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Preliminary Investigation on Organic Petrology of Shale in Phnom Mrech, Angkor Chum District, Siemreap Province, Onshore Cambodia

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Abstract: *The aim of this study is to investigate the organic petrology of shale in Phnom Mreach, Angkor Chum District, Siem Reap province, onshore Cambodia. Thin-section is carried out to analyze mineral compositions, sedimentary texture, and shale classification. Polish-section is used to identify the types of organic matter under reflected light. Scanning electron microscope (SEM) is analyzed for further detailed study on types and morphology of organic matter. The results showed that shales are mainly composed of quartz, clay minerals, calcite, mica, and small amount of plagioclase. Moreover, shales are classified into silica-rich argillaceous mudstone and clay-dominated lithotype. These shales consist of parallel and wavy lamina-structures. Furthermore, there are three types of organic matter are identified under SEM and polish section, such as vitrinite, inertinite, and alginite. Moreover, the organic petrology of shales can contribute to better understanding sources of organic matter. The presence of vitrinite and inertinite is suggested that organic matter has a source from woody tissues and plant materials that belong to a humic-type deposit.*

Keywords: Organic petrology; Organic matter; Shale; Phnom Mrech; Onshore Cambodia

1. INTRODUCTION

Black shale is a dark-colored, thinly laminated shale containing organic matter and silt -and clay-sized mineral grains accumulated together [1]. This rock is generally rich in organic matters occurring throughout the geologic record, but special conditions are responsible for their occurrences [1,2]. Shale deposits in both terrestrial (i.e., lacustrine, blackish) and marine environments in which organic matters can deposit along with small sediment particles. Shales are usually the main source of hydrocarbons and typically are also important as hydrocarbon seals. Moreover, shales can be unconventional hydrocarbon reservoirs and sources of metallic minerals [2,3]. Understanding shale petrology and organic matter can reveal the origin of organic matter, which is a key goal in hydrocarbon exploration.

Phnom Mrech is located in the northern part of the Tole Sap sedimentary basin (Fig.1), onshore Cambodia, where the shale was deposited. According to the preliminary study obtained from geophysical surveys (airborne gravity, magnetic and seismic), the Tonle Sap basin has several sub-sedimentary basins potential for hydrocarbon resources [4]. Moreover, this basin may have two potential source rocks, Carboniferous-Permian of shallow marine behind carbonate reefs and Jurassic lacustrine shale [5]. The few studies of the Tonle Sap basin have included petroleum geology of Cambodia [5] and a preliminary assessment of geological CO_2 storage in Cambodia [6]. However, the organic matter types, characteristics of organic matter, and shale composition in or around the Tonle Sap basin have not been well revealed yet. Therefore, this study focuses on organic petrology to characterize organic matter and its sources of sediments in Phnom Mrech in the northern part of the Tonle Sap basin (Fig.1). Thus, this allows an understanding of shale classification, mineral compositions, sedimentary structures, and organic matter types.

2. GEOLOGICAL SETTING

Tonle Sap basin is a foreland basin-type, which covers an area of 23,800 km2. It is generally occurred by tectonic activity [7]. The basin is bordered to the north by a regional orogenic uplift comparable to the northwest-southeast-trending of Mae Ping Fault Zone and farther to the north by the southernmost

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monocline of the north Khorat Basin [5,6]. This basin may have developed between the late Carboniferous and Middle Triassic and is filled with sediments and carbonates with a total thickness above 1,000m [5]. The "oil window" occurs between 2,000 and 3,500 m. This interval includes transgressive marine strata of the Late Triassic - Jurassic ages, which may possibly be a source of liquid hydrocarbons [5]. Upper Carboniferous to Middle Triassic rocks in the late catagenetic zone may have generated gas, which has migrated into reservoirs, including both overlying Mesozoic formations and a carbonate unit of Late Carboniferous to Permian age [5]. According to the geological map, Phnom Mrech comprises eluvial sand, Jurassic -Cretaceous sandstone, and Deveni -Carboniferous sand and shale [8].

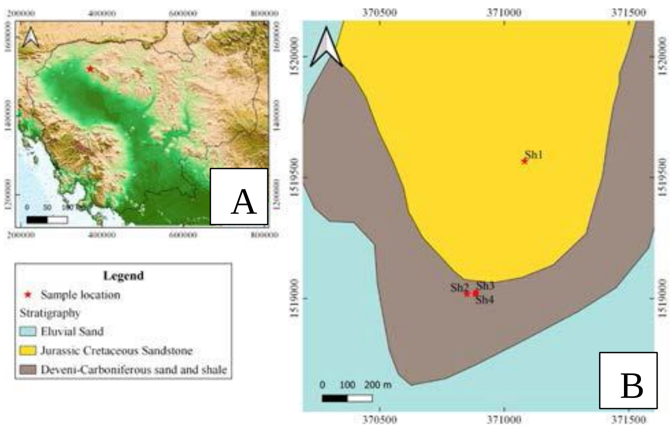
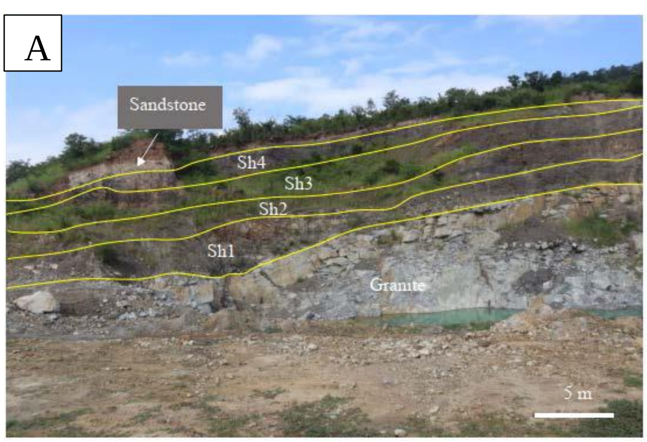


Fig. 1. Location of study area Phnom Mrech, Angkor Chum district, Siem Reap province. Red stars indicate the shale location. (A) GMT map of study area [9,10] and (B) Geologcal map of study area [8]

3. CHARACTERISTICS OF SHALE SAMPLES

Four shale samples were obtained from an outcrop in Phnom Mrech, Angkor Chum district, Siem Reap Province, onshore Cambodia (Fig.1 and 2). This area consists of the hill, foothill, and some parts were covered by recent sediment.



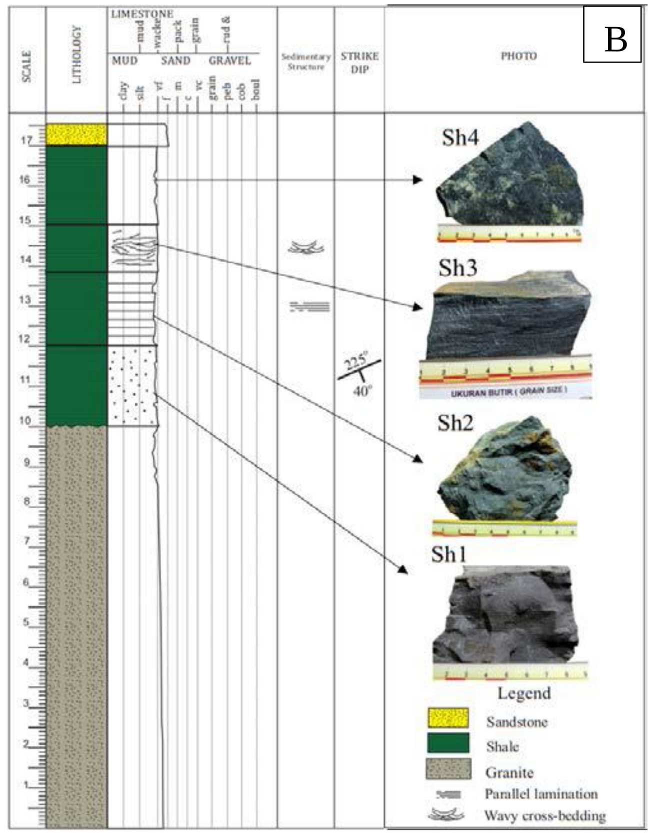


Fig. 2 (A) Outcrop view of Phnom Mrech consisting of three facies, granite in the lowest part, shale facies in the middle part and sandstone facies in the top. The sample collection were done from the bottom to the upper part, Sh1, Sh2, Sh3, and Sh4, respectively and (B)Stratigraphy column of Phnom Mrech

The sampling was done on four shale layer between 1 m intervals in each layer, Sh1, Sh2, Sh3, and Sh4. Shale layers were deposited in the middle part between sandstone and dark grey to black color of granite (Fig. 2). These shale layers consist of parallel and wavy laminae structures.

4. METHODOLOGY

4.1 Petrology

Four shale samples were prepared for thin section and polish section petrography. Thin section is used to identify the minerals compositions depend on the optical properties of the minerals. It is used to reveal the origin and deposition of sediments. In addition, the percentage of minerals is used to counting to make the shale classification using Ternary shale classification [11].

Polish section is the common method that uses to identify organic macerals type in the sediments by using reflected light. The types of organic matter can be recognized by their morphology, such as color, shape (elongate, rounded, angular), and associated minerals.

4.2 Scanning Electron Microscope (SEM)

SEM is an analytical method that captures high-resolution images of objects from micro to nanometers scale. It was used to identify the organic matter, mineralogy, pore size distribution, clay minerals or cement, and crystalline structures of other minerals. SEM produces images by scanning samples with a focused beam of electrons. The electrons interact with the atoms on the surface of the sample and collect information about the sample topography and composition. There are four samples to analyze using SEM model SU3500 HITACHI High-Technologies under the operating work conditions of 15kV.

5. RESULTS AND DISCUSSION

5.1 Minerals and lithology identification

Shale in Phnom Mrechcomposed of quartz, clay mineral, calcite, and mica, and small amount of plagioclase (Fig. 3-6; Table 1). Sh1 consists of quartz ~ 22.6%, calcite ~0.4%, mica ~1.4% and clay mineral ~75.6% (Fig. 3). The presence of quartz has fine-grained white to gray color and sub-rounded to sub-angular of grain shape. Calcite identifies as orange color (XPL), fine-grained, and no specific shape filled with quartz. Mica shows as the elongated shape with orange color (XPL). Clay is filled between quartz grain and dark gray color. Sh2 consists of quartz ~20.8%, calcite ~1.6%, and clay minerals ~77.6%, dominated in this shale. Quartz is fine-grained with colors as white to gray in XPL and colorless in PPL. Calcite is fine-grained with orange color in XPL without a specific shape like cement-filled between quartz grains and some parts mixed with clay (Fig. 4). Clay minerals are very fine-grained, showing brown to gray (XPL) filled between quartz grains.

Sh2 consists of quartz ~20.8%, calcite ~1.6%, and clay minerals ~77.6%, dominated in this shale. Quartz is fine-grained with colors as white to gray in XPL and colorless in PPL. Calcite is fine-grained with orange color in XPL without a specific shape like cement-filled between quartz grains and some parts mixed with clay (Fig. 4). Clay minerals are very fine-grained, showing brown to gray (XPL) filled between quartz grains.

Sh3 mainly consists of clay minerals ~81.2% and quartz ~18.8%. In this sample, clay minerals are recognized by the color change from gray to dark gray. The grans of quartz are medium-grained ~50µm with a sub-angular shape (Fig. 5).

Sh4 consists of quartz ~3.8%, calcite ~3.2%, and clay mineral ~93%. The grains of quartz are fine-grained with subangular shapes (Fig. 6). Clay minerals are very fine-grained, filled between quartz grains.

Table 1 Sumary result of mineral composition in shale and its lithology; Qtz: Quartz; CL: Clay minerals; Cal: Calcite; and Mic: Mica

ID	Qtz (%)	CL (%)	Cal (%)	Mic (%)	Lithology
Sh1	22.6	75.6	0.4	1.4	Silica-rich argillaceous mudstone
Sh2	20.8	77.6	1.6	0	Silica-rich argillaceous mudstone
Sh3	18.8	81.2	0	0	Clay-dominate lithotype
Sh4	3.8	93	3.2	0	Clay-dominate lithotype

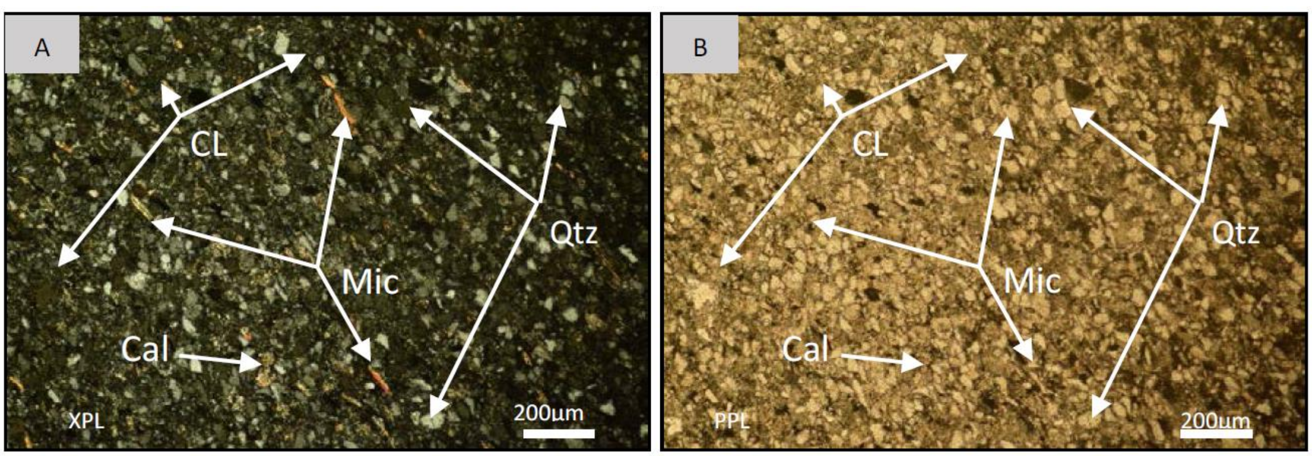


Fig. 3. Sh1 images under microscope. (A) Cross-polarized light and (B) Plane polarized light; Qtz: Quartz; Cal: Calcite; Mic: Mica; CL: Clay mineral

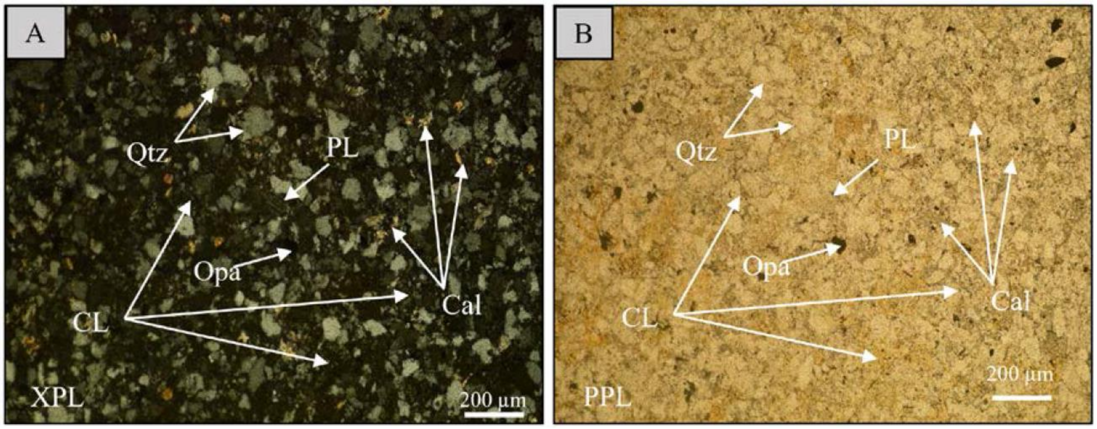


Fig. 4. Sh2 images under microscope. (A) Cross-polarized light and (B) Plane polarized light; Qtz: Quartz; Cal: Calcite; Mic: Mica; CL: Clay mineral

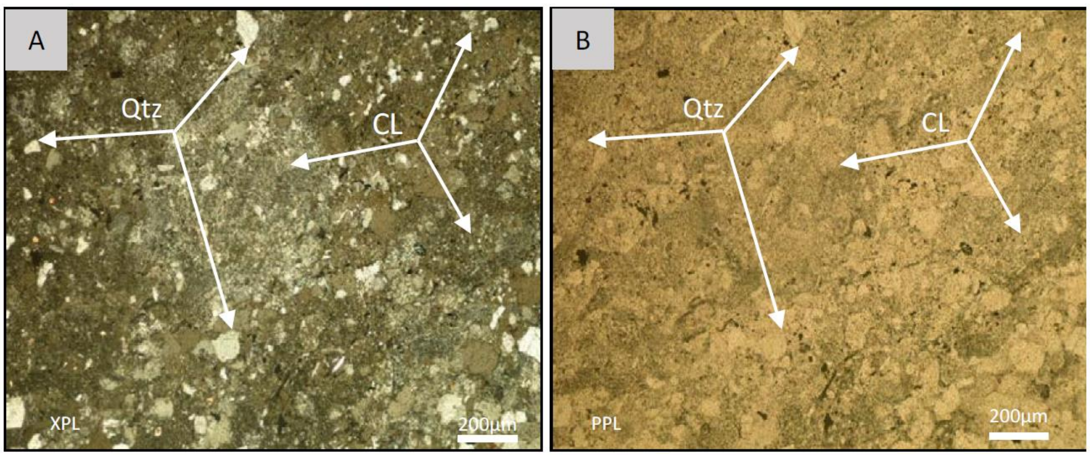


Fig. 5. Sh3 images under microscope. (A) Cross-polarized light and (B) Plane polarized light; Qtz: Quartz; Cal: Calcite; Mic: Mica; CL: Clay mineral

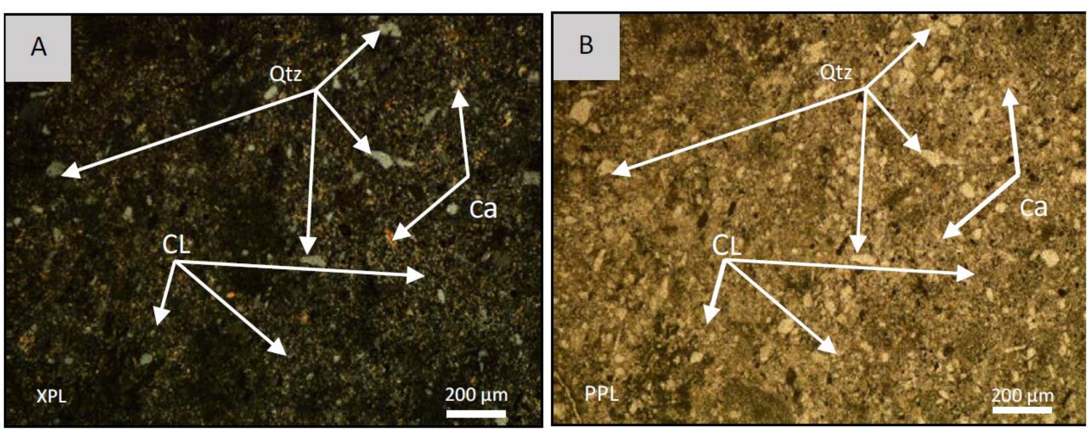


Fig.6. Sh4 image under microscope, (A) Cross-polarized light and (B) Plane polarized light; Qtz: Quartz; Cal: Calcite; CL: Clay mineral

According to the results of the mineral composition in Table 1, the main minerals can be plotted in the Ternary plot [12] of the shale lithofacies classification diagram (Fig.7) to identified lithology type of shales. After plotting, four shale samples are classified into two types, such as silica-rich argillaceous mudstone and clay dominant lithotype (Table 1). These two lithofacies shown as four different layers due to the changing in the environment condition or frequency level fluctuation.

Furthermore, the result of petrography is shown that shales comprised of thin parallel laminae bedding (Fig.8). Parallel lamination occurs in Sh1 and Sh3 sample of dark laminae (Fig.8A, white arrow), which is around 0.5 mm of light laminae (Fig.9B, yellow arrow). Moreover, light laminas are mainly quartz (yellow arrow), and dark laminas are mainly clay rich in organic matter (white arrow). This structure may be formed by suspension settling and slow sedimentation rate at the condition of less severe, shorter lives, and fluctuation in sedimentation [13-16].

5.2 Organic matter identification under reflecting light- polish section

The analysis of organic matter under reflected light reveals that Phnom Mrech zone comprises vitrinite, inertinite, and alginite. Sh1 consists of vitrinite, inertinite, and alginite, while Sh2, Sh3, and Sh4 consist only of vitrinite (Fig. 9 -11).

Under reflecting light, vitrinite, inertinite, and alginite macerals are found in Sh1 (Fig. 9). Vitrinite is observed in the microscope as a light gray to gray color whereas, inertinite a reddish-brown color (Fig. 9). Vitrinite and inertinite are derived from terrestrial vegetation, which shows as discrete particles in the mineral matrix.

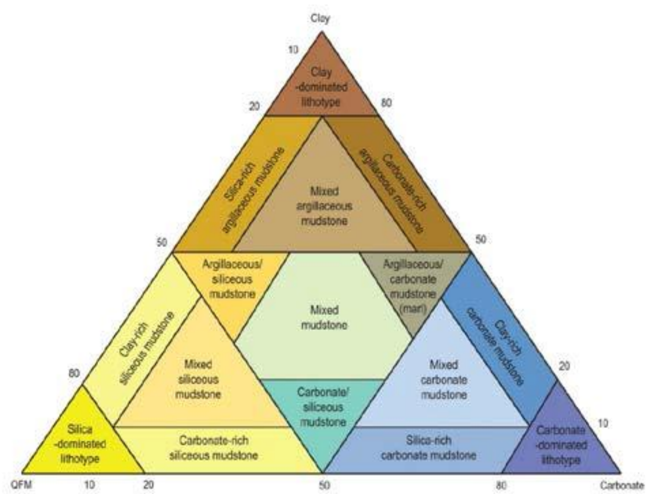


Fig. 7. Ternary plot of shale classification lithofacies

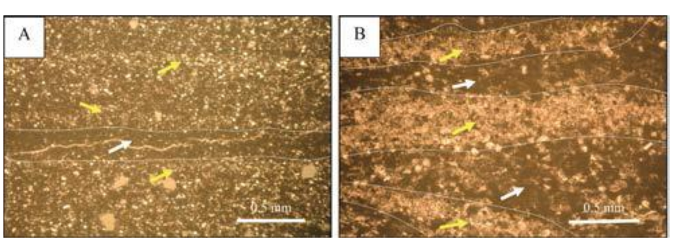


Fig. 8. Thin section photomicrograph shows of sedimentary structures of shale. (A) Sh1 sample show about parallel lamina with light and dark lamina (arrow) and (B) Sh3 sample with wavy lamina structure by which rich of clay, dark laminae (white arrow) and quartz, light laminae (yellow arrow).

Such a case, they are transported from the continent [17]. Alginite is represented by elongated algal bodies, which is no longer present simply as flattened and occurred between quartz grains. Under the optical microscope, alginite is dark and reddish-brown in reflected light (Fig.8B).

Sh2 comprises of vitrinite maceral. In this sample, vitrinite is observed as light grey to dark grey, with angular bodies and grain size around 20 µm (Fig.10A). Vitrinite is derived from terrestrial, which occurs as discrete particles in the mineral matrix, and no pore was observed in vitrinite [17]. It is also derived from woody tissues of roots, stems, barks, and leaves composed of cellulose and lignin [18].

Sh3 comprises vitrinite maceral (V). Vitrinite shows as angular to rounded with grain size around 50 µm (Fig.10B-C). Under microscope observation, vitrinite is a dark gray color, and it occurs in authigenic quartz.

Sh4 consists of vitrinite that is shown as gray color, rounded to sub-angular bodies, and grain size between 50 to 70 µm (Fig.11). It is also moderate reflectance and typically smooth surfaces in the sediments. Vitrinite is a major source of natural gas of primary origin [18].

5.3 Organic matter identification under SEM

Based on scanning electron microscopy (SEM) analysis, the Phnom Mrech zone comprises three types of organic matter (OM) such as vitrinite, inertinite, and alginite. Sh1 consists of inertinite while; Sh2 consists of alginite and vitrinite, and Sh3 consists of vitrinite. Sh4 consists of inertinite and vitrinite (Fig. 12 and 13).

Inertinite in Sh1 is occurred between quartz and clay minerals (Fig.12A), with an angular shape and the grain size is about 50 µm. No pore was observed in inertinite of this maturity and shown as the smooth of the surface.

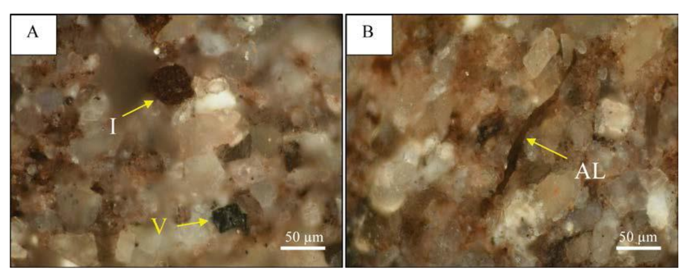


Fig. 9. Microscope analysis of Sh1 under reflected light. (A) Inertinite is reddish-brown with rounded of grain and vitrinite as gray color which angular of grain. (B) Alginite show as elongate bodies with reddish-brown color; AL: Alginite; I: Inertinite; V: Vitrinite.

Sh2 consists of alginite and vitrinite. Under SEM observation, alginite represents elongate bodies, dark grey color (Fig.12B and C), and moderate reflectance. Vitrinite represents a subangular shape with grain size around 60 µm (Fig.12B) and low reflectance.

Sh3 composes of vitrinite maceral. Vitrinite is observed in SEM occurs as sub-rounded bodies with grain shape around 120µm, black color, and significantly lower reflectance (Fig.13A; [18]).

Sh4 consists of inertinite and vitrinite macerals. Under SEM, Inertinite is recognized as rounded bodies as black color, low reflectance (Fig.13B and C), and sometimes, difficult to distinguish its grain shape. Vitrinite is dark in color with subrounded in shape, and the grain size is about 20 µm.

The organic matters observed from petrography and SEM analysis are mainly vitrinite and inertinite (Fig. 9-13). This indicates that organic matter belongs to humic-type [17-19], a source from woody tissues and plant materials of terrestrial vegetation. In such a sense, vitrinite are formed from the humification and gelification of woody tissues composed of lignin, cellulose, and a hemicellulose fraction [18,20]. Even though the inertinite macerals are derived from terrestrial vegetation, they form through the aerial oxidation of parechymatous and xylem tissues [21,22]. Moreover, other inertinite macerals form through the degradation of plant matter by macrinite organisms and from the remains of the funginite organisms [20,23]. Therefore, the presence of vitrinite and inertinite macerals may be produced the kerogen as humic-sapropelic-type and humic-type [19].

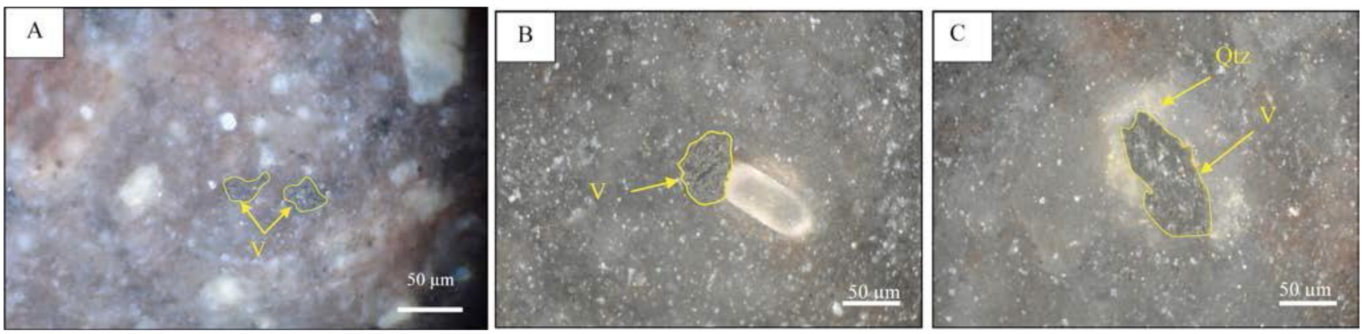


Fig. 10. (A) Sh2 showing of vitrinite maceral, and Sh3 sample under microscope observation show of vitrinite of (B) vitrinite is dark gray with rounded in shape and of (C) is vitrinite is dark gray occur in authigenic quartz; V: Vitrinite; Qtz: Quartz

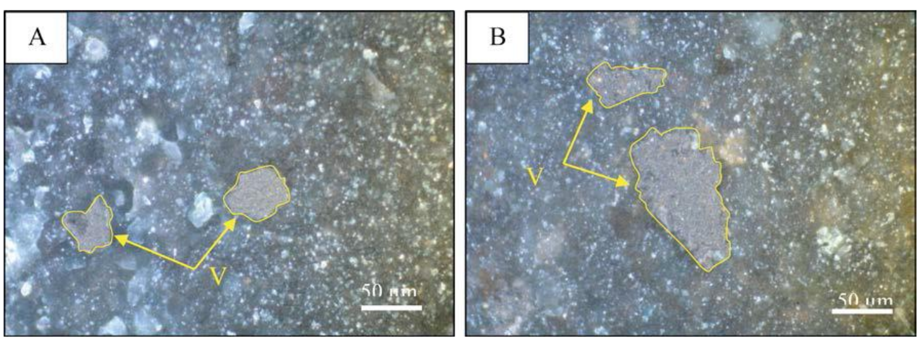


Fig. 11. Microscope analysis of Sh4 sample under reflected light. (A) Vitrinite is gray color and grain size around 50 µm and (B) Vitrinite is gray color and grain size around 50 to 70 µm

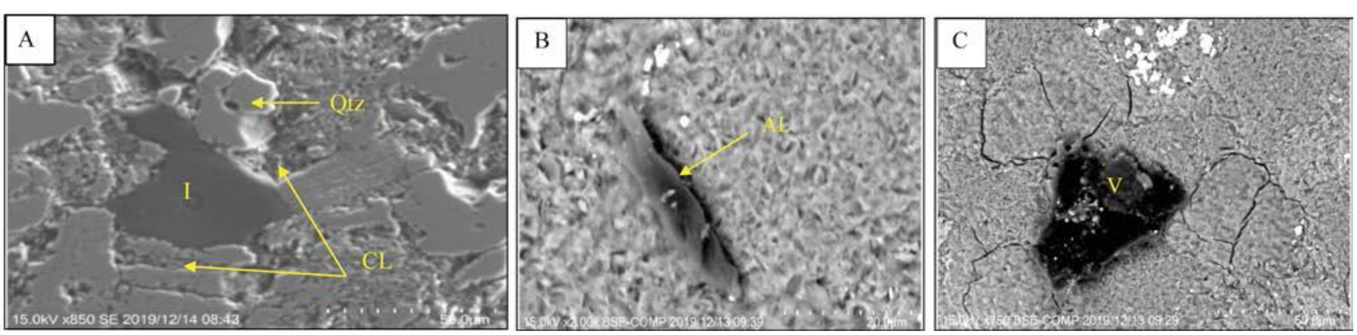


Fig. 12. Organic matter under SEM. (A) Sh1 shows inertinite organic matter, (B) Sh2 shows alginate orgaic matter as elongate shape and (C) Sh2 shows vitrinite organic matter as dark color with subangular; I: Inertinite; AL: Alginite; V: Vitrinite; CL: clay mineral; Qtz: Quartz

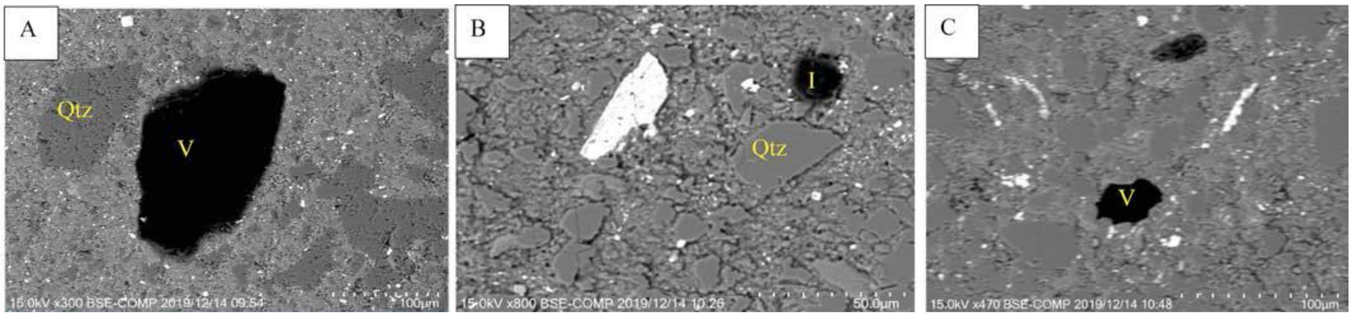


Fig.13. Organic matter under SEM. (A) Sh3 shows vitrinite organic matter as black color with subrounded shape, (B) Sh4 shows inertinite maceral and (C) Sh4 shows vitrinite maceral; Qtz: Quartz, V: Vitrinite; I: Inertinite

6. CONCLUSIONS

The results obtained from petrography and SEM analyses were used to interpret the lithofacies, mineral composition, organic matter, and sources of organic matter of the shales in Phnom Mrech, northern Tonle Sap basin. The main findings in this study are:

• Two lithofacies of shale in Phnom Mrech, such as (1) silica-rich argillaceous mudstone and (2) clay-dominated lithotype.

• Two types of structure are characterized, such as parallel lamination and wavy lamination. Parallel lamina structure observed in lithofacies 1 (Sh1 and Sh2), which is formed by suspension settling and slow sedimentation rate at the condition of less severe, shorter lives, and fluctuation in sedimentation. Wavy lamination of lithofacies 2 (Sh3 and Sh4) deposited due to suspension settling of fine-size sediments in low energy flow on the bottom bed under anoxic conditions.

• Three types of organic matter are identified in the shale formation, alginite, vitrinite, and inertinite. Vitrinite and inertinite belong to humic-type from terrestrial vegetation.

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