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Geological interpretation of Spectral Gamma Ray (SGR) of fine clastic rocks from the Nyalau Formation central Sarawak, Malaysia

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Abstract: The increasing interest for shale gas exploitation as unconventional resources is aided by the new technological advancement that has marked the pathway to explore shale gas for local utilization and national economy in Malaysia. The Nyalau Formation which is an Oligocene - Middle Miocene in age. This article attempts to analyze the depositional environment, Gamma Ray, clay mineralogy and evaluate the relationship between uranium concentration and total organic carbon (TOC) of the Nyalau Formation comprise of shales and mudstones using Spectral Gamma Ray (SGR). The results from SGR indicate to compose principally kaolinite and Smectite, XRD analysis and FESEM reveals the presence of illite. The Th/U ratios vary between 0.57 and 0.85 indicate formation is deposited in a reduced marine environment. Calculated API reveals the ability of the clay minerals to absorb uranium and thorium through cation exchange capacity. The relationship between the cross plot of TOC% / U shows positive correlation.

Keywords: Nyalau Formation, ctral Gamma-Ray log (SGR), clay minerals, organic matter, Shale, Mudstone.

INTRODUCTION

Shale is a fine-grained clastic sedimentary rock (grain size less than 4 microns in diameter) consist of mud and small fragments (silt-sized particles) of other minerals, mainly quartz and calcite (Passey *et al*., 2010) with fissility absent in mudstones (Tucker, 1991; Blatt *et al*., 2006). The increasing interest for shale gas exploitation as unconventional resources aided by new technologies is recently gaining attention in Malaysia to explore shale gas potentials for the national economy and local utilization. There is an emphasis to physically and chemically characterize properties such as TOC%, clay contents and radioactive elements composition and its distribution to understanding their depositional environments by interpretation of varying gamma-ray signatures for non-cored outcrops becomes paramount.

Further studies to evaluate their relationship to critical shale properties such as sorption and adsorption that plays an essential role in shale gas exploration. For decades, reconnaissance investigation in hydrocarbon reservoirs potential entails measuring natural gamma radiation to differentiate between shale and non-shale interludes, while the spectral gamma ray (SGR) procedure is used to subdivide the homogenous marine black shale intervals by fine-scale changes in the distribution of potassium (K), uranium (U), and thorium (Th). This reflect minute mineralogical variances (Fertl & Chilingarian, 1990; McGowan, 2015). Gamma-ray peaks have been a valuable tool used to correlate exposures in outcrop to the subsurface (Aigner *et al*., 1995). Therefore, this necessitates field investigation on outcrops of black shales and mudstones in Nyalau Formation in central Sarawak, Malaysia (Figure 1). Typically, the occurrence of fine-clastic clay-rich rock formation (shale, clay stone, mudstone) indicate high response of gamma-ray while the existence of coarse-grained sandstone and carbonate rock indicate low response of gamma radiation which displays higher water-transmitting capacity (Schon, 2011; Chou *et al*., 2014). The dispersal of U, Th and K mineralas are controlled by the main factors which are the origin of the clastic constituents, chemical and physical stability of these components in the sedimentary environment (Nielsen *et al*., 1987). High gamma-ray activity, high resistivity, and low bulk density is petrophysically described the typical black shale as a sedimentary rock. Moreover, sedimentary rocks like shales show a higher concentration of thorium (Th), uranium (U) and Th/U ratio compare to the igneous rocks (Larsen & Gottfried, 1960). The thorium content of

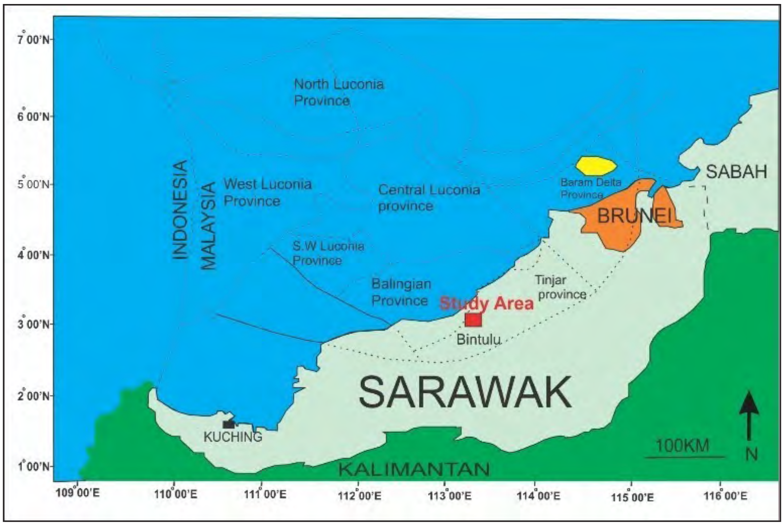

Figure 1: Location map of the study area (Iqbal *et al.*, 2017).

shales differs considerably less than the uranium content (Adams & Weaver, 1958).

Earlier investigation made more assessment of sandstone reservoir textural properties and reservoir interconnectivity of the various sandstone lithofacies in Bintulu and Miri, to develop 2-D intermediate-scale model (Siddiqui *et al.*, 2014). Furthermore, partly the Nyalau Formation was considered as a source rock unit, characterized mainly with extensively shale distributed across the Sarawak Basin (Togunwa *et al.*, 2015). The textural characteristics of the shallow marine sandstones of the Nyalau Formation is well-exposed from Oligocene–Middle Miocene comprising of minor shale and massive sandstone that were deposited under shallow water marine conditions (Siddiqui *et al.*, 2016). Iqbal *et al.* (2017) assessed the Nyalau Formation on the base of measurements for porosity/ permeability and evaluate impact of pore throat size on porosity and permeability in different lithofacies. Moreover, investigation on inorganic and organic of the Paleogene-Neogene coals and related black shales to investigate their origin, depositional environment, and hydrocarbon potential in different formations including the Nyalau Formation (Baioumy *et al.*, 2018). Most previous studies focused mainly on reservoir properties with no attempt to explore shale gas potential properties in black shales and mudstones formation.

This article challenges to evaluate clay mineralogical composition to determine depositional environment of the Nyalau Formation black shale and mudstone using Spectral Gamma Ray and the relationship between TOC% and U concentrations in Nyalau Formation onshore, Central Sarawak Basin.

LOCAL GEOLOGY

The Sarawak Basin (Madon, 1999) was considered Late Eocene to Recent age, proposed deposited during Oligocene - Early Miocene times (Wolfenden, 1960). It was also considered as a foreland basin developed from the collision of the West Borneo basement and the Luconia block through Eocene age (Madon *et al.*, 2013).

MATERIAL AND METHOD

Onshore samples (9) were taken from three outcrops (Figure 2) from Nyalau Formation, Central Sarawak, Bintulu city. The main specimen used in this study is fine clastic rocks (shale and mudstone) from the Nyalau Formation (Figure 3). Three outcrops of the Nyalau Formation is characterized of mudstones with iron nodules, sandstone and coaly shale (Oligocene–Middle Miocene age), located at coordinates 03° 09' 29.2" N 113° 05' 35.7" E, 03° 09' 24.1" N 113° 05' 51" E and 03° 11' 34.1" N 113° 05' 28.8" E for NY1-A, NY1-B and NY-2, respectively in Bintulu area, Sarawak. Spectral gamma ray (SGR) reading from the outcrops were taken and recorded. The mineralogical analysis was acquired from the X-ray diffraction (XRD) and patterns were generated by Philips-P Analytical X'pert Pro powder diffractometer using Cu Kα radiation. The diffraction data was listed from 3 to 60 2ϴ with a step width of 0.02° and a counting time of 4 s per step.

A chip of the samples was coated with a conductive material (gold) and an apparent image of an insulated material is obtained. These coated samples were placed in the chamber, vacated and was scanned using field emission scanning electron microscopy (FESEM). The EDX spectrum points were also carried out by using SEM Petrography Atlas (Welton, 1984). The crushed specimen was weighed and treated with 10% hydrochloric acid (HCl) to remove the inorganic carbon and carbonate minerals. Total organic carbon (TOC)% measurements were obtained using Analytikjena HT 1300 Solids Carbon Analyzer using the direct method proposed by Dow & Pearson, 1975).

Figure 2: Location map of the outcrops in the study area.

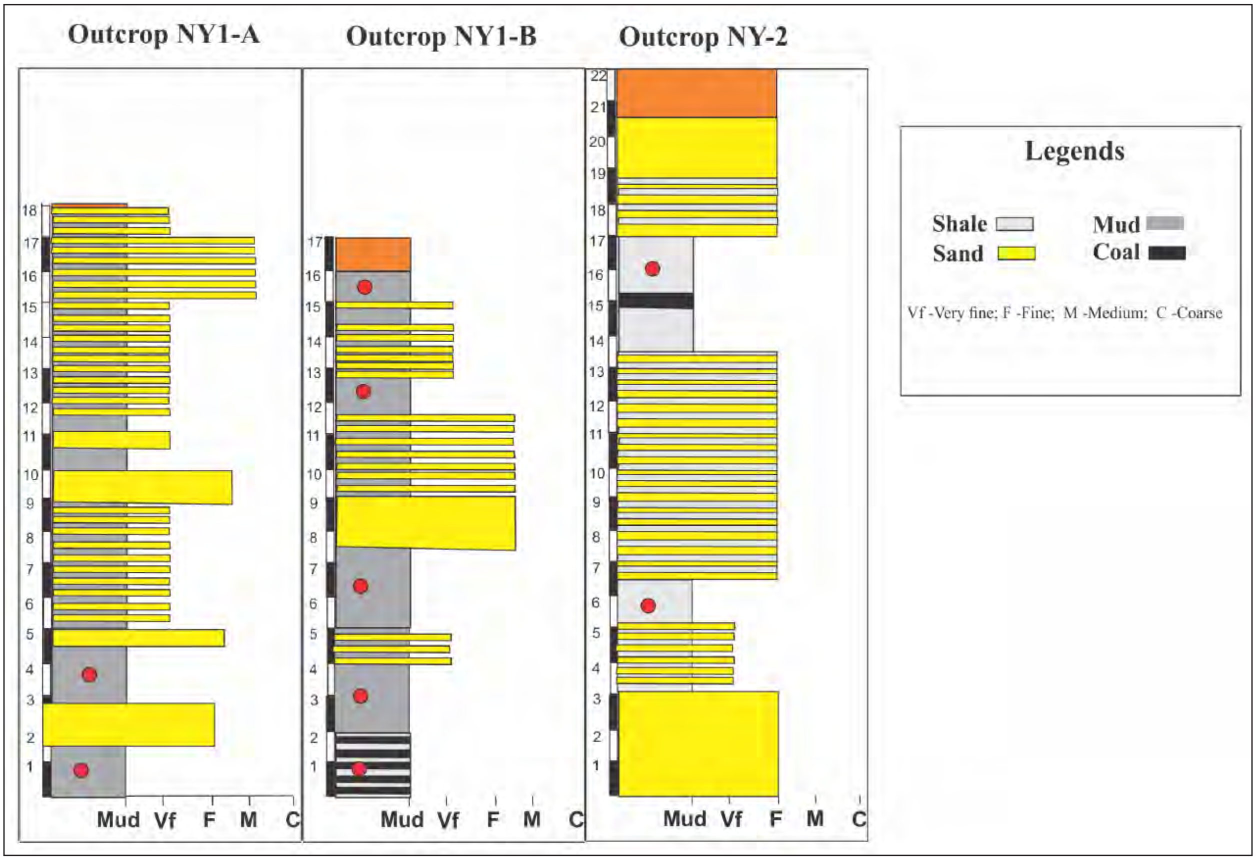

Figure 3: Lithological logs of three outcrops of Nyalau Formation; outcrop NY1-A, outcrop NY1-B and outcrop NY-2 (location in Figure 2) with different packages showing the thickness of sandstone and mudstone within the packages**.**

RESULTS AND DISCUSSION

Clay mineral identification

Table 1 presents the spectral gamma-ray concentration values from all measured outcrop specimen samples. The concentration composition of K40 varies from 0.56 to 0.98 %, and U 238 range from 12.87 to 18.90 ppm. While Th 232 differs from 9.59 ppm to 12.46 ppm. Thorium (ppm) against potassium (%) plots were used to identify definite clay types (Figure 4), Th/K plots recognized smectite and kaolinite clay minerals with no existence of illite. Uranium high compositions indicate organic-rich shales are potential source beds. These interpretations are general as the identification of clay type using SGR is limited. The minerals of kaolinite, smectite, and illite are observe in most specimen from FESEM analysis (Figure 5). These minerals are confirmed and also revealed occurrence of chlorite (Figure 6A and B) from XRD analysis.

Depositional environment

The Th/U ratios in sedimentary rocks differ from 0.02 to more than 21, and in many continental oxidized deposits values is above 7, while in marine exhibits considerably less than 7 (Adams & Weaver, 1958). Previous researcher proposed that Th/U concentrations ratios serve as critical indicators of sedimentary environments. Koczy (1949) suggested with a little analysis that the Th /U ratio should reduce as the distance from the shore enlarged. Then, the ratios of Th/U differ with the difference in sedimentary depositional environment. The Th/U concentration ratios differs (Table 1) from 0.57 to 0.85, that have indicated Nyalau Formation is deposited in marine and reduced environment.

Gamma ray calculation

The formula adopted from the website https://en.wikipedia.org/wiki/Gamma_ray_logging is used to calculate Gamma Ray in API and the results is presented in Table 2:

$$GR\ API = 8 \times (U)\ ppm + 4 \times (Th)\ ppm + 16 \times (K)$$

The Gamma ray concentration values in shales are more than in other clastic sedimentary rocks, such as sandstone, coal, gypsum, salt and carbonate. This is attributed to occurrence of radioactive element prevalent in the clay content of shales that have the ability to absorb uranium and thorium via cation exchange capacity. Gamma Ray (GR) values in the specimen ranging between 152.76 and 207.12 API is interpreted as high estimated value. This is attributed to occurrence of organic matter which generated a reduction environment that results in precipitation of uranium and subsequent high activity of gamma-ray.

Quantitative relationship between TOC (%) and U concentration

The TOC values range from 0.58 - 1.96 %, indicate that shale and mudstone specimen have fair to good hydrocarbon generative potential, while the coaly shale facies reveals highest value for TOC % (1.96%) as presented in Table 3. This variability is attributed to occurrence of coal within stratigraphic sequence as known to vary from 58.1 to 80.9 wt (Hakimi & Abdullah, 2013) in the study area in the Nyalau Formation.

The plot reveals a good correlation between the TOC determined in laboratory and U concentration from SGR (Figure 7) in different facies type. The occurrence of a high U (ppm) concentration confirms organic matter indicator associated to relatively high organic matter and clay contents present in Nyalau Formation.

CONCLUSION

The representative specimen of the mudstone and black shale from the Nyalau Formation were evaluated to determine their clay minerals composition, depositional environment and also determine relationship between TOC (%) / U concentrations.

A radiometric analysis shows that smectite and kaolinite clay minerals are the dominant obtained from the cross plots of Th against K, revealing occurrence of illite, and validated by FESEM and XRD analysis.

Table 1: Values of potassium, uranium and thorium concentration obtained from Nyalau Formation samples.

Sample No	*Lithology*	*K %*	*U (ppm)*	*Th (ppm)*	*Th/U*
NY1A-1	Massive Mudstone	0.78	17.99	11.31	0.63
NY1A-2	Massive Mudstone	0.57	17.83	10.23	0.57
NY1B-1	Laminated Mudstone	0.73	18.90	11.06	0.59
NY1B-2	Laminated Nodular Mudstone	0.76	18.55	10.54	0.57
NY1B-3	Laminated Nodular Mudstone	0.98	14.84	11.07	0.75
NY1B-4	Laminated Nodular Mudstone	0.66	12.87	09.81	0.76
NY1B-5	Laminated Shale	0.88	16.00	12.11	0.76
NY2-1	Coaly Shale	0.56	14.73	12.46	0.85
NY2-2	Coaly Shale	0.86	14.41	09.59	0.67

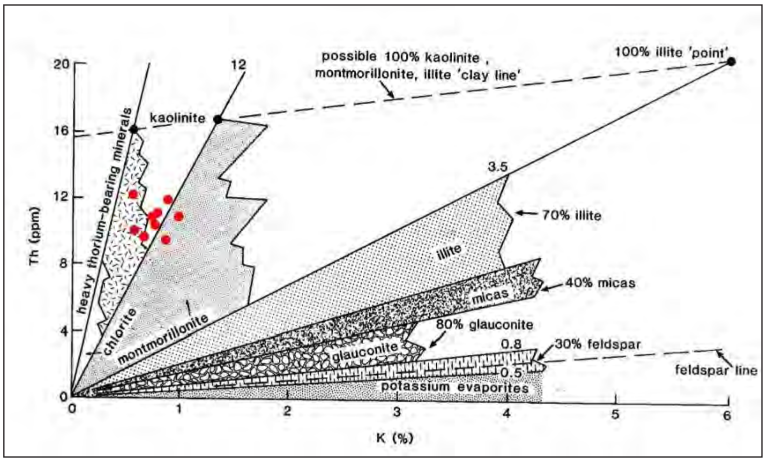

Figure 4: Results of the K % and Th (ppm) cross plot of Spectral Gamma Ray (SGR), using Schlumberger plots (http://www1.uis.no/Fag/Learningspace_kurs/PetBachelor/webpage/tech%5CSchlumberger%20charts%5C07_cp_4-20_4-33.p11.pdf).

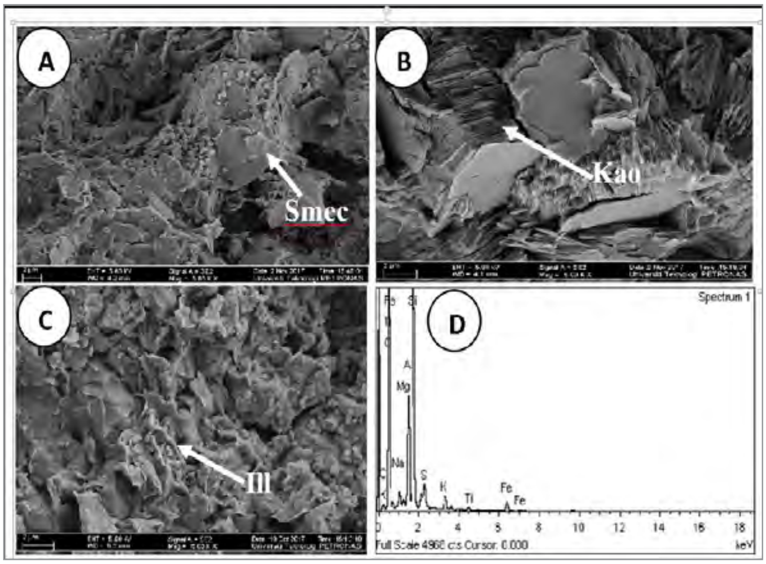

Figure 5: FESEM micrograph showing the clay mineral in the mudstone and shale samples. A) Smec = Smectite mineral with, B) Kaol= Kaolinite and C) Ill= Illite mineral and D) their Dispersive (EDX) Spectrum.

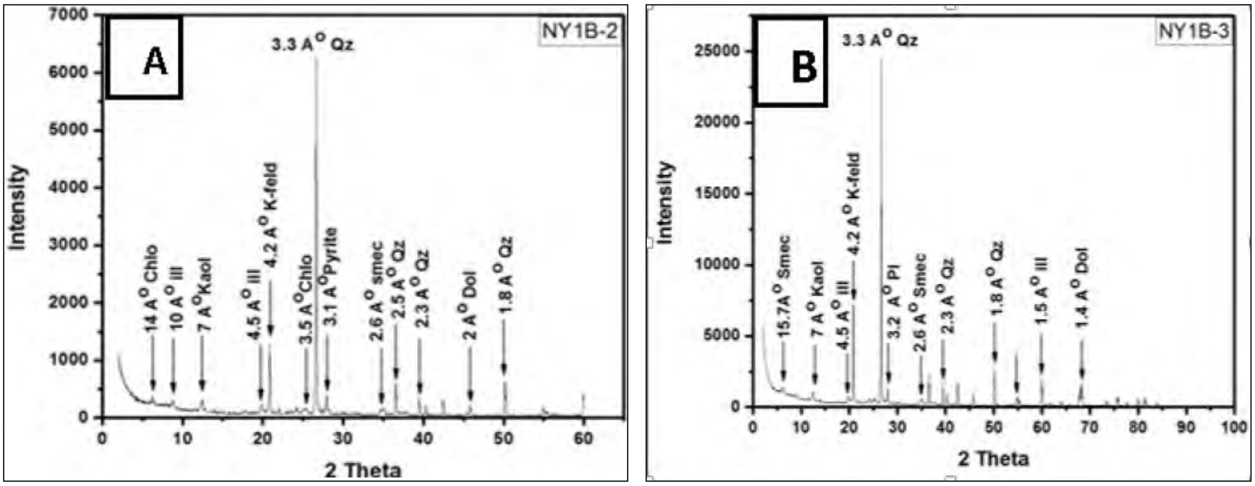

Figure 6: XRD spectrums showing different clay mineral present in the mudstone and shale samples in the Nyalau Formation: A) NY1B-2 and B) NY1B-3 outcrops. Ill= Illite, Kaol= Kaolinite and Smec=Smectite.

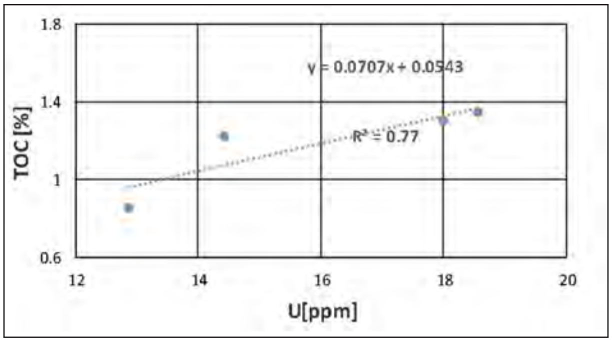

Figure 7. TOC % / U cross plots of mudstone and shale samples in different facies

The indirect application of the Th/U ratios interprets the depositional environment at reduction conditions in marine depositional environment revealing to have ratio value from 0.57 to 0.85.

The high values of the Gamma Ray (GR) range from 152.76 to 207.12 API indicate the ability of clays to absorb uranium and thorium through cation exchange capacity. The cross plots of TOC (%) against U shows considerable positive correlation with the organic matter evolution. This relationship confirmed high presence of U concentration ascribed their relatively higher clay contents and organic matter present in Nyalau Formation

Table 2: Calculated Gamma Ray (GR) values from Nyalau Formation.

Sample No	*Lithology*	*Dose Rate (DR) nGY/h*	*Gamma Ray (GR) API*
NY1A-1	Massive Mudstone	102.11	201.64
NY1A-2	Massive Mudstone	103.78	192.68
NY1B-1	Laminated Mudstone	97.15	207.12
NY1B-2	Laminated Nodular Mudstone	105.27	202.72
NY1B-3	Laminated Nodular Mudstone	84.21	178.68
NY1B-4	Laminated Nodular Mudstone	73.03	152.76
NY1B-5	Laminated Shale	90.78	190.52
NY2-1	Coaly Shale	83.60	176.64
NY2-2	Coaly Shale	81.76	167.4

Table 3: Relationship between the TOC content and the uranium content in the Nyalau Formation.

Sample No	*Lithology*	*U(ppm)*	*TOC%*
NY1A-2	Massive Mudstone	17.99	1.3
NY1B-4	Massive Mudstone	17.83	0.76
NY1B-2	Laminated Mudstone	18.90	0.83
NY1A-1	Laminated Nodular Mudstone Mudstone	18.55	1.35
NY1B-3	Laminated Nodular Mudstone	12.87	0.86
NY1B-5	Laminated Nodular Mudstone	14.84	0.98
NY2-1	Laminated Shale	16.00	0.58
NY1B-1	Coaly Shale	14.73	1.96
NY2-2	Coaly Shale	14.41	1.22

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