International Journal of Oil, Gas and Coal Engineering
2022; 10(4): 90-96
http://www.sciencepublishinggroup.com/j/ogce
doi: 10.11648/j.ogce.20221004.11
ISSN: 2376-7669 (Print); ISSN: 2376-7677 (Online)

Study on Organic Identification of Black Shale in Bokor Formation, Kampot Province, Cambodia

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To cite this article:
Ratha Heng, Sopheap Pech, Sreymean Sio, Chandoeun Eng, Chanmoly Or. Study on Organic Identification of Black Shale in Bokor Formation, Kampot Province, Cambodia. *International Journal of Oil, Gas and Coal Engineering*. Vol. 10, No. 4, 2022, pp. 90-96.
doi: 10.11648/j.ogce.20221004.11

Received: August 1, 2022; **Accepted**: August 24, 2022; **Published**: September 16, 2022

Abstract: Organic petrology is the key study to identify the favorable geological condition of black shale as a hydrocarbon source rock. The study aims to identify the organic matter types in the black shale of Bokor Formation, Kampot province. Three outcrop cross-sections (Phnom Khley, Phnom Chakrey, and Phnom Monprey), which extend from the West to the East of Kampot province, were investigated for stratigraphic sequences, sedimentary structures/textures, fossil contents through fieldwork observation. Rock sampling was conducted to performed polish pellet for organic petrology. The result demonstrated that the western part consisted of repeated sequences of thin laminated shale layers interbedded with massive sandstone layers. In the eastern part, the shale layers are continually deposited as a thick bedding with fossils of syringopora, crinoid, and foraminifera, which indicates a low energy flow environment during sediment deposition. Organic petrologic analysis in shale samples revealed that alginate and bituminite were dominantly found shale samples in the Phnom Khley section, whereas macrinite and vitrinite were observed in Phnom Monprey and Phnom Chakrey, respectively. The presence of alginate, bituminite, and macrinite, suggest a potential for hydrocarbon source rock. The maceral types, such as alginite, bituminite, micrinite, and vitrinite, indicate deposition in periodically oxygenated bottom water and a sulfidic marine water environment. Based on the existing macerals and cubic pyrite that presented in the collected samples, those source rocks are suggested as thermally mature petroleum source rock.

Keywords: Organic Identification, Black Shake, Bokor Formation, Cambodia

1. Introduction

Clay-rich, fine-grained sedimentary rocks (mudstones and shales) are the earth's most important rock types for conventional and unconventional petroleum sources [14]. These mudstones are deposited in low-energy environments, from fluvial to deep marine. Moreover, these fine-grained sedimentary rocks deposited under suitable conditions that may contain a large amount of organic matter may become potential source rocks for hydrocarbons [9]. The petroleum source rocks are evaluated by the abundance of total organic content (TOC), quality and type of organic matter, and maturity of the organic matter using several geochemical analyses. However, organic matter type is one of the major ingredients to predict hydrocarbon's quality and generic products [9]. Three outcrop locations have been investigated in this study, which is located in Tuek Chhue District, Kampot province, "Figure 1". FYHN, M. B. et al. [4] and Vysotsky, V. R. [16], however, documented that the hydrocarbon source rocks from the Triassic to Jurassic period in the Kampong Som basin entered the main stage of the oil and gas window. Moreover, based on lithological and fossil content, the depositional environment of the Bokor Formation has been interpreted as a marine deposit, which is suitable for petroleum occurrence [15]. However, study details on organic matter types in shale, which is the source of oil and gas generation in this formation, have not been documented yet.

Thus, the organic matter type in shale in this area remains poorly known. Therefore, this paper focuses on identifying organic matter types in the study area (Bokor Formation), which leads to an understanding of the source of organic matter to predict the generation product of hydrocarbons, whether oil or gas generation.

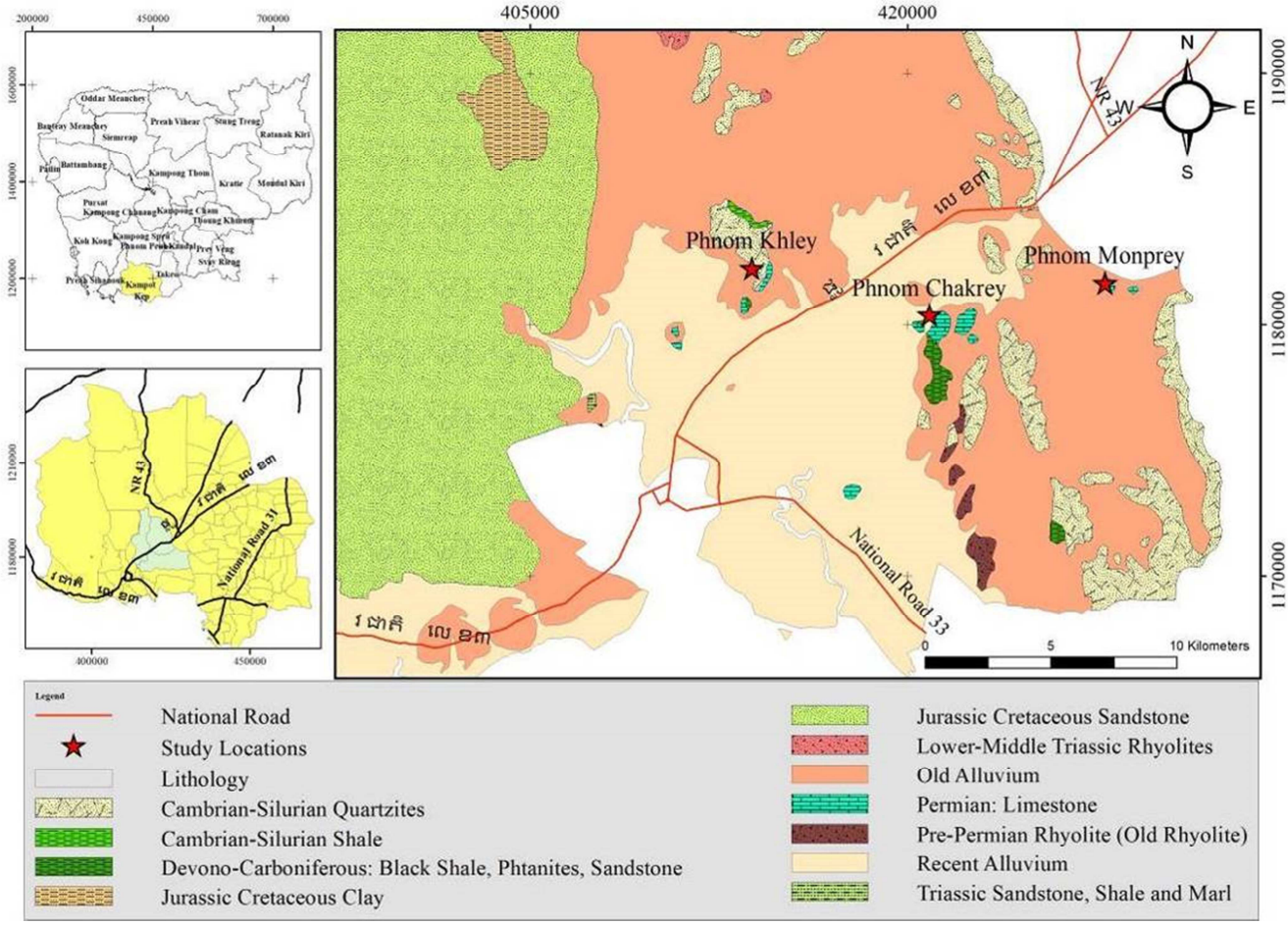

Figure 1. *Study locations are located in Kampot province, southern Cambodia. The red stars represent the study locations.*

2. Background

2.1. Geological Setting and Depositional History

The Kampong Som basin is located in the south-western part of Cambodia, which extends more than 80, 000 square kilometers. The basement of this basin is made up of strongly deformed Indosinian complexes that outcrop along the basin boundary and deformed Paleozoic complexes [16]. The sedimentary cover in this basin is composed of Upper Carboniferous to Lower Permian terrigenous carbonate units. From the Upper Permian to the Middle Triassic, it is covered by terrigenous carbonate and volcaniclastic units that filled in local rifts. From the Upper Triassic to the Middle Jurassic, it was composed mainly of terrigenous units that were deposited as transgressive silt and clay horizons, and from the Upper Jurassic to the Cretaceous, it consists of continental formation [16]. In the Late Triassic to Early Cretaceous units, the thick sandstone strata were deposited as an interbedded shale/carbonate mudstone in the Bokor Formation, which links to the Phuquoc Formation [4]. The Kampong Som basin was considered a petroleum system and consisted of thick sandstone strata mixed with claystone in the western part and black shale/calcareous shale continually in the eastern part of Kampot province [16]. Moreover, oil seepage has been discovered on the surface in the Preah Sihanouk and Kampot provinces, which leads to a favorable target for hydrocarbon exploration. Furthermore, the Kampong Som basin indicated that it is a foreland-type basin in which the upper Jurassic-Cretaceous unit's source rock has undergone the oil window's main stage [12, 16]. The study area is located in Tuek Chhue District, Kampot Province, in the southern part of Cambodia. Three main locations will be included in this research study, such as Phnom Khley in the western part, Phnom Chakrey, and Phnom MonPrey in the eastern region “Figure 2A to 2F”. These three locations were studied in detail for lithofacies, microtextural, fossil content, and organic matter type to get more information relating to the sedimentary process, depositional environment, and source of hydrocarbon generation in the study area.

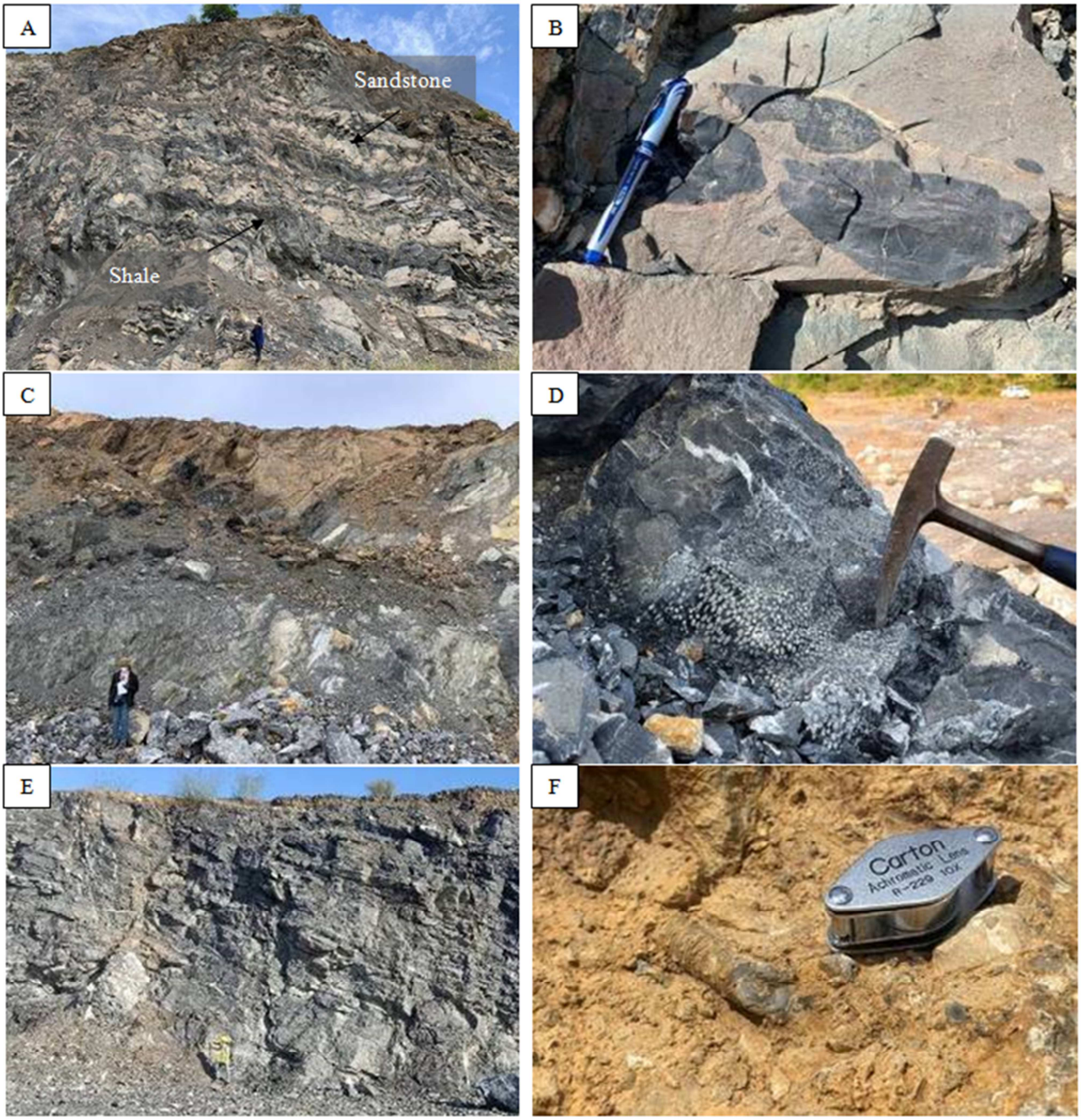

Figure 2. *Outcrops of shale from Bokor Formation in southern Cambodia. (A) Phnom Khley section. (B) 5 cm to 10 cm of shale lens deposited in sandstone layer in Phnom Khley section. (C) Phnom Monprey section. (D) Syringopora fossil observed in dark grey limestone of Phnom Monprey section. (E) Phnom Chakrey section. (F) Crinoide observed from Phnom Chakrey section (Achromatic lens 3.5 cm is for reference).*

2.2. Organic Matter and It Relationship to Depositional Environment

The organic macerals and the association provide necessary information for assessing depositional systems. While transgression of the sea promotes organic matter accumulation in deltaic fans in deep water, regression of the sea promotes organic matter accumulation in shelf regions [6]. Deltaic and fluvial sediments, in general, do not contain much organic matter generated by aquatic animals. Still, they have large amounts of residues of higher plants that are less hydrogen-rich and oil-prone than aquatic sediments. The organic petrology of a clastic sedimentary rock (e.g., shale) or an organic-rich coal source rock reveals numerous distributed organic matters. Liptinite, vitrinite, and inertinite are three organic macerals widely found in coal and shale [5, 6, 10].

Liptinite is made up of hydrogen-rich plant components such as sporopollenin, cutin, resin, and waxes, as well as bacterial decomposition of proteins, cellulose, and other carbohydrates. Liptodetrinite macerals are made up of many different fragments of finely degraded residues of sporinite, cutinite, resinite, and alginite, but they also derive from

unicellular algae [4]. Bituminite particles belong to the liptinitic group of macerals, which have poor reflectance in reflected white light (weak brownish reflectance or none at all) and lack geometries and structure. Exsudatinite is a secondary maceral that forms during the bituminization process [3, 8, 11]. Vitrinite is generated from humic substances, which are dark-colored complex-composition compounds derived mostly from lignin and cellulose (maximum hydrogen concentration), which are found in woody tissues such as roots, stems, bark, and leaves. Vitrinite is a set of gray macerals with a reflectance that is normally between the related darker liptinites and lighter inertinites [3, 8, 11]. Inertinite macerals are derived from the same plant materials as vitrinite and liptinite, but they have undergone a different primary transformation and have higher degrees of breakdown [3, 8, 11]. Fusinite, semifusinite, micrinite, and inertodetrinite are the sub-macerals of the inertinite group. In addition, inertinite macerals lack or have less fluorescence than vitrinite macerals [3, 8, 11]. Micrinite results from diagenetic alterations in the oil formation zone, where oil-like compounds such as exsudatinite are created and micrinite is formed as a remnant [3, 8, 11]. Liptinites maceral groups, such as cutinite and alginite, with admixtures of bituminite and micrinite, as well as small inertinite, vitrinite, and pyrite, are common found in shallow marine sources [3, 8, 11]. Moreover, vitrinite macerals generated under anoxic conditions are commonly found in mudstone deposition during maritime transgression or the wet period. On the other hand, mudstones dominated by inertinite macerals may represent a dry and oxidizing depositional environment [2, 3, 8, 11].

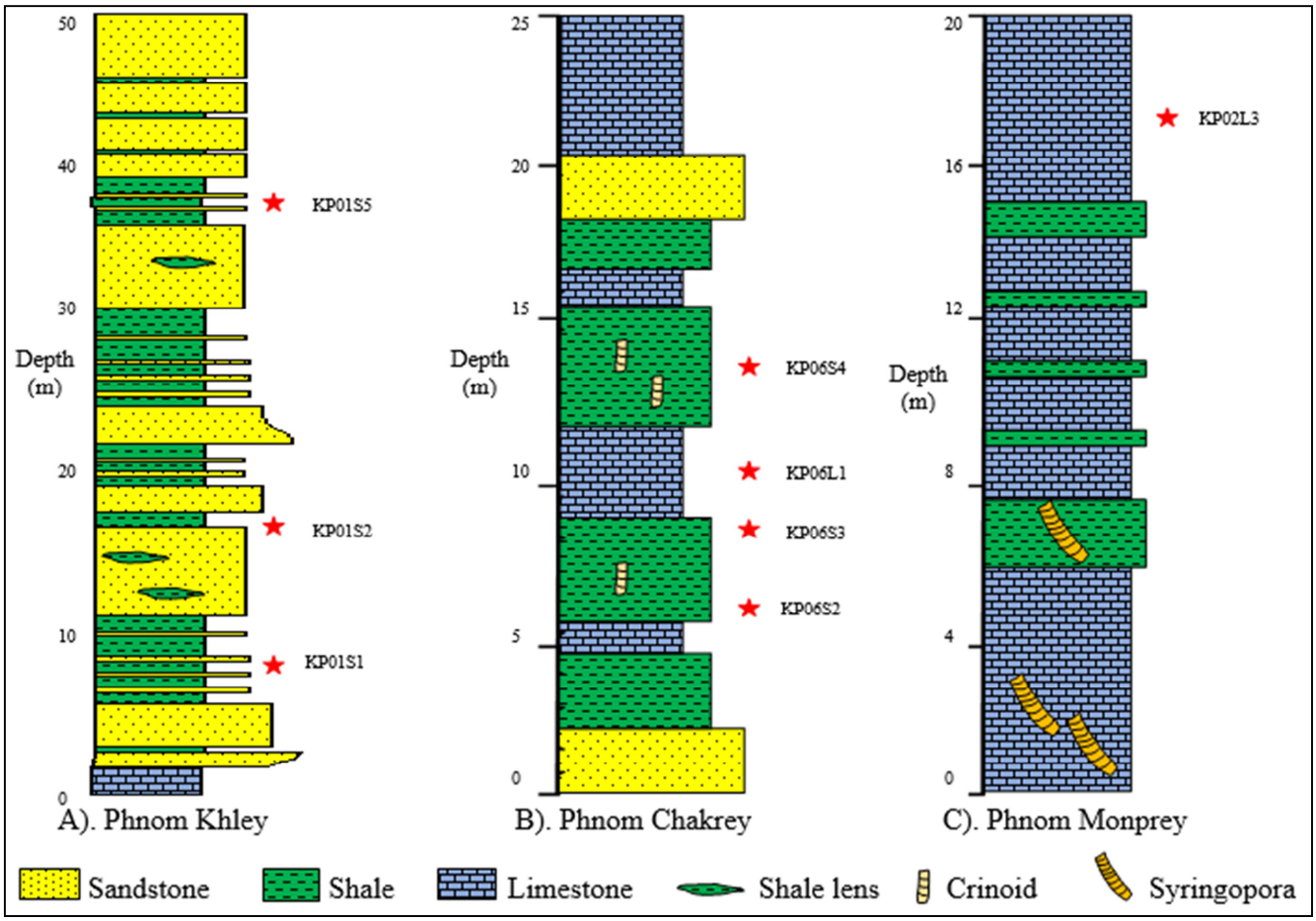

Figure 3. *Stratigraphy columns of the outcrop sections of Bokor Formation from southern Cambodia. (A) Phnom Khley section. (B) Phnom Chakrey section. (C) Phnom Monprey section. Red stars show the stratigraphic position of samples.*

3. Methods and Data Collection

In this research, geological fieldwork investigation and rock sampling were carried out only on the outcrop section of shale in the Bokor Formation. The specimen samples were collected by hammer, mobile rotary drilling, and chisel. In addition, the surface materials were removed before sampling to minimize the effects of surface weathering. To identify the organic matter types, eight samples from the Bokor Formation were selected: three samples from Phnom Khley (KP01S1, KP01S2, and KP01S5); four samples from Phnom Chakrey (KP06S2, KP06S3, KP06S4, and KP06L1); and one from Phnom Monprey (KP02L3). The samples were cut into small pieces and the flat surface was polished with carborundum and diamond fluid polishing. The prepared polished specimens were analyzed under the reflected white light of the Nikon ECLIPSE Ci-POL with a magnification lens of 50X and 100X.

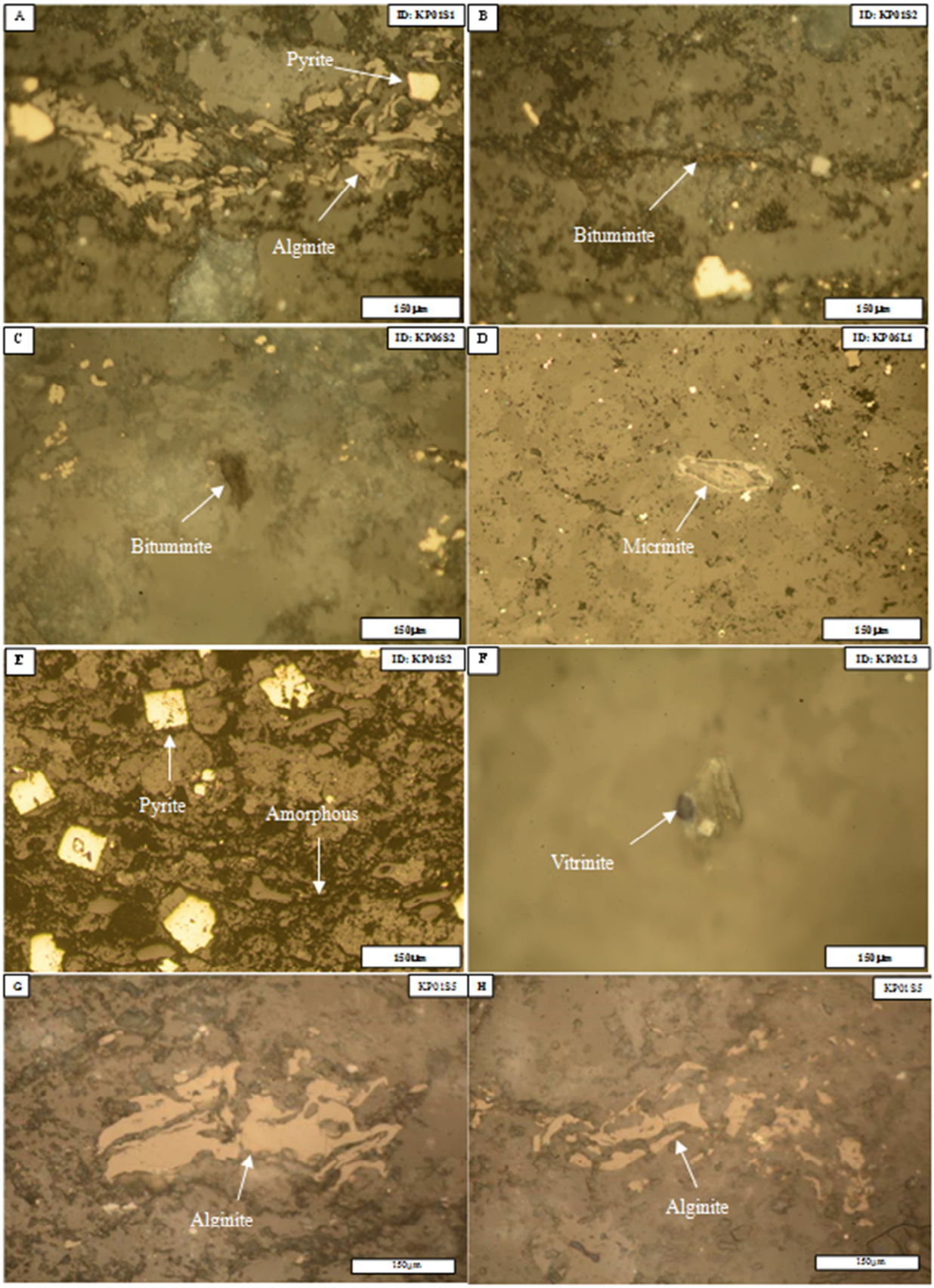

Figure 4. *Photomicrographs of shale in the Bokor Formation, taken under reflected white light (A-F). (A) Alginite with a moderately yellowish reflectance. (B) Bituminite with a weakly brownish reflectance. (C) Bituminte shows darker reflectance. (D) Micrinite in full bloom. Cubic pyrite and amorphous maceral (E). (F) Plant cell structure in blueish-floring vitrinite. (G) and (H) alginate from shale samples in the Phnom Khley section.*

4. Results

4.1. Stratigraphy Interpretation

The Phnom Khley cross-section is 100 m long and 50 m high. The beddings have a dip angle of approximately 33° to the North and consist of grain-supported packstone at the bottom and a frequency deposit of an interbedded layer of grey fine-medium grain sandstone and black shale "Figure 3A". Black shale is characterized by abundant horizontal lamination, and some beds contain lenticular grains of very fine-grain sandstone. This was presumed to be deposited in a low-energy flow bottom bed [2]. A single layer of laminated black shale was as thick as 0.1 m to 4 m, and those single layers were not homogeneous. They are characterized by a centimeter to decimeter scale with a thin layer of shale interbedded with sandstone. This variation was understood to be a high frequency of sea-level fluctuation deposited [2]. Moreover, a single sandstone layer was 0.4–2 m thick, fine to medium grain, sub-rounded to a rounded shape, well-sorted, and formed as a massive structure. Occasionally, sandstone bedding in this outcrop is more dominant than laminated black shale layers. This occurrence indicated that the outcrop exposed in this area was deposited near the shoreline [2].

Phnom Chakrey's cross-section has a 70-m length and a 25-m height. The outcrop exposed at this location has a dip angle of approximately 40° to the south. This outcrop consists of three main lithofacies: grey mud-supported limestone, calcareous shale, and grey fine-grained sandstone "Figure 3B". The lithofacies in the Phnom Chakrey outcrop are differentiated from those in the Phnom Khley outcrop. The limestone in this outcrop was deposited as a thick bed, mud-supported, and consisted of a fragment of coral fossil. In contrast, calcareous shale was observed as black with a massive structure. A single calcareous shale layer was as thick as 2–10 m. This indicated that limestone and calcareous shale facies were deposited in a calm environment, which was not affected by waves or tidal motion [2]. Moreover, only two sandstone beddings appeared in this outcrop. Many small layers of sandstone are included in these two beddings. Moreover, in these two beddings, one was a grey-colored, very fine-grained massive structure and the other was a shaly sandstone formed with a laminated structure, and this indicated that the sediments of these sandstone facies were transported or escaped from the shelf to mix with shaly sediments in the sea trough [7, 13].

The Phnom Monprey cross-section has a dip angle of approximately 41° to the North. Moreover, the outcrop is 50 m long and 20 m high, and there are two lithofacies, such as mud-supported grey limestone and strongly weathered, laminated black shale. Limestone in this location is deposited as a massive, thick succession. A single layer of this limestone ranges from 1 meter to 6 meters thick. Moreover, two types of fossils have been found in limestone facies, such as fusulinid foraminifera and syringopora fossils "Figure 2D, Figure 3B". In general, these fossils were widespread during the Silurian, Devonian, and Carboniferous periods. These fossils lived in a high-oxygen environment [1, 13]. The stratigraphy analysis of the Bokor Formation (including Phnom Khley, Phnom Chakrey, and Phnom Monprey sections) revealed three different lithology types such as shale with a laminated structure, fine-grained sandstone with a massive structure including the lens of shale, and limestone "Figure 3A". Normal and reversed graded bedding have been observed in Figure 3A, which suggests sediment deposition during transgression and regression of sea level [8].

4.2. Organic Petrology Analysis

Organic petrology analysis of shale in the Bokor Formation under reflected white light revealed several types of macerals such as alginate, bituminite, macrinite (Liptinite group), vitrinite, and amorphous organic matter. Alginite in shale is identified by moderate reflectance with a yellowish color and an elongated shape "Figure 4A, 4G, and 4F". Bituminite was observed in weakly brownish and darker reflectance and lacked the characteristics of shape and structure in "Figure 4B, 4C". Micrinite was observed in shale samples from Phnom Chakrey; it shows brightly fluorescent "Figure 4D". Occasionally, macrinite is a maturation product of marine to shallow marine bituminite shale [1, 8]. Moreover, the presence of weakly bituminite and macrinite in the Bokor Formation indicates a mature petroleum source rock [8]. The cubic pyrites that appeared in the Phnom Khley shale indicate the presence of a sulfidic water environment [1, 8]. Vitrinite "Figure 4F" is a humic substance and a major natural gas source, observed as blueish blossoms with a cell structure of a plant [8].

5. Discussion

The stratigraphic analysis of the Bokor Formation revealed three different lithology types, such as shale with a laminated structure, fine-grained sandstone with a massive structure including the lens of shale, and limestone. Normal and reversed graded bedding have been observed, suggesting sediment deposition during transgression and regression of sea level [8]. Organic petrologic analysis of shale and calcareous mudstone samples revealed a large amount of bituminite and micrinite, representing the liptinite group's maceral, indicating a mature petroleum source rock [8]. Occasionally, macrinite is a maturation product of marine to shallow marine bituminite shale [8]. The presence of cubic pyrite was also observed in shale samples "Figure 4E". The presence of pyrite and liptinite maceral groups in shale suggests that the diagenetic sulphate reduction took place at a shallow depth [1, 8, 11].

6. Conclusion

Based on stratigraphic analysis, grey fine-grained sandstones with a massive structure including the lens of shale, laminated black shale, and mud-supported limestone with some fossils (syringopora, crinoid, and foraminifera) are

defined, which indicate the sediments deposited in a marine setting. Organic petrologic analysis revealed cubic pyrite and macerals in shale samples such as alginite, bituminite, micrinite, and vitrinite. Additionally, alginate, bituminite, micrinite (liptinite group) and cubic pyrite were the most dominant macerals observed in most shale samples, suggesting that the source rock is thermally matured.

Acknowledgements

The research study was funded by the Cambodia Higher Education Improvement Project (Credit No. 6221-KH). We would like to thank the Ministry of Mine and Energy and the General Department of Petroleum for coordinating during the fieldwork investigation.

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