Petroleum and Coal

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Lithological Variations in Black shales and Mudstone Formations of Central Sarawak, Malaysia

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Received February 13, 2018; Accepted April 27, 2018

Abstract

This paper examines the Cretaceous – Upper Pliocene shale and mudstone outcrops in Central Sarawak. Related geological studies focused basically on sandstone and coals of Sarawak Basin, with no comprehensive outcrop study on lithological variations in the black shales and mudstone formations. Detailed lithological variations of these formations will allow us discretize potential shale gas intervals. Therefore, the aim of this study is to investigate the field geological characteristics of the Black shales and mudstone formations of Central Sarawak by using outcrop description, sedimentary log analysis, spectral gamma ray (SGR) data and geochemical characteristics (TOC %) of the selected mudstones and black shales. The study covers Nyalau, Tatau, Begrih, Liang and Belaga formations. Representative samples of the formations were subjected to detailed description in terms of lithology, structures and stratigraphy. Features such as laminations, sandstone intercalations, coal lenses, iron nodules, phyllite inclusions and fault structures were identified in the black shale and mudstone. The lowest U (ppm) was recorded for Belaga Formation, which can be attributed to the low grade metamorphism of the Formation, whereas the higher U (ppm) in Tatau and other formations is possibly due to their relatively higher clay content. The TOC values for all formations varied from 0.8% to 3.17%, suggesting they have fair to good hydrocarbon generative potential.

Keywords: *Geological; Black shale; Mudstone; Central Sarawak.*

1. Introduction

Shale is a fine-grained (grain size less than 4 microns in diameter) clastic sedimentary rock composed of mud and tiny fragments (silt-sized particles) of other minerals, particularly quartz and calcite [1]. Shale is distinguished by its fissility, which is the ability of a rock to break along parallel bedding or thin laminae less than one centimetre in thickness [2]. However, fissility is absent in mudstones [2-3]. Shale gas is a natural unconventional gas produced in shale rocks rich in organic matter [4]. The shale gas can be stored via two principal ways: (1) as chemically and/or physically adsorbed gas to/or within organic matter, and (2) as free gas in pore space and/or fractures [5].

A short field trip was carried out to study outcrops of black shales and mudstones in Central Sarawak. The study area covers Nyalau, Tatau, Begrih, Liang and Belaga formations in central Sarawak, Malaysia (Figures 1&2). The Sarawak Basin is considered Late Eocene to Recent in age [6]. It is a foreland basin developed from the collision of the Luconia block and West Borneo basement during Eocene times [7]. Basin modelling suggest a strike –slip origin due to the rapid subsidence in the early stages during Oligocene [8].

Sarawak Basin has a wide predominance of shale outcrops. However, previous studies have indicated that the source beds for hydrocarbon in Sarawak basin are coals and organic-rich clays of Oligocene to Lower Miocene age [9]. Rocks in the study area are considered the onshore analogue of the hydrocarbon-rich, offshore Balingian Province [10-11]. The rocks in the area consists mainly of sandstone, mudstone and shale. The rock formations are Mesozoic to Cenozoic in age [12].

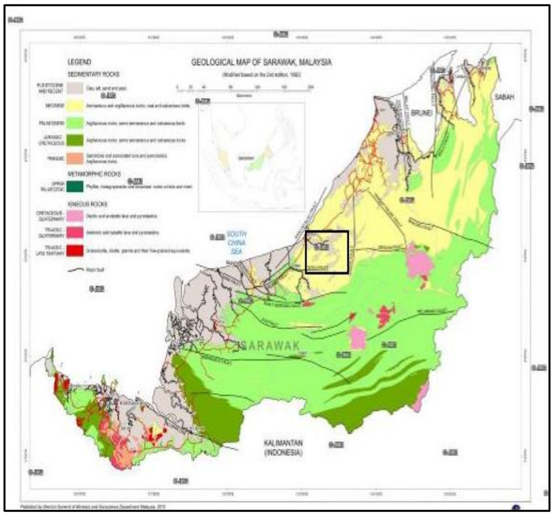

Figure 1. Location map of the study area [6]

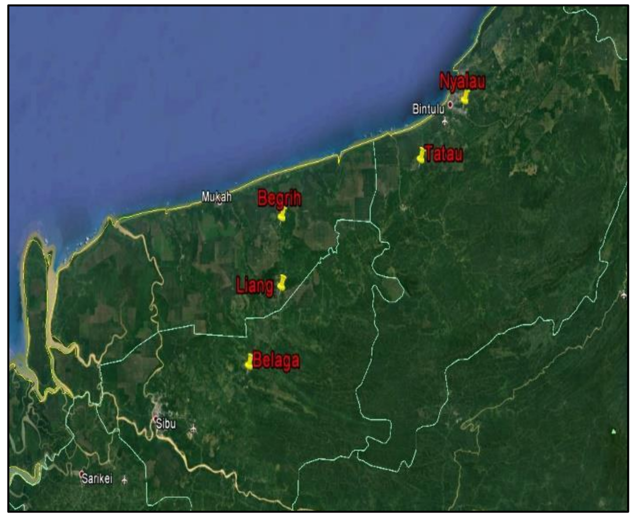

Figure 2. Location map of the formations

Zin [13] discussed the tertiary tectonics and sedimentation history of Sarawak Basin. The Tatau Formation consists of a succession of sandstone, siltstone and shales with intercalations of marls, limestones and locally developed conglomerates. The sediments of this formation were deposited as submarine fan and slope deposits during the late Eocene-Oligocene times. The Liang Formation consists of shale, sandstone, conglomerates and abundant lignite, which were deposited during Middle Miocene to Upper Miocene in predominantly coastal plain with some influences of shallow marine deposition [13]. Nyalau Formation is a thick succession of friable sandstone, laminated clay, and coal seams.

Furthermore, Bakar, Madon *et al.* [15] documented the different facies types in deep-marine rocks of the Belaga Formation (Cretaceous-Eocene) in the Sibu-Tatau area, Sarawak, aged from Late Cretaceous to late Eocene. The lithology of the Belaga Formation consists of thin to thick, fine to medium grain interbedded bedded sandstone with argillaceous rocks, mudstone facies with dark grey carbonaceous shale intercalated with fine grained silty sand along Bintulu Sibu road [15-16]. Recently, Siddiqui, Rahman *et al.* [14] studied the textural characteristics of shallow marine sandstone (well-exposed outcrops) of the Nyalau Formation (Oligocene–Middle Miocene), Bintulu area, Sarawak. The sandstone layers of Miocene Nyalau Formation are 4.5-9 m thick and alternated with soft carbonaceous clays [14].

However, the above mentioned studies focused ONLY on sandstone. Moreover, there is no comprehensive outcrop study on lithological variations in black shales and mudstone formations of Sarawak Basin. Detailed study of the lithological variations of these formations will allow us discretize potential gas shale intervals. This current study employs the use of outcrop description, sedimentary logs analysis and spectral gamma ray data.

2. Materials and methods

Core and hand specimens of thirty two onshore samples were collected from Central Sarawak, Bintulu and Mukah city. The study focused on shale and mudstone samples from 19 locations. 13 shale and 19 mudstone samples were obtained from different formations (Table 1). Spectral gamma ray (SGR) readings of the outcrop were taken, as shown in Figure 3**.**

TOC analysis was carried out on powders of 6 onshore samples (labelled S1- S6) from different outcrop locations in central Sarawak formations. Total organic carbon (TOC%) measurement was carried out using the direct method proposed in an earlier study [17]. The weighed crushed samples were treated with 10% hydrochloric acid (HCl) to remove the inorganic carbon. Carbonate minerals were also removed from the clays using HCl acid. Organic carbon content was reported on a dry weight basis [17].

Figure 3. Spectral Gamma Ray (SGR) reading of the outcrop

Table 1 Number of shale and mudstone samples in the study area

Formation	Number of samples		
	Shale	Mudstones	Total
Nyalau Formation	3	6	9
Tatau Formation	3	6	9
Begrih Formation	0	3	3
Liang Formation	1	3	4
Belaga Formation	6	1	7
Grand Total	13	19	32

3. Results and discussion

3.1. Outcrop description

3.1.1. Nyalau Formation

Three outcrops of Nyalau Formation (Oligocene–Middle Miocene) are located at different sites in Bintulu area, Sarawak. The location coordinates of the outcrop**s** range between Longitudes E 113° 05′ 28.8″ - E 113° 05′ 51. 0″ and Latitudes N 03° 09′ 24. 1″ - N 03° 11′ 34.1″. It consists of mudstones with iron nodules (Figure 4) and coal lenses (Figure 5), ferruginous reddish fine sandstone intercalated with mudstones, shale intercalated with thin layers of sandstones (Figure 6), fine to medium sandstones, sandy mudstones and laminated shale (Figure 7).

Fig.4. Mudstone with iron nodules from NY1-A outcrop

Figure 5. Mudstone with coal lenses from NY1-A outcrop

3.1.2. Tatau Formation

Four outcrops of the Tatau formation are located at different sites in Kampung Tatau Baru**.** The location coordinates of the outcrop**s** range between Longitudes E 112° 50′ 22.6″ - E 112° 54′ 40.7″ and Latitudes N 02° 52′ 18.6″- N 02° 59′ 30.1″**.** The lithology consists of mudstone, laminated mudstone interbedded with sandstone (Figure 8), fine sandstone interbedded with shale (Figure 9) and coal lenses (Figure 10).

3.1.3. Begrih Formation

There are three outcrops of Begrih Formation located at different sites. The location coordinates of the outcrops range between Longitudes E 112° 20′ 23.0″- E 112° 20′ 36.5″ and Latitudes N 02° 45′23.7″- N 02° 49′44.5″. The lithology of this outcrops consists of highly weathered mudstones interbedded with coal layers, gravel sandstones and fine sandstones (Figure 11).

Figure 6. Shale intercalated with thin layers of sandstone from NY-2 outcrop

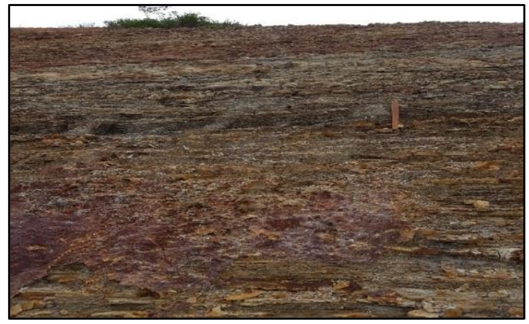

Figure 7. laminated shale formation from NY-2 outcrop

Figure 8. Laminated mudstone (red arrow) interbedded with sandstone (black arrow) from TA-2 Outcrop

Figure 9. Sandstones (red arrow) interbedded with shale (black arrow) from TA-3 Outcrop

Figure 10. Fine sandstone with coal lenses from TA-3 Outcrop

Figure 11. Mudstones (black arrow) with sandstone (red arrow) from BEG-3 outcrop

3.1.4. Liang Formation

Three outcrops of Liang Formation were identified at different locations. The location coordinates of the outcrops range between Longitudes E 112° 20′ 16.0″- E 112° 20′43.4″ and Latitudes N 02° 36′04.2″- N 02° 38′02.9″. The lithology of the outcrop consists of shales, sandy mudstones and dark grey mudstones (Figure 12).

3.1.5. Belaga Formations

Six outcrops of Belaga Formation were identified at different locations. The location coordinates of the outcrops range between Longitudes E 112° 20′ 16.0″- E 112° 20′43.4″ and Latitudes N 02° 36′04.2″- N 02° 38′02.9″. The lithology of the outcrops consists of dark grey shale (example for sedimentological log Figure 15), highly fractured shale with quartz and phyllite inclusions (Figure 13) and lateral variation of black shales to sandstones to shales. Quartz veins were identified, indicating the outcrop is faulted. Another identified faulting structure is the alignment of the shale layer and sandstones at the same depth (Figure 14).

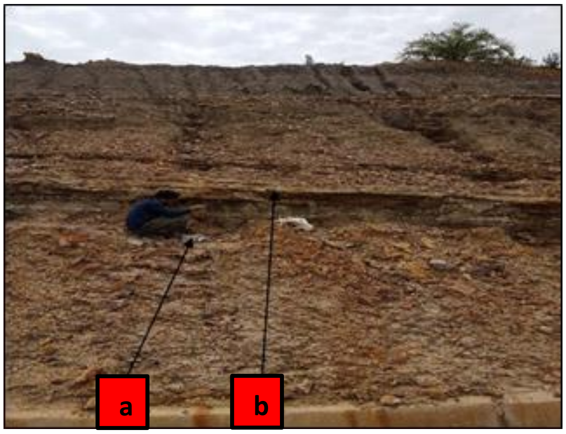

Figure 12. [a] Shale, and [b] sandy mudstones LI-1 outcrop

Fig. 13. Highly fractured shale with quartz and phyllite inclusions

Fig. 14. Fault structure indicated by the alignment of shale and sandstone at the same depth from BEL-3 outcrop

3.2. Uranium concentration

Natural gamma radiation provides information on the composition and lithology of a Formation. The spectral gamma-ray activity concentrations (uranium (U/ppm) of the shale and mudstone outcrops of different formations are shown in Table 2. The uranium concentration in Nyalau Formation range from 12.87 - 18.55ppm with an average of 16.12 ppm. Meanwhile, the Uranium concentration (ppm) of Tatau Formation range from 12.54 - 22.56 ppm with an average of 17.17 ppm. The uranium concentration in Begrih Formation ranges between 12.45-13.74 ppm with an average of 13.14ppm. The uranium concentrations in Liang Formation vary between 10.34 - 14.60 ppm with an average of 12.46 ppm, whereas Belaga Formation exhibited a wider range between 2.49-19.21ppm, with an average of 10.46ppm. The lowest U/ppm value was recorded for Belaga Formation, which can be attributed to the low grade metamorphism of the Formation, whereas the higher U (ppm) in Tatau and other formations is possibly due to their relatively higher clay content.

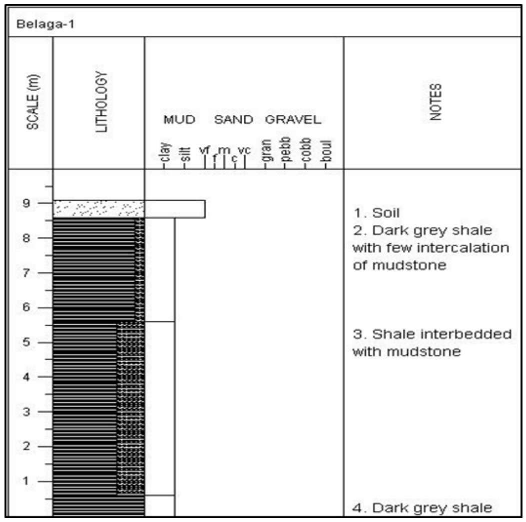

Figure 15. Sedimentological log for Belaga-1

Table 2. Uranium concentration of shale and mudstone in study area

Sample ID	Lithology	U/ppm	Sample ID	Lithology	U/ppm
NY1A-1	Mudstone	17.99	TA4-1	Shale	20.80
NY1A-2	Shale	18.27	TA4-2	Mudstone	15.88
NY1B-1	Shale	17.45	BEG-1	Mudstone	12.45
NY1B-2	Mudstone	18.55	BEG-2	Mudstone	13.23
NY1B-3	Mudstone	14.84	BEG-3	Mudstone	13.74
NY1B-4	Mudstone	12.87	LI1-1	Shale	12.91
NY1B-5	Mudstone	16.00	LI1-2	Mudstone	12.00
NY2-1	Shale	14.73	LI-3	Mudstone	14.60
NY2-2	Shale	14.41	BEL-1	Shale	3.79
TA1-1	Shale	13.00	BEL-2	Shale	2.49
TA1-2	Mudstone	12.65	BEL-3	Shale	4.73
TA-2	Mudstone	12.54	BEL4-1	Mudstone	11.62
TA3-1	Mudstone	19.48	BEL4-2	Shale	16.33
TA3-2	Shale	22.56	BEL5-A	Shale	15.02
TA3-3	Mudstone	17.37	BEL5-B	Shale	19.21
TA3-4	Mudstone	20.26			

3.3. Total Organic Carbon (TOC) % Analysis

The TOC values range from 0.8- 3.17 %, as shown in Table 3. Sample S1 (Begrih-1Formation) exhibited the highest TOC (3.17%), while S3 (Nyalau-1 Formation) has the least TOC (0.8%), indicating the shale and mudstone samples have fair to good hydrocarbon generative potential [18]. On the other hand, the Total carbon (TC) values range from 1.6 to 4.8% (Table 3). Sample S2 (Tatau-2 Formation) showed the highest TC of 4.8%, while S5 (Nyalau-4 Formation) exhibited the least TC (1.6%).

Table 3. TOC % and TC % values from study area

Formation	Lithology	Sample ID	TOC %	TC %
Begrih-1Formation	Shale	S1	3.17	3.19
Tatau-2 Formation	Mudstone	S2	1.2	4.8
Nyalau-1 Formation	Mudstone	S3	0.8	6.0
Belaga Formation	Shale	S4	1.1	3.3
Nyalau-4 Formation	Mudstone	S5	1.5	1.6
Nyalau-3 Formation	Mudstone	S6	1.3	1.7

4. Conclusion

Representative samples of various formations of mudstone and black shale were subjected to detailed description in terms of lithology, sedimentary structures and stratigraphy to improve the geological understanding of the area. Features such as laminations, sandstone intercalations, coal lenses, iron nodules, phyllite inclusions and fault structures were identified in the shale and mudstone. The lowest U (ppm) was recorded for Belaga Formation, which can be attributed to the low grade metamorphism of the Formation, whereas the higher U (ppm) in Tatau and other formations is possibly due to their relatively higher clay content. Based on the TOC% values from different formations (0.8-3.17%), this study predicts the black shale of the study area is a potential unconventional source of energy.

Acknowledgments

We thank Universiti Teknologi PETRONAS for providing the Graduate Research Assistantship Scheme (GRA) and shale gas grant.

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