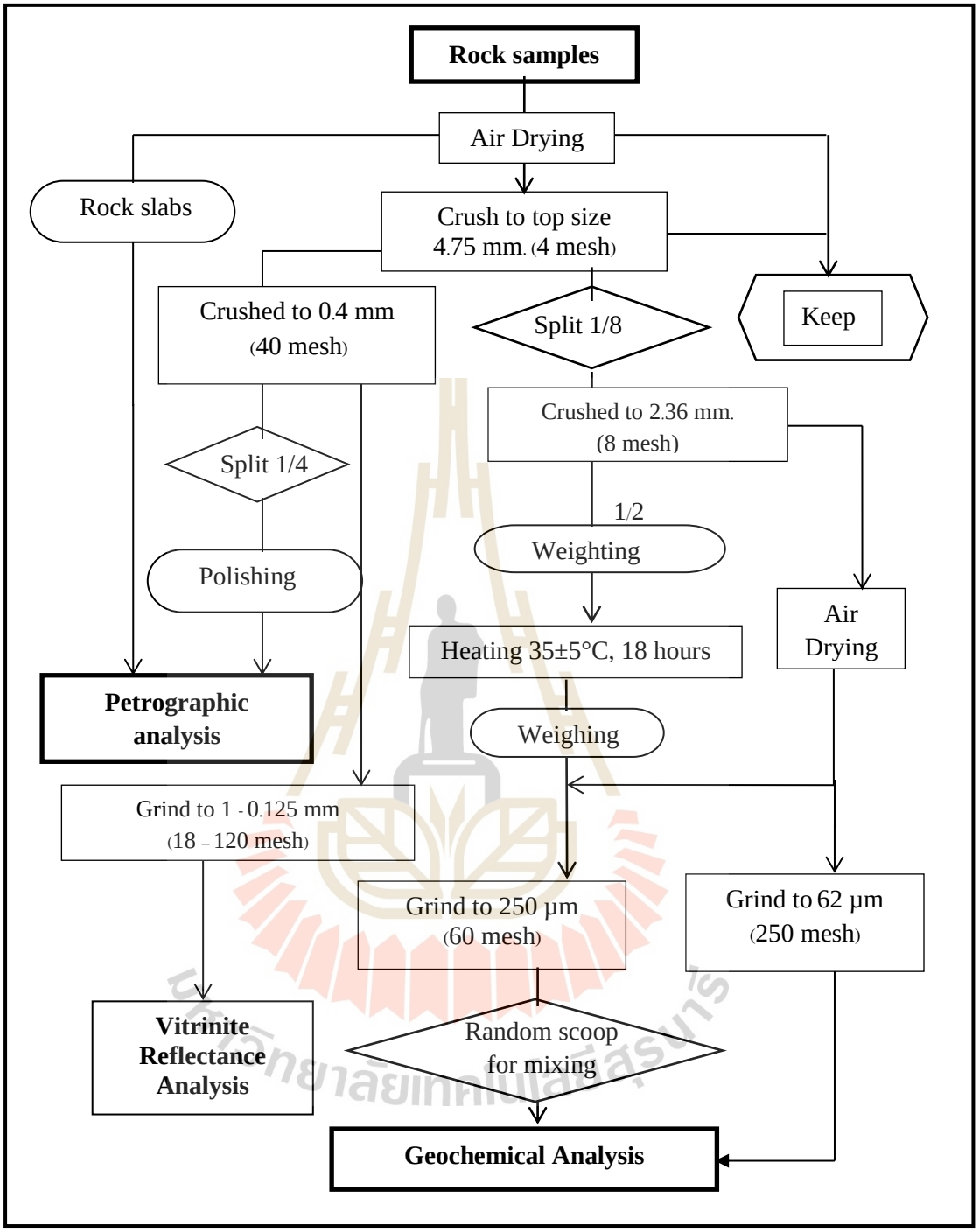


Figure 3.3 Processes of samples preparation for geochemical and petrographical analysis.

3.3 Methodology of sample analysis

In this research geochemical and petrographical analysis were applied. The geochemical analysis was used to determine composition and quality of coal samples. The chemical contents of elements and compositions in organic source rocks samples in this study were examined by proximate, ultimate, heating value and HAWK pyrolysis methods. Whereas the physical property of organic source rocks samples was examined by reflected light microscopic in petrographic analysis. This technique was used to determine the depositional environments and to classify organic rock samples maceral type; vitrinite, liptinite and inertinite, which hint to indicate the quality of source rocks. In addition, the composition of source rocks was also considered together with results from maceral analysis and values of vitrinite reflectance (Ro).

3.3.1 Geochemical analysis

Proximate analysis, ultimate analysis, heating value analysis and hydrocarbon source rock analysis, were conducted for geochemical analysis in this study. The procedure details of each method are as follows:

3.3.1.1 Proximate analysis

In this study the rock samples were analyzed their moisture, volatile matter, fixed carbon and ash content by the Leco TGA-701 (an automatic instrument for proximate analysis) (Figure 3.4) at the Laboratory Section of Geology Department, Mae Moh Mine Planning and Administration Division.

Figure 3.4 Leco TGA-701 (an automatic instrument for proximate analysis).

These instrumental test methods cover the determination sequentially of moisture, volatile matter, and ash in a single instrumental procedure whereas the fixed carbon can be determined by calculation. Theoretically, the instrumental of proximate analysis is recorded repeatedly as a function of temperature and time (Figure 3.5). The sequentially process for moisture, volatile and ash content determination can be listed as follows;

A) Prepared rock powder sample was dried up by heating at 35 °C for 18 hours and grinding to smaller than 60 mesh.

B) Put rock sample powder into the 18 sample slots (1 gram/sample slot).

C) The temperature was elevated up to 107 ± 3°C in nitrogen gas and measure the weight of the samples for moisture calculation. Then the temperature was elevated up to 950 °C for 7 min to measure the volatile matter of the

samples. Decrease the temperature down to 750 ±10 °C in oxygen gas for ash analysis until the combustion completed and weight what left over as the ash content.

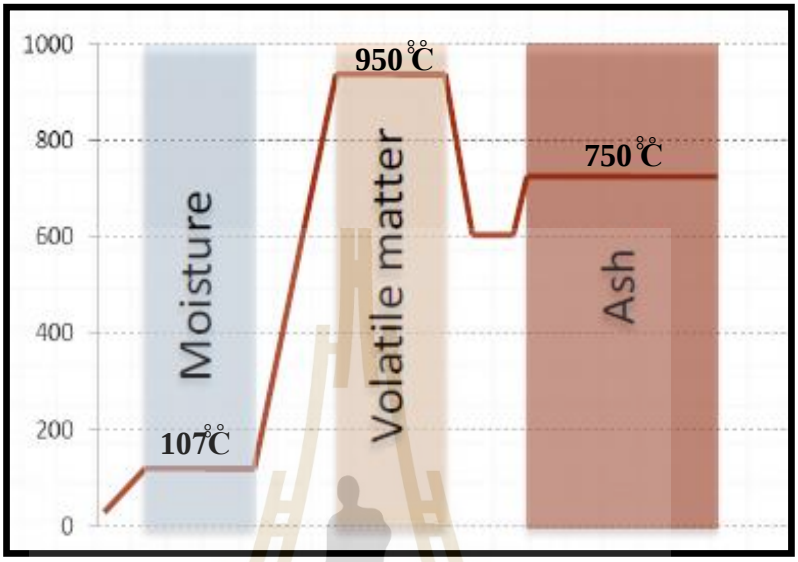


Figure 3.5 The temperate process during conducting the proximate analyses for moisture, volatile matter and ash content determination.

D) The total moisture of the rock sample can be calculated according to the ASTM D3302/D3302M standard (ASTM, 2011d) by equation 3-1.

$$M_{ar} = [M_{ad} \times 100 - \frac{Mf_{(-2.36\ mm)}}{100}] + Mf_{(-2.36\ mm.)} \quad (3\text{-}1)$$

where

M_{ar} = moisture content by weight at As-Received (percentage)

M_{ad} = moisture content by weight at As-Determined (percentage)

$M_{f(-2.36\ mm)}$ = free moisture content (percentage)

E) The fixed carbon percentage of the samples can be calculated from equation 3-2.

$$\%\text{Fixed Carbon} = 100 - (\%M + \%VM + \%Ash) \quad (3\text{-}2)$$

Where

%Fixed carbon = fixed carbon content (percentage)

%M = moisture content (percentage)

%VM = volatile matter content (percentage)

%Ash = ash content (percentage)

3.3.1.2 Ultimate analysis

In this study the ultimate analysis was conducted to determine carbon, hydrogen, nitrogen and sulfur content of the studied samples by LECO Model Tru Spec CHN following the ASTM D5373 – 08 standard (ASTM, 2011f). Carbon, hydrogen and nitrogen content were determined by the automatic calculation of the instrument while sulfur and nitrogen were released in solution form. The quantity of elements in form of their corresponding gases (CO_2, H_2O, and NO_x) were then detected by the Infrared detector (IR) and thermal conductivity detector cell. The steps of the ultimate analysis as illustrated in Figure 3.6 are listed as follows;

A) Place the studied samples (0.1 gram) in the sample hole of the instrument for combustion at 950℃ in oxygen to form oxides forms of carbon, hydrogen and nitrogen. Combustion products which can be interfered with the subsequent gas analysis were removed by specific reagent, especially SO_2.

B) Water vapor and carbon dioxide were detected and removed from the gas stream at the Infrared detector (IR) cell while oxides of nitrogen (NO_x) was separated to be N_2 before sending to the thermal conductivity detector cell to detect the nitrogen.

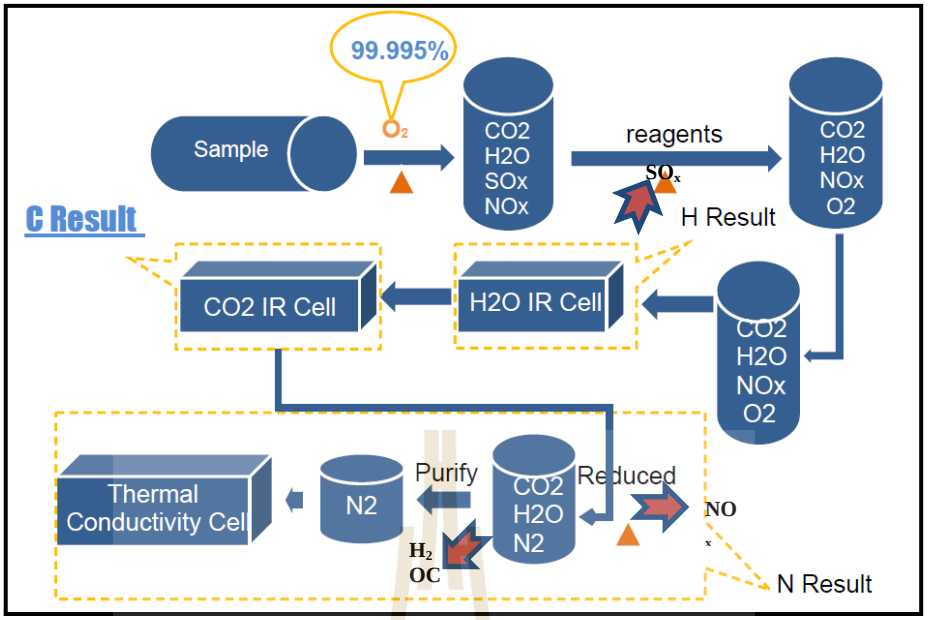


Figure 3.6 The process of the ultimate analysis to detect carbon, hydrogen and nitrogen content by IR cell and thermal conductivity detector cell.

Sulfur content determination was obtained from the total sulfur spectrum produced by complete burning to flame of sulfur compounds (ASTM 4239 – 12, 2011g). The process to detect sulfur content of the studied samples as showed in Figure 3.7 are listed as follows;

A) A 0.3 gram of sample was burned in a furnace tube at 1350℃ in a stream of oxygen.

B) During combustion, the sulfur and sulfur compounds were decomposed and oxidized to be sulfur dioxide (SO_2).

C) Moisture and particulates were removed from the gas stream by filters.

D) Sulfur dioxide was then detected and absorbed at IR cell by a precise wavelength filter.

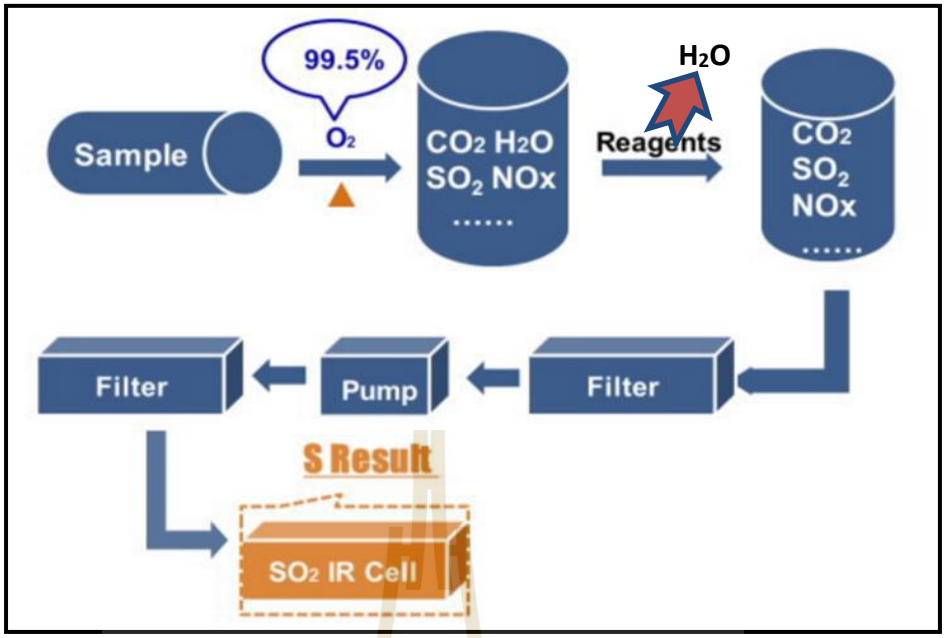


Figure 3.7 The process of ultimate analysis for sulfur detection.

Oxygen content can be determined by subtraction the sum of the percentage of C, H, N, and S, and ash from 100 as expressed in equation 3-3. The ash content can be got from proximate analysis.

$$\%Oxygen = 100 - (\%C + \%H + \%N + \%S + \%Ash)_{ad} \quad (3\text{-}3)$$

Where

%Oxygen = oxygen content (percentage)

%C = carbon content (percentage)

%H = hydrogen content (percentage)

%N = nitrogen content (percentage)

%S = sulfur content (percentage)

3.3.1.3 Heating Value analysis

The gross calorific values measurement of the studied coal samples in this study had been conducted following the ASTM D5865 – 10a standard.

The bomb calorimeter Leco AC-350 at geochemical laboratory of Mae Moh Mine (Figure 3.8) was used in this study. The heat capacity in the calorimeter is determined by burning a specified mass in oxygen and measuring the increase temperature of water in the calorimeter. The steps start with mass of specimen around 1 g was accurately weighed in to specific cup, weight of wire length 10 cm. (fuse) before burned. Electricity per with cylindrical container which connect fuse for burning ensure some part of wire contact with sample for completely burning, then put the sample into the close cylindrical which connect to electrode and filled oxygen combustion in to it. A comparable amount of the analysis sample is burned under the same conditions in the calorimeter. The equipment detected water temperature change by burning of coal. The last step is to weigh of remain wire after burned and titration nitrogen. The calorific value of the analysis sample is computed by multiplying the corrected temperature rise, adjusted for extraneous and fuse heat effects, deducting value of sulfur, nitrogen, and other composition, by the heat capacity and dividing by the mass of the sample.

Figure 3.8 The bomb calorimeter Leco AC-350.

3.3.1.4 HAWK pyrolysis analysis

HAWK (Hydrocarbon Analyzer with Kinetics) system was used in this study to measure TOC, oil and kerogen yields as well as thermal maturity. Selected organic sediments were sent to the Energy Resources Consulting Pty. Ltd., Australia, to conduct the HAWK pyrolysis analysis. The amounts of hydrocarbons were measured by a flam ionization detection (FID) while CO and CO_2 were measured by an infrared (IR) detector cell of the HAWK instrument during the temperature was elevated at each step. The relationship among oil yield (S1), kerogen yield (S2), CO_2 (S3), CO, elevated temperature and time during the pyrolysis process of the HAWK instrument is illustrated graphically in Figure 3.9.

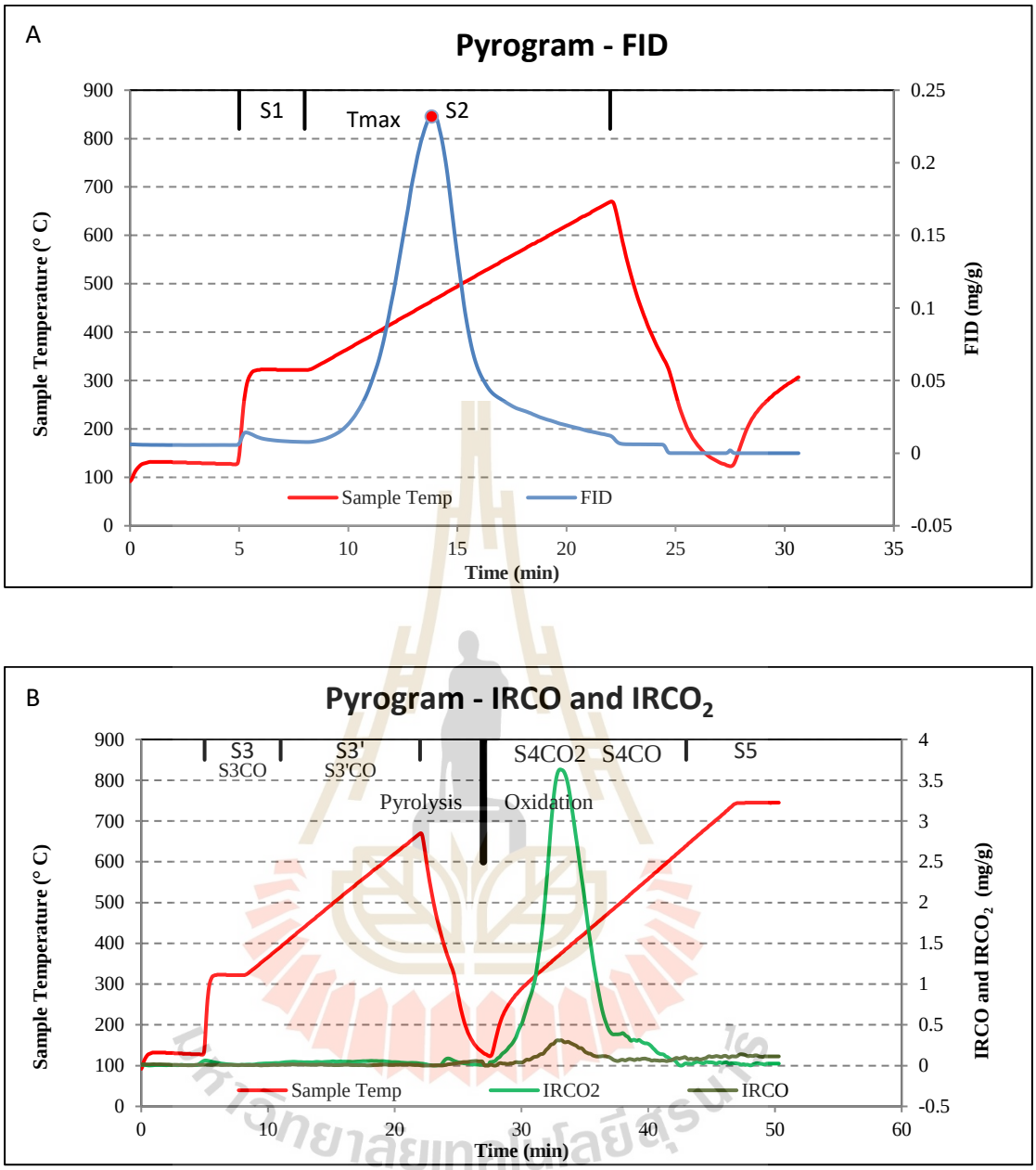


Figure 3.9 The relationship among S1, S2, S3, CO2, CO generating and elevated temperature and time during the pyrolysis process of the HAWK instrument: the FID detector to detect S1, S2 and Tmax (A) and the IR detector to detect CO on S3, CO2 and CO on S4 (B).

3.3.2 Petrographic analysis

In this study the petrographic analysis was conducted on polished specimens made from rock slabs, cutting both perpendicular and parallel sections and crushed samples mounting in epoxy resin to identify maceral and mineral composition and to determine the vitrinite reflectance pf the studied organic samples. The basis of organic petrography is optical microscopy that includes reflected and transmitted white light, fluorescence (UV and blue light excitation), and polarized light analysis of the organic matter (Ruiz *et al*., 2012).

The identification of maceral types conducted in this study was based on the simplified classification and volume percent of organic composition and mineral matter by composition from petrography. The determinations were point counting procedure to obtain the volume percent of the various macerals. The petrography can also be used to determine contaminants and to detect the sample oxidation. The maturation of the studied organic samples was determined by using maximum vitrinite reflectance (VR) which present in unit of %Ro.

3.3.2.1 Maceral composition

The maceral compositions and types of the selected polished specimens were identified under a microscope based on their light reflectance, optical properties and morphology by using reflected light microscope equipped with polarizer and UV-excitation, follow the maceral nomenclature as described in Stach *et al*. (1975), ASTM D2799 – 11 (2011) and ICCP (1994; 1998; 2001). Under 10x10magnification, four observed area were selected from each of the studied sample. Maceral and mineral matter were then identified under Plane Polarized Light (PPL), Cross-Polarized Light

(XPL) and the Ultraviolet (UV) excitation and were counted up to 100 points from each observed area (400 observed points for each of the studied sample).

3.3.2.2 Vitrinite reflectance (Ro)

The vitrinite reflectance analysis is the major method to determine the thermal maturity of the organic sediments. It is determined by illuminating a polished surface in immersion oil. In this study the vitrinite reflectance analysis was made using a Leica MP4500P system with Hilgers DISKUS software of ERC Pty. Ltd., Australia. The microscopic system measures amount of light which recorded in percent reflectance and calibration of photometric by calculated from their refractive indices.

The 2 samples from Coal A and Coal B, were prepared by crushing the samples to smaller than 1 mm (18 mesh). The samples were sub-sampled by evenly spreading the coal and taking between 10 and 15 scoops using 5 mm wide spatula. Ensuring the samples obtained evenly spreading was about 10 g of sample. Then, these samples were mounted in epoxy resin and polished for microscopic. The polished sample was desiccated at least 12 hours prior to analysis. The microscopic examination is using polished in oil in reflected light. Place the polished in mechanical stage to traverse the sample at regular intervals. Reflectance was determined of a 20 μm^2 area at the wavelength of 546 nm using a total magnification of 500X. The determinations are mean maximum and random in term of vitrinite reflectance (Ro) which Ro_{max} and range of Ro with point count number. A minimum of 50 measurements per sample were made. The vitrinite reflectance measurement was identified by a Leica MP4500P system with Hilgers DISKUS software following the Maceral classification of the Australian Standard AS2856-1986 by Energy Resources Consulting Pty Ltd. The result of mean and maximum reflectance measured in oil are to be reported.

CHAPTER IV

RESULTS AND DISCUSTION

According to the objectives of this research, results of the study and experiments can be categorized into 4 main parts as geology of the studied sedimentary succession, organic petrological analysis, geochemical analysis, and discussion, respectively.

4.1 Geology of studied sedimentary succession

Mae Teep basin is a small half-graben basin. The basin trends north-northeast – south-southwest direction. Results from fieldwork at the mine front indicate that the strata on the western margin of the basin strike N10º – 30ºE with monocline dipping eastward at 40º for lower sequences, and less than 20º for the upper sequences (Figure 4.1). The main rock units in the Mae Teep coal mine consist of Tertiary sequences, which are overlain by Quaternary deposits. Quaternary sediments are unconsolidated sediments including gravel, sand, silt, clays, mud, and lateritic soil with the total thickness about 5 meters. The Tertiary sedimentary deposited in the studied coal mine can be classified (Cook and Sherwood, 2003) by their distinguished characters into 3 main depositional environments (Fluvial, Lacustrine and Swamp), 5 rock units (Fluvial sequences, Fine-grained sedimentary sequences, Oil Shale, Coal, and Leonardite), and 7 sub-units (Upper Oil Shale, Lower Oil Shale, Oil Shale in Coal A, Coal A, Coal B, Coal C, and Leonardite) as showed in Table 4.1 and Figure 4.2

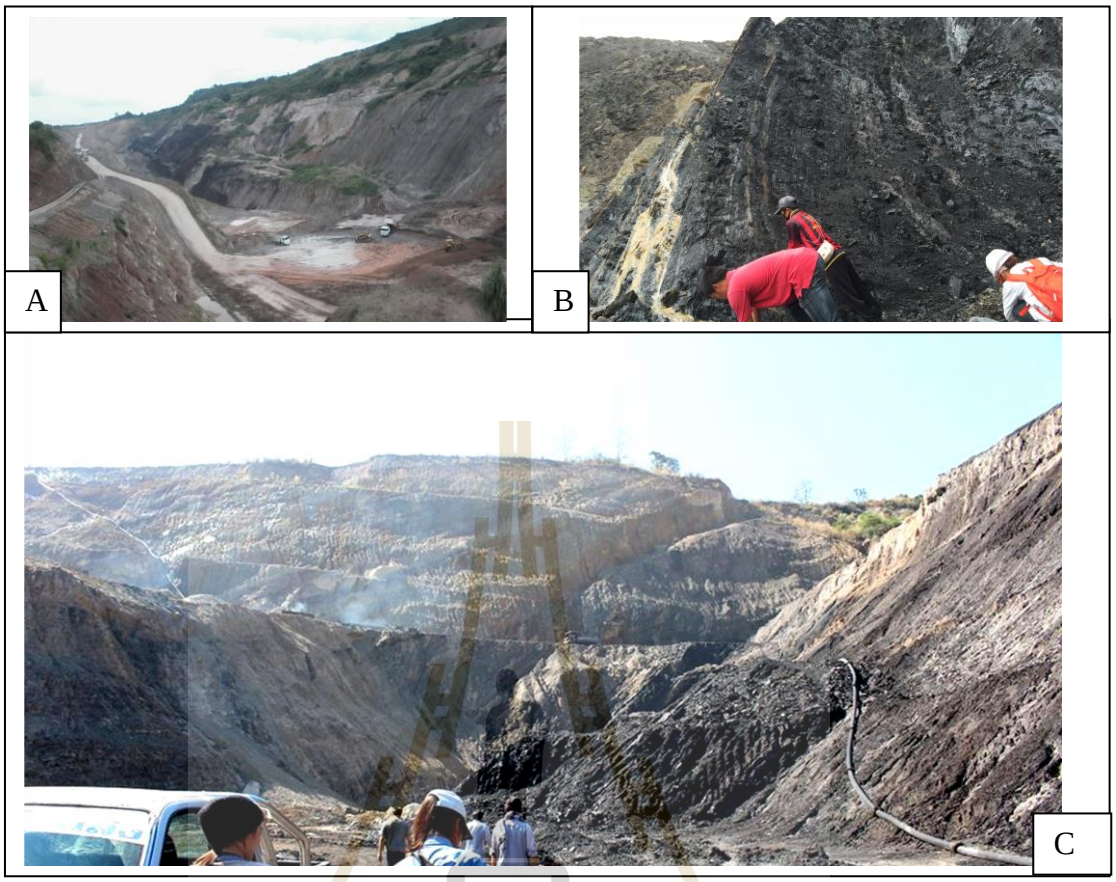


Figure 4.1 Overview of Mae Teep coal mine (A) (look south-west), the strata showing bedding plane strike NE direction (B) and dip eastwards (C) (look south).

Table 4.1 Tertiary rock units of Mae Teep coal mine deposits.

Environments	Unit	Sub-units	Thickness (m)
Fluvial	Fluvial sequences (semi-consolidated)		65.50
Lacustrine	Fine-grained sedimentary sequences		5.50
	Oil Shale	Upper Oil Shale	3.14
		Lower Oil Shale	2.16
		Oil Shale in Coal A	1.13
Swamp	Coal	Coal A	9.26
		Coal B	3.95
		Coal C	4.65
	Leonardite	Leonardite	>3.00

The uppermost part is the youngest Tertiary fluvial deposits. The boundary of the Quaternary and Tertiary deposits is clearly seen by its color. This deposit is made up mainly of greenish gray to gray and reddish-brown sandstone and gravel bed sequences. They consist of semi- consolidated quartz, feldspar and volcanic rock fragments with calcite cement locally. Figure 4.2 A shows difference color and feature of sediments sequences of fluvial (light color) and lacustrine deposits (dark color). Moreover, the lacustrine sequences show the distinguished laminated layers. At the west wall of the Mae Teep coal mine shows darker color organic rocks of the swampy environment (Figure 4.2 B).

The lower part of the Tertiary sequences is the organic sediments which deposited in lacustrine and swamp environment. The 3 main units consist mainly of oil shale, coal, and leonardite. The bedding shows several sub- units striking in the SSW direction and the clear boundary of lacustrine and swampy environments.

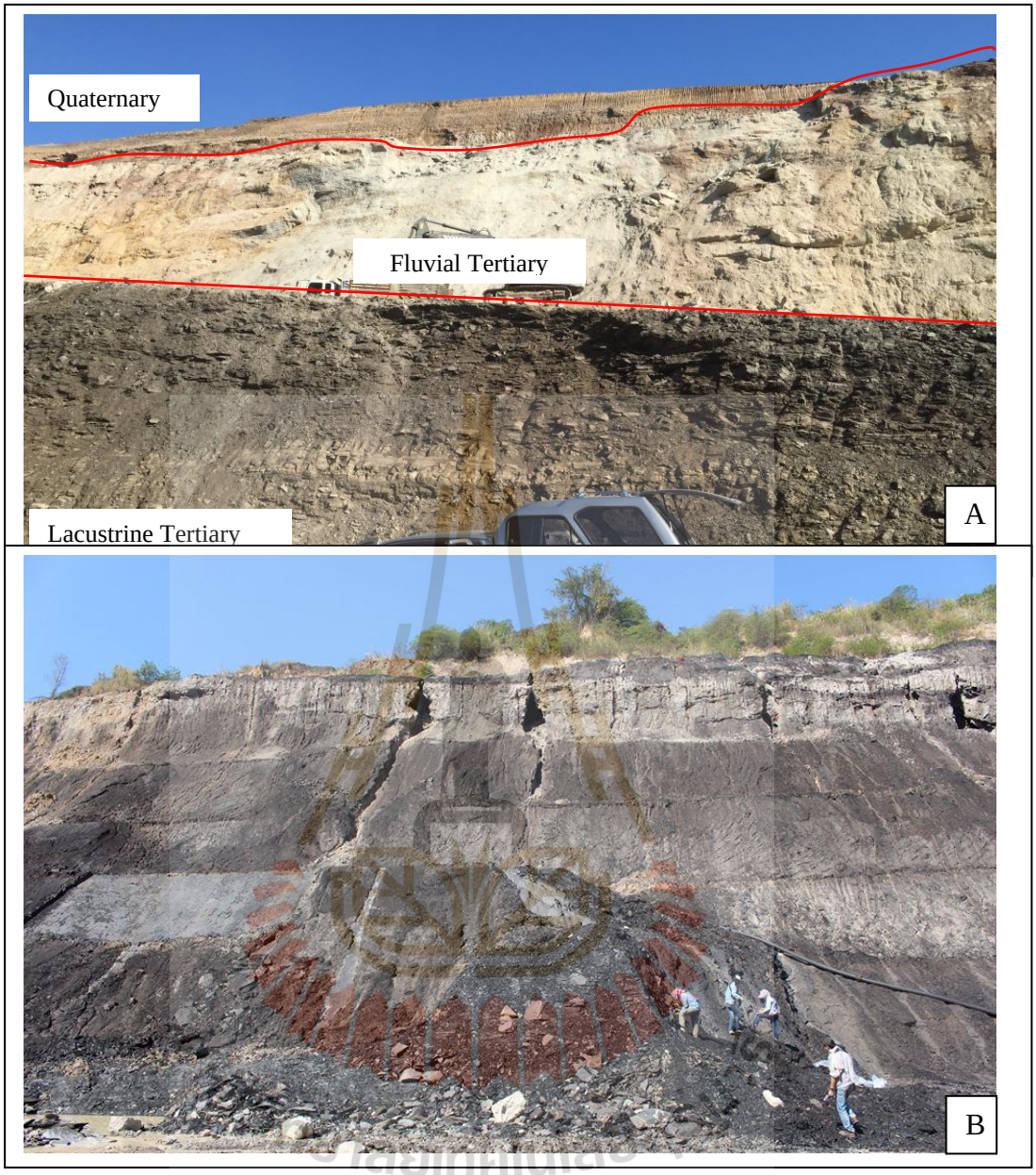


Figure 4.2 The western wall of the Mae Teep coal mine showing units boundary between the Quaternary, fluvial, and lacustrine sequences(A) (look east), the feature of coal and leonardite in the swampy environment at the western wall of mine (B) (look west).

Based on lithology, the lacustrine environment can be divided into 2 units; the Fine-grained sedimentary sequences unit in the upper part which are rare organic material, and the Oil Shale units in the lower part. Deposits of the swampy environment consist of Coal units in the upper part and Leonardite unit in the lower part (Figure 4.3).

The boundaries of the possible petroleum source rock according to their depositional environments from the bottom to the top are depicted in Figure 4.4. The oil shale units in lower lacustrine can be divided into 2 sub-units as the Lower and the Upper Oil Shale sub-unit. The coal formations in the swampy environment deposits can be divided into 3 sub-units; Coal C, Coal B and Coal A sub-unit. All these coal sub-units show the coal bearing sequences starting from the carbonaceous clays or leonardite, sapropelic coal and end up with humic coal (Francis, 1961; Bertrandd, 1984). The Coal A sub-unit has 2 parting of oil shale which deposits in lacustrine environment. The lithostratigraphic units of Mae Teep deposits at the Mae Teep coal mine are sequenced and illustrated in Figure 4.5.

The lithologic details of each unit and sub-units are described in ascending order as follows.

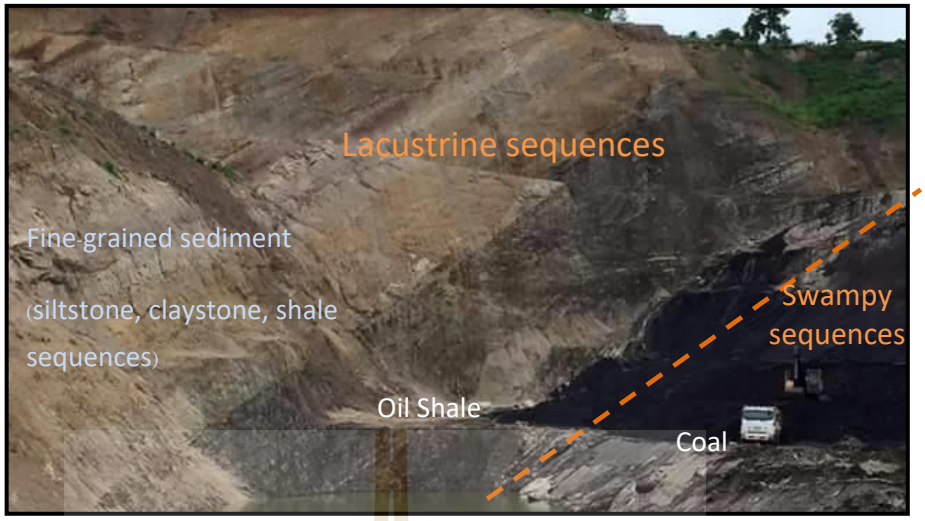


Figure 4.3 The contact boundary between oil shale unit (dark color) and the Fine-grained sediment unit (light color) can be observed at the Mae Teep coal mine front (look south).

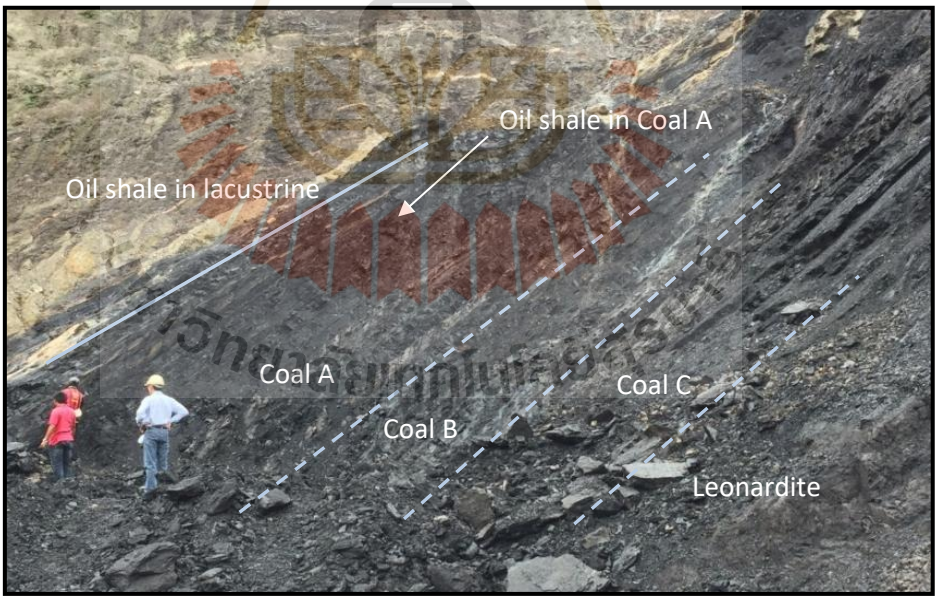


Figure 4.4 Contact boundaries of the swamp environment deposits (Leonardite, Coal C, Coal B, and Coal A sub-unit) and lacustrine environment deposits (Oil shale) at the Mae Teep coal mine (look south).

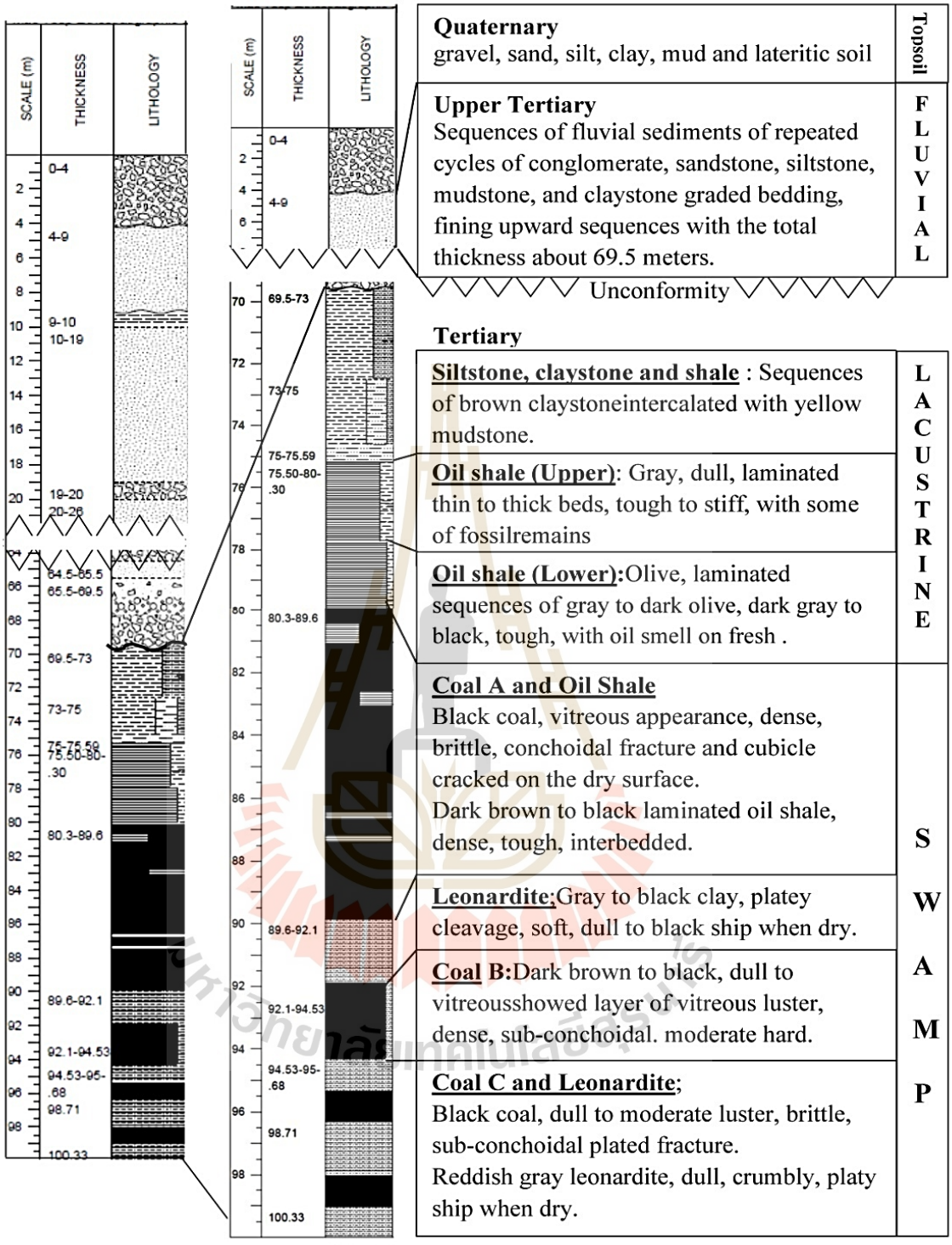


Figure 4.5 Lithostratigraphic column of Mae Teep deposit at the Mae Teep coal mine showing the sedimentary sequences and their related depositional environment.

4.1.1 Leonardite sub-unit

The leonardite sub-unit is the lowermost organic layer deposited in the swamp environment of the studied sedimentary succession at Mae Teep coal mine. Leonardite is carbonaceous clay of various amount of organic contents, dark gray to black, clay sized, platy cleavage, and approximately 5 – 10 m thick. The lower leonardite appears as a thick bed with clay features at the surface (Figure 4.6). It is also found in the lower part of all coal sub-units. This indicates that the depth of water prior to coal deposits starting from deep water and then gradually shallower with having more plants before the ending up of the sequences. It is noticed that the leonardite parting in coal sub-units show feature of less clays than the lowermost leonardite unit.

4.1.2 Coal C sub-unit

Coal C is the lowest coal sub-unit. It is impure coal, dark gray to black, dull to moderate glossy luster, dense, sub-conchoidal to conchoidal, and shows platy cleavage. The lower part of the sub-unit is interbedded with clay- to silt- sized leonardite, unconsolidated, dull, crumbly and platy cleavage (Figure 4.7). The upper part shows moderate glossy luster to dull interbedded with claystone of 1-2 cm thick (Figure 4.8 A). The total thickness of the Coal C sub-unit with leonardite parting is 4.65 m.

4.1.3 Coal B sub-unit

Coal B is the sub-unit in between the Coal C and Coal A. It is separated from Coal A and Coal C by the upper and lower leonardite respectively. It is dark brown to black coal, dense, hard, sub-conchoidal fracture. The coal in this sub-unit still deposited with clays or organic sediments that showed moderate dull to moderate glossy luster (Figure 4.8 B). Coal B are dark brown to black, dull to vitreous, dense,

moderate hard with sub-conchoidal fracture. The lower part starting from leonardite, sapropelic coal, show clay- to silt- sized, unconsolidated, dull, crumbly and platy cleavage. The thickness of this coal sub-unit with leonardite is 3.95 m.

4.1.4 Coal A sub-unit

Coal A is the uppermost unit of the coal sub-units. In the lower part, it is dull coal seating on leonardite and sapropel coal of the Coal B sub-unit. It displays clay- to silt- sized, unconsolidated, dull, crumbly and platy cleavage, gradually increases to moderate glossy luster upwards to the higher layer. The lowermost part of the Coal A siltstone is interbedded with siltstone. In the upper part, coal shows moderate glossy to glossy luster. It consists of 2 parting of dark gray to black oil shale (Figure 4.9). This part is massive, black color, vitreous luster, brittle, conchoidal fracture, cubicle cracked on the dry surface. The total thickness of the Coal A sub-unit with leonardite and oil shale parting layers is 9.26 m.

Figure 4.6 The western wall of Mae Teep coal mine showing the bedding plane of leonardite sub-unit: the layer of the lower leonardite sub-unit (A) (look west), leonardite showing surface character of clays (B) (look south-west).

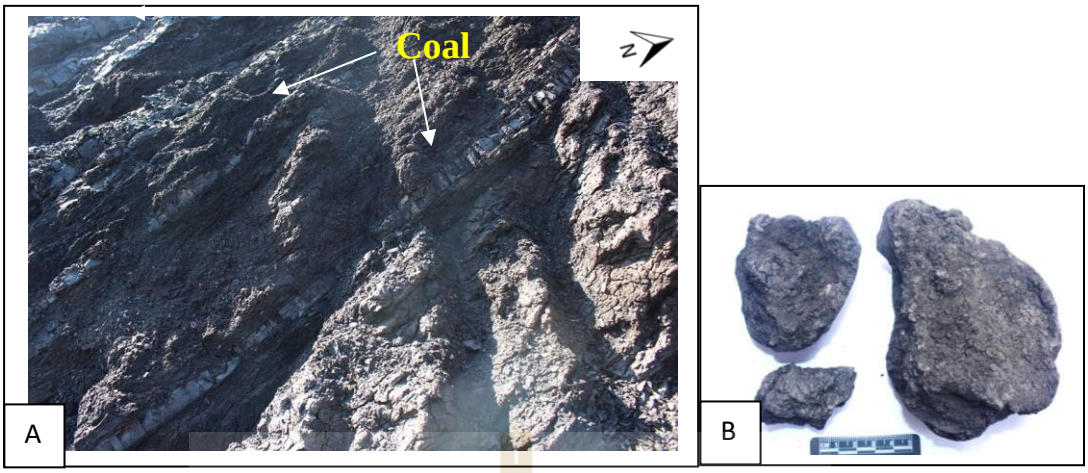


Figure 4.7 Thin layer of coal interbedded in the leonardite (A), the platy cleavage and crumbly surface of leonardite (B).

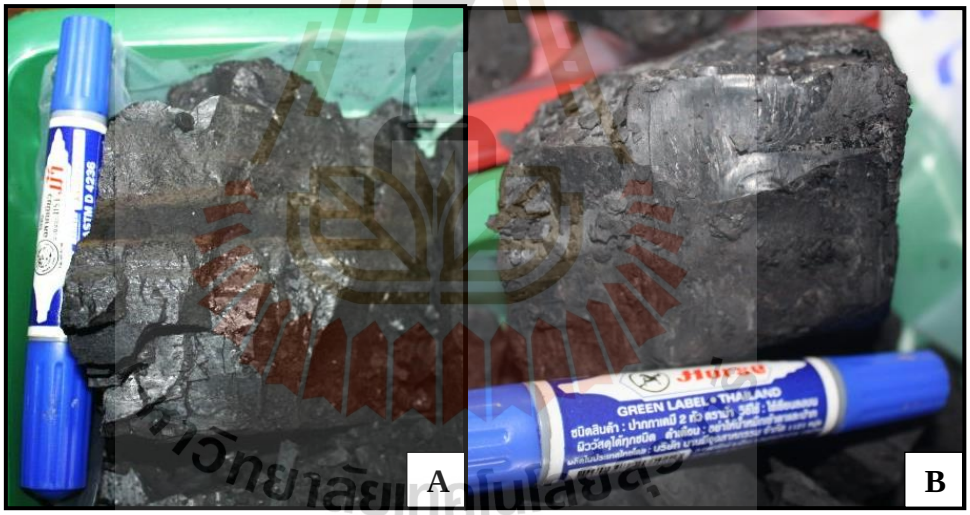


Figure 4.8 Thin layer claystone with impure coal interbedded in the Coal C (A), glossy luster and conchoidal fracture of the Coal B (B).

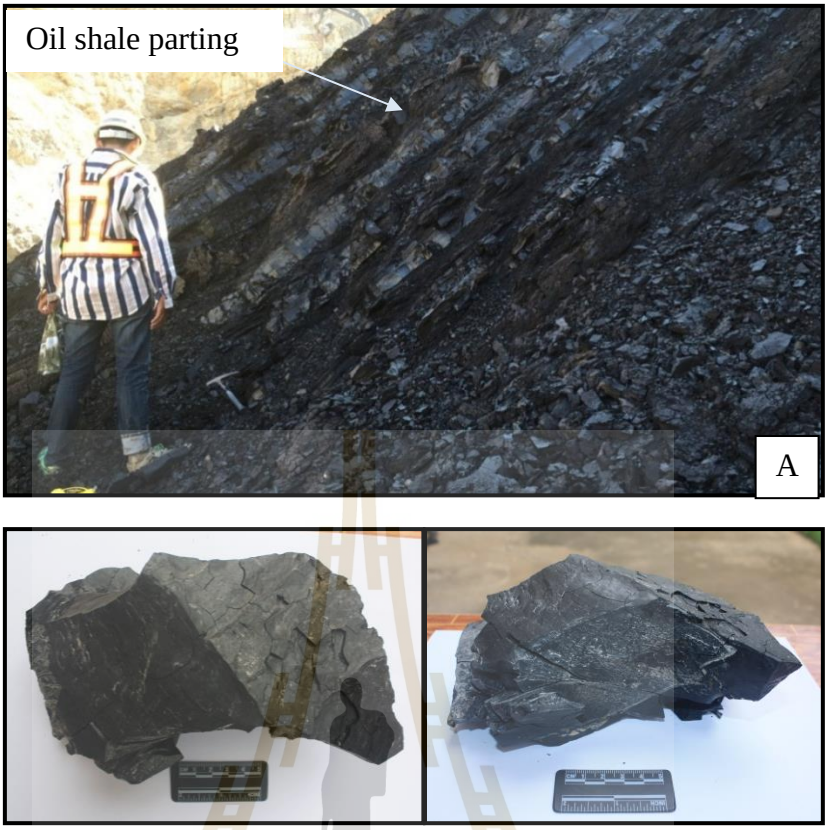


Figure 4.9 The Coal A sub-unit showing the oil shale parting in the upper part (A), Coal A massive texture (B) and Coal A conchoidal fracture with cubicle crack (C).

4.1.5 Oil shale in Coal A sub-unit

This sub-unit is the parting layers of oil shale in the Coal A sub-unit (Figure 4.10). They are made up of fine-grained sediments deposited together with organic material. It was occurred during high stand deep water in forested swamps. The characters of oil shale are likely black shale which is gray to black, dull, dense, fine-sand to clay- sized, tough to break, and stiff (Figure 4.11). Some parts of oil shale show laminated shale layers which are interbedded with some thin yellowish-brown siltstone partings of 1-5 cm thick (Figure 4.11). Mineral matters are coarse-grained

sand to clay sized, poor sorted with sub-round to sub angular. Boundaries of oil shales, coals and siltstone are very clearly seen. The thickness of the lower and upper oil shale in the Coal A sub-unit are 0.60 and 0.53 m respectively.

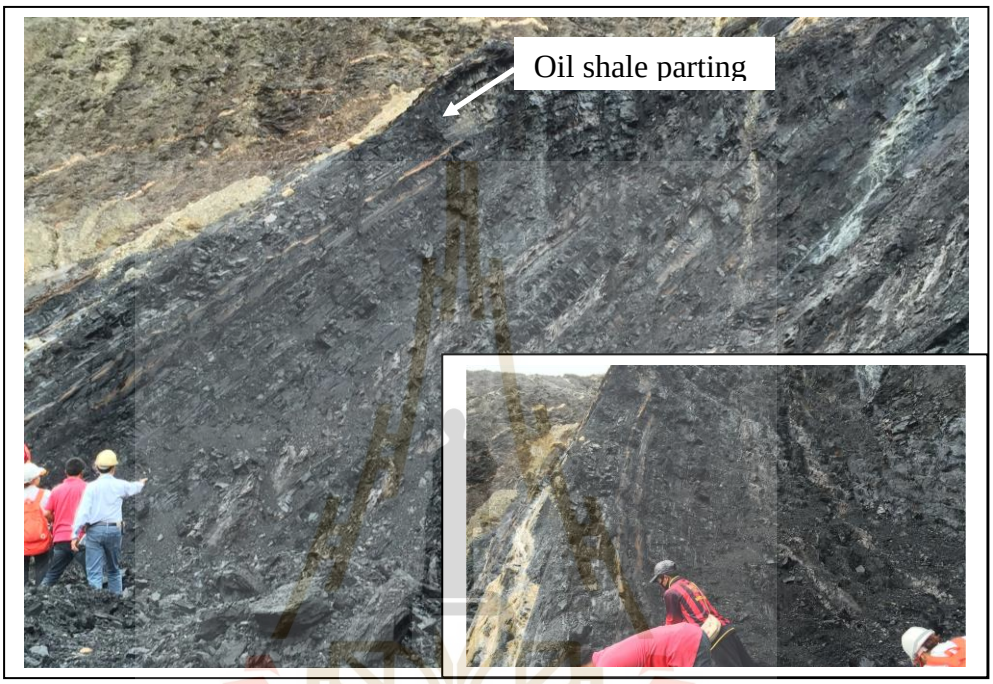


Figure 4.10 The oil shale parting layers in Coal A (look west).

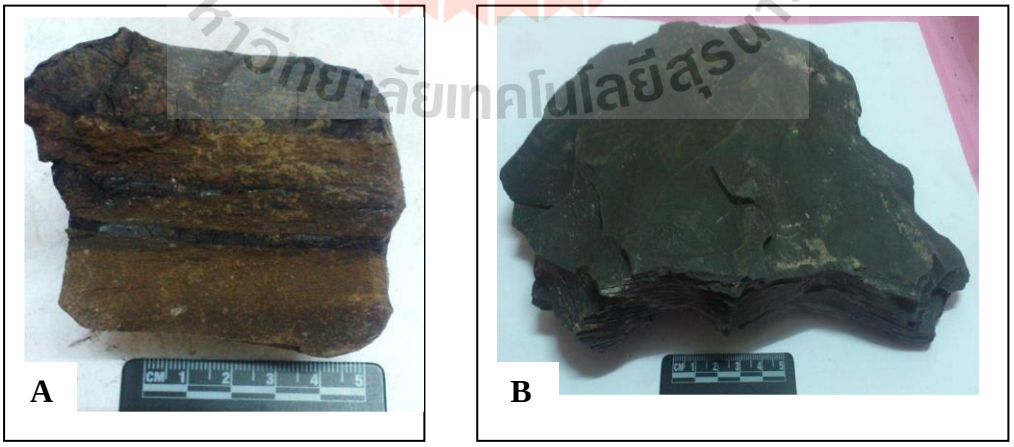


Figure 4.11 The samples show both character of oil shale, dark brown oil shale with thin layer of coal and siltstone (A) and laminated black shale (B).

4.1.6 Lower Oil Shale sub-unit

They are deposited in the lacustrine environment and laid conformably over the Coal A. It is indicated the environmental conditions changing suddenly from the shallow water of forest-peat swamp to the high stand water by successive unit from coal to oil shale. These oil shales show character of pale gray to yellowish brown, and dark gray to dark brown, dull, tough, consolidated, sub-conchoidal fracture in very thin laminated bed with platy cleavage to the thick bed (Figure 4.12 A and B). They have smell of oil in fresh rocks and some layers show shell fossil (Figure 4.12 C). The thickness of the lower oil shale sub-unit is 2.16 m.

4.1.7 Upper Oil Shale sub-unit

The Upper Oil Shale is overlain conformably to the Lower Oil Shale sub-unit and they can be separated from each other by a thick bed of lacustrine sediments. They are brownish black to dark olive laminated oil shale with characters of dull, massive, stiff and hard to break (Figure 4.13). Some layers show remains of shell fossil and platy cleavage. The upper part of this sub-unit has more clay to silt sized particles than the lower part. It is interbedded with brown to yellowish brown siltstone of 1-3 cm thick. The color of uppermost layer is the key to separate fined-grained sedimentary sequences from this oil shale sub-unit. It is reddish brown to brownish black, dull, massive and very hard. The environment of deposition of this sub-unit is the high stand stagnant water and nutrient rich led to thick algal deposit and gradually recedes before the strong current with large amount of fine-grained sediments flooding into the basin and end of organic matter accumulation.

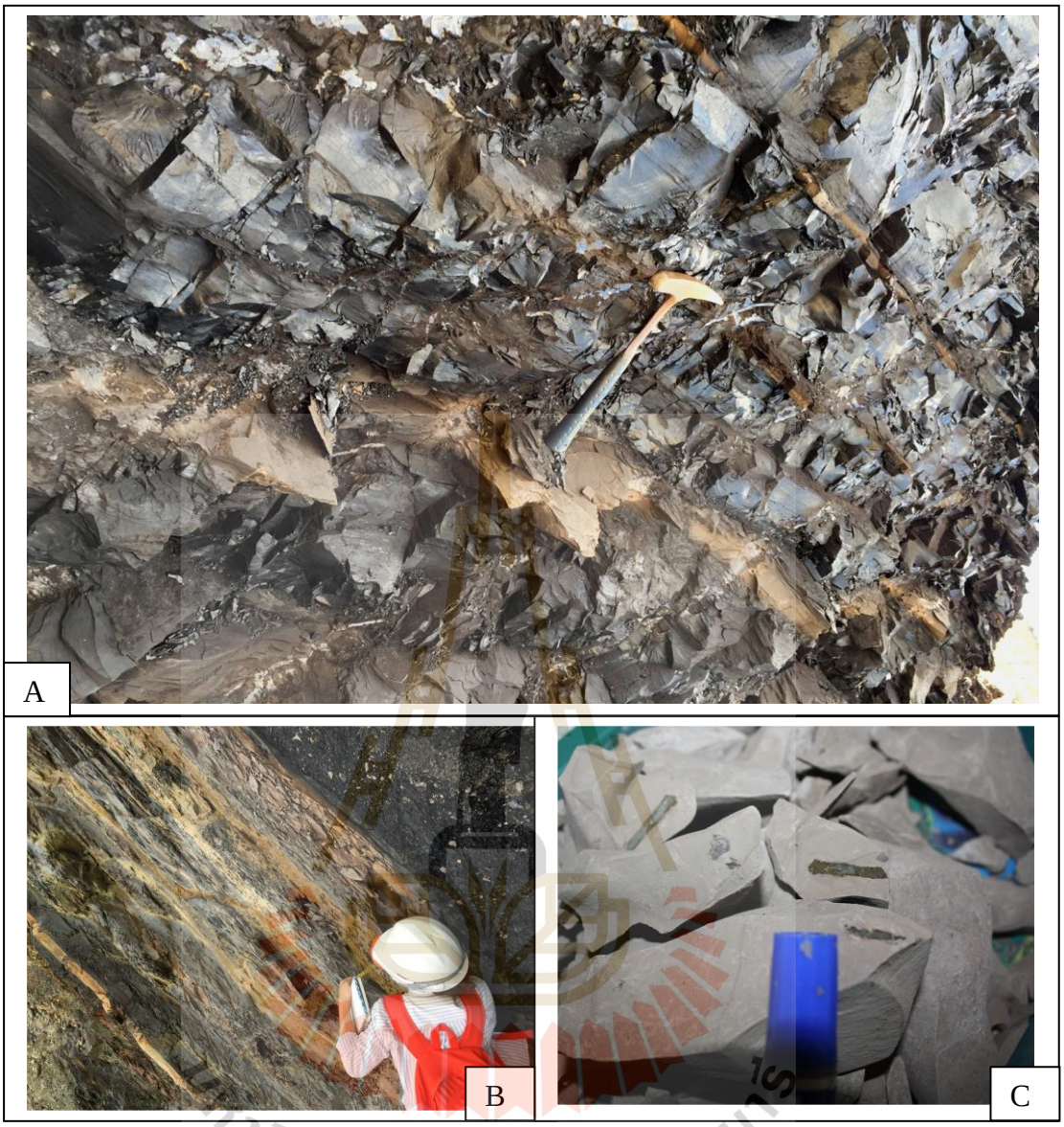


Figure 4.12 The character of the oil shale in fresh rock show dark gray to yellowish brown (A), weathered laminated oil shale show yellowish brown and pale gray (B), and fossils remains found in the Lower Oil Shale sub-unit (C).

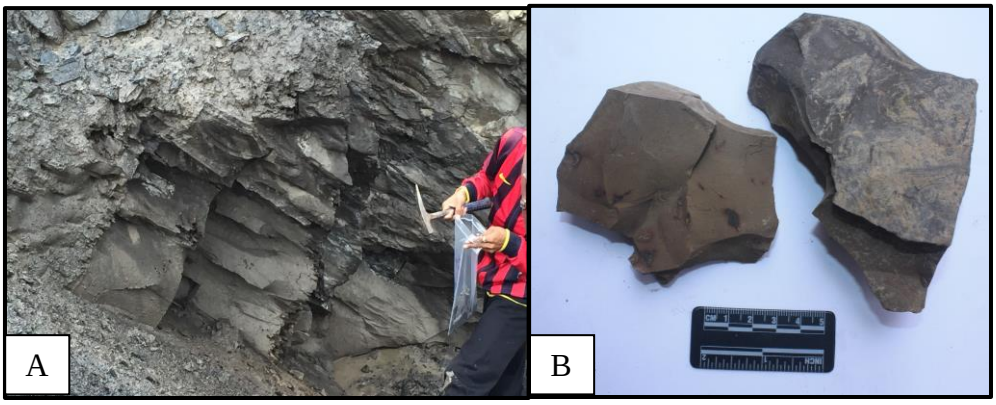


Figure 4.13 Out crop of the upper sub-unit oil shale interbedded with siltstone (A) and brown oil shale with fossils remains (B).

4.1.8 Fine-grained sediment unit

The fine-grained sediment unit is the uppermost part of the lacustrine deposits. It is overlain by fluvial deposits. It is made up of variegated sequences of thin fining upward sediments laying conformably on oil shale (Figure 4.14 A). The total thickness of this unit is 5.5 m. The characters of this unit are varied color and graded bedding of silt to very fine-grained sandstone interbedded with fine-grained mudstone. In figure 4.14 the pale-yellow layers are siltstone and pale gray layers are claystone. Weathered sample shows desiccation cracks perpendicular to the bedding plane (Figure 4.14 B). Moreover, there is a parting of fossil about 1-5 cm thick which is deposited with mudstone and shows same remains of leaves and shells (Figure 4.14 C).

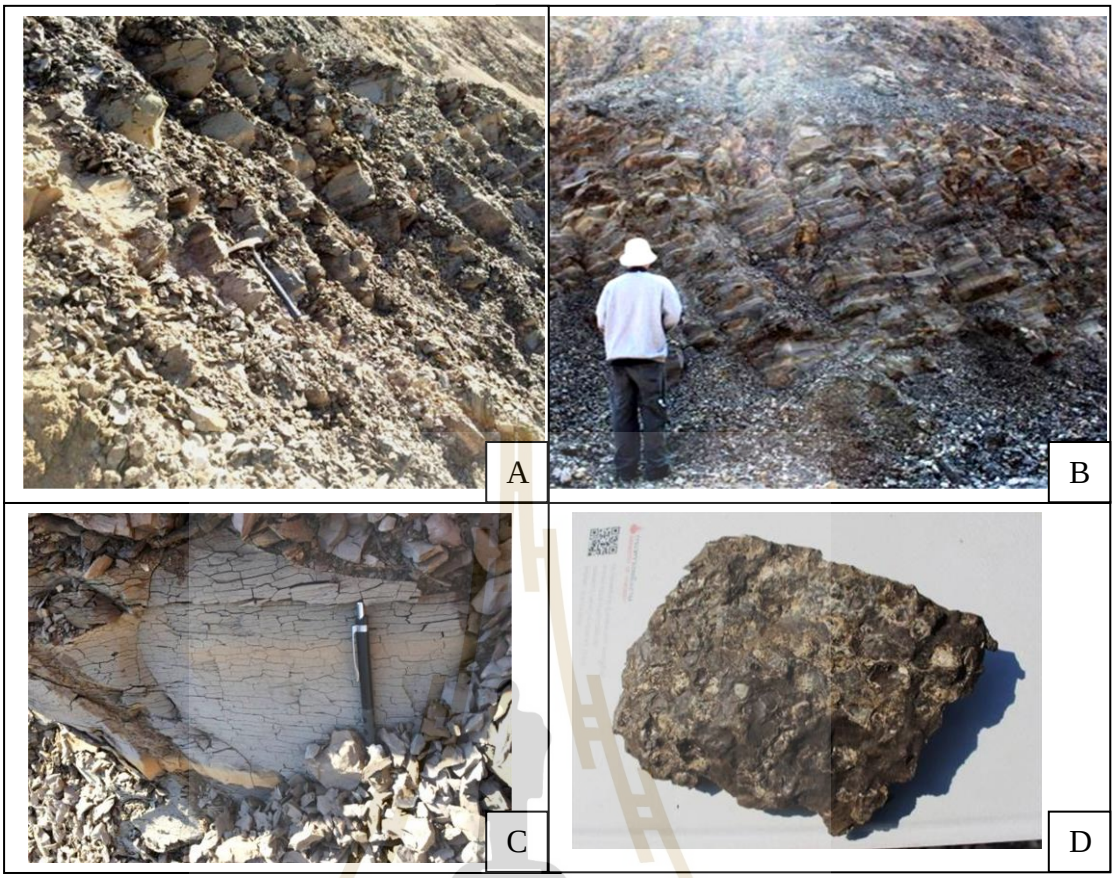


Figure 4.14 The Fine-grained sediment unit from mine front. The outcrop shows intercalated siltstone and mud rock sequences (A and B), the weathered sample displaying desiccation cracks (C)and fossil remains of leaves and shells in the mud rocks (D).

4.1.9 Fluvial deposits

The fluvial sediments are the overburden of Mae Teep deposits at the Mae Teep coal mine. They consist mainly of semi-consolidated of conglomerate, sandstone, siltstone, mudstone, and claystone (Figure 4.15). They are pale gray color, granule to pebble size, poorly sorted, sub-rounded of sandstone clast, conglomeratic limestone cemented by fine to coarse sand matrix (Figure 4.16). They are interbedded

with gravel bed, sandstone and limestone, fine to coarse sand, very poorly sorted, sub angular matrix. The total thickness of the fluvial sediments is 65.50 m and they can be divided into 3 main sequences as follows:

- The lower sequence shows graded bedding, fining upward sequences of conglomerate and sandstone, pale gray to greenish gray and gray, poorly sorted, sub-round to round, very coarse to fine sand. Matrix is white, pale gray to gray with layer of various sized coal fragments. The sequence displays cross bedding of coal with coal lens (Figure 4.17).

- The middle sequence consists of conglomerate and sandstone, reddish brown to purple, medium sorted, sub-round to round, coarse to fine sand. The faulting systems found in sediment beds are both normal and reverse faults striking NW-SE (Figure 4.18).

- The upper sequence consists of reddish-brown sandstone and gravel bed layers. They are fine to medium sand size, moderately sorted, sub-rounded to sub-angular, composed of quartz, feldspar and volcanic rock fragments with calcite cement.

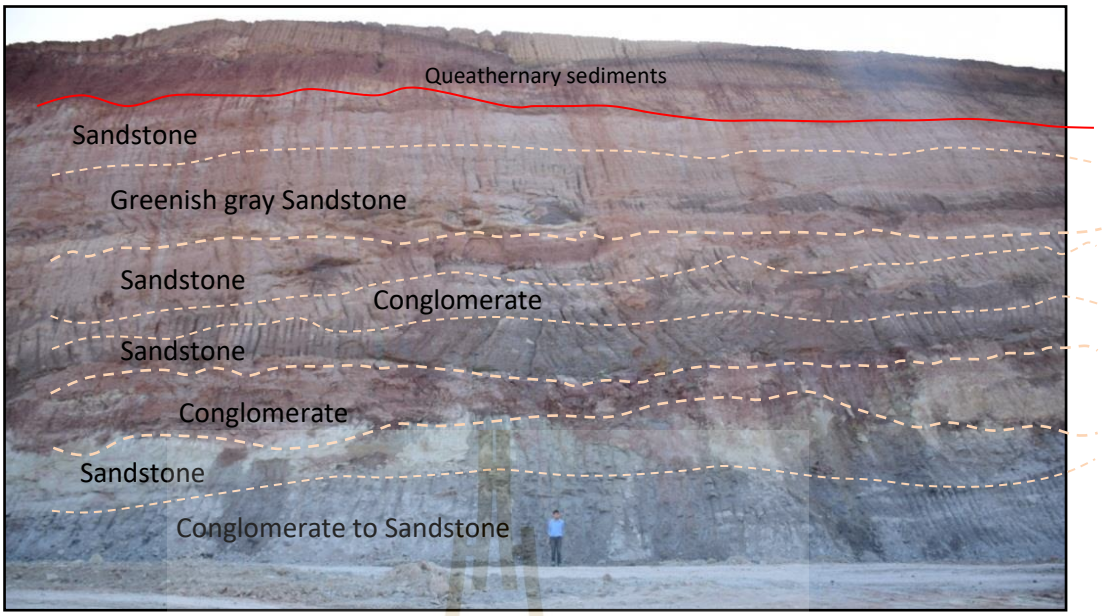


Figure 4.15 Overburden fluvial sedimentary sequences at the Mae Teep coal mine.

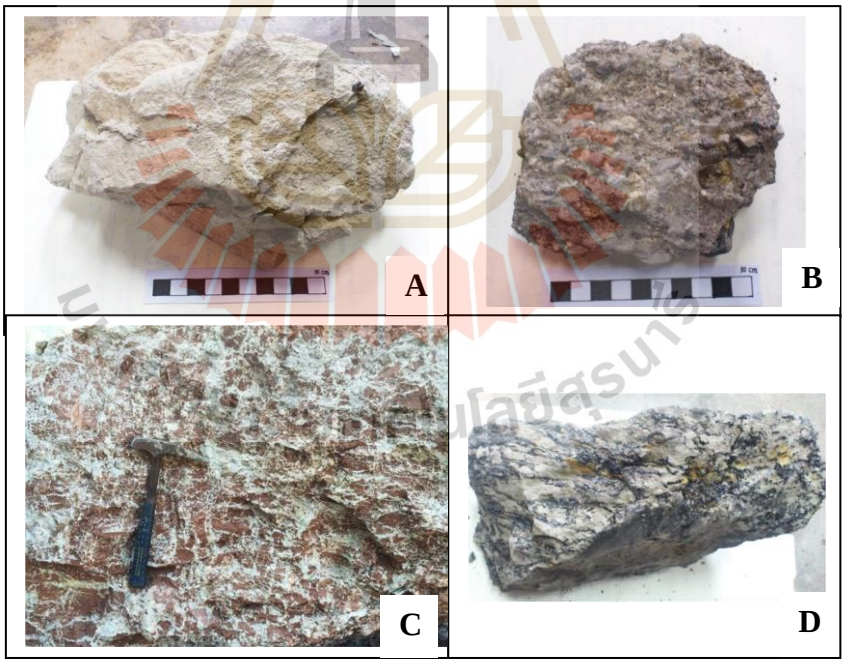


Figure 4.16 Overburden sedimentary rocks: gray sandstone (A), conglomerate (B), reddish mottled sandstone calcite cement (C)and conglomeratic sandstone with coal fragments (D).

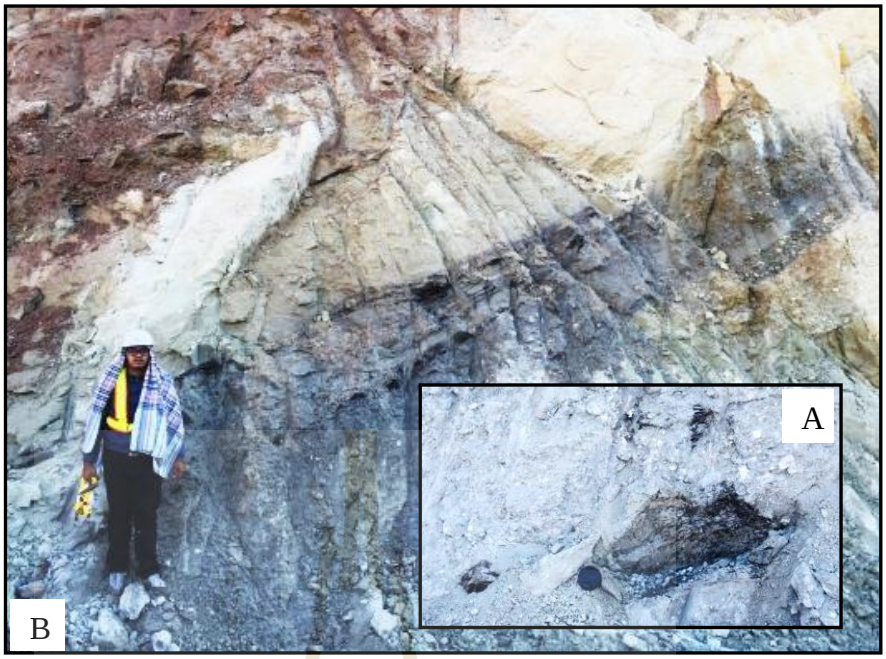


Figure 4.17 Conglomerate and sandstone deposited with coal lens (A) and planar cross bedded and laminar of coal (B) at the lower part of the fluvial sequences (look north-earth).

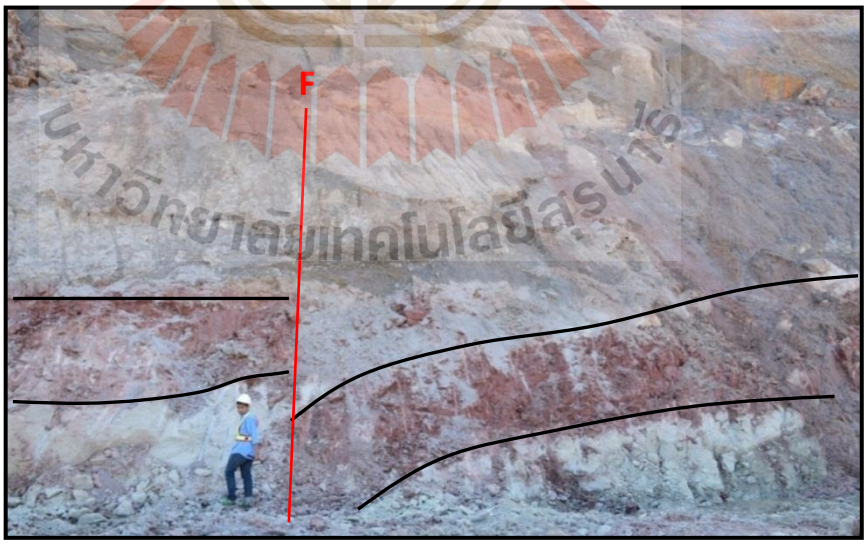


Figure 4.18 Reverse faults trending N 10 – 38 W cut conglomerate and sandstone sequences of the fluvial sediment sequences (look east).

In order to conduct geochemical and petrographic analysis, 14 oil shale samples of lacustrine environment, 26 coal and 4 leonardite samples of swampy environment had been collected. The 26 coal samples were collected from the lower to the upper coal unit consisting of 11 samples from the Coal C sub-unit, 4 samples from the Coal B sub-unit and 11 samples from the Coal A sub-unit. The oil shale samples are 4 samples of Oil Shale in Coal A sub-unit, 6 samples of the Lower Oil Shale sub-unit and 4 samples of the Upper Oil Shale. Number of collected samples, organic rock unit and sub-unit are summarized and showed in Table 4.2. Details of collected organic rock samples from each sub-unit are summarized and showed in Table 4.3. As a result, the correlation among lithostratigraphic unit, environment of deposition and locations of collected organic rock samples of the studied organic sedimentary succession can be illustrated graphically in Figure 4.19.

Table 4.2 Environment of deposition, rock units, sub-units and number of samples collected from each sub-unit.

Environments	**Rock Unit**	**Sub-units**	**Number of collected samples**
Fluvial	Fluvial sequences (semi-consolidated)		-
Lacustrine	Fine-grained sedimentary sequences		-
	Oil Shale	Upper Oil Shale	4
		Lower Oil Shale	6
		Oil Shale in Coal A	4
Swamp	Coal	Coal A	11
		Coal B	4
		Coal C	11
	Leonardite	Leonardite	4

Table 4.3 Organic rock sample descriptions of the studied organic sedimentary succession.

Sub-units	Sample NO.	Descriptions	Thickness (cm)
Upper Oil Shale	OH10	Reddish brown to light brown oil shale, clay- to silt-sized particles, dull, very hard, consolidated, tough with calcite cement, laminated thin to medium beds.	24
	OH 9	Black to brownish black oil shale, dull, moderately hard, semi-consolidated, laminated wavy thin bed, with shell remains interbedded with 1 cm. thick brown siltstone.	107
	OH 8	Black oil shale, dull, dense, moderate hard, clay-sized particles, tough, semi-consolidated, platy cleavage laminated wavy to parallel very thin beds.	96
	OH 7	Brownish black and dark green oil shale, clay- to silt- sized particles, dull, dense, hard, tough, laminated thin beds, sub-consolidated fracture with fossil remains.	87
Lower Oil Shale	OH 6	Yellowish gray to grayish green oil shale, dull, hard, tough, uneven laminated layers, with fossil remains.	56
	OH 5	Grayish green to greenish black oil shale, dull, tough, moderate hard, semi-consolidated, sub-conchoidal fracture, wavy to curved lamination.	28
	OH 4	Yellowish gray to grayish green oil shale, dull, hard, tough, laminated curve with fossil remain.	32

Table 4.3 Organic rock sample descriptions of the studied organic sedimentary succession. (Continued)

Sub-units	Sample NO.	Descriptions	Thickness (cm)
Lower Oil Shale	OH 3	Dark grayish yellow to greenish gray oil shale, clay- to silt- sized particles, dull, hard, sub-conchoidal fracture, platy cleavage, laminated to very thin beds, with smell of oil shown in fresh rocks.	27
	OH 2	Black gray to greenish black oil shale, dull, hard, tough, wavy laminated to thin beds, with fossil remain. Smell of oil shown in fresh rocks.	39
	OH 1	Greenish gray oil shale, dull, hard, tough, sub-conchoidal fracture, platy cleavage, laminated to very thin beds, with fossil remains.	34
Oil shale in Coal A	AS 4	Dark brown to black oil shale, clay- to silt- sized particles, dull, very hard, stiff, consolidated, platy cleavage, micro lens in places, very fine to fine lamination, with yellowish brown siltstone interbedded 3-5 cm. thick.	23
	AS 3	Dark gray to black oil shale, clay- to silt- sized particles, dull, tough, hard, semi-consolidated, even, platy cleavage, micro lens in places, very thin to thin laminated beds.	30

Table 4.3 Organic rock sample descriptions of the studied organic sedimentary succession. (Continued)

Sub-units	Sample NO.	Descriptions	Thickness (cm)
Oil shale in Coal A	AS 2	Dark gray and yellow oil shale, clay-to silt- sized particles, dense, platy cleavage, micro lens in places, wavy very thin to thin laminated beds.	28
	AS 1	Dark gray to black interbedded with yellowish brown oil shale, dull, dense, waxy luster, tough, platy cleavage, very thin laminated layers.	32
Coal A	A 11	Black coal, moderately glossy luster, brittle, conchoidal fracture with sub-cubic cracking, semi-consolidated, very thin lamina siltstone interbedded.	143
	A 10	Dark gray to black coal, moderately dull to moderate glossy luster lamination, brittle to stiff, sub-cubicle cracked, 0.5 – 1 cm. thick beds.	51
	A 9	Black coal, glassy luster, dense, brittle, conchoidal fracture, cubicle cracked.	56
	A 8	Dark brown to black coal, dull, moderately hard, tough, platy cleavage, alternate siltstone 2 mm. to 1 cm. thick interbedded.	21
	A 7	Black coal, dull, dense, moderately hard, moderately brittle, sub-conchoidal fracture to plate cleavage.	89

Table 4.3 Organic rock sample descriptions of the studied organic sedimentary succession.

(Continued)

Sub-units	Sample NO.	Descriptions	Thickness (cm)
Coal A	A 6	Dark brown to black coal, moderately glossy luster, dense, moderately brittle, sub- conchoidal fracture to platy cleavage.	58
	A 5	Black coal, glossy luster, brittle, dense, conchoidal fracture with sub-cubicle cracked.	84
	A 4	Black coal, moderately glossy, dense, moderately brittle, sub-conchoidal fracture to platy cleavage, with brown to yellowish brown siltstone 0.3-2 cm. thick interbedded.	97
	A 3	Black coal, moderately dull to moderately glossy luster band of 0.3 – 0.5 cm. thick, moderately brittle, sub-conchoidal fracture to platy cleavage.	63
	A 2	Dark gray to black coal, dull, dense, moderately hard, tough, semi- consolidated, platy cleavage, thin to medium lamination.	78
	A 1	Black coal, dull to moderately glossy luster in discontinuous wavy very thin lamination, dense, moderately brittle, sub-conchoidal fracture.	94
Leonardite	L19	Black leonardite, clay- sized particles, sticky, waxy luster and platy cleavage when fissile.	137

Table 4.3 Organic rock sample descriptions of the studied organic sedimentary succession. (Continued)

Sub-units	Sample NO.	Descriptions	Thickness (cm)
Coal B	B18	Dark gray to black coal, discontinuous dull to moderately glossy luster band, moderate brittle, platy cleavage, sub- conchoidal fracture, sub- cubical cracking.	87
	B17	Black coal, moderately dull, dense, moderately brittle, sub-conchoidal fracture to platy cleavage.	47
	B16	Black coal, moderately glossy luster, brittle, sub-conchoidal fracture, cubical cracking.	39
	B15	Black coal, dull, moderate brittle, dense, sub-conchoidal fracture to platy cleavage.	35
Leonardite	L14	Black leonardite, clay- to silt- sized particles, sticky, waxy luster, crumble and platy cleavage, fissile.	50
Coal C	C13	Dark brown to black coal, moderately dull to moderately glossy luster band of 0.1 – 0.3 cm. thick, dense, moderately brittle, sub- conchoidal fracture, sub-cubical cracking.	58
	C12	Brown to black coal, dull to moderately glossy luster band of 1 cm. thick, moderate brittle, sub-conchoidal, sub- cubical cracking to platy cleavage, alternate siltstone 0.1 cm. laminated layer.	23

Table 4.3 Organic rock sample descriptions of the studied organic sedimentary succession.

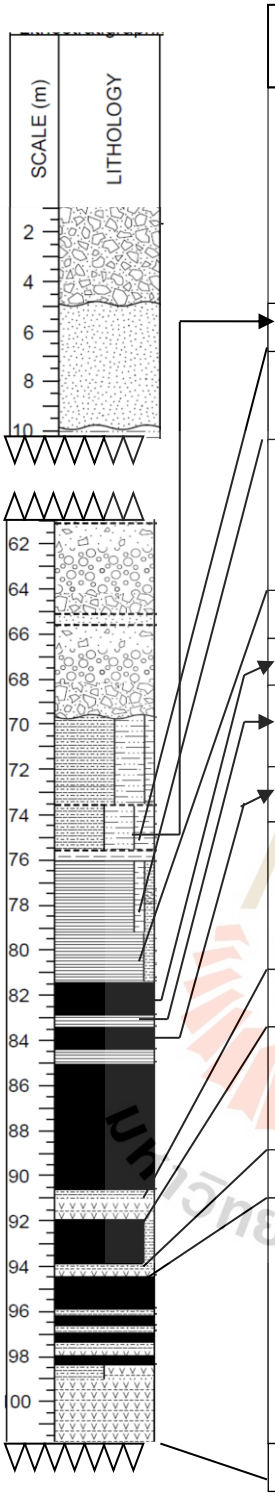
(Continued)

Sub-units	Sample NO.	Descriptions	Thickness (cm)
Coal C	C11	Black coal, dull to glossy luster band of 0.5 – 2 cm. thick, dense, brittle, sub- conchoidal to conchoidal fracture, sub-cubicle cracked.	34
	C10	Black coal, discontinuous dull to moderately glossy luster, dense, moderate brittle, sub- conchoidal to platy cleavage, fissile.	31
	C 9	Black coal, discontinuous dull to moderate dull luster, dense, moderately brittle, sub- conchoidal to platy cleavage.	22
	C 8	Dark gray to black coal, dull, stiff to lightly sticky, moderately brittle, platy cleavage, fissile.	27
Leonardite	L 7	Reddish black to dark gray leonardite, dull, dense, sticky, crumble when dry.	67
Coal C	C 6	Black coal, moderately glossy luster, moderately brittle, sub-conchoidal fracture to platy cleavage.	46
	C 5	Black and brown coal, dull with glossy locally luster, brittle, platy cleavage with sub- conchoidal fracture locally.	37
	C 4	Black coal, dull, moderately brittle, platy cleavage, fissile.	41

Table 4.3 Organic rock sample descriptions of the studied organic sedimentary succession.

(Continued)

Sub-units	Sample NO.	Descriptions	Thickness (cm)
Coal C	C 3	Dark gray to black coal, dull to moderately glossy locally luster, sub- conchoidal fracture with platy locally.	23
	C 2	Dark gray to black leonardite, dull, dense, stiff, platy cleavage, lightly sticky, with crumble when dry.	56
Leonardite	L 1	Reddish gray leonardite, dull, dense, clay- to silt-sized particles, sticky, crumble when dry.	N/A



SAMPLE COLLECTION		Thickness (m)
Sampling number	Quaternary Sediments Gravel, Sand, Silt, Clays, Mud and lateritic soil	5
	Tertiary Sediments	100.16
	Fluvial sequences	65.50
OH 10	Lacustrine; Fine-grained sediment	5.50
OH 9, OH 8, OH 7	Lacustrine Upper Oil Shale sub-unit	3.14
OH 6, OH 5, OH 4 OH 3, OH 2, OH 1	Lacustrine Lower Oil Shale sub-unit	2.16
A 11	Swampy; Coal	1.43
AS 4, AS	Swampy-Lacustrine; Oil shale	0.53
A 10 A 9	Swampy; Coal	1.07
AS 2, AS	Swampy-Lacustrine; Oil shale	0.60
A 8, A 7, A 6, A 5, A 4, A 3, A 2, A 1	Swampy; Coal	5.63
L 19	Swampy; Leonardite	1.37
B 18 B 17 B 16, B 15	Swampy; Coal	2.08
L 14	Swampy; Leonardite	0.50
C 13 C 12 C 11 C 10 C 9, C 8 L 7, C 6, C 5 C 4, C 3, C 2	Swampy; Coal and Leonardite	4.65
L 1	Swampy; Leonardite	N/A

Figure 4.19 Correlation among lithostratigraphic unit, environment of deposition, and locations of the collected organic rock samples of the studied organic sedimentary succession at the Mae Teep coal mine.

4.2 Organic petrological results

Under microscopy, characters of macerals in organic sediments of Mae Teep deposits can be observed. Details of macerals and their depositional environment of each sub-unit can be summarized in ascending order as follows.

4.2.1 Leonardite sub-unit

Leonardite was found at the lowermost of the organic bearing formation in the swampy unit and it was also found at the lower part of coal sub-units. They are carbonaceous clays which are made up of fine-grained sediments deposited with small number of organic compounds. This formation shows characters of high supply of fine-grained sediments which were transported into deep water and deposited with small amount of detrital or colloidal organic sediments. Depositional processes occurred under water during slowly subsidence or rising of water level in the basin. The associated organic matter causes them to display dark brown to black in color, moderately soft and stiff to moderate hard, mild fissile, with platy cleavage when dry.

Under microscopy, leonardite shows maceral groups mainly of vitrinite and liptinite which are associated with fine-grained sediments. The percentage of vitrinite varies from 12 – 25%. It consists of decomposed organic matter in form of gel (gelovitrinite) and minor organic fragments. The percentage of liptinite varies from 12 – 24%. It consists mainly of resinite, sporinite, and liptodetrinite, which are the oxidation products of other liptinitic macerals. Lamalginite was found only in sample L7-4 and L14-1. Cutinite, fluorinite, suberinite, and telalginite were not found in these leonardite samples. Details of macerals; vitrinite (V), liptrinite (L), inertinite (I), and mineral matter (MM) under petrographic study of 7 leonardite samples are summarized and showed in Table 4.4 and Figure 4.20 to Figure 4.26.

Table 4.4 Composition in percentage of leonardite samples.

Sample	Vitrinite				Liptinite									In	MM
								Alginite							
	Telo	Detro	Gelo	Total	Sp	Cu	Lip	Lam	Te	Re	Fl	Su	Total		
L7-1	1	5	13	**19**	3	0	17	0	0	4	0	0	**24**	0	57
L7-3	0	0	25	**25**	1	0	9	0	0	3	0	0	**13**	0	62
L7-4	0	2	19	**21**	2	0	8	12	0	1	0	0	**23**	0	56
L14-1	0	7	18	**25**	2	0	10	1	0	1	0	0	**14**	0	61
L14-2	3	1	17	**21**	1	0	17	0	0	0	0	0	**18**	0	61
L14-3	0	3	9	**12**	4	0	11	0	0	2	0	0	**17**	0	71
L19-1	0	2	19	**21**	0	0	9	0	0	3	0	0	**12**	0	67
min	0.00	0.00	9.00	**12.00**	0.00	0.00	8.00	0.00	0.00	0.00	0.00	0.00	**12.00**	0.00	56.00
max	3	7	25	**25**	4	0	17	12	0	4	0	0	**24**	0	71
%	**0.57**	**2.86**	**17.14**	**20.57**	**1.86**	**0.00**	**11.57**	**1.86**	**0.00**	**2.00**	**0.00**	**0.00**	**17.29**	**0.00**	**62.14**

Tel = Telovitrinite, Det= Detrovitrinite, Gel = Gelovitrinite, In = Inertinite, MM. = Mineral Matter
Sp = Sporinite, Re = Resinite, Lip = Liptodetrinite, Cu = Cutinite, Fl= Fluorinite, Su = Suberinite, Lam = Lamalginite and Te = Telalginite

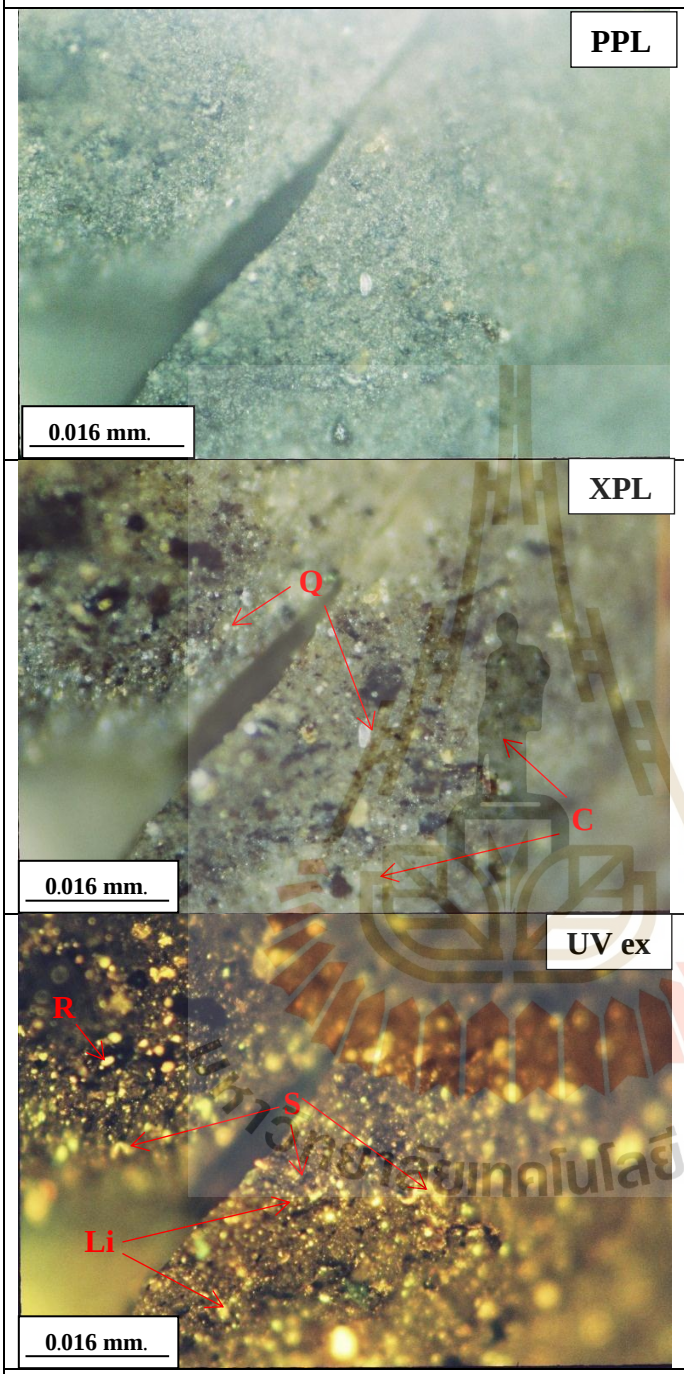
Microscopic Picture	Explanation
	**Sample No. L7-1** **Leonardite** (sapropelitc origin). Composition (%) V = 19 % L = 24 % I = 0 % MM = 57 % **Vitrinite** consisted mainly of gelinite show small globules of pale gray to dark gray in PPL and dark brown to black in XPL and UV excitation. **Liptinite** consist mainly of liptodetrinite, sporinite, and resinite. They display colorless and white yellow to pale gray with high relief in PPL, yellowish brown in XPL. Under UV excitation liptodetrinite show small yellow dots, resinite show yellow lager dots, and sporinite show yellowish brown with spore shape. **Mineral Matter** are of quartz and clay minerals cemented by gelinite. Quartz and clays display white to gray in PPL, white to pale gray in XPL and dark gray to black in UV excitation.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Re = Resinite, S = Sporinite, Q = Quartz, C = Clay, Li = Liptodetrinite	

Figure 4.20 The microscopic picture of leonardite sample No. L7-1.

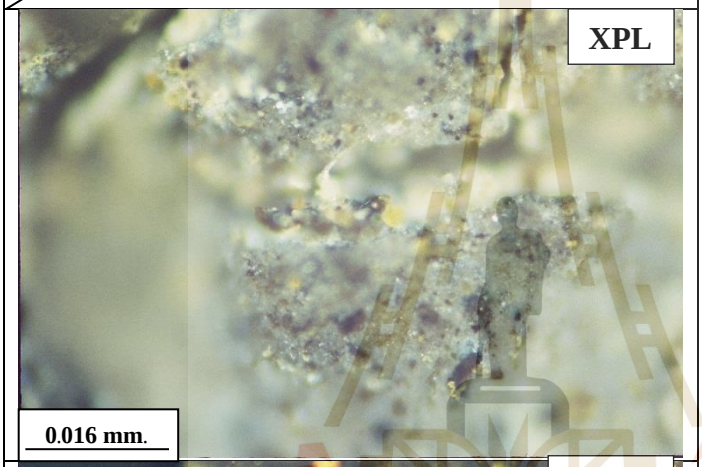
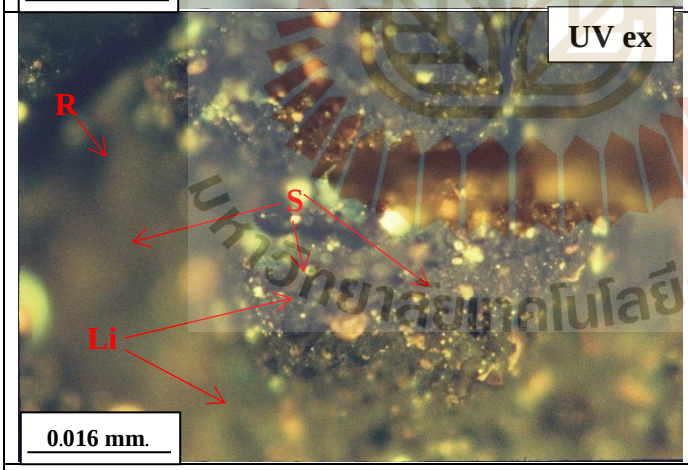
Microscopic Picture	Explanation
 	**Sample No. L7-3** **Leonardite** Composition (%) V = 25 % L = 13 % I = 0 % MM = 62 % **Vitrinite** consisted mainly of gelovitrinite show small globules of dark gray in XPL and black in UV excitation. **Liptinite** consist of liptodetrinite, sporinite, resinite and alginite remain. They display yellowish brown in XPL and bright yellow to brownish yellow in. Under UV excitation. **Mineral Matter** are clay minerals. They display pale gray in XPL and dark gray to black in UV excitation.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Re = Resinite, S = Sporinite, Q = Quartz, C = Clay, Li = Liptodetrinite	

Figure 4.21 The microscopic picture of leonardite sample No. L7-3.

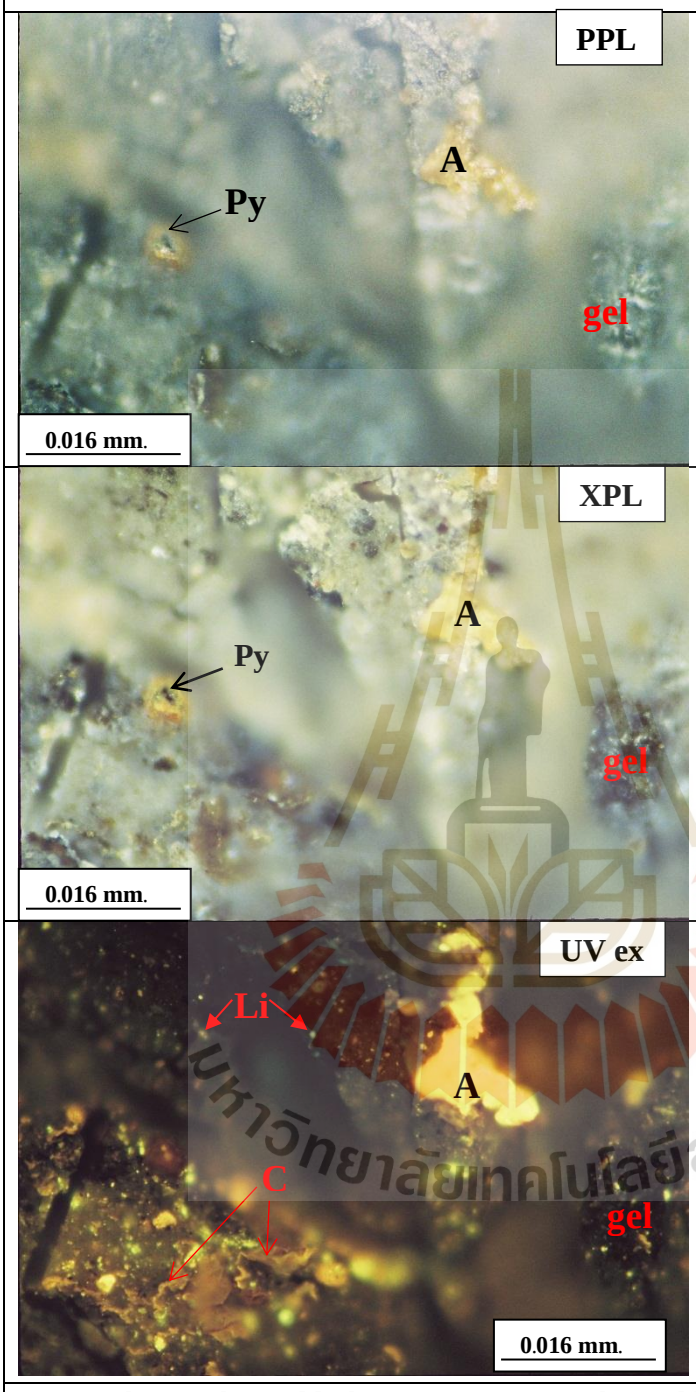
Microscopic Picture	Explanation
	**Sample No. L7-4** **Leonardite** Composition (%) V = 21 % L = 23 % I = 0 % MM = 56 % **Vitrinite** consisted mainly of gelinite shows pale gray in PPL and dark in XPL and UV excitation. **Liptinite** consist mainly of liptodetrinite, with some of alginite and fragment of cutinite. Under UV excitation, liptodetrinite is dark yellow to brown spots and greenish yellow dots. Cutinite shows dark yellow thin and short lines of leaves fragments. Alginite shows white yellow in PPL and XPL with bright yellow under UV excitation. **Mineral Matter** are mainly of clay and silica minerals with some of pyrite. Clays and silica show white to pale gray ground mass in PPL, black in XPL and dark under UV excitation. .Pyrite display yellow sphere with brown oxide rim in PPL and XPL and dark brown under UV excitation.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter A = Alginite, Li = Liptodetrinite, Cu = Cutinite, Py = Pyrite, C = Clay	

Figure 4.22 The microscopic picture of leonardite sample No. L7-4.

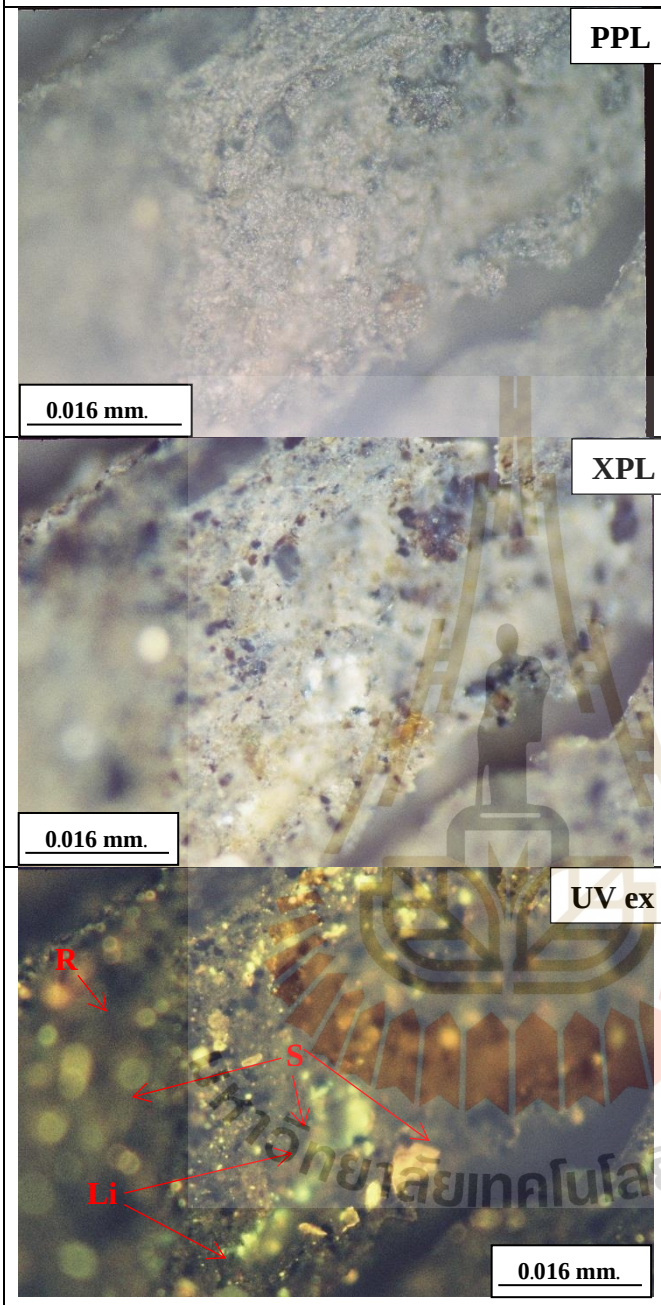
Microscopic Picture	Explanation
	**Sample No. L14 - 1** **Leonardite** Composition (%) V = 25 % L = 14 % I = 0 % MM = 61 % **Vitrinite** consist of mainly of gelovitrinite show small globules and dot of dark gray in XPL and black in UV excitation. **Liptinite** consist of liptodetrinite, sporinite, resinite and other maceral remain. They display yellowish brown dots in XPL and bright yellow to brownish yellow under UV excitation. **Mineral Matter** are clay minerals and they display pale gray in PPL and XPL, and dark in UV excitation.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Re = Resinite, S = Sporinite, Q = Quartz, C = Clay, Li = Liptodetrinite	

Figure 4.23 The microscopic picture of leonardite sample No. L14-1.

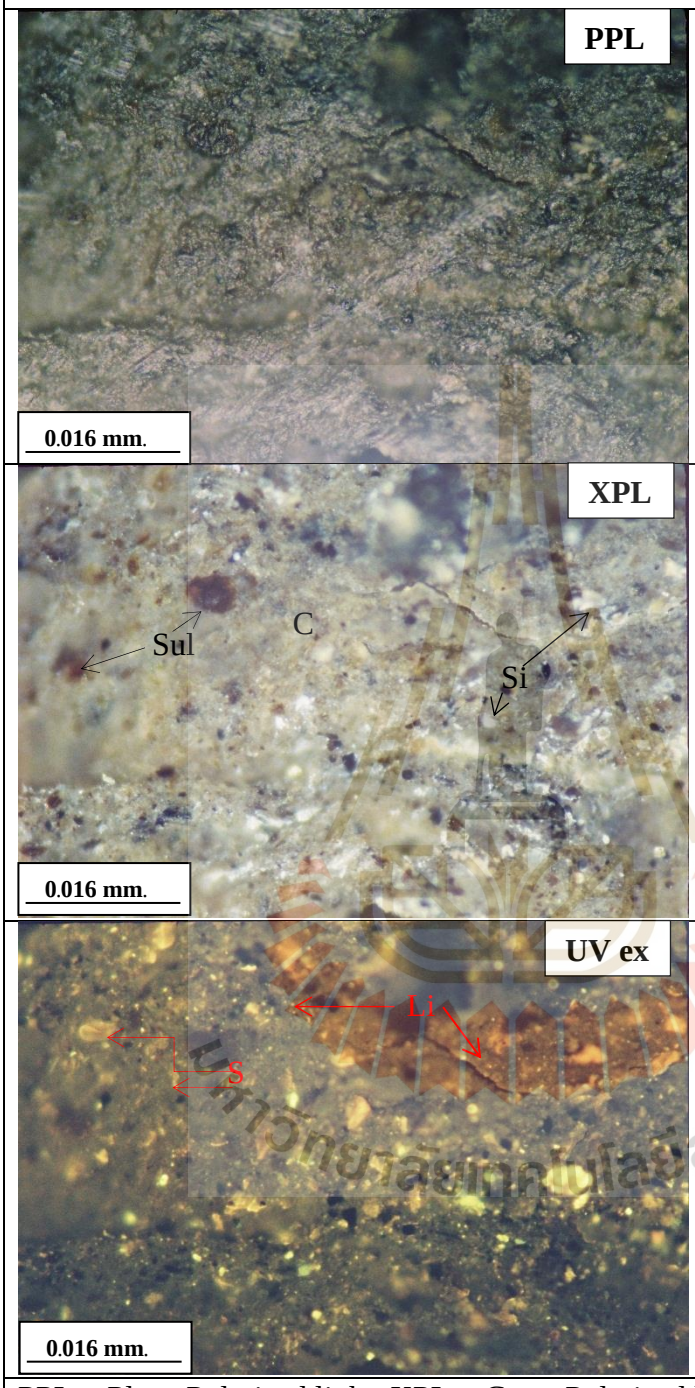
Microscopic Picture	Explanation
	**Sample No. L14-2** Leonardite Composition (%) V = 21 % L = 18 % I = 0 % MM = 61 % **Vitrinite** consisted mainly of gelinite globules display pale gray in PPL and black in XPL and UV excitation**.** **Liptinite** made up mainly of liptodetrinite and sporinite. Sporinite show dark gray in PPL and dark brown in XPL. Under UV excitation, they display yellow to dark yellow of small to big dots with spore shape. Liptodetrinite display bright yellow of very small spots under UV excitation. **Mineral Matter** made up mainly of clay minerals with silica and some of sulfide minerals. Clay and silica show pale gray in PPL, white to yellowish brown in XPL and dark in UV excitation. Sulfide mineral show dark gray to black in PPL, brown in XPL and dark brown under UV excitation.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter S = Sporinite, Li = Liptodetronite, C = Clay, Si = Silica, Sul = Sulfide mineral	

Figure 4.24 The microscopic picture of leonardite sample No. L14-2.

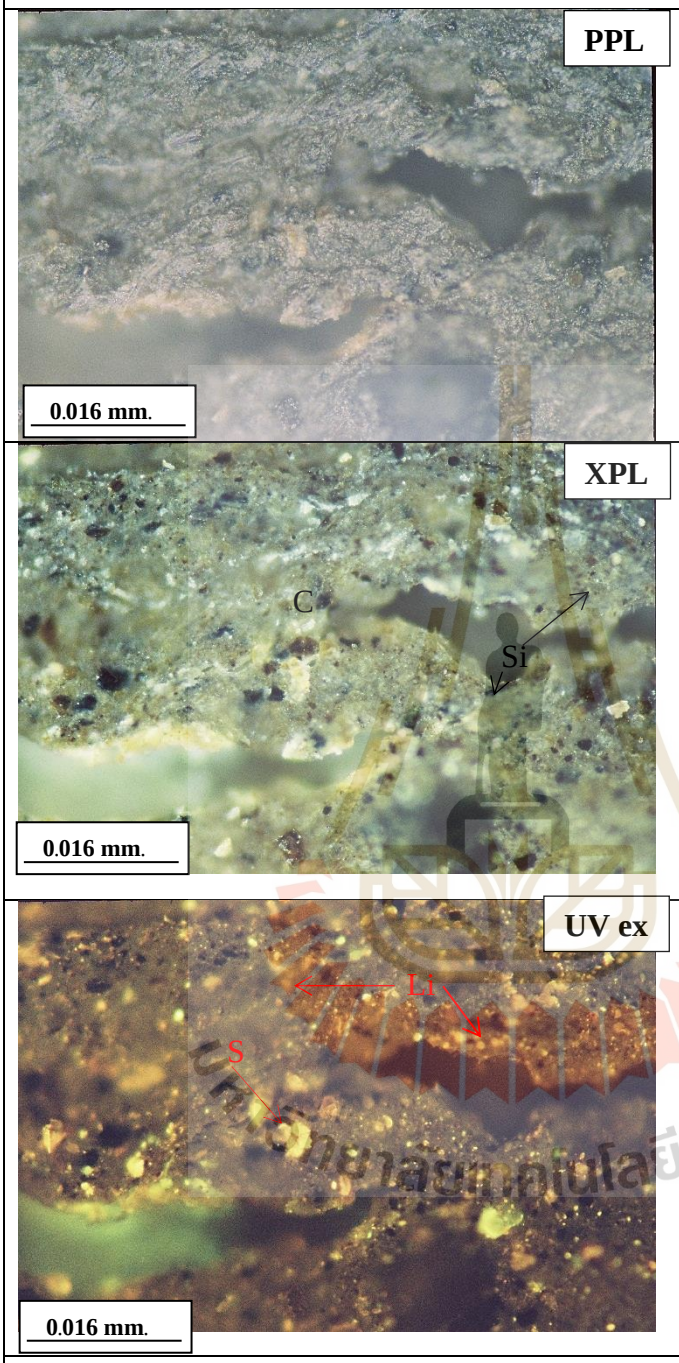
Microscopic Picture	Explanation
	**Sample No. L14-3** Leonardite Composition (%) V = 12 % L = 17 % I = 0 % MM = 71 % **Vitrinite** consist mainly of gelinite globules They display pale gray in PPL and black in XPL and UV extinction**.** **Liptinite** are mainly of liptodetrinite and sporinite. Sporinite show dark gray in PPL and dark brown in XPL. Under UV excitation, they display yellow to dark yellow of small to big dots with spore shape. Liptodetrinite display bright yellow of very small spots under UV extinction. **Mineral Matter** made up mainly of clay minerals with silica. Clay and silica show pale gray in PPL, white to yellowish brown in XPL and dark in UV extinction.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter S = Sporinite, Li = Liptodetronite, C = Clay, Si = Silica	

Figure 4.25 The microscopic picture of leonardite sample No. L14-3.

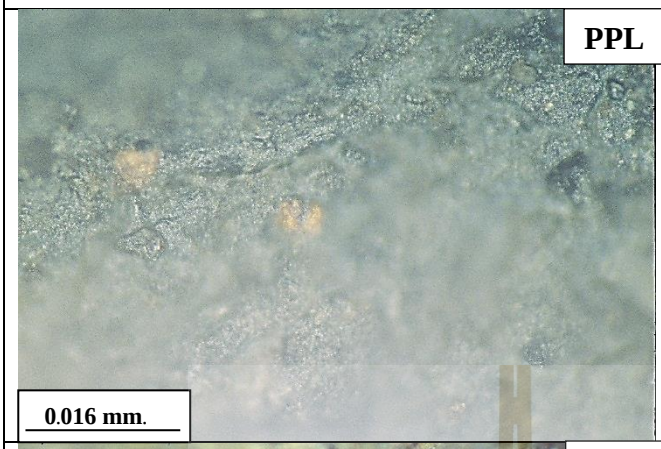
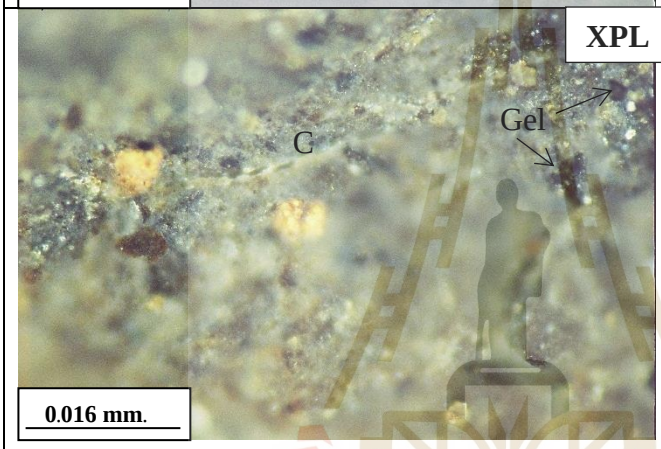
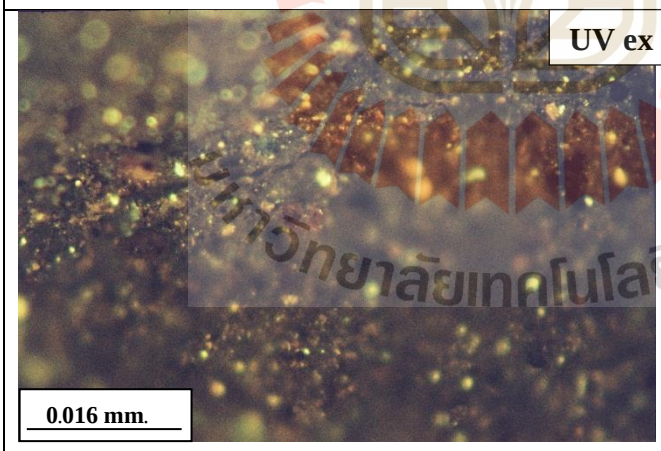
Microscopic Picture	Explanation
  	**Sample No. L19-1** **Leonardite** Composition (%) V = 21 % L = 12 % I = 0 % MM = 67 % **Vitrinite** consisted mainly of gelinite display small globule pale gray in PPL and black in XPL and UV extinction**.** **Liptinite** are mainly of liptodetrinite and sporinite. Sporinite show dark gray dot in PPL and dark brown in XPL. Under UV extinction, they display yellow to dark yellow of small to big dots with spore shape. Liptodetrinite display bright yellow of very small spots under UV extinction**.** **Mineral Matter** are mainly of clay minerals with silica. Clay and silica show pale gray in PPL, white to yellowish brown in XPL and dark in UV extinction**.**
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter S = Sporinite, Li = Liptodetronite, C = Clay, Si = Silica, Sul = Sulfide mineral	

Figure 4.26 The microscopic picture of leonardite sample No. L19-1.

4.2.2 Coal C sub-unit

The Coal C is the lowest sub-unit of coal succession laid on the leonardite sub-unit. They display both organic and inorganic rich layers. The impure coal layers (high mineral matters) are in the lower part while more pure coal layers (low mineral matter) are in the upper part. The vitrinite maceral group (sapropelic origin) is varied from 21% (Sample C2-10) to 100% (Sample C4-7) (Table 4.5). Vitinite are mainly of texto-ulminite, densinite, gelinite and phlobaphinite. The mineral matters contents are varied from 0 (Sample C4-7 and C13-2) to 73% (Sample C12-5). The sapropelite is the dominant character of these coals. This suggests that they were deposited under water and consisted of densinite, gel globules and mineral matters. Vitrinite found in the lower part of the Coal C sub-unit consist mainly of texto-ulminite and gelovitrinite with some of detrovitrinite. These vitrinites indicate the less oxidized to mild reducing condition shallow water where reed peat with other submerged plant are deposited and produced vitrinite. The texto-ulminite resembles the original cell walls characterized by open cell lumens and fill up by ulmin gel and mineral matter (Figure 4.27). The upper part of the Coal C sub-unit layer shows layers of sapropel. They display telinite and densinite (Figures 4.27). Gelinite are mostly show gel cracking and cloudy structure of cork tissue which indicated porigelinite or textinite and texto-ulminite (Figures 4.27). These could imply the water level changing from deep stagnant water to shallow water. The top layer of peat bog could have been highly oxidized and led to highly decomposed of plant tissue and form gel which prevent the access of oxygen to the lower part of Coal C sub-unit. The more reducing condition occurred, the more well preserved. This led to the presence of undecomposed plant tissue such as cuticles with essential structure and cell walls of wood, barks, or roots

which indicated the preservation under the protection from air by oxidized gel layer (Figure 4.28).

The liptinite maceral group vary from 0 – 68 %. They consist mainly of liptodetrinite, sporinite, cutinite, resinite and suberinite. They are high resistance from oxidation maceral. The water level changing significantly affected the amount of oxygen dissolved in water. The shallow water or forest swamp could completely preserve cutinite (Figure 4.28), suberinite (Figure 4.29), telovitrinite and gelovitrinite. The cutinite and suberinite display in pale gray with highly relief in PPL and dark in XPL. Under UV excitation cutinite and suberinite show cuticle ledge structure and cell walls. They fluoresce yellow to dark brown (Figure 4.30). Most of sporinite was often found as a group of bright yellow and some were associated with thick cutinite which could be spores in sporangium. The liptodetrinite are the degradation remains of sporinite, cutinite, resinite and suberinite which are concentrated in subaquatic, especially in sapropelic coals. Under microscopy, liptodestinite display in yellow to yellowish brown irregular shape, whereas resinite and sporinite display in globule and various shapes and ornaments respectively.

The inertinite found in Coal C sub-unit samples is vary from 0 to 24 %. They consist mainly of funisite-pyrofusinite and a few of sclerotinite. The mineral matters are mainly clay minerals which are filled in cell lumens and textinite voids and in the groundmass. The mineral materials replace organic matter (gelinite) which are also found as autogenic minerals associated with woody tissue. The found minerals are marcasite and siderite (Figure 4.31 and 4.32) which are intergrowth or replaced by pyrite.

Table 4.5 Composition in percentage of Coal C sub-unit samples.

Sample	Vitrinite				Liptinite									In	MM.
								Alginite							
	Tel	Det	Gel	Total	Sp	Cu	Lip	Lam	Te	Re	Fl	Su	Total		
C2-1	77*	0	0	77	0	0	0	0	0	0	0	0	0	0	23
C2-2	3	17	48	68	3	0	9	0	0	5	0	0	17	0	15
C2-4	86*	0	0	86	0	0	0	0	0	0	0	0	0	0	14
C2-7	84*	0	0	84	0	0	0	0	0	0	0	0	0	0	16
C2-8	27	17	35	79	0	0	0	0	0	0	0	0	0	0	21
C2-9	27	9	35	71	0	0	0	0	0	0	0	0	0	0	29
C2-10	0	0	21	21	0	0	9	0	0	2	0	0	11	0	68
C3-1	1	10	37	48	5	0	40	0	0	0	0	0	45	0	7
C4-1	0	2	48	50	12	0	6	0	0	2	0	0	20	0	30
C4-2	0	0	51	51	12	0	12	0	0	2	0	0	26	0	23
C4-3	43	0	12	55	1	0	8	0	0	0	0	0	9	1	35
C4-5	53	4	8	65	10	3	13	0	0	1	0	0	27	0	8
C4-6	28	43	14	85	0	0	0	0	0	0	0	0	0	0	15
C4-7	94	0	6	100	0	0	0	0	0	0	0	0	0	0	0
C5-1	68	0	0	68	0	6	13	0	0	0	0	0	19	0	13
C6-1	48	0	5	53	20	16	2	0	0	0	0	0	38	0	9
C6-2	4	0	18	22	21	44	3	0	0	0	0	0	68	0	10
C6-4	0	5	43	48	24	0	8	0	0	0	0	0	32	0	20

* = Texto-Ulminitel, Tel = Telovitrinite, Det= Detrovitrinite, Gel = Gelovitrinite, In = Inertinite, MM. = Mineral Matter
Sp = Sporinite, Re = Resinite, Lip = Liptodetrinite, Cu = Cutinite, Fl= Fluorinite, Su = Suberinite, Lam = Lamalginite, Te= Telalginite

Table 4.5 Composition in percentage of Coal C sub-unit samples (Con.).

Samples	Vitrinite				Liptinite									In	MM.
								Alginite							
	Tel	Det	Gel	Total	Sp	Cu	Lip	Lam	Te	Re	Fl	Su	Total		
C8-1	32	11	17	60	6	2	12	0	0	0	0	0	20	0	20
C8-2	20	12	18	50	7	0	31	0	0	2	0	0	40	0	10
C8-3	0	0	38	38	18	0	12	0	0	0	0	0	30	0	32
C8-4	0	0	29	29	38	8	0	0	0	12	0	0	58	0	13
C9-1	94	2	1	97	0	0	0	0	0	0	0	0	0	0	3
C9-2	83*	0	9	92	0	0	0	0	0	0	0	0	0	0	8
C10-1	91	0	0	91	0	0	0	0	0	0	0	0	0	4	5
C10-3	84	0	2	86	0	0	0	0	0	0	0	0	0	1	13
C10-4	68	0	6	74	0	0	0	0	0	0	0	0	0	0	26
C10-5	95	0	3	98	0	0	0	0	0	0	0	0	0	0	2
C11-1	0	0	67	67	8	8	5	0	0	0	0	0	21	0	12
C11-2	0	0	56	56	6	4	8	0	0	2	0	0	20	0	24
C11-3	95	0	1	96	0	0	0	0	0	0	0	0	0	0	4
C11-5	0	0	20	20	4	0	3	0	0	0	0	0	7	0	73
C11-6	25	0	19	44	0	0	0	0	0	0	0	42	42	0	14
C11-7	86	0	3	89	3	0	4	0	0	0	0	0	7	0	4
C11-8	96	0	0	96	0	0	0	0	0	0	0	0	0	0	4

* = Texto-Ulminitel, Tel = Telovitrinite, Det= Detrovitrinite, Gel = Gelovitrinite, In = Inertinite, MM. = Mineral Matter
Sp = Sporinite, Re = Resinite, Lip = Liptodetrinite, Cu = Cutinite, Fl= Fluorinite, Su = Suberinite, Lam = Lamalginite, Te= Telalginite

Table 4.5 Composition in percentage of Coal C sub-unit samples (Con.).

Samples	Vitrinite				Liptinite									In	MM.
								Alginite							
	Tel	Det	Gel	Total	Sp	Cu	Lip	Lam	Te	Re	Fl	Su	Total		
C12-1	94	0		94	0	0	0	0	0	0	0	0	0	0	6
C12-2	0	0	43	43	0	0	0	0	0	0	0	0	0	0	57
C12-3	0	0	75	75	0	0	0	0	0	0	0	0	0	0	25
C12-5	0	0	29	29	0	0	0	0	0	0	0	0	0	0	71
C12-6	0	0	67	67	0	0	0	0	0	0	0	0	0	0	33
C12-7	71	0	0	71	0	0	0	0	0	0	0	0	0	24	5
C13-2	82	0	6	88	7	0	0	0	0	0	0	0	12	0	0
C13-3	96	0	0	96	0	0	0	0	0	0	0	0	0	0	4
C13-5	0	0	90	90	0	0	0	0	0	0	0	0	0	0	10
min	0	2	1	20	1	0	2	0	0	1	0	42	0	0	0
max	96	43	90	100	38	44	40	0	0	12	0	42	68	24	73
average	34.66	3.01	22.32	67.59	4.67	2.07	4.62	0.00	0.00	0.64	0.00	0.96	12.96	0.68	19.00

Tel = Telovitrinite, Det= Detrovitrinite, Gel = Gelovitrinite, In = Inertinite, MM. = Mineral Matter
Sp = Sporinite, Re = Resinite, Lip = Liptodetrinite, Cu = Cutinite, Fl= Fluorinite, Su = Suberinite, Lam = Lamalginite, Te= Telalginite

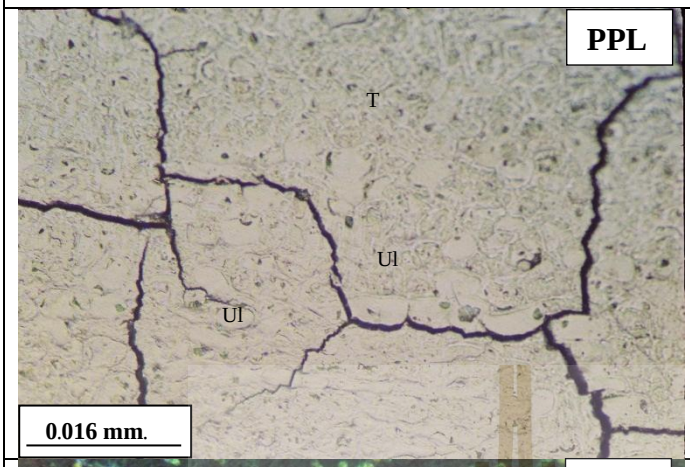
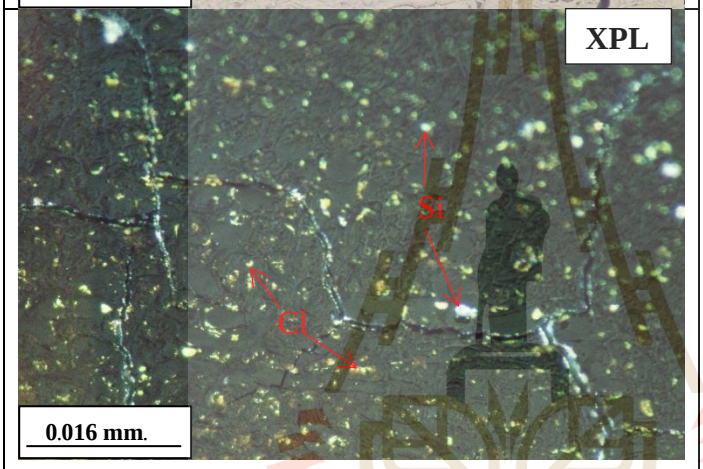
Microscopic Picture	Explanation
 	**Sample No. C2-1** **Texto-ulminite** show well preserve cell walls and cell ulmin but highly cracked due to high moisture content in coal. **Composition (%)** V = 77 % L = 0 % I = 0% MM = 23 % **Vitrinite** consist of texto-ulminite in telovitrinite subgroup. They show structure of cell walls (**textinite**)filled with gelified material (**ulminite**). **Texto-ulminite** display pale gray in PPL and black in XPL. **Mineral Matter** consist mainly of clay minerals and silica filling in dry ulminite voids. They show brownish yellow to dark dots in PPL. In XPL clay display yellow to yellowish brown and silica display white.
PPL = Plane Polarized light, XPL = Cross Polarized light V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter T = Textinite Ul = Ulminite, Cl = Clay, Si = Silica	

Figure 4.27 The microscopic picture of coal sample No. C2-1.

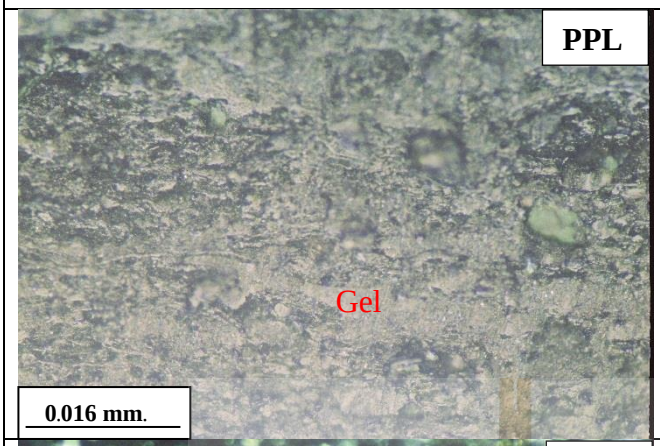
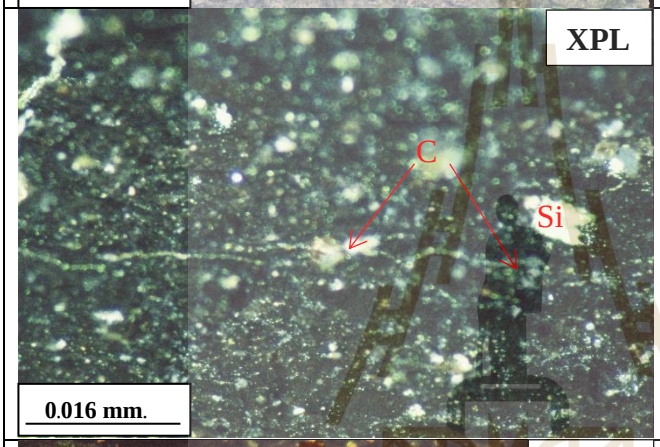
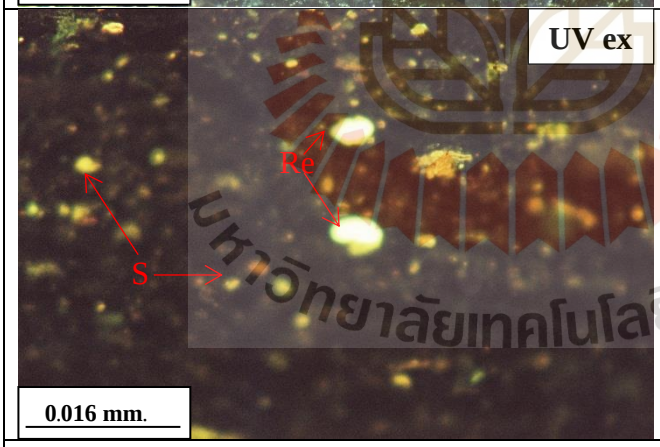
Microscopic Picture	Explanation
  	**Sample No. C2-2** **Densinite** (sapropelic coal) show the accumulation of organic matter. Composition (%) V = 68 % L = 17 % I = 0 % MM = 15 % **Vitrinite** consist of densinite, several of organic matter and gelinite cements. They show pale gray in PPL with high relief, black in XPL and UV extinction. **Liptinite** consist mainly of liptodetrinite and resinite. Liptodetrinite display dark yellow to orange spots, various sizes without shape. Resinite display bright yellow of big spots with sphere shape. **Mineral matter** consist mainly of clay and silica minerals. They display white dots in XPL and black under UV extinction
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Re = Resinite, S = Sporinite, C = Clay, Si = Silica	

Figure 2.28 The microscopic picture of coal sample No. C2-2

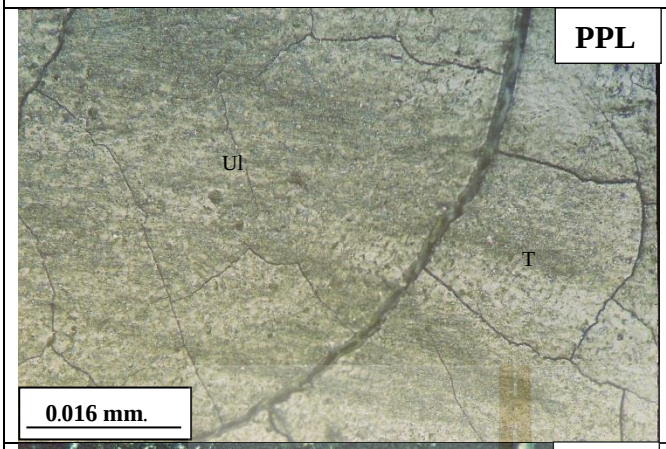
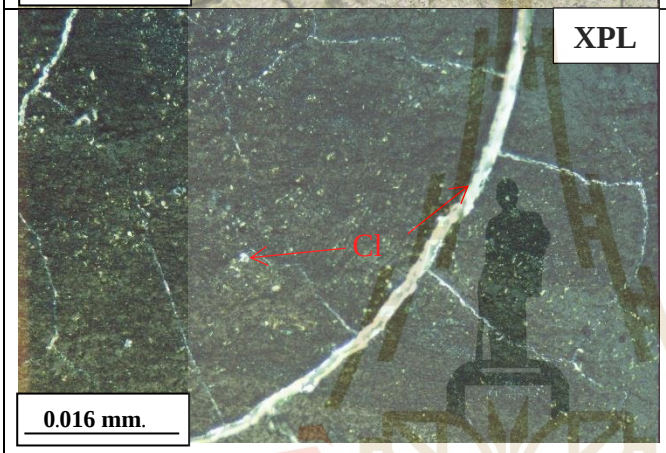
Microscopic Picture	Explanation
 	**Sample No. C2-4** **Textinite** consist mainly of well preserve cell walls and cell ulmin in coal. **Composition (%)** V = 86 % L = 0 % I = 0 % MM = 14 % **Vitrinite** consist of texto-ulminite in telovitrinite subgroup. They show structure of wood cell walls and display pale gray in PPL and black in XPL. **Mineral Matter** consist of clay minerals filling in dry ulminite voids. They show dark dots and line in PPL. In XPL they display white color.
PPL = Plane Polarized light, XPL = Cross Polarized light V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter T = Textinite Ul = Ulminite, Cl = Clay, Si = Silica	

Figure 2.29 The microscopic picture of coal sample No. C2-4.

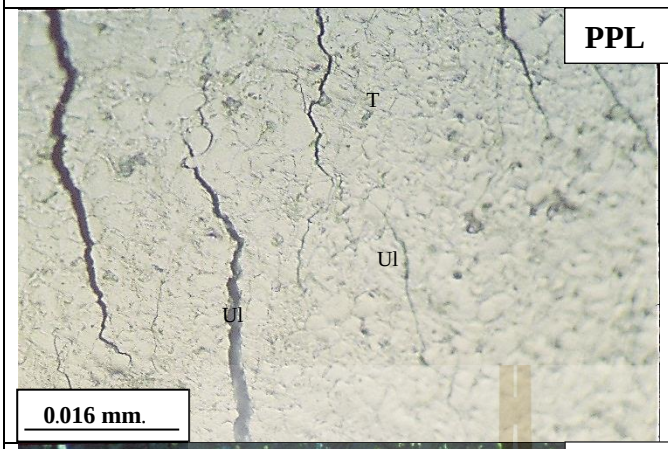
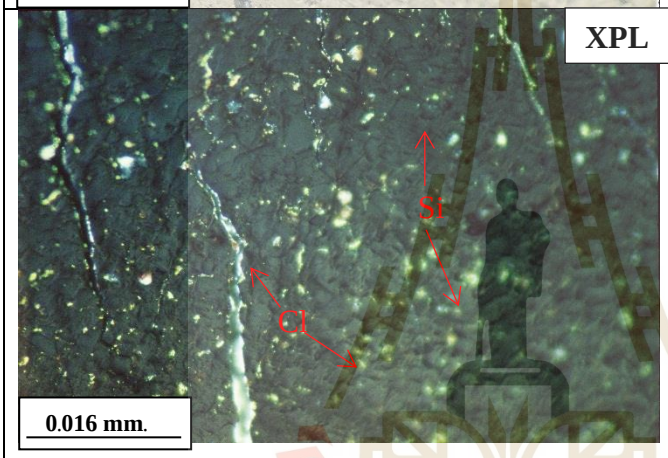
Microscopic Picture	Explanation
 	**Sample No. C2-7** **Texto-ulminite** consist mainly of well preserve cell walls and cell ulmin but highly cracked due to high moisture content in coal. **Composition (%)** V = 84 % L = 0 % I = 0 % MM = 16 % **Vitrinite** consist of texto-ulminite in telovitrinite subgroup. They show structure of cell walls (**textinite**) filled with gelified material (**ulminite**). **Texto-ulminite** display pale gray in PPL and black in XPL. **Mineral Matter** consist of clay minerals and silica filling in dry ulminite voids. They show brownish yellow to dark dots in PPL. In XPL clay display yellow to yellowish brown and silica display white.
PPL = Plane Polarized light, XPL = Cross Polarized light V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter T = Textinite Ul = Ulminite, Cl = Clay, Si = Silica	

Figure 4.30 The microscopic picture of coal sample No. C2-7.

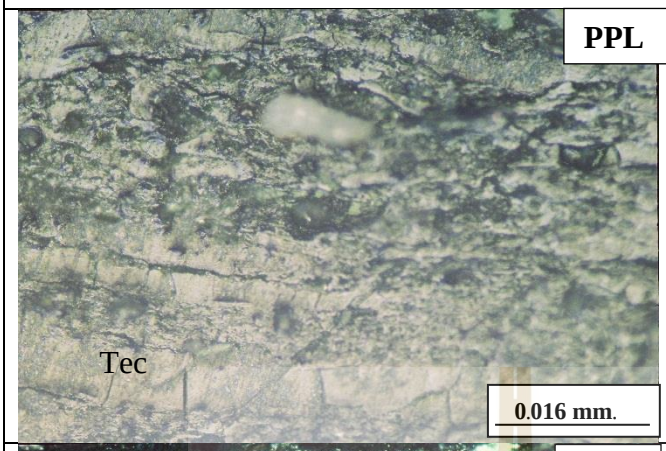
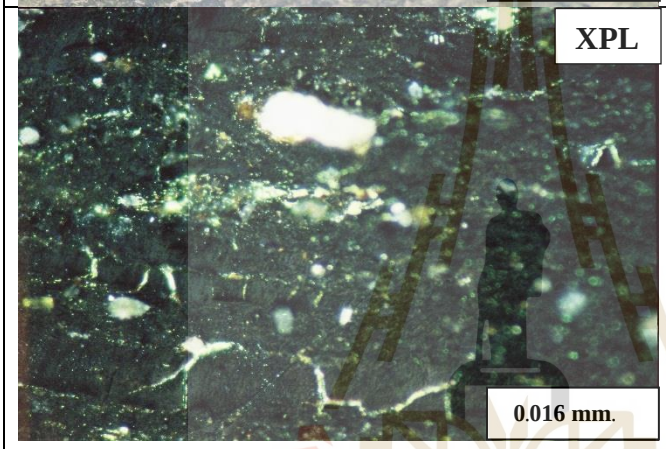
Microscopic Picture	Explanation
 	**Sample No.C2-8** **Gelovitrinite** show character of wood tissue with desiccation crack of gel. Composition (%) V = 79 % L = 0 % I = 0 % MM = 21 % **Vitrinite** consist of collotelinite with ulminite. They display structure of wood tissue and densinite. They display colorless and pale gray to light brown in PPL and black in XPL. **Mineral Matter** consists of clay minerals filled in crack, display black in PPL and white dots in XPL.
PPL = Plane Polarized light, XPL = Cross Polarized light V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Gel = Gelinite, Cl = Clay, Tec = Telocollinite, Ul = Ulminite	

Figure 4.31 The microscopic picture of coal sample No. C2-8.

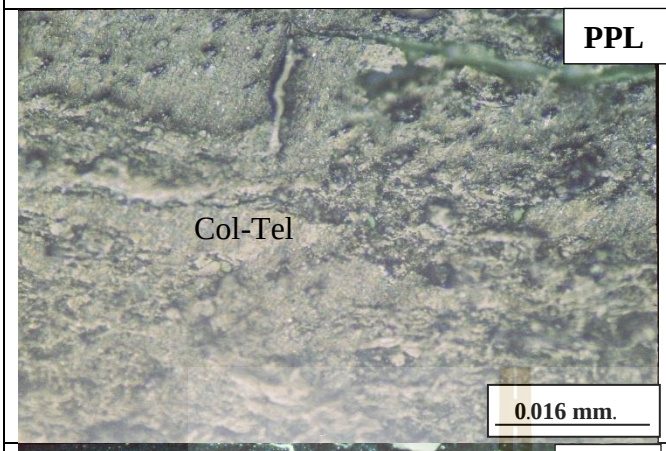
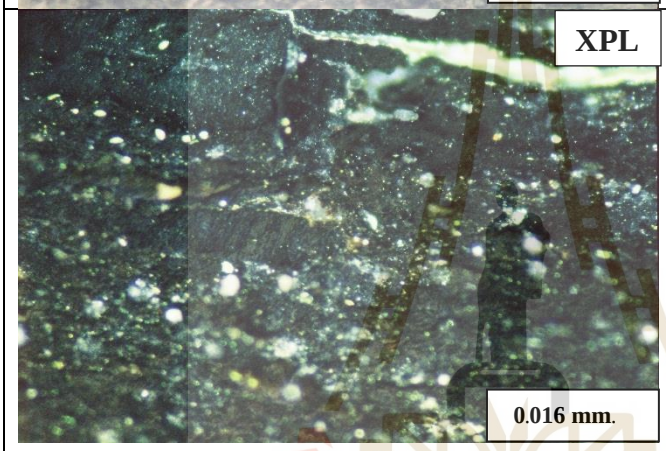
Microscopic Picture	Explanation
 	**Sample No.C2-9** **Gelovitrinite** show character of wood tissue with desiccation crack of gel. Composition (%) V = 71 % L = 0 % I = 0 % MM = 29 % **Vitrinite** consist of collotelinite with ulminite. They display structure of wood tissue and densinite. They display colorless and pale gray to light brown in PPL and black in XPL. **Mineral Matter** consist of clay minerals filled in crack, display black in PPL and white dots in XPL.
PPL = Plane Polarized light, XPL = Cross Polarized light V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Gel = Gelinite, Cl = Clay, Tec = Telocollinite, Ul = Ulminite, Col-Tel = Collotelinite	

Figure 4.32 The microscopic picture of coal sample No. C2-9.

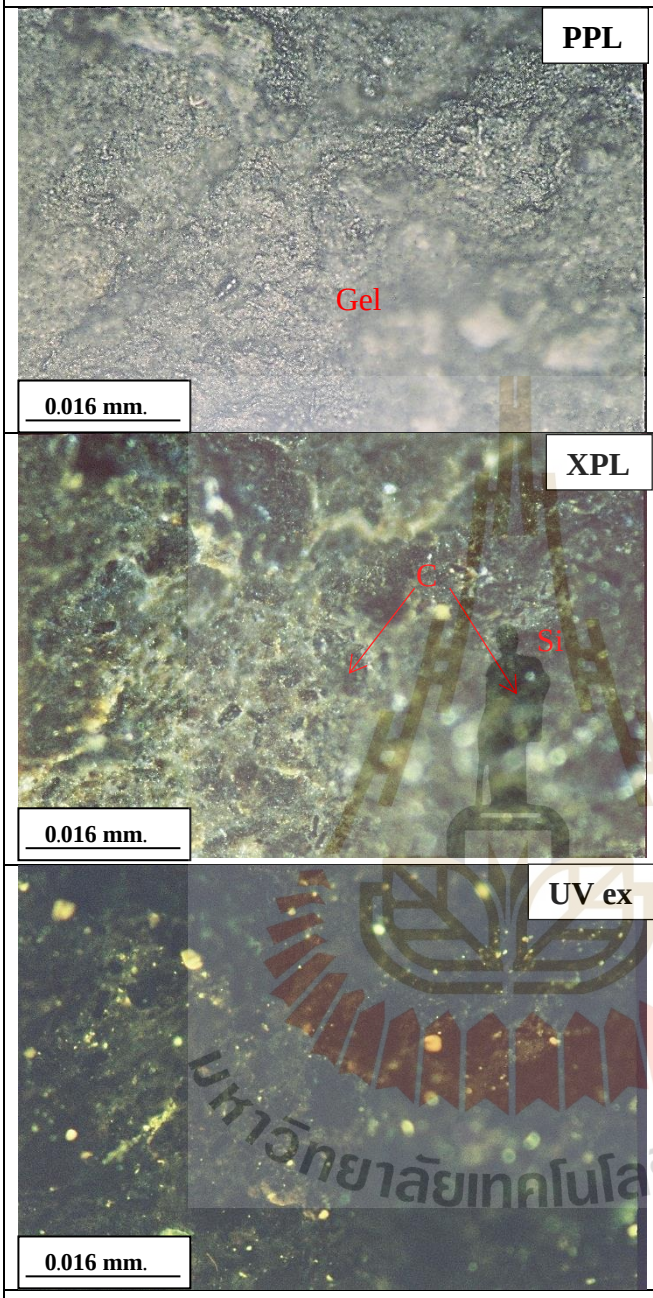
Microscopic Picture	Explanation
	**Sample No. C2-10** **Densinite** (sapropelic coal) show the accumulation of organic matter. Composition (%) V = 21 % L = 11% I = 0 % MM = 68 % **Vitrinite** consist of densinite, several of organic matter and gelinite cements. They show pale gray in PPL with high relief, black in UV excitation. **Liptinite** consist mainly of liptodetrinite and resinite. Liptodetrinite display dark yellow to orange spots, various sizes without shape. **Mineral matter** consist mainly of clay and silica minerals. They display white dots in XPL and black under UV ex.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Re = Resinite, S = Sporinite, C = Clay, Si = Silica	

Figure 4.33 The microscopic picture of coal sample No. C2-10.

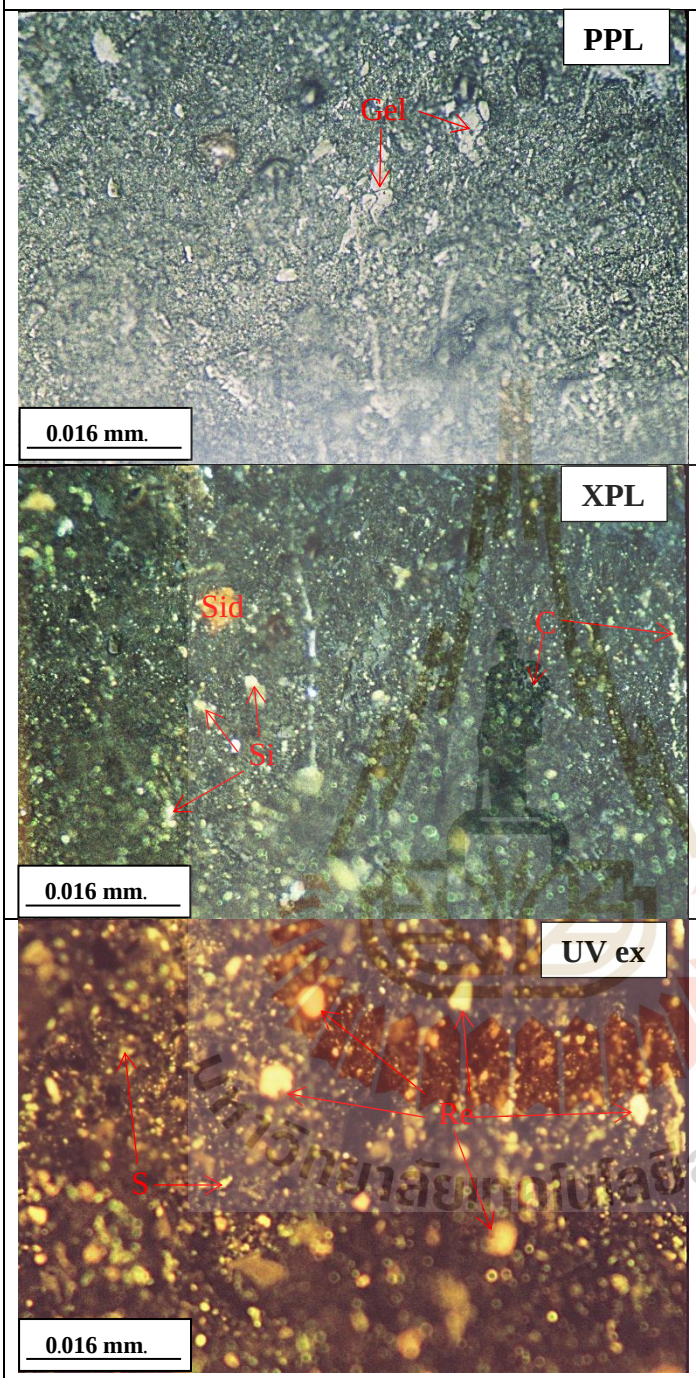
Microscopic Picture	Explanation
	**Sample No. C3-1** **Densinite** (sapropelic coal) show the accumulation of organic matter. **Composition (%)** V = 48 % L = 45 % I = 0 % MM = 7 % **Vitrinite** consist of densinite, several of organic matter and gelinite cements. They show pale gray in PPL with high relief, dark gray to black in XPL and black in UV excitation. **Liptinite** consist mainly of liptodetrinite and resinite. They show pale gray in PPL and white to light yellow in XPL. Under UV excitation, Liptodetrinite display dark yellow to orange spots, various sizes without shape. Resinite show bright yellow of big spots with sphere shape. **Mineral matter** consist mainly of clay and silica minerals. They display dark in PPL with white dots in XPL and black under UV ex. The orange crystal in XPL and dark brown to black in UV ex could be siderite.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Re = Resinite, S = Sporinite, C = Clay, Sid = Siderite, Si = Silica	

Figure 4.34 The microscopic picture of coal sample No. C3-1.

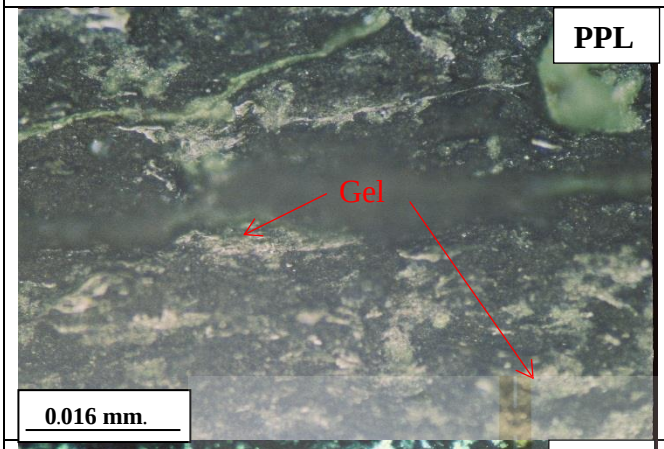
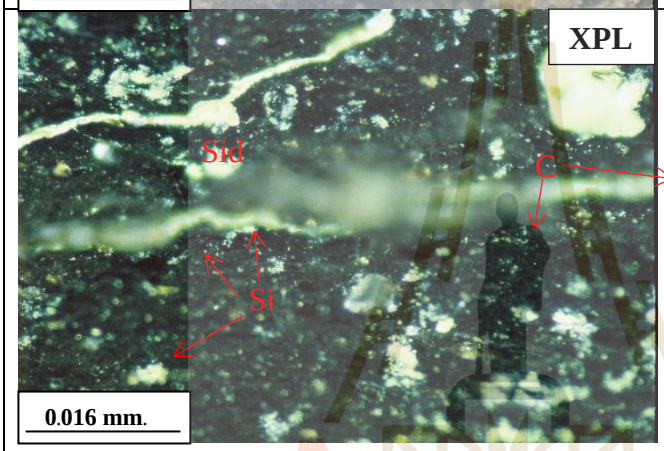
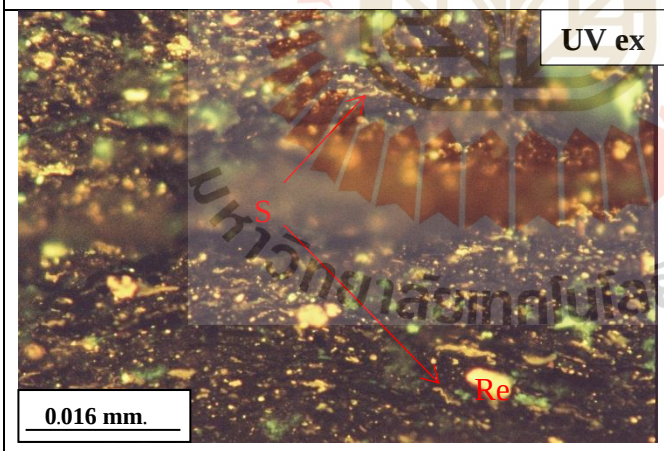
Microscopic Picture	Explanation
  	**Sample No. C4-1** **Densinite** (sapropelic coal) show the accumulation of organic matter. Composition (%) V = 50 % L = 20 % I = 0 % MM = 30 % **Vitrinite** consist of densinite, several of organic matter and gelinite cements. They show pale gray in PPL with high relief, dark gray to black in XPL and black in UV excitation. **Liptinite** consist mainly of liptodetrinite and sporinite with some of resinite. They show pale gray in PPL and white to light yellow in XPL. Under UV excitation, Liptodetrinite and resinite display dark yellow to orange spots, various sizes without shape. Sporinite remains show yellow of spore shape. **Mineral matter** consist mainly of clay and silica minerals. They display dark in PPL with white dots in XPL and black under UV ex.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Re = Resinite, S = Sporinite, C = Clay, Sid = Siderite, Si = Silica	

Figure 4.35 The microscopic picture of coal sample No. C4-1.

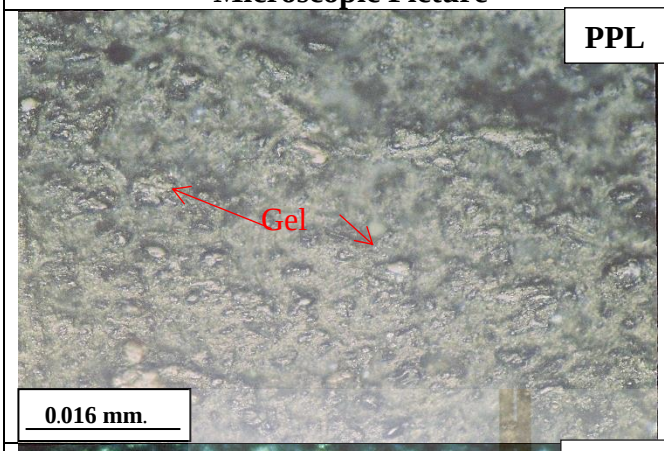
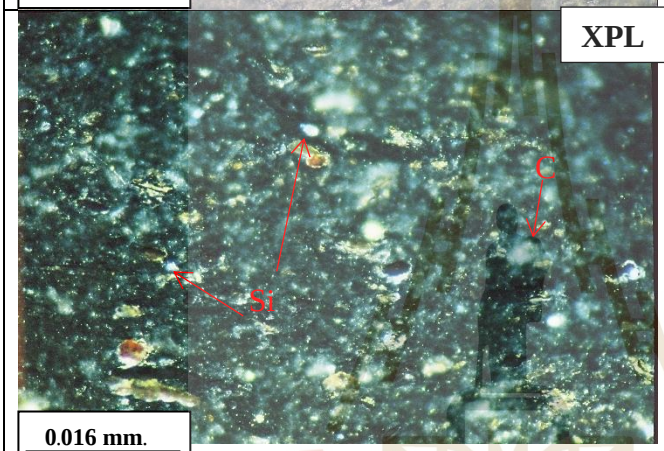
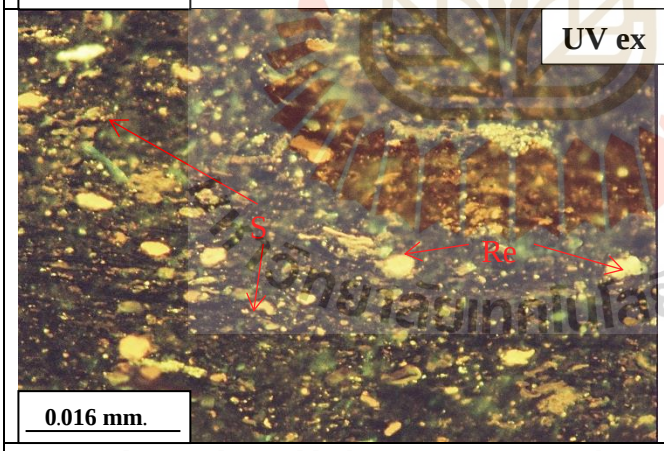
Microscopic Picture	Explanation
  	**Sample No. C4-2** **Telovitrinite** show cell ulmin of gel Composition (%) V = 51 % L = 26 % I = 0 % MM = 23 % **Vitrinite** consist of ulminite and display colorless with high relief and pale gray in PPL and black in XPL. **Liptinite** consist mainly of liptodetrinite sporinite and some of resinite. They show pale gray in PPL and light yellow to brown in XPL. Liptodetrinite display dark yellow to orange spots, various sizes without shape. Sporinite show yellow with shape. Resinite show bright yellow of big spots with sphere shape. **Mineral matter** consist mainly of clay and silica minerals. They display white dots in XPL and black under UV ex.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Re = Resinite, S = Sporinite, C = Clay	

Figure 4.36 The microscopic picture of coal sample No. C4-2.

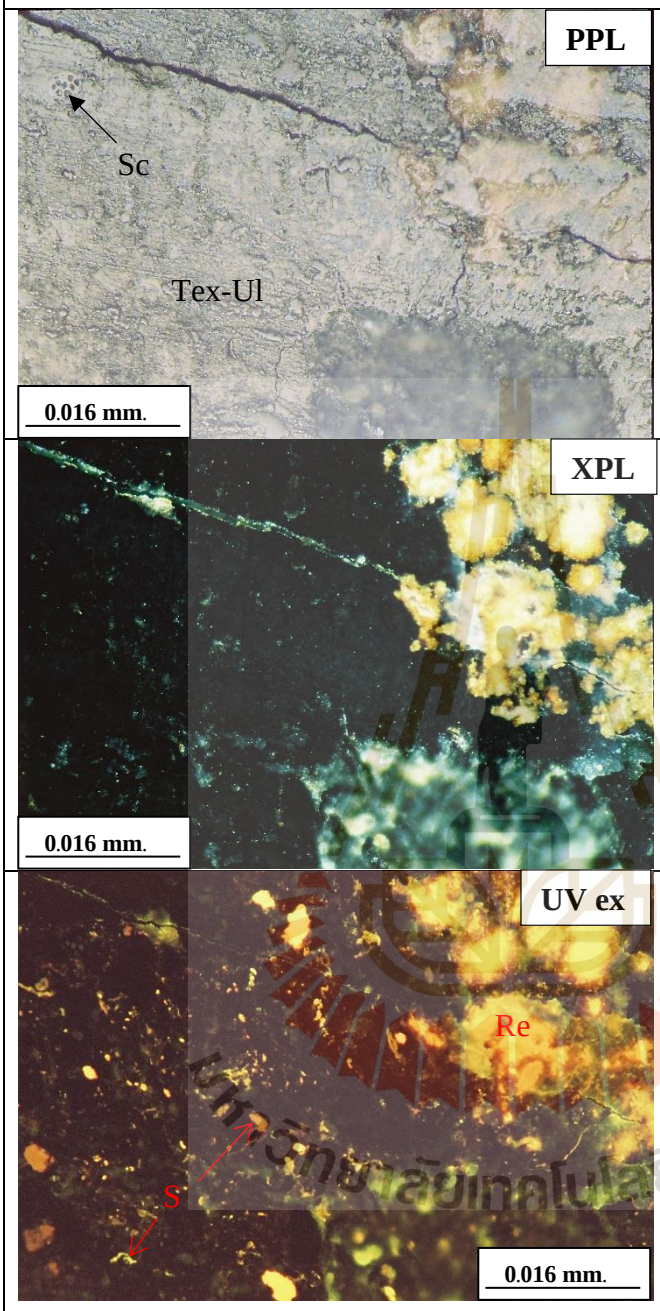
Microscopic Picture	Explanation
	**Sample No. C4-3** **Telovitrinite** with gelovitrinite and Resinite **Composition (%)** V = 55 % L =9 % I = 1 % MM = 35 % **Vitrinite** consist of gelinite with structure of ulmin and gel dry. They display pale gray with strongly reflect layer in PPL and black in XPL and UV ex. **Liptinite** consist of resinite, with some sporinite. Resinite show colorless to light yellow in PPL, white to orange in XPL, bright yellow with sphere shape and highly orange rim, and small sphere shape in UV excitation. **Inertinite** is a sclerotinite in gelovtrinite. **Mineral Matters** consist mostly of clay minerals and display pale gray to dark in PPL, white spread in XPL and black under UV excitation.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Re = Resinite, S = Sporinite, Sc = Sclerotinite	

Figure 4.37 The microscopic picture of coal sample No. C4-3.

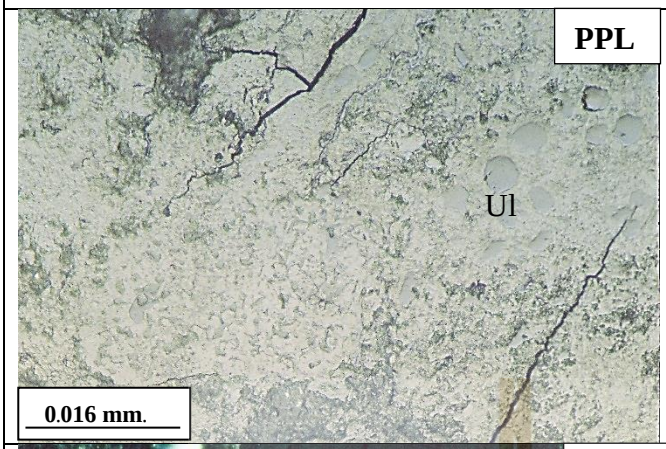
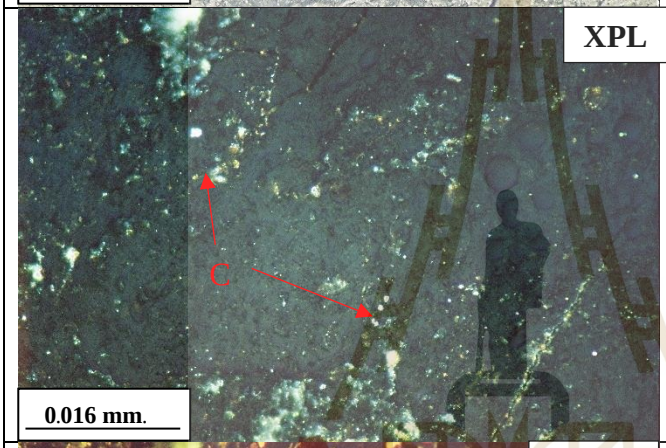
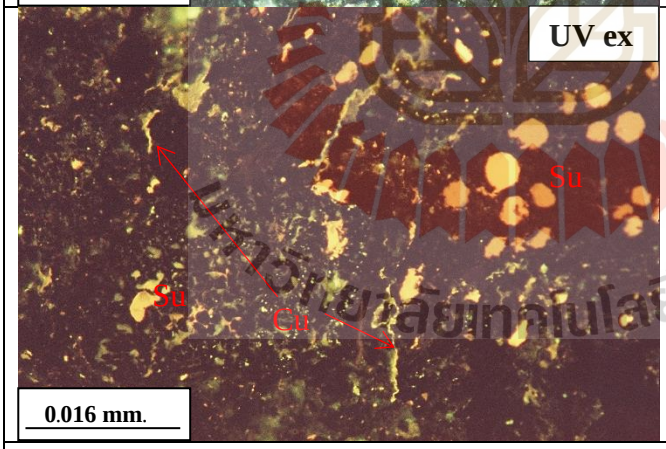
Microscopic Picture	Explanation
  	**Sample No. C4-5** **Telovitrinite (Ulminite) with suberinite** **Composition (%)** V = 65 % L = 27 % I = 0 % MM = 8 % **Vitrinite** consist of gelinite with structure of dry cell ulmin. They display pale gray with strongly reflect layer in PPL and black in XPL. **Liptinite** consist of Suberinite, cutinite remains and some liptodestrinite. Suberinite show yellow circle and shape of dry cell. Cutinite show remains of yellow line in UV excitation. **Mineral Matters** consist mostly of clay minerals and display pale gray to dark in PPL, white spread in XPL, and black under UV excitation.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation, V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Li = Liptodetrinite, Su = Suberinite, Ul = Ulminite, C = Clay mineral, Cu = Cutinite	

Figure 4.38 The microscopic picture of coal sample No. C4-5.

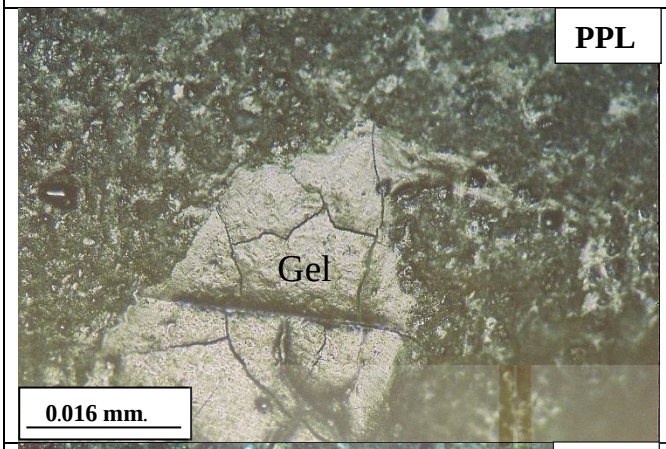
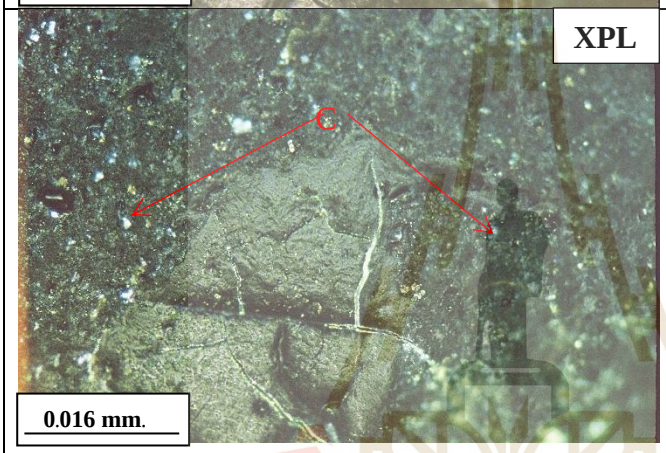
Microscopic Picture	Explanation
 	**Sample No. C4-6** **Gelovitrinite** with densinite consist mainly of wood gel remains. **Composition (%)** V = 85 % L = 0 % I = 0 % MM = 15 % **Vitrinite** consist of gelovitrinite in detrovinite. Gelovitrinite show structure of wood cell walls. They display pale gray in PPL and black in XPL. **Mineral Matter** consist of clay minerals deposited in detrovinite. They display white dots in XPL.
PPL = Plane Polarized light, XPL = Cross Polarized light V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Gel = Gelovinite, C = Clay	

Figure 4.39 The microscopic picture of coal sample No. C4-6.

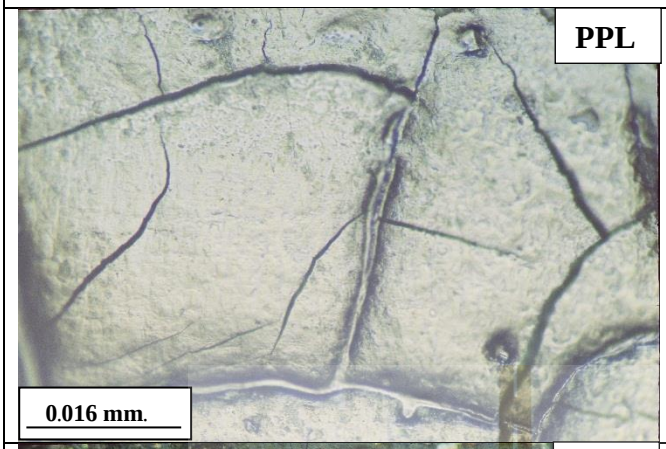
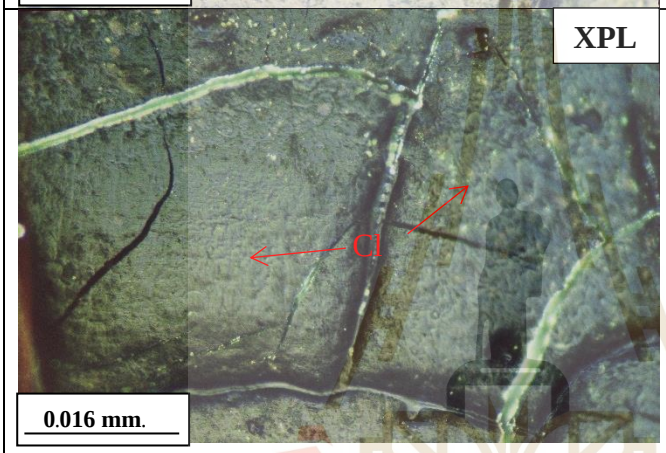
Microscopic Picture	Explanation
 	**Sample No. C4-7** **Telovitrinite** It shows well preserve wood cell in coal. **Composition (%)** V = 100 % L = 0 % I = 0 % MM = 0 % **Vitrinite** consist of telovitrinite subgroup. They show structure of wood cell walls and display pale gray in PPL and black in XPL.
PPL = Plane Polarized light, XPL = Cross Polarized light V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter T = Textinite Ul = Ulminite, Cl = Clay, Si = Silica	

Figure 4.40 The microscopic picture of coal sample No. C4-7.

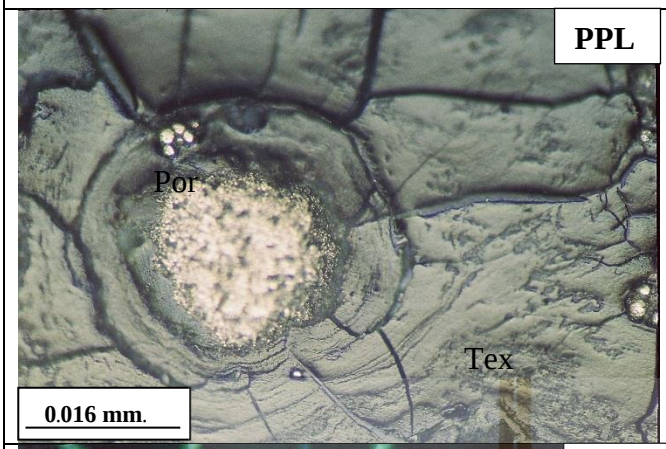
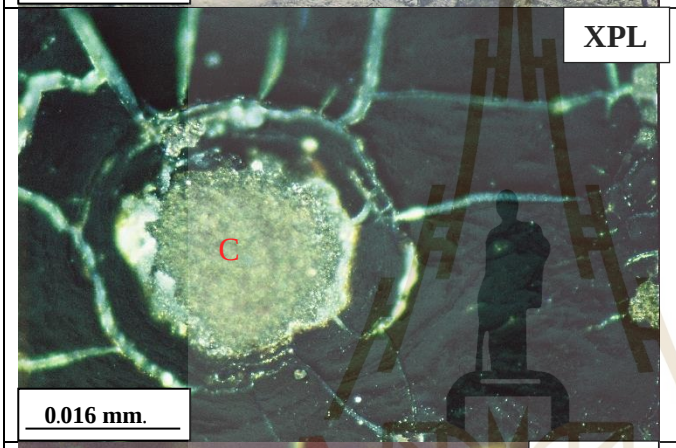
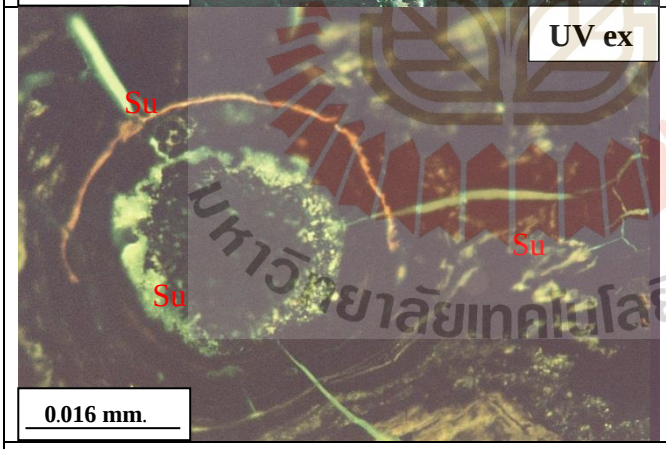
Microscopic Picture	Explanation
  	**Sample No. C5-1** **Porigelinite with suberinite** **Composition (%)** V = 68 % L = 19 % I = 0 % MM = 13 % **Vitrinite** consist of gelovitrinite (porigelinite) with textinite. They show structure of wood and display pale gray with strongly reflect in PPL and black in XPL **Liptinite** consist of Suberinite of essential oil (terpenite) filled in brunk or branch and twig surface. Suberinite display pale green to yellow orange in UV excitation. **Mineral Matters** consist mostly of clay minerals and display pale gray to pale green in PPL and in XPL. They fill in gap of surface brunk and display dark under UV excitation.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation, V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Su = Suberinite, C = Clay mineral, Por = Porigelinite, Tex = Texinite	

Figure 4.41 The microscopic picture of coal sample No. C5 – 1

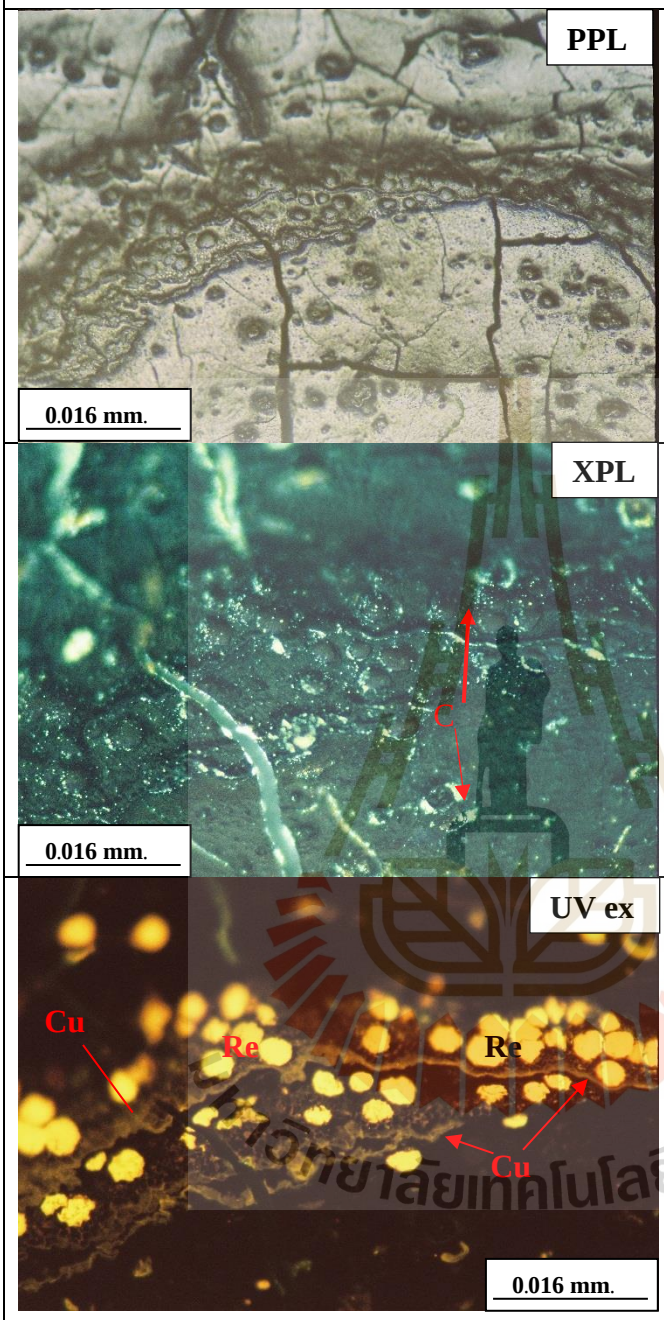
Microscopic Picture	Explanation
	**Sample No. C6-1** **Gelovitrinite** display well preserve cutinite with resinite. Composition (%) V = 53 % L =38 % I = 0 % MM = 9 % **Vitrinite** consist of gelinite and show cell lumens of tissue with highly structure of porigelinite (Gelovitrinite). They display pale gray in PPL and black in XPL. **Liptinite** consist of cutinite and resin. They display cuticle ledges, high relief and pale gray in PPL and black in XPL. In UV excitation, they display orange light line (cutin) with ledges indicative of cutinite. Resinite show bright yellow with various sphere sizes, droplet groups associated with cutinite. **Mineral Matter** consist mainly of clay mineral filling in voids. They display gray to dark in PPL, white dots dispersed in XPL and black under UV excitation.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Cu = Cutinite, Re = Resinite, F = Fluorinite, Cl = Clay minerals	

Figure 4.42 The microscopic picture of coal sample No. C6 – 1

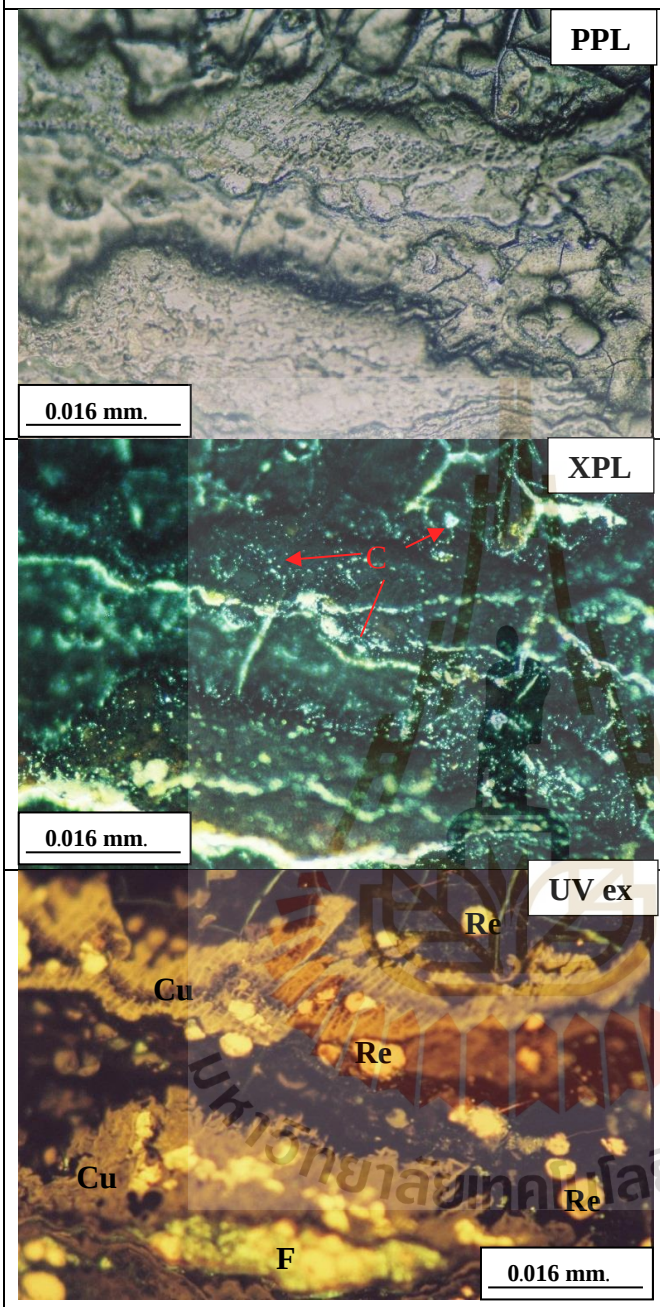
Microscopic Picture	Explanation
	**Sample No. C6-2** **Gelovitrinite** display well preserve cutinite and show cuticle ledges at a slightly oblique angle cut. Composition (%) V = 22 % L =68 % I = 0 % MM = 10 % **Vitrinite** consist of gelinite and show cell lumens of tissue with highly structure of porigelinite. They display pale gray in PPL and black in XPL and UV excitation. **Liptinite** consists of cutinite and resin. They display cuticle ledges, high relief and pale gray in PPL and black in XPL. In UV excitation, they display orange light with bright field illumination and appear dark in the middle (cutin) with ledges indicative of cutinite. Resinite show bright yellow with various sphere sizes. Fluorinite display bright yellow to greenish yellow droplet groups associated with cutinite. **Mineral Matter** consist mainly of clay mineral filling in voids. They display pale gray to dark in PPL, white dots dispersed in XPL and black under UV excitation.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Cu = Cutinite, Re = Resinite, F = Fluorinite, Cl = Clay minerals	

Figure 4.43 The microscopic picture of coal sample No. C6 – 2

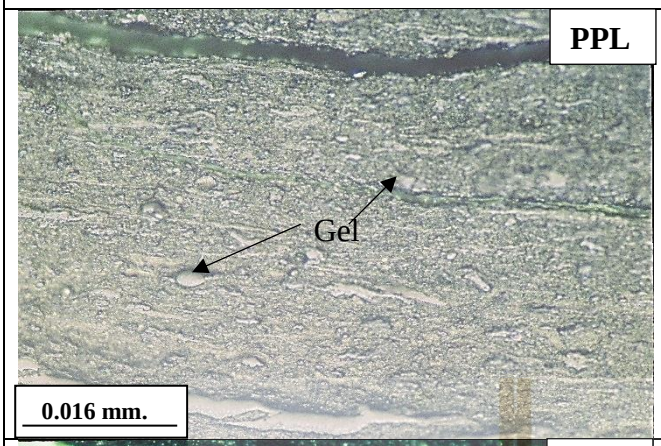
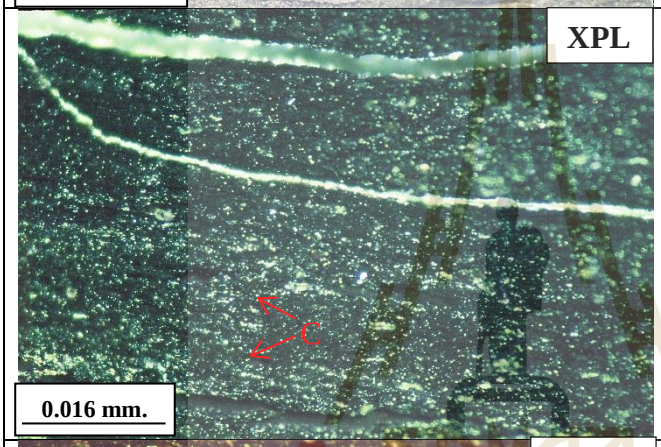
Microscopic Picture	Explanation
  	**Sample No. 6-4** **Telocolinite** (gelinite subgroup) show structure of wood tissue. Composition (%) V =48 % L = 32 % I = 0 % MM = 20 % **Vitrinite** show structure of bark woods with gelovitrinite. They display pale gray in PPL, dark gray in XPL and black in UV excitation. **Liptnite** consist of sporinite with liptodestrinite (terpentinite) and display pale gray in PPL, dark gray in XPL and white yellow to yellow under UV excitation. Sporinite show white to dark yellow with S-shape and telephone shape. **Mineral matter** consist of clay mineral and display dark gray in PPL, white in XPL and black under UV ex.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Li = Liptodetrinite, S = Sporinite, C = Clay, Gel = Gelovitrinite	

Figure 4.44 The microscopic picture of coal sample No. C6 – 4

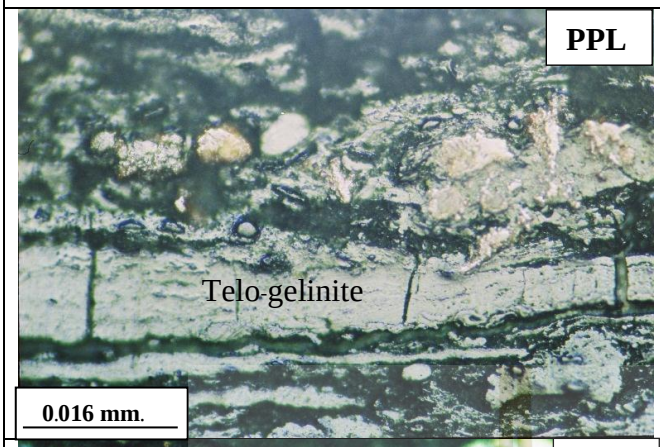
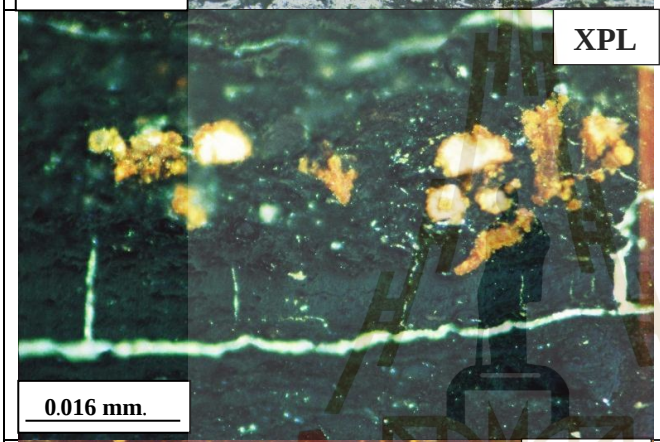
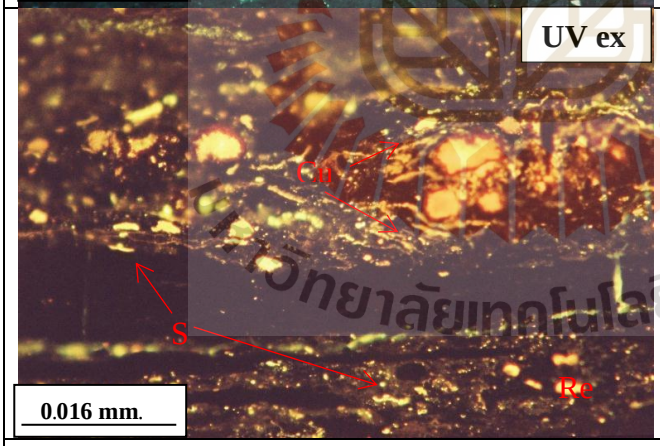
Microscopic Picture	Explanation
  	**Sample No. C8-1** **Densinite** show sapropelic coal indicated by layers of detrovitrinite and gelovitrinite. Composition (%) V = 60 % L =20 % I = 0 % MM = 20 % **Vitrinite** consist of gelinite with wood structure of telinite and gel cracking. Telo-gelinite display pale gray with strongly reflect layer in PPL and black in XPL and UV ex. **Liptinite** consist of liptodetrinite, resinite, sporinite and cutinite. They display dark gray to black in PPL and XPL. Resinite show colorless to light yellow in PPL, white to orange in XPL, bright yellow with sphere shape and highly orange rim in UV excitation. Sporinite show yellow spore shape. Liptodetinite show yellow to yellowish brown spots. Cutinite show yellow line with ledge structure. **Mineral Matters** consist mostly of clay minerals with silica. They display pale gray to dark in PPL, white dots spread in XPL and black under UV excitation.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Cu = Cutinite, Re = Resinite, S = Sporinite, Li = Liptodetinite	

Figure 4.45 The microscopic picture of coal sample No. C8 – 1

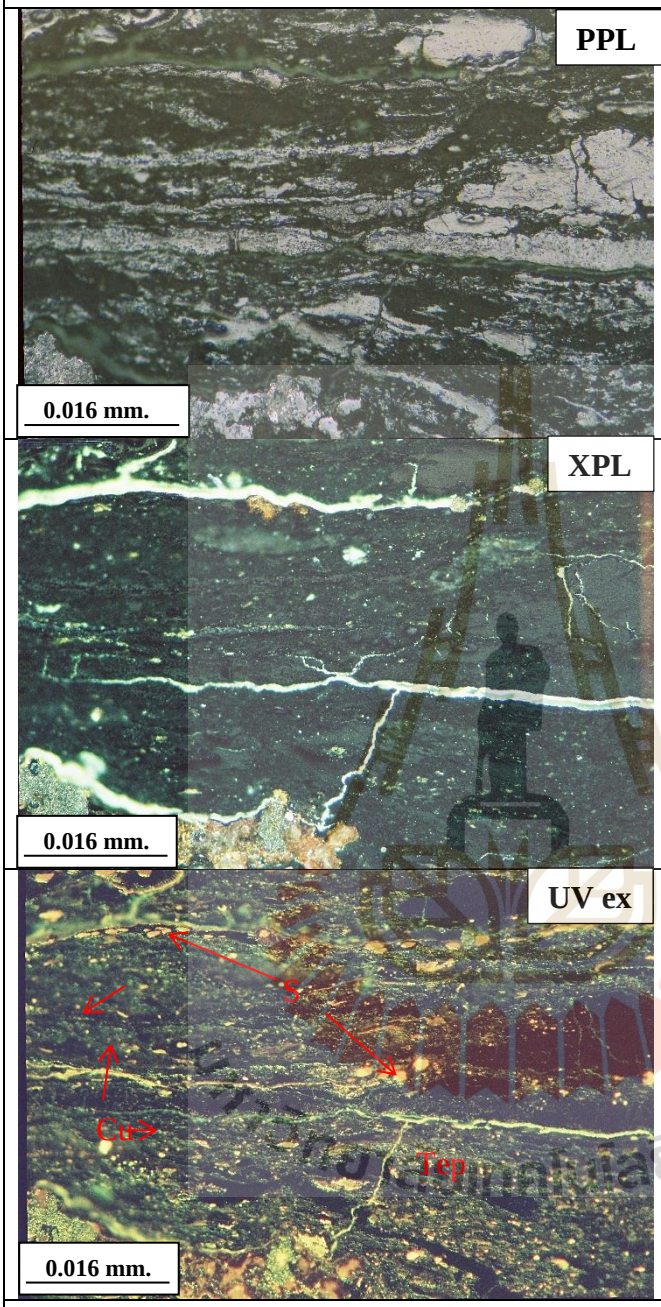
Microscopic Picture	Explanation
	**Sample No. C8-2** **Collotelinite**, (gelinite subgroup) show structure of wood tissue and related with algae. Composition (%) V =50 % L = 40 % I = 0 % MM = 10 % **Vitrinite** consist of tellinite and show structure of bark woods with essential oil. They display pale gray in PPL, dark gray in XPL and black in UV excitation. **Liptnite** consist of liptodestrinite with sporinite and cutinite. Most of liptodestrinite are terpenite. They display pale gray in PPL, dark gray in XPL and pale green to white yellow under UV excitation. Sporinite show white to dark yellow globule-shape lined up with cutinite line. **Mineral matter** consist of clay and display dark gray in PPL, white in XPL and black under UV ex.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Li = Liptodetrinite, Tep = Terpenite, S = Sporinite, C = Clay, Py = Pyrite	

Figure 4.46 The microscopic picture of coal sample No. C8 – 2

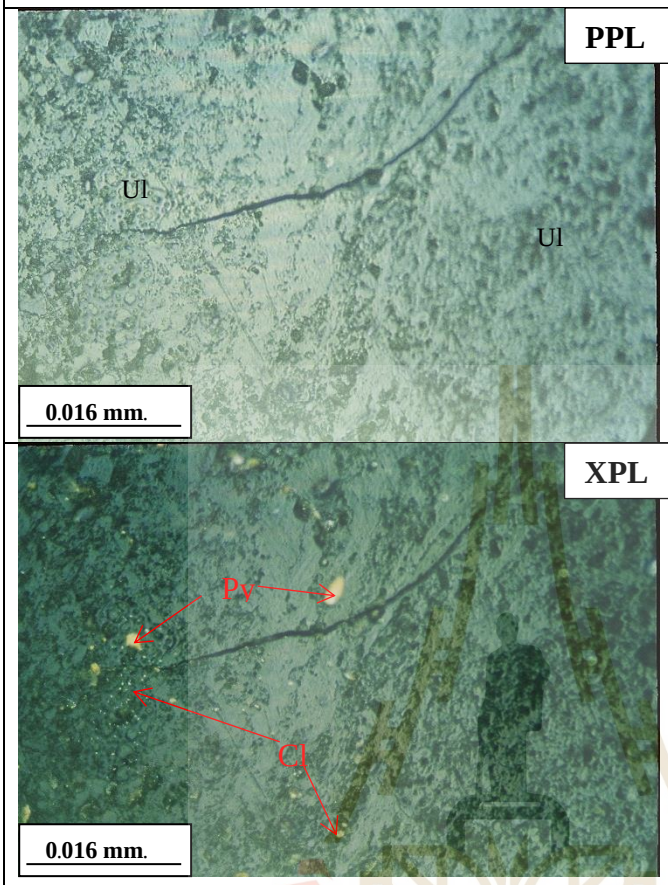
Microscopic Picture	Explanation
	**Sample No. C9-1** **Telovitrinite** consist mainly of cell ulmin in coal. **Composition (%)** V = 97 % L = 0 % I = 0 % MM = 3 % **Vitrinite** consist of ulminite in telovitrinite subgroup. They show structure of cell walls (**textinite**)filled with gelified material (**ulminite**). They displayed pale gray in PPL and black in XPL. **Mineral Matter** consist of clay minerals and pyrite filling in dry ulminite voids. They show brownish yellow to dark dots in PPL. In XPL clay display yellow to yellowish brown and pyrite display bright yellow.
PPL = Plane Polarized light, XPL = Cross Polarized light V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter T = Textinite Ul = Ulminite, Cl = Clay, Py = Pyrite	

Figure 4.47 The microscopic picture of coal sample No. C9 – 1

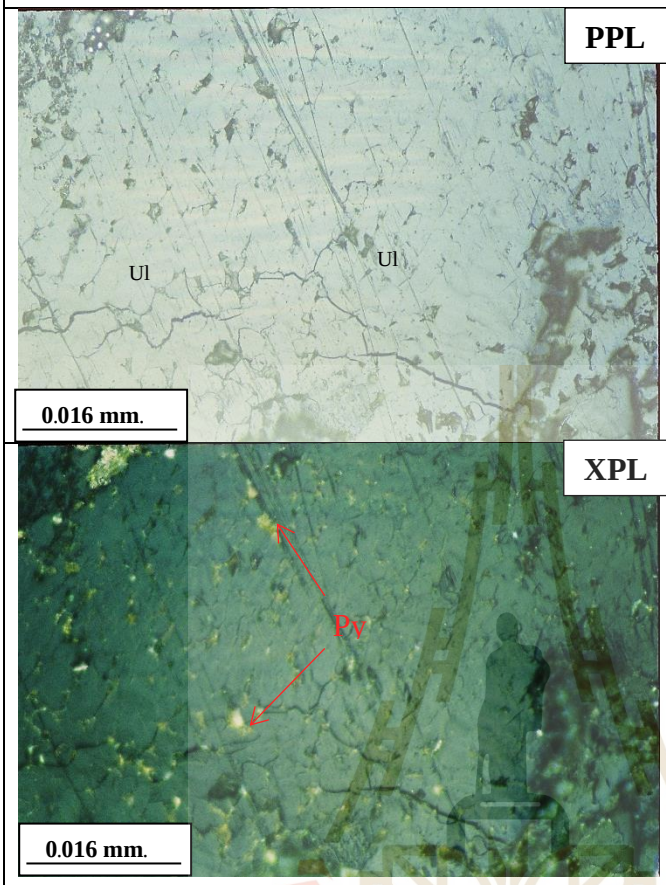
Microscopic Picture	Explanation
	**Sample No. C9-2** **Gelovitrinite of Texto-ulminite** consist mainly of cell ulmin but highly cracked due to high moisture content in coal. **Composition (%)** V = 92 % L = 0 % I = 0 % MM = 8 % **Vitrinite** consist of texto-ulminite in gelovitrinite subgroup. They show structure of cell walls (**textinite**) filled with gelified material (**ulminite**). They display pale gray in PPL and black in XPL. **Mineral Matter** consist of sulfide mineral (Pyrite) filling in rim of dry ulminite voids. They show brownish yellow to dark dots in PPL. In XPL clay display yellow to yellowish brown and silica display white color.
PPL = Plane Polarized light, XPL = Cross Polarized light V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter T = Textinite Ul = Ulminite, Py = Pyrite	

Figure 4.48 The microscopic picture of coal sample No. C9 – 2

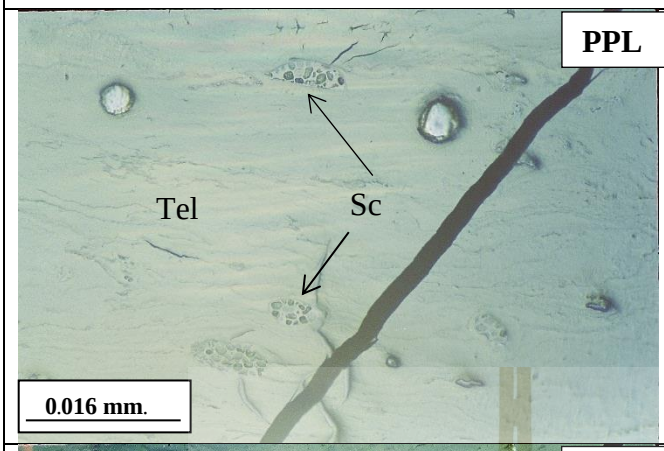
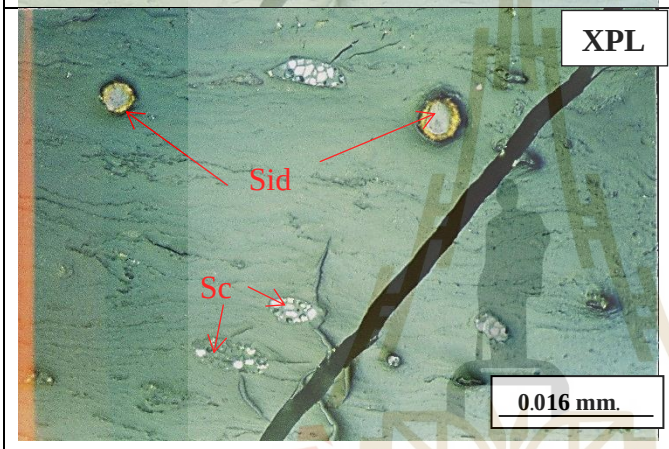
Microscopic Picture	Explanation
 	**Sample No.C10-1** **Telinite** associated with sclerotinite show cracking and siderite replacement. Composition (%) V = 91 % L = 0 % I = 4 % MM = 5 % **Vitrinite** consist of telinite derived from wood and display pale gray in PPL and black in XPL with gel cracking. **Inertinite** consist of sclerotinite and display exhibiting varying reflectance with high relief in PPL and black in XPL. **Mineral Matter** consist of siderite. They show sphere shape with layer of radius and display light brown and colorless in PPL and white yellow to yellowish brown with oxidize layer in XPL. The central radial is indicated primary siderite transformed to pyrite.
PPL = Plane Polarized light, XPL = Cross Polarized light V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Sc = Sclerotinite, Sid = Siderite, Tel = Telinite	

Figure 4.49 The microscopic picture of coal sample No. C10 – 1

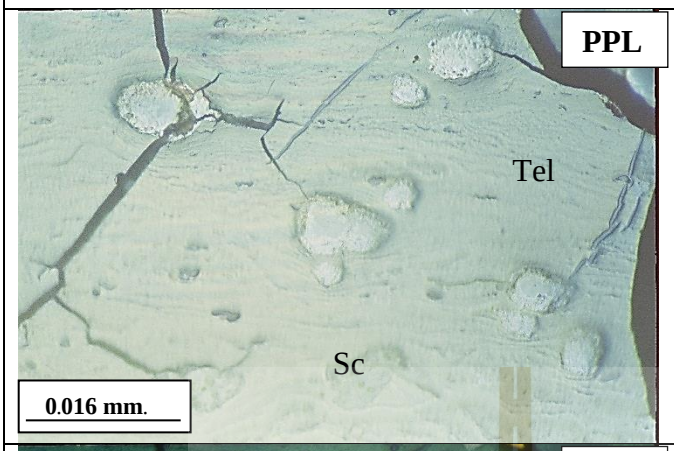
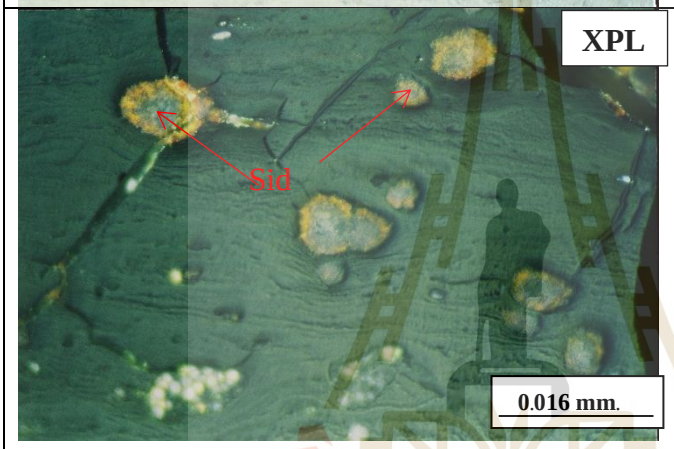
Microscopic Picture	Explanation
 	**Sample No.C10-3** **Telinite** associated with sclerotinite, show cracking and siderite replacement. Composition (%) V = 86 % L = 0 % I = 1 % MM = 13 % **Vitrinite** consist of telinite derived from wood. They display pale gray in PPL and black in XPL with gel cracking. **Inertinite** consist of sclerotinite. They display exhibiting varying reflectance with high relief in PPL and black in XPL. **Mineral Matter** consist of siderite. They show sphere shape with layer of radius. They display light brown and colorless in PPL and white yellow to yellowish brown with oxidize layer in XPL. The central radial is indicated primary siderite transformed to pyrite. Clay display gray to dark gray in PPL, white dots in XPL and filled in voids of sclerotinite.
PPL = Plane Polarized light, XPL = Cross Polarized light V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Sc = Sclerotinite, Sid = Siderite, Tel = Telinite	

Figure 4.50 The microscopic picture of coal sample No. C10 – 3

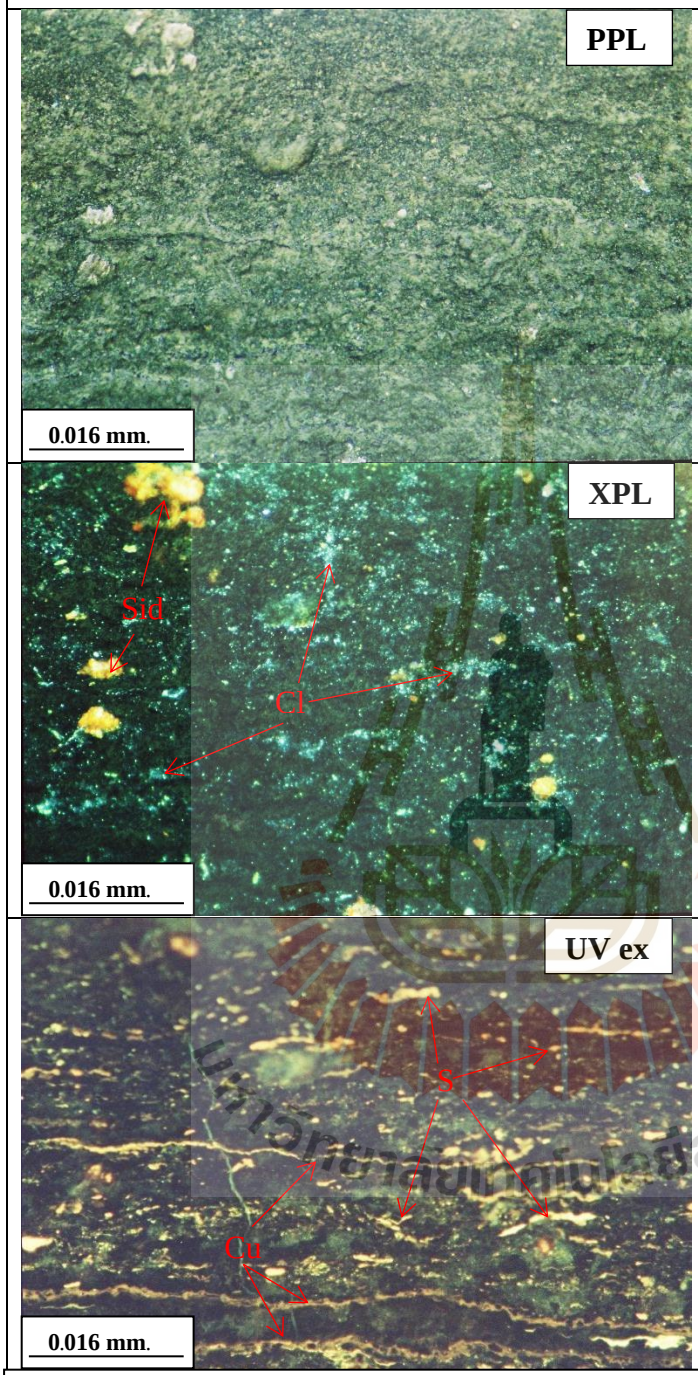
Microscopic Picture	Explanation
	**Sample No. C11-1** **Densinite** (detrovitrinite subgroup) consist of organic material and mineral matter showing sapropelic deposited. Composition (%) V = 67 % L = 21 % I = 0 % MM = 12 % **Vitrinite** consist of gelinite. They show pale gray in PPL and black in XPL and UV excitation. **Liptinite** consist of cutinite, sporinite and liptodetinite. They display dark gray in PPL and dark brown to black in XPL. Under UV excitation, sporinite display light yellow and small yellowish-brown spots with various spore shape. Cutinite display yellow to yellowish brown line with ledges shape. Liptodetinite display yellow to dark orange dots dispersed in gelinite. **Mineral Matters** consist of clays and silica mineral with some siderite. They show white to pale gray in PPL. Clay and silica display white sparse droplets in XPL and greenish black to black under UV ex. Siderite display pale gray in PPL, bright yellow to yellow orange in XPL with black under UV ex.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Cl = Clays, Cu = Cutinite, S = Sporinite, Sid = Siderite	

Figure 4.51 The microscopic picture of coal sample No. C11 – 1

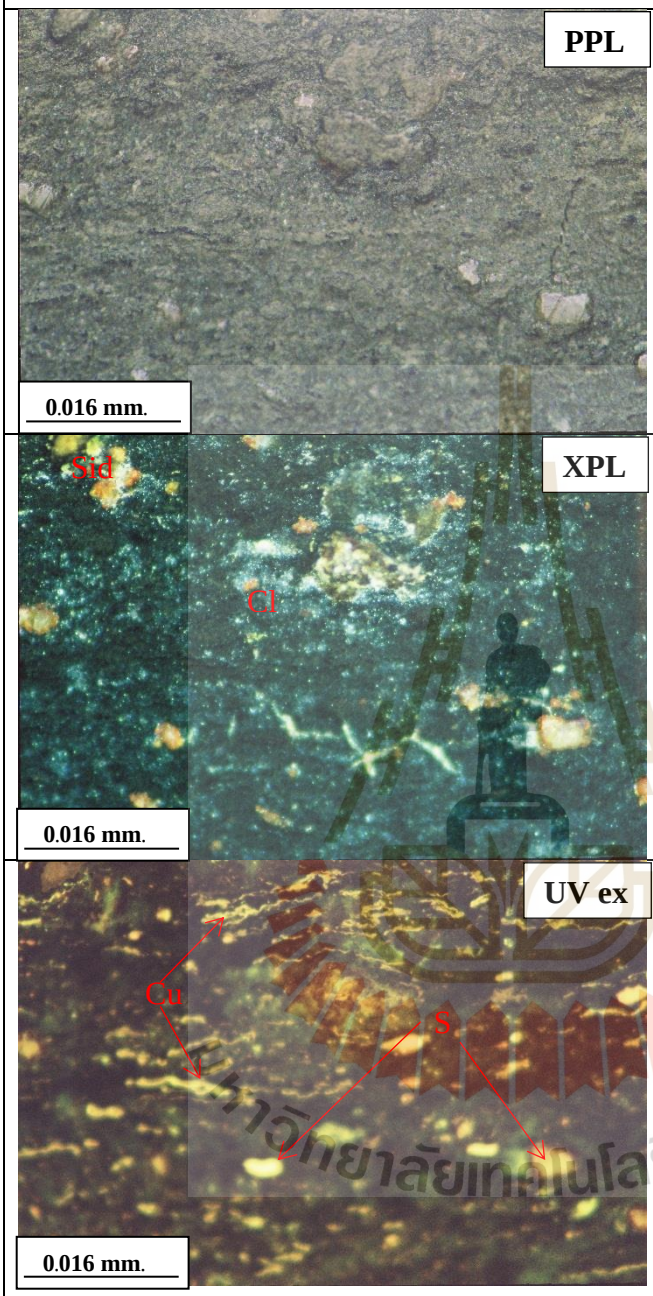
Microscopic Picture	Explanation
	**Sample No. C11-2** **Gelovitrinite** consist of organic material and mineral matter showing sapropelic deposited. **Composition (%)** V = 56 % L = 20 % I = 0 % MM = 24 % **Vitrinite** consist of gelinite. They show pale gray in PPL and black in XPL and UV excitation. **Liptinite** consist of cutinite, sporinite and liptodetinite. They display dark gray in PPL and dark brown to black in XPL. Under UV excitation, sporinite display light yellow and small yellowish-brown spots with various spore shape. Cutinite display yellow to yellowish brown line with ledges shape. Liptodetinite display yellow to dark orange dots dispersed in gelinite. **Mineral Matters** consist of clays and silica mineral with siderite. They show white to pale gray in PPL. Clay and silica display white sparse droplets in XPL and greenish black to black under UV ex. Siderite display pale gray in PPL, bright yellow to yellow orange in XPL with black under UV ex.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Cl = Clays, Cu = Cutinite, S = Sporinite, Sid = Siderite	

Figure 4.52 The microscopic picture of coal sample No. C11 – 2

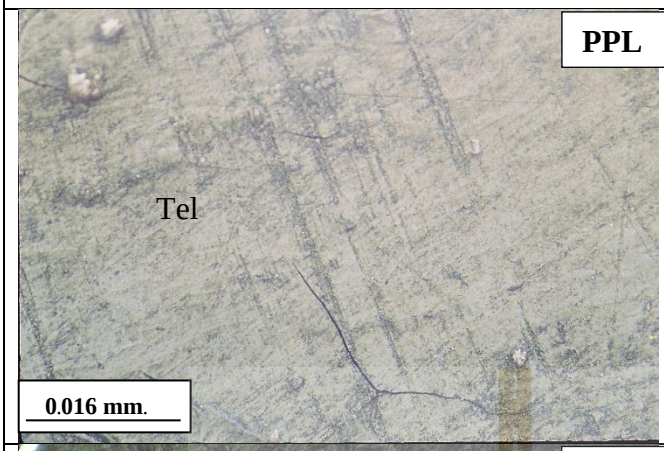
Microscopic Picture	Explanation
 	**Sample No.C11-3** **Telinite** associated with sclerotinite, show cracking and siderite replacement. Composition (%) V = 96 % L = 0 % I = 0 % MM = 4 % **Vitrinite** consist of telinite derived from wood. They display pale gray in PPL and black in XPL with gel cracking. **Mineral Matter** consists of siderite. They show sphere shape with layer of radius. They display light brown and colorless in PPL and white yellow to yellowish brown with oxidize layer in XPL.
PPL = Plane Polarized light, XPL = Cross Polarized light V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Sc = Sclerotinite, Sid = Siderite, Tel = Telinite	

Figure 4.53 The microscopic picture of coal sample No. C11 – 3

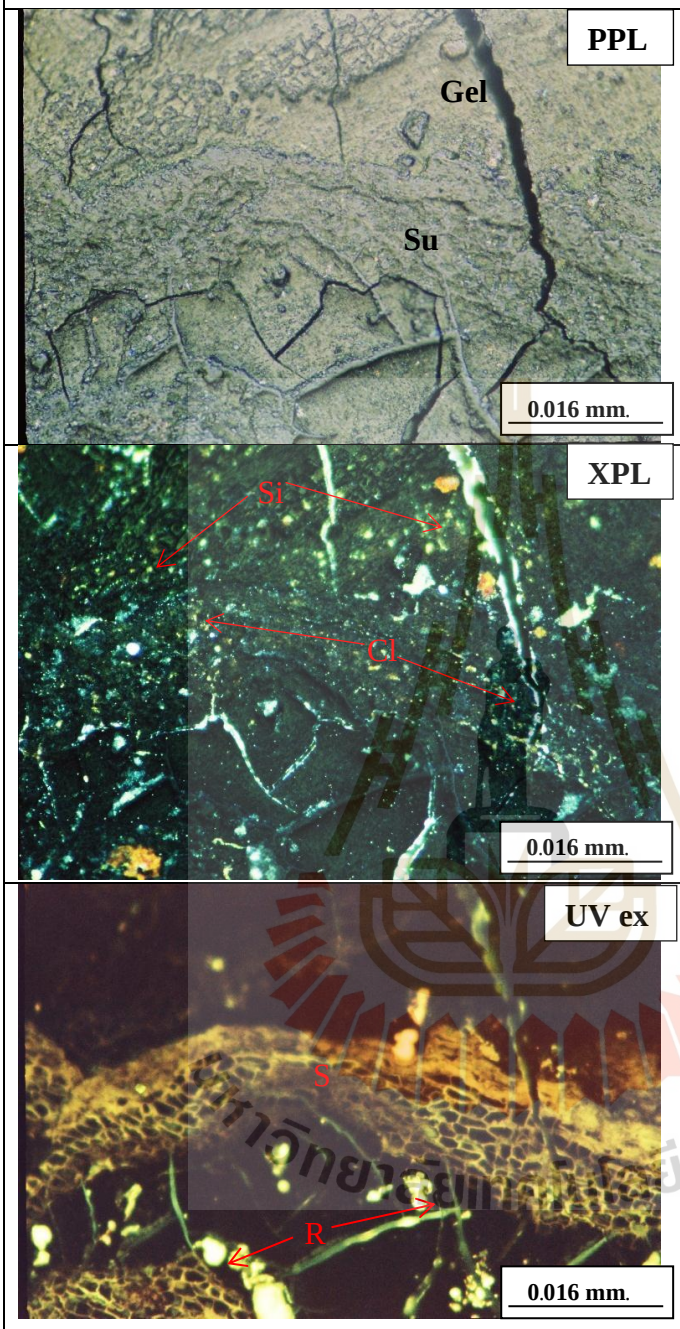
Microscopic Picture	Explanation
	**Sample No. C11-6** **Suberinite** in liptinite group with gelinite crack. Composition (%) V = 44 % L = 42 % I = 0 % MM = 14 % **Vitrinite** consist of texto-ulminite and some gelinite**.** They display pale gray in PPL and black in XPL. **Liptinite** consist mainly of suberinite. They show structure cell walls of cortex are pale gray in PPL, black in XPL and yellow under UV excitation. Resinite display pale gray with high relief in PPL, black in XPL and white bright to light yellow in UV excitation. **Mineral Matters** consist mostly of clay and silica deposited with gelinite. They show pale gray to dark spots in PPL and black in UV excitation. In XPL, clay display white spots and silica display yellowish green and brownish yellow dots.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Cl = Clay, Si = Silica, Su = Suberinite, Re = Resinite, Cg = Gel = Gelinite	

Figure 4.54 The microscopic picture of coal sample No. C11 – 6

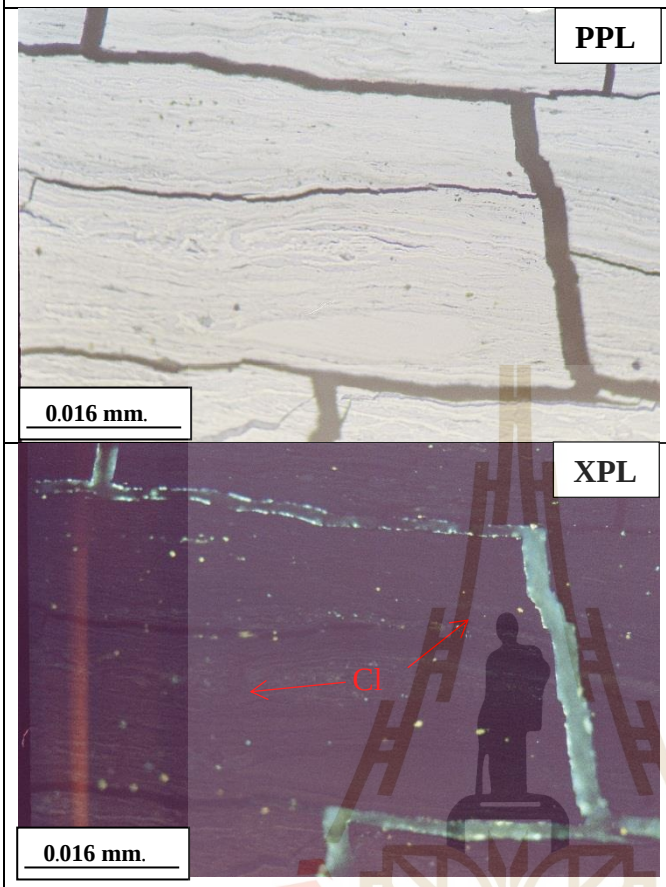
Microscopic Picture	Explanation
	**Sample No. C12-1** **Telovitrinite** show well preserve wood cell in coal. **Composition (%)** V = 94 % L = 0 % I = 0 % MM = 6 % **Vitrinite** consist of telovitrinite subgroup. They show structure of wood cell walls. They display pale gray in PPL and black in XPL. **Mineral Matters** consist mostly of clay. They display white spots and yellowish green and brownish yellow dots in XPL.
PPL = Plane Polarized light, XPL = Cross Polarized light V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter T = Textinite Ul = Ulminite, Cl = Clay, Si = Silica	

Figure 4.55 The microscopic picture of coal sample No. C12 – 1

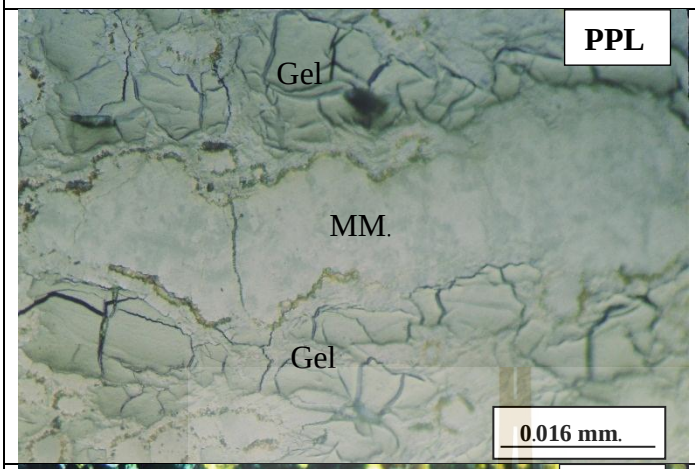
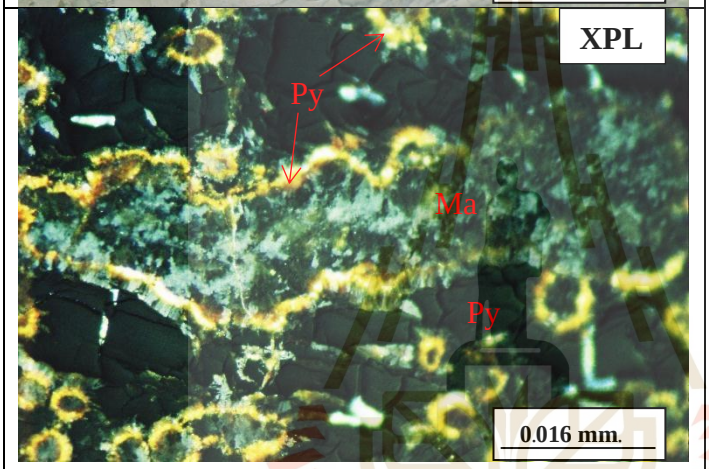
Microscopic Picture	Explanation
 	**Sample No.C12-2** **Gelovitrinite** show gelinite with crack and layer of mineral matter replacing in coal. Composition (%) V = 43 % L = 0 % I = 0 % MM = 57 % **Vitrinite** consist of gelinite. They show gel cracking and display colorless in PPL and black in XPL. **Mineral matter** consist of iron sulfide, group of marcasite. Marcasite display pale gray in PPL, pale to dark gray and black with radiation structure in XPL. They show oxidation rim, yellowish brown to brow in PPL and white yellow to brown in XPL.
PPL = Plane Polarized light, XPL = Cross Polarized light V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Gel = Gelinite, MM = Mineral Matter, Cl = Clay, Ma = Marcasite	

Figure 4.56 The microscopic picture of coal sample No. C12 – 2

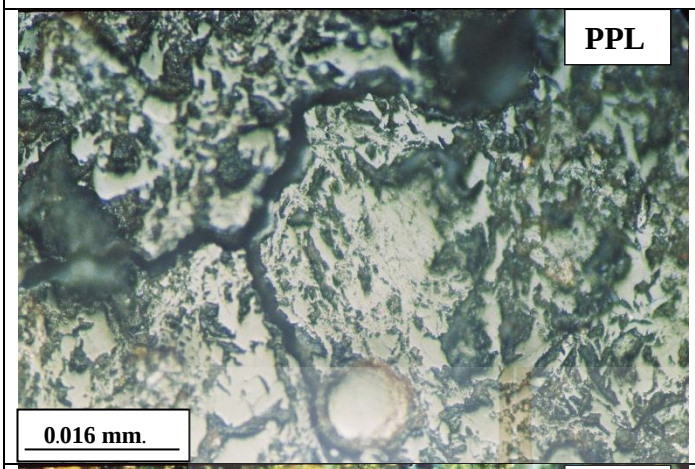
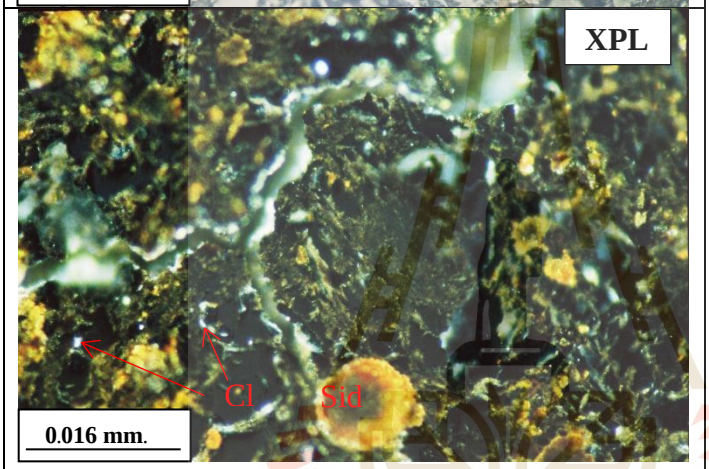
Microscopic Picture	Explanation
 	**Sample No.C12-5** **Gelovitrnite** of fusinite display preserved cell structure, intercellular space filled with mineral matter. Composition (%) V = 29 % L = 0 % I = 0 % MM = 71 % **Vitrinite** consist of gelinite with fusinite and show cell deforms with cells empty that are pyrofusinite. They display strong relief, pale gray to dark gray in PPL and black in XPL. **Mineral matter** consist mainly of siderite with a few of clay minerals. Siderite show sphere shape filled in cell lumen empty. They display light brown and pale to dark gray in PPL and yellow to yellowish brown with radius oxidize in XPL. The middle sphere displays dark yellowish brown to dark gray in XPL. Clay display dark gray to black in PPL and white dots filled in voids and crack.in XPL
PPL = Plane Polarized light, XPL = Cross Polarized light V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Cl = Clay, Sid = Siderite	

Figure 4.57 The microscopic picture of coal sample No. C12 – 5

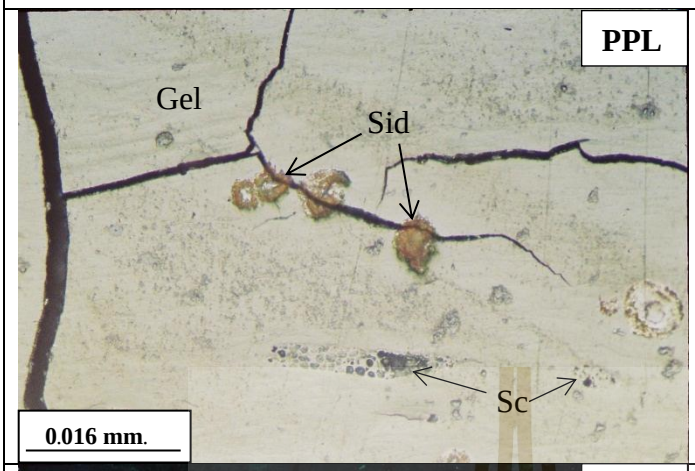
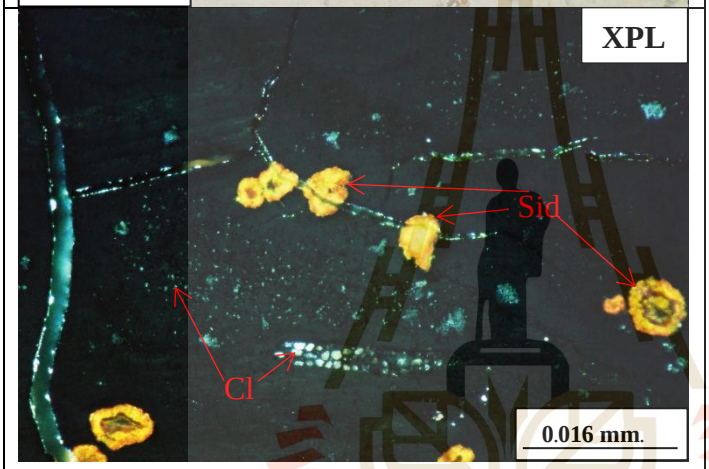
Microscopic Picture	Explanation
 	**Sample No.C12-7** **Telinite** associated with sclerotinite show cracking and siderite replacement. Composition (%) V = 71 % L = 0 % I = 24 % MM = 5 % **Vitrinite** consist of telinite derived from wood. They display pale gray in PPL and black in XPL with gel cracking. **Inertinite** made up of sclerotinite, display exhibiting varying reflectance with high relief in PPL and black in XPL. **Mineral Matter** consists of siderite and clay minerals. Siderite show sphere shape with layer of radius. They display light brown and colorless in PPL and white yellow to yellowish brown with oxidize layer in XPL.The central radial is indicated primary siderite transformed to pyrite. Clay display gray to dark gray in PPL, white dots filled in voids of sclerotinite.in XPL.
PPL = Plane Polarized light, XPL = Cross Polarized light V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Sc = Sclerotinite, Cl = Clay, Sid = Siderite	

Figure 4.58 The microscopic picture of coal sample No. C12 – 7

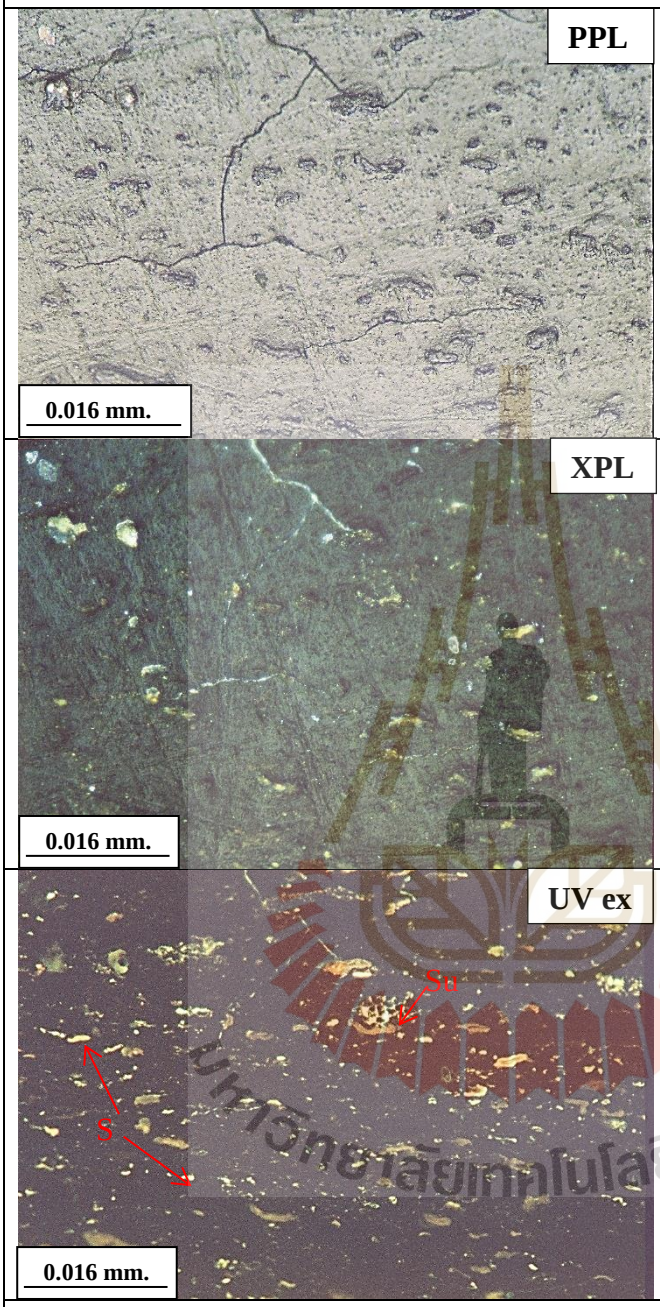
Microscopic Picture	Explanation
	**Sample No. C13-2** **Collotelinite** show structure of wood tissue and related with suberinite. Composition (%) V =88 % L = 12 % I = 0 % MM = 0 % **Vitrinite** consist of tellinite, show structure of bark woods with essential oil. They display pale gray in PPL, dark gray in XPL and black in UV excitation. **Liptnite** consist of liptodestrinite and suberinite with some sporinite. Most of liptodestrinite and suberinite are terpenite. They display pale gray in PPL, dark gray in XPL and white yellow to yellow under UV excitation. Sporinite show white to dark yellow with S-shape and telephone shape.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Li = Liptodetrinite, Tep = Terpenite, S = Sporinite, Su = Suberinite	

Figure 4.59 The microscopic picture of coal sample No. C13 – 2

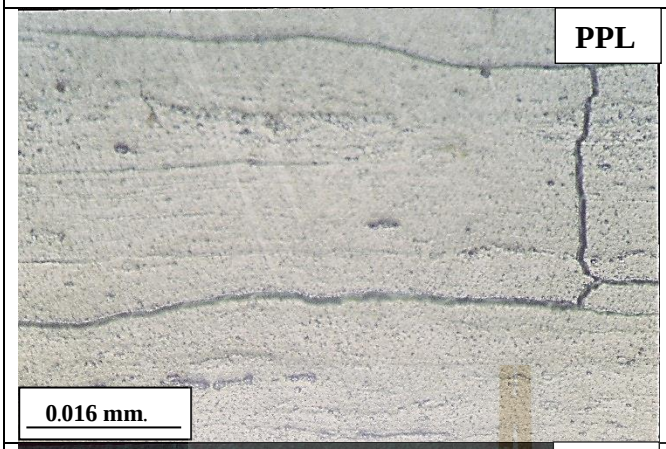
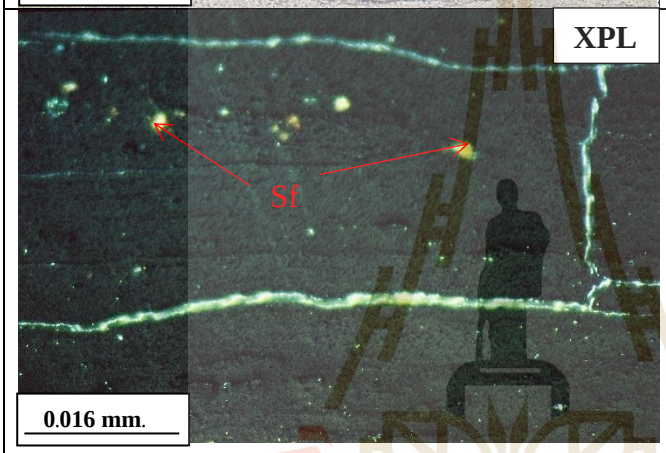
Microscopic Picture	Explanation
 	**Sample No. C13-3** **Telovitrinite** show well preserve wood cell in coal. **Composition (%)** V = 96 % L = 0 % I = 0 % MM = 4 % **Vitrinite** consist of telovitrinite subgroup. They show structure of wood cell walls. They display pale gray in PPL and black in XPL. **Mineral Matters** consist mostly of clay and sulfide mineral. They display white spots and yellowish and brownish yellow dots in XPL.
PPL = Plane Polarized light, XPL = Cross Polarized light V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter T = Textinite Ul = Ulminite, Cl = Clay, Sf = Sulfide mineral	

Figure 4.60 The microscopic picture of coal sample No. C13 – 3

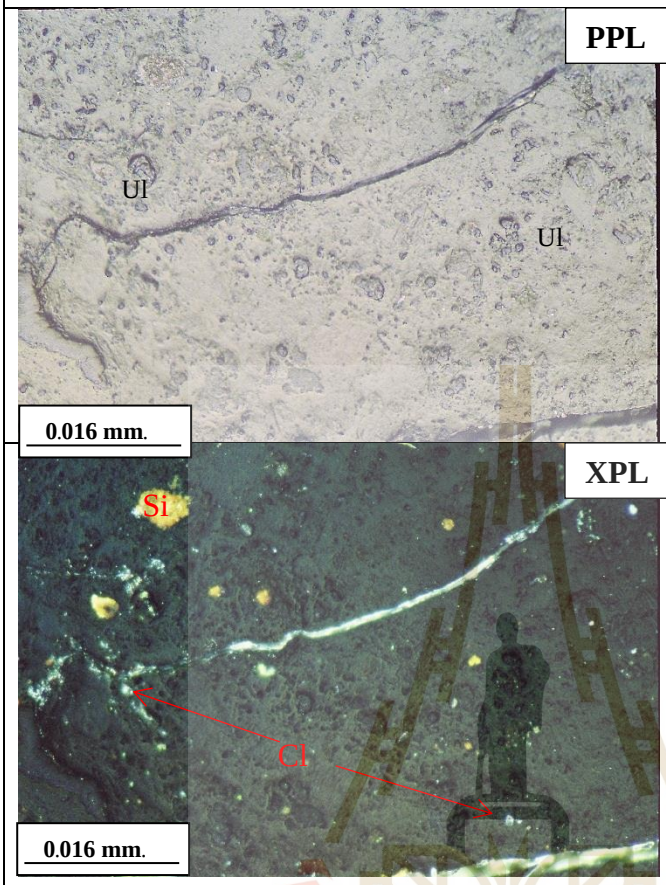
Microscopic Picture	Explanation
	**Sample No. C13-5** **Gelovitrinite** consist mainly of cell ulmin in coal. **Composition (%)** V = 90 % L = 0 % I = 0% MM = 10 % **Vitrinite** consist of ulminite in Gelovitrinite subgroup. They show structure of cell walls (**textinite**)filled with gelified material (**ulminite**). They display pale gray in PPL and black in XPL. **Mineral Matter** consist of siderite and clay minerals. Siderite show sphere shape with layer of radius, display light brown and colorless in PPL and white yellow to yellowish brown with oxidize layer in XPL.The central radial is indicated primary siderite transformed to pyrite. Clay display gray to dark gray in PPL, white dots in XPL and filled in voids of ulminite
PPL = Plane Polarized light, XPL = Cross Polarized light V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter T = Textinite Ul = Ulminite, Cl = Clay, Si = Siderite	

Figure 4.61 The microscopic picture of coal sample No. C13 – 5

4.2.3 Coal B sub-unit

Coal B sub-unit deposits between the coal C and coal A. The Coal B sub-unit is characterized by banded luster of moderate dull to glossy luster. The Coal B consists mainly of vitrinite 75.29%, liptinite 11.88% with a few of inertinite 0.12%, and mineral matter 12.71% (Table 4.6). The vitrinite consist of telovitrinite (38.47%) and gelovitrinite (44.71%). Telovitrinite shows characters of plant tissue which are telinite, texto-ulminite or porigelinite. Some of them show discernible characters of woods and barks displaying faint outline structure so called telinite. Some of them are highly decomposed and undergone gelification processes led to gelinite of gelovitrinite. Both gelinite and textinite usually display bright banded coals of vitrain and clarain (Figure 4.63 – 4.67). They display white to pale gray in PPL and dark gray to black in XPL. They occurred preferentially through oxidation of peat in abundant of water and near surface where oxygen easily contact the surface of peat deposit or in subaquatic environment. The coal consists mainly of vitrinite vary from 35 – 97% and they are particularly liptinite poor less than 42%. This represents forest peat origin and lack of terpenite associated in wood structure. The sclerotinites of inertinite group was also found in this Coal B sub-unit (Figure 4.63).

Liptinite found in this coal sub-unit consist mainly of resisted to oxidation maceral i.e. sporinite, resinite and liptodetrinite. Some of samples are dominated by sporinite which are deposited into humic gel and transformed to gelinite by absorption of water. They are cannel coal where the sporinite are more dominated than alginate. They should be represented the reed peats in the forest swamp. They display bright to dark yellow in fluorescence light with the character of spore shape (Figure 4.72). The resinite in gelovitrinite could be derived from leaf tissues which

generally tend to be very rich in resin, especially conifers found in the Tertiary flora. There are also isolated resinite bodies which are original cell excretion when the tissues are destroyed. They remain as individual entities that are commonly found in Tertiary coals. They display pale gray in PPL with high relief and brown to black in XPL. Under UV excitation they display bright yellow with rodlets bodies which resin embedded in cell tissues (Figure 4.69 and 4.71). The liptodetrinite together with sporinite should indicate the extension of reed swamp to subaquatic area where 'gyttja' deposit with organic mud. They display pale gray to dark gray in PPL and brown to black in XPL, and yellow to yellowish brown in irregular shape and other fine-grained clearly distinguished under the UV excitation

The small amount of mineral matters is found in this sub-unit, but in some layers there are silica diatomite, deposited with sporinite and a few of other materials. Diatomite display pale gray to white in PPL, white in XPL and fluorescence in white yellow to greenish yellow under UV excitation (Figure 4.70). The present of diatomite in coal layers could be indicated the prevailing contribution of high silica volcanic ash from distant volcanic eruption

Table 4.6 Composition in percentage of Coal B sub-unit samples.

Sample	Vitrinite				Liptinite									In	MM.
								Alginite							
	Tel	Det	Gel	Total	Sp	Cu	Lip	Lam	Te	Re	Fl	Su	Total		
B15-4	96	0	0	96	0	0	0	0	0	0	0	0	0	2	2
B15-5	75*	0	18	93	0	0	0	0	0	0	0	0	0	0	7
B15-7	93	0	2	95	0	0	0	0	0	0	0	0	0	0	5
B15-8	90*	0	5	95	0	0	0	0	0	0	0	0	0	0	5
B16-2	94	0	3	97	0	0	0	0	0	0	0	0	0	0	3
B16-4	95	0	0	95	0	0	0	0	0	0	0	0	0	0	5
B17-2	0	0	35	35	2	5	17	0	0	2	0	0	26	0	39
B17-4	0	0	65	65	2	0	13	0	0	9	0	0	24	0	11
B17-8	0	0	37	37	3	0	12	0	0	4	0	0	19	0	44
B17-7	0	0	48	48	0	0	4	0	0	0	0	0	4	0	48
B17-10	0	0	49	49	3	14	4	0	0	2	0	0	23	0	28
B17-11	0	0	50	50	0	20	9	0	0	13	0	0	42	0	8
B17-14	96*	0	0	96	0	0	0	0	0	0	0	0	0	0	4
B17-12	0	0	87	87	9	0	4	0	0	0	0	0	13	0	0
B18-2	0	0	69	69	7	0	22	0	0	2	0	0	31	0	0
B18-4	15	0	79	94	0	0	0	0	0	0	0	0	0	0	6
B18-5	0	0	79	79	4	0	15	0	0	1	0	0	20	0	1
min	0	0	2	35	2	5	4	0	0	1	0	0	0	0	0
max	96	0	87	97	9	20	22	0	0	13	0	0	42	2	48
Average	**23.12**	**0.00**	**36.82**	**75.29**	**1.76**	**2.29**	**5.88**	**0.00**	**0.00**	**1.94**	**0.00**	**0.00**	**11.88**	**0.12**	**12.71**

* = Texto-Ulminitel, Tel = Telovitrinite, Det= Detrovitrinite, Gel = Gelovitrinite, In = Inertinite, MM. = Mineral Matter
Sp = Sporinite, Re = Resinite, Lip = Liptodetrinite, Cu = Cutinite, Fl= Fluorinite, Su = Suberinite, Lam = Lamalginite, Te= Telalginite

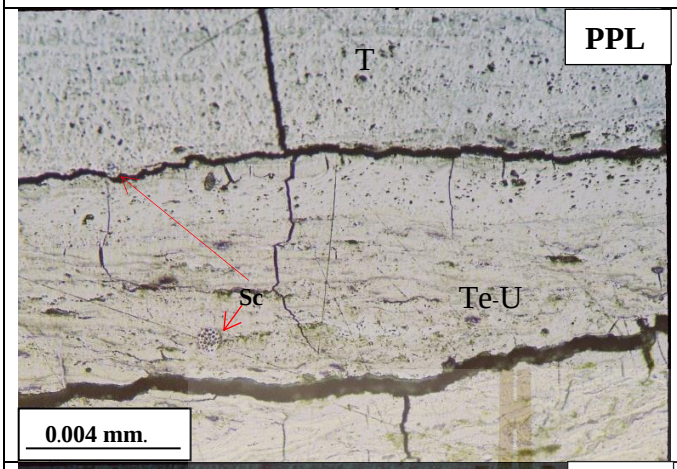
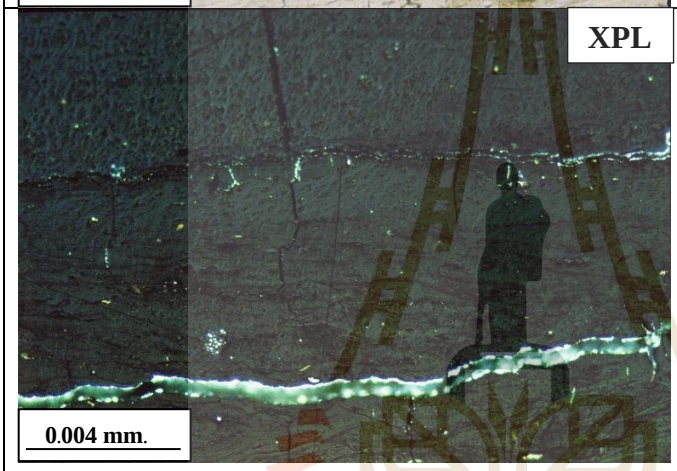
Microscopic Picture	Explanation
 	**Sample No. B15-4** **Telovitrinite** show character of texto-ulminite in corpocollinite at perpendicular tree trunk. V = 96 % L = 0 % I = 2 % MM = 2 % **Vitrinite** consist of **copocollinite.** They display bark and cork of wood showing structure of cell walls (textinite) filled by gel (ulminite). **Texto-ulminite** display dark brown in PPL for dry ulmin, pale gray in PPL for textinite and black in XPL. **Inertinite** consist of sclerotinite. They display pale gray with highly relief with sphere shape in PPL and black in XPL. **Mineral Matter** consist of small amount clay minerals. They display black in PPL and white dots in XPL filling in crack and sclerotinite voids.
PPL = Plane Polarized light, XPL = Cross Polarized light V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Te = Textinite, Te-U = Texto-Ulminite, Sc = Sclerotinite, Cl = Clays	

Figure 4.62 The microscopic picture of coal sample No. B15 – 4

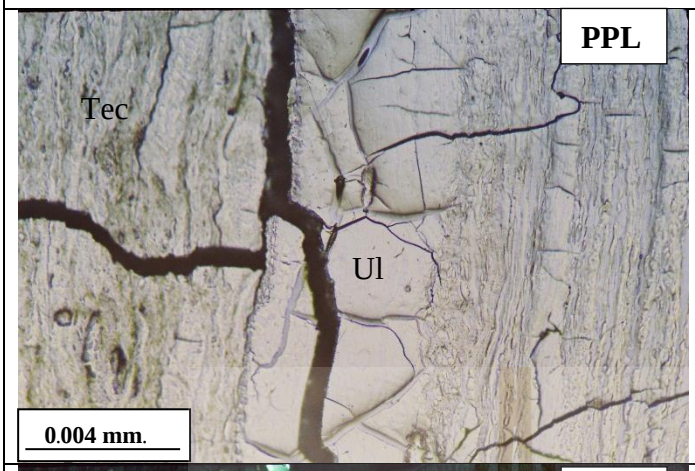
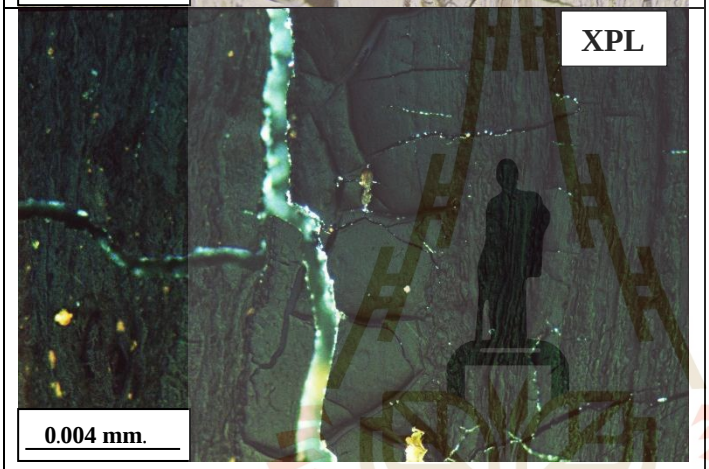
Microscopic Picture	Explanation
 	**Sample No. B15-5** **Telovitrinite** show character of wood tissue with desiccation crack of gel in collotelinite of duet tissue in the section cut parallel to the tree trunk. Composition (%) V = 93 % L = 0 % I = 0 % MM = 7 % **Vitrinite** consist of collotelinite with ulminite. They display structure of wood tissue (telocollinite) and filled with gelified (Ulminite) in xylems duets. They display colorless and pale gray to light brown in PPL and black in XPL. **Mineral Matter** consist of clay minerals filled in crack. They display black in PPL and white dots in XPL. A few of siderite display pale gray with strongly relief in PPL and white to light yellow in XPL.
PPL = Plane Polarized light, XPL = Cross Polarized light V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Gel = Gelinite, Cl = Clay, Tec = Telocollinite, Ul = Ulminite	

Figure 4.63 The microscopic picture of coal sample No. B15 – 5

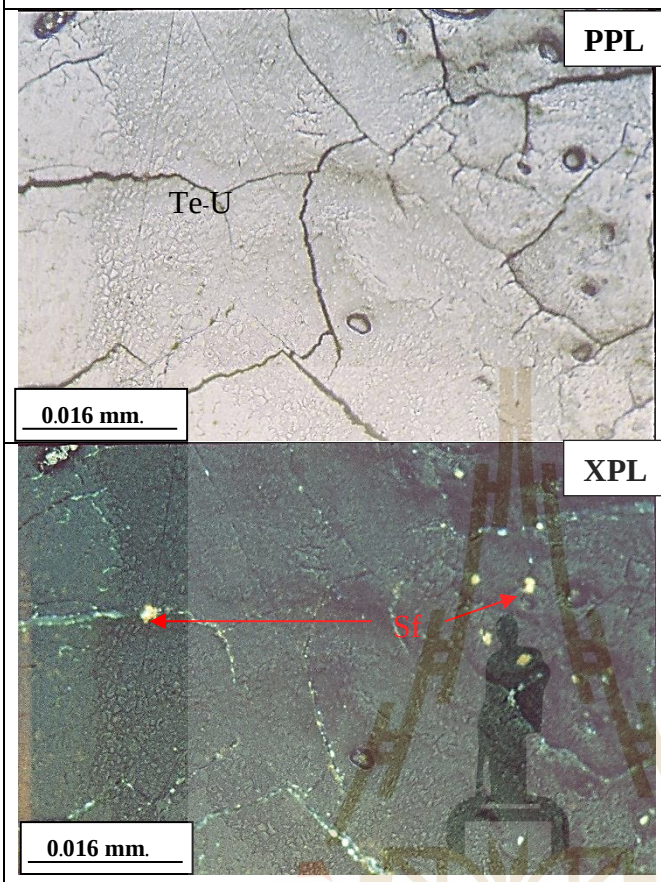
Microscopic Picture	Explanation
	**Sample No. B15-8** **Telovitrinite** show character of texto-ulminite in corpocollinite. Composition (%) V = 95 % L = 0 % I = 0 % MM = 5 % **Vitrinite** consist of **copocollinite.** They display bark and cork of wood showing structure of cell walls (textinite) filled by gel (ulminite). **Texto-ulminite** display dark brown in PPL for dry ulmin, pale gray in PPL for textinite and black in XPL. **Inertinite** consist of sclerotinite. They display pale gray with highly relief with sphere shape in PPL and black in XPL. **Mineral Matter** consist of small amount clay and sulfide mineral. They display black in PPL and white dots in XPL filling in crack and voids.
PPL = Plane Polarized light, XPL = Cross Polarized light V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Te = Textinite, Te-U = Texto-Ulminite, Sf = Sulfide mineral, Cl = Clays	

Figure 4.64 The microscopic picture of coal sample No. B15 – 8

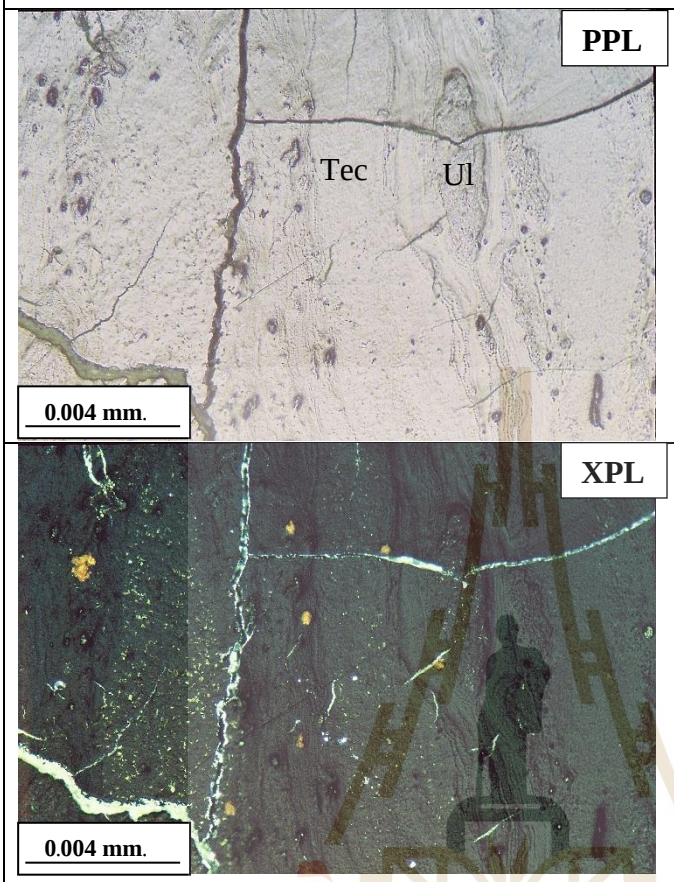
Microscopic Picture	Explanation
	**Sample No. B16-2** **Telovitrinite** show character of wood tissue with desiccation crack of gel in collotelinite of duet tissue in the section cut parallel to the tree trunk. **Composition (%)** V = 97 % L = 0 % I = 0 % MM = 3 % **Vitrinite** consist of collotelinite with ulminite. They display structure of wood tissue (telocollinite) and filled with gelified (Ulminite) in xylems duets. They display colorless and pale gray to light brown in PPL and black in XPL. **Mineral Matter** consist of clay minerals filled in crack. They display black in PPL and white dots in XPL.
PPL = Plane Polarized light, XPL = Cross Polarized light V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Gel = Gelinite, Cl = Clay, Tec = Telocollinite, Ul = Ulminite	

Figure 4.65 The microscopic picture of coal sample No. B16 – 2

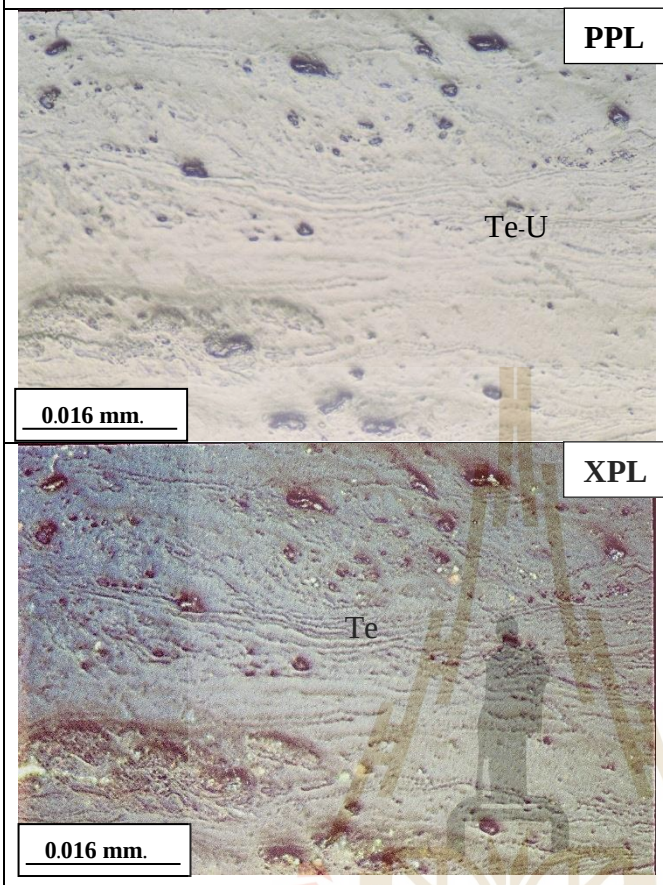
Microscopic Picture	Explanation
	**Sample No. B16-4** **Telovitrinite** show character of texto-ulminite in corpocollinite in the section cut perpendicular to the tree trunk. Composition (%) V = 95 % L = 0 % I = 0 % MM = 5 % **Vitrinite** consist of **copocollinite.** They display bark and cork of wood showing structure of cell walls (textinite) filled by gel (ulminite). They display dark brown in PPL for dry ulmin, pale gray in PPL for textinite and black in XPL. **Mineral Matter** consist of small amount clay minerals. They display black in PPL and white dots in XPL filling in voids.
PPL = Plane Polarized light, XPL = Cross Polarized light V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Te = Textinite, Te-U = Texto-Ulminite, Cl = Clays	

Figure 4.66 The microscopic picture of coal sample No. B16 – 4.

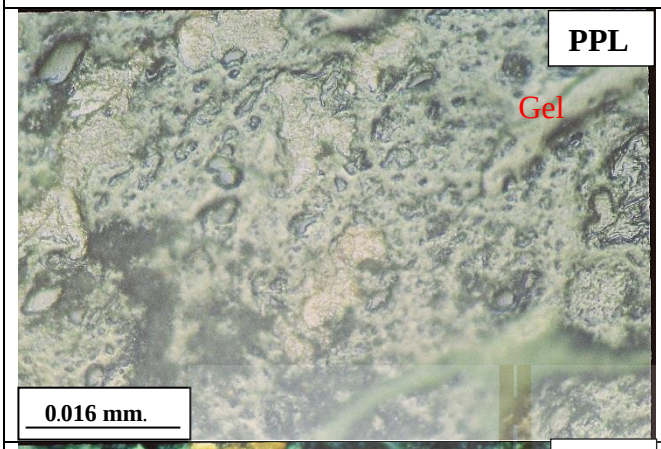
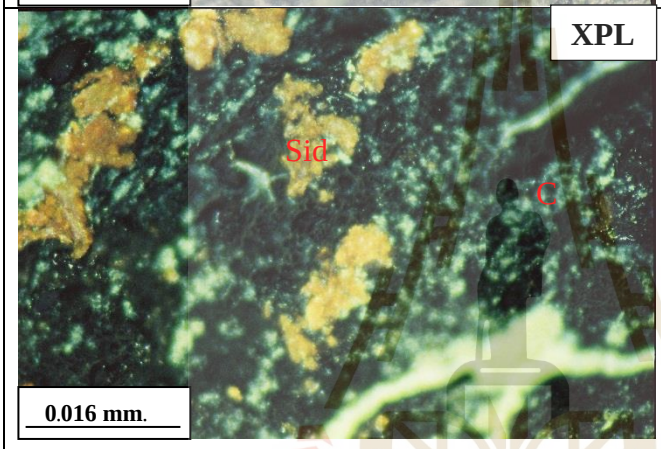
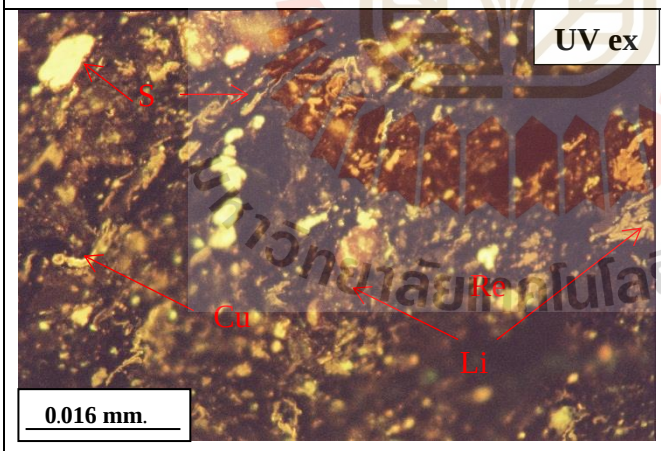
Microscopic Picture	Explanation
  	**Sample No. B17-2** **Gelovitrinite** show the accumulation of organic matter. Composition (%) V = 35 % L = 26 % I = 0 % MM = 93 % **Vitrinite** consist of densinite, several of organic matter and gelinite cements. They display pale gray in PPL with high relief, dark gray to black in XPL and black in UV excitation. **Liptinite** consist mainly of liptodetrinite, sporinite, cutinite remain and resinites. They display pale gray in PPL and white to light yellow in XPL. Under UV excitation, Liptodetrinite displayed dark yellow to orange spots, various sizes without shape. Resinite display as bright yellow of big spots with sphere shape. **Mineral matter** consist mainly of clay and silica minerals. They display dark in PPL with white dots in XPL and black under UV ex. The orange crystal in XPL and dark brown to black in UV ex could be siderite.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Re = Resinite, S = Sporinite, C = Clay, Sid = Siderite, Cu = Cutinite, Li = Liptodestrinite	

Figure 4.67 The microscopic picture of coal sample No. B17 – 2.

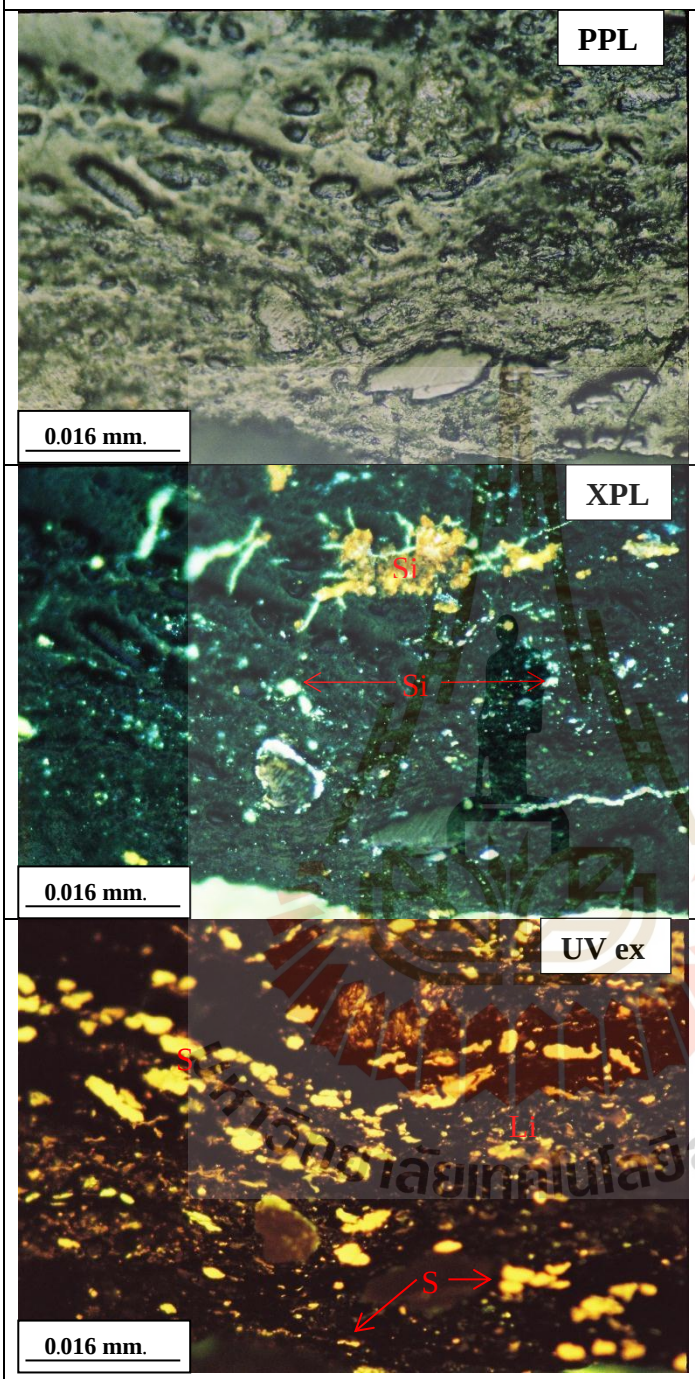
Microscopic Picture	Explanation
	**Sample No. B17-4** **Cannel coal (Sapropelic coal)** show layer of sporinite various sized and s-shape. Composition (%) V = 65 % L = 24 % I = 0 % MM = 11 % **Vitrinite** consist of gelinite. They display pale gray to dark gray in PPL and black in XPL. **Liptinite** consist mainly of sporinite with some of liptodetrinite. Sporinite display dark gray with highly relief in in PPL, black and white yellow in XPL. Under UV excitation they show lined up in layers of spore deposited. They display sized of bright yellow spots with sphere shape and yellow to dark brown with s-shape. Liptodetrinite display as small dark yellow spots. **Mineral Matter** consist of clay. They display as a few of very small spots, white and yellow in XPL and black in PPL and UV excitation. Siderite display yellowish pale gray in PPL and white to dark yellow radial in XPL, and dark brown to black in UV excitation.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter S = Sporinite, Li = Liptodestinite, Cl = Clay, Si = Siderite	

Figure 4.68 The microscopic picture of coal sample No. B17 – 4.

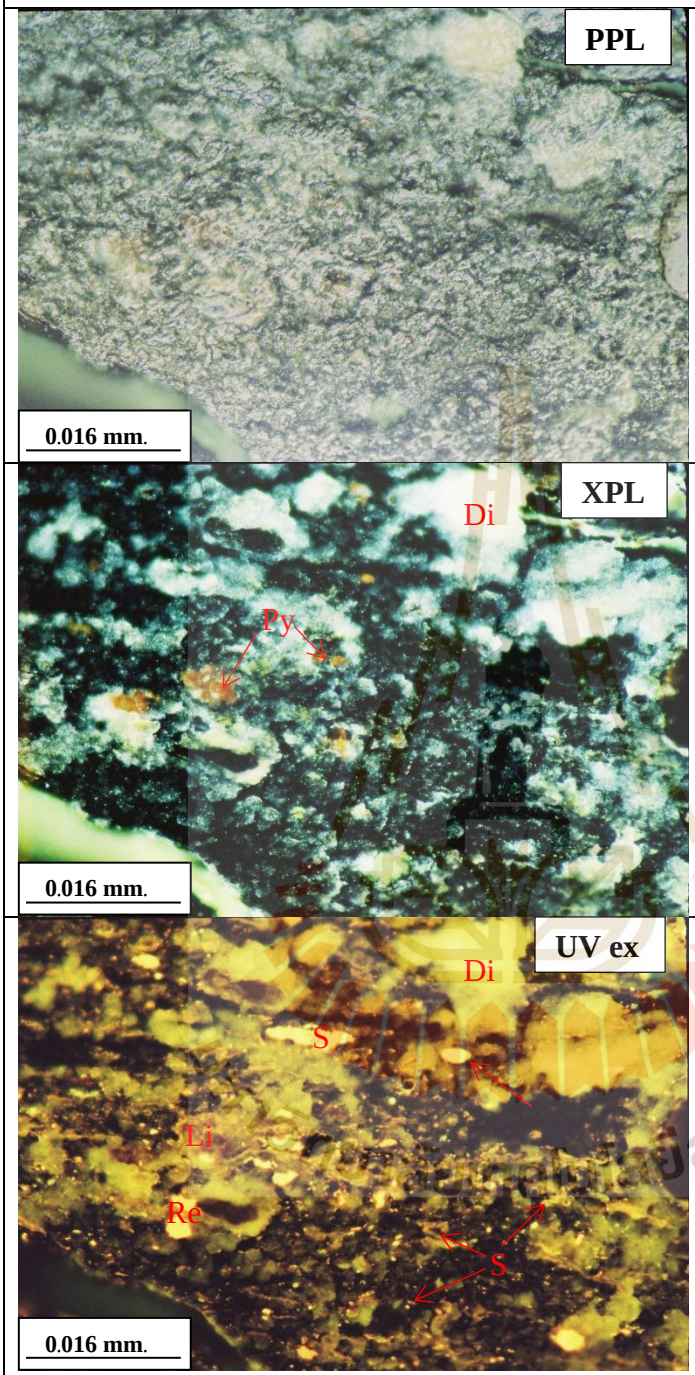
Microscopic Picture	Explanation
	**Sample No. B17-8** **Densinite** show sapropelic deposit with diatom. Composition (%) V = 37 % L = 19 % I = 0 % MM = 44 % **Vitrinite** consist of very fine-grained of organic sediment. They are densinite cemented by gelovitrinite. They display white to pale gray in PPL and black in XPL. **Liptinite** consist mainly of liptodetrinite and sporinite. They display pale gray to dark gray in PPL and black in XPL. Under UV excitation, liptodetrinite display as yellow to dark yellow spots without shape. Sporinite display as bright yellow to brownish yellow dots with various sized and spore shape. **Mineral Matter** consist mainly of diatomite with few of pyrite. Diatomite display as fine-grained structure (cloudy structure). They display white to pale gray in PPL, bright white in XPL and white yellow to greenish yellow in UV ex. Pyrite display light yellow in PPL, brown in XPL and dark brown to black in UV excitation.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Di=diatomite, S=Spore, Re = Resinite, Li = Liptodestrinite	

Figure 4.69 The microscopic picture of coal sample No. B17 – 8.

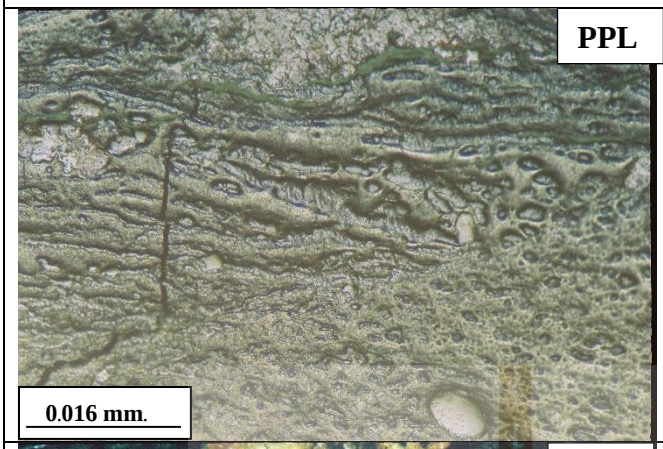
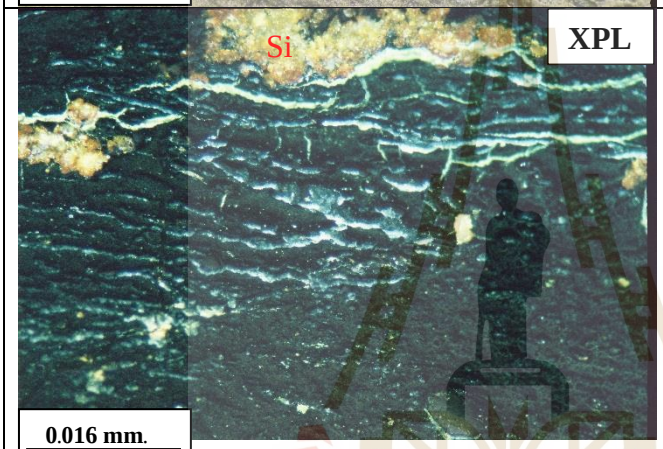
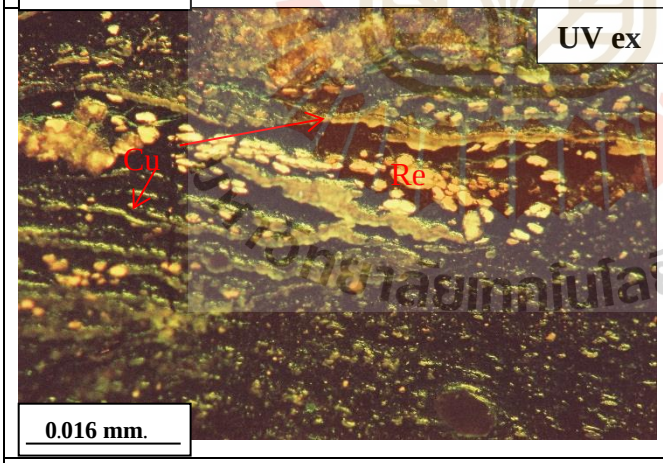
Microscopic Picture	Explanation
  	**Sample No. B17-11** **Corpogelinite** Composition (%) V = 50 % L = 42 % I = 0 % MM = 8 % **Vitrinite** consist of gelovitrinite subgroup. They show corpogelinite of wood tissue. They display colorless to pale in PPL and black in XPL. **Liptinite** consist mainly of cutinite and sporinite. They display dark gray with highly relief in in PPL and black and white yellow in XPL. Under UV excitation, cutinite and sporinite display as orderly white yellow to yellowish brown spots and various sizes of spore shape. **Mineral Matter** consist of clay. They display as a few of very small spots, white and yellow in XPL and black in PPL and UV excitation. Siderite display yellowish pale gray in PPL, white to dark yellow radial in XPL and dark brown to black in UV excitation.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation, V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Cl = Clay, Cu = Cutinite, Re = Resinite Si = Siderite	

Figure 4.70 The microscopic picture of coal sample No. B17 – 11

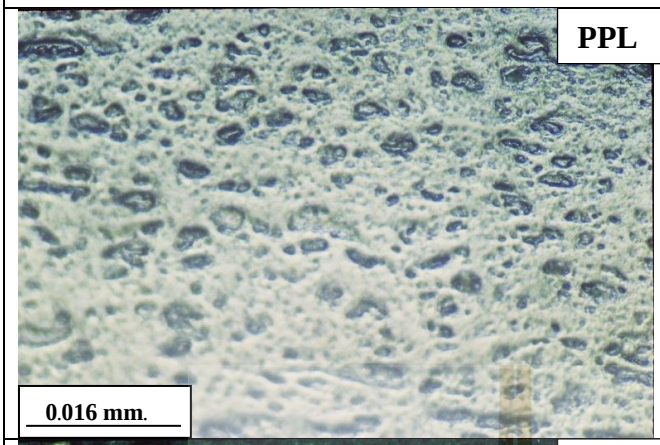
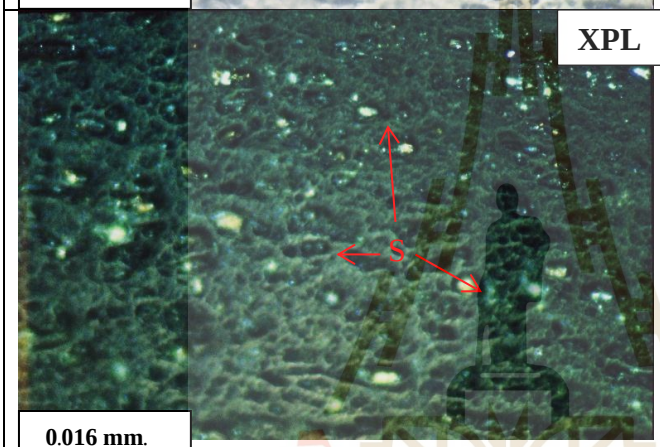
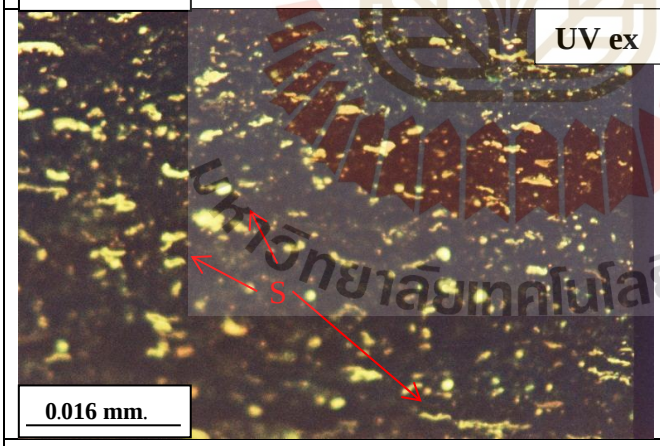
Microscopic Picture	Explanation
  	**Sample No. B17-12** **Cannel coal** show sapropelic deposit of gelovitrinite with sporinite. Composition (%) V = 87 % L = 13 % I = 0 % MM = 0 % **Vitrinite** consist of gelinite. They display colorless to pale in PPL and black in XPL. **Liptinite** consist mainly of sporinite with some of liptodetrinite. They display dark gray with highly relief in in PPL and black and white yellow in XPL.Under UV excitation, sporinite display as white yellow to yellowish brown spots and various sizes of spore shape. Liptodetrinite display as dark yellow spots. **Mineral Matter** consist of clay. They display as a few of very small spots, white and yellow in XPL and black in PPL and UV excitation.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter S = Sporinite, Cl = Clay	

Figure 4.71 The microscopic picture of coal sample No. B17 – 12

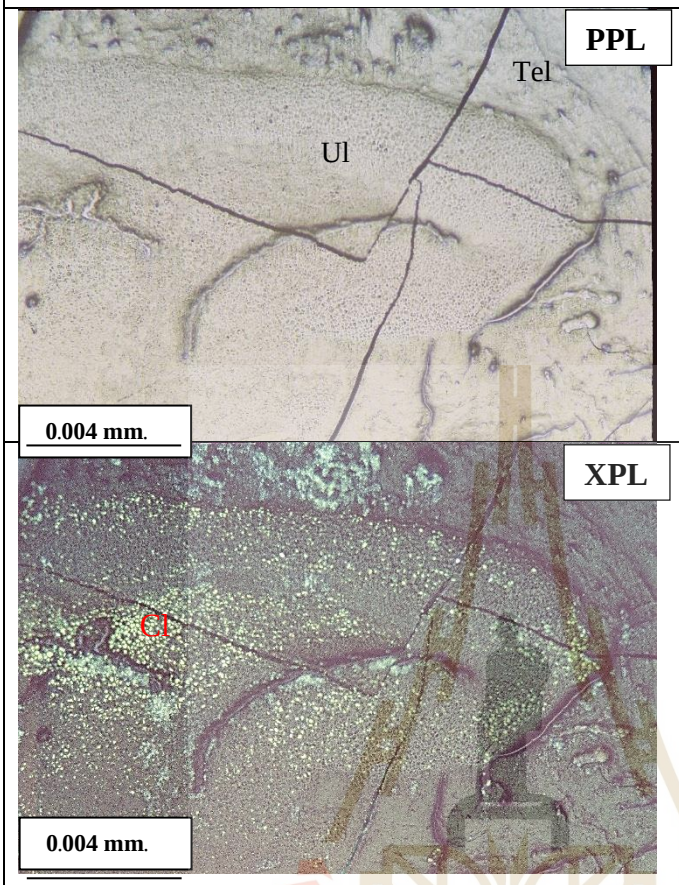
Microscopic Picture	Explanation
	**Sample No. B17-14** **Texto-ulminite** consist mainly of well preserve cell walls and cell ulmin but highly cracked due to high moisture content in coal. **Composition (%)** V = 96 % L = 0 % I = 0 % MM = 4 % **Vitrinite** consist of texto-ulminite in telovitrinite subgroup. They show structure of cell walls (**textinite**)filled with gelified material (**ulminite**). **Texto-ulminite** display pale gray in PPL and black in XPL. **Mineral Matter** consist of clay minerals and silica filling in dry ulminite voids. They display as brownish yellow to dark dots in PPL. In XPL clay display greenish yellow and silica display pale green color.
PPL = Plane Polarized light, XPL = Cross Polarized light V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter T = Textinite Ul = Ulminite, Cl = Clay, Si = Silica	

Figure 4.72 The microscopic picture of coal sample No. B17 – 14.

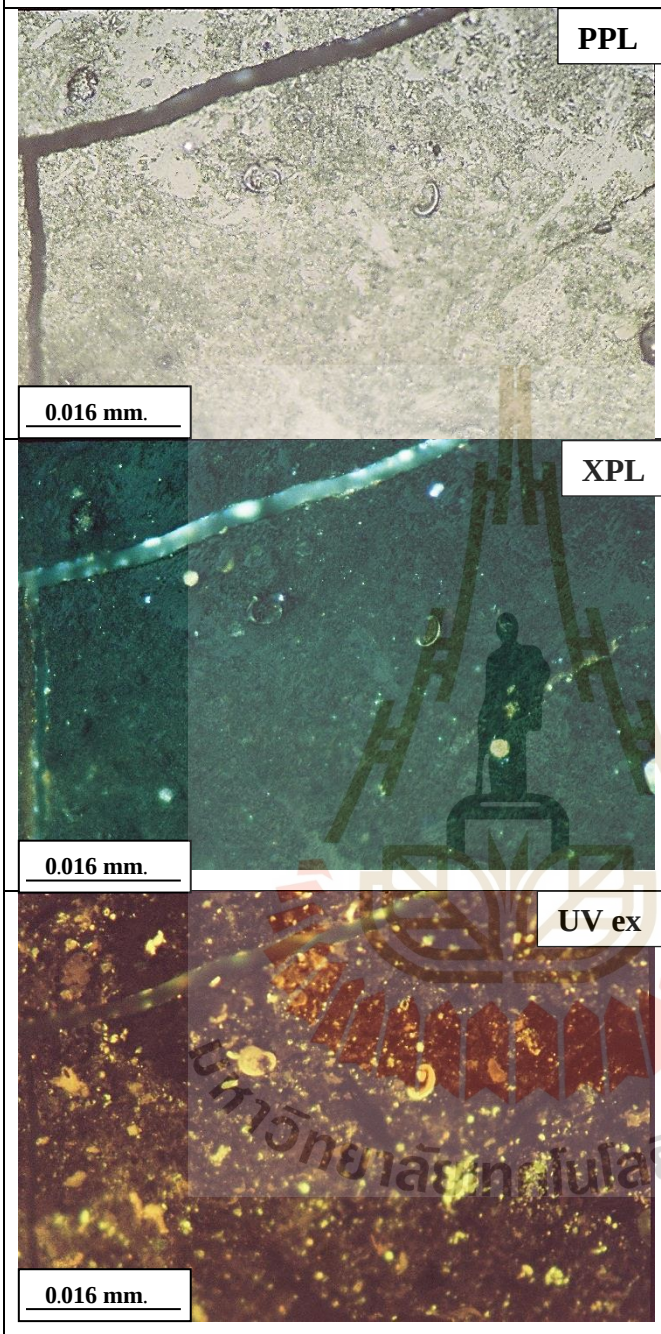
Microscopic Picture	Explanation
	**Sample No. B18 – 2** **Densinite** show sapropelic deposit with liptinite cemented by gelovitrinite. Composition (%) V = 69 % L = 31 % I = 0 % MM = 0 % **Vitrinite** consist of gelovitrinite. They display pale gray in PPL and dark gray to black in XPL and UV excitation. **Liptinite** consist mainly of liptodetrinite and sporinite. They display pale gray with highly relief in PPL and dark gray to black in XPL.Under UV excitation, liptodetrinite display as group of yellow to dark yellow without shape. Sporinite display as bright yellow to yellow dots, various sized and spore shape.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter	

Figure 4.73 The microscopic picture of coal sample No. B18 – 2.

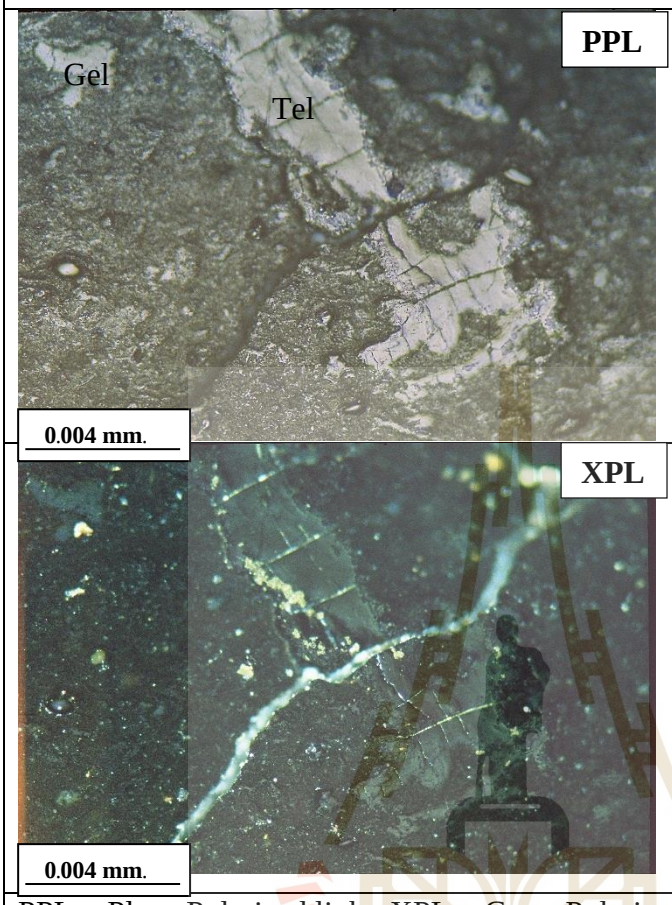
Microscopic Picture	Explanation
	**Sample No. B18-4** **Gelovitrinite** show parts of wood tissue in gelovitrinite Composition (%) V = 94 % L = 0 % I = 0 % MM = 6 % **Vitrinite** consist of telocollinite remains with gelified cement. They display colorless and pale gray to light brown in PPL and black in XPL. **Mineral Matter** consist of clay minerals. They display as black in PPL and white dots in XPL.
PPL = Plane Polarized light, XPL = Cross Polarized light V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Gel = Gelinite, Cl = Clay, Tel = Telocollinite,	

Figure 4.74 The microscopic picture of coal sample No. B18 – 4.

4.2.4 Coal A sub-unit

Coal A is the uppermost layer of the coal sub-units. The characters of this sub-unit show the coal bearing sequences from the lower part consisting of leonardite, sapropelic coal, and the upper part which is ended up with humic coal and preserved plant tissue. The vitrinite are vary from 28 – 100%. They consist mainly of telovitrinite (48.17%) and gelovitrinite (20.94%) which are represents the forest-peat swamp environment (Table 4.7). The sapropelic coal consists mainly of detrovitrinite deposited with liptinite group in gelovitrinite. They display difference fluorescence character of various liptinite in dark background of gelovitrinite under UV excitation (Figure 4.75 – 83). The coal derived from plant tissues as originate mainly from wood part show the ongoing processes that the lignin and cellulose of plant-cell walls and peatification are transformed to humic substance. They display dark color under microscope.

Telovitrinite consist of telinite, collotelinite and porigelinite which show character of wood structure (Figure 4.84). The vitrinite found in this coal sub-unit are believed to deposit in high water since they show character of gel associated with liptinite and a few of inertinite. Liptinite are filled in lacuna of porigelinite, collotelinite or dry cell and well preserve of plants (Figure 4.88, 4.95 and 4.96). The telovitrinite in gel can preserve plant tissues which are derived from wood stems, roots and barks (Figure 4.86 and 4.88). They also show difference fluorescing color under microscope with UV excitation. A few of sclerotinite which derived from fungal (a minor inertinite group) was found associated with telinite (Figure 4.101).

The liptinite display white or pale gray in PPL, black in XPL. The well-preserved leaf layers coal show cutinite with fluorinite (chlorophyllinite) which indicate

strongly reducing environment. Under UV excitation, the well preserved cutinite display as long wavy thin line, with cuticle ledges high relief in PPL. The fluorinite (chlorophyllinite) display as arrayed small bright white, yellow to greenish yellow dots under cutinite strips (Figure 4.95 and 4.99) which indicate the well preservation under reducing condition. The sporinite can be observed a typical structural feature of the exine, which are noticeable by double lines, yellow to brownish yellow under UV excitation (Figure 4.95, 4.96 and 4.99). Exsudatinite are presented in vitrinite and filled cracks of gelinite. They display as white-yellow to greenish-yellow fluorescing mass filled in void and fine cracks (Figure 4.94). The small amount of mineral matters in this Coal A sub-unit consist of framoidal pyrite, clay minerals, quartz, and other silica minerals. Framoidal pyrite display as white dots in PPL and XPL and dark under UV excitation. They are fill in crack of gelinite associate with exsudatinite (Figure 4.94, 104 and 4.106). Marcasite display colorless in PPL and white, gray to black with radiated structure in XPL which indicate the siderite intergrowth associated with pyrite (Figure 4.102, 4.103 and 4.109).

Table 4.7 Composition in percentage of Coal A sub-unit samples.

Sample	Vitrinite				Liptinite										In.	MM.
								Alginite								
	Tel	Det	Gel	Total	Sp	Cu	Lip	Lam	Te	Re	Fl	Su	Ex	Total		
A1-1	0	4	55	59	0	16	7	0	0	3	11	0	0	37	0	4
A1-3	0	2	69	71	0	2	12	0	0	1	0	0	0	15	0	14
A1-4	0	8	68	76	2	0	15	0	0	0	0	0	0	17	0	7
A1-5	19	1	36	56	0	9	5	0	0	9	11	0	0	34	0	10
A1-7	56	0	0	56	1	18	9	0	0	0	16	0	0	44	0	0
A2-3	50	8	19	77	6	6	7	0	0	0	4	0	0	23	0	0
A2-4	15	0	76	91	3	0	0	0	0	0	0	0	4	7	0	2
A2-5	0	0	28	28	0	0	5	64	0	0	0	0	0	69	0	3
A2-6	0	0	70	70	0	0	0	29	0	0	0	0	0	29	0	1
A2-7	2	1	27	30	6	0	8	35	0	0	0	0	0	49	0	21
A2-8	49	4	9	62	2	16	6	10	0	0	3	0	0	37	0	1
A2-1	87	0	3	90	0	0	0	0	0	0	0	0	0	0	0	10
A3-1	97*	1	0	98	0	0	0	0	0	0	0	0	0	0	0	2
A5-2	40*	0	29	69	0	15	6	0	0	7	3	0	0	31	0	0
A5-3	58	0	4	62	1	18	5	1	0	0	0	0	0	25	0	13
A5-4	100	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0
A5-5	10	0	57	67	4	0	29	0	0	0	0	0	0	33	0	0
A5-6	95	0	0	95	0	0	0	0	0	0	0	0	0	0	0	5
A6-1	28	0	18	46	6	0	25	13	4	0	0	0	0	48	0	6
A6-2	49	0	12	61	0	0	10	0	0	9	0	0	0	19	0	20

* = Texto-Ulminitel, Tel = Telovitrinite, Det= Detrovitrinite, Gel = Gelovitrinite, In = Inertinite, MM. = Mineral Matter, Sp = Sporinite, Ex=Exsudatinite, Re = Resinite, Lip = Liptodetrinite, Cu = Cutinite, Fl= Fluorinite, Su = Suberinite, Lam = Lamalginite, Te= Telalginite

Table 4.7 (Con.) Composition in percentage of Coal A sub-unit samples.

Sample	Vitrinite				Liptinite										In.	MM.
								Alginite								
	Tel	Det	Gel	Total	Sp	Cu	Lip	Lam	Te	Re	Fl	Su	Ex	Total		
A6-3	76	0	0	76	0	0	0	3	0	0	0	0	0	3	0	21
A7-2	72	0	26	98	0	0	0	0	0	0	0	0	0	0	0	2
A7-4	81	0	13	94	0	0	0	0	0	0	0	0	0	0	0	6
A7-5	0	0	88	88	0	0	0	0	0	0	0	0	7	7	0	5
A9-1	1	0	57	58	4	8	8	0	0	0	22	0	0	42	0	0
A9-3	82	0	0	82	5	0	6	0	0	0	7	0	0	18	0	0
A9-6	0	0	50	50	9	0	23	18	0	0	0	0	0	50	0	0
A9-9	24	0	30	54	5	0	17	22	2	0	0	0	0	46	0	0
A9-11	74	0	0	74	6	3	6	0	0	0	5	0	0	20	0	6
A9-13	59	0	0	59	5	12	2	0	0	0	12	0	0	31	0	10
A10-1	89	0	0	89	0	0	0	0	0	0	0	0	0	0	5	6
A10-3	96	0	0	96	0	0	0	0	0	0	0	0	0	0	0	4
A10-4	90	0	0	90	0	0	0	0	0	0	0	0	0	0	6	4
A10-6	68	0	0	68	0	0	0	0	0	0	19	0	0	19	1	12
A10-8	75	0	7	82	2	1	7	0	0	0	6	0	0	16	0	2
A10-9	63	0	2	65	2	4	25	0	0	1	3	0	0	35	0	0
A10-10	17	0	37	54	1	24	9	0	0	0	8	0	0	42	0	4
A10-11	10	0	46	56	0	14	8	0	0	0	8	0	5	35	0	9
A11-3	88	0	0	88	0	0	0	0	0	0	12	0	0	12	0	0
A11-5	73	0	21	94	1	0	0	3	0	0	0	0	0	4	0	2
A11-7	0	0	69	69	0	0	1	0	0	0	14	0	0	15	0	16

* = Texto-Ulminitel, Tel = Telovitrinite, Det= Detrovitrinite, Gel = Gelovitrinite, In = Inertinite, MM. = Mineral Matter, Sp = Sporinite, Re = Resinite, Lip = Liptodetrinite, Cu = Cutinite, Fl= Fluorinite, Su = Suberinite, Ex=Exsudatinite, Lam = Lamalginite, Te= Telalginite

Table 4.7 (Con.) Composition in percentage of Coal A sub-unit samples.

Sample	Vitrinite				Liptinite										In.	MM.
								Alginite								
	Tel	Det	Gel	Total	Sp	Cu	Lip	Lam	Te	Re	Fl	Su	Ex	Total		
A11-8	88	0	0	88	0	0	0	0	0	0	0	0	0	0	0	12
A13-1	98	0	0	98	0	0	0	0	0	0	0	0	0	0	1	1
A13-2	87	0	0	87	5	0	6	0	0	0	1	0	0	12	0	1
A13-3	98	0	0	98	0	0	0	0	0	0	0	0	0	0	0	2
A13-4	96	0	0	96	0	0	0	0	0	0	0	0	0	0	1	3
min	0.00	1.00	2.00	28.00	1.00	1.00	1.00	1.00	2.00	1.00	1.00	0.00	4.00	0.00	0.00	0.00
max	100	8	88	100	9	24	29	64	4	9	22	0	7	69	6	21
%	**48.33**	**0.63**	**22.30**	**74.24**	**1.65**	**3.61**	**5.80**	**4.30**	**0.13**	**0.65**	**3.59**	**0.00**	**0.35**	**20.09**	**0.30**	**5.37**

* = Texto-Ulminitel, Tel = Telovitrinite, Det= Detrovitrinite, Gel = Gelovitrinite, In = Inertinite, MM. = Mineral Matter
Sp = Sporinite, Re = Resinite, Lip = Liptodetrinite, Cu = Cutinite, Fl= Fluorinite, Su = Suberinite, Ex = Exsudatinite,
Lam = Lamalginite, Te= Telalginite

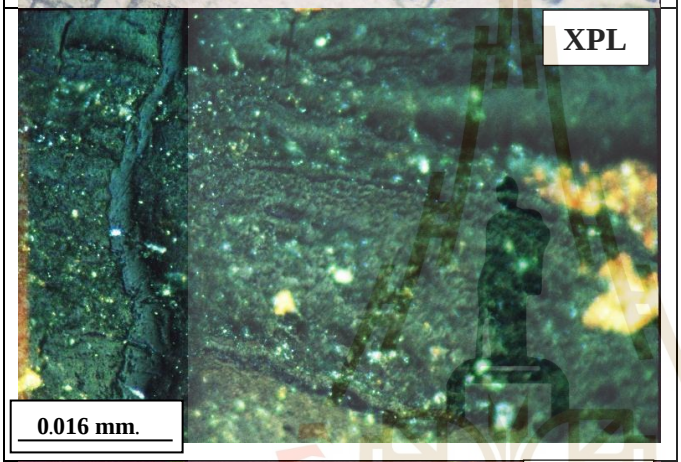
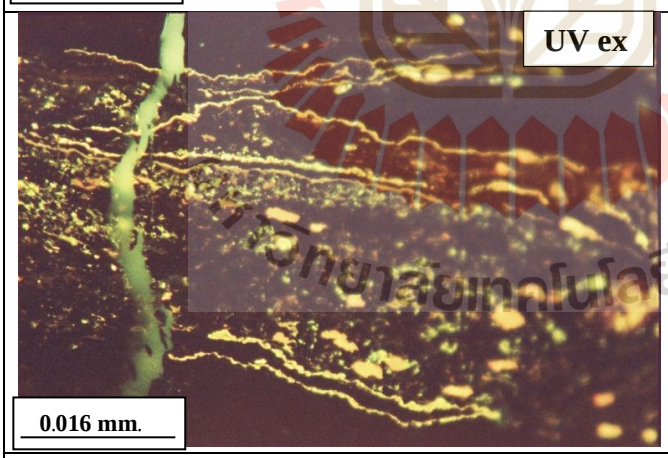
Microscopic Picture	Explanation
	**Sample No. A1-1** **Telovitrinite** in the section cut cross bedding shows structure of wood tissue. Composition (%) V = 59 % L = 37 % I = 0 % MM = 4 %
	**Vitrinite** show difference in reflectance of **textinite** and **ulminite** cemented by **gelinite**. Ulminite are body of cell filling in clay. They display pale gray in PPL and black in XPL. **Liptnite** display bright gray in PPL and dark in XPL. Under UV excitation resinite display light yellow spots and liptodestrinite display yellow without shape. The yellow line are cutinite with fluorinite. **Mineral matters** consist of clay and siliceous minerals. They display dark color in PPL, white dots in XPL and black under UV ex.
	
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation Li = Liptodestrinite, Rai = Rei, Reinschia = Resinite, S = Sporinite, C = Clay	

Figure 4.75 The microscopic picture of coal sample No. A1 – 1.

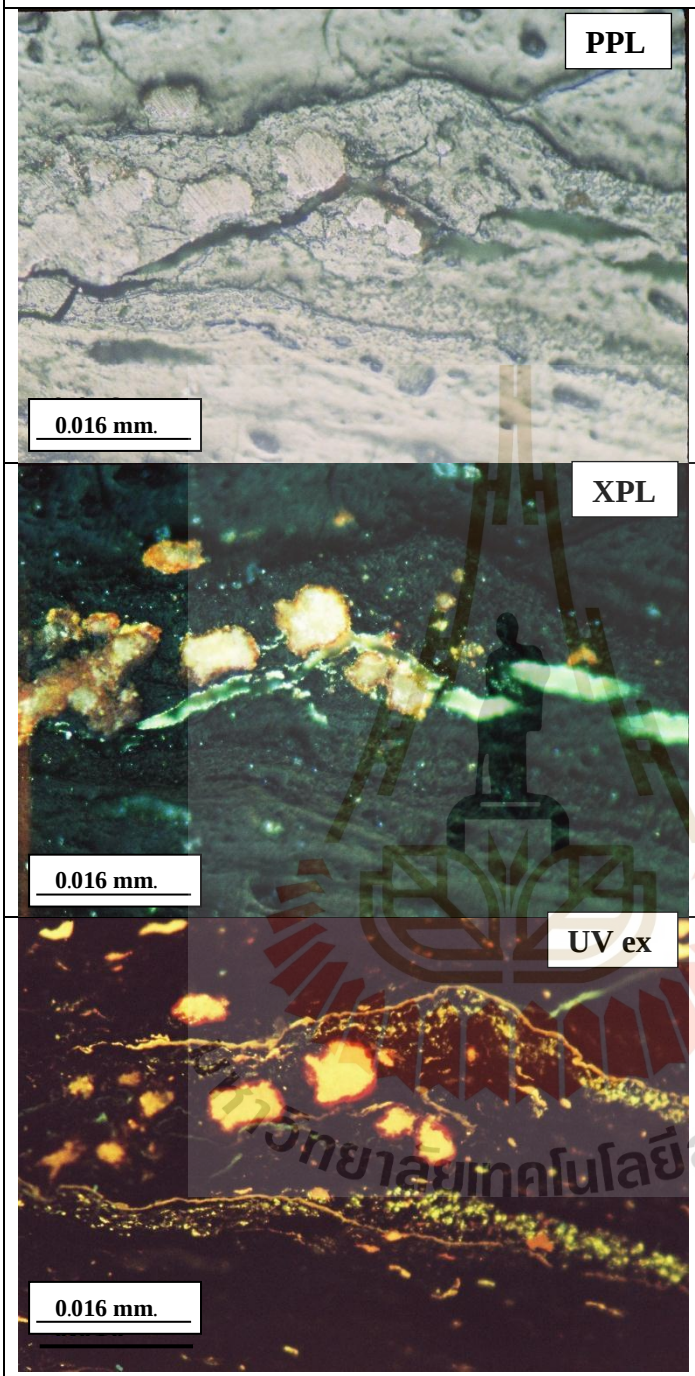
Microscopic Picture	Explanation
	Sample No. A1-5 **Gelovitrinite** show well preserve plant tissues. Composition (%) V = 56 % L = 34 I = 0 % MM = 10 % **Vitrinite** consist of gelovitrinite. They show structure of cell walls (textinite and ulminite) transforming to gelinite. They display colorless to pale gray in PPL, dark gray in XPL and black under UV ex. **Liptinite** consist mainly of cutinite, fluorinate, resinite and some sporinite. Cutinite display very high relief in PPL, black line in XPL and line of yellowish brown to dark brown with v-shape and ledge shape under UV ex. Fluorinite display as pale gray to dark gray with high relief in PPL, and bright yellow dots in row near cutinite under UV excitation. Resinite display as yellowish-brown filling in voids of wood tissues. **Mineral Matter** consist of clay and silica.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation Li = Liptodestrinite, Rai = Rei, Reinschia = Resinite, S = Sporinite, C = Clay	

Figure 4.76 The microscopic picture of coal sample No. A1 – 5.

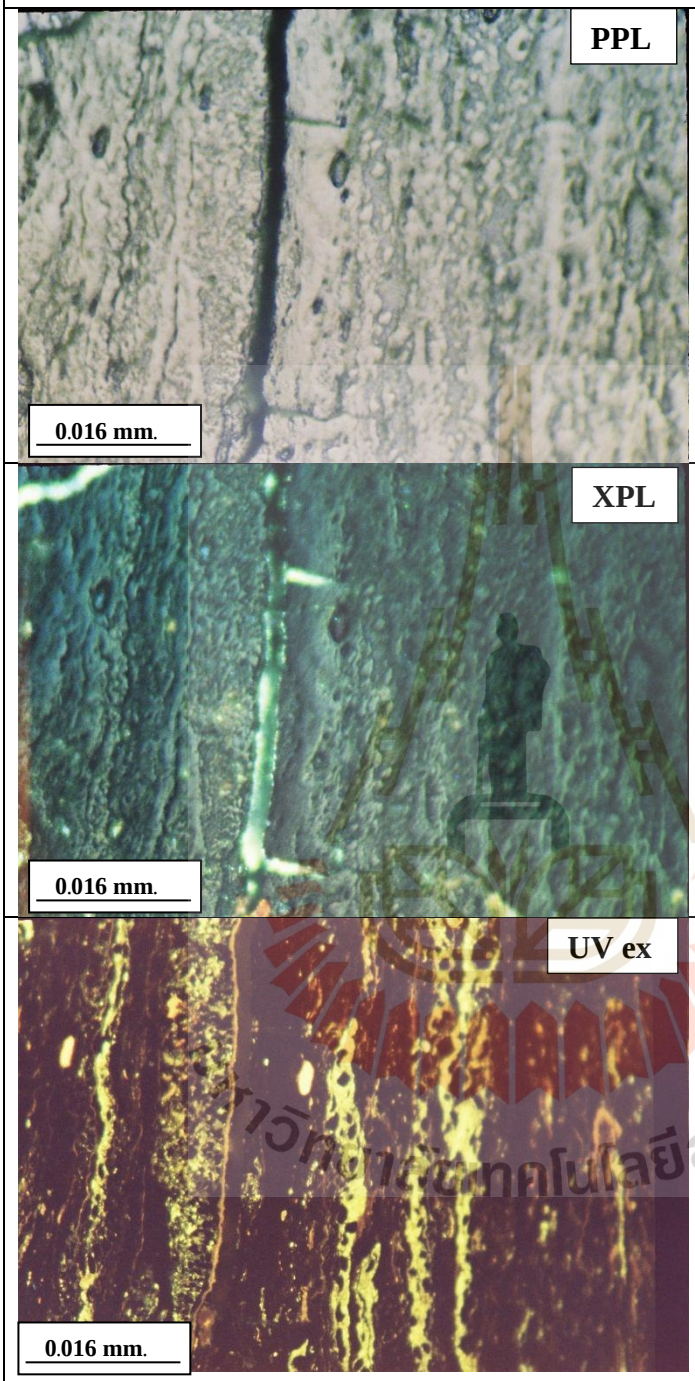
Microscopic Picture	Explanation
	**Sample No. A1-7** Porigelinite show well preserve plant tissues. Composition (%) V = 56 % L = 44 % I = 0 % MM = 0 % **Vitrinite** consist of gelovitrinite. They show plant remains (bark) transforming to gelinite (Porigelinite). They display colorless to pale gray in PPL, dark gray in XPL and black under UV ex. **Liptinite** consist mainly of cutinite, fluorinate and suberinite (terpenite). Cutinite display as very high relief in PPL, black line in XPL and line of yellowish brown to dark brown with v-shape and ledge shape under UV ex. Fluorinite display as pale gray to dark gray with high relief in PPL, yellowish brown to dark gray in XPL and group of bright yellow dots in row near cutinite under UV excitation. Suberinite display as yellowish-brown filling in voids of wood tissues.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation Li = Liptodestrinite, Rai = Rei, Reinschia = Resinite, S = Sporinite, C = Clay	

Figure 4.77 The microscopic picture of coal sample No. A1 – 7.

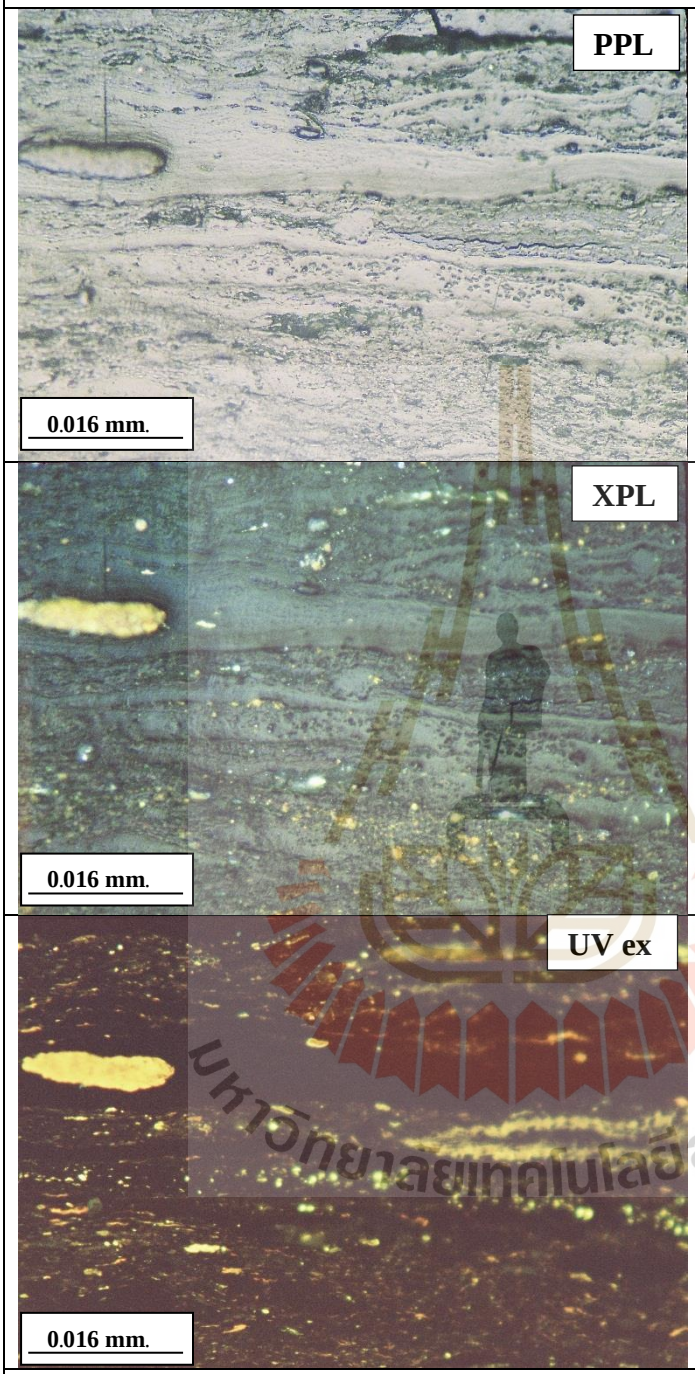
Microscopic Picture	Explanation
	**Sample No. A2-3** **Porigelinite** show well preserve plant tissues. Composition (%) V = 77 % L = 23 % I = 0 % MM = 0 % **Vitrinite** consist of gelovitrinite. They show plant remains (bark) transforming to gelinite (Porigelinite). They display colorless to pale gray in PPL, dark gray in XPL and black under UV ex. **Liptinite** consist mainly of fluorinate, sporinite and liptodestrinite. Fluorinite display pale gray to dark gray with high relief in PPL, yellowish brown to dark gray in XPL. Sporinite display as bright yellow to yellow dots, various sized and spore shape.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation Li = Liptodestrinite, Rai = Rei, Reinschia = Resinite, S = Sporinite, C = Clay	

Figure 4.78 The microscopic picture of coal sample No. A2 – 3.

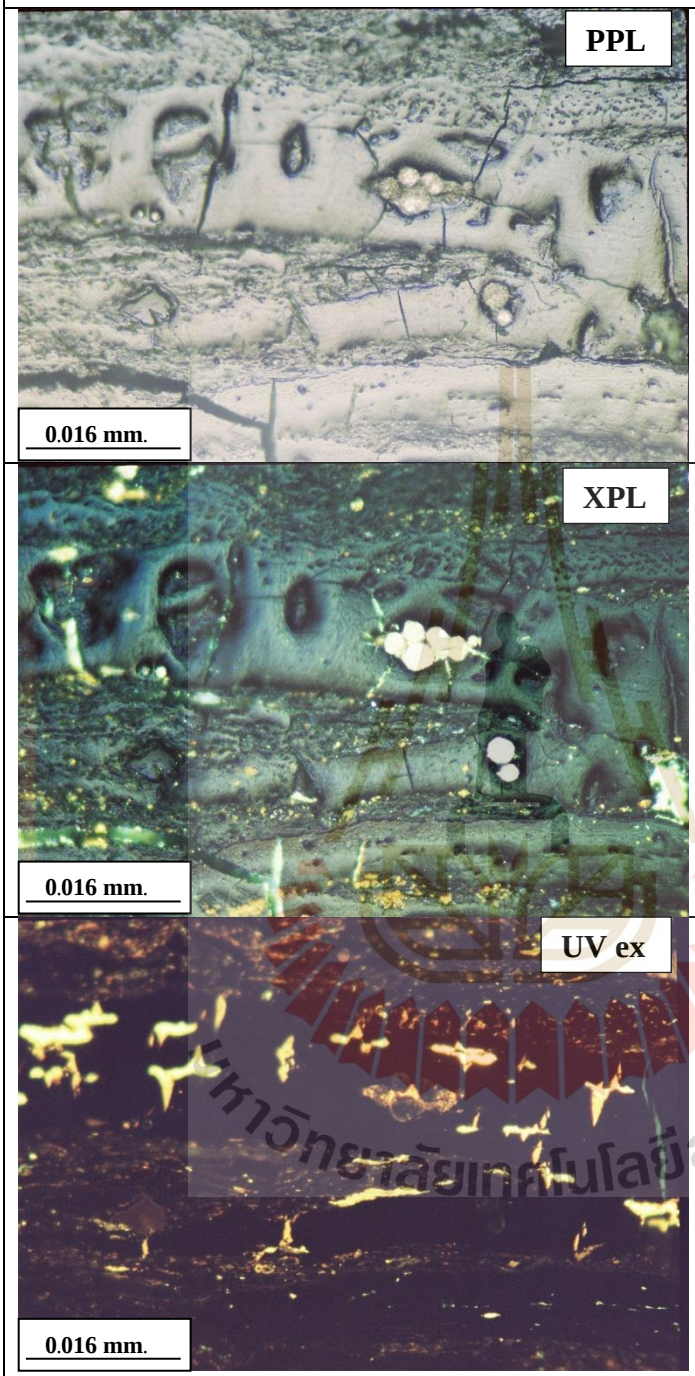
Microscopic Picture	Explanation
	**Sample No. A2-4** **Corpogelinite** show gel of xylems and wood tissues in the section of parallel cut. **Composition (%)** V = 91 % L = 7 % I = 0 % MM = 2 % **Vitrinite** consist mainly of gelinite. They show wood tissue and xylems decay transforming to gelinite. They display pale gray and highly relief in PPL and dark gray to black in XPL and black in UV ex. **Liptnite** consist mainly of liptodetrinite with Exsudatinite (terpenite). They display dark gray in PPL, dark gray to black in XPL. Under UV excitation Liptodetrinite display as dark yellow to brown dots without shape. Terpenite display as white yellow to yellow filled in voids of dry gel and wood tissue. **Mineral matter** consist of clay and pyrite. Clay display as white to yellow dots in XPL. Pyrite display as sphere body (framboidal pyrite) filled in voids, white to pale gray in PPL, bright white in XPL and black in UV ex.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Li = Liptodestrinite, Ex = Exsudatinite, Py = Pyrite, C = Clay	

Figure 4.79 The microscopic picture of coal sample No. A2 – 4.

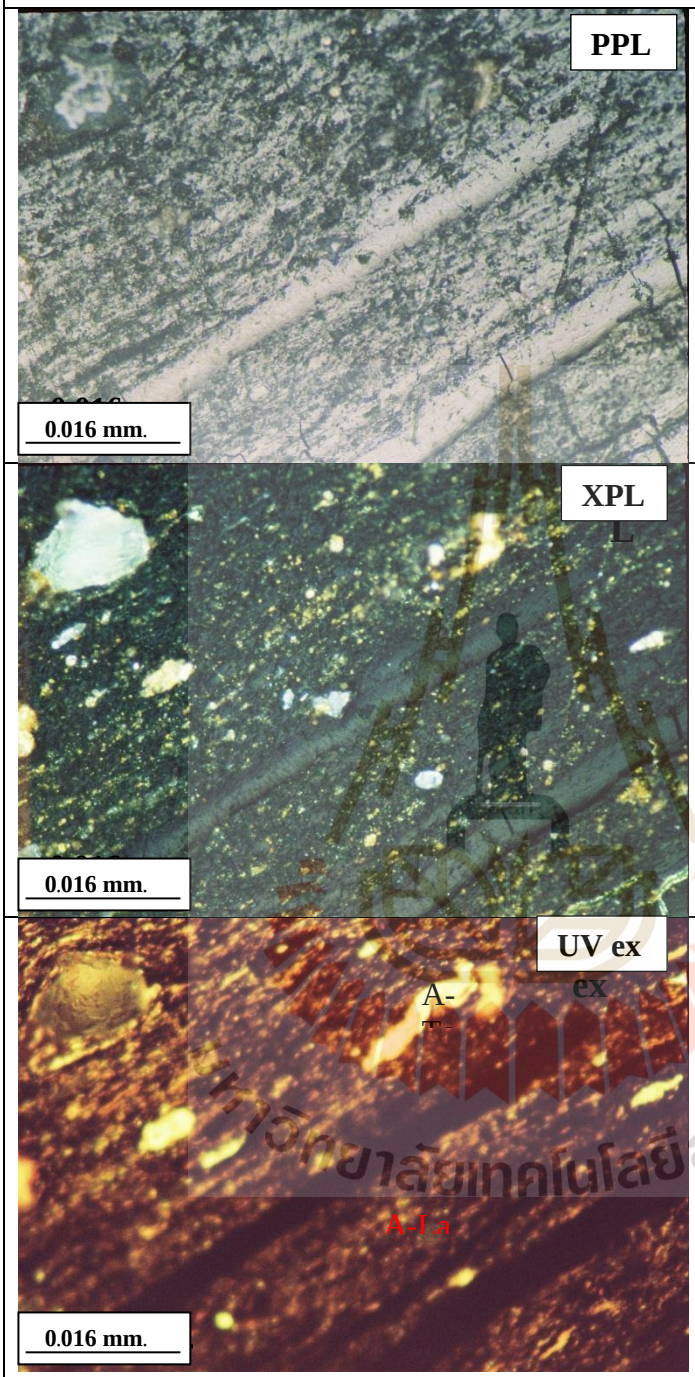
Microscopic Picture	Explanation
	**Sample No. A2-5** **Gelovitrinite** with alginite **(boghead coal)** Composition (%) V = 28 % L = 69 % I = 0 % MM = 3 % **Vitrinite** consist mainly of gelovitrinite. They display as layer of dark gray to black in PPL and black in XPL. **Liptinite** consist mainly of alginite. Alginite display as small dots of yellow in XPL and yellowish brown in UV excitation. **Telalginite** display as bright white to yellow thick line and sphere shape (*botryococcus* sp.). **Lamalginite** display as yellowish-brown dots and short lines. Some yellowish-brown dots are sporinite and liptodetrinite. **Mineral matter** display in various sizes, sub-round to round grain. They display pale gray to black in PPL and white to light yellow and pale gray in XPL. The silica crystal display as big pale gray sphere in PPL and bright white in XPL.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Li = Liptodestrinite, A-Te = Telalginite, A-La = Lamaginite, = Pyrite, C = Clay	

Figure 4.80 The microscopic picture of coal sample No. A2 – 5.

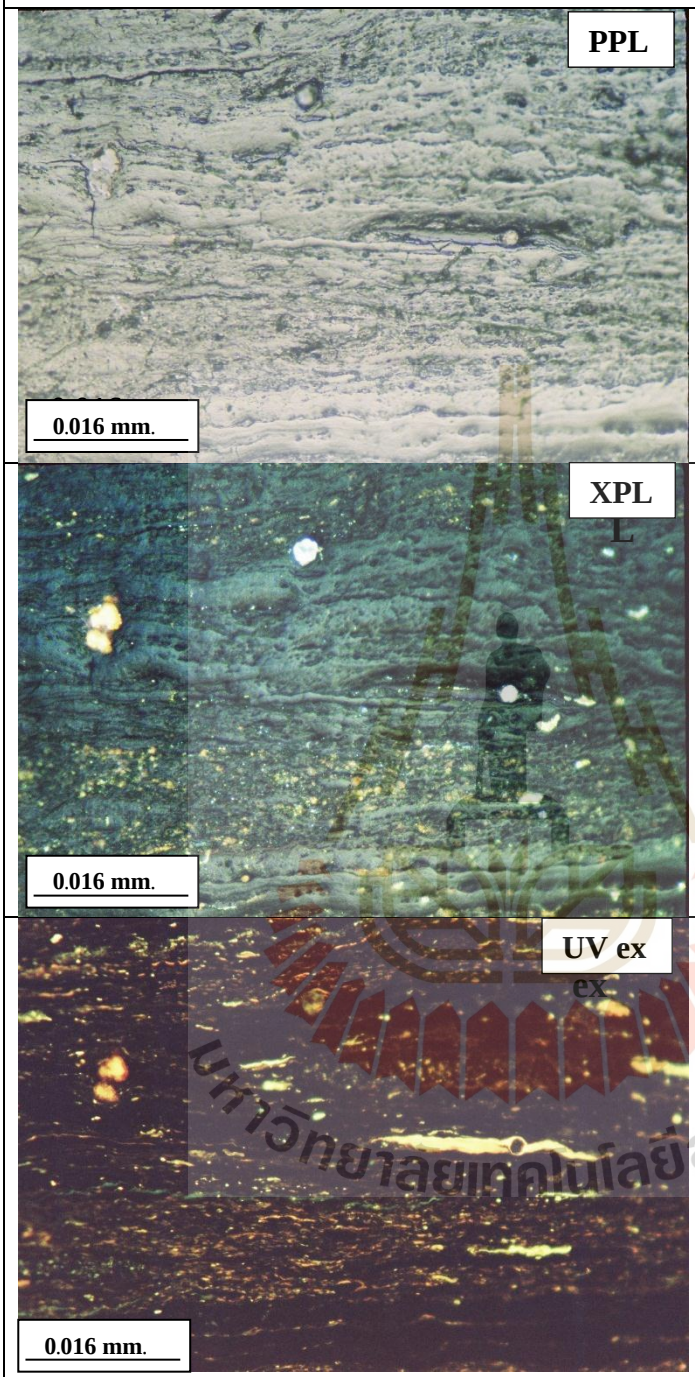
Microscopic Picture	Explanation
	**Sample No. A2-6** **Porigelinite** show well preserve plant tissues. Composition (%) V = 70 % L = 29 % I = 0 % MM = 1 % **Vitrinite** consist of gelovitrinite. They show plant remains (bark) transforming to gelinite (Porigelinite). They display colorless to pale gray in PPL, dark gray in XPL and black under UV ex **Liptinite** consist mainly of alginate. Alginite display as small dots of yellow in XPL and yellowish brown in UV excitation. **Telalginite** display as bright white to yellow thick line and sphere shape (*botryococcus* sp.) and lamalginite display as yellowish-brown dots and short lines. Some yellowish-brown dots are sporinite and liptodetrinite. **Mineral matter** display in various sizes sub-round to round grain. They display pale gray to black in PPL and white to light yellow and pale gray in XPL. Under UV excitation, the black sphere dots are framboidal pyrite.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Li = Liptodestrinite, A-Te = Telalginite, A-La = Lamaginite, Py = Pyrite, C = Clay	

Figure 4.81 The microscopic picture of coal sample No. A2 – 6.

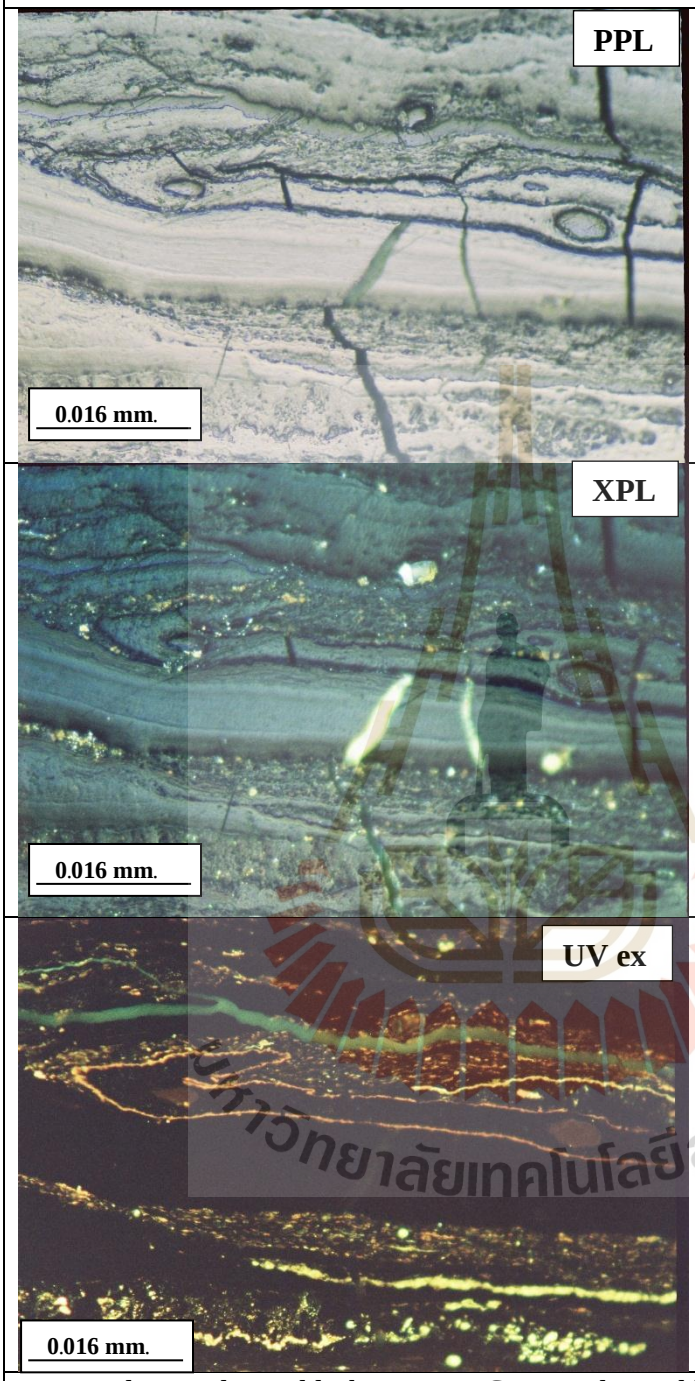
Microscopic Picture	Explanation
	**Sample No. A2-8** **Porigelinite** show well preserve plant tissues. Composition (%) V = 62 % L = 37 % I = 0 % MM = 1 % **Vitrinite** consist of gelovitrinite. They show plant remains (textinite) transforming to gelinite (Porigelinite). They display colorless to pale gray in PPL, dark gray in XPL and black under UV ex. **Liptinite** consist mainly of cutinite and fluorinite. Cutinite display as very high relief in PPL, black line in XPL and line of yellowish brown to dark brown with v-shape and ledge shape under UV ex. Fluorinite display as group of bright yellow to pale green dots in row. **Mineral Matter** The silica crystal display as big pale gray sphere in PPL and bright white in XPL.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation, Cu = Cutinite, Tep = Terpenite, = Fl = Fluorinite, Cl = Clay, Py = Pyrite, V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter	

Figure 4.82 The microscopic picture of coal sample No. A2 – 8.

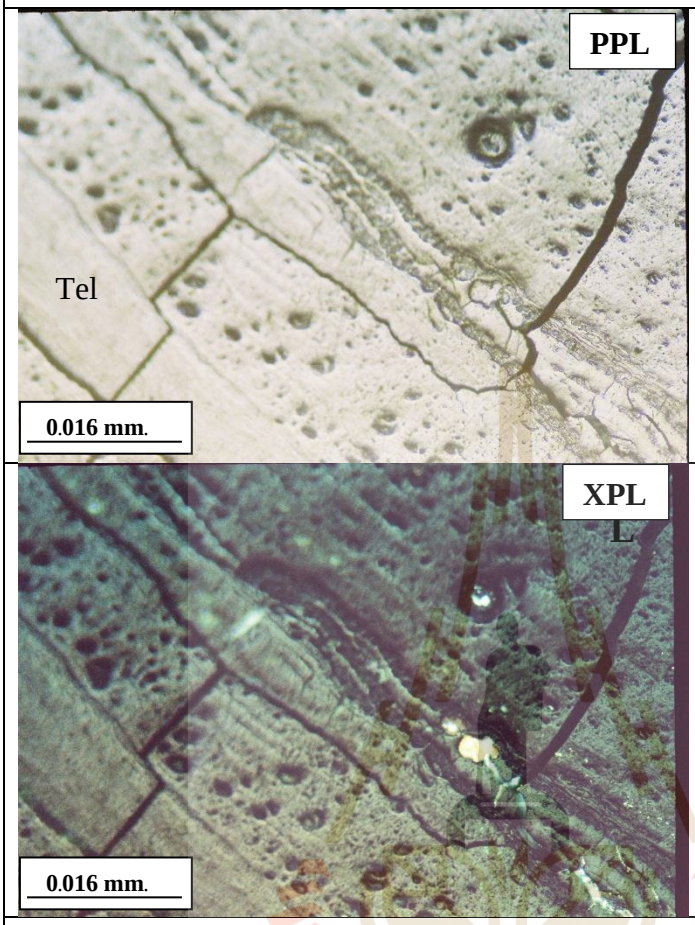
Microscopic Picture	Explanation
	**Sample No. A3-1** **Telovitrinite** show structure of wood associated with crack. Composition (%) V = 98 % L = 0 % I = 0 % MM = 2 % **Vitrinite** consist of telinite, display texture of wood tissue. They display pale gray in PPL and black in XPL. **Mineral matter** consist of pyrite display as sphere body (framboidal pyrite) filled in voids, white to pale gray in PPL, bright white in XPL.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Tel = Telovitrinite, Te = Telinite, Ul = Ulminite, Cl = Clay, Py = Pyrite	

Figure 4.83 The microscopic picture of coal sample No. A3 – 1.

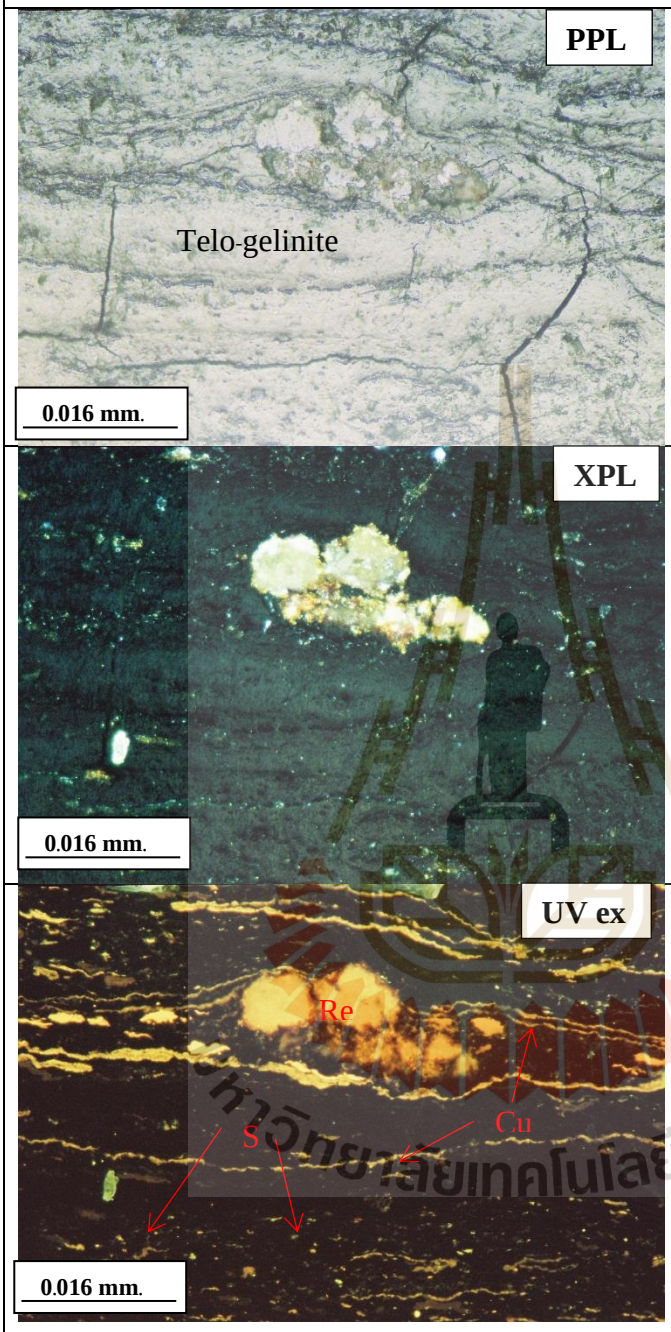
Microscopic Picture	Explanation
	**Sample No. A5-3** **Gelovitrinite** show ulmin gel of wood xylem. Composition (%) V = 62 % L =25 % I = 0 % MM = 13 % **Vitrinite** consist of gelinite with wood structure of telinite and gel cracking. Telo-gelinite display as pale gray with strongly reflect layer in PPL and black in XPL and UV ex. They display black in XPL. **Liptinite** consist of resinite, sporinite and cutinite. They display dark gray to black in PPL and XPL. Resinite display colorless to light yellow in PPL, white to orange in XPL, bright yellow with sphere shape and highly orange rim in UV excitation. Sporinite display as yellow spore shape. Cutinite display as yellow line with ledge structure. **Mineral Matters** consist mostly of clay minerals with silica. They display as pale gray to dark in PPL, white dots spread in XPL and black under UV excitation.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Cu = Cutinite, Re = Resinite, S = Sporinite, Li = Liptodetinite	

Figure 4.84 The microscopic picture of coal sample No. A5 – 3.

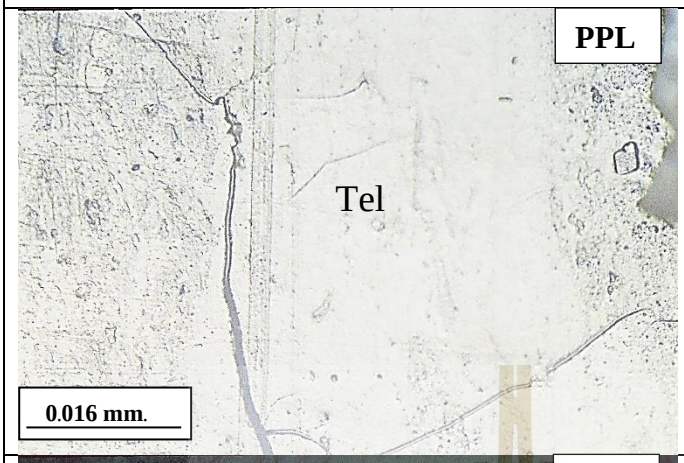
Microscopic Picture	Explanation
 	**Sample No. A5-4** **Telinite** consist mainly of well preserve wood tissue. **Composition (%)** V = 100 % L = 0 % I = 0 % MM = 0 % **Vitrinite** consist of telinite or textinite in telovitrinite. They show structure of wood cell walls. They display pale gray in PPL and black in XPL. **Mineral Matter** consist of pyrite replacing in telinite. They display as orange dots in XPL.
PPL = Plane Polarized light, XPL = Cross Polarized light V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Tel = Telinite, Cl = Clay, Py = Pyrite	

Figure 4.85 The microscopic picture of coal sample No. A5 – 4.

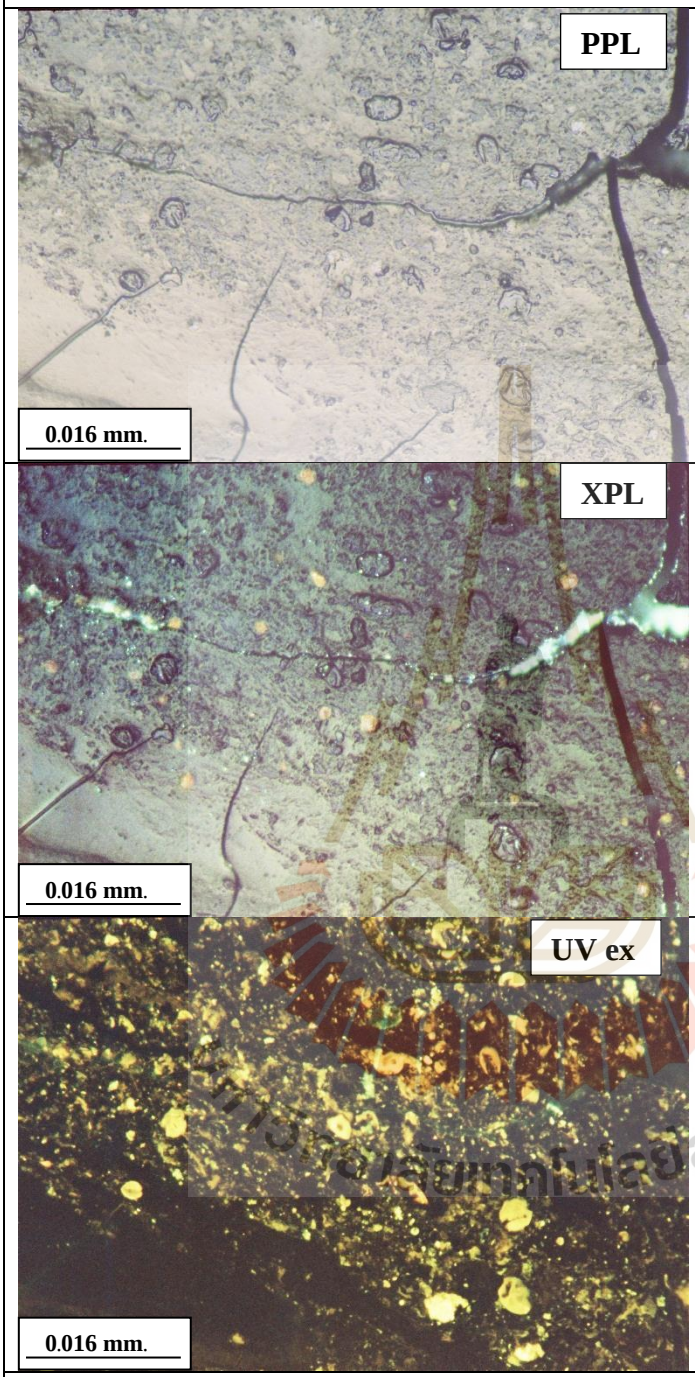
Microscopic Picture	Explanation
	**Sample No. A5-5** **Gelovitrinite** show dry ulmin with liptinite in void. Composition (%) V = 67 % L = 33 % I = 0 % MM = 0 % **Vitrinite** consist of detrovitrinite and gelovitrinite. They display pale gray in PPL and dark gray to black in XPL and UV excitation. **Liptinite** consist mainly of liptodetrinite and sporinite. They display pale gray with highly relief in PPL and dark gray to black in XPL.Under UV excitation, liptodetrinite display as group of yellow to dark yellow without shape. Sporinite display as bright yellow to yellow dots, various sized and spore shape.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter	

Figure 4.86 The microscopic picture of coal sample No. A5 – 5.

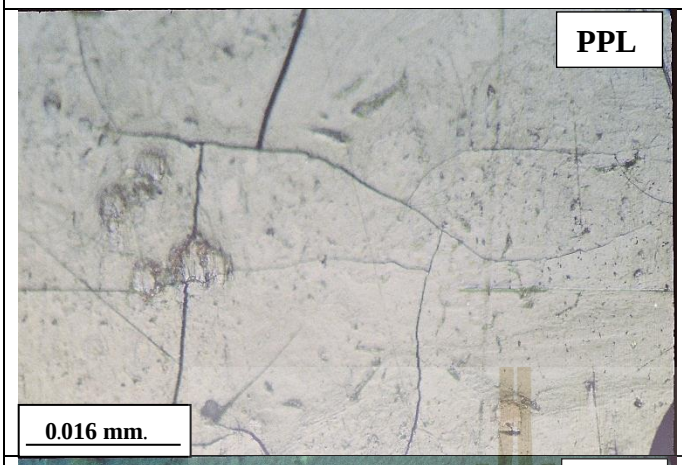
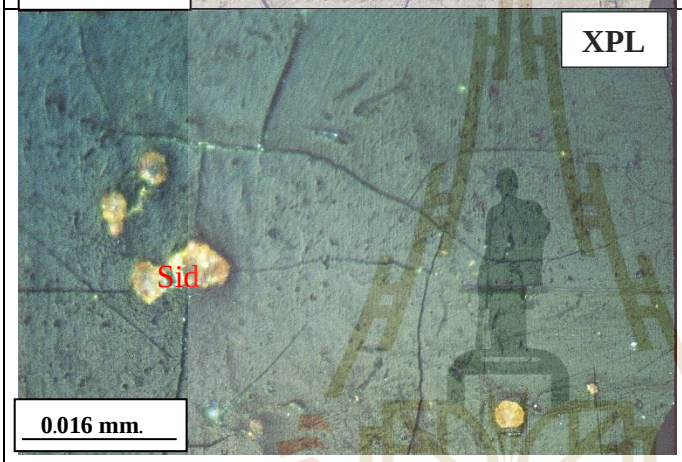
Microscopic Picture	Explanation
 	**Sample No. A5-6** **Telinite** show cracking and siderite replacement. Composition (%) V = 95 % L = 0 % I = 0 % MM = 5 % **Vitrinite** consist of telinite derived from wood. They display pale gray in PPL and black in XPL with gel cracking. **Mineral Matter** consist mainly of siderite. They display as sphere shape with layer of radius, light brown and colorless in PPL and white yellow to yellowish brown with oxidize layer in XPL. The central radial is indicated primary siderite transformed to pyrite.
PPL = Plane Polarized light, XPL = Cross Polarized light V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Sid = Siderite, Tel = Telinite	

Figure 4.87 The microscopic picture of coal sample No. A5 – 6.

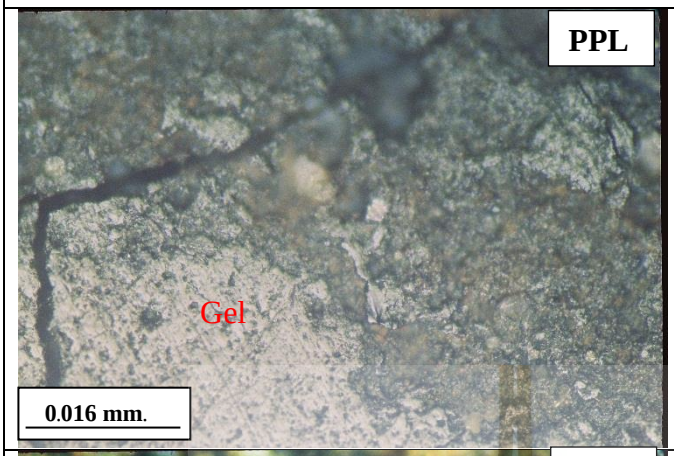
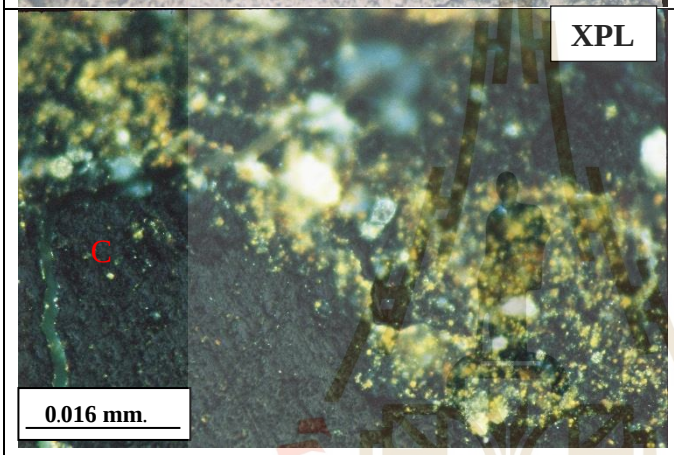
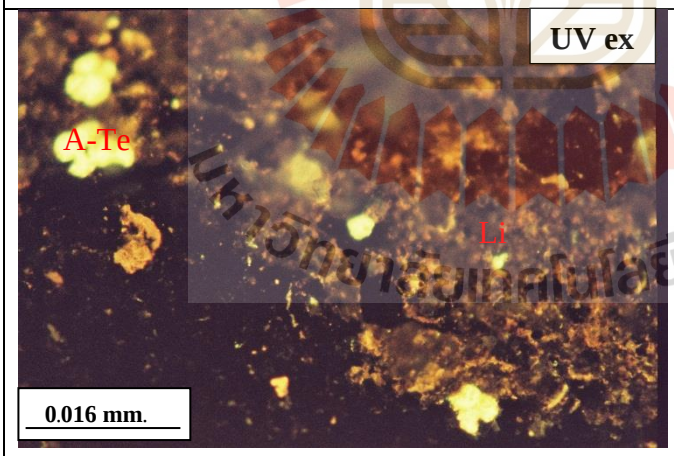
Microscopic Picture	Explanation
  	**Sample No. A6-1** **Gelovitrinite** show the accumulation of organic matter. Composition (%) V = 46 % L = 48 % I = 0 % MM = 6 % **Vitrinite** consist of densinite, several of organic matter and gelinite cements. They show pale gray in PPL with high relief, dark gray to black in XPL and black in UV excitation. **Liptinite** consist mainly of liptodetrinite with some alginate. They show pale gray in PPL and white to light yellow in XPL. Under UV excitation, Liptodetrinite display dark yellow to orange without shape. **Mineral matter** consist mainly of clay and silica minerals. They display as dark in PPL with white dots in XPL and black under UV ex.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter A-Te = Telalginite, C = Clay, Li = Liptodestrinite	

Figure 4.88 The microscopic picture of coal sample No. A6 – 1.

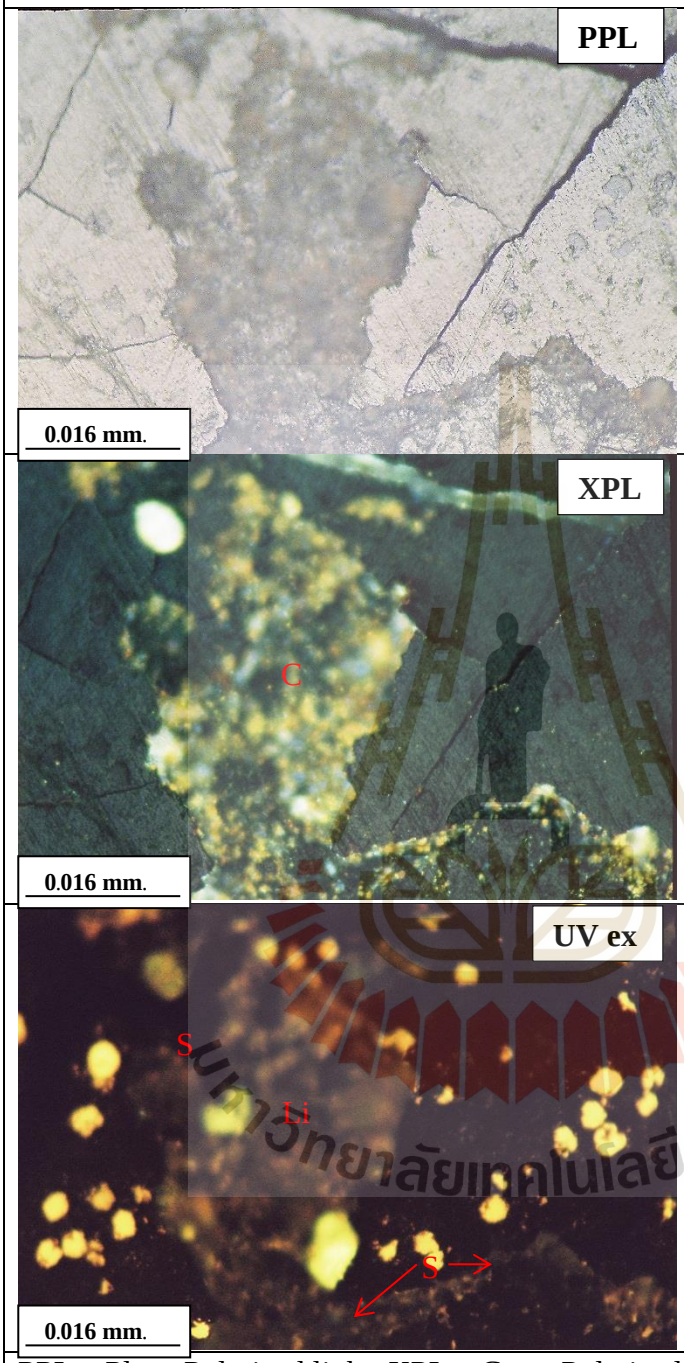
Microscopic Picture	Explanation
	**Sample No. A6-2** **Telovitrinite** Composition (%) V = 61 % L = 19 % I = 0 % MM = 20 % **Vitrinite** consist of telinite and gelinite. They display pale gray to dark gray in PPL and black in XPL. **Liptinite** consist mainly of liptodetrinite and suberinite. They display dark gray with highly relief in in PPL, black and white yellow in XPL. Under UV excitation, suberinite display as yellow sphere, deposited in dry ulmin and liptodestrinite display as yellow to dark brown without shape. **Mineral Matter** consist mainly of clay. They display as a few of very small spots, white and yellow in XPL and black in PPL and UV excitation.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter S = Sporinite, Li = Liptodestinite, Cl = Clay, Si = Siderite	

Figure 4.89 The microscopic picture of coal sample No. A6 – 2.

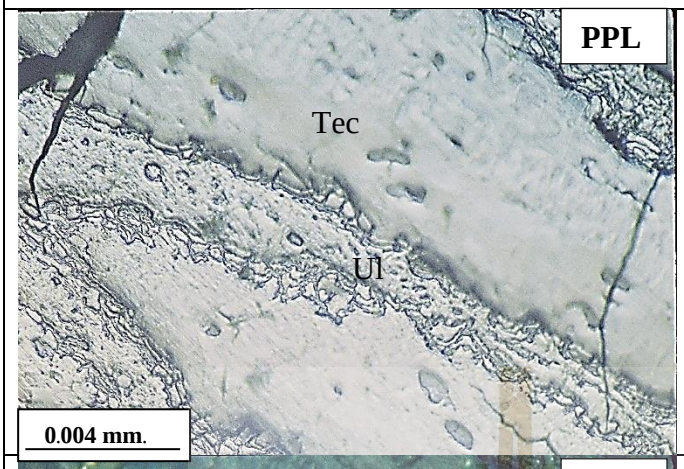
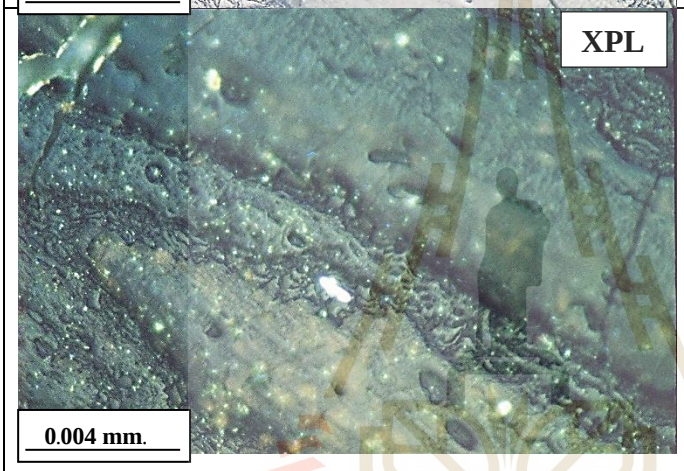
Microscopic Picture	Explanation
 	**Sample No. A7-2** **Telovitrinite** show character of wood tissue with desiccation crack of gel in collotelinite of duet tissue in the section cut parallel to the tree trunk. Composition (%) V = 98 % L = 0 % I = 0 % MM = 2 % **Vitrinite** consist of collotelinite with ulminite. They show structure of wood tissue (telocollinite) and filled with gelified (Ulminite) in xylems duets. They display colorless and pale gray to light brown in PPL and black in XPL. **Mineral Matter** consist mainly of clay minerals filled in crack. They display as black in PPL and white dots in XPL.
PPL = Plane Polarized light, XPL = Cross Polarized light V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Gel = Gelinite, Cl = Clay, Tec = Telocollinite, Ul = Ulminite	

Figure 4.90 The microscopic picture of coal sample No. A7 – 2.

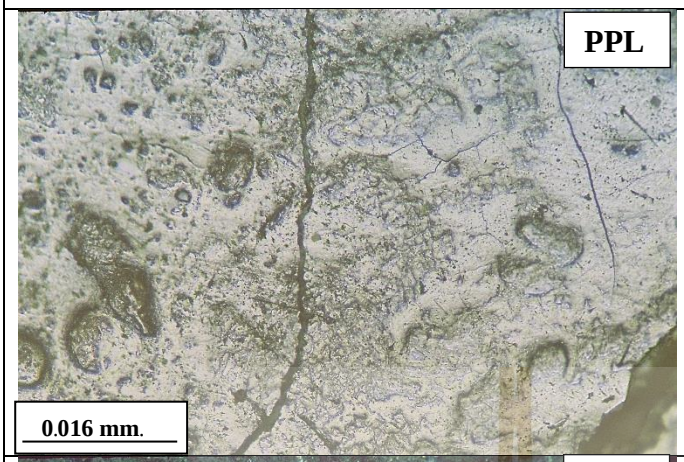
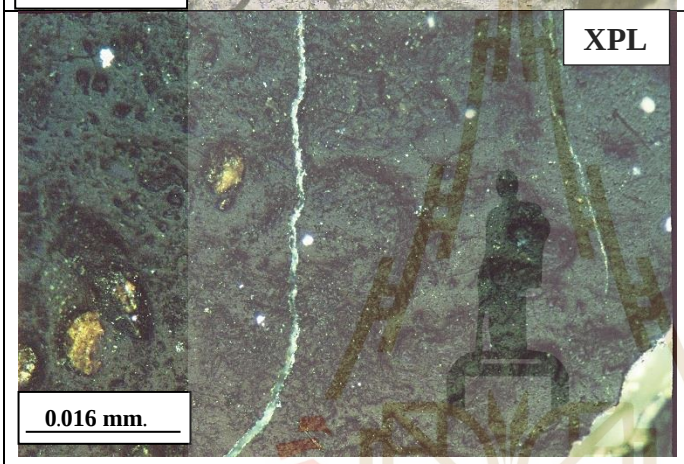
Microscopic Picture	Explanation
 	**Sample No. A7-4** **Telovitrinite** show character of corpocollinite in the section cut perpendicular to tree trunk. Composition (%) V = 94 % L = 0 % I = 0 % MM = 6 % **Vitrinite** consist mainly of **copocollinite.** They display bark and cork of wood showing structure of cell walls (textinite) filled by gel (ulminite). Ulminite (dry) display dark brown in PPL and textinite display pale gray in PPL and black in XPL. **Mineral Matter** consist of small amount clay and sulfide minerals. They display as black in PPL and white dots in XPL filled in voids.
PPL = Plane Polarized light, XPL = Cross Polarized light V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Te = Textinite, Te-U = Texto-Ulminite, Cl = Clays	

Figure 4.91 The microscopic picture of coal sample No. A7 – 4.

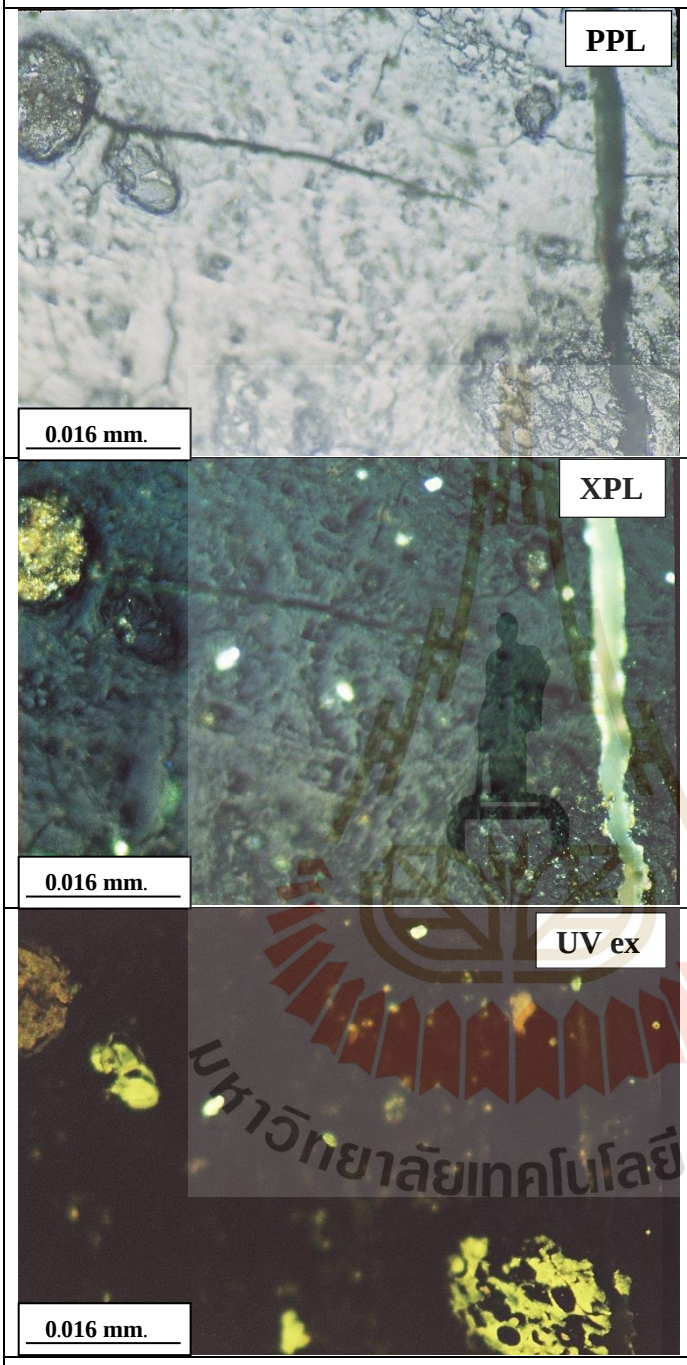
Microscopic Picture	Explanation
	**Sample No. A7-5** **Corpogelinite** show gel of wood tissues in the parallel cut section. **Composition (%)** V = 88 % L = 7 % I = 0 % MM = 5 % **Vitrinite** consist mainly of gelinite. They show wood tissue transforming to gelinite. They display pale gray and highly relief in PPL, dark gray to black in XPL and black in UV ex. **Liptnite** consist mainly of exsudatinite. They display dark gray in PPL, black in XPL. Under UV excitation exsudatinite display as dark yellow to greenish yellow filled in voids of dry gel and wood tissue. **Mineral matter** consist of clay and pyrite. Clays display as white to yellow dots in XPL.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Ex = Exsudatinite, Py = Pyrite, C = Clay	

Figure 4.92 The microscopic picture of coal sample No. A7 – 5.

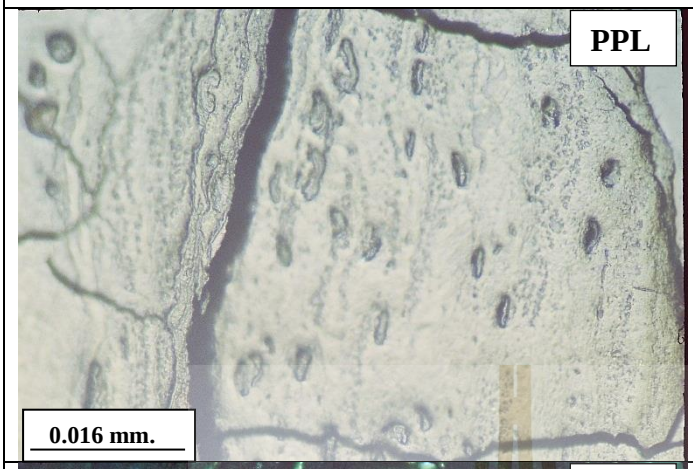
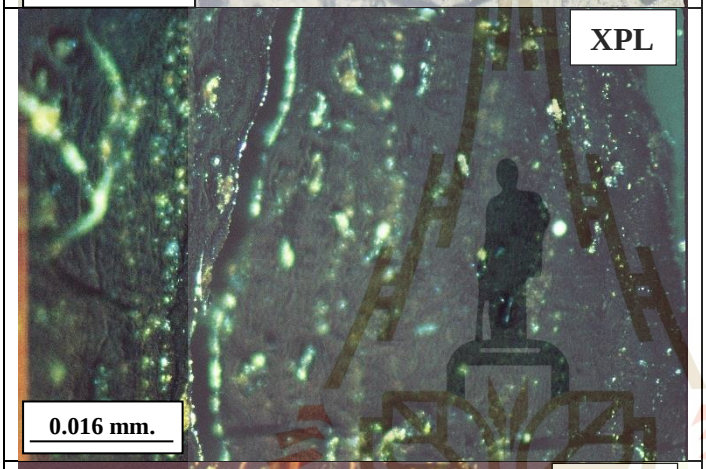
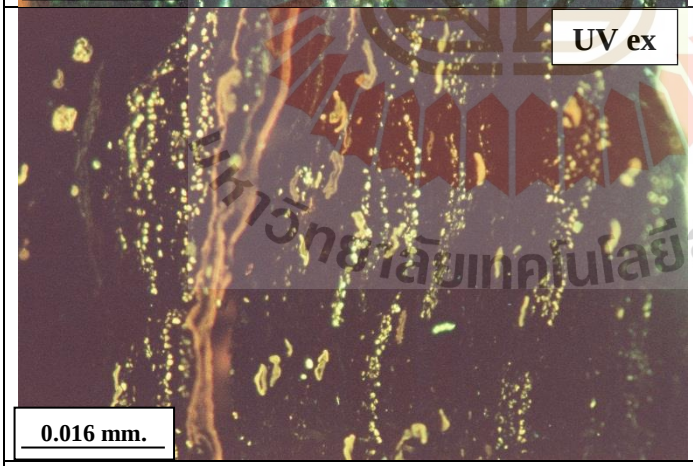
Microscopic Picture	Explanation
  	**Sample No. A9-1** **Porigelinite** show well preserve plant tissues. Composition (%) V = 58 % L = 42 % I = 0 % MM = 0 % **Vitrinite** consist mainly of gelovitrinite. They show plant remain (textinite) transforming to gelinite (Porigelinite). They display colorless to pale gray in PPL, dark gray in XPL and black under UV ex. **Liptinite** consist mainly of cutinite, fluorinate and sporinite. Cutinite display as very high relief in PPL, black line in XPL and line of yellowish brown to dark brown with v-shape and ledge shape under UV ex. Fluorinite display as group of bright yellow to pale green dots in row near cutinite. Sporinite display as white to dark yellow with S-shape and telephone shape.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation, Cu = Cutinite, Tep = Terpenite, = Fl = Fluorinite, Cl = Clay, Py = Pyrite, V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter	

Figure 4.93 The microscopic picture of coal sample No. A9 – 1.

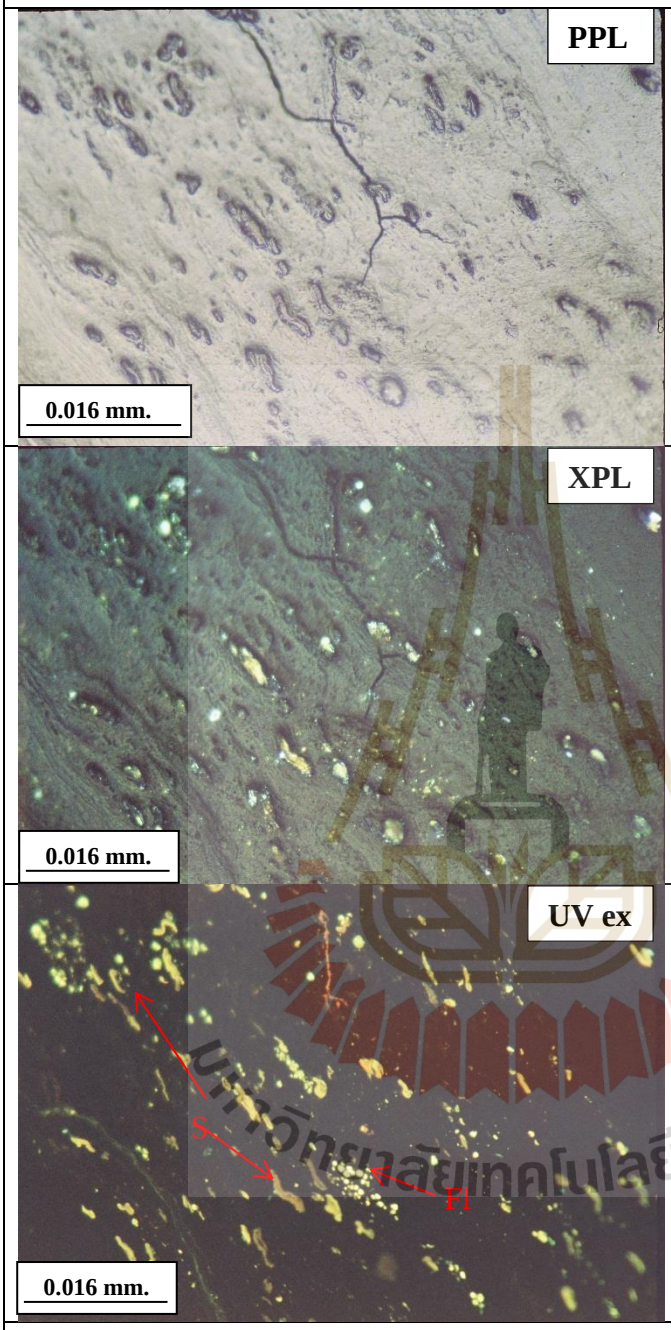
Microscopic Picture	Explanation
	**Sample No. A9-3** **Collotelinite** show structure of wood tissue. Composition (%) V =82 % L = 18 % I = 0 % MM = 0 % **Vitrinite** consist of tellinite. They show structure of bark woods with essential oil. They display pale gray in PPL, dark gray in XPL and black in UV excitation. **Liptnite** consist of sporinite and fluorinite. Sporinite display as white to dark yellow with S-shape and telephone shape. Fluorinate display as group of bright yellow dots filled in dry ulmin in UV excitation.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Li = Liptodetrinite, Tep = Terpenite, S = Sporinite, Fl - Fluorinite	

Figure 4.94 The microscopic picture of coal sample No. A9 – 3.

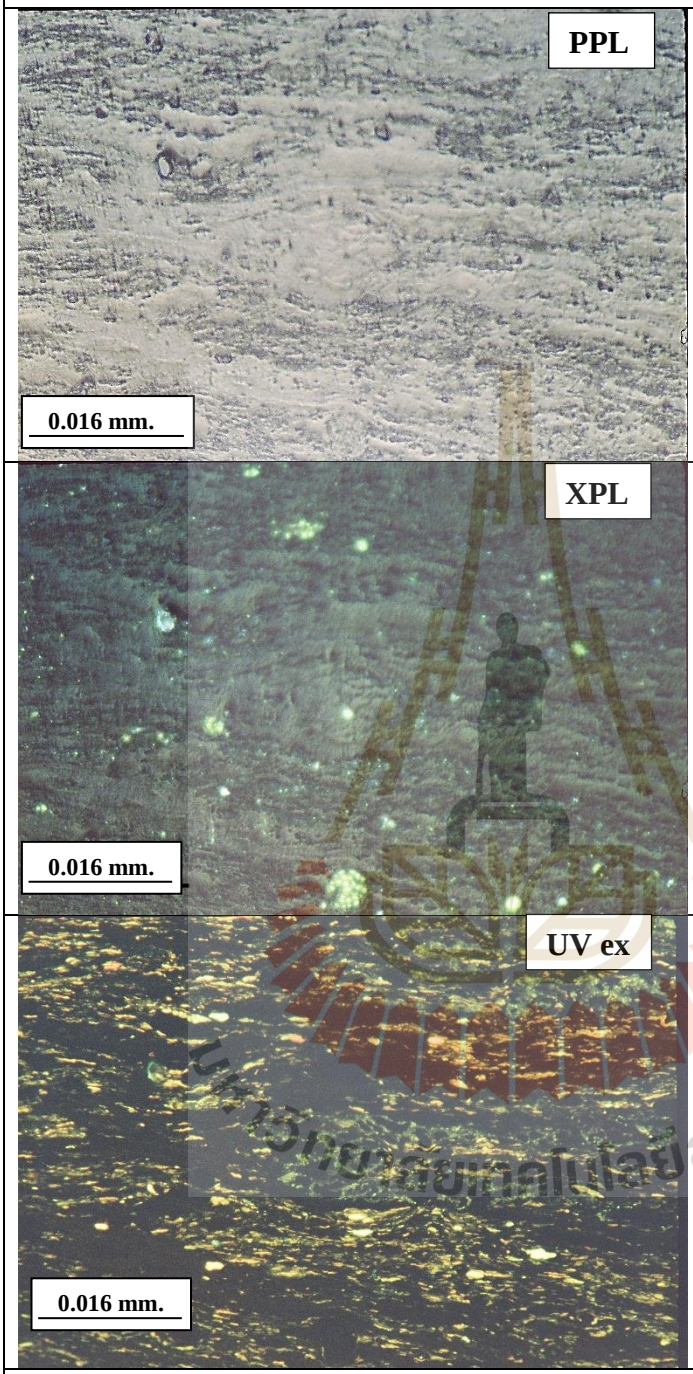
Microscopic Picture	Explanation
	**Sample No. A9-6** **Porigelinite** show well preserve plant tissues with alginite **(boghead coal)** Composition (%) V = 50 % L = 50 % I = 0 % MM = 0 % **Vitrinite** consist of gelovitrinite. They show plant remains (bark) transforming to gelinite (Porigelinite). They display colorless to pale gray in PPL, dark gray in XPL and black under UV ex **Liptinite** consist mainly of alginite. Alginite display as small dots of yellow in XPL and yellowish brown in UV excitation. **Telalginite** display as bright white to yellow thick line and sphere shape (*botryococcus* sp.). **Lamalginite** display as yellowish-brown dots and short lines. Some yellowish-brown dots are sporinite and liptodetrinite.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Li = Liptodestrinite, A-Te = Telalginite, A-La = Lamaginite, = Pyrite, C = Clay	

Figure 4.95 The microscopic picture of coal sample No. A9 – 6.

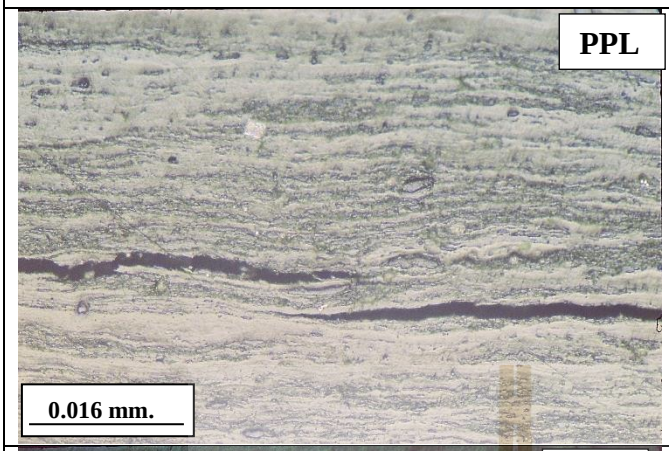
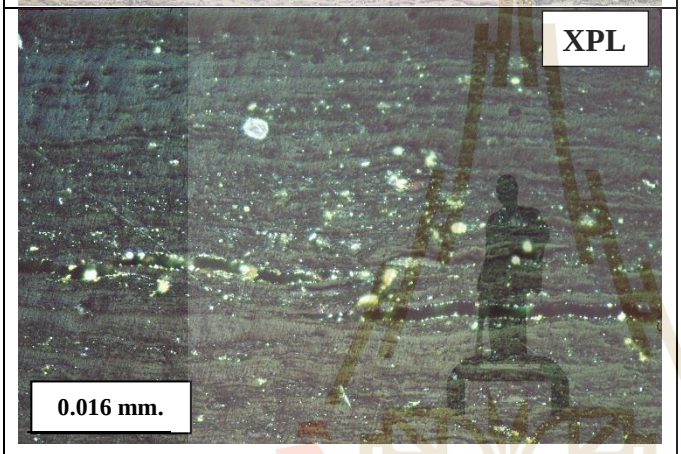
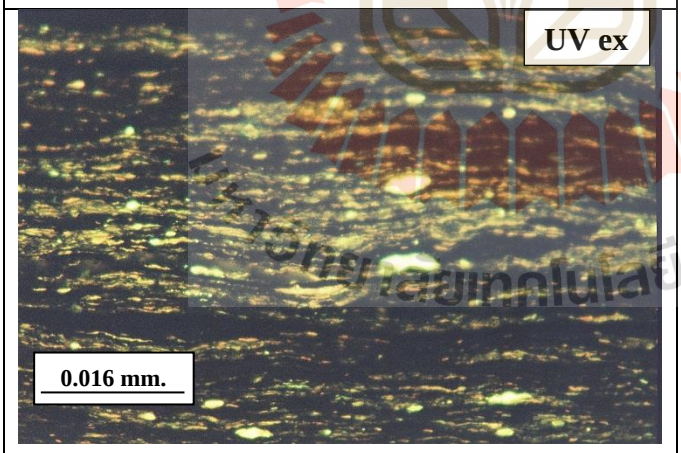
Microscopic Picture	Explanation
  	**Sample No. A9-9** **Porigelinite** show well preserve plant tissues with alginite **(boghead coal)** Composition (%) V = 54 % L = 46 % I = 0 % MM = 0 % **Vitrinite** consist mainly of gelovitrinite. They show plant remains (bark) transforming to gelinite (Porigelinite). They display colorless to pale gray in PPL, dark gray in XPL and black under UV ex **Liptinite** consist of alginite. Alginite display as small dots of yellow in XPL and yellowish brown in UV excitation for alginite. **Telalginite** display as bright white to yellow thick line and sphere shape (*botryococcus* sp.). **Lamalginite** display as yellowish-brown dots and short lines. Some yellowish-brown dots are sporinite and liptodetrinite.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Li = Liptodestrinite, A-Te = Telalginite, A-La = Lamaginite, = Pyrite, C = Clay	

Figure 4.96 The microscopic picture of coal sample No. A9 – 9.

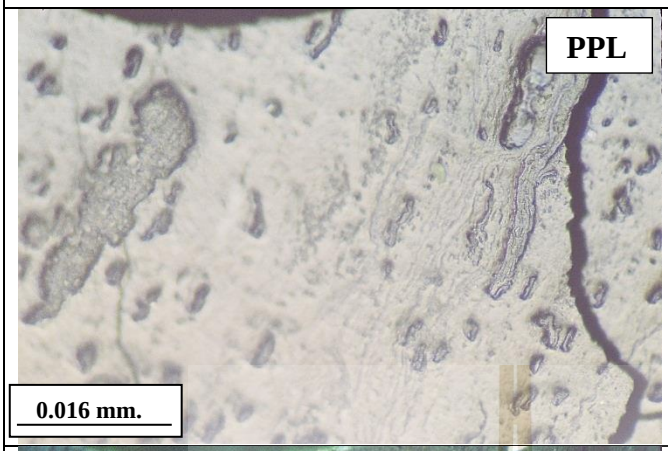
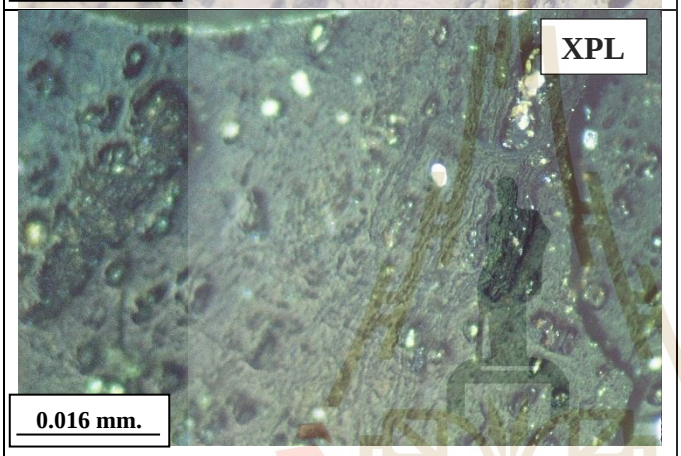
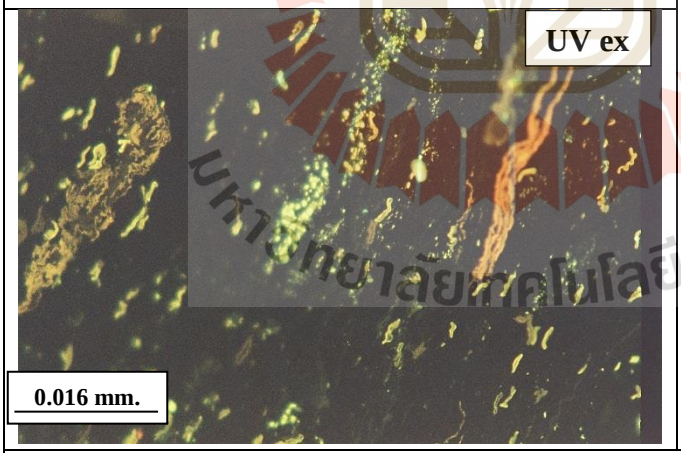
Microscopic Picture	Explanation
	**Sample No. A9-11** **Gelovitrinite** in the section cut cross bedding show liptinite in gel. Composition (%) V = 74 % L = 20 % I = 0 % MM = 6 %
	**Vitrinite** show difference in reflectance of **gelinite.** They show body of gel filled by plant remain. They display pale gray in PPL and black in XPL. **Liptnite** consist of fluorinite, cutinite sporinite and liptodestrinite. They display bright gray in PPL and dark in XPL. Under UV excitation, fluorinate display as light-yellow spots and liptodestrinite display as yellow without shape. Orange line is the cutinite with fluorinite. **Mineral matters** consist of clays and siliceous minerals. They display dark color in PPL, white dots in XPL and black under UV ex.
	
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation Li = Liptodestrinite, Fl = Fluorinite, Cu = Cutinite, S = Sporinite, C = Clay	

Figure 4.97 The microscopic picture of coal sample No. A9 – 11.

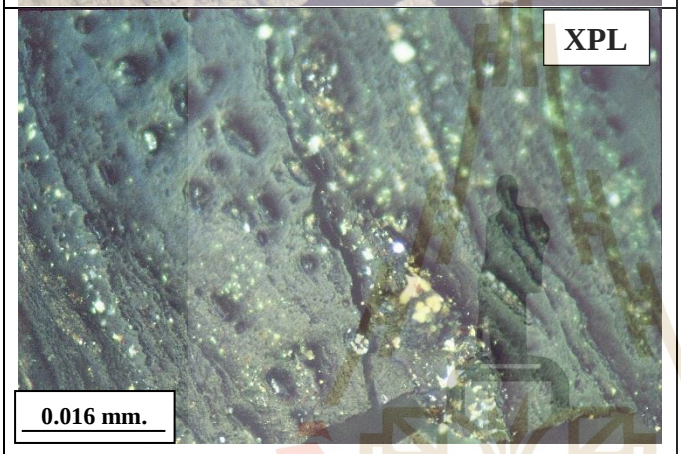
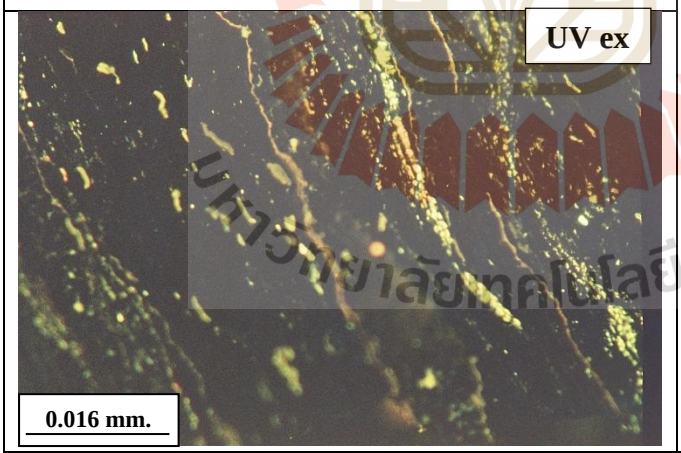
Microscopic Picture	Explanation
	**Sample No. A9-13** **Gelovitrinite** in the section cut cross bedding show structure of liptinite in gel. Composition (%) V = 59 % L = 31 % I = 0 % MM = 10 %
	**Vitrinite** show difference in reflectance of **gelinite.** They show body of gel filled by plant remain. They display pale gray in PPL and black in XPL. **Liptnite** consists of fluorinate, cutinite sporinite and liptodestrinite. They display bright gray in PPL and dark in XPL. Under UV excitation fluorinite display as light-yellow spots and liptodestrinite display as yellow without shape. Orange line is the cutinite with fluorinite. **Mineral matters** consist of clays and siliceous minerals. They display as dark color in PPL, white dots in XPL and black under UV ex.
	
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation Li = Liptodestrinite, Fl = Fluorinite, Cu = Cutinite, S = Sporinite, C = Clay	

Figure 4.98 The microscopic picture of coal sample No. A9 – 13.

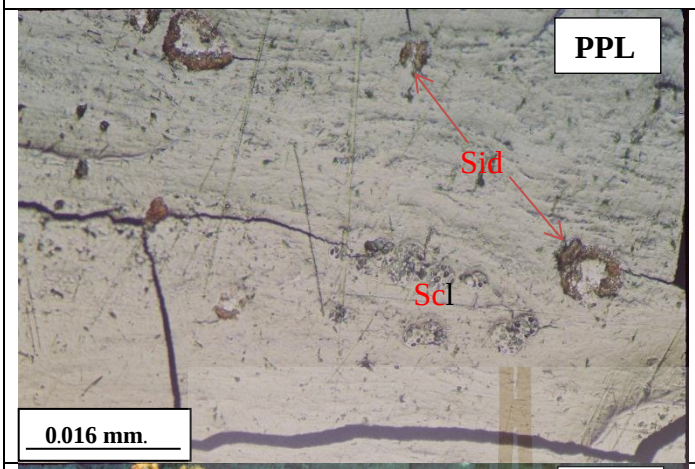
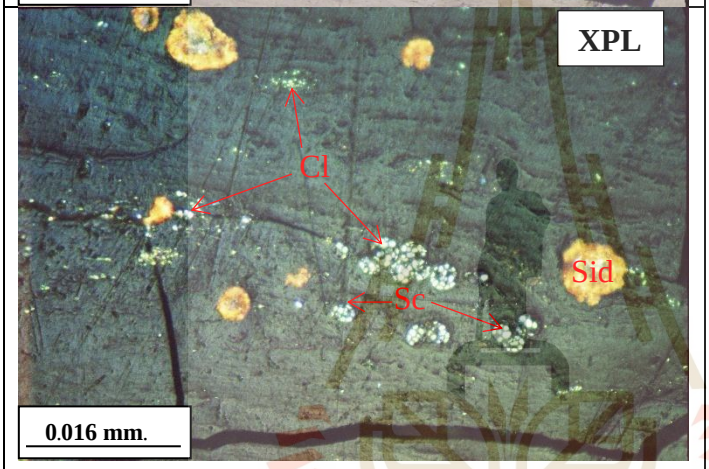
Microscopic Picture	Explanation
 	**Sample No. A10 – 1** **Textinite** of telovitrinite show weakly structure of wood, perpendicular crack of gel and sclerotinite. Composition (%) V = 90 % L = 0 % I = 7 % MM = 3 % **Vitrinite** consist of **telinite**, display texture of wood tissue (Textinite) cemented by **gelinite**. They display pale gray in PPL and black in XPL. **Inertinite** consist mainly of sclerotinite and display as group of spherical shape with high relief of fungi body in PPL and white in XPL. **Mineral Matter** consist of clay and siderite. Clays display dark spots in PPL, white to greenish white in XPL. Siderite display spherical layer of yellowish orange and white in middle sphere in XPL.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Scl = Sclerotinite, Cl = Clay, Sid = Siderite	

Figure 4.99 The microscopic picture of coal sample No. A10 – 1

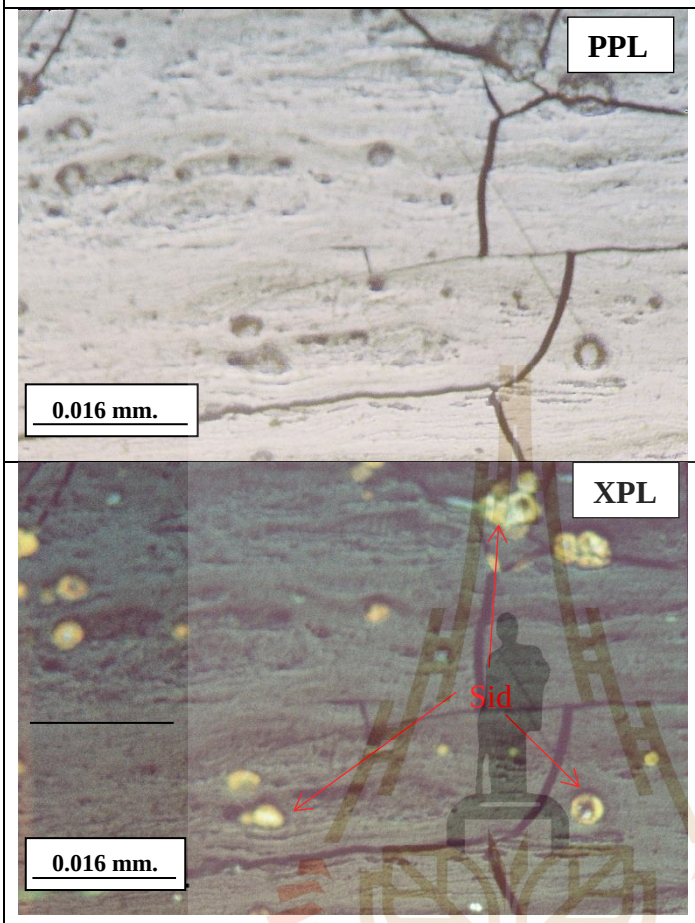
Microscopic Picture	Explanation
	**Sample No. A10 – 3** **Textinite** of telovitrinite subgroup show weakly structure of wood with crack of gel. Composition (%) V = 96 % L = 0 % I = 0 % MM = 4 % **Vitrinite** consist mainly of telinite. They show texture of wood tissue and display pale gray in PPL and black in XPL. **Mineral Matter** consist of clay minerals and siderite. Clays display as dark spots in PPL, white to greenish white in XPL. Siderite show spherical layer of dark yellow and display white in middle sphere and yellowish orange of outside layer in XPL.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation Tex = Textinite, Gel = Gelinite, Sid = Siderite, Flu = Fluorinite, Re = Resinite, Cl = Clay	

Figure 4.100 The microscopic picture of coal sample No. A10 – 3

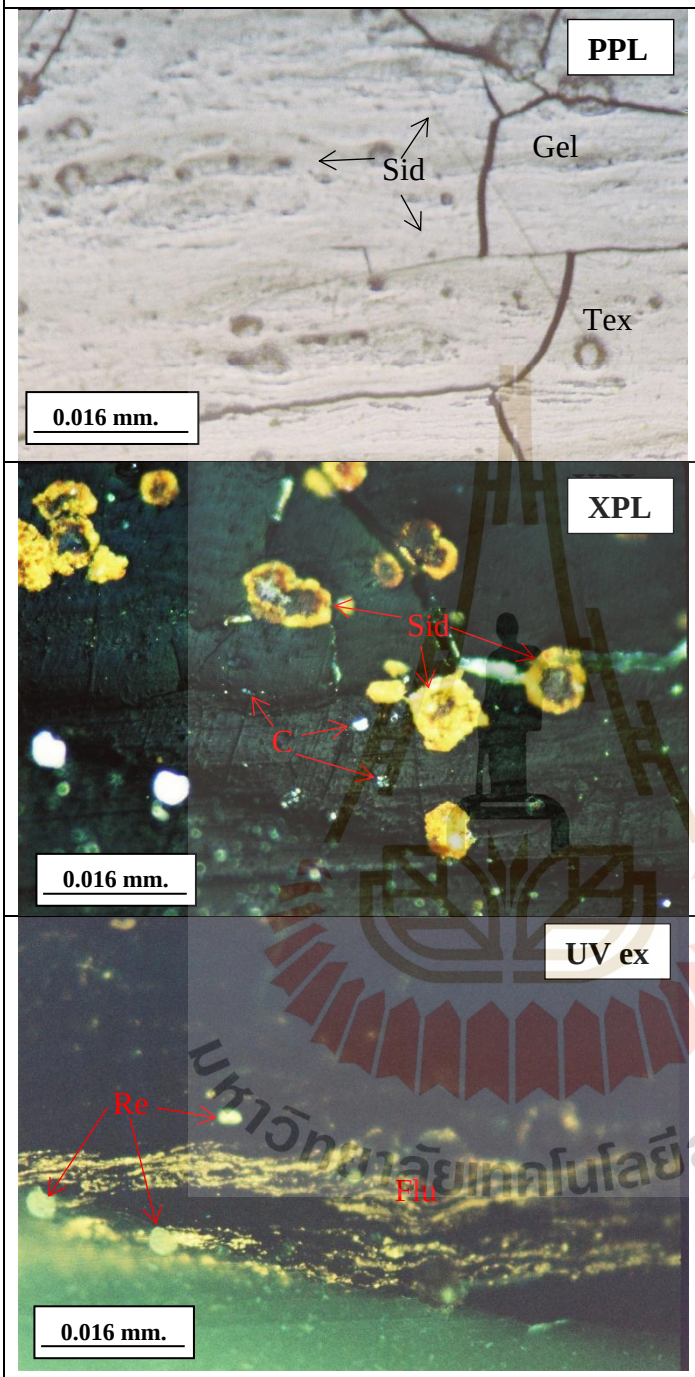
Microscopic Picture	Explanation
	**Sample No. A10 – 6** **Textinite** of telovitrinite subgroup show weakly structure of wood with crack of gel. Composition (%) V = 68 % L = 19 % I = 1 % MM = 12 % **Vitrinite** consist of wood tissue (**textinite**) cemented by **gelinite**. They display pale gray in PPL and black in XPL. **Litinite** consist of fluorinite and resinite. Fluorinite display pale gray in PPL, black in XPL and bright yellow points in a row in UV excitation. Resinite display the high relief and pale gray in PPL, white in XPL and light-yellow spot in UV excitation **Mineral Matter** consist of clay minerals and siderite. Clays display as dark spots in PPL, white to greenish white in XPL. Siderite show spherical layer of dark yellow and display white in middle sphere and yellowish orange of outside layer in XPL.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation Tex = Textinite, Gel = Gelinite, Sid = Siderite, Flu = Fluorinite, Re = Resinite, Cl = Clay	

Figure 4.101 The microscopic picture of coal sample No. A10 – 6

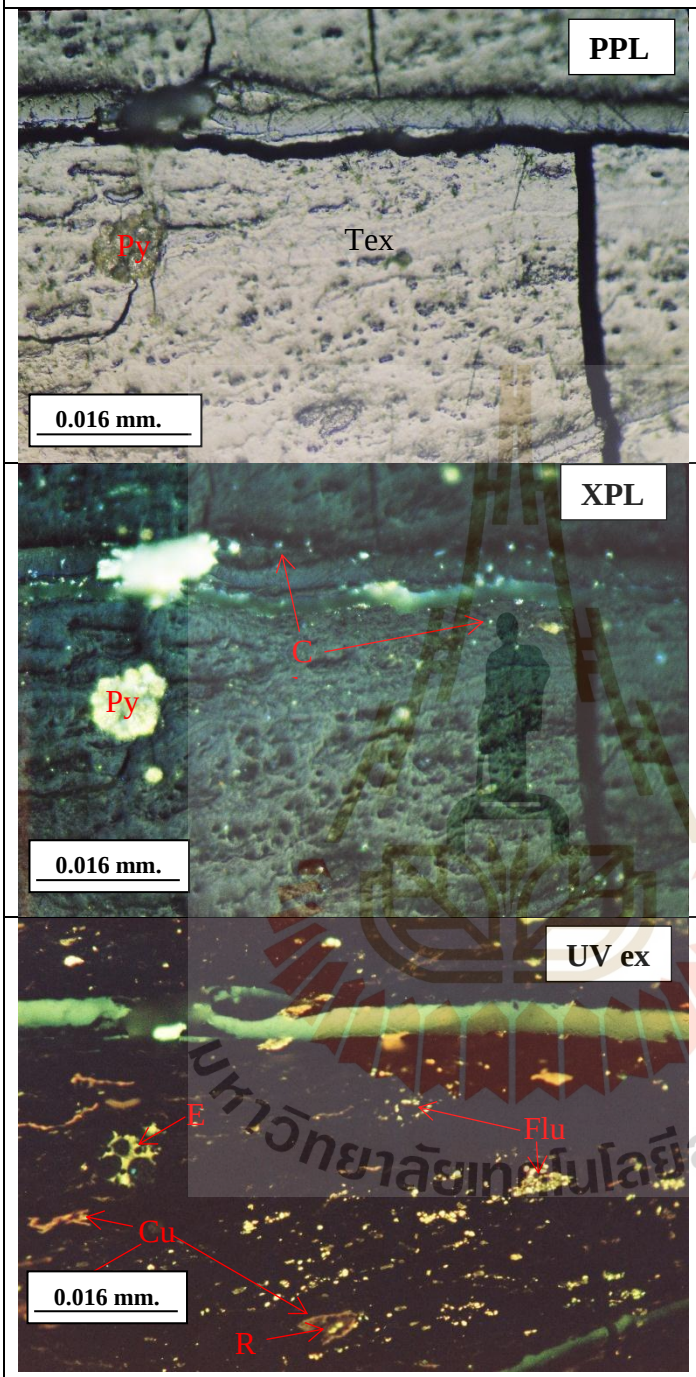
Microscopic Picture	Explanation
	**Sample No. A10 – 8** **Porigelinite** of gelovitrinite subgroup show structure of wood tissue and perpendicular crack of gel. Composition (%) V = 82 % L = 16 % I = 0 % MM = 2 % **Vitrinite** consist of wood tissue (**textinite**) cemented by **gelinite**. They display pale gray in PPL and black in XPL. **Liptinite** consist of flurinite, cutinite, resinite and exsudatinite. **Fluorinite** display pale gray to dark gray in PPL and dark gray to black in XPL. Under UV excitation they display light yellow dots in group. **Cutinite** (fragment) display yellowish brown to brown with highly relief in PPL. **Resinite** display as yellow spot in cutinite. **Exsudatinite** display as greenish yellow surround pyrite. **Mineral matter** display dark brown to black in PPL and display as white dots in sphere group in XPL (**framboidal pyrite)**. The white dots in XPL are clay filling in voids.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation Tex = Textinite, Ex = Exsudatinite, Cu = Cutinite, Re = Resinite, Flu = Fluorinite, Py = Pyrite, Cl = Clay	

Figure 4.102 The microscopic picture of coal sample No. A10 – 8

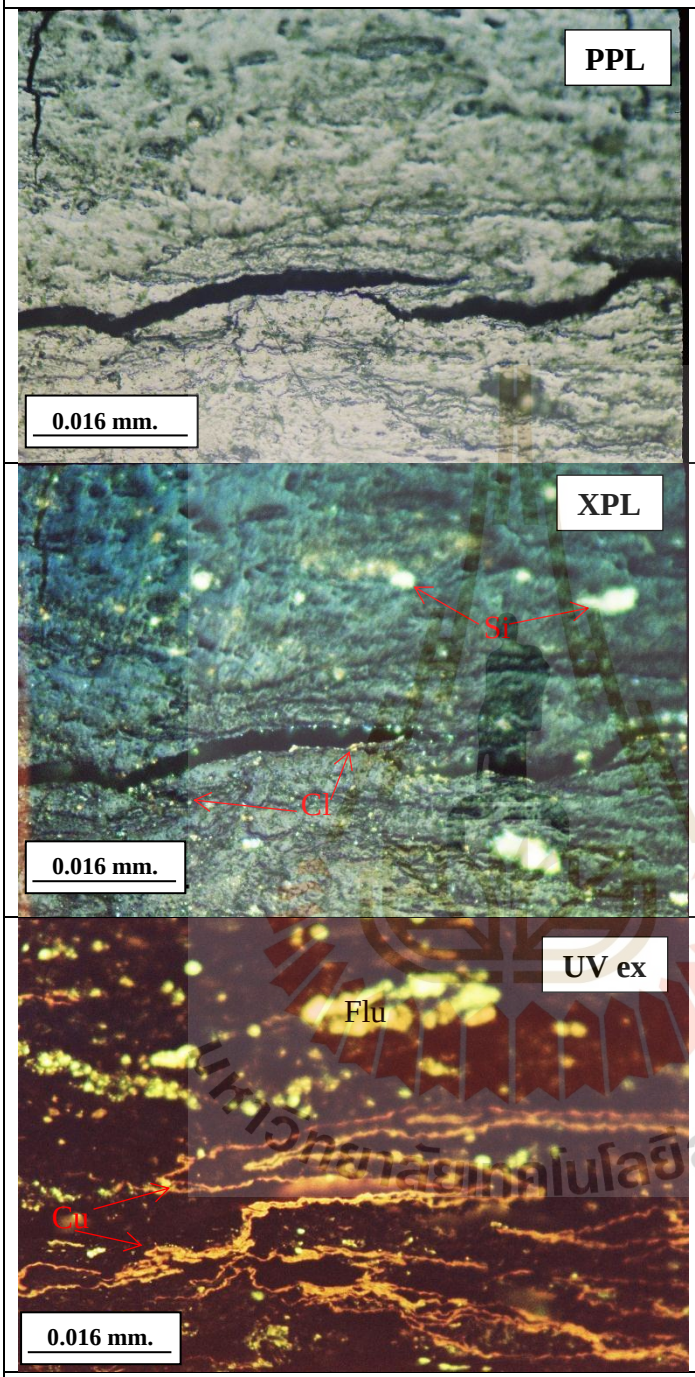
Microscopic Picture	Explanation
	**Sample No. A10 – 10** **Porigelinite** of gelovitrinite subgroup Composition (%) V = 54 % L = 42 % I = 0 % MM = 4 % **Vitrinite** consist of plant tissue cemented by **gelinite**. They display gray in PPL and dark gray to black in XPL. **Liptinite** consist of preserve plant tissues. They display as high relief and pale gray to dark gray in PPL and brown to black in XPL. Under UV excitation fluorinite display as group of bright yellow dots and cutinite display as line of yellowish brown to dark brown. Cutinite display as end of leaves with V-shape, ledge shape and double line. **Mineral Matter** consist mainly of clay and silica minerals. The white and yellow dots and white spots in XPL are clay and silica filling in voids.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation Flu = Fluorinite, Cu = Cutinite, Cl = Clay, Si = Silica	

Figure 4.103 The microscopic picture of coal sample No. A10 – 10

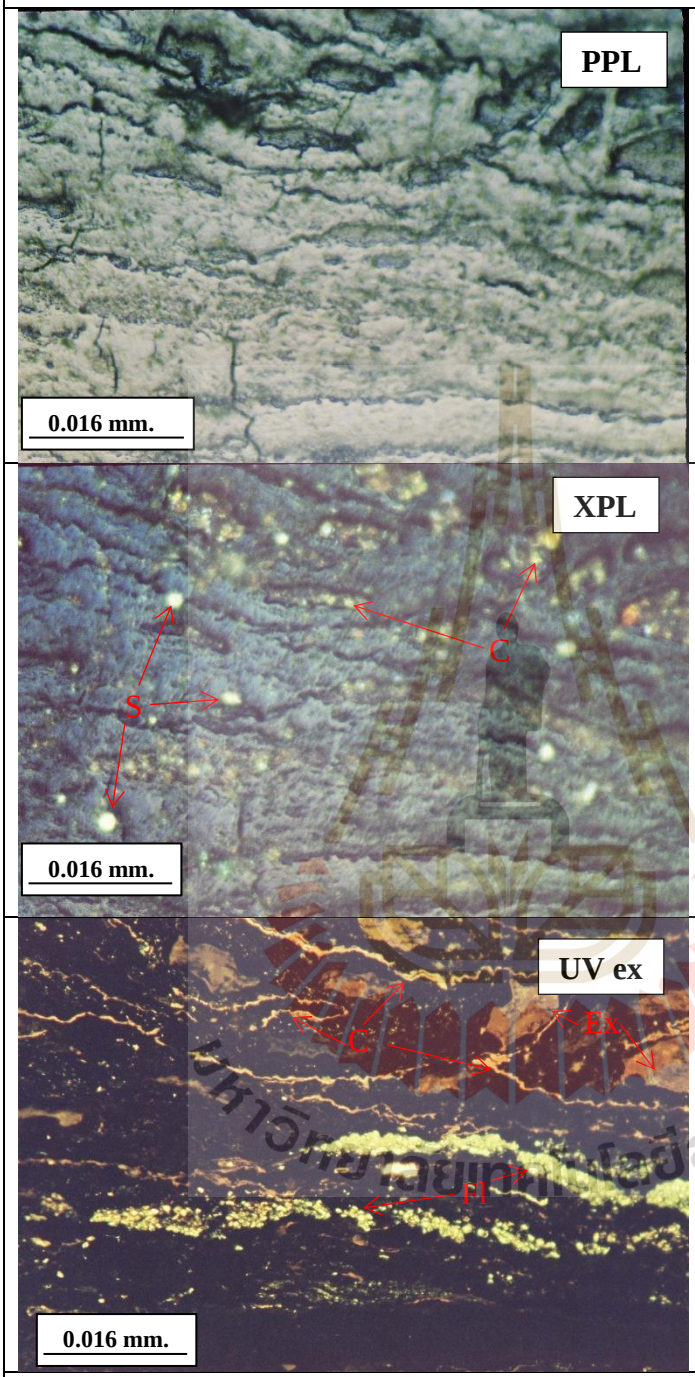
Microscopic Picture	Explanation
	**Sample No. A10 – 11** **Porigelinite** of gelovitrinite subgroup Composition (%) V = 56 % L = 35 % I = 0 % MM = 9 % **Vitrinite** consist of plant tissue cemented by **gelinite**. They display gray to dark gray in PPL and dark gray to black in XPL. **Liptinite** consist of preserve plant tissues. They display pale gray to dark gray in PPL and yellowish-brown to black in XPL. Under UV excitation **fluorinite** display as group of bright yellow dots in row. **Cutinite** display as line of yellowish brown to dark brown with V-shape and ledge shape. **Exsudatinite** display as brown filling in voids without structure. **Mineral Matter** consist of clay and silica mineral. The white and yellow dots and white spots in XPL are clay and silica filling in voids.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation Cu = Cutinite, Ex = Exsudatinite, = Flu = Fluorinite, Cl = Clay, Si = Silica	

Figure 4.104 The microscopic picture of coal sample No. A10 – 11

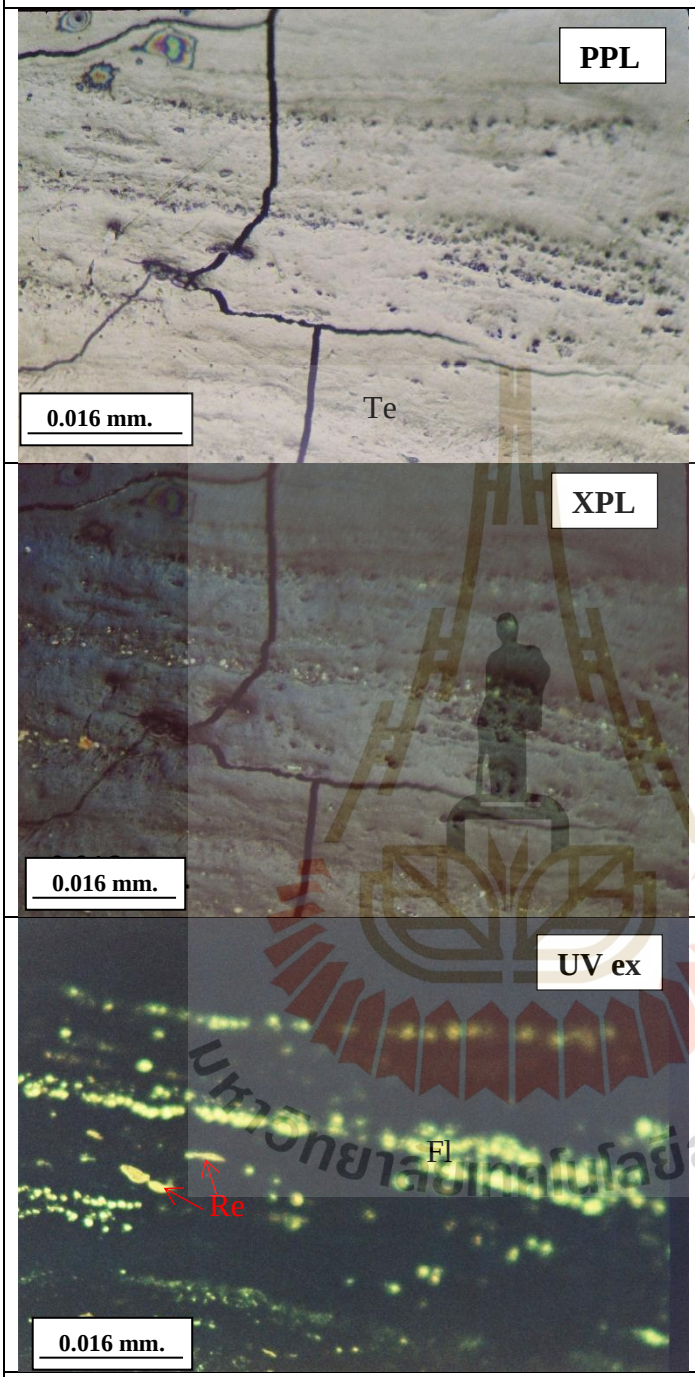
Microscopic Picture	Explanation
	**Sample No. A11-3** **Porigelinite** of gelovitrinite subgroup **Composition (%)** V = 88 % L = 12 % I = 0 % MM = 0 % **Vitrinite** consist of plant tissue (**textinite**) cemented by **gelinite**. They display pale gray in PPL and black in XPL with gel crack. **Liptinite** display dark gray and high relief in PPL and dark gray to black in XPL. Under UV excitation fluorinate display as light yellow to greenish yellow of spots in a row and resinite display as yellow spots filling in voids.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation Tex = Textinite, Flu = Fluorinite, Re = Resinite,	

Figure 4.105 The microscopic picture of coal sample No. A11 – 3

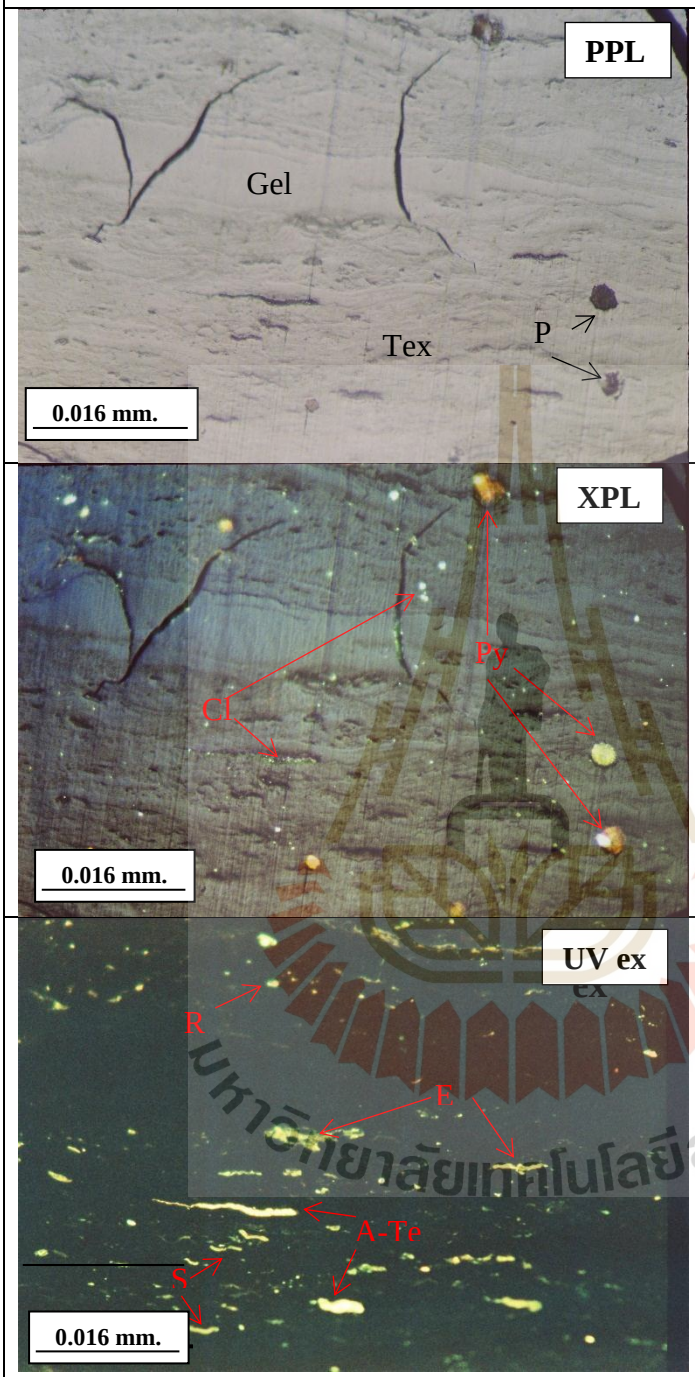
Microscopic Picture	Explanation
	**Sample No. A11-5** **Porigelinite** of gelovitrinite subgroup show **textinite** with **gelinite.** **Composition (%)** V = 94 % L = 4 % I = 0 % MM = 2 % **Vitrinite** consist of wood tissue (**textinite**) cemented by **gelinite**. They display pale gray in PPL and black in XPL. **Liptinite** materials are mostly filling in voids and display dark gray in PPL and black in XPL. Under UV excitation **exsudatinite** display light yellow to greenish yellow with fill up structure. **Sporinite** and **resinite** display as yellow dots with s-shave and sphere shape. **Telalginite** (*botryococcus* sp.) display as light-yellow which body of algae. **Mineral Matter** consist of clay and pyrite. The white dots filling in voids are clay. The dark gray to black in PPL and yellow to brown in XPL are pyrite.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation Te = Textinite, Gel = Gelinite, Re = Resinite, Ex = Exsudatinite, A-Te = Telalginite, S = Sporinite, Cl = Clay, Py = Pyrite	

Figure 4.106 The microscopic picture of coal sample No. A11 – 5

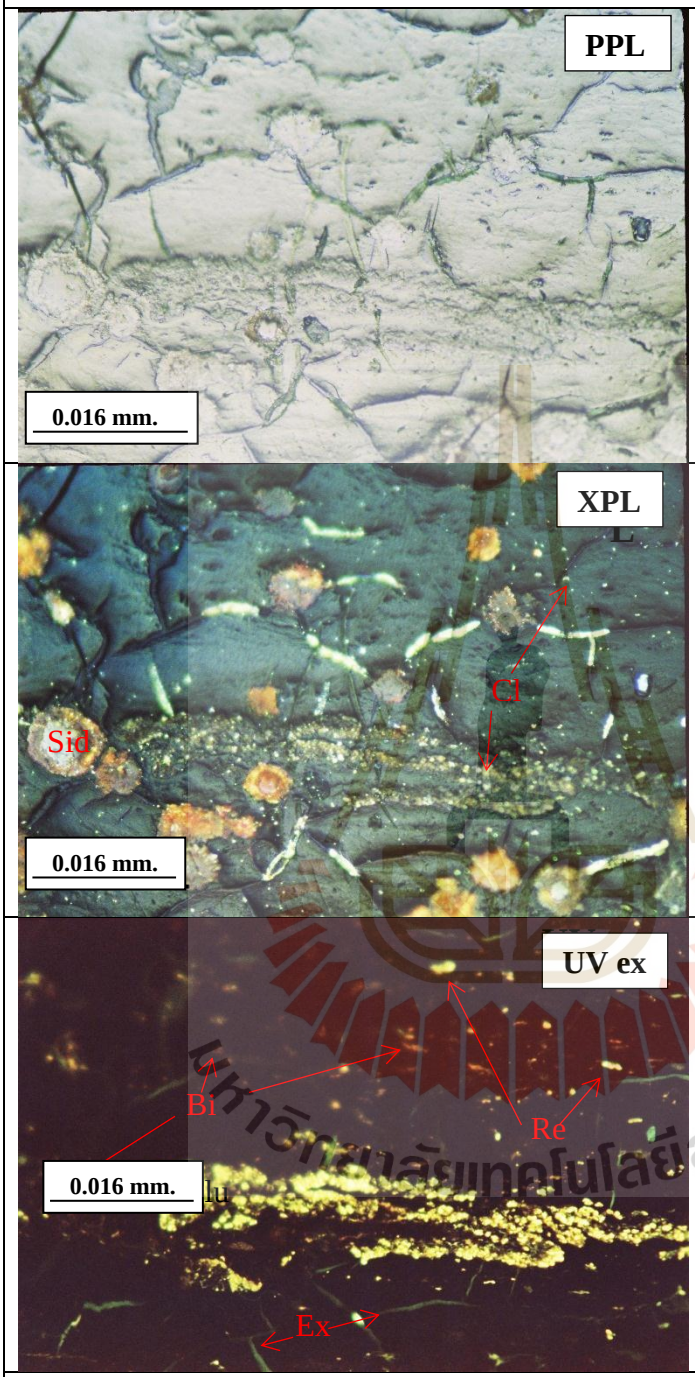
Microscopic Picture	Explanation
	**Sample No. A11-7** **Gelinite** of gelovitrinite subgroup with gel crack and mineral alteration. Composition (%) V = 69 % L = 15 % I = 0 % MM = 16 % **Vitrinite** consist mainly of organic matter transform to **gelinite.** They show gel crack and display pale gray in PPL and black in XPL. **Liptinite** materials are mostly filling in voids and display pale gray in PPL and yellowish brown to black in XPL. Under UV excitation fluorinite display as light yellow to greenish yellow dots in a row group. **Resinite** display as yellow dots with sphere shape. Bituminite display as dark brown with structure fill up in voids. Exsudatinite display as green filled in gel crack. **Mineral matter** consist mainly of clay and siderite. The white and yellow dots filling in voids are clay. The highly reflected in PPL and yellow to brown in XPL with ring structure for oxidation rim are siderite.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation Gel = Gelinite, Re = Resinite, Ex = Exsudatinite, Bi = Bituminite, Cl = Clay, Sid = Siderite	

Figure 4.107 The microscopic picture of coal sample No. A11 –7

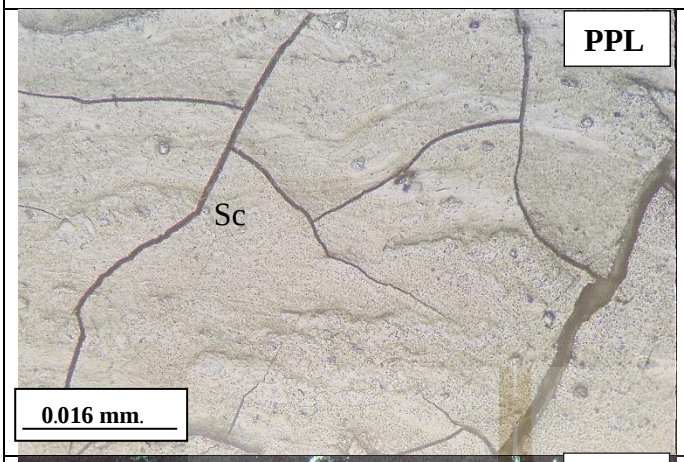
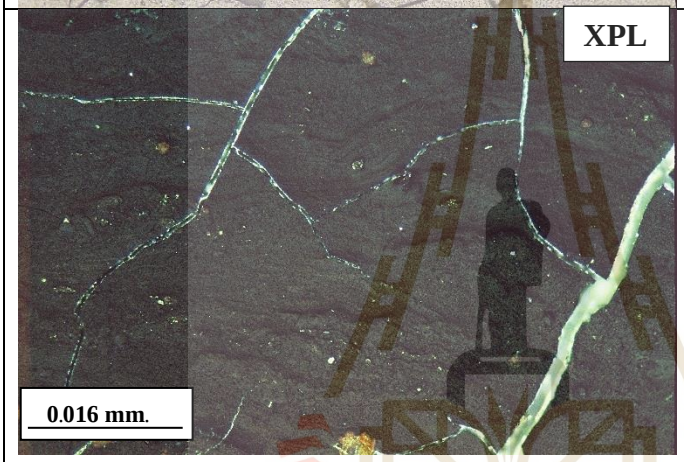
Microscopic Picture	Explanation
 	**Sample No. A13-1** **Telovitrinite** show character of texto-ulminite in corpocollinite. Composition (%) V = 98 % L = 0 % I = 1 % MM = 1 % **Vitrinite** consist mainly of **copocollinite.** They display bark and cork of wood showing structure of cell walls (textinite) filled by gel (ulminite). **Texto-ulminite** display dark brown in PPL for dry ulmin and pale gray in PPL for textinite. Both of them display black in XPL. **Inertinite** consist mainly of sclerotinite. They display as pale gray with highly relief with sphere shape in PPL and black in XPL. **Mineral Matter** consist mainly of small amount clay and sulfide mineral. They display as black in PPL and white dots in XPL filling in crack and voids.
PPL = Plane Polarized light, XPL = Cross Polarized light V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Te = Textinite, Te-U = Texto-Ulminite, Sf = Sulfide mineral, Cl = Clays	

Figure 4.108 The microscopic picture of coal sample No. A13 –1

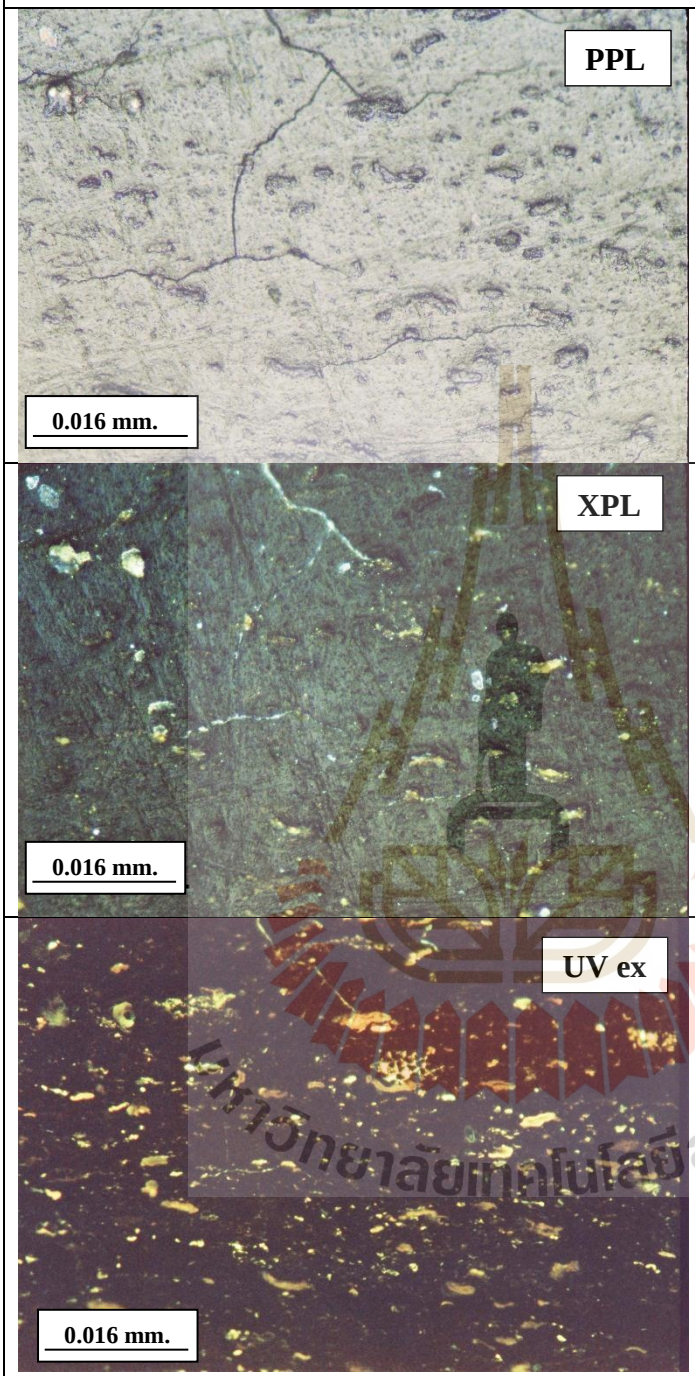
Microscopic Picture	Explanation
	**Sample No. A13-2** **Corpogelinite** show gel of wood tissues in parallel cut section. Composition (%) V = 87 % L = 12 % I = 0 % MM = 1 % **Vitrinite** consist mainly of tellinite. They show structure of bark woods with essential oil and display pale gray in PPL, dark gray in XPL and black in UV excitation. **Liptnite** consist of sporinite, liptodestrinite and fluorinate with some exsudatinite. **Sporinite** display as white to dark yellow with S-shape and telephone shape. Fluorinate display as group of bright yellow dots filling in dry ulmin in UV excitation. Exsudatinite display dark gray in PPL, black in XPL. Under UV excitation exsudatinite display dark yellow to greenish yellow filled in voids of dry gel and wood tissue.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation Gel = Gelinite, Re = Resinite, Ex = Exsudatinite, Bi = Bituminite, Cl = Clay	

Figure 4.109 The microscopic picture of coal sample No. A13 –2

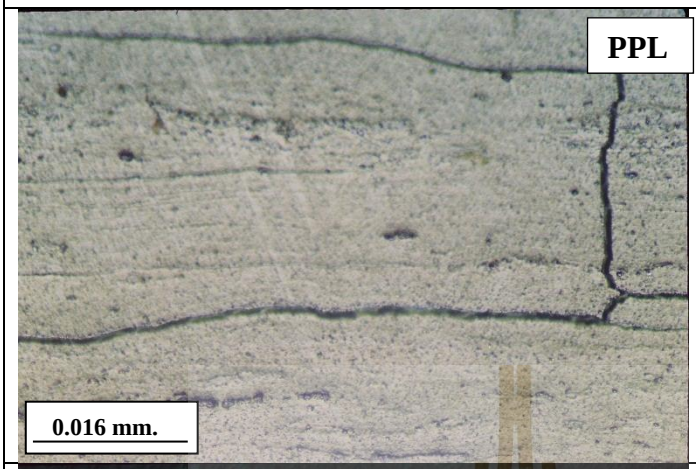
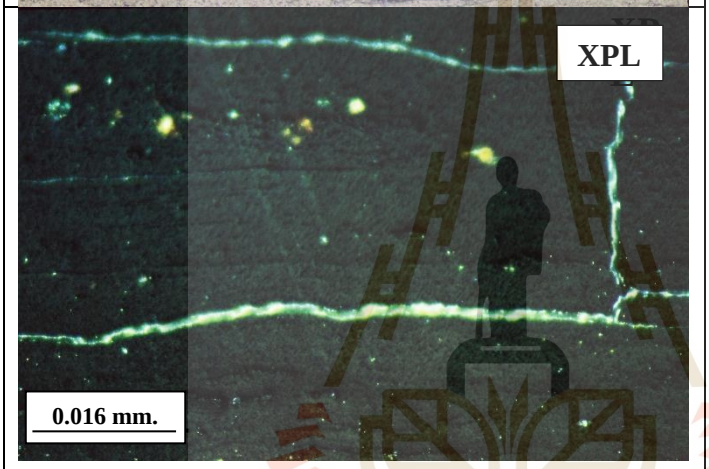
Microscopic Picture	Explanation
 	**Sample No. A13-3** **Textinite** consist mainly of well preserve cell walls and cell ulmin in coal. Composition (%) V = 98 % L = 0 % I = 0 % MM = 2 % **Vitrinite** consist of texto-ulminite in telovitrinite. They show structure of wood cell walls. They display pale gray in PPL and black in XPL. **Texto-ulminite** show structure of cell walls (textinite) filled by gel (ulminite). **Mineral Matter** consist of clay minerals filling in dry ulminite voids. They display as dark dots and line in PPL. In XPL they display white color.
PPL = Plane Polarized light, XPL = Cross Polarized light V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter T = Textinite Ul = Ulminite, Cl = Clay, Si = Silica	

Figure 4.110 The microscopic picture of coal sample No. A13 –3

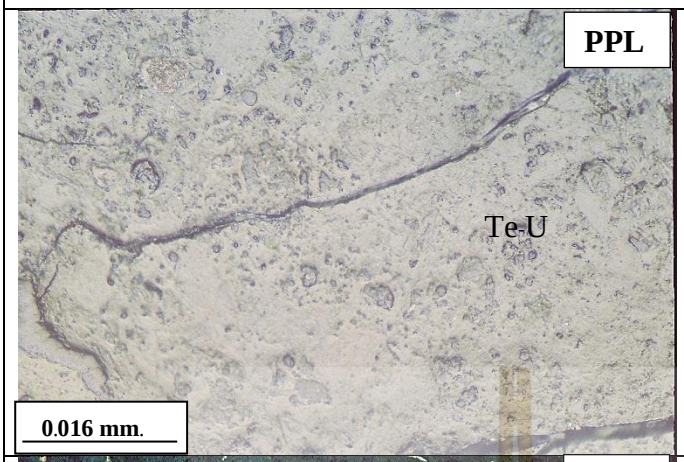
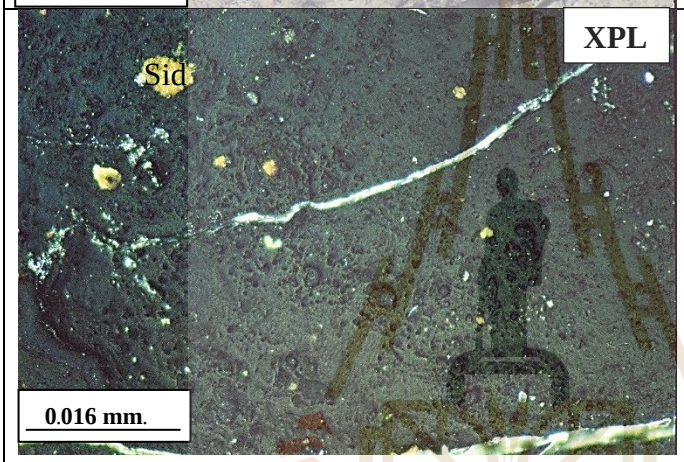
Microscopic Picture	Explanation
 	**Sample No. A13-4** **Telovitrinite** show character of texto-ulminite in corpocollinite in the section perpendicular to the tree trunk. Composition (%) V = 96 % L = 0 % I = 1 % MM = 3 % **Vitrinite** consist mainly of **copocollinite.** They display bark and cork of wood showing structure of cell walls (textinite) filled by gel (ulminite). They display dark brown in PPL for dry ulmin and pale gray in PPL for textinite. Both of them are black in XPL. **Mineral Matter** consist mainly of small amount clay minerals. They display as black in PPL and white dots in XPL filling in voids. The yellow in XPL is siderite
PPL = Plane Polarized light, XPL = Cross Polarized light V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter Te = Textinite, Te-U = Texto-Ulminite, Cl = Clays, Sid = Siderite	

Figure 4.111 The microscopic picture of coal sample No. A13 –4

4.2.5 Oil Shale in Coal A sub-unit

These oil shales consist of fine-grained sediments deposited together with algae and were cemented by gelinite. They are laminated black shale interbedding in Coal A sub-unit. Their major compositions are mineral matter deposit associated with liptinite (mostly of alginate) and some of vitrinite (Table 4.8). The vitrinite (1 – 25%) consist mainly of gelinite with some telovitrinite. They display essential oil filled in wood tissues, white yellow and greenish yellow to orange under UV-excitation (Figure 4.115 and 4.116). Alginite show difference layers of algae which consist mainly of lamalginite (63.81%) and telalginite (3.14%). The difference of algae abundance both number and size could reflect to the level of nutrients in water. The stagnant of coming up water for a long time with rich of nutrient led to algae booms and produced thick bed of algal mats. Under microscopic of the perpendicular section, various sizes of lamalginite with limited recognizable structure can be observed. Liptodestrinite display as the groundmasses without structure and show dark brown under UV excitation. The mineral matter consists of coarse diagenetic crystals of sand to silt sizes deposited with groundmass of clay minerals.

Alginite in this sub-unit is dominated by lamalginite type. They display yellow to orange with lamellar shape. They show different character and abundant in 2 types: the long form (0.004 to 0.016 mm) and the short form (0.001 to 0.004 mm) with the thickness of 0.001 to 0.006 mm in the perpendicular section (Figure 4.119, 4.125, 4.126 and 4.127). The sizes of the algal could depend on the pH and nutrient of the swamp water. From the photosynthesis, different conditions of water have different nutrients in them. Algae take waste (dead animal and plant) in water and provide oxygen and nitrogen. Some parts of oil shale consist of telalginite (*Botryococcus* sp.),

fluorescing greenish yellow to white yellow. Most of colonies are *Pila* algae which live in freshwater lakes. They show ovoid to circular with 0.004 to 0.024 mm long and 0.004 to 0.005 mm thick. The parallel cross-sections show the circular colonies with shapes which is the significant morphological features used to identify the algae as *Pediastrum* (Tsukii, 2014) (Figure 4.120 and 4.129).

Table 4.8 Composition in percentage of Oil Shale in Coal A sub-unit samples.

Sample	Liptinite											Vitrinite	Mineral Matter			
	Alginite			Lip	Sp	Cu	Fl	Re	Su	Ex	Total (%)		Clay	Q+Si	Py	Total (%)
	Lam	Tela														
		Botry	Pila													
AS1-1	66	0	0	0	2	0	0	0	0	0	68	13	3	16	0	19
AS1-2	67	0	0	0	3	0	0	0	0	0	70	15	10	5	0	15
AS1-3	73	0	0	0	1	0	0	0	0	0	74	9	16	0	1	17
AS2-1/1	67	3	2	12	4	0	0	0	0	0	88	1	10	0	1	11
AS2-1/2	85	2	0	0	0	0	0	0	0	0	87	7	6	0	0	6
AS2-2	83	5	0	1	0	0	0	0	0	0	89	2	6	0	3	9
AS2-3	60	0	0	1	1	0	0	0	0	0	62	18	16	0	4	20
AS3-1	50	6	0	5	3	0	0	1	0	0	65	9	23	3	0	26
AS3-2	55	9	0	1	1	0	0	0	0	0	66	25	4	4	1	9
AS3-3	56	0	0	12	0	0	0	0	0	0	68	14	10	7	1	18
AS3-4	45	0	0	12	11	0	0	3	0	0	71	18	8	1	2	11
A11-1	73	4	0	0	0	0	0	0	0	0	77	10		13	0	13
A11-2/1	74	2	0	3	0	0	0	0	0	0	79	9	8	4	0	12
A11-2/2	61	1	0	19	4	0	0	2	0	0	87	3	6	1	3	10
A11-3	54	4	0	0	5	0	0	2	0	0	65	23	11	0	1	12
A11-4	52	12	0	6	4	0	0	0	0	0	74	16	5	5	0	10
max	85	12	2	19	11	0	0	3	0	0	89	25	23	16	4	26
min	45	0	0	0	0	0	0	0	0	0	62	1	3	0	0	6
%	**63.81**	**3.00**	**0.13**	**4.50**	**2.44**	**0.00**	**0.00**	**0.50**	**0.00**	**0.00**	**74.38**	**12.00**	**8.88**	**3.69**	**1.06**	**13.63**

Lam = Lamalginite, Tela = Telalginite, Bot = Botryococcus brounii, Pil = Pila algae, Lip = Liptodestrinite, Sp = Sporinite, Cu = Cutinite, Fl= Fluorinite, Re = Resinite, Su = Suberinite, Ex = Exsudatinite, V = Vitrinite (consist of telovitrinite, detrovitrinite and gelovitrinite)
Q = Quartz, Si = Silica, Py = Pyrite

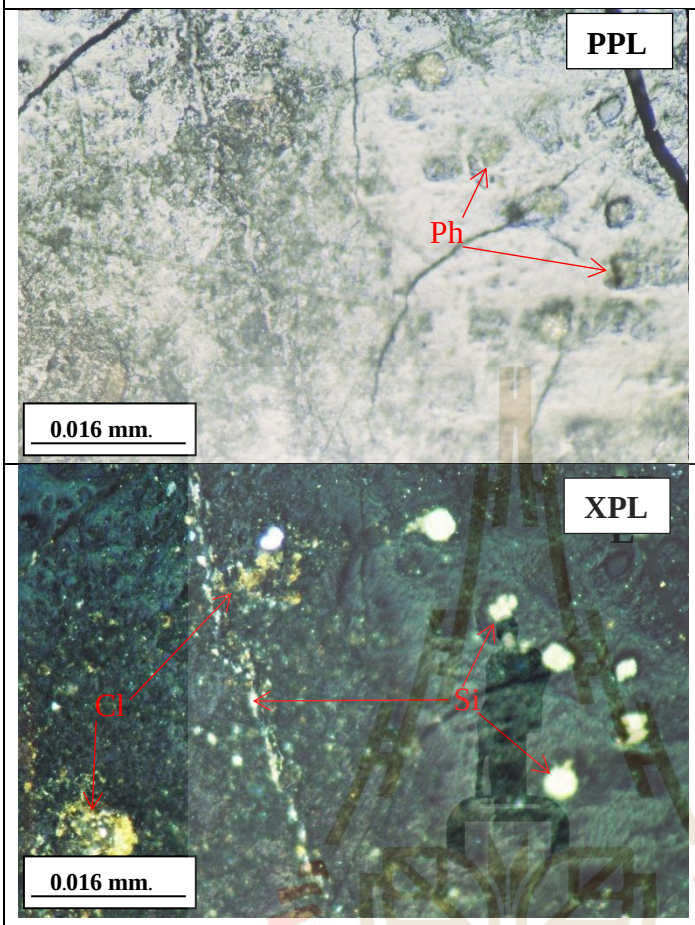
Microscopic Picture	Explanation
	**Sample No. AS1-1** **Porigelinite** of gelovitrinite subgroup Composition (%) V = 13 % L = 68 % I = 0 % MM = 19 % **Vitrinite** consist of wood tissue cemented by gelified material. **Phlobaphinite** with zone of transformed display pale gray to dark gray in PPL and black in XPL. **Mineral matter** consist mainly of clay and silica. Silica display as various size white spots filled in voids. Clay display white yellow to yellow.
PPL = Plane Polarized light, XPL = Cross Polarized light Ph = Phlobaphinite, Si = Silica, Cl = Clay	

Figure 4.112 The microscopic picture of oil shale sample No. AS1 – 1

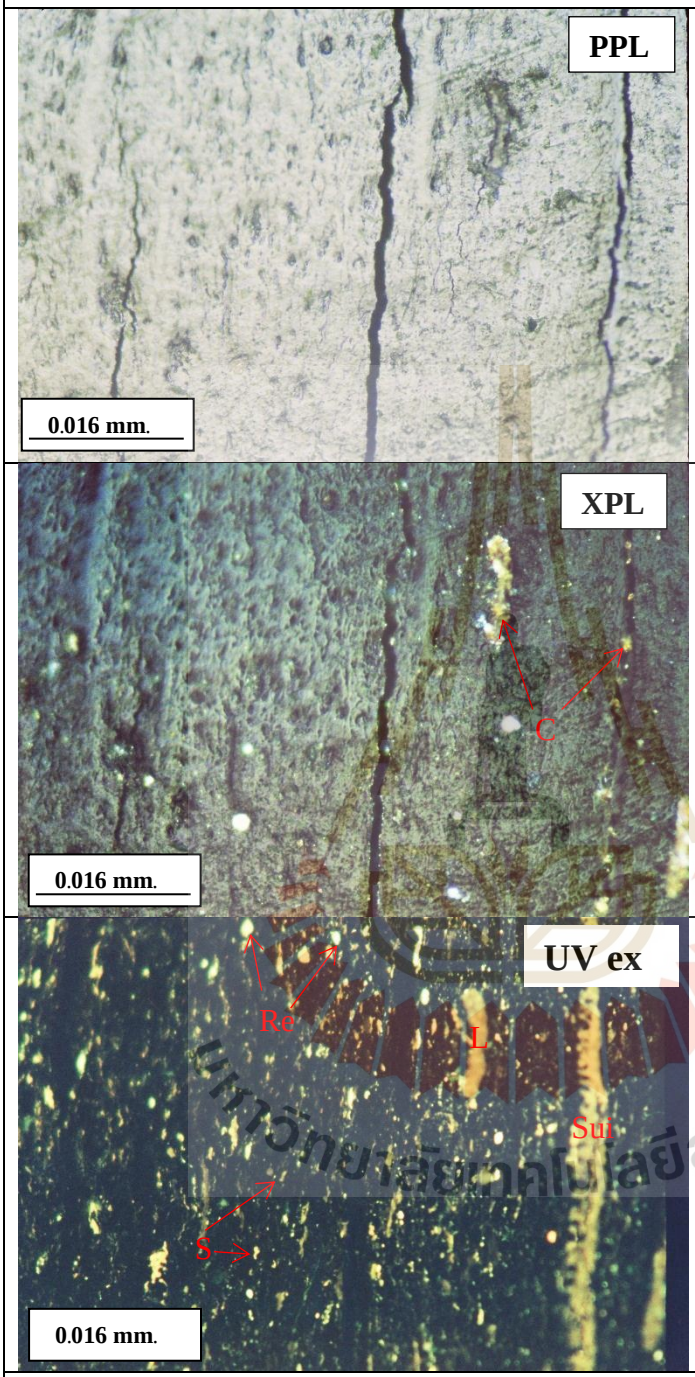
Microscopic Picture	Explanation
	**Sample No. AS1-2** **Texo-ulminite** of telovitrinite subgroup in cut cross bedding section show structure of wood tissue. Composition (%) V = 15 % L = 70 % I = 0 % MM = 15 % **Vitrinite** show difference in reflectance of **textinite** and **ulminite** cemented by **gelinite**. Ulminites are body of cell filling in clay. They display pale gray in PPL and black in XPL. **Liptnite** display bright gray in PPL and dark in XPL. Under UV excitation, **resinite** display as light-yellow spots. **Sporinite** display as yellow with spore shape. **Liptodestrinite** display yellow without shape. **Suberinie** display as yellow thick line with serrated teeth. **Mineral matter** consist of clay and framboidal pyrite. Clay display as white and yellow filling in voids.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation Li = Liptodestrinite, Su= Suberinite, S = Sporinite, C = Clay	

Figure 4.113 The microscopic picture of oil shale sample No. AS1 – 2

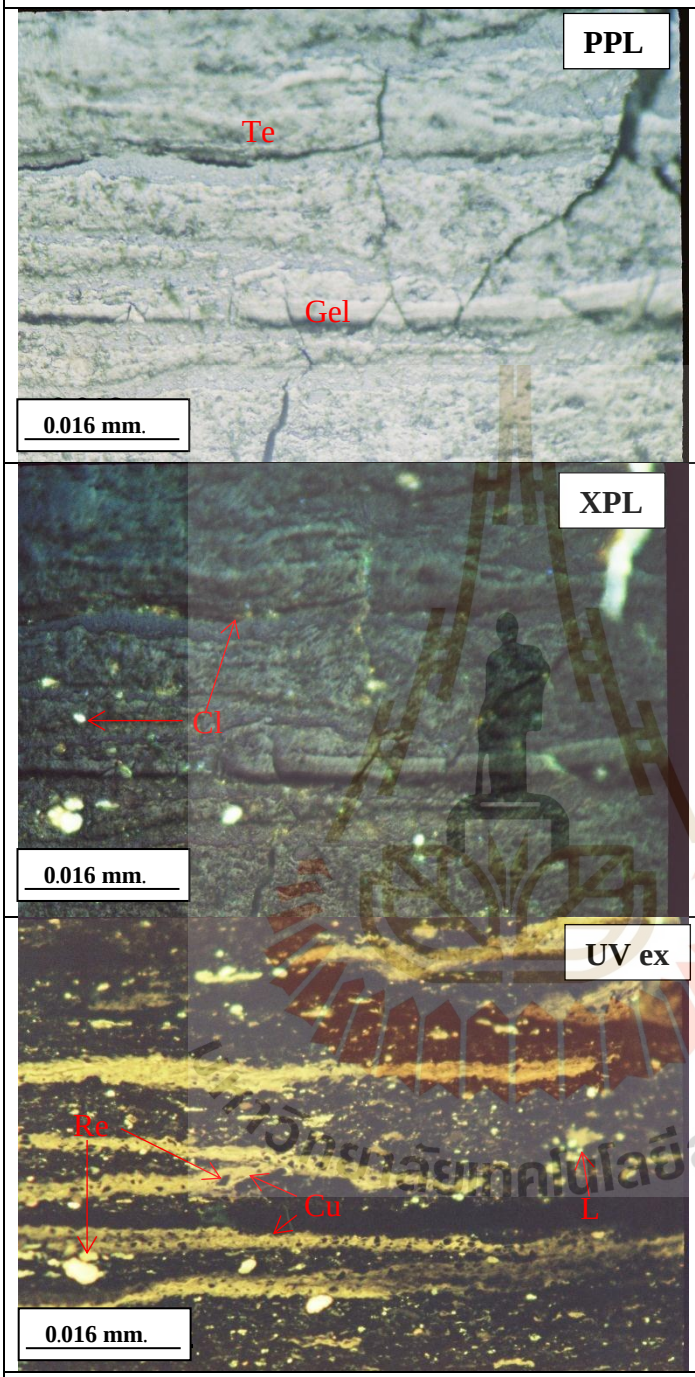
Microscopic Picture	Explanation
	**Sample No. AS1-3** **Textinite** of telovitrinite subgroup show layer of textrinite and gelinite. Composition (%) V = 9 % L = 74 % I = 0 % MM = 17 % **Vitrinite** consist of wood tissue cemented by gelified material. **Gelinite** and **textinite** display pale gray to dark gray in PPL and black in XPL. **Liptinite** display bright reflect in PPL and dark gray to black in XPL. Under UV excitation **resinite** display as light yellow with sphere shape. **Liptodestrinite** display yellow without shape. **Cutinite** display as yellow thick line and cover resinite (dark). **Mineral matter** consist of clay. They display white and yellow spots and filling in voids in XPL.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation Tex = Textinite, Gel = Gelinite, Li = Liptodestrinite, Re = Resinite, Cu = Cutrinite, C = Clay	

Figure 4.114 The microscopic picture of oil shale sample No. AS1 – 3

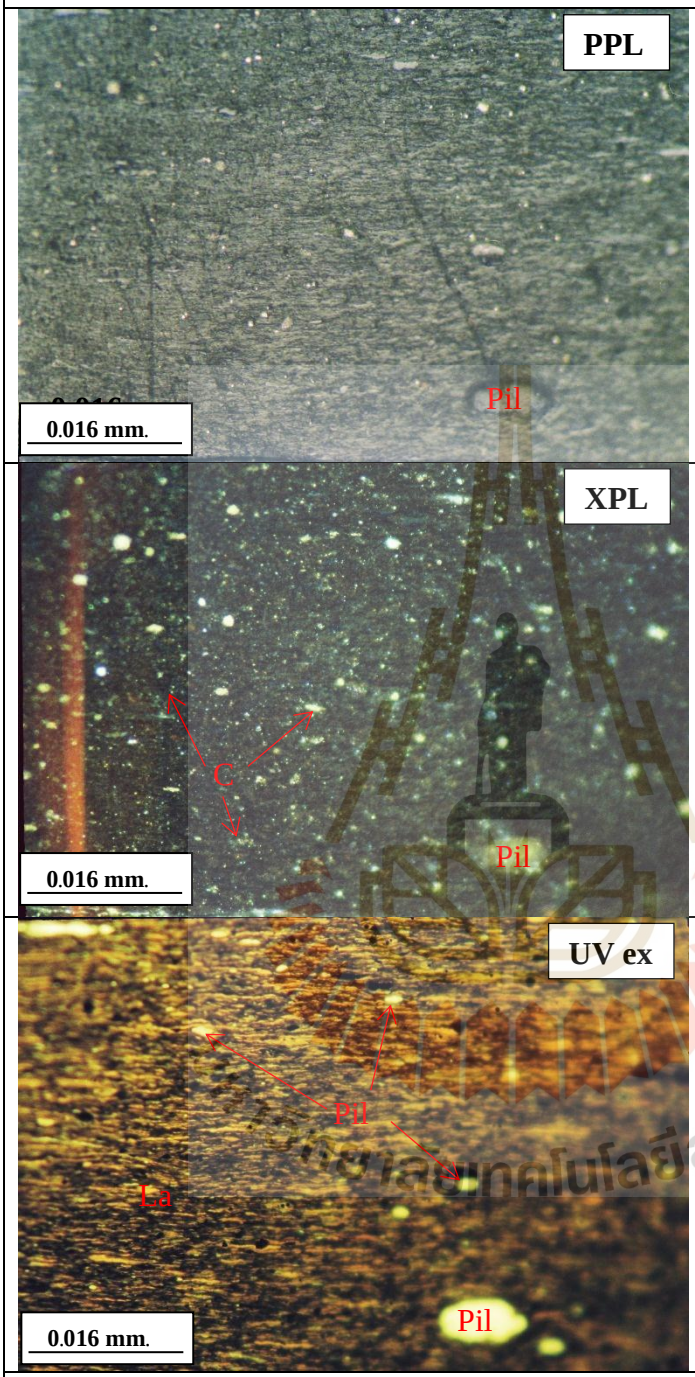
Microscopic Picture	Explanation
	**Sample No. AS2-1/1** **Oil Shale (Algite)** in the cross section of bedding shows foliation of sediment deposited with algae. Composition (%) V = 1 % L = 88 % I = 0 % MM = 11 % **Vitrinite** consist mainly of densinite**. Densinite** display dark gray to black in PPL and black in XPL. **Liptinite** consist mainly of **alginite.** They display highly relief and reflect pale gray in PPL. The colonies of *pila* algae are various size and shape. They display shave, light yellow in XPL and white yellow in UV ex. The **lamaginite** algae are dark brown to black in XPL and yellowish-brown short line in UV ex. **Mineral matter** consist of clay. They display white dots in XPL are clay deposited with organic sediment.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation La = Lamaginite algae, Pila = Pila algae, C = Clay	

Figure 4.115 The microscopic picture of oil shale sample No. AS2 – 1/1

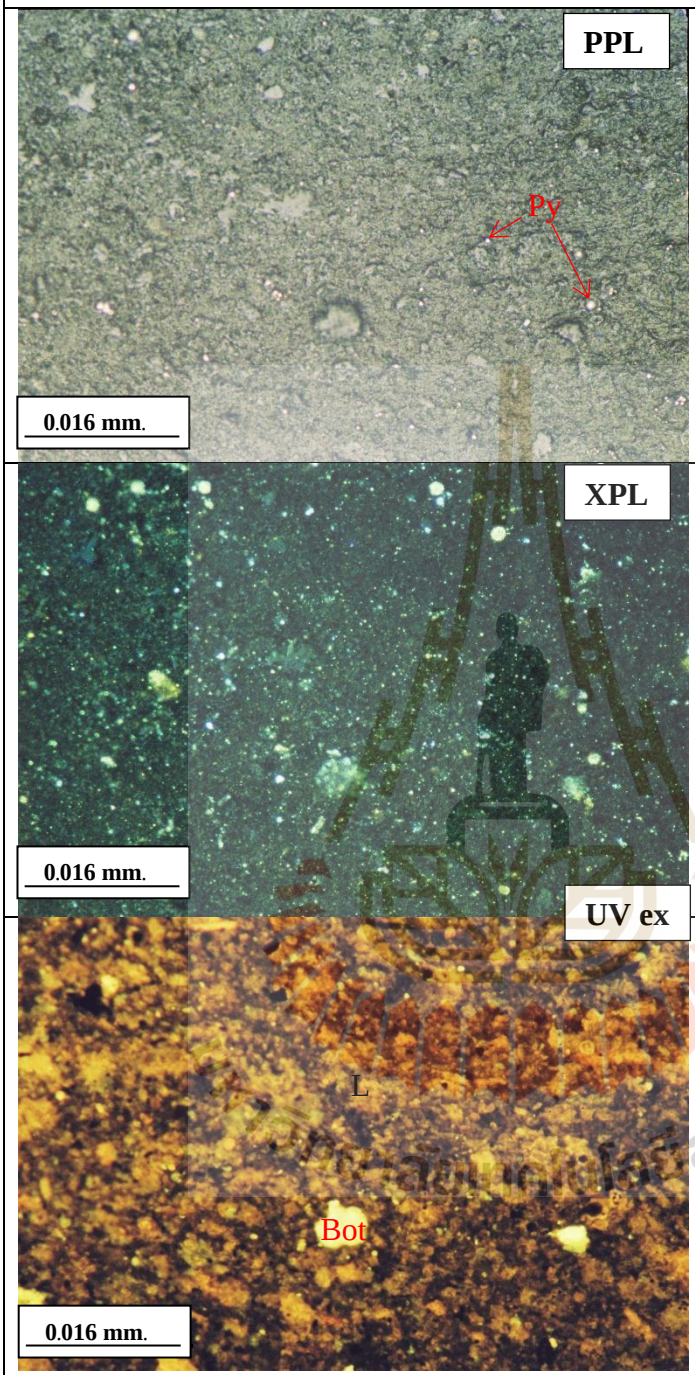
Microscopic Picture	Explanation
	**Sample No. AS2-1/2** **Oil Shale (Algite)** in the section parallel to bedding of sediment deposited with algae. Composition (%) V = 7% L = 87 % I = 0 % MM = 6 % **Vitrinite** consist mainly of **densinite**. They display dark gray to black in PPL and black in XPL. **Liptinite** consist mainly of **alginite** (**Telalginite**) *Botryococcus braunii* showing 4 cup of body structure and display highly relief and reflect pale gray in PPL, white to greenish yellow in XPL and white yellow in UV excitation. **Lamalginite** display as parallel body and gray to dark gray in PPL and black in XPL and yellowish brown to brown in UV excitation. **Mineral matter** consist of clay and pyrite. The white dots in XPL are clay deposited with organic sediment. The bright dots in PPL, white in XPL and dark in UV ex are pyrite.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation La = Lamaginite algae, Bot = Botryococcus algae, C = Clay, Py = Pyrite	

Figure 4.116 The microscopic picture of oil shale sample No. AS2 – 1/2

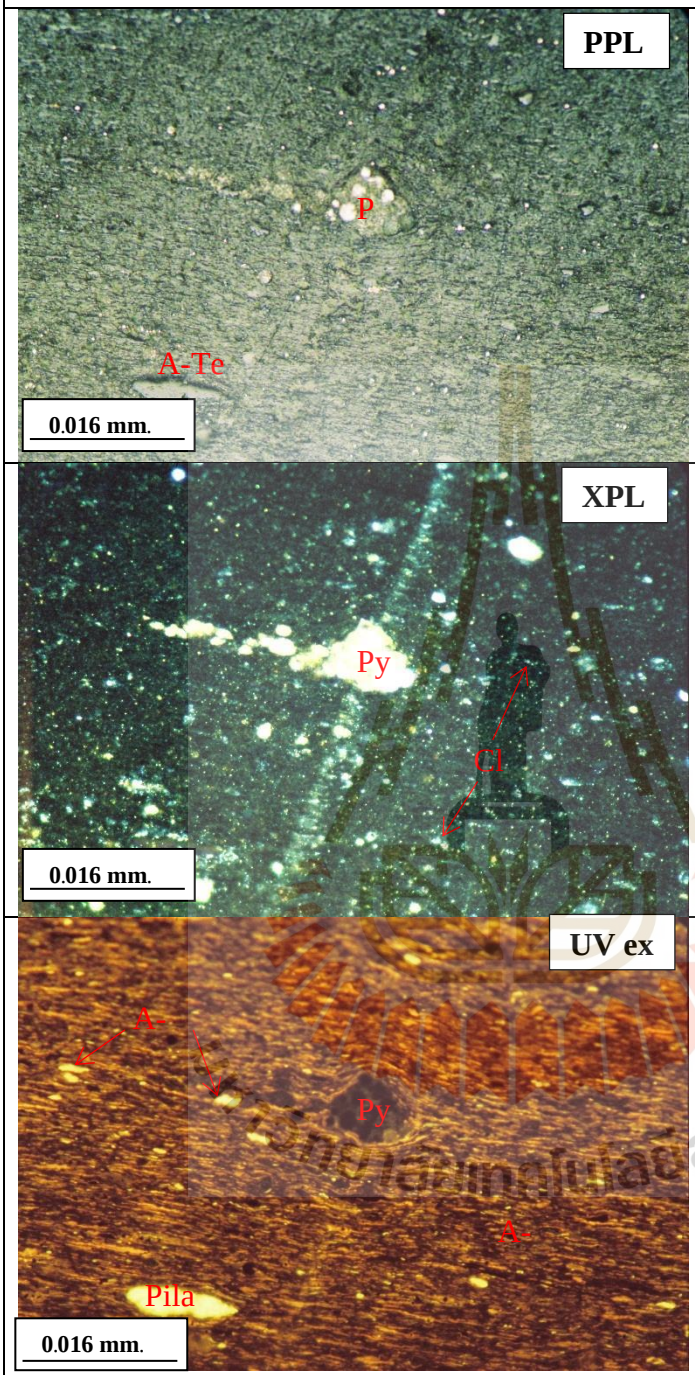
Microscopic Picture	Explanation
	**Sample No. AS2-2** **Oil Shale (Algite)** in the cross section of bedding shows foliation of sediment deposited with algae Composition (%) V = 2 % L = 89 % I = 0 % MM = 9 % **Vitrinite** consist mainly of densinite. **Densinite** display dark gray to black in PPL and black in XPL. **Liptinite** consist mainly of **alginate**. They display highly relief and reflect pale gray in PPL. The **telalginite** algae is colonies of *pila* algae. They are varying in size and shape. They display light yellow in XPL and white yellow in UV ex. The **lamaginite** algae are dark brown to black in XPL and yellowish-brown short line in UV ex. **Mineral matter** consist of clay and pyrite. The white dots in XPL are clay deposited with organic sediment. The group of bright and white in PPL and XPL with circle shave and dark in UV ex are framboidal pyrite.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation A-La = Lamaginite algae, A-Te = Telalginite algae, C = Clay, Py = Pyrite	

Figure 4.117 The microscopic picture of oil shale sample No. AS2 – 2

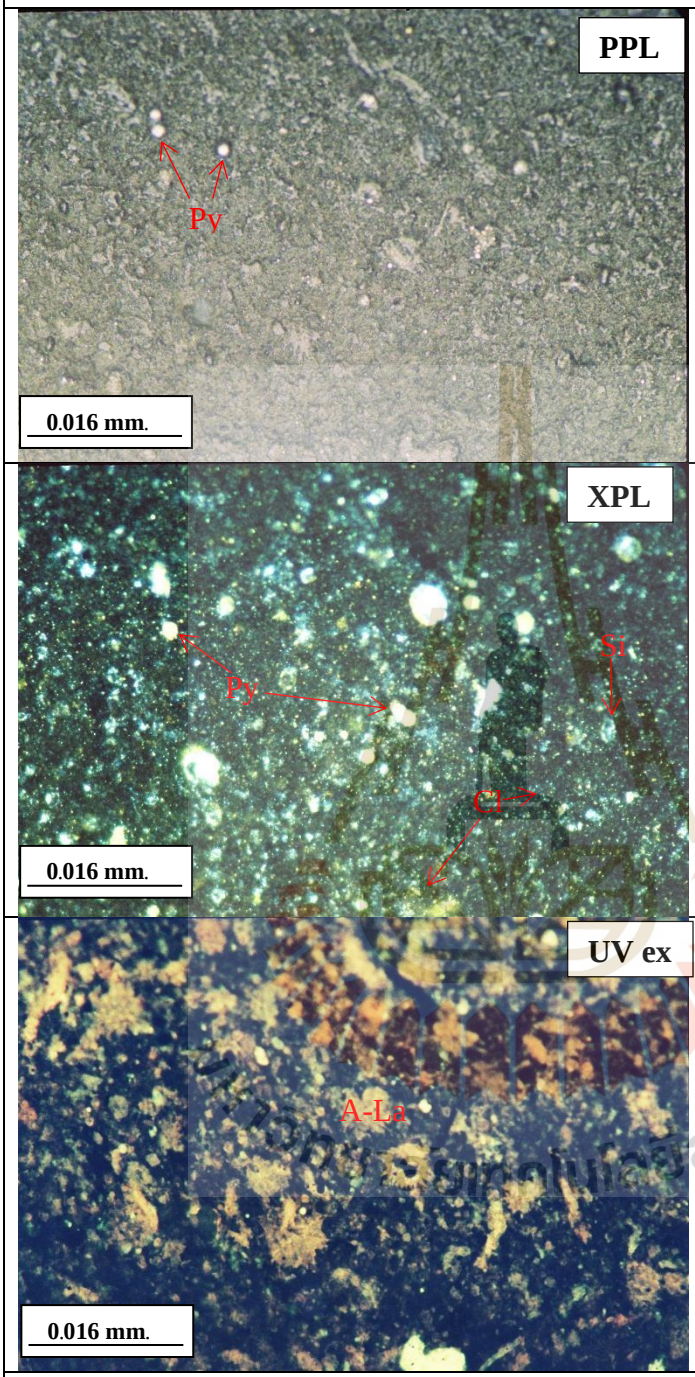
Microscopic Picture	Explanation
	**Sample No. AS2-3** **Oil Shale (Algite)** in the section parallel to bedding of sediment deposited with algae. Composition (%) V = 18 % L = 62 % I = 0 % MM = 20 % **Vitrinite** consist mainly of **densinite**. They display dark gray to black in PPL and black in XPL. **Liptinite** consist mainly of **alginate**. They display gray to dark gray in PPL and black in XPL. **Lamaginite** display as parallel body and yellowish brown to brown in UV ex. **Mineral matter** consist of clay, silica and pyrite. The white and yellowish-brown dots and white spot in XPL are clay and silica deposited with organic sediment. The bright dots in PPL, white in XPL and dark in UV ex showing group of circles are framboidal pyrite.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation A-La = Lamaginite algae, C = Clay, Py = Pyrite, Si = Silica	

Figure 4.118 The microscopic picture of oil shale sample No. AS2 – 3

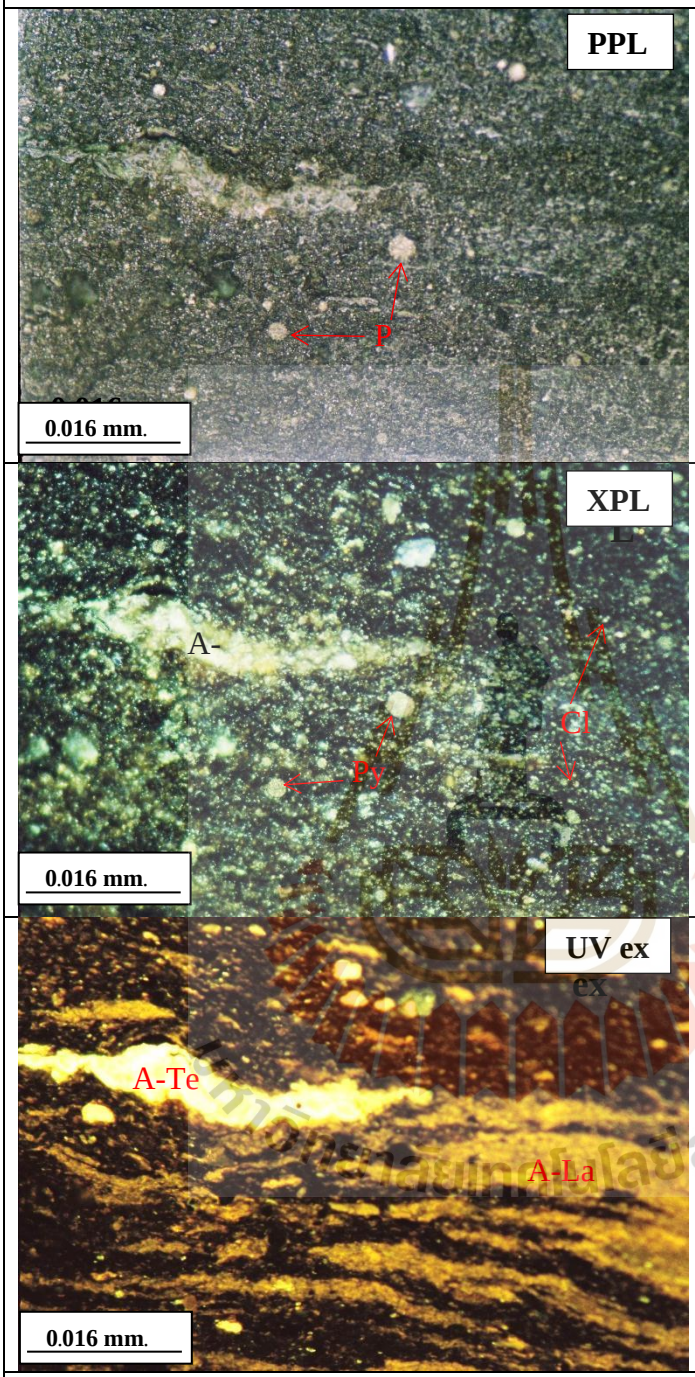
Microscopic Picture	Explanation
	**Sample No. AS3-1** **Oil Shale (Algite)** show sediment deposited with algae. Composition (%) V = 9 % L = 65 % I = 0 % MM = 26 % **Vitrinite** consist mainly of **attrinite.** They show dark gray to black in PPL and black in XPL. **Liptinite** consist mainly of **alginate**. **Telalginite** (colonies of *pila* algae) display highly relief and reflect dark gray in PPL, white to light yellow in XPL and white yellow in UV ex. **Lamaginite** display white to yellow in XPL and yellowish-brown short line in UV ex. **Mineral matter** consist of pyrite and clay. The white circle in PPL and XPL and dark in UV ex is pyrite. The white and yellow dots are clay.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation A-La = Lamaginite algae, A-Te = Telalginite, C = Clay, Py = Pyrite	

Figure 4.119 The microscopic picture of oil shale sample No. AS3 – 1

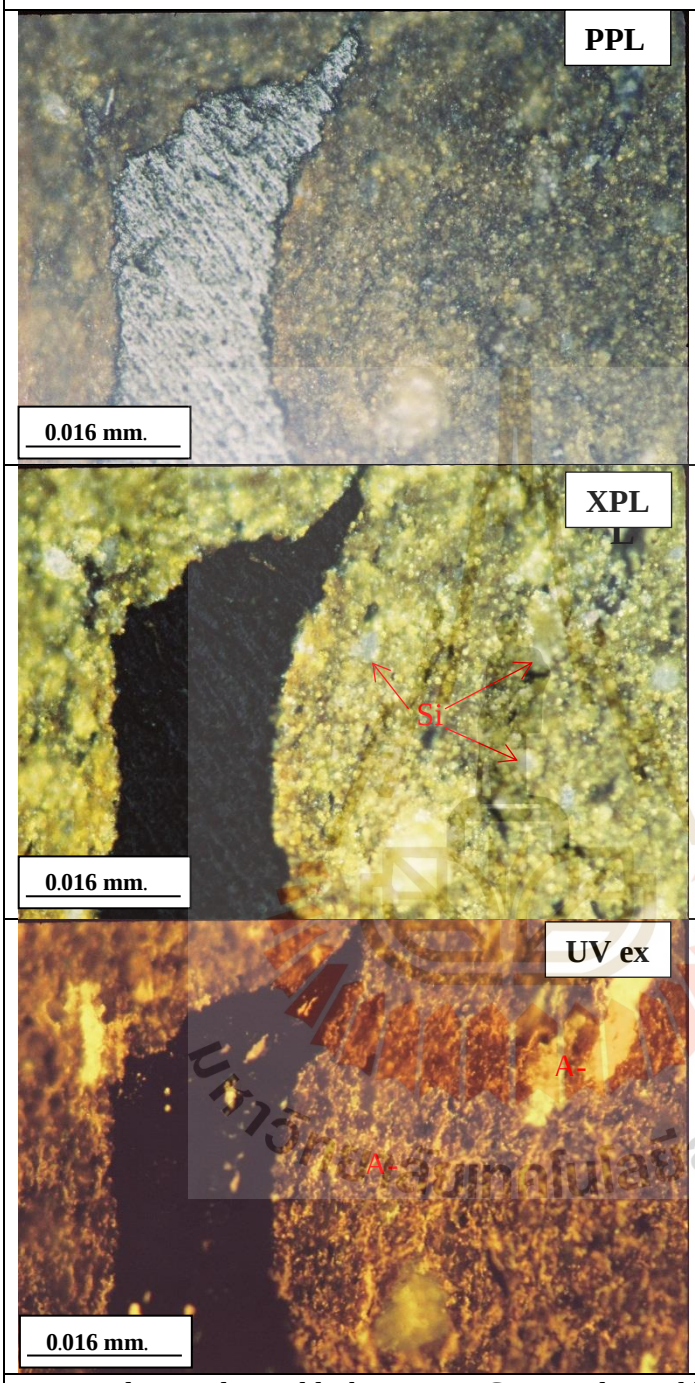
Microscopic Picture	Explanation
	**Sample No. AS3-2** **Oil Shale** shows sediment deposited which oxide. Composition (%) V = 25 % L = 66 % I = 0 % MM = 9 % **Vitrinite** consist of white fine-grained organic sediment. They display bright reflected and yellow in PPL and black and white yellow in XPL. **Liptinite** consist mainly of **alginate**. **Telalginite** (colonies of *pila* algae) display yellow in PPL and white to light yellow in XPL. Under UV excitation they show bright yellow. **Lamaginite** display brown to dark brown. **Mineral matter** consist of silica and oxide sediment. The white to yellow in PPL and XPL is silica. The yellow dots in PPL and XPL are oxide sediment.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation A-La = Lamaginite algae, A-Te = Telalginite, Py = Pyrite	

Figure 4.120 The microscopic picture of oil shale sample No. AS3 – 2

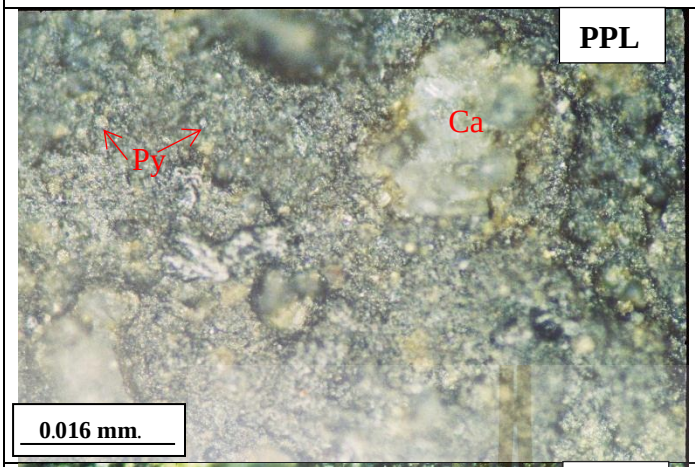
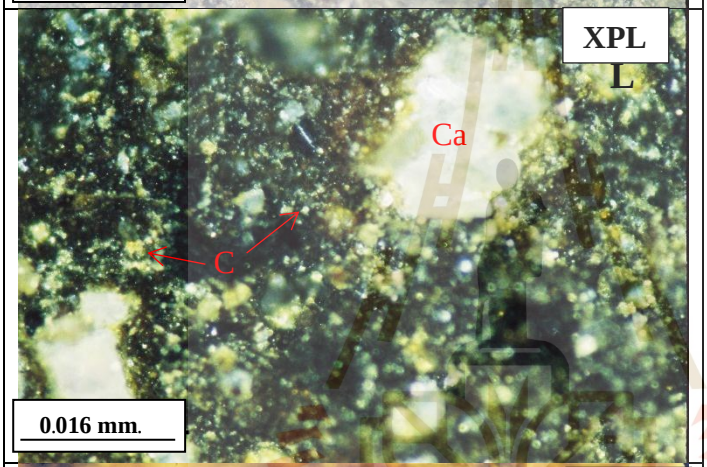
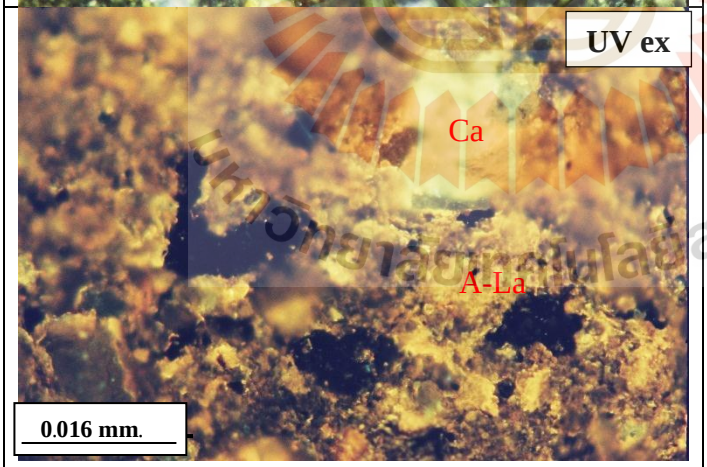
Microscopic Picture	Explanation
  	**Sample No. AS3-3** **Oil Shale (Algite)** in the section parallel to bedding of sediment deposited various sizes with algae. Compositions (%) V = 14 % L = 68 % I = 0 % MM = 18 % **Vitrinite** consist mainly of **densinite**. They display dark gray in PPL and black in XPL. **Liptinite** consist mainly of **lamaginite** algae in parallel body. They display pale gray in PPL and dark brown to black in XPL. Under UV excitation they display yellow to yellowish brown. **Mineral matter** consist of calcite, pyrite and clay. The crystal white to gray in PPL, white in XPL and white yellow reflect in UV ex are calcite. The white dots in PPL and XPL and dark in UV ex showing group of circles are framboidal pyrite. The dark gray dots in PPL and white to yellowish brown in XPL are clay.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation A-La = Lamaginite algae, Py = Pyrite, Ca = Calcite	

Figure 4.121 The microscopic picture of oil shale sample No. AS3 – 3

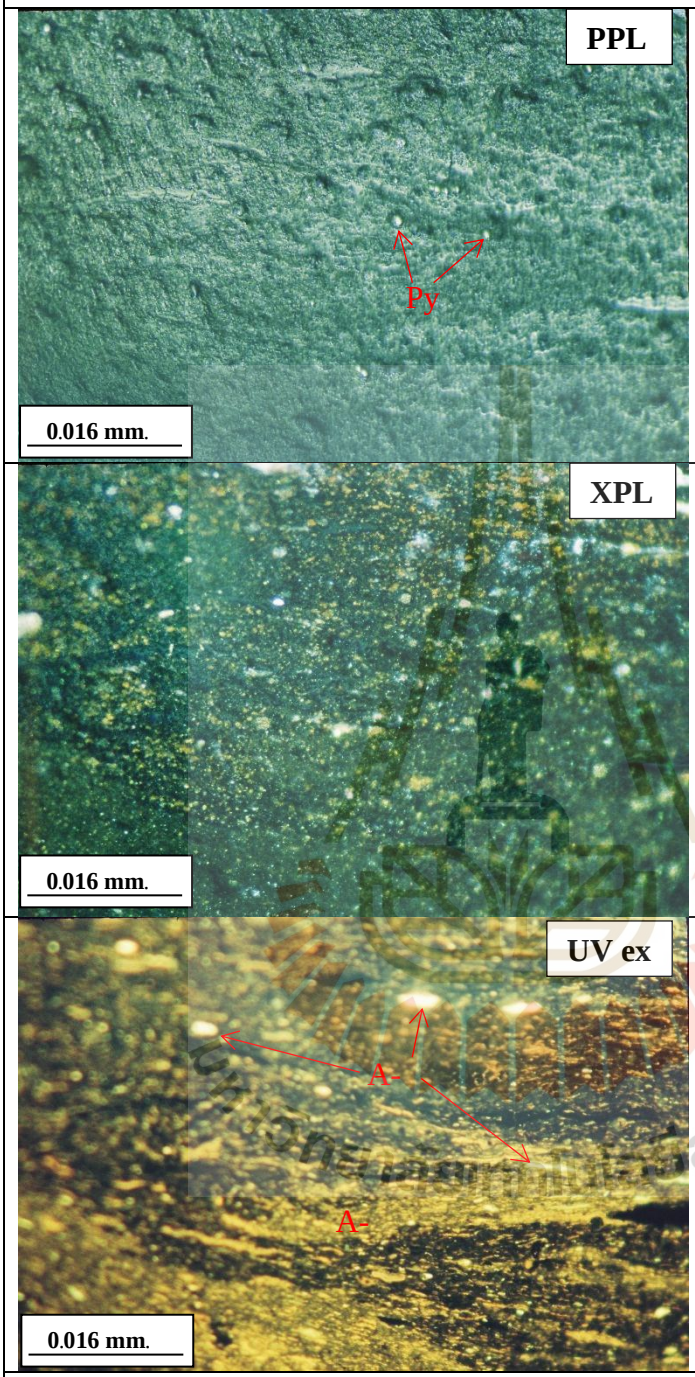
Microscopic Picture	Explanation
	**Sample No. AS3-4** **Oil Shale (Algite)** shows sediment deposition with algae. Composition (%) V = 18 % L = 71 % I = 0 % MM = 11 % **Vitrinite** consist mainly of **attrinite**. They display dark gray to black in PPL and black in XPL. **Liptinite** display dark gray and black in PPL and XPL. Under UV excitation. **Telalginite** display bright yellow. **Lamaginite** display as yellow with long shape. **Mineral matter** consist mainly of oxide sediment. They display yellow dots in XPL. The white in PPL and XPL with circle shave and dark in UV ex are framidol pyrite.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation A-La = Lamaginite algae, A-Te = Telalginite, Py = Pyrite	

Figure 4.122 The microscopic picture of oil shale sample No. AS3 – 4

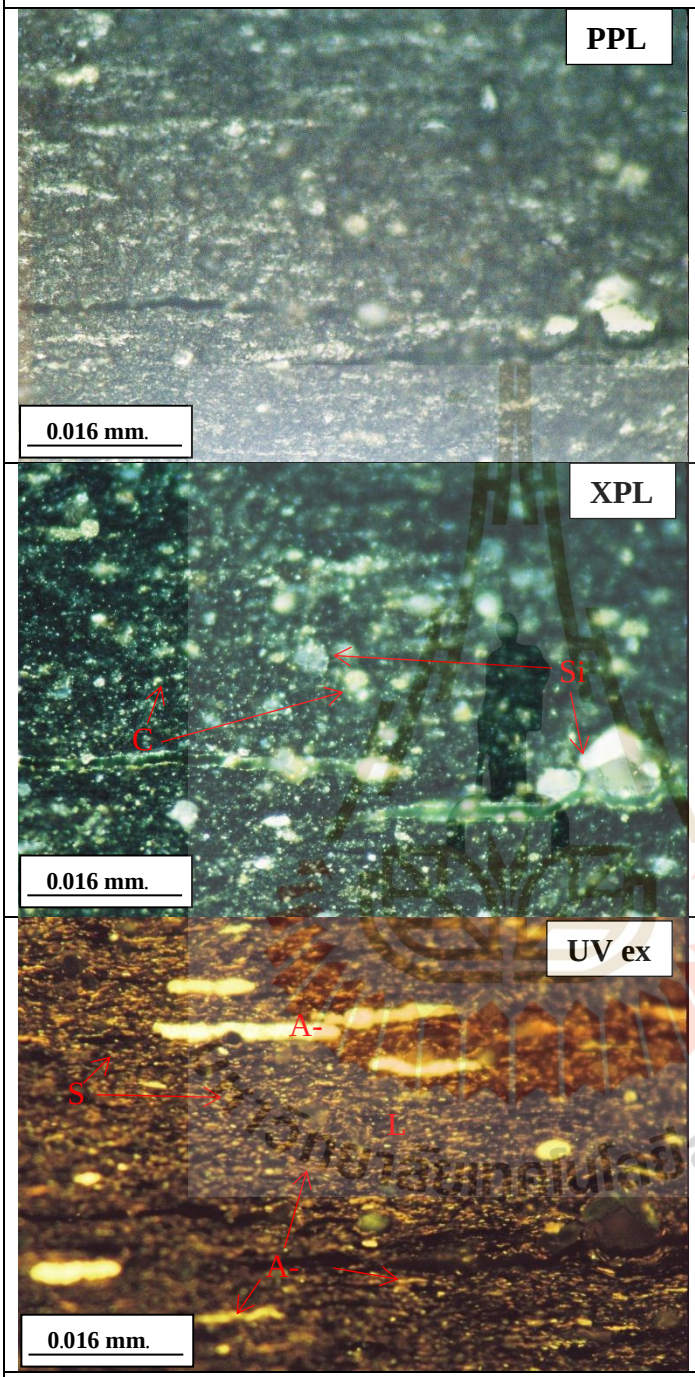
Microscopic Picture	Explanation
	**Sample No. AS 3/21** **Oil shale** shows sapropelite deposited with **alginite** which indicates **boghead-cannel coal**. **Composition (%)** V = 10 % L = 77 % I = 0 % MM = 13 % **Vitrinite** consist mainly of **attrinite**. They dark gray to black in PPL and black in XPL. **Liptinite** consist mainly of alginate. They display white yellow and yellowish brown in UV excitation. **Telalginite** (*botryococcus* sp.) are bright white to yellow thick line and sphere in shape. **Lamaginite** display as thin of yellowish-brown short line. **Sporinite** or **liptodestrinite** display as yellowish to yellowish brown dots. **Mineral matter** consist mainly of clay and silica. They are various in sizes, sub-round to round. They display pale gray to black in PPL and white to light yellow and pale gray in XPL.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation A-Te = Telalginite, A-La = Lamaginite, S = Sporinite, Li = Liptodestrinite, Cl = Clay, Silica	

Figure 4.123 The microscopic picture of oil shale sample No. AS3/21

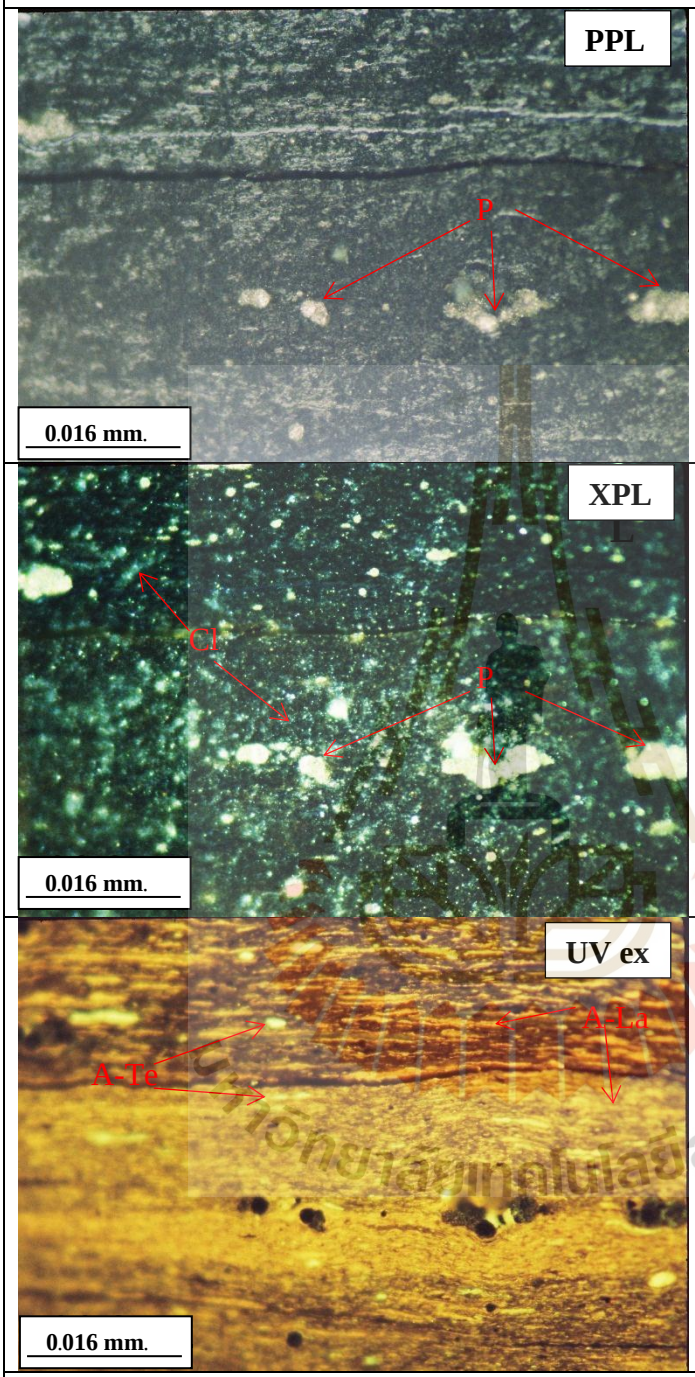
Microscopic Picture	Explanation
	**Sample No. AS3-2/1** **Oil shale (boghead coal)** shows sapropelites deposit of different type of **alginite** layer and mineral matters. **Composition (%)** V = 9 % L = 79 % I = 0 % MM = 12 % **Vitrinite** consist mainly of **attrinite**. They display dark gray to black in PPL and black in XPL. **Liptinite** consist mainly of **alginite and liptodestrinite**. They display bright yellow and yellowish brown in UV excitation. **Telalginite** (*botryococcus* sp.) display as white to bright yellow thick line and sphere shape. **Lamaginite** display thin of yellow line and shows layers of short and long lamaginite body. **Liptodestrinite** show dark brown ground mass in UV ex without structure. **Mineral matters** show dark gray to black in PPL and white to light yellow dots in XPL are clay. Pyrite display group of circular shape with light yellow to pale gray in PPL, white in XPL and black in UV ex are framboidal pyrite.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation A-Te = Telalginite, A-La = Lamaginite, Cl = Clay, Silica	

Figure 4.124 The microscopic picture of oil shale sample No. AS3 – 2/1

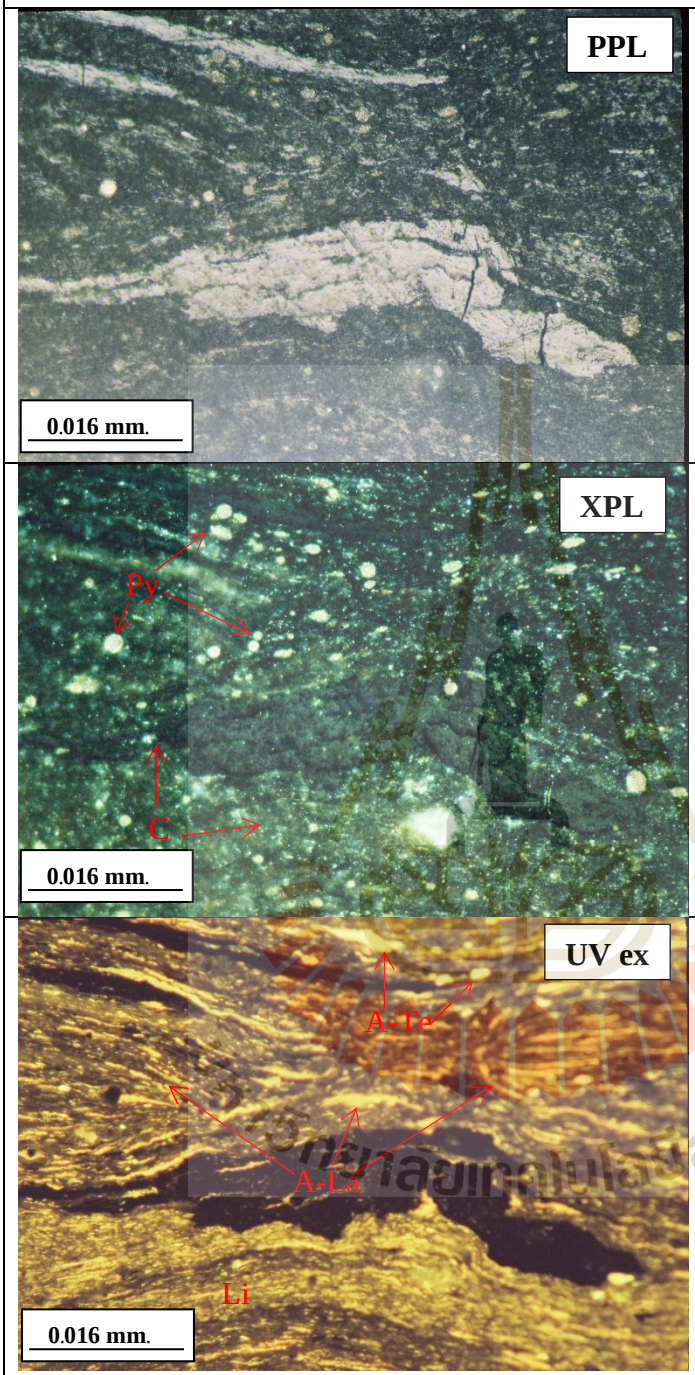
Microscopic Picture	Explanation
	**Sample No. AS 3-2/2** **Oil shale (boghead coal)** shows sapropelite deposits of **alginite** layer and mineral matters. Composition (%) V = 3 % L = 87 % I = 0 % MM = 10 % **Vitrinite** consist mainly of **attrinite**. They display pale gray to dark gray in PPL and black in XPL. **Liptinite** consist mainly of **alginate.** They display dark gray in PPL, dark brown to black in XPL and yellow under UV ex. **Telalginite** are bright yellow of *botryococcus* sp. **Lamaginite** are various sizes, thick to thin and short to long. They display layer movement and compaction deposited. Under UV ex, **liptodestrinite** shows yellow to dark brown dots and without structure. **Mineral matter** consist of clay. They display white and light-yellow dots in XPL.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation A-Te = Telalginite, A-La = Lamaginite, Py = Pyrite, Cl = Clay	

Figure 4.125 The microscopic picture of oil shale sample No. AS3 – 2/2

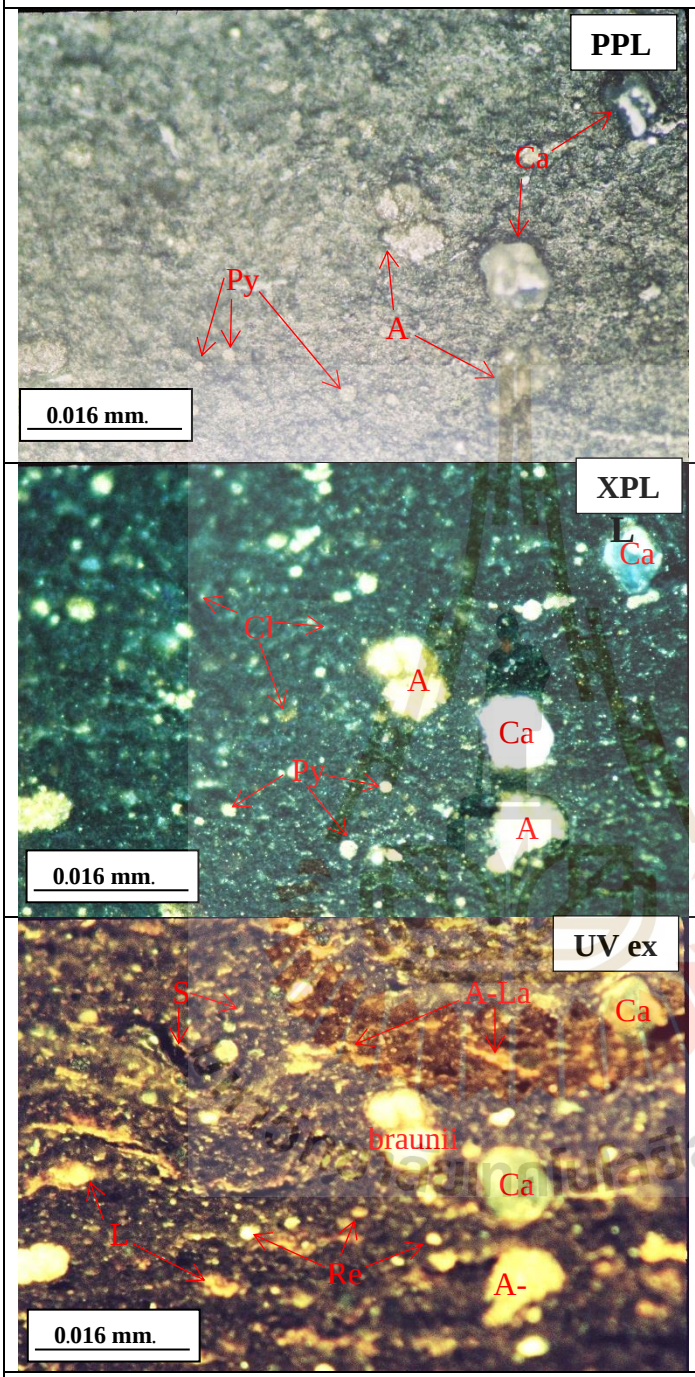
Microscopic Picture	Explanation
	**Sample No. AS3/21-3** **Oil Shale** shows sapropelite deposits of alginite and mineral matters. Composition (%) V = 23 % L = 65 % I = 0 % MM = 12 % **Vitrinite** consist of fine grain of organic sediment cement by **gelinite.** **Densinite** display pale gray to dark gray in PPL and black in XPL. **Liptinite** display pale gray to dark gray in PPL and light brown to black in XPL. Under UV excitation. **Resinite** display bright yellow spots with sphere shape. **Sporinite** display as yellow dots with spore shape. **Alginite** (*botryococcus braunii*) display bright yellow with sphere shape and **alginite (lamaginite)** or **Liptodestrinite** display yellow to yellowish-brown long body without shape **Mineral matters** consist of pyrite, clay and carbonate. Carbonates show rectangular crystal diamond and fluorescent pale gray in PPL, white to gray and yellow to greenish yellow in UV ex. Pyrites are framboidal pyrite.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation Re = Resinite, S = Sporinite, A = Alginite, Li = Liptodestrinite, Py = Pyrite, Cl = Clay, Ca = Carbonate	

Figure 4.126 The microscopic picture of oil shale sample AS3/21 – 3

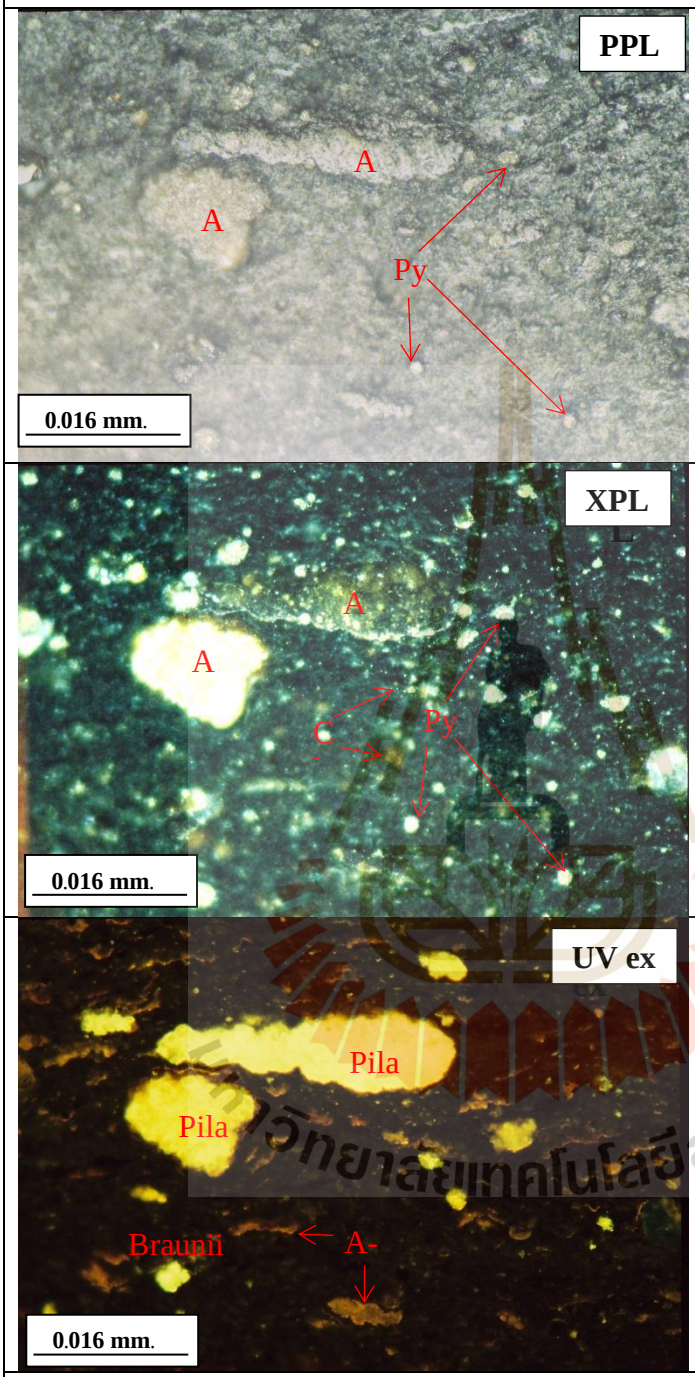
Microscopic Picture	Explanation
	**Sample No. AS3/21-4** **Oil Shale** shows sapropelites deposited and mineral matters. Composition (%) V = 16 % L = 74 % I = 0 % MM = 10 % **Vitrinite** consist of fine grain of organic sediment cement by **gelinite.** **Densinite** display pale gray to dark gray in PPL and black in XPL. **Liptinite** display pale gray to dark gray and light brown in PPL and light brown to black in XPL. Under UV excitation colonies of *botryococcus* sp. display white yellow to yellow. *Botryococcus braunii* display as white with body. **Lamaginite** display as brown to dark brown line. **Mineral matters** consist of clay and pyrite. Clay display dark gray to black in PPL and white dots in XPL and dark in UV ex. The circle bright in PPL, white dots in XPL and dark in UV ex for framboidal pyrite.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation Cl = Clay, Py = Pyrite, A = Algrinite, A-La = Lamaginite	

Figure 4.127 The microscopic picture of oil shale sample No. AS3/21 – 4

4.2.6 Lower Oil Shale sub-unit

The Lower Oil Shale sub-unit is a successive sequence above the Coal A. The unit indicates the environmental conditions changing suddenly from the shallow water in forest-peat swamp (Coal A sub-unit) to high stand water (Oil Shale unit). The high stand deep water with high nutrient result in the accumulation of thick algae deposited with gelinite and fine-grained sediments. Under microscopy, the composition of the lower oil shale sub-unit consists mainly of mineral matter vary from 62 – 87% (Table 4.7). Most of sediments are clay mineral which display fluffy character with white in PPL and XPL. Some layers consist of pyrite displaying as metallic bright spots in PPL with dark in XPL and under UV excitation.

Maceral is mainly of liptinite and vitrinite. Liptinite consist mainly of alginite deposited together with fine-grained sediments cemented by gelinite. The alginite consist mainly of lamalginite (3 – 23%) and some telalginite (4%). The lamalginite in this sub-unit display as both long and short bodies, but they are thinner and shorter than those of the other sub-units. The thick and thin algal mats indicated the algal booms related to the seasoning nutrient supply and the flavoring temperature conditions which led to the different character of algae (Tsukii, 2014). Both of long and short body lamalginite in this oil shale sub-unite are very small and thin. Therefore, this could indicate the lower nutrients supply than other sub-units. The other liptinite are liptodetrinite and sporinite.

The long and short body of lamalginite display dark brown to black in XPL and white yellow to greenish yellow under UV-excitation. The long body has length vary from 0.001 to 0.003 mm while the short body has the length less than a half of the long body (less than 0.001 mm) (Figure 4.132). The short lamalginite look like

sporinite, but lamalginite have shape on both of nibs while the sporinite have bend on the end of body. In addition, the color of sporinite often brighter than lamalginite and display. White yellow to orange in fluorescence. The telalginite is mostly of *Pila* algae which display spheroid, ovoid to circular shape in massive colony. *Pila* colony is 0.016 to 0.024 mm long and 0.002 to 0.008 mm thick in the perpendicular section. They might be *Botryococcus* sp. and the related algae of telalginite (Figure 4.130 and 4.131).

Table 4.9 Composition in percentage of the Lower Oil Shale sub-unit.

Sample	Liptinite											Vitrinite (%)	Mineral Matter			
	Alginite			Lip	Sp	Cu	Fl	Re	Su	Ex	Total		Clay	Q+Si	Py	Total
	Lam	Tela														
		Bo	Pil													
OH1-1	23	8	0	5	0	0	0	0	0	0	36	2	45	13	4	62
OH2-1	3	15	0	12	0	0	0	0	0	0	30	5	57	6	2	65
OH2-2	9	13	0	2	0	0	0	0	0	0	24	3	62	10	1	73
OH3-1	8	2	0	5	0	0	0	0	0	0	15	1	68	15	1	84
OH3-2	13	2	0	2	0	0	0	0	0	0	17	5	68	5	5	78
OH4-1	7	3	0	3	0	0	0	0	0	0	13	0	79	6	2	87
OH4-2	9	0	1	3	0	0	0	0	0	0	13	2	76	7	2	85
OH4-3	13	0	0	4	0	0	0	0	0	0	17	2	77	2	2	82
OH5-1	14	1	0	3	0	0	0	0	0	0	18	5	76	1	0	77
OH5-2	17	1	0	3	1	0	0	0	0	0	22	8	65	3	2	70
OH5-3	14	0	0	0	1	0	0	0	0	0	15	8	62	5	10	77
OH6-1	3	3	2	5	4	0	0	0	0	0	17	4	78	1	0	81
OH6-2	6	3	0	8	2	0	0	0	0	0	19	7	72	2	0	74
Max	23	15	2	12	4	0	0	0	0	0	36	8	79	15	10	87
Min	3	1	1	2	1	0	0	0	0	0	13	1	45	1	1	62
%	**10.69**	**3.92**	**0.231**	**4.231**	**0.615**	**0**	**0**	**0**	**0**	**0**	**19.69**	**4**	**68.08**	**5.846**	**2.385**	**76.31**

Vitrinite (consist of telovitrinite, detrovitrinite and gelovitrinite), Q = Quartz, Si = Silica, Py = Pyrite
Lam = Lamalginite, Tela = Telalginite, Bot = Botryococcus brounii, Pil = Pila algae, Lip = Liptodestrinite, Sp = Sporinite, Cu = Cutinite, Fl= Fluorinite, Re = Resinite, Su = Suberinite, Ex = Exsudatinite

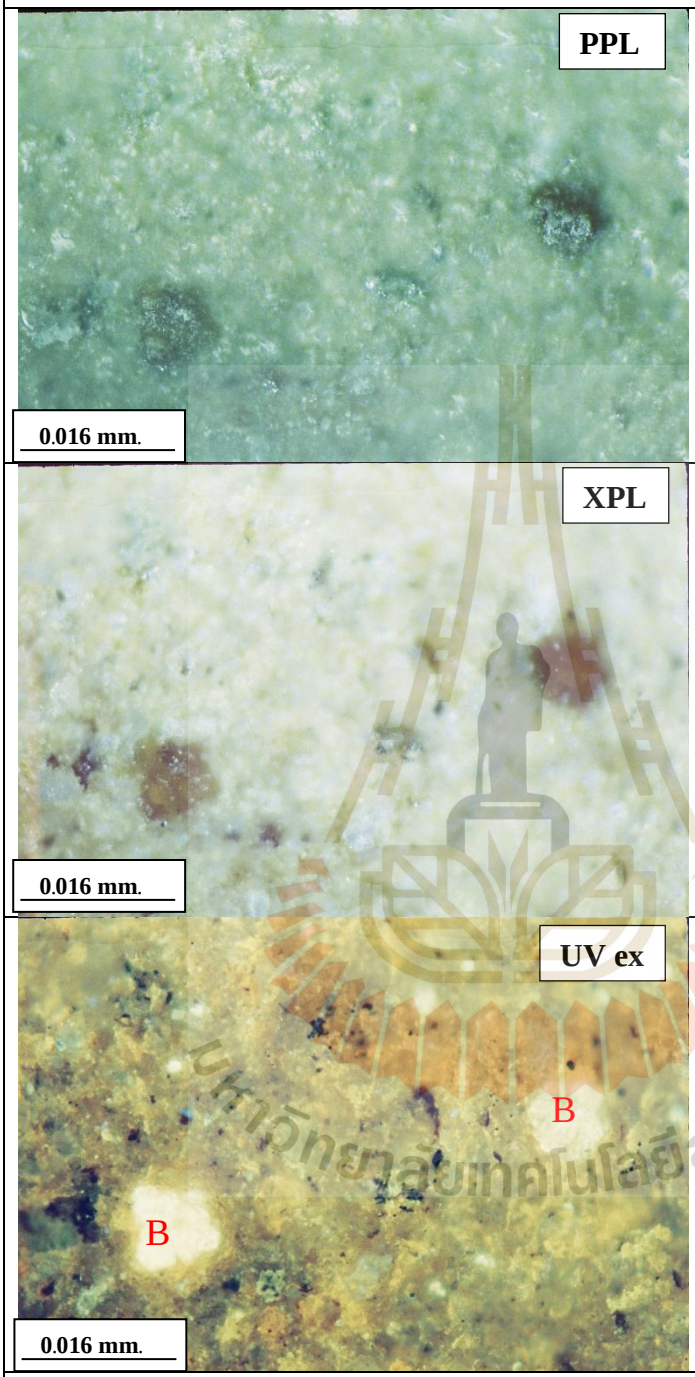
Microscopic Picture	Explanation
	**Sample No. OH1-1** **Oil Shale (Algite)** shows sediment deposited with algae. Composition (%) V = 2 % L = 36 % I = 0 % MM = 62 % **Vitrinite** consist of coal fragment. They display dark gray to black in PPL and black in XPL. **Liptinite** display dark gray and black in PPL and yellowish brown to dark brown in XPL. Under UV excitation, **telalginite** algae display white to bright yellow and *botryococcus braunii* show 4 cup structure. **Lamaginite** display yellow with long shape. **Mineral matter** consist of silica. They display white fume in XPL are clay/ silica fume. The bright crystal in PPL, white in XPL and dark in UV ex are quartz.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation A-La = Lamaginite algae, A-Te = Telalginite, Py = Pyrite	

Figure 4.128 The microscopic picture of oil shale sample No. OH1 – 1.

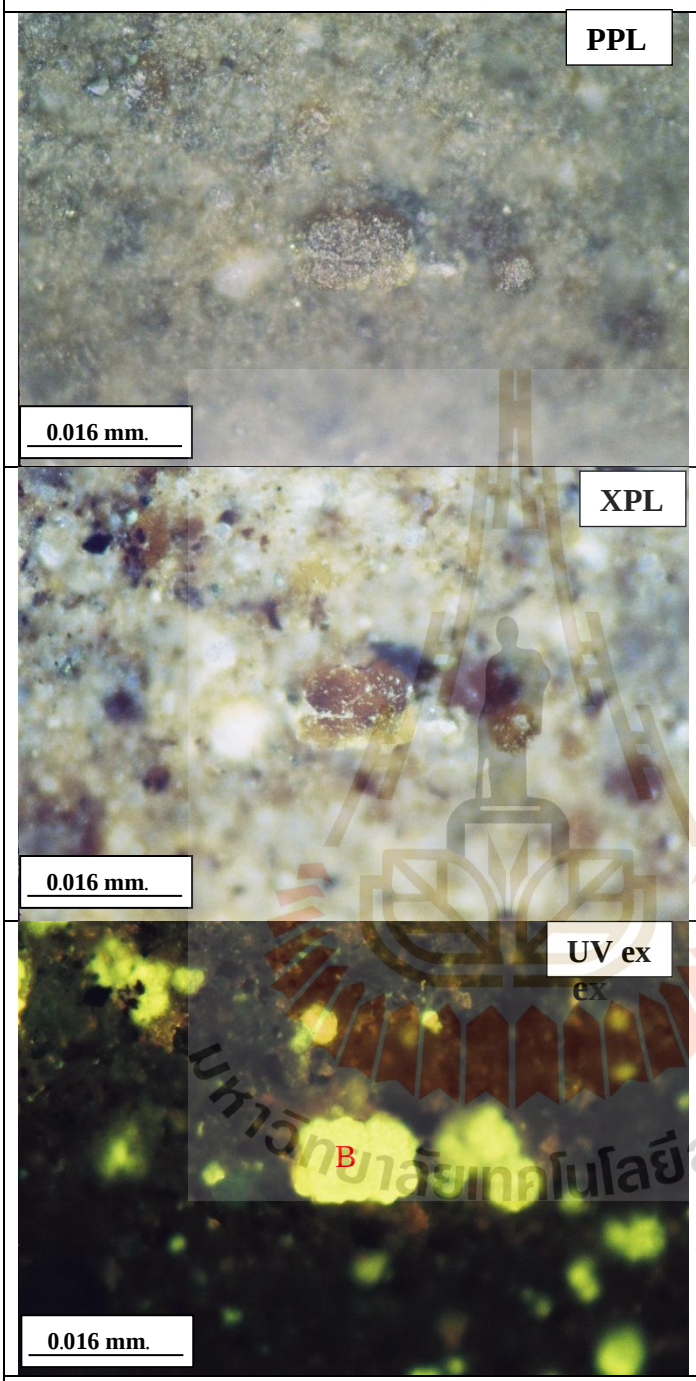
Microscopic Picture	Explanation
	**Sample No. OH2-1** **Oil Shale** shows sediment deposited with algae. Composition (%) V = 5 % L = 30 % I = 0 % MM = 65 % **Vitrinite** consist of coal fragment. They display show dark gray to black in PPL and black in XPL. **Liptinite** display dark gray and black in PPL and yellowish brown to dark brown in XPL. Under UV excitation **telalginite** algae display white to bright yellow for *botryococcus braunii*. It shows 4 cup structure. **Mineral Matter** The white fume in XPL are clay/ silica fume. The bright crystal in PPL, white in XPL and dark in UV ex are quartz.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation A-La = Lamaginite algae, A-Te = Telalginite, Py = Pyrite	

Figure 4.129 The microscopic picture of oil shale sample No. OH2 – 1.

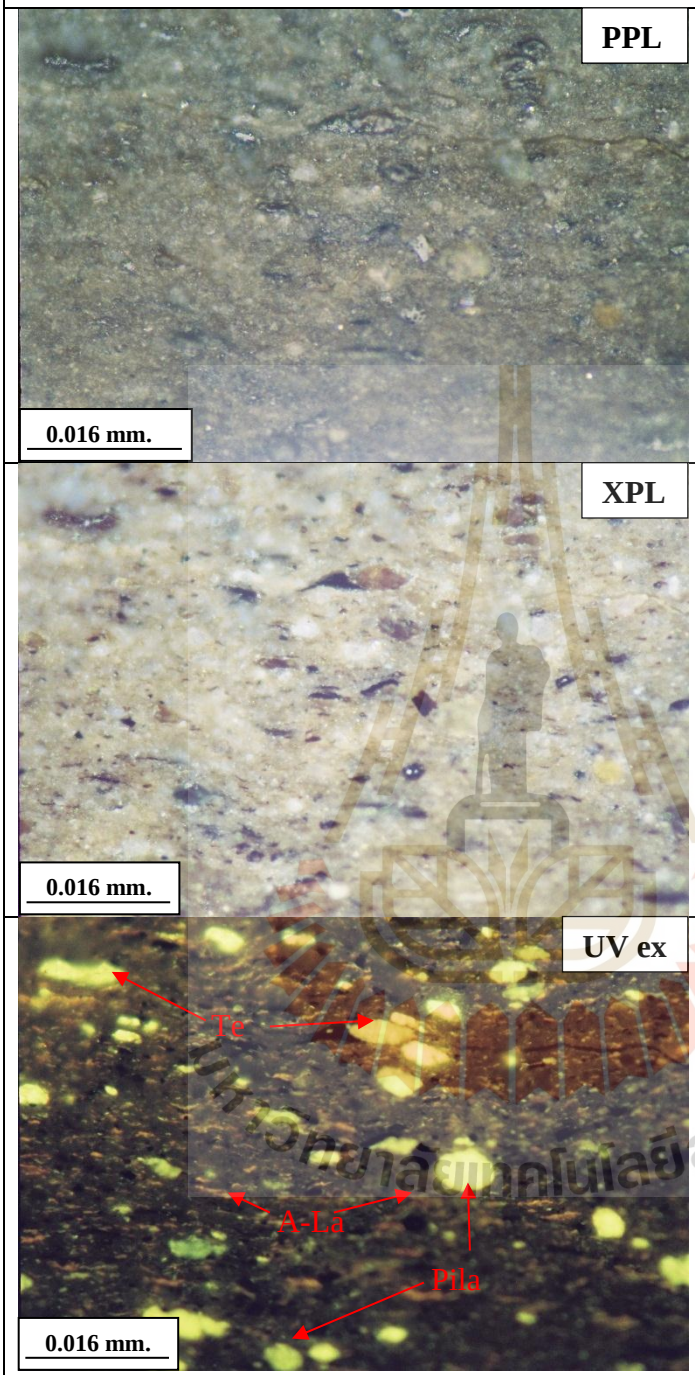
Microscopic Picture	Explanation
	**Sample No.OH2-2** **Oil Shale** shows algae mat deposited with organic sediment in the section cut in perpendicular. Composition (%) V = 3 % L = 24 % I = 0 % MM = 73 % **Vitrinite** consist mainly of gelinite. They display pale to dark gray in PPL and dark color in XPL to black under UV excitation. **Liptinite** consist mainly of lamalginite with minor telaginite. **Lamalginite** display white to yellow in PPL and XPL. Under UV excitation they display short and thin body with yellow to dark brown groundmass. **Telaginite** (*Pilla* algae) display pale gray to light yellow with high relief in PPL, white, dark brown in XPL and bright yellow under UV excitation. **Mineral matter** consist mainly of fine-grained sediments. They display white in XPL and dark in UV excitation. Some of pyrite display pale gray in PPL, and cubic dark brown to black in XPL and UV ex.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter A-La = Lamaginite algae, A-Te = Telalginite, Py = Pyrite	

Figure 4.130 The microscopic picture of oil shale sample No. OH2 – 2.

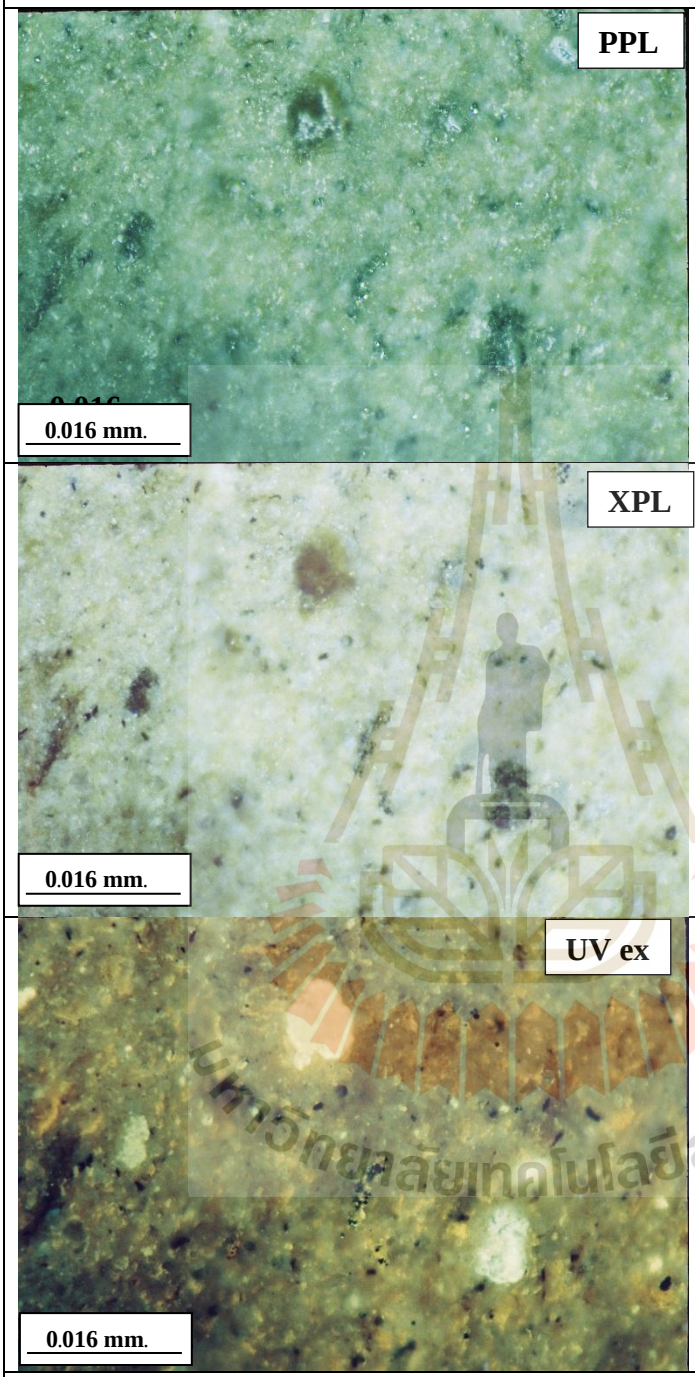
Microscopic Picture	Explanation
	**Sample No. OH3-1** **Oil Shale** shows fine-grained sediment deposited with algae. Composition (%) V = 1 % L = 15 % I = 0 % MM = 84 % **Vitrinite** consist of coal fragment. They display dark gray to black in PPL and black in XPL. **Liptinite** display dark gray and black in PPL and yellowish brown to dark brown in XPL. Under UV excitation **telalginite** algae display white to bright yellow. **Lamaginite** display yellow with long shape. The telalginite *botryococcus braunii*.show 4 cup structure. **Mineral Matter** consist of silica and quartz. The white fume in XPL are clay/ silica fume. The bright crystal in PPL, white in XPL and dark in UV ex are quartz.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation A-La = Lamaginite algae, A-Te = Telalginite, Py = Pyrite	

Figure 4.131 The microscopic picture of oil shale sample No. OH3 – 1.

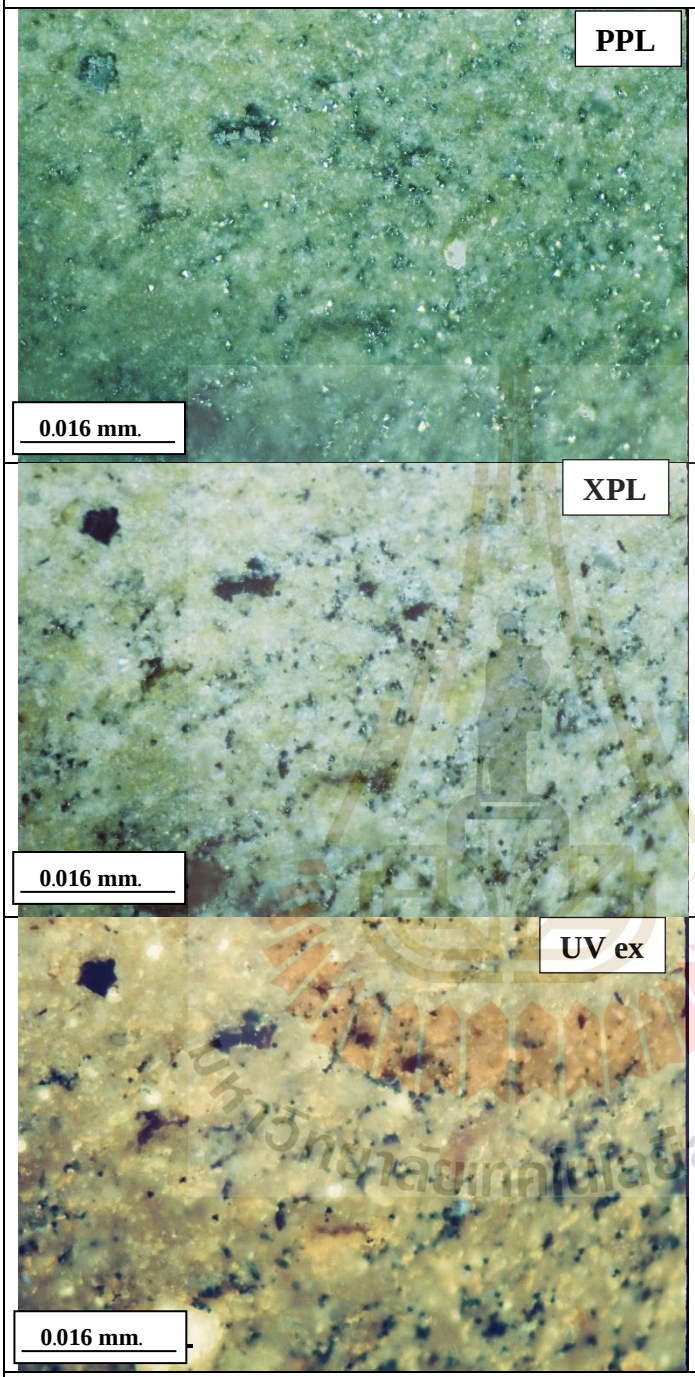
Microscopic Picture	Explanation
	**Sample No. OH3-2** **Oil Shale (Algite)** shows sediment deposited with algae. Composition (%) V = 5 % L = 17 % I = 0 % MM = 78 % **Vitrinite** consist mainly of **gelovitrinite**. They display dark gray to black in PPL and black in XPL. **Liptinite** show matrix of white to light yellow in XPL and yellow to orange under UV excitation. **Telalginite** algae display bright yellow and **lamaginite**.display yellow with long shape. **Mineral matter** consist of clay and silicate with pyrite. The white and yellow dots in XPL. The black dot are framboidal pyrite.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation A-La = Lamaginite algae, A-Te = Telalginite, Py = Pyrite	

Figure 4.132 The microscopic picture of oil shale sample No. OH3 – 2.

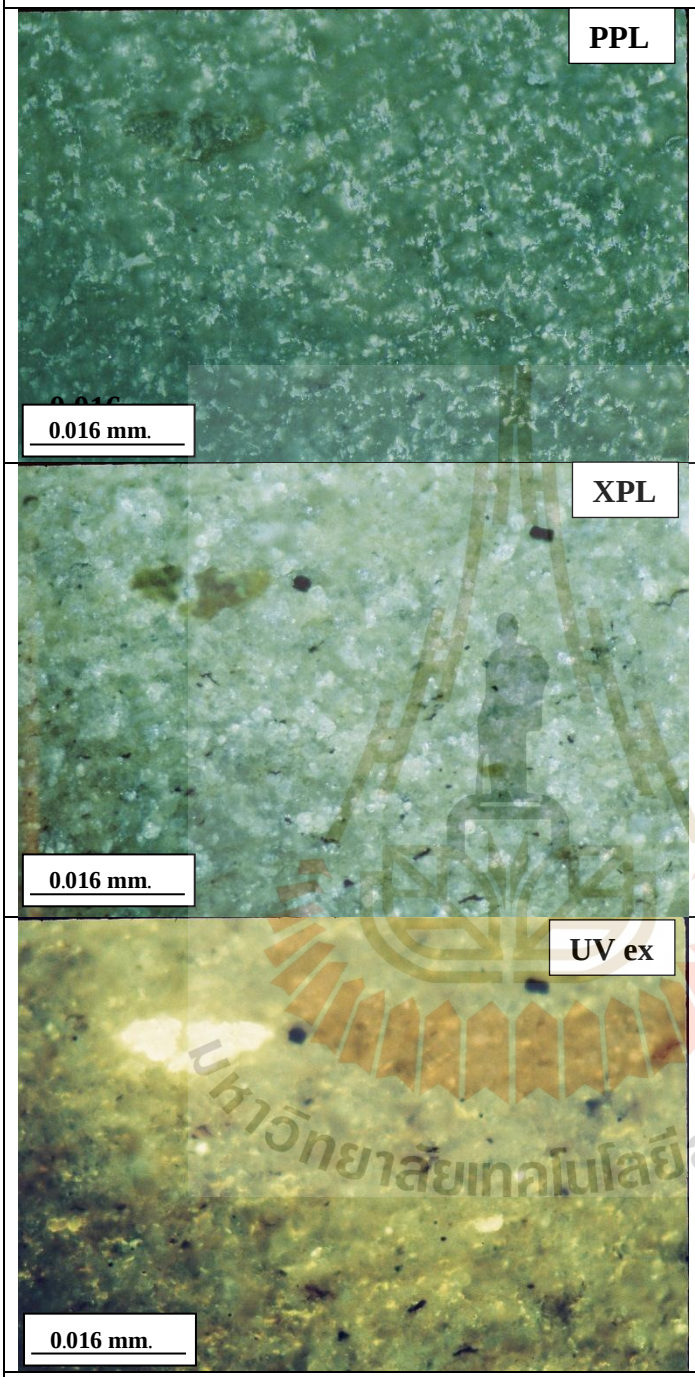
Microscopic Picture	Explanation
	**Sample No. OH4-1** **Oil Shale** shows very fine-grained sediments deposited with organic sediments. Composition (%) V = 0 % L = 13 % I = 0 % MM = 87 % **Vitrinite** consist mainly of **gelovitrinite.** They display dark gray to black in PPL and black in XPL. **Liptinite** show matrix of white to light yellow in XPL and yellow to orange under UV excitation. **Telalginite** algae display bright yellow and **lamaginite**.display yellow with long shape. **Mineral matter** consist mainly of silicate crystal and clay mineral. They display white to yellow in XPL.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation A-La = Lamaginite algae, A-Te = Telalginite, Py = Pyrite	

Figure 4.133 The microscopic picture of oil shale sample No. OH4 – 1.

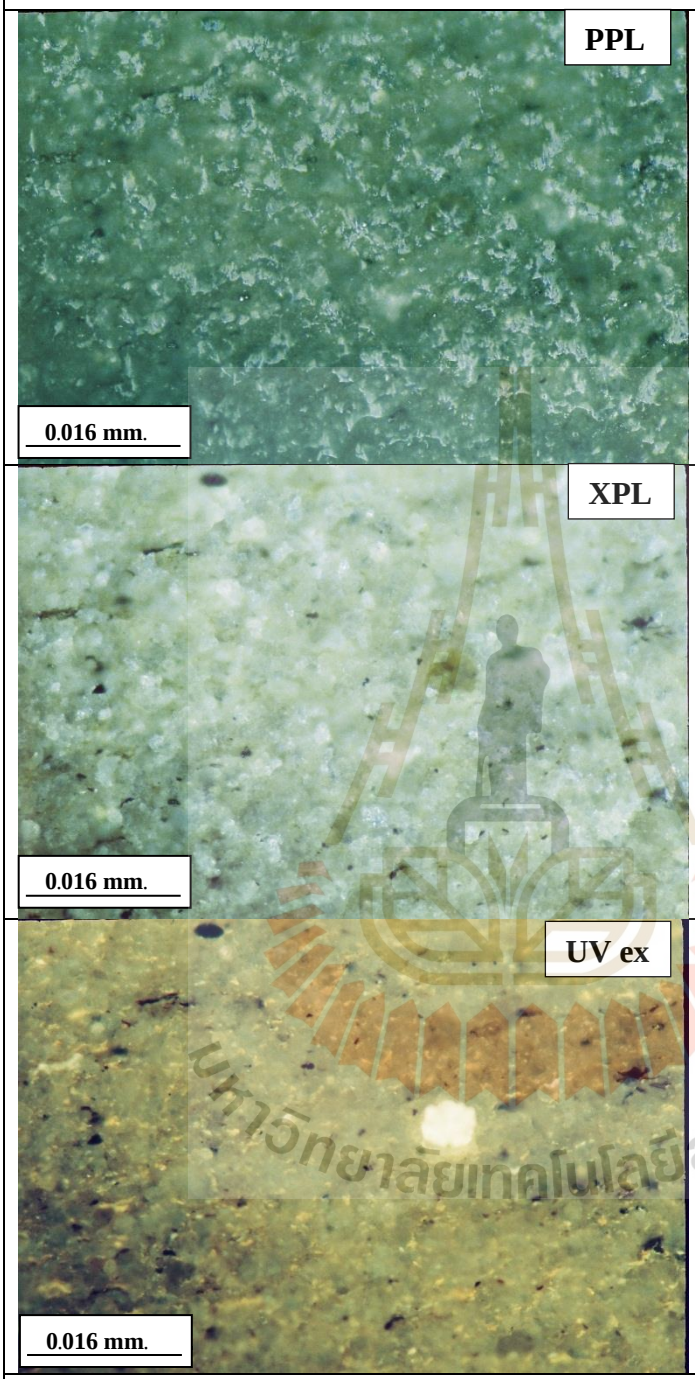
Microscopic Picture	Explanation
	**Sample No. OH4-2** **Oil Shale** shows very fine-grained sediments deposited with organic sediments Composition (%) V = 2 % L = 13 % I = 0 % MM = 85 % **Vitrinite** consist mainly of **gelovitrinite.** They display dark gray to black in PPL and black in XPL. **Liptinite** show matrix of white to light yellow in XPL and yellow to orange under UV excitation. **Telalginite** algae display bright yellow and **lamaginite**.display yellow with long shape. **Mineral matter** are mostly of silicate crystal and clay mineral. They display white to yellow in XPL.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation A-La = Lamaginite algae, A-Te = Telalginite, Py = Pyrite	

Figure 4.134 The microscopic picture of oil shale sample No. OH4 – 2.

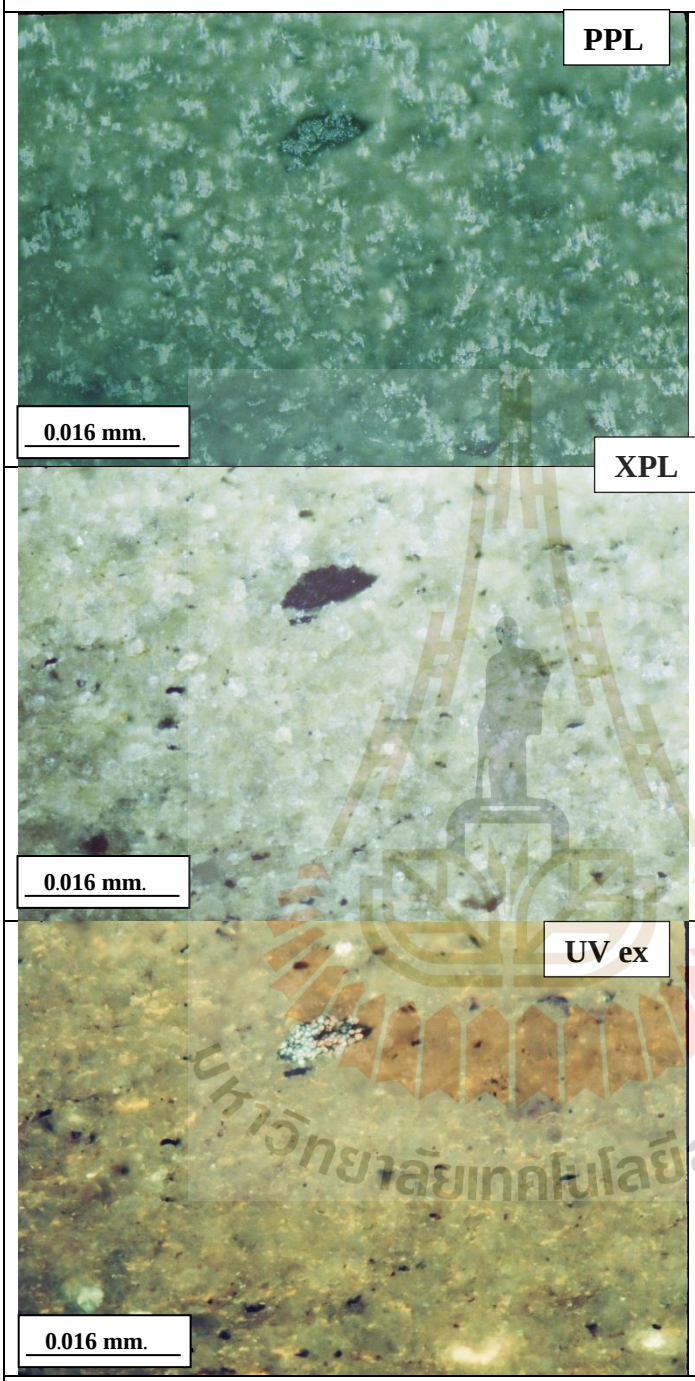
Microscopic Picture	Explanation
	**Sample No. OH4-3** **Oil Shale** shows very fine-grained sediments deposited with organic sediments. Composition (%) V = 2 % L = 17 % I = 0 % MM = 81 % **Vitrinite** consist mainly of **gelovitrinite.** They display dark gray to black in PPL and black in XPL. **Liptinite** show matrix of white to light yellow in XPL and yellow to orange under UV excitation. **Telalginite** algae display bright yellow and **lamaginite**.display yellow with long shape. **Mineral matter** are mostly of silicate crystal and clay mineral. They display white to yellow in XPL.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation A-La = Lamaginite algae, A-Te = Telalginite, Py = Pyrite	

Figure 4.135 The microscopic picture of oil shale sample No. OH4 – 3.

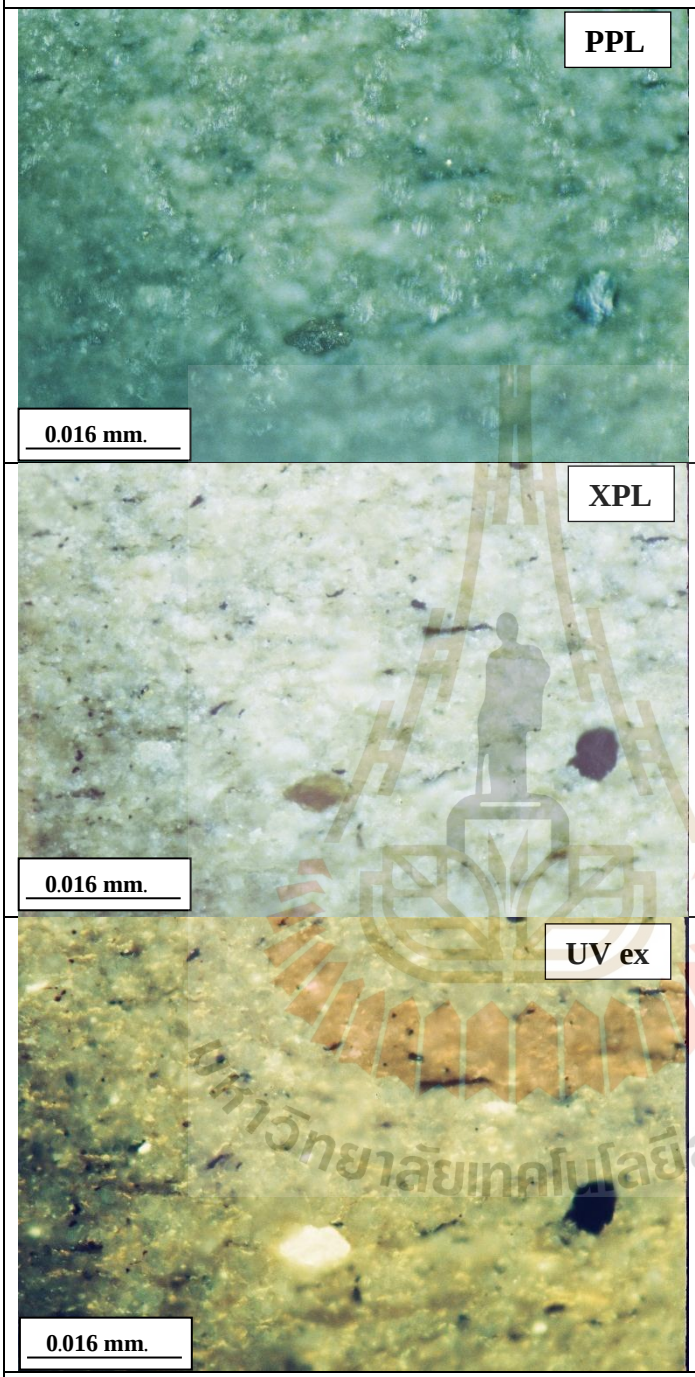
Microscopic Picture	Explanation
	**Sample No. OH5-1** **Oil Shale** shows very fine-grained sediments deposited with organic sediments. Composition (%) V = 5 % L = 18 % I = 0 % MM = 77 % **Vitrinite** consist mainly of **gelovitrinite.** They display dark gray to black in PPL and black in XPL. **Liptinite** show matrix of white to light yellow in XPL and yellow to orange under UV excitation. **Telalginite** algae display bright yellow and **lamaginite**.display yellow with long shape. **Mineral matter** are mostly of silicate crystal and clay mineral. They display white to yellow in XPL.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation A-La = Lamaginite algae, A-Te = Telalginite, Py = Pyrite	

Figure 4.136 The microscopic picture of oil shale sample No. OH5 – 1.

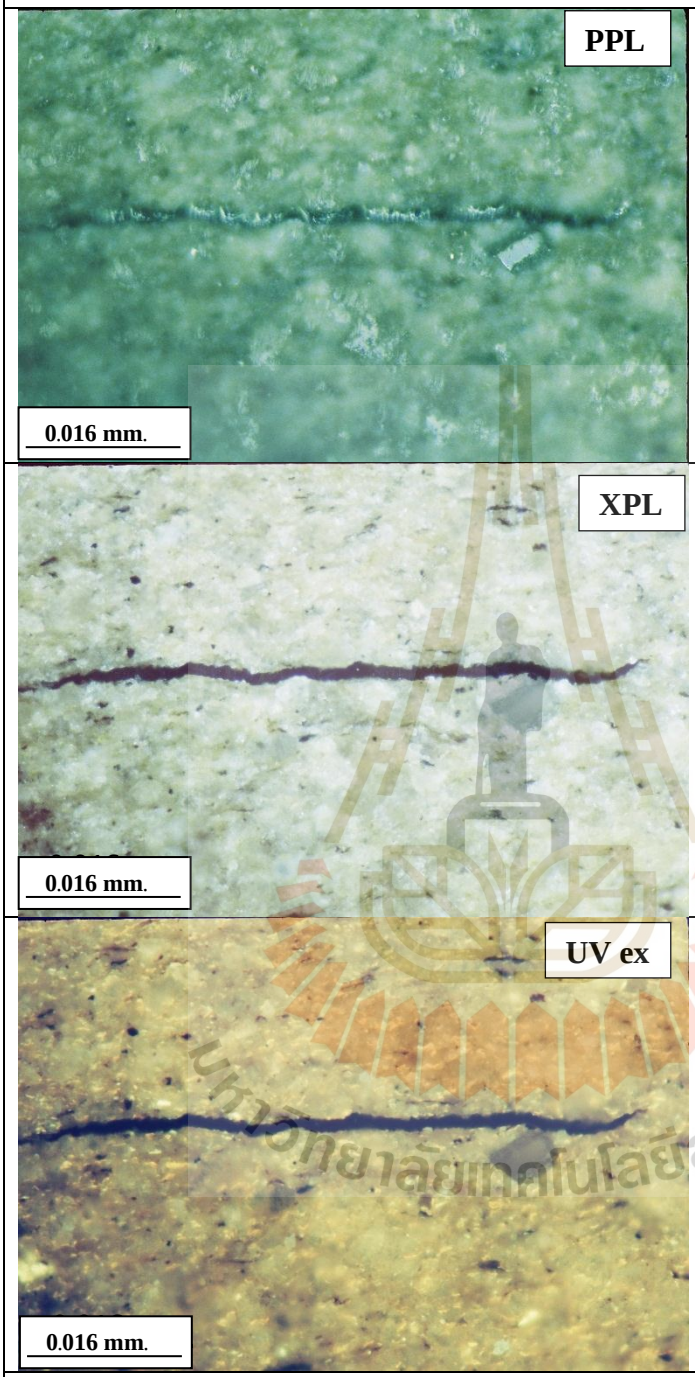
Microscopic Picture	Explanation
	**Sample No. OH5-2** **Oil Shale** shows gelovirinite deposited with fine-grained sediments in horizontal bed. Composition (%) V = 8 % L = 22 % I = 0 % MM = 70 % **Vitrinite** consist mainly of **gelovitrinite.** They display dark gray to black in PPL and black in XPL. **Liptinite** show matrix of white to light yellow in XPL and yellow to orange under UV excitation. **Telalginite** algae display bright yellow and **lamaginite**.display yellow with long shape. **Mineral matter** are clay and silicate crystal. Silica crystal display bright white in XPL and dark brown under UV ex with cubic shape.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation A-La = Lamaginite algae, A-Te = Telalginite, Py = Pyrite	

Figure 4.137 The microscopic picture of oil shale sample No. OH5 – 2.

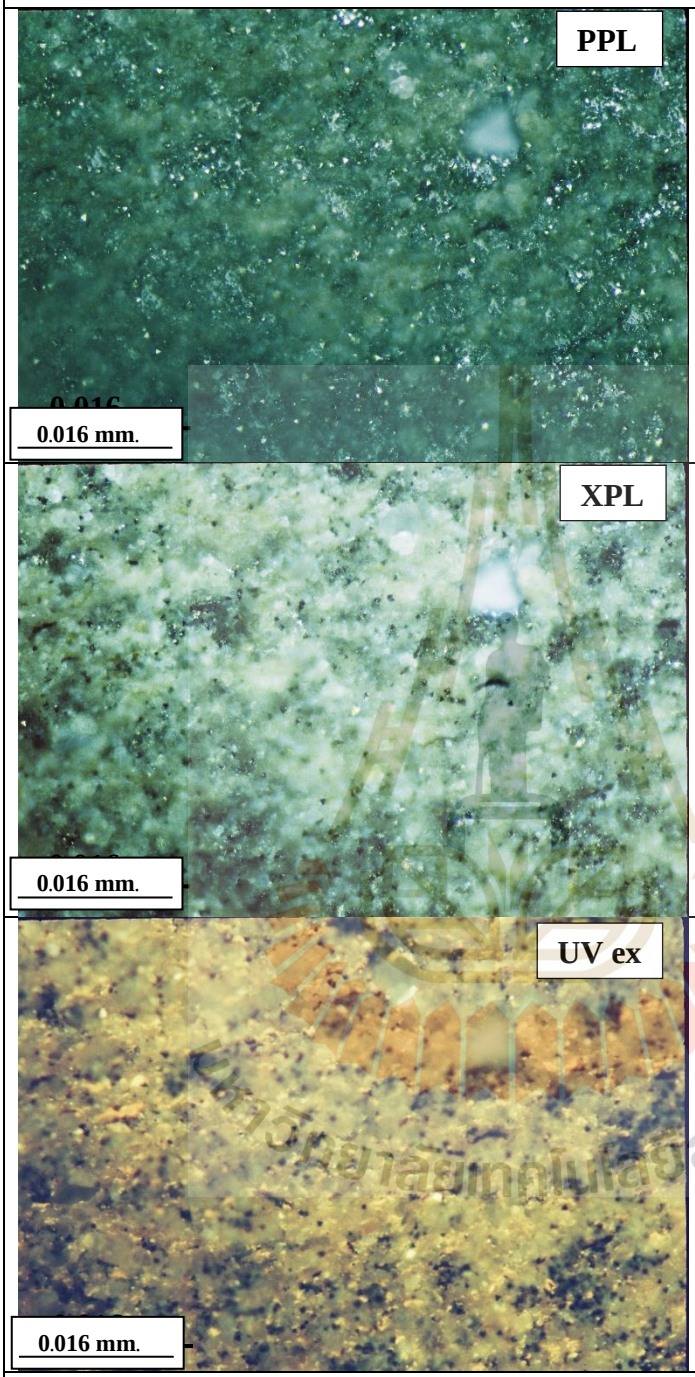
Microscopic Picture	Explanation
	**Sample No. OH5-3** **Oil Shale** shows sediment deposited with algae and framboidal pyrite. Composition (%) V = 8 % L = 15 % I = 0 % MM = 77 % **Vitrinite** consist mainly of **gelovitrinite.** They display dark gray to black in PPL and black in XPL. **Liptinite** show matrix of white to light yellow in XPL and yellow to orange under UV excitation. **Telalginite** algae display bright yellow and **lamaginite**.display yellow with long shape. **Mineral matter** consist mainly of clay and silicate. The white and yellow dots in XPL. The black dots are framboidal pyrite.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation A-La = Lamaginite algae, A-Te = Telalginite, Py = Pyrite	

Figure 4.138 The microscopic picture of oil shale sample No. OH5– 3.

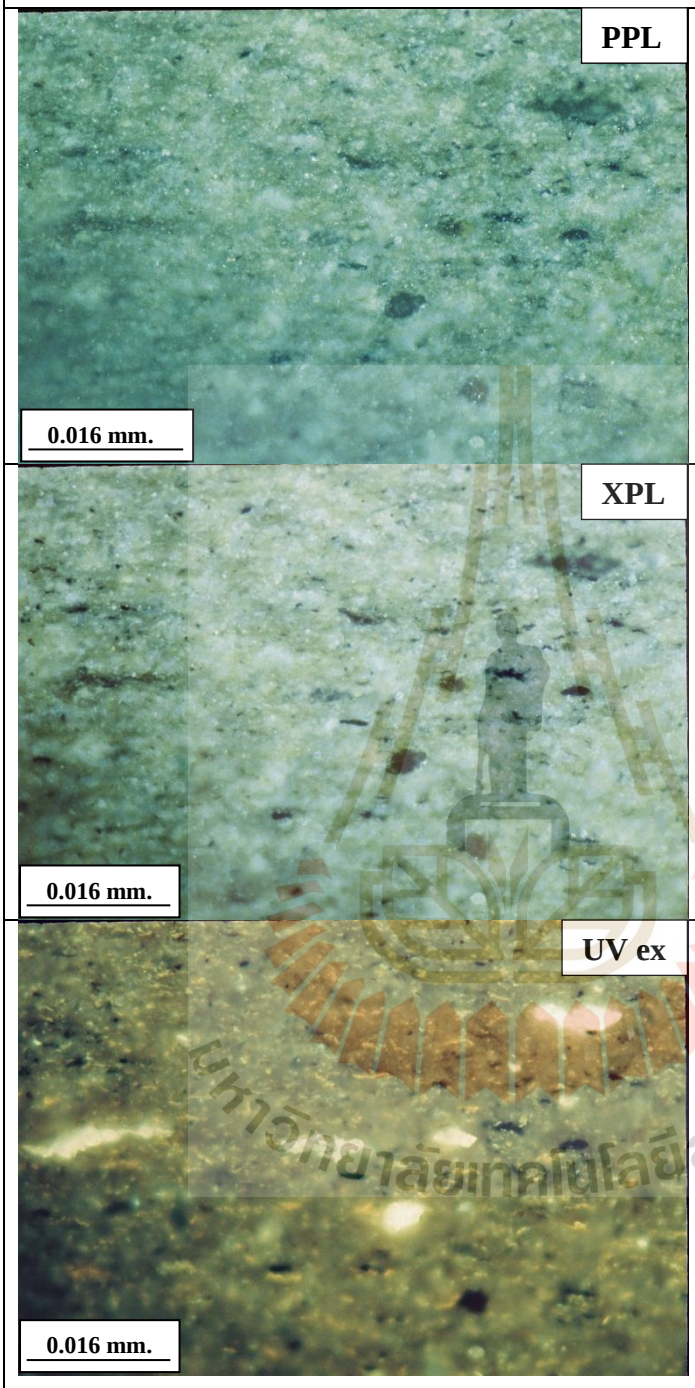
Microscopic Picture	Explanation
	**Sample No.OH6-1** **Oil Shale** shows fine-grained sediments deposited with algae. Composition (%) V = 4 % L = 17 % I = 0 % MM = 79 % **Vitrinite** consist mainly of **gelinite**. They display white to pale gray in PPL and black in XPL and UV excitation. **Liptinite** consists mainly of lamaginite. They display short and thin body. Under UV excitation, they display light yellow to orange groundmass with some telalginite colony. Telalginite display pale gray to light yellow in PPL, white to light brown in XPL and bright white to light yellow under UV ex. **Mineral matter** consist mainly of fine-grained clays. They display white in XPL and dark in UV excitation. Some of pyrite display dark gray in PPL, yellowish brown in XPL with cubic dark brown to black under UV excitation.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter A-La = Lamaginite algae, A-Te = Telalginite, Py = Pyrite	

Figure 4.139 The microscopic picture of oil shale sample No. OH6 – 1.

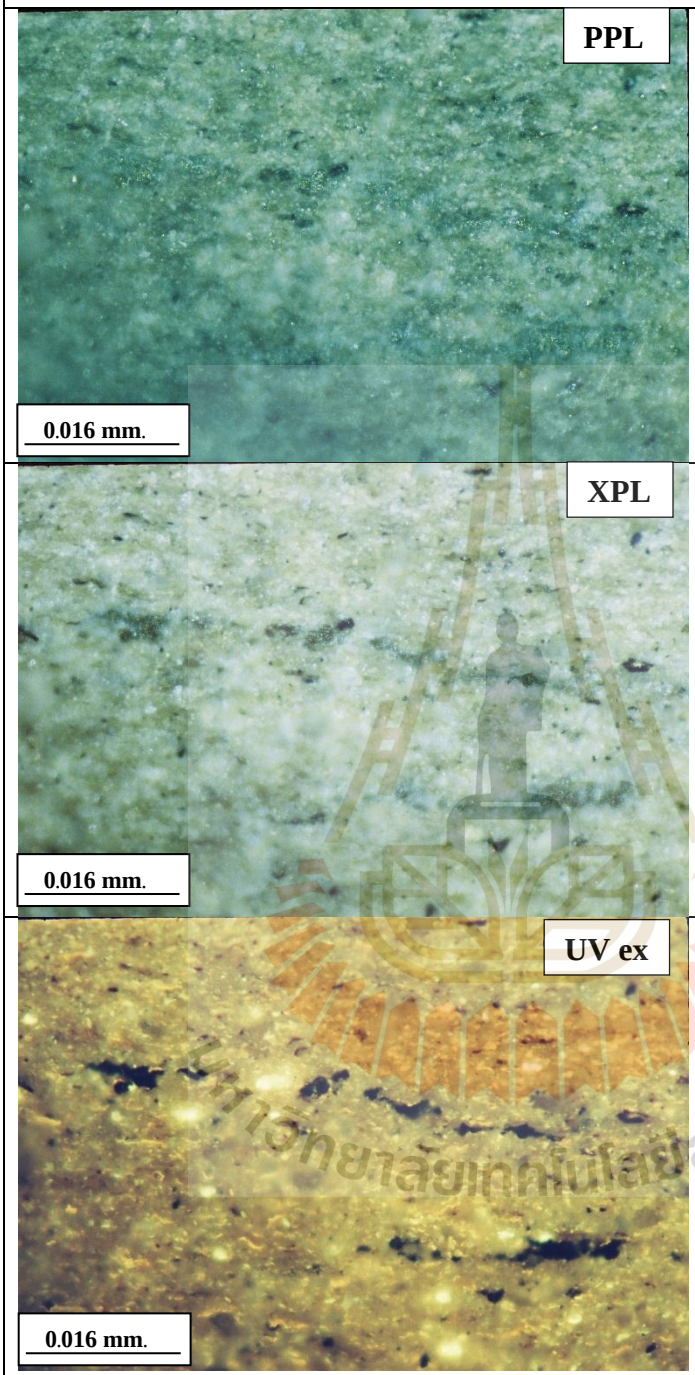
Microscopic Picture	Explanation
	**Sample No. OH6-2** **Oil Shale** shows gelovirinite deposited with fine-grained sediments in horizontal bed. Composition (%) V = 7 % L = 19 % I = 0 % MM = 74 % **Vitrinite** consist mainly of **gelinite**. They display white to pale gray in PPL and black in XPL and UV excitation. **Liptinite** consist mainly of **lamaginite**. They display short and thin body. Under UV excitation, they display light yellow to orange groundmass with some telalginite colony. **Telalginite** display pale gray to light yellow in PPL, white to light brown in XPL and bright white to light yellow under UV ex. **Mineral matter** consist mainly of fine-grained clays. They display white in XPL and dark in UV excitation. Some of pyrite display small dot dark gray in PPL, yellowish brown in XPL and black in UV ex.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation A-La = Lamaginite algae, A-Te = Telalginite, Py = Pyrite	

Figure 4.140 The microscopic picture of oil shale sample No. OH6 – 2.

4.2.7 Upper Oil Shale sub-unit

Upper Oil Shale sub-unit overlay conformably to the Lower Oil Shale sub-unit. They show character of clays. The environment of deposition was high stand quiet water with nutrient rich. This led to thick algal deposited and gradually receded before the strong current with large amount of inorganic sediments flooding into the basin and end of organic accumulation. The algal mat accumulated in the Upper Oil Shale sub-units are similar to those deposited in the Lower Oil Shale, but the seams are slightly longer and denser. These could be the result of better nutrients supply which led to richer algal booms and deposited as thicker oil shale beds and more uniform.

From petrographic study, the Upper Oil Shale consist of inorganic sediments (67.85%), liptinite (26.62%) and vitrinite (5.54%). The sediments are mostly of clay (55.15%) and the rest are quartz, silica and carbonate mineral and pyrite (Table 4.10). The liptinite macerals are mainly of lamalginite with some of telalginite. They display dark in PPL and pale gray to white in XPL (Figure 4.143 – 4.144). The coarser inorganic sediments of silt size were found at the contact between the Lower and the Upper oil shale sub-unit. The lamalginite (18.85%) is short to medium with thicker body. They are 0.0032 to 0.0048 mm long in the perpendicular section. They display dark yellow to orange fluorescence in UV-excitation.

The upper part of this sub-unit shows algal mats found associated only with lamalginite. They show paler color and thinner body. This layer is rich in lamalginite with minor telalginite (*Botryococcus* sp.) colony which are varying in size and shape. Framboidal pyrite was also found in this part. The lamalginite bodies become thinner and longer than 0.0032 mm. They display lighter yellow fluorescence in UV-excitation, than those of the lower sub-unit.

Table 4.10 Composition in percentage of the Upper Oil Shale sub-unit samples.

	Liptinite											Mineral Matter			
		Tela													
Sample	Lama	Bo	Pila	Lip	Sp	Cu	Fl	Re	Su	Ex	Total	Vitrinite	Clay	Q+Si	Py	Total
OH7-1	2	4	0	9	0	0	0	0	0	0	15	5	74	5	1	80
OH7-2	4	15	0	7	0	0	0	0	0	0	26	4	58	12		70
OH8-1	28	7	0	3	0	0	0	0	0	0	38	6	45	9	2	56
OH8-2	31	7	0	4	2	0	0	0	0	0	44	4	38	9	5	52
OH8-3	31	1	0	1	2	0	0	0	0	0	35	28	27	10		37
OH8-4	40	4	0	0	0	0	0	0	0	0	44	7	35	9	5	49
OH9-1	16	3	0	8	0	0	0	0	0	0	27	6	57	10		67
OH9-2	16	4	0	1	0	0	0	0	0	0	21	1	69	6	3	78
OH9-3	20	0	0	3	0	0	0	0	0	0	23	4	65	7	1	73
OH9-4	17	2	1	2	0	0	0	0	0	0	22	3	60	10	5	75
OH10-1	16	2	2	3	0	0	0	0	0	0	23	2	64	9	2	75
OH10-2	11	1	0	0	0	0	0	0	0	0	12	1	77	10		87
OH10-3	13	1	0	2	0	0	0	0	0	0	16	1	65	17	1	83
Max	40	15	2	9	2	0	0	0	0	0	44	28	77	17	5	87
Min	2	0	0	0	0	0	0	0	0	0	12	1	27	5	1	37
average	**18.85**	**3.92**	**0.23**	**3.31**	**0.31**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**26.62**	**5.54**	**56.46**	**9.46**	**1.92**	**67.85**

Vitrinite (consist of telovitrinite, detrovitrinite and gelovitrinite), Q = Quartz, Si = Silica, Py = Pyrite
Lam = Lamalginite, Tela = Telalginite, Bot = Botryococcus brounii, Pil = Pila algae, Lip = Liptodestrinite, Sp = Sporinite, Cu = Cutinite, Fl= Fluorinite, Re = Resinite, Su = Suberinite, Ex = Exsudatinite

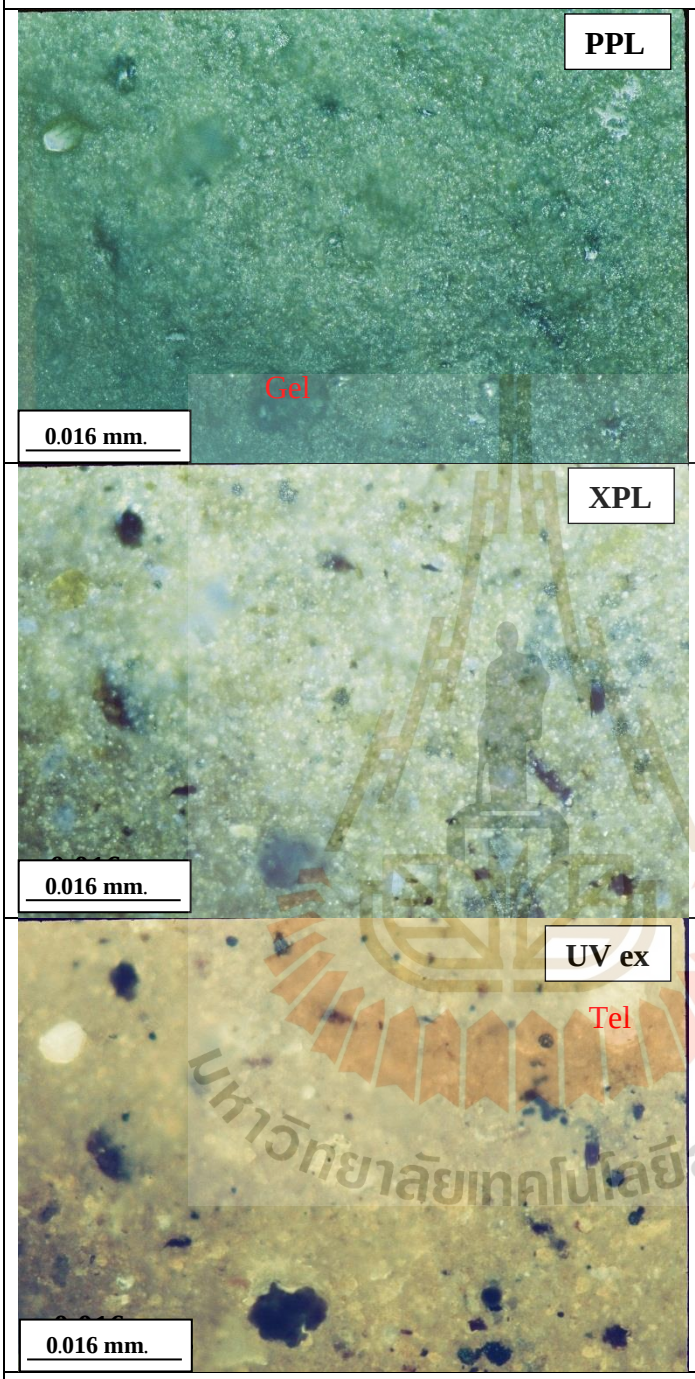
Microscopic Picture	Explanation
	**Sample No. OH7-1** **Oil Shale** shows fine-grained sediments deposited with algae and remains of coal gel in the section cut perpendicular to the cross bedding. Composition (%) V = 5 % L = 15 % I = 0 % MM = 80 % **Vitrinite** consist mainly of gelinite. They display colorless in PPL and black in XPL and UV excitation. **Liptinite** consist mainly of lamalginite and telaginite. Under UV excitation, lamalginite display yellow round body while telaginite display yellow groundmass. **Mineral matter** consists mainly of pyrite and clays. Pyrite is bright spots in PPL and dark in both of XPL and UV excitation. Clay minerals display dark gray to black in PPL and white to pale gray in XPL with cloudy texture.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation A-La = Lamaginite algae, A-Te = Telalginite, Py = Pyrite	

Figure 4.141 The microscopic picture of oil shale sample No. OH7 – 1

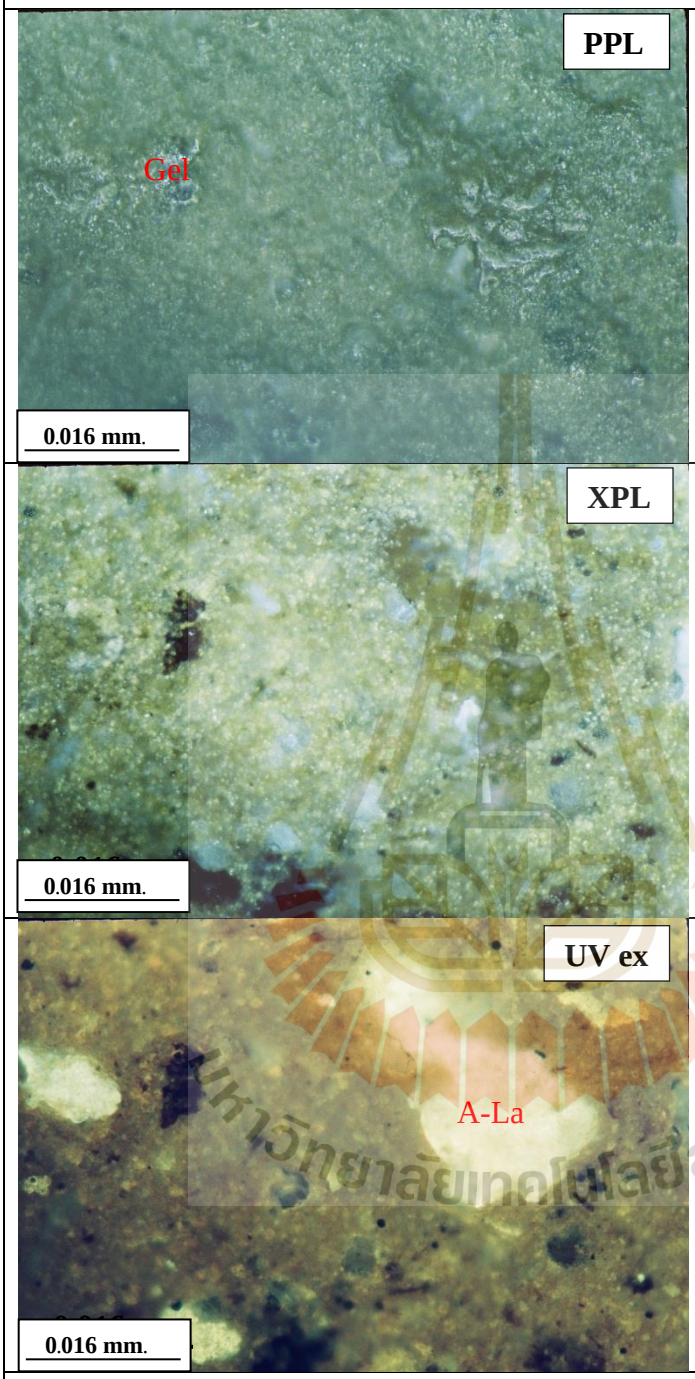
Microscopic Picture	Explanation
	**Sample No. OH7-2** **Oil Shale (Algite)** shows sediment deposited with algae in the section cut perpendicular to the cross bedding. Composition (%) V = 4 % L = 26 % I = 0 % MM = 70 % **Vitrinite** consist mainly of gelinite. They display colorless in PPL and black in XPL and UV excitation. **Liptinite** consist mainly of lamalginite. Under UV excitation, they display yellow groundmass with line body of lamalginite. **Mineral matter** consist mainly of pyrite and clays. Pyrite is bright spots in PPL and dark in both of XPL and UV excitation. Clay minerals display dark gray to black in PPL and white to pale gray in XPL with cloudy texture.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation A-La = Lamaginite algae, A-Te = Telalginite, Py = Pyrite	

Figure 4.142 The microscopic picture of oil shale sample No. OH7 – 2

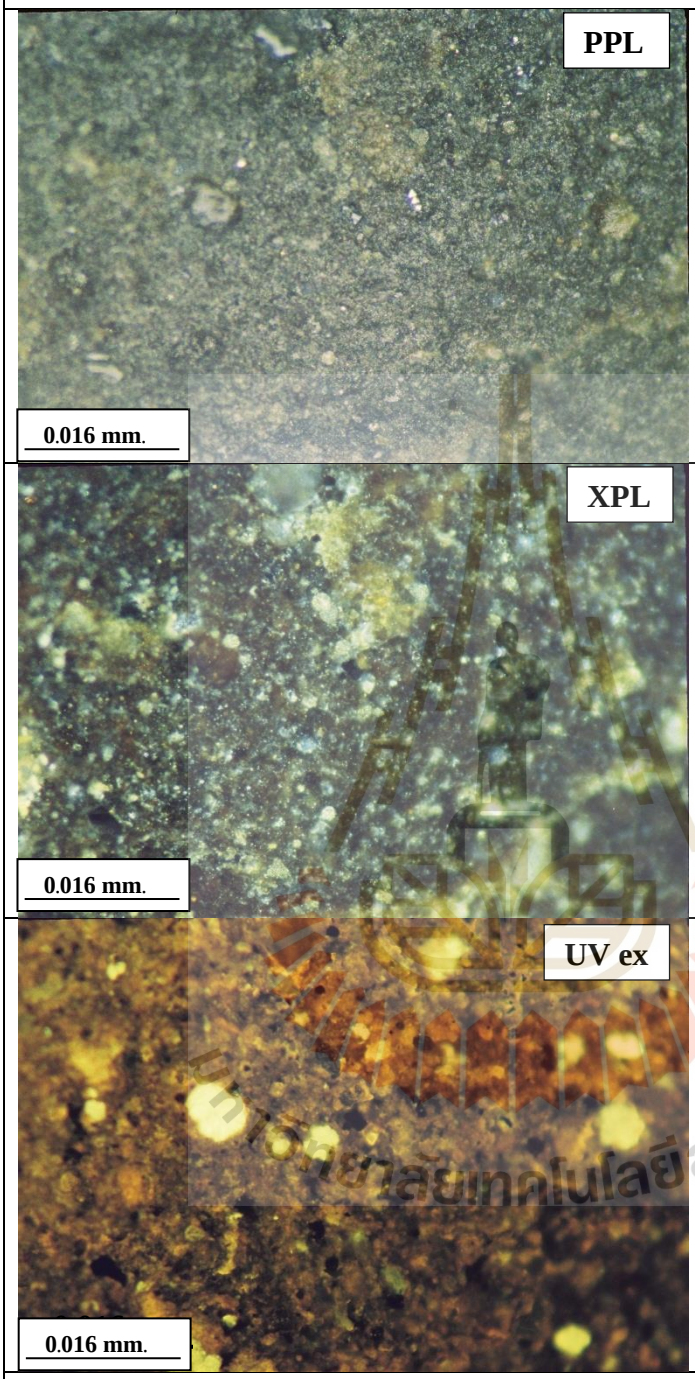
Microscopic Picture	Explanation
	**Sample No. OH8-1** **Oil Shale (Algite)** cut in the section perpendicular to bedding deposited with algae. Composition (%) V = 6 % L = 38 % I = 0 % MM = 56 % **Vitrinite** consist mainly of gelinite. They display dark gray to black in PPL and black in XPL. **Liptinite** consist mainly of alginite (lamalginite). Alginite display gray to dark gray in PPL and black in XPL and yellowish brown to brown in UV ex. They are remaining of lamalginite. **Mineral matter** are mainly of clays and silica. They display bright dots in PPL, white in XPL and dark in UV ex. Group of circles are silicate crystal.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation A-La = Lamaginite algae, A-Te = Telalginite, Py = Pyrite	

Figure 4.143 The microscopic picture of oil shale sample No. OH8 – 1

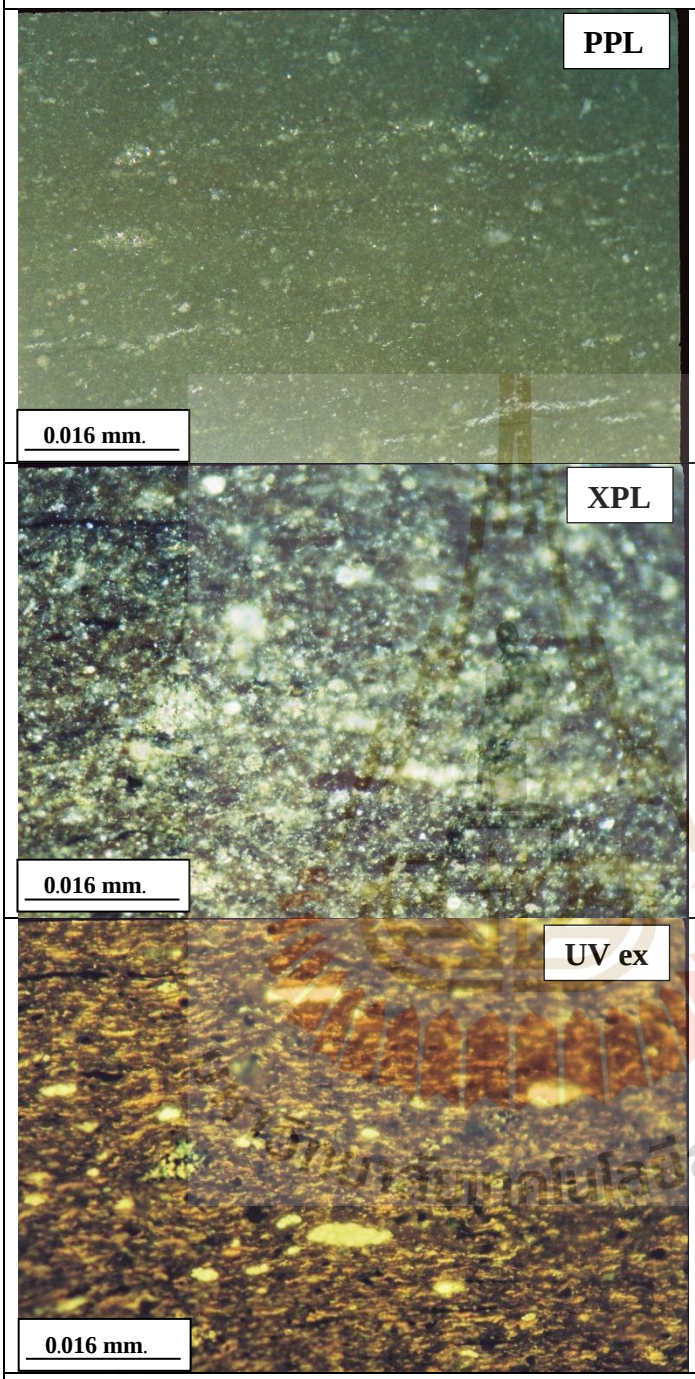
Microscopic Picture	Explanation
	**Sample No. OH8-2** **Oil Shale (Algite)** in the section cut parallel to bedding dominated by algae. Composition (%) V = 4 % L = 44 % I = 0 % MM = 52 % **Vitrinite** consist mainly of **densinite**. They display dark gray to black in PPL and black in XPL. **Liptinite** consist mainly of **alginate**. They display highly relief and reflect pale gray in PPL. The **telalginite** are colonies of *pila* algae of various size and shape. They display light yellow in XPL and white yellow in UV ex. The **lamalginite** algae are dark brown to black in XPL and yellowish-brown short line in UV ex. **Mineral Matter** are mainly of clay. They display white dots in XPL. Framboidal pyrite display group of spheres bright and white in PPL and XPL and black in UV excitation.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation A-La = Lamaginite algae, A-Te = Telalginite, Py = Pyrite	

Figure 4.144 The microscopic picture of oil shale sample No. OH8 – 2

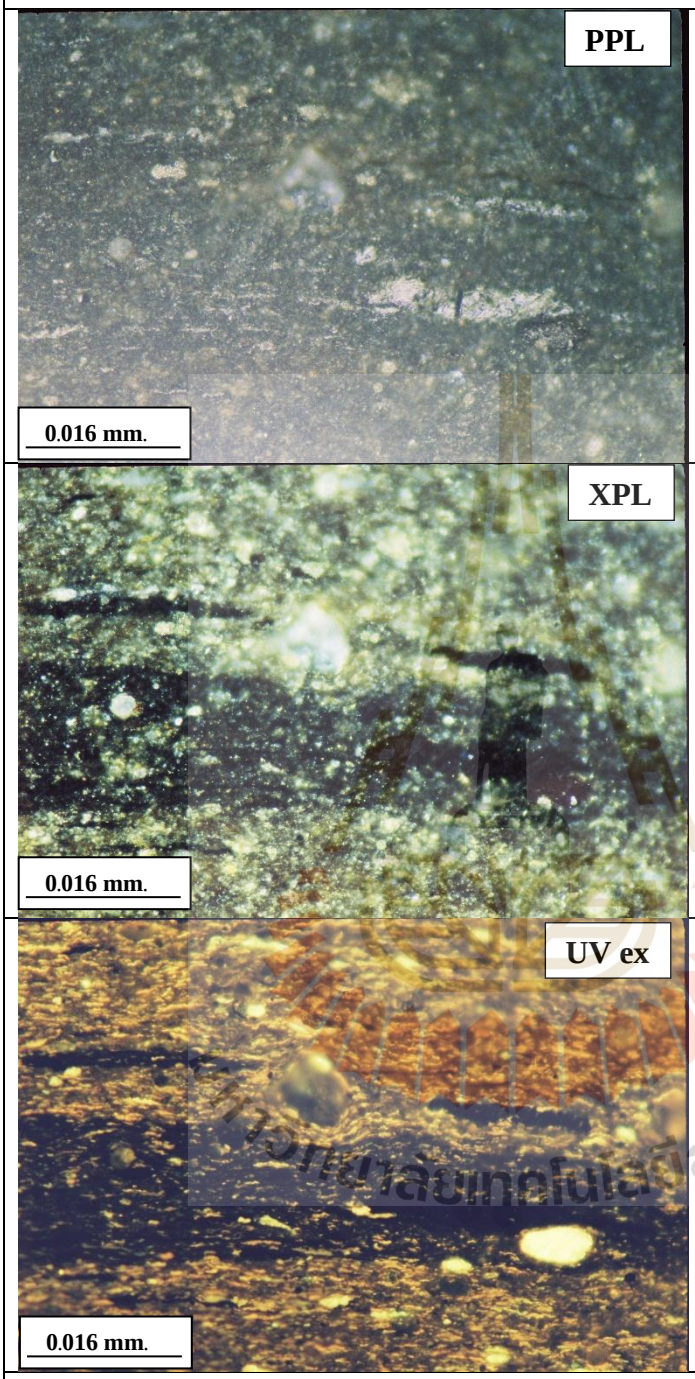
Microscopic Picture	Explanation
	**Sample No. OH8-3** **Oil Shale** shows sediment deposition with algae. Composition (%) V = 28 % L = 34 % I = 0 % MM = 38 % **Vitrinite** consist mainly of **densinite**. They show dark gray to black in PPL and black in XPL. **Liptinite** consist mainly of **alginate**. They display highly relief and reflect pale gray in PPL. The **telalginite** are colonies of *pila* algae of various size and shape. They display light yellow in XPL and white yellow in UV ex. The **lamalginite** algae are dark brown to black in XPL and yellowish-brown short line in UV ex. **Mineral matter** are mainly of clay. They display white dots in XPL. Silicate crystal show sphere bright and white in PPL and XPL and black in UV excitation.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation A-La = Lamaginite algae, A-Te = Telalginite, Py = Pyrite	

Figure 4.145 The microscopic picture of oil shale sample No. OH8 – 3

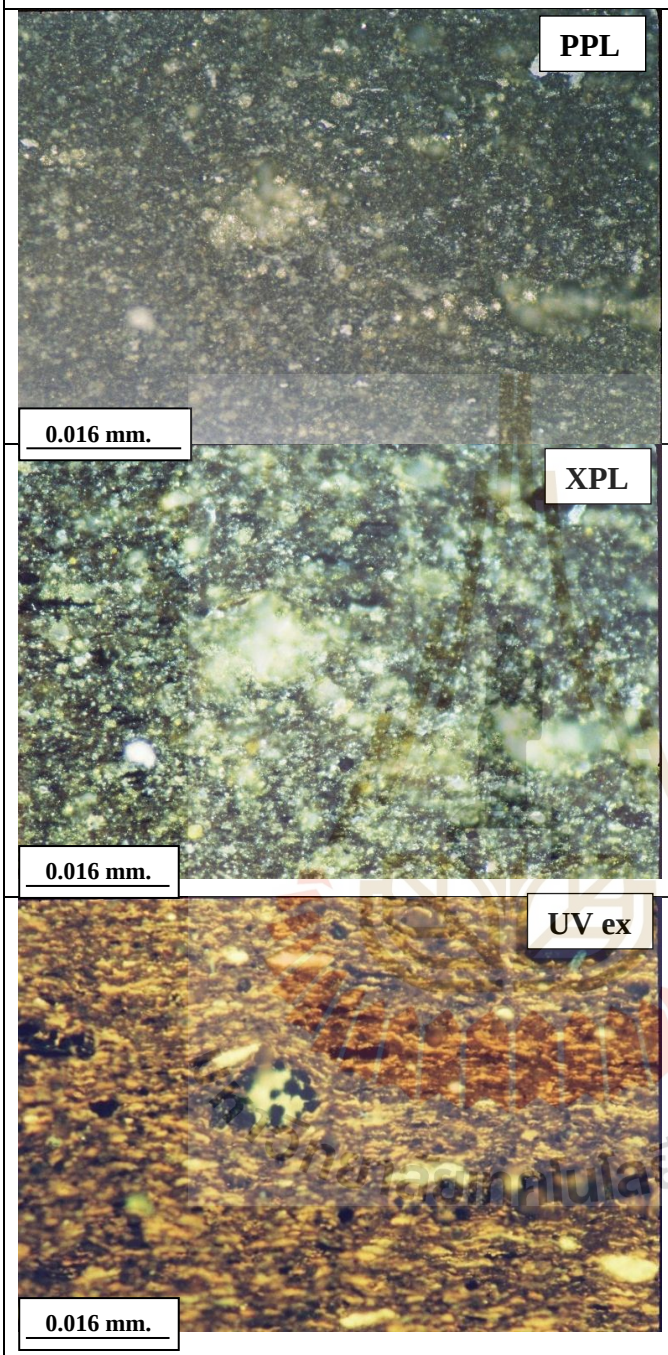
Microscopic Picture	Explanation
	**Sample No.OH8-4** **Oil Shale (Algite)** in the section cut perpendicular to bedding. Composition (%) V = 7 % L = 40 % I = 0 % MM = 53 % **Vitrinite** consist mainly of **gelinite.** They display dark gray to black in PPL and black in XPL. **Liptinite** are mostly of malginite and some telalginite. They show the compaction of algal mat. Lamalginite display dark gray to light yellow in PPL, strong color of white yellow dark gray in XPL. Under UV excitation they show yellow to yellowish brow, dark orange with body shape. Telalginite (*Botrycoccus* sp.) display bright to white yellow to greenish white group. **Mineral matter** are mainly of clays. They display white in XPL with fluffy character. Framboidal pyrite show circle shape and dark in UV excitation associated with telaginite algae.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter A-La = Lamaginite algae, A-Te = Telalginite, Py = Pyrite	

Figure 4.146 The microscopic picture of oil shale sample No. OH8 – 4

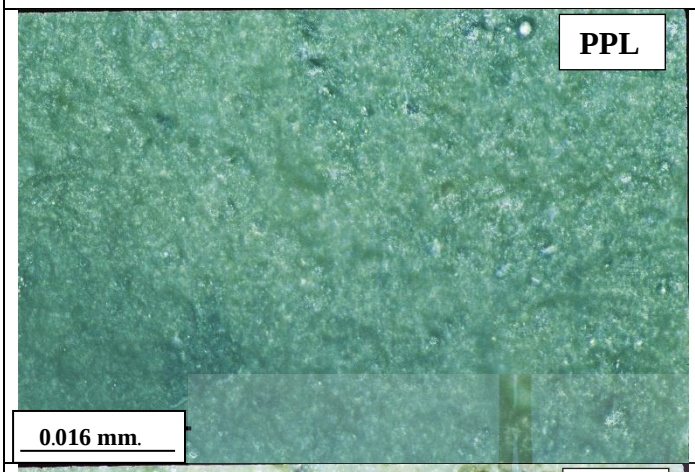
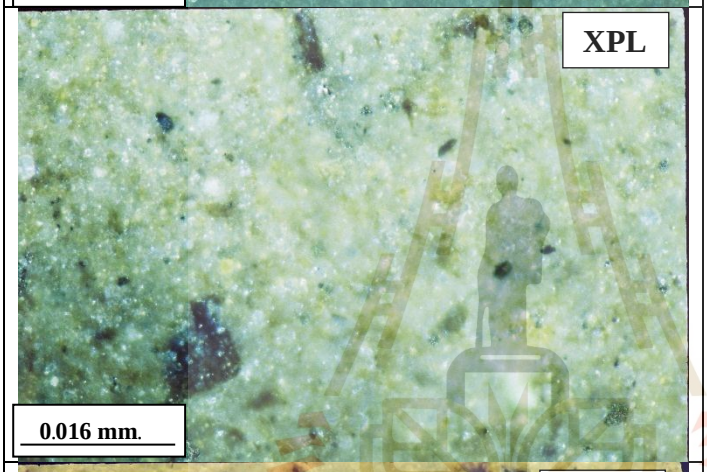
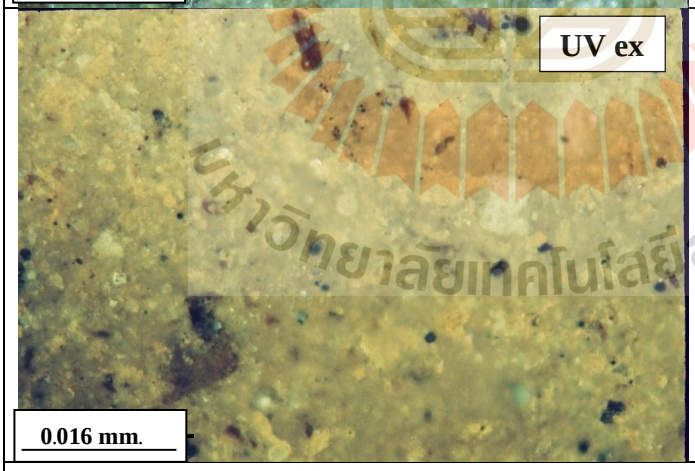
Microscopic Picture	Explanation
	**Sample No. OH9-1** **Oil Shale** shows fine-grained sediment deposition with algae. Composition (%) V = 6 % L = 27 % I = 0 % MM = 67 % **Vitrinite** consist of coal fragment. They display dark gray to black in PPL and black in XPL. **Liptinite** consist mainly of algae. They display dark gray and black in PPL and yellowish brown to dark brown in XPL. Under UV excitation alginite display white to bright yellow. **Mineral matter,** they display white fume in XPL are clay/ silica fume. The bright crystal in PPL, white in XPL and dark in UV ex are quartz
	
	
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation A-La = Lamaginite algae, A-Te = Telalginite, Py = Pyrite	

Figure 4.147 The microscopic picture of oil shale sample No. OH9 – 1

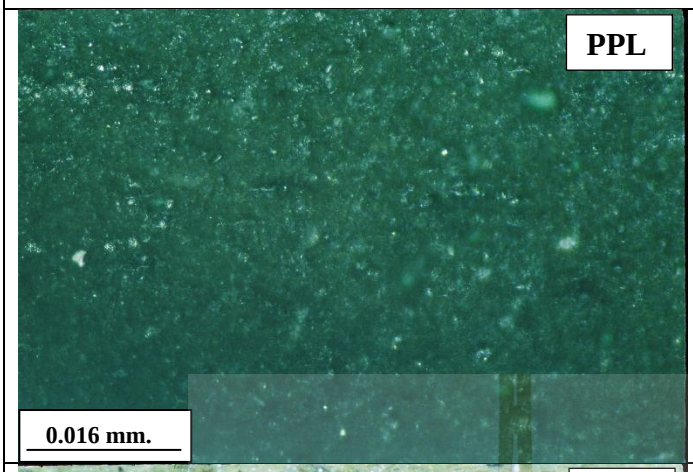
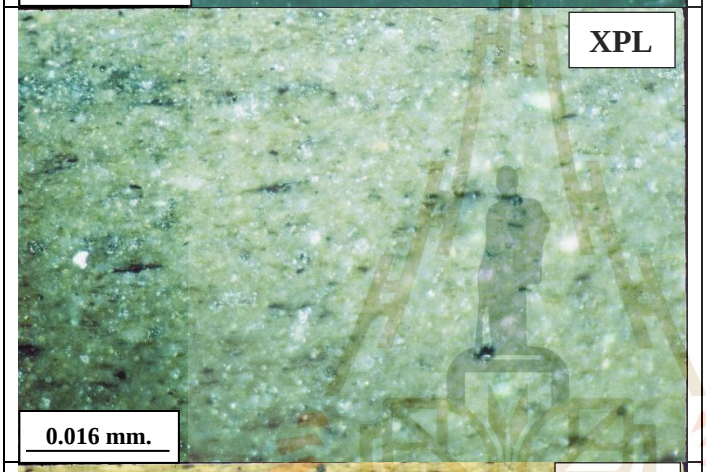
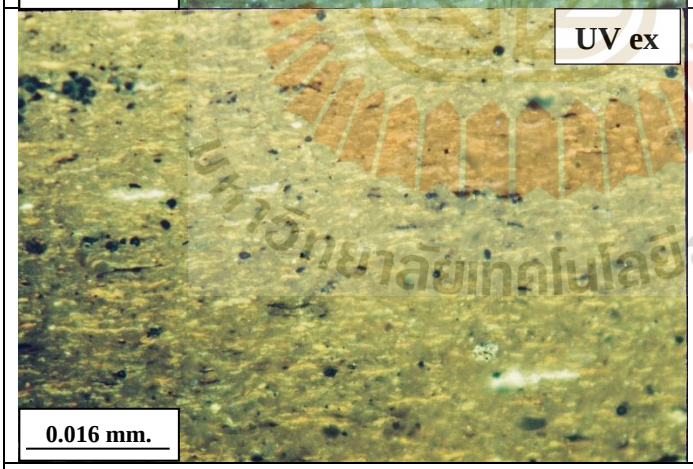
Microscopic Picture	Explanation
	**Sample No.OH9-2** **Oil Shale (Algite)** in the section cut perpendicular to bedding. Composition (%) V = 1 % L = 21 % I = 0 % MM = 78 %
	**Vitrinite** consist mainly of minor gelinite. **Liptinite** consist mainly of lamalginite and show algal mat of thin body compact. Lamalginite display dark gray in PPL, white to yellow in XPL. Under UV excitation, they display light yellow to yellow with some of telaginite colony (*Botryococcus* sp.) which display bright white to yellow.
	**Mineral matter** are mainly of clays. Clay display white in XPL and dark in UV excitation. Pyrite show sphere dots and framboidal pyrite display white in PPL, bright white in XPL and dark under UV ex.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter A-La = Lamaginite algae, A-Te = Telalginite, Py = Pyrite	

Figure 4.148 The microscopic picture of oil shale sample No. OH9 – 2

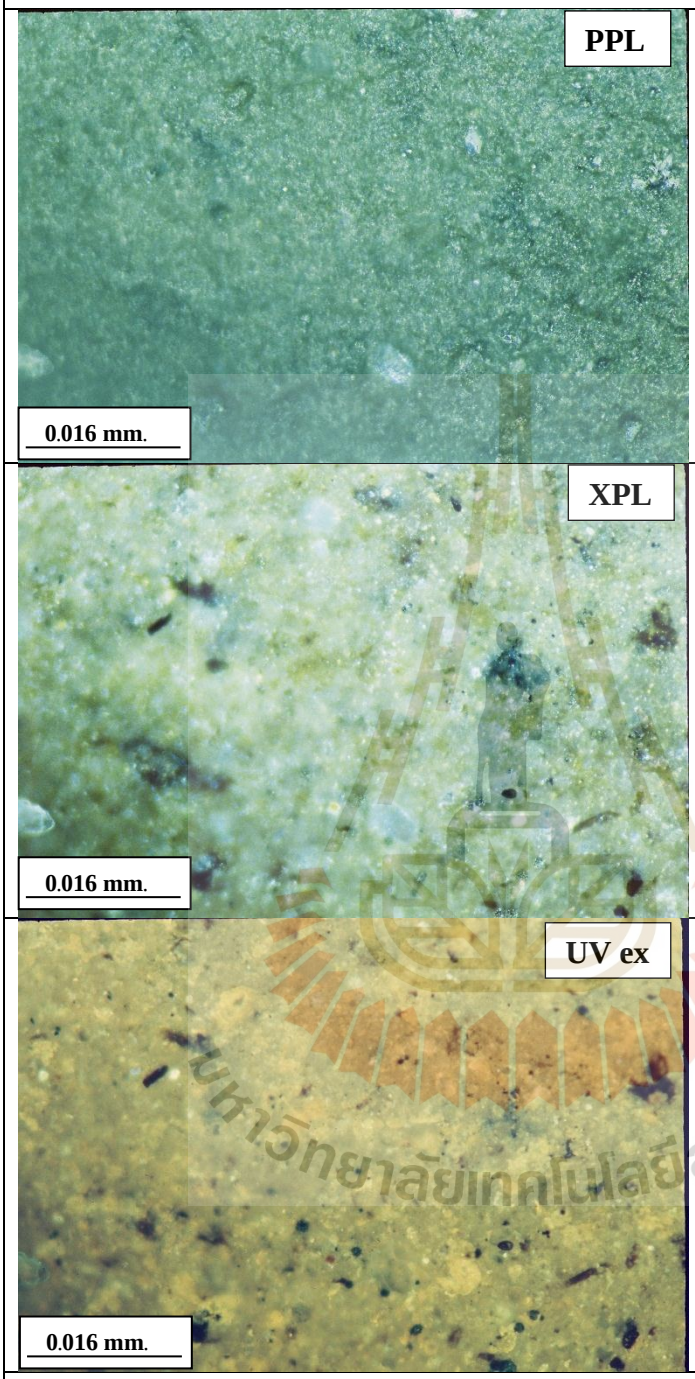
Microscopic Picture	Explanation
	**Sample No. OH9-3** **Oil Shale** shows sediment deposition with algae. Composition (%) V = 4 % L = 23 % I = 0 % MM = 73 % **Vitrinite** consist mainly of coal fragment. They display dark gray to black in PPL and black in XPL. **Liptinite** are mainly of algae. They display dark gray and black in PPL and yellow to yellowish brown in XPL. Under UV excitation alginite display white to bright yellow. **Mineral matter** display white fume in XPL are clay/ silica fume. The bright crystal in PPL, white in XPL and dark in UV ex are quartz
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation A-La = Lamaginite algae, A-Te = Telalginite, Py = Pyrite	

Figure 4.149 The microscopic picture of oil shale sample No. OH9 – 3

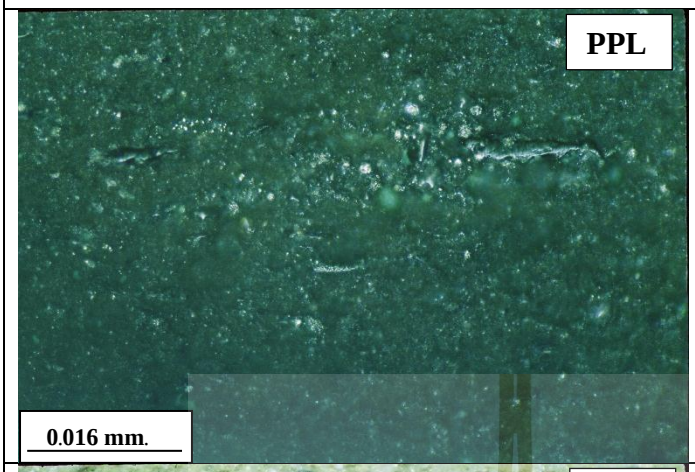
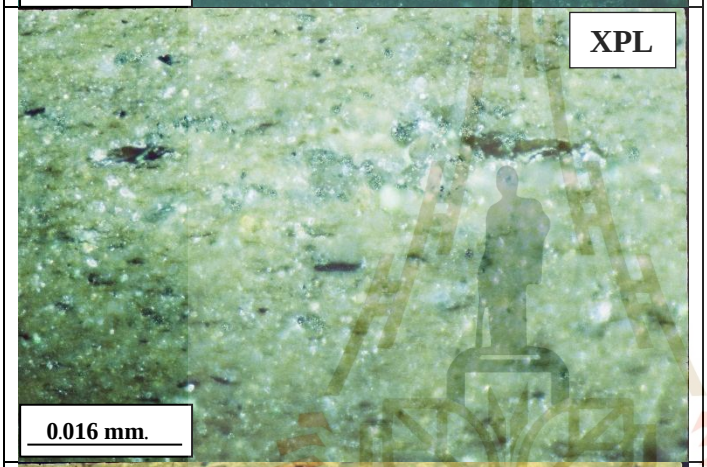
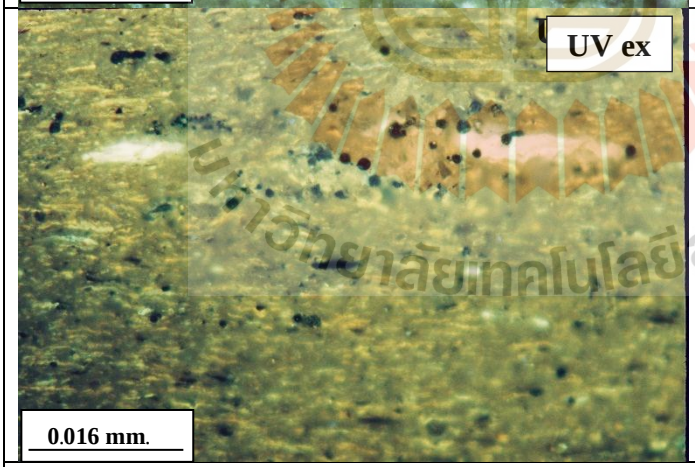
Microscopic Picture	Explanation
  	**Sample No. OH9-4** **Oil Shale (Algite)** in the section cut perpendicular to bedding. Composition (%) V = 3 % L = 22 % I = 0 % MM = 75 % **Vitrinite** consist mainly of gelinite. **Liptinite** consist mainly of lamalginite and show algal mat of thin body compact. Lamalginite display dark gray in PPL, white yellow to yellow in XPL. Under UV excitation, they display bright yellow to dark yellow with some of telaginite colony *(Botryococcus* sp.) which display bright white **Mineral matter** are mainly of clays. Clay display white in XPL and dark in UV excitation. Pyrite show sphere dots and framboidal pyrite display white in PPL, bright white in XPL and dark under UV ex, and
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation A-La = Lamaginite algae, A-Te = Telalginite, Py = Pyrite	

Figure 4.150 The microscopic picture of oil shale sample No. OH9 – 4

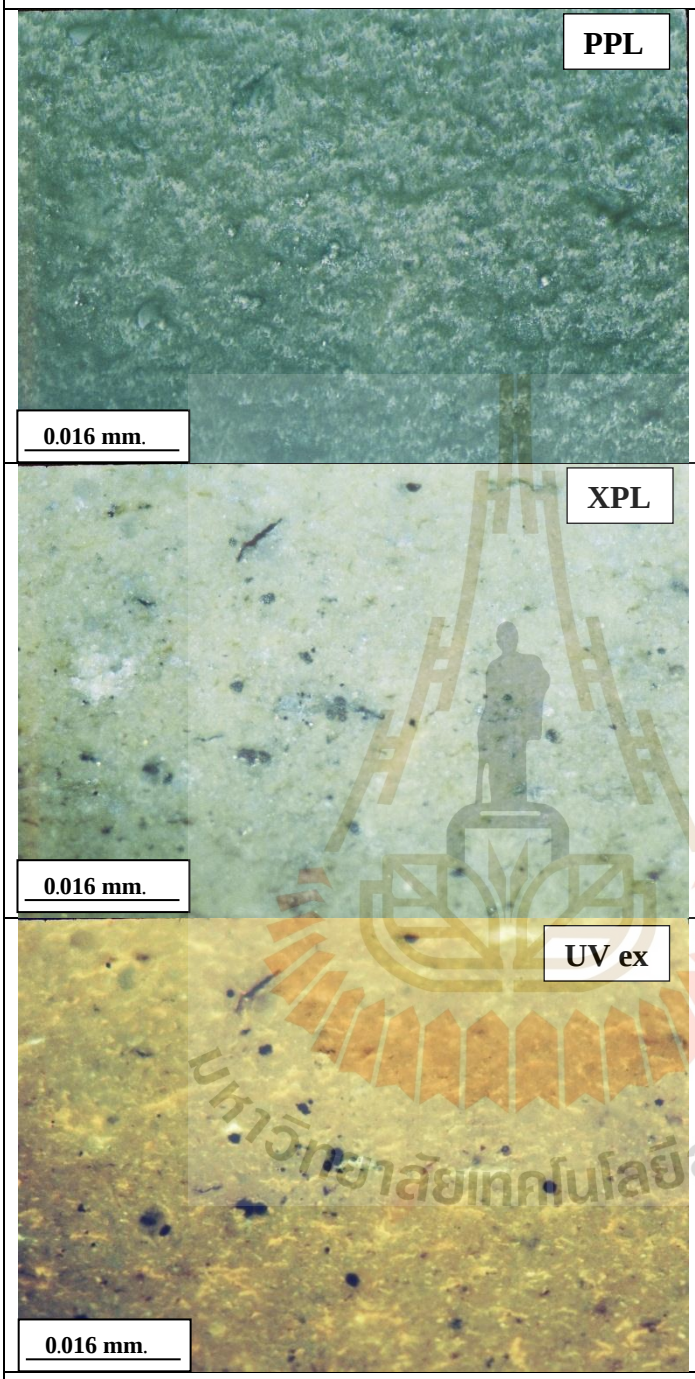
Microscopic Picture	Explanation
	**Sample No. OH10-1** **Oil Shale** shows very fine-grained sediment deposition Composition (%) V = 2 % L = 23 % I = 0 % MM = 75 % **Vitrinite** consist mainly of minor gelinite and show special pattern of pale gray and black in PPL. **Liptinite** consist mainly of lamaginite and show algae mat compact and body decay. They display pale gray to black in PPL and white to light yellow in XPL and under UV excitation show light yellow to yellow groundmass. **Mineral matter** consist of very fine-grained clay with pattern in PPL and white in XPL. Pyrite display small dots of black in XPL and UV excitation.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation A-La = Lamaginite algae, A-Te = Telalginite, Py = Pyrite	

Figure 4.151 The microscopic picture of oil shale sample No. OH10 – 1

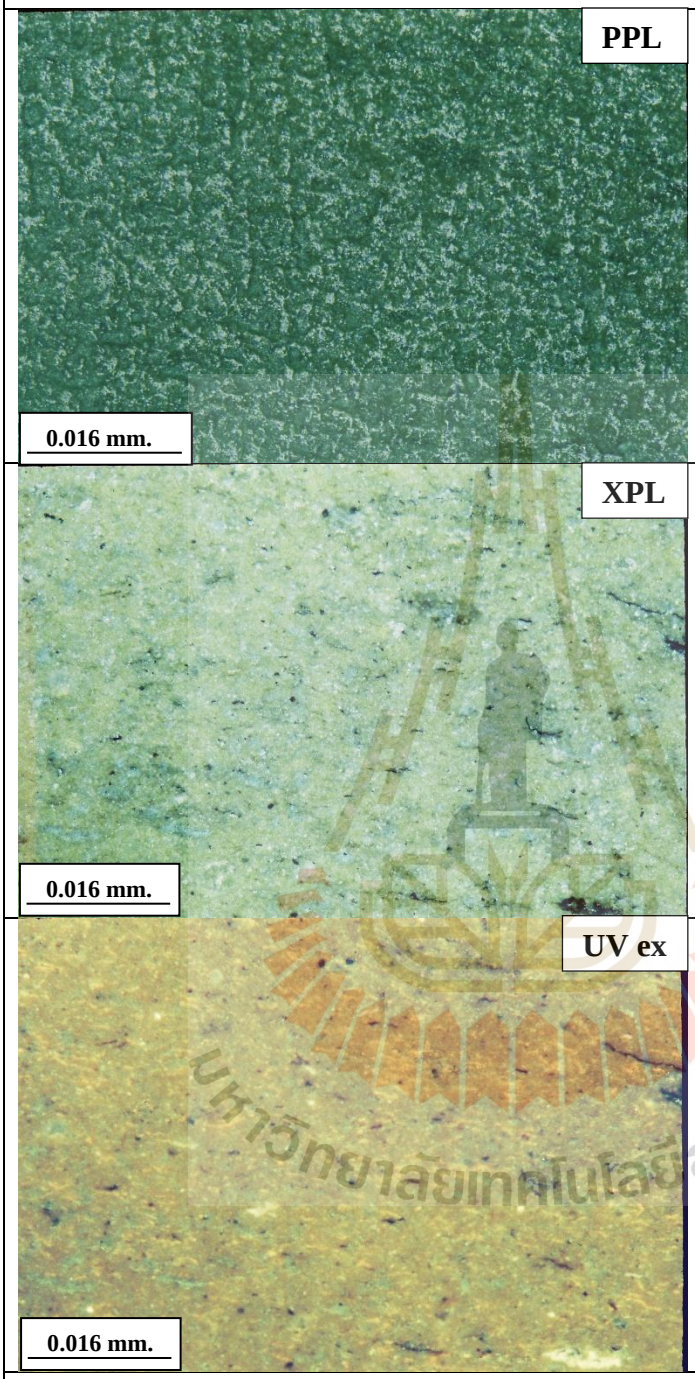
Microscopic Picture	Explanation
	**Sample No.OH10-2** **Oil Shale (Algite)** in the section cut perpendicular to bedding Composition (%) V = 1 % L = 12 % I = 0 % MM = 87 % **Vitrinite** consist mainly of gelinite. They show special pattern of pale gray and black in PPL. **Liptinite** consist mainly of lamaginite and show algae mat compact and body decay. They display pale gray to black in PPL and white to light yellow in XPL. Under UV excitation show light yellow to yellow groundmass. **Mineral matter** consist mainly of very fine-grained clay with pattern in PPL. They display white in XPL. Pyrite display small dots of black in XPL and UV excitation.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation V = Vitrinite, L = Liptinite, I = Inertinite, MM = Mineral Matter A-La = Lamaginite algae, A-Te = Telalginite, Py = Pyrite	

Figure 4.152 The microscopic picture of oil shale sample No. OH10 – 2

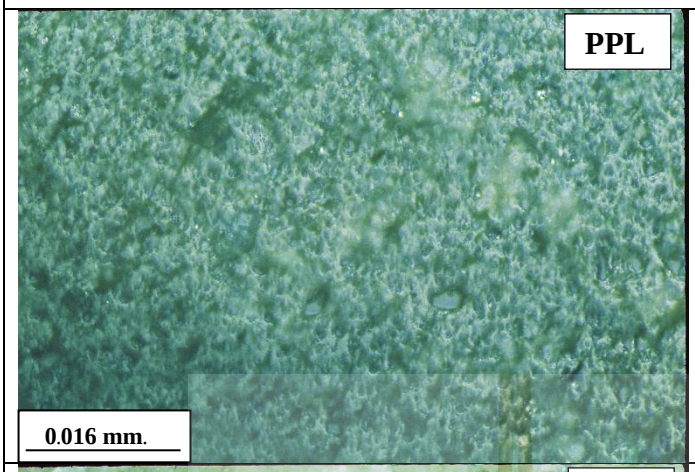
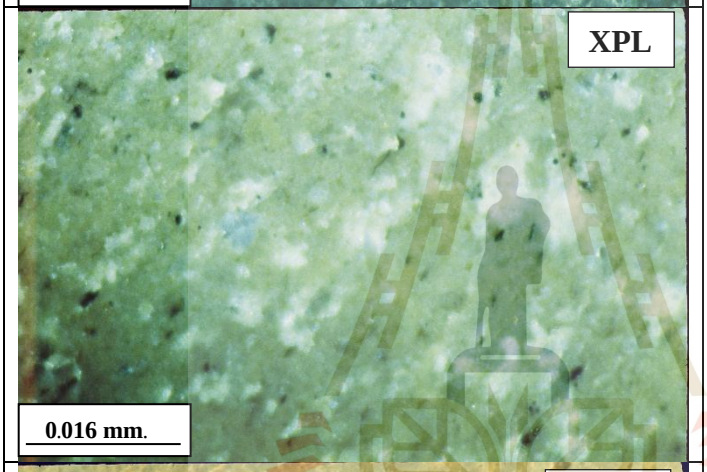
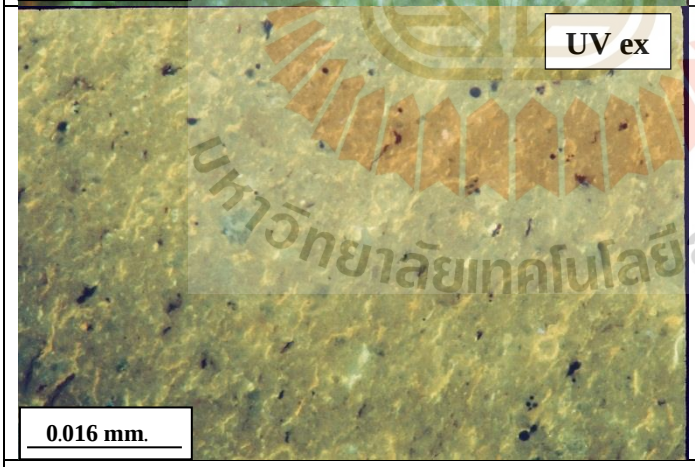
Microscopic Picture	Explanation
  	**Sample No. OH10-3** **Oil Shale (Algite)** shows very fine-grain sediments deposition with algae. Composition (%) V = 1 % L = 16 % I = 0 % MM = 83 % **Vitrinite** consist mainly of gelinite. They display special pattern of pale gray and black in PPL. **Liptinite** consist mainly of **lamaginite** and shows algae mat compact and body decay. They display pale gray to black in PPL and white to light yellow in XPL. Under UV excitation they display light yellow to yellow groundmass. **Mineral matter** consist mainly of very fine-grained clay with pattern in PPL. They display white in XPL. Pyrite show small dots of black in XPL and UV excitation. The silicate crystal display bright white in XPL.
PPL = Plane Polarized light, XPL = Cross Polarized light, UV ex = UV excitation A-La = Lamaginite algae, A-Te = Telalginite, Py = Pyrite	

Figure 4.153 The microscopic picture of oil shale sample No. OH10 – 3

4.2.8 Vitrinite reflectance

In this study, Coal A and Coal B sub-unit samples were conducted vitrinite reflectance (Ro) measurement under microscopic study using a Leica MP4500P system with Hilgers DISKUS software of ERC Pty. Ltd., Australia. Results of the measurement show that Ro of the studied samples varies from 0.31 – 0.50 %Ro. Results of Ro measurement are presented in Table 4.11 and Figure 4.154.

Table 4.11 Vitrinite Reflectance (Ro) of Coal A and Coal B sub-unit.

Sub-units	Maceral	Ro max	Range	n*
Coal A	Telovitrinite	0.41	0.31 – 0.50	47
	Detrovitrinite	0.41	0.36 – 0.49	3
	Total Vitrinite	**0.41**	**0.31 – 0.50**	**50**
Coal B	Telovitrinite	0.41	0.34 – 0.49	50
	Detrovitrinite	-	-	-
	Total Vitrinite	**0.41**	**0.34 – 0.49**	**50**

*n = Number of test samples

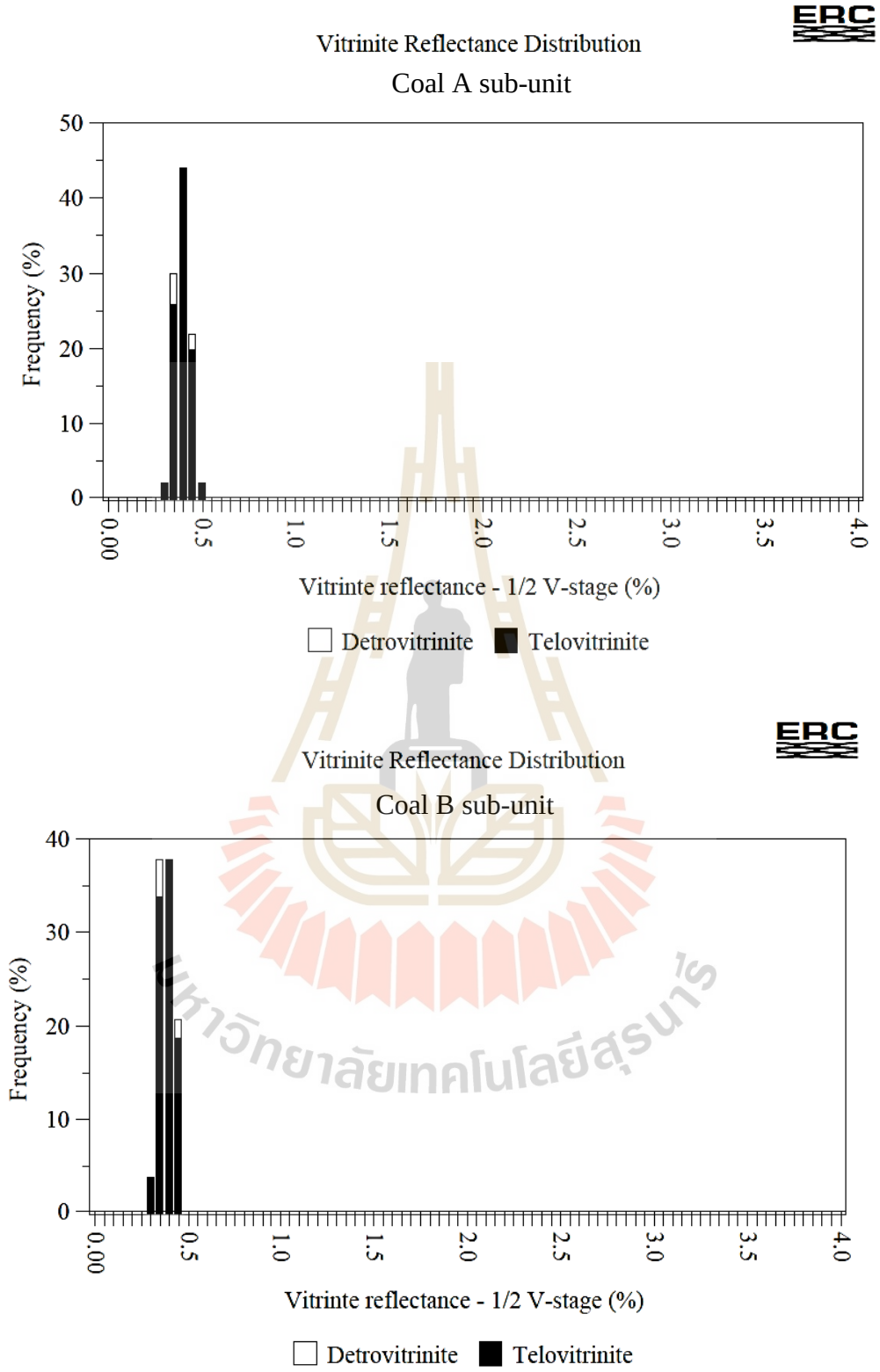


Figure 4.154 Results of the vitrinite reflectance (Ro) measurement of coal samples of Coal A and Coal B sub-unit.

4.3 Geochemical analysis

In this study, the studied organic matter compositions were analyzed by proximate and ultimate method to determine the content of fixed carbon, volatile matter, ash and other elements such as sulfur, nitrogen, and oxygen. In addition, they were also measured their heating value and vitrinite reflectance (Ro). The hydrocarbon potential of the studied organic sediments was analyzed by pyrolysis technique in term of oil yield, kerogen yield, carbon and total organic carbon. Results of geochemical analysis conducted in this study can be summarized as follows.

4.3.1 Result of proximate, ultimate and heating value analysis

4.3.1.1 Leonardite unit

Four leonardite samples, which were collected from the lowest part of the studied organic sediment succession (L1), the interbedded part of Coal C sub-unit (L7), the upper part of Coal C (L14) and Coal B sub-unit (L19), were chosen for conducting geochemical analyses.

Results of proximate analysis (moisture, volatile matter, ash and fixed carbon content in wt.%), ultimate analysis (carbon, hydrogen, nitrogen, sulfur and oxygen content in wt.%), and heating value (kcal/kg) of each leonardite sample were presented in Table 4.12.

Results from proximate analysis show that the average value of moisture, volatile matter, ash and fixed carbon content of the studied leonardite samples is 7.22, 13.49, 78.66 and 0.63 wt.% respectively. It was remarkable that the ash content of all leonardite sample was very high (more than 77 wt.%). And results from ultimate analysis indicate the average content of carbon, hydrogen, nitrogen, sulfur and oxygen of the studied leonardite samples is 7.24, 1.95, 0.19, 0.30 and 11.65 wt.% respectively.

The heating value of sample L1, L7, L14 and L19 is 302.8, 277.9, 303.0 and 355.4 kcal/kg respectively.

Table 4.12 Results of proximate, ultimate and heating value analysis of the studied leonardite samples (Air dry basis).

Sub-units	L1	L7	L14	L19	Average
Proximate analysis (wt.%)					
Moisture	5.14	7.64	8.23	7.86	7.22
Volatile Matter	12.57	13.17	13.61	14.60	13.49
Ash	81.28	78.51	77.82	77.04	78.66
Fixed Carbon	1.01	0.68	0.34	0.50	0.63
Ultimate analysis (wt.%)					
Carbon	7.08	6.86	7.15	7.88	7.24
Hydrogen	1.43	2.03	2.12	2.22	1.95
Nitrogen	0.24	0.20	0.19	0.13	0.19
Sulfur	0.30	0.31	0.30	0.30	0.30
Oxygen	9.67	12.09	12.41	12.42	11.65
Heating Value (kcal/kg)	302.8	277.9	303.0	355.4	309.8

4.3.1.2 Coal unit

The 26 coal samples, 11 samples from Coal C sub-unit, 4 samples from Coal B sub-unit, and 11 samples from Coal A sub-unit, were collected and conducted geochemical analysis and were assessed their heating value in this study.

Results in range and an average value of proximate, ultimate and heating analysis of coal samples were presented in Table 4.13. It is noticeable that all of

proximate, ultimate analysis results and heating value of coal samples are higher than those of leonardite samples, especially the heating value.

Table 4.13 Results of proximate, ultimate and heating value analysis of the studied coal samples (Air dry basis).

Geochemical methods	Coal C		Coal B		Coal A	
	Range	Avg.	Range	Avg.	Range	Avg.
Proximate analysis (wt.%)						
Moisture	10.48 – 17.97	14.14	10.42 – 20.38	14.74	4.28 – 17.86	10.52
Volatile Matter	25.17 – 42.18	32.45	31.53 – 36.08	33.31	25.94 – 41.32	31.51
Ash	17.06 – 53.38	32.35	8.28 – 43.64	28.70	12.00 – 65.56	30.33
Fixed Carbon	10.61 – 28.97	21.06	13.79 – 35.26	23.26	4.22 – 34.84	22.63
Ultimate analysis (wt.%)						
Carbon	27.87 – 44.72	35.01	28.19 – 35.27	31.73	19.34 – 50.48	42.19
Hydrogen	3.53 – 5.09	4.54	4.01 – 4.84	4.43	3.10 – 5.56	4.84
Nitrogen	0.92 – 1.26	1.08	0.75 – 1.17	0.96	0.48 – 1.72	1.30
Sulfur	0.38 – 3.31	1.87	0.64 – 3.53	2.09	0.30 – 0.58	0.44
Oxygen	20.22 – 29.28	24.75	19.88	19.88	28.46 – 30.96	30.12
Heating Value (kcal/kg)	2565 – 4170	3179	4689.1	4689.1	4581 – 4588	4584

4.3.1.3 Oil Shale unit

In this study oil shale samples collected from oil shale in Coal A sub-unit, Lower Oil Shale sub-unit, and Upper Oil Shale sub-unit were conducted proximate, ultimate, and heating value analysis.

Results of analyses are presented in Table 4.14. It is found that the ash content of oil shale samples is quite high as those of leonardite samples and the heating value of these oil shale samples is in between leonardite and coal.

Table 4.14 Results of proximate, ultimate and heating value analysis of the studied oil shale samples (Air dry basis).

Geochemical methods	Oil Shale in Coal A		Lower Oil Shale		Upper Oil Shale	
	Range	Average	Range	Average	Range	Average
Proximate analysis (wt.%)						
Moisture	6.25 – 7.65	6.76	1.98 – 4.97	3.90	1.21 – 3.86	2.80
Volatile Matter	31.80 – 34.08	33.27	16.05 – 30.32	19.47	19.38 – 29.65	23.04
Ash	45.78 – 58.23	50.77	67.77 – 80.29	76.92	70.15 – 76.33	73.73
Fixed Carbon	9.97 – 20.14	15.96	1.91 – 5.28	3.61	0.20 – 5.90	3.22
Ultimate analysis (wt.%)						
Carbon	24.02		11.73		12.50	
Hydrogen	3.13		2.13		2.30	
Nitrogen	0.62		0.17		0.19	
Sulfur	0.68		0.94		0.30	
Oxygen	16.46		8.91		10.00	
Heating Value (kcal/kg)	1534.2		946.3		1161.8	

4.3.2 HAWK pyrolysis

The HAWK pyrolysis was conducted in this study to determine values of total organic carbon (TOC), oil yield (S1), kerogen yield (S2), amount of CO_2 (S3), amount of CO (S4 and S5) and maximum temperature (Tmax) of the studied organic sediment samples. In addition, results from pyrolysis analysis can be used for calculating hydrogen index (HI) and oxygen index (OI) which are used to identify

kerogen type on the modified van Krevelen's diagram. The results of the HAWK pyrolysis analysis of organic sediments samples from each sub-unit are presented in Table 4.15.

Table 4.15 Results of HAWK pyrolysis analysis of studied organic sediment samples from each sub-unit.

Sub-units	**Oil Yield; (S1)** (mg/g)	**Kerogen Yield; (S2)** (mg/g)	**Amount of CO_2; (S3)** (mg/g)	**TOC** (wt.%)	**Tmax** (°C)	**HI**	**OI**
Leonardite	0.64	21.49	1.33	6.37	432	337	20
Coal C	2.11	59.14	9.35	39.18	426	150	23
Coal B	2.32	69.80	8.88	36.43	424	191	24
Coal A	2.19	69.77	12.30	46.65	427	149	26
Oil Shale in Coal A	1.49	67.80	5.25	19.13	422	371	31
Lower Oil Shale	0.58	42.59	0.72	5.98	434	712	12
Upper Oil Shale	0.96	40.39	1.19	7.57	425	533	15
Average	**1.47**	**53.00**	**5.57**	**23.04**	**427.14**	**349**	**21.57**

HI; Hydrogen Index = (S2*100)/TOC
OI; Oxygen Index = (S3*100)/TOC

Oil yield (S1) of all samples are less than 3 mg/g and vary from 0.64 – 2.32 mg/g. The Leonardite sample shows very low S1 value (0.64 mg/g). All coal samples have similar S1 values around 2.11 – 2.32 mg/g. The oil yield (S1) of all oil shale samples is lower than 2 mg/g. The S1 value of Oil Shale in Coal A is the highest among the oil shale samples (1.49 mg/g).

Kerogen yield (S2) of all samples are vary from 21.49 – 69.80 mg/g. Leonardite has the lowest S2 value (21.49 mg/g) while the highest S2 value is of the Coal B sub-unit sample (69.80 mg/g).

CO_2 (S3) content of all samples are less than 13 mg/g. The highest CO_2 content is of the Coal A sub-unit samples (12.30 mg/g) while the lowest CO_2 content is of the lower oil shale sub-unit samples (0.72 mg/g).

Total organic carbon (TOC) (wt.%) of all samples are vary from 5.98 – 46.65 wt.%. TOC of the Coal A sub-unit samples is the highest (46.65 wt.%) while TOC of the lower oil shale sub-unit samples is the lowest (5.98 wt.%).

The maximum temperature (Tmax) of all studied sample varies from 422 – 434 ºC. The highest Tmax is of the Lower Oil Shale sub-unit samples (434 ºC).

Hydrogen Index (HI) of all samples are between 149 and 712. Lower Oil Shale sub-unit samples have the highest HI (712) while Coal A sub-unit samples have the lowest HI (149)

Oxygen Index (OI) of all samples are lower than 31 of the oil shale samples of the Coal A sub-unit. The lowest OI is of the Lower Oil Shale sub-unit sample (12).

Jarvie *et al*. (2001) proposed the correlation between Tmax and vitrinite reflectance as the following equation.

$$Ro = 0.018 (Tmax) – 7.16 \quad (4.1)$$

Therefore, Tmax values from HAWK pyrolysis analysis (Table 4.14) were used to calculate Ro based on the equation 4.1. The results of the calculated Ro are showed in Table 4.16.

The evolution of volatile matter begins with the expel of H_2O, CO_2 and CO before large amounts of CH_4 are released. In contrast to during coalification, low molecular weight hydrocarbons, especially methane and other volatiles are generated. Moreover, some methane is liberated from liptinite at relatively low rank (0.2 – 0.5%Ro) (Petersen *et al*., 2006). While the first volatile products liberated in coal at temperature below 100 ºC are mainly H_2O and CO_2 and small amounts of CH_4 (Petersen, 2006). The oil window for the source rocks are depending on the geothermal which is estimated oil window from ~ 0.82 to 0.98 %Ro and burial depths of ~ 1300 – 1400 m. are necessary for efficient oil expulsion to occur (Petersen *et al*., 2006).

The effective oil window is estimated to occurs at 0.7%Ro for type I, 0.5 %Ro for type II and 0.6 %Ro for type III and kerogen type I and II are early 0.5%Ro for generating dry gas (Tissot and Welte, 1984; Tissot, Pelet and Ungerer, 1987).

Therefore, the organic source rock maturation based on the calculated Ro, kerogen type and Tmax for each studied organic matter sub-unit can be estimated and showed in Table 4.16. Consequently, results of the source rock maturation study based on kerogen type, Tmax and calculated vitrinite reflectance (%Ro) indicate that all of organic matter sub-unit of the Mae Teep organic succession are in between immature and early mature stage.

Table 4.16 The organic source rock maturation estimation based on kerogen type, Tmax and Ro.

Sub-units	**Kerogen Types**	**Tmax** (°C)	**Ro** (%)	**Maturation**
Leonardite	II and III	432	0.616	Early Mature
Coal C	II and III	426	0.508	Immature to Early Mature
Coal B	II and III	424	0.472	Immature
Coal A	II	427	0.526	Immature to Early Mature
Oil Shale in Coal A	I and II	422	0.436	Immature
Lower Oil Shale	I	434	0.652	Immature to Early Mature
Upper Oil Shale	I	425	0.490	Immature

4.4 Discussions

The implication of the petrographical and geochemical results reveal the history of the depositional environments, the source rocks quality for petroleum generation and/or expulsion, the type of organic matter (kerogen), and source rock potential of the Mae Teep organic sediment succession. In this study, the thermal maturation of source rocks was considered by maximum temperature (Tmax), Quality Index (QI) and vitrinite reflectance (%Ro).

4.4.1 Depositional environment of the Mae Teep organic sediment succession.

Depositional environment appearances in lithological source rocks indicated that the organic deposits in the Mae Teep basin had been involved with the water fluctuation. The change of water levels led to the organic matter and fine-grained sediments depositing, maceral types and geochemical composition in the Mae Teep basin. These situations caused the deposition of leonardite at the high-water stand, impure coal (Coal C sub-unit) at the intermediate water stand to coal beds (Coal B sub-unit and Coal A sub- unit) at the low water stand and toward the forest swamp. The water level changing significantly affected the amount of oxygen dissolved in water which caused the level of oxidization. Since, leonardite is interbedded with coal in the lower part of coal units, this may refer to continuality submergence of organic sediments in Mae Teep basin. The encounter of liptodetrinite together with sporinite may indicate the extension of grass swamp to subaquatic area where organic mud is deposited. The environment of deposition and its related macerals can be summarized as follows.

The environment of deposition of the lower part of the Mae Teep organic succession could be lake. It was deep water in the middle part, and gradually shallower along the bank slope and the swampy toward the land. Macerals of this part consists mainly of vitrinite and liptinite groups with some inertinite group and mineral matters. Later on, the coal sub-units were deposited starting from the water dwelling plants such as reed and grass in the marshland or salt marsh that edging the lake and followed by forest swamp on land with woods and ferns. These coals are mainly impure coal with high mineral matter in the lower part and less mineral matter in the upper part.

In general, the ash content in organic sediments can be used to predict the water level during their accumulation. Sapropelic deposits (leonardite and oil shale) having high ash contents may indicate the high-water level environment. Results from geochemical analyses indicate that leonardite samples have the highest ash content but has the lowest carbon and fixed carbon content. Results from coal petrography study of the studied leonardite samples show that the studied samples comprise mineral matter presents (less than 60%) and organic macerals (liptodetrinite, resinite and sporinite with minor alginate). The sapropelic leonardite is subaquatic deposited in high level or open water slowly to the bottom by floating plant debris including algae together with muds.

The Coal C sub-unit is a humic coal which deposited both in reed marsh and forest swamp environments. Results of proximate and ultimate analysis indicate that this coal has low ash content but the highest fixed carbon and carbon. This is agreeable to the highest vitrinite maceral in petrography study results. This vitrinite consists mainly of detovitrinite and gelovitrinite with some of telovitrinite. They were derived from wood stems, root leaves and barks that represents the swampy forest peat

environment and refer to low level of water. The ratio of plant cell structure and gel can reflect the association of water/ moisture and oxidizing environments. In high moisture and oxidation condition vitrinite would be gelovitrinite from gelification process. In lower moisture and oxidation condition vitrinite would be detrovitinite while in very low moisture and/ or oxidizing condition some discernible characters of woods and barks would display only their cell structure outline.

The volatile matter and hydrogen contents show the same direction of the percentage of liptinite content in coal petrography. The liptinite macerals in oil shale are mostly of alginite which deposited with fine- grained sediments while the liptinite in the coals are dominated by several of liptinite derived from plant remains or wood tissues. In the reducing condition, the plant tissues are almost completely preserved e.g. cell wall of bark or root structure, cutical and chlorophyllinite (fluorinite) (Table 4.17).

In mild reducing condition, some of liptinite containing relatively large amounts of fat-wax group can display their shape which can be easily identified. Beside the liptinite, alginite in oil shale, sporinite, cutinite, resinite and suberinite can be distinguished by their shape and ornament. Sporinite dominated coal (cannel coal) may indicate the higher oxidizing condition where all structural tissues are gelified. Resinite were usually found associated with cutinite especially in conifer leave in the temperate Tertiary flora in northern Thailand.

Table 4.17 Depositional environments of each Mae Teep deposit sub-unit based on maceral type and petrography study results.

Environments	Unit	Sub-units	Maceral Type	Composition			
				V (%)	L (%)	In (%)	MM. (%)
Fluvial	Fluvial sequences (semi-consolidated)		N/A	N/A	N/A	N/A	N/A
Lacustrine	Fine-grained sedimentary sequences		N/A	N/A	N/A	N/A	N/A
	Oil Shale*	Upper Oil Shale	Alginite and liptinite	5.54	26.62	0	67.84
		Lower Oil Shale	Alginite and liptinite	4.33	19.54	0	76.46
		Oil Shale in Coal A	Alginite liptinite and sporinite	12.00	74.36	0	13.62
Forest-Swamp	Coal*	Coal A	Telovitrinite, gelinite, alginite, cutinite, sporinite, fluorinate, liptinite, resinite, and some of extinite	70.45	23.18	0.29	5.04
		Coal B	Telovitrinite, gelinite, cutinite, sporinite liptinite, resinite	75.29	11.88	0.12	12.71
		Coal C	Telovitrinite, detrovitrinite and gelinite, cutinite, sporinite, liptinite, resinite	67.59	12.96	0.68	19.00
	Leonardite*	Leonardite	Detrovitrinite, gelinite, sporinite, liptinite resinite and some of alginite	20.57	17.29	0	62.14

*organic sub-units in this study, V = Vitrinite, L = Liptinite, In = Inertinite, MM. = Mineral Matter

Two oil shale parting in the Coal A sub-unit may indicate the temporary long period deep-water flooding in the forest swamp. The stagnant of water for a long time with rich of nutrient led to algae booms and produced thick bed of algal mats. This part of the Coal A sub-unit indicated the environmental conditions changing suddenly from the shallow water in forest-peat swamp to high stand water by successive unit from Coal A to the above Oil Shale sub-unit.

The oil shale deposit is normally restricted in the lacustrine environment. They have high inorganic sediments and ash content which derived from fine-grained sediment deposited together with algae during the algal boom period. This is related to the seasoning nutrient supplied and the flavoring temperature conditions which led to the variety of the algae characters. In general, alginite maceral cause both of high volatile matter and hydrogen contents in oil shale sub-unit.

Layers of algae in oil shale consist mainly of lamalginite and telalginite. Under microscopic, lamalginite in the Lower oil shale show both long and short bodies, but they are thinner and shorter than those of other sub-units. The size of the algae normally depends on the pH and nutrient of the swamp water. In general algae can be better absorb nitrogen and grow faster in warmer temperature. Later on, the oil shale deposition was terminated by waterflooding. After waterflooding, the fluvial process had been developed and fluvial sediments have been deposited.

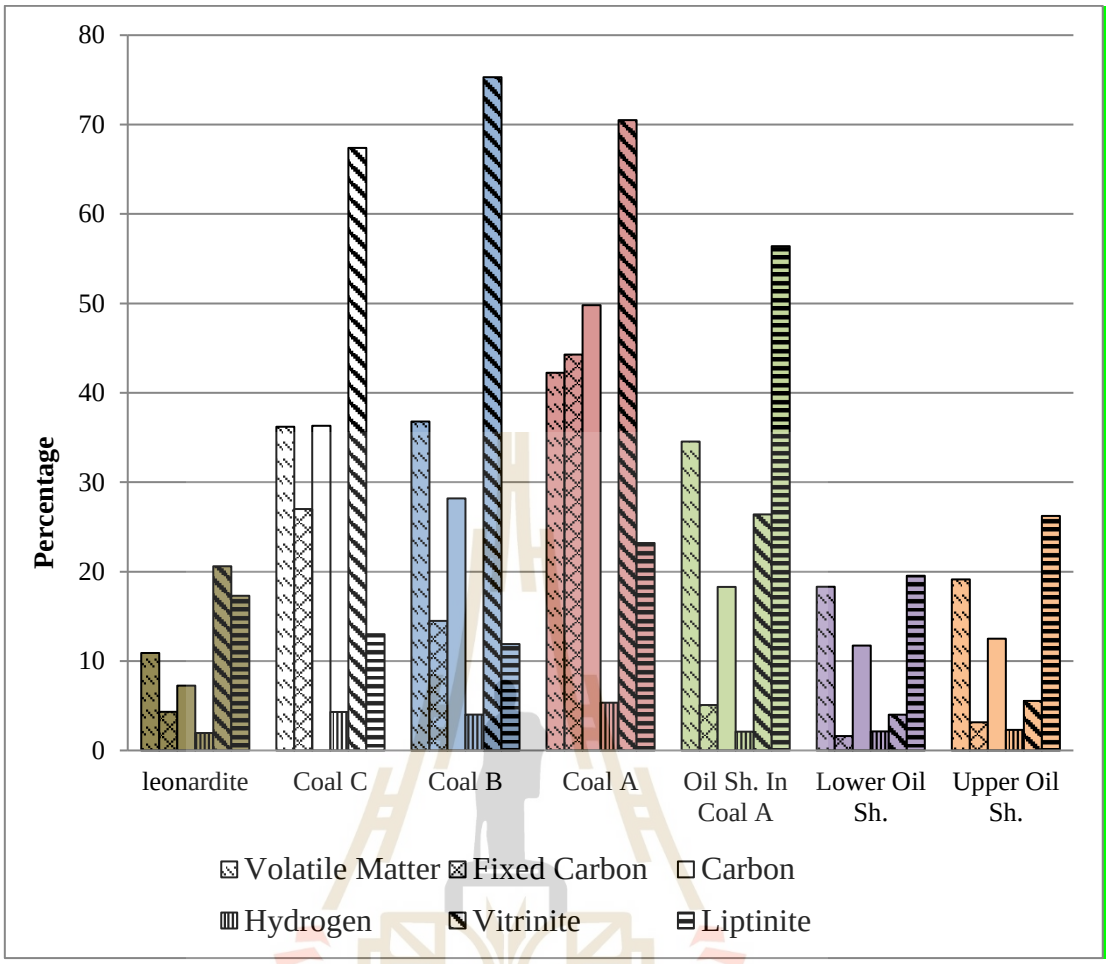


Figure 4.155 Geochemical compositions and dominated maceral type of each sub-unit.

4.4.2 The thermal maturation of petroleum source rocks potential of Mae Teep organic sediments.

According to the depositional environment from high to shallow water led to the component of organic sediments in form of maceral types. The rate of organic matter transformation during burial normally related to compositions of source rocks and the stage of evolution.

Results of the study indicate that in the pyrolysis stage the oil yield (S1) is low and carbon are in form of carbon dioxide while the kerogen yield (S2) is high in

Coal B, Coal A and Oil Shale in Coal A sub-unit. The oil yield (S1), kerogen yield (S2) and total organic carbon (TOC) are low in leonardite and oil shale. However, Oil Shale in Coal A has kerogen yield (S2) as high has those of the coal units.

The carbon contents (S3) indicates carbon in form of CO_2 and CO which are normally low in organic sediments such as leonardite and oil shale. Hydrogen index (H) and oxygen index (OI) can be calculated from the kerogen yield (S2), carbon contents (S3) and total organic carbon (TOC). In this study, the calculated HI and OI were cross-plotted on the modified Van Krevelen diagram to classify the kerogen type of the studied samples (Figure 4.156). Results of the plots indicate that the of oil shale, leonardite and coal studied samples are classified as kerogen type I, type II and type II respectively. However, oil shale samples from coal A sub-unit are classified as both kerogen type II and type III.

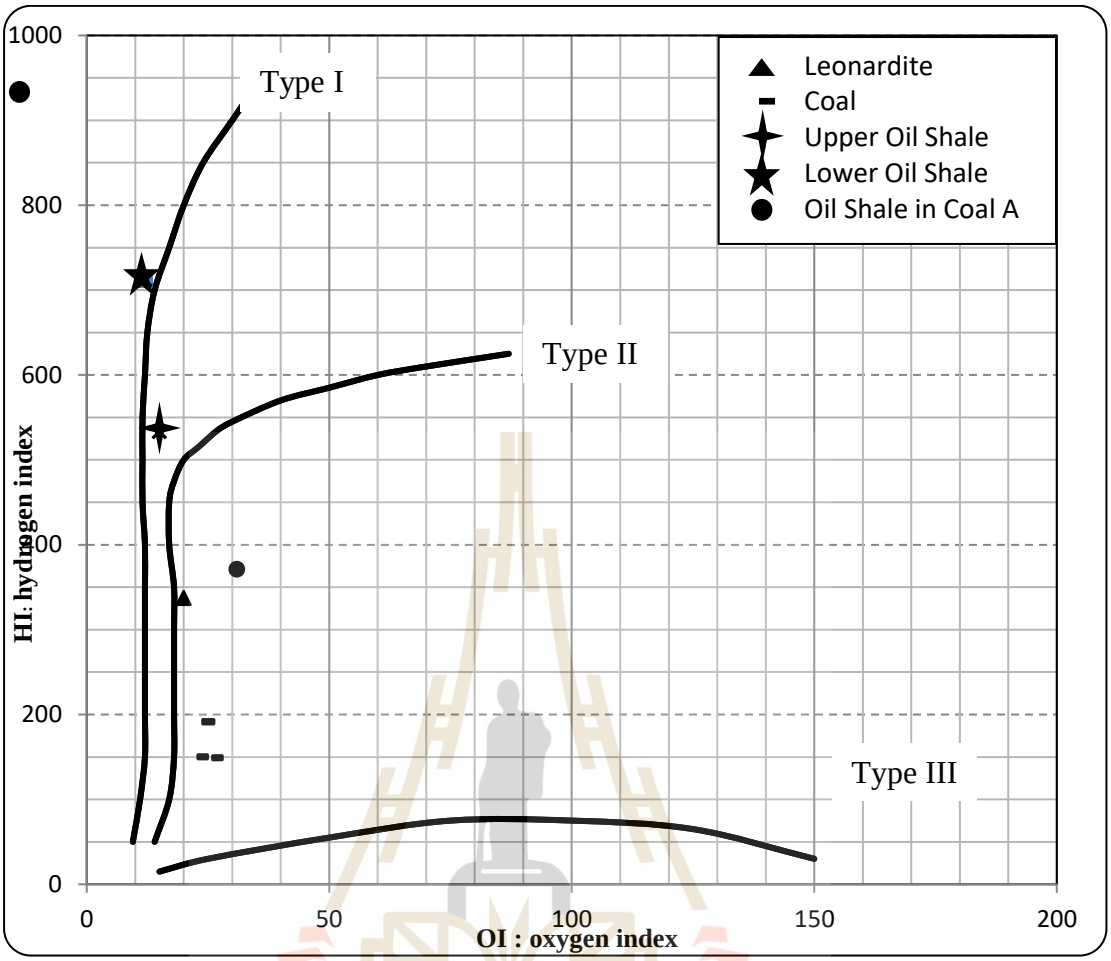


Figure 4.156 Kerogen type classification of the studied samples by the HI and OI cross-plot on the Modified Van Krevelen diagram.

The amount of free hydrocarbon (S1) and the quantity of remaining hydrocarbon which has not yet been transformed to hydrocarbons (S2) can be measured in mg/g of rock. Therefore, the genetic potential (S1+S2) which relate to production index or productivity index (PI) can be derived from the relationship of S1/(S1+S2). As a result, the calculated PI of the studied samples are between 0.1 and 0.3 mg HC/g TOC and this indicates the immature stage of the source rock. Coal and leonardite samples have high

PI while the lowest PI is of the Lower Oil Shale sub-unit samples. The highest PI is show at the coals and leonardite and lowest at the Lower Oil Shale sub-unit. Results of the cross-plot between S2 and TOC indicate that the studied samples have good to excellent hydrocarbon generation potential (Figure 4.157).

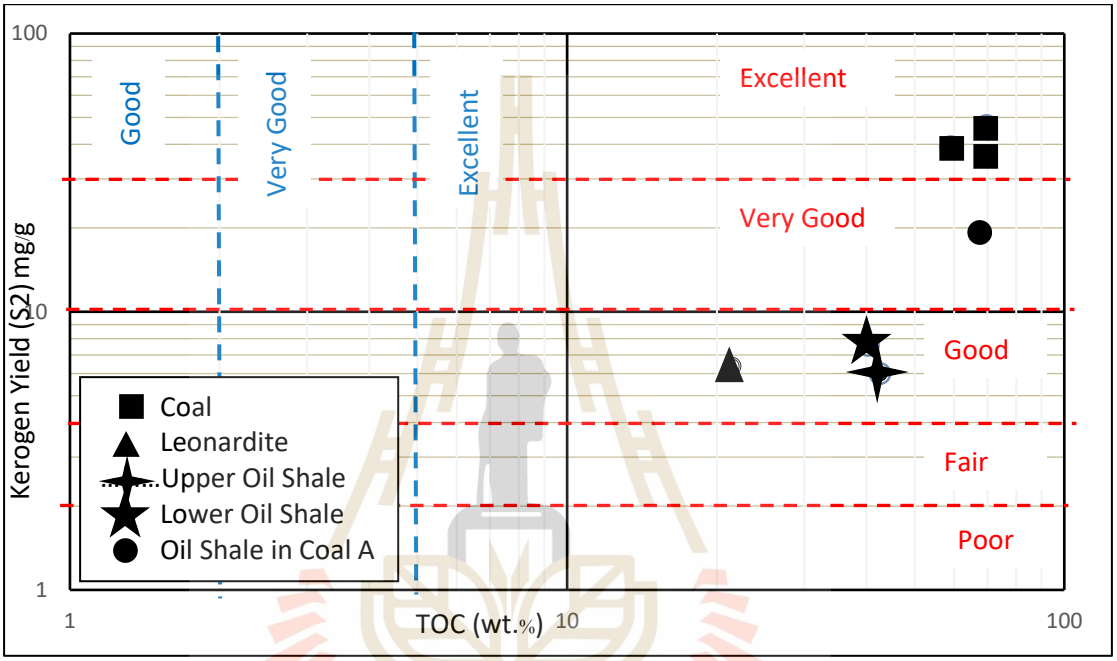
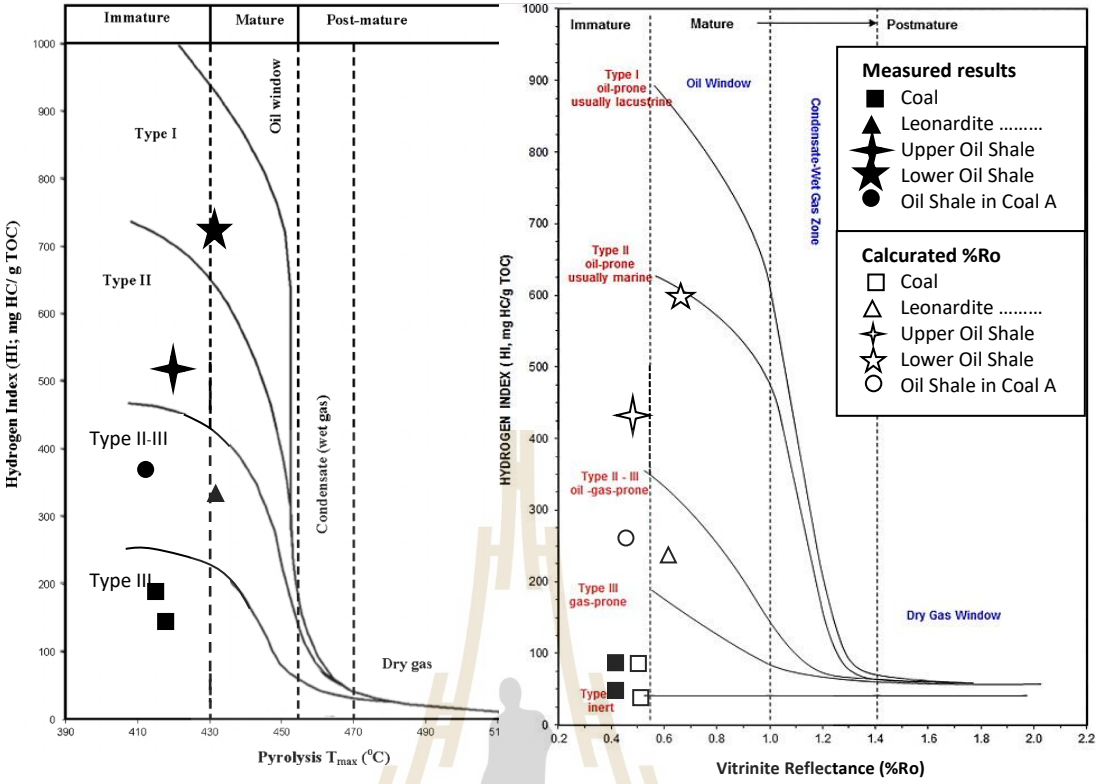


Figure 4.157 Cross-plot of remaining hydrocarbon potential (S2) and TOC (wt.%) show good to excellent potential hydrocarbon generation of the studied samples.

The maturation of the organic matter can be estimated by the maximum temperature (Tmax). In general, a Tmax of 430ºC is the boundary between immature and mature (oil production zone). In this study, leonardite samples have Tmax over 430ºC and the highest Tmax (434 ºC) is of the Lower Oil Shale sub-unit sample (Figure 4.158A).



(A) (B)

Figure 4.158 Evaluation of the thermal maturity stage of the studied organic samples based on HI vs Tmax cross-plot (A) and HI vs measured vitrinite reflectance cross-plot (B).

Results of the HI vs Tmax cross-plot indicate that the thermal maturity of the studied leonardite, oil shale and coal samples are mostly fallen in the immature stage. However, there are a sample of Lower Oil Shale and a sample of Leonardite fall in the early mature stage (Figure 4.158A).

The vitrinite reflectance (Ro) is an optical method for measuring the source rock maturity (Tissot and Welte, 1984). The maturity ranges for generated hydrocarbons can be start at vitrinite reflectance of 0.4 %Ro (or Tmax of~420ºC) is onset of petroleum

generation (Petersen, 2002., Sykes *et al.*, 2002). In this study, the calculated vitrinite reflectance are between 0.436 - 0.652 %Ro (Table 4.16) while the average measured vitrinite reflectance is 0.41 %Ro. The results of the HI vs measured vitrinite reflectance cross-plot indicate that the studied organic samples are all in the immature stage. However, results of the HI vs calculated vitrinite reflectance indicate that the Lower Oil Shale and Leonardite samples are fallen in the early mature stage (Figure 4.158B).

Productivity index (PI) and maximum temperature (Tmax) cross-plot can be used to identified the generated hydrocarbon type of the source rock. Results of the PI vs Tmax cross-plot of the studied samples in this study are depicted in Figure 4.159. The cross-plot indicate that all of studied organic samples are fallen in the oil zone generation.

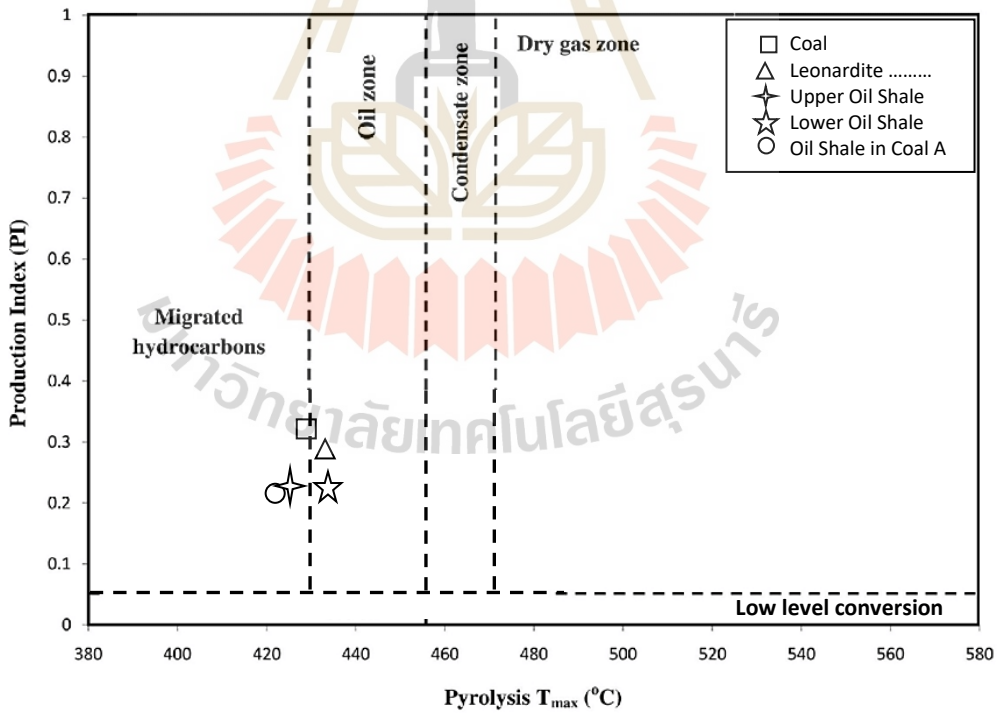


Figure 4.159 Cross-plot of Productive Index (PI) versus Tmax of the studied organic samples.

CHAPTER V

CONCLUSION AND RECOMMENDATION

In this study, the depositional environment and petroleum potential of Mae Teep organic sediments had been studied and evaluated. Field work, petrography study and geochemical analyses had been conducted to achieve the objectives of this study. Some conclusions from this study can be drawn as follows.

5.1 Depositional environment and characteristics of Mae Teep organic sediments

Mae Teep basin is the small terrestrial Cenozoic basin located in northern of Thailand. There are 3 environments of depositional systems in this basin including fluvial depositional system in the upper part, lacustrine depositional system in the middle part and swamp depositional system in the lower part of basin. The common organic sediments found in this basin are oil shale, coal and leonardite, and the main factor to directly control of these rocks' deposition is the changing of water level in the basin. Based on lithology, organic sediments in Mae Teep basin can be subdivided into 7 sub-units from the lower part to the upper part of basin as Leonardite, Coal C, Coal B, Coal A, Oil Shale in Coal A, Lower Oil Shale and Upper Oil Shale, respectively.

The investigations regarding to organic compositions of Mae Teep deposits and their depositional environments based on the results of the petrographic and geochemical analyses indicate three types of depositional environment in the ascending

order as: (a) swampy to forest swamp environment, (b) lacustrine environment, and (c) fluvial environment.

The sediments accumulation in Mae Teep basin began deposit concurrently with the rising of water level in basin due to the basin subsidence. This event induced the deposit of fine-grained particles that were absence or low organic matter, consisting of clays and organic mud (gyttja) in the near shore. Later, leonardite was deposited in low water level. When water became shallower, reed peat and peat from forest swamp were deposited, increasing organic contents in the deposits, making coal sequences as the Coal C, Coal B and Coal A sub-units at the lower part of basin as swamp environmental area, and then the sediments of low energy lacustrine were accumulated in the middle part. These depositional processes regular supply of clay particles and organic material accumulation together especially resulted from rich algal boom. The oil shale with more uniform and richer organic matter bed was formed in this event. The main rock sub-units in this process are oil shale in Coal A, the Lower Oil Shale and the Upper Oil Shale sub-unit. Finally, sediments from high energy fluvial environment had been deposited at the upper part.

Results of the study indicate that leonardite sub-unit deposited in the high-water level swamp environment with a few of plant growth. It presents large amount of fine-grained inorganic matter with some of organic contents dominated by gelovitrinite which indicates moderately oxidizing environment. In the Coal C, Coal B, and Coal A sub-units, the present of detrovitrinite, liptodetrinite and moderately high ash contents indicates the low-water level swamp environment with moderately oxidized of reed peat. The low ash coal with good preservation of plant tissues, some cutinite, fluorinite,

sporinite, and resinite association indicates the reducing condition in the forest swamp environment. In the addition, the maceral composition of these coal units corresponds to type II and type III kerogen.

The product of lacustrine environment deposition in Mae Teep basin is mainly oil shale with uniform, rich organic matter and containing plenty of algal deposit. These fine-grained sediments are high ash contents with alginite maceral which indicates the high stand, deep water and undisturbed environment. Moreover, this alginite rich thick algal mat also indicates the availability of nutrient which is resulted in good oil source rocks of type I kerogen.

5.2 Potential of petroleum source rocks

According to chemical compositions, Mae Teep coals contain large quantity of carbon and hydrocarbon contents but the ash volume is quite low. This characteristic presents the high heating values as a good potential fuel. Moreover, the present of high vitrinite and liptinite content may contribute these coals to have the high potential for gas generation.

The heating values of leonardite and oil shale are lower than those of the Mae Teep coals because the organic carbon content in both rocks is low volumes. However, leonardite might be a potential petroleum source since it has high TOC (6.37 wt.%). Therefore, based on the genetic potential, leonardite can be classified as a moderate quality source rock.

Oil shales in Mae Teep basin contain lower carbon but higher ash contents than the Mae Teep coals. They also have high TOC and kerogen yield. The Lower Oil

Shale characteristics are similar to those of the Upper Oil Shale, except having larger the volume of alginite.

Results form HI vs OI cross-plot on the modified Van Krevelen diagram indicate that organic sediments of both the Lower and the Upper Oil Shale sub-unit are Type I kerogen. Therefore, based on the kerogen type, Mae Teep oil shales have a potential for oil generation.

Results of the HI vs Tmax cross-plot indicate that the thermal maturity of the studied leonardite, oil shale and coal samples are mostly fallen in the immature stage. However, there are a sample of Lower Oil Shale and a sample of leonardite fall in the early mature stage.

In this study, the calculated vitrinite reflectance are between 0.436 - 0.652 %Ro while the average measured vitrinite reflectance is 0.41 %Ro. The results of the HI vs measured vitrinite reflectance cross-plot indicate that the studied organic samples are all in the immature stage. However, results of the HI vs calculated vitrinite reflectance indicate that the Lower Oil Shale and leonardite samples are fallen in the early mature stage.

Though the results of pyrolysis analysis of the studied samples show low oil yields (S1) (0.58 – 2.32 mg/g), they are considered to be the high potential hydrocarbon source rock since they have high kerogen yield (S2) (up to 69.8 mg/g). They also have high total generated petroleum potential (22.13 - 72.12 mg/g). These may contribute them to be a good - very good source rock. Moreover, the encounter of the associated macerals of resinite, i.e. suberinite with small amount of exsudatinite in these studied

organic sediments could indicate the early expel of heavy petroleum generation from these immature - early mature source rocks.

5.3 Recommendation

This research covered the study of depositional environments and petroleum potential of organic sediments of the Mae Teep deposits which showed the possibility to be the good petroleum potential source rocks. The study methodologies used in this study could be applied to study the depositional environment and to evaluate the petroleum potential of the expected petroleum source rocks in other petroleum province where has the similar source rocks, successive tectonics and geological setting, especially Tertiary basins in Thailand.

Therefore, it is recommended to apply these study methodologies to Thai Tertiary basins which were setting at the same time of Mae Teep basin but were offset by tectonic and deeper burial (Chinbunchorn et. al., 1989), such as Phrae, Ngao, Chiang Muan, Mae Moh, Lampang, Chae Hom, Na Noi, Fak Tha, Wang Nua, Mae Suai, Wiang Pa Pao and Phraw basin.

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