Petroleum source rock assessment using outcrop data and geochemical analysis in Phetchabun and Loei Province, Thailand

Adventino[1] and Piyaphong Chenrai[1,2]

[1] Petroleum Geoscience Program, Department of Geology, Faculty of Science, Chulalongkorn University, Bangkok, 10330, Thailand
[2] Applied Mineral and Petrology Special Task Force for Activating Research (AMP STAR), Department of Geology, Faculty of Science, Chulalongkorn University, Bangkok, 10330 Thailand
[1]Author email: iadventino96@gmail.com

Received: 18 Jun 2021
Revised : 8 Jul 2021
Accepted: 9 Jul 2021

Abstract

The study areas have five locations consisting of Amphoe Lom Sak (ALS), Amphoe Nam Nao (ANN), Grand Canyon Nam Nao (GCNN), Amphoe Mueang Loei (AML) and Amphoe Pak Chom (APC). This study focuses on Huai Hin Lat Formation, Wang Saphung Formation and Nong Dok Bua Formation. Lithology in the study areas consists of calcareous mudstone, argillaceous mudstone, coal-shale, calcilutite, calcarenite and argillaceous shale. A total of eighteen samples for geochemical analysis included quantity, quality, and maturity are useful for identifying and interpreting petroleum source rock and depositional environment. The Total Organic Carbon (TOC) ranges from 0.03 - 20.17 wt.% which is poor to excellent capacity for petroleum potential. Extractable Organic Matter (EOM) ranges are 60 - 4127 ppm (poor-excellent). Type of kerogen is type III (gas prone) and someplace found in type-IV (inert/dry gas) since the components value of Oxygen Index (OI) is higher than Hydrogen Index (HI). Maturity levels of the rock samples in the study area are in immature to over mature stages. The stratigraphic section shows the depositional environment in Amphoe Nam Nao (ANN) and Grand Canyon Nam Nao (GCNN) part of Huai Hin Lat Formation is lacustrine-floodplain or levees and the Amphue Mueang Loei (AML) part of Wang Saphung Formation deposited in foreslope-backreef or lagoon.

Keywords: Petroleum source rock, Huai Hin Lat Fm, Wang Saphung Fm, Nong Dok Bua Fm

1. Introduction

The Khorat Plateau is the largest basin located in northeastern Thailand. This plateau is one of producing gas fields and covers an area of 200,000 square kilometers of Mesozoic continental sedimentary rocks of Khorat Group (Chantong, 2007). Racey (2011) summarized a potential source rock in Khorat Plateau and suggested three potential source rocks including 1) Lower Cretaceous Khorat Group containing few centimeters of woody organic material in its lateral red bed sequence producing minimal gas by locally mature stage, 2) Triassic Huai Hin Lat organic-rich shale (Kuchinarai Group) and then, 3) Upper Carboniferous – Upper Permian in Saraburi Group (Si That Formation). The Khorat basin has been explored for petroleum potential since 1962 and two commercial petroleum fields have been discovered since 1988 (Racey, 2011).

This study focuses on stratigraphic frameworks and rocks samples for geochemistry data that would help to get an understanding of hydrocarbon source rocks in the study areas. The outcrop sample of the Huai Hin Lat Formation, Wang Saphung (equivalence to subsurface Si That Formation) and Nong Dok Bua Formations were studied to determine their organic geochemical characteristic and depositional environment (Fig. 1). The physical characteristics of the rock samples in these study areas are fine-grained sedimentary rock with dark grey until black color. In some studied outcrop, coaly-shale and mudstone are found to have organic content.

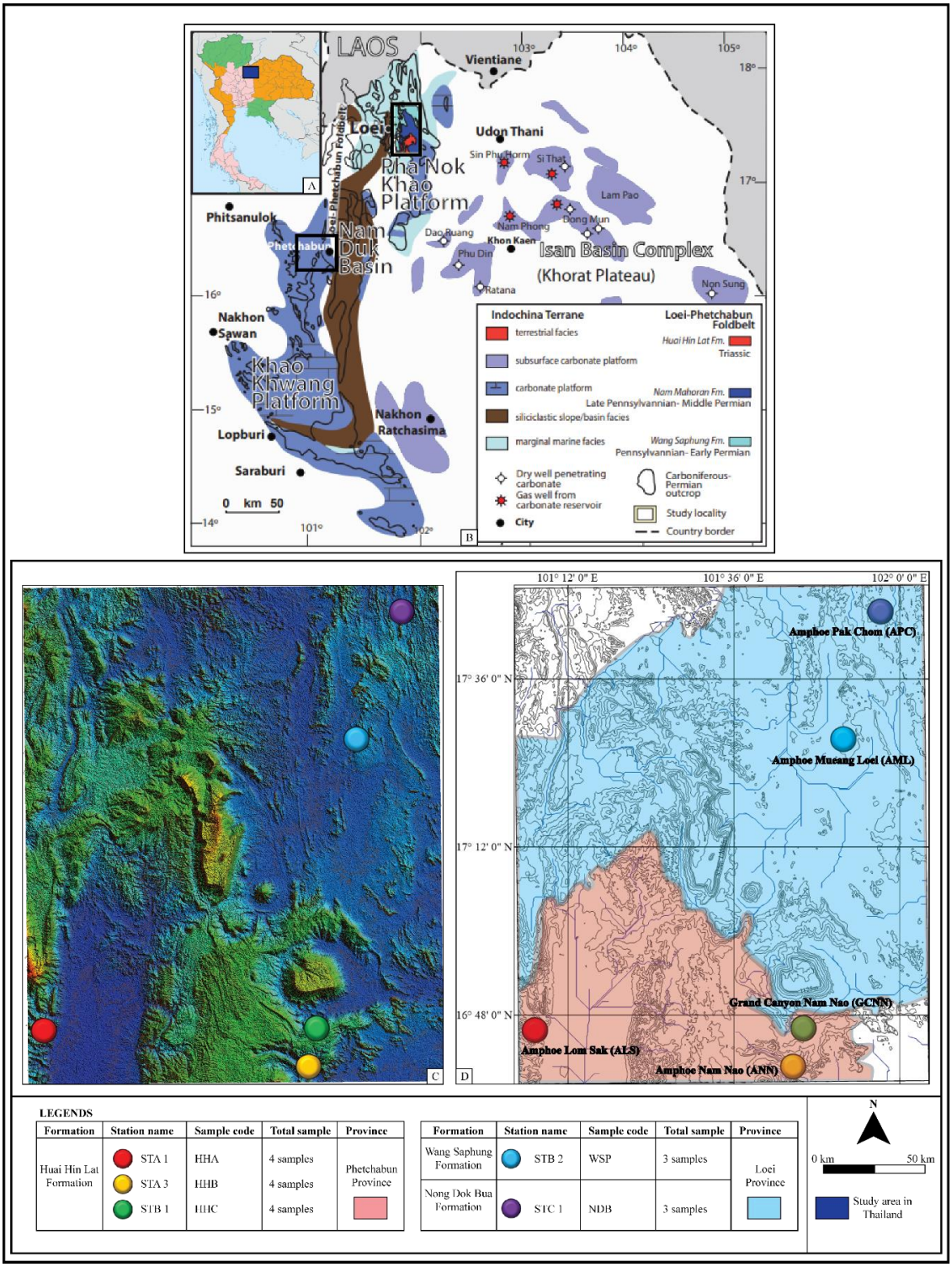

Figure 1. (A) Location of Phetchabun Province and Loei Province, Thailand, **(B)** Distribution of Permo-Carboniferous in the Loei-Phetchabun Fold Belt with the Khorat Plateau shows the major Pha Nok Khao (PNK) and Khao Khwang (KK) carbonate platforms and intervening Nam Duk Basin (Ueno and Charoentitirat, 2011), **(C)** Close up of the study area with the topographic 3D surface condition, **(D)** Outcrop samples collected from five outcrops in each Formation and boundary of the study area consists of 5 stations; STA 1 is Amphoe Lom Sak (ALS), STA 3 is Amphoe Nam Nao (ANN), STB1 is Grand Canyon Nam Nao (GCNN), STB2 is Amphoe Mueang Loei (AML), and STC 1 is Amphoe Pak Chom (APC).

2. Geological setting

Saraburi Group nomenclature should be applied only to Khao Khwang Platform, and proposed the term Loei Group for the Pha Nok Khao Platform stratigraphic succession (Ueno and Charoentitirat, 2011). However, Loei Group is already in use for Upper Silurian to Lower Carboniferous strata in the Khorat region (Mouret, 1994) and has been widely used for many years by petroleum companies to refer to these older sedimentary units (Booth and Sattayarak, 2011). Saraburi Group in the Loei Fold Belt includes Wang Saphung Formation, Nam Mahoran Formation, E-Lert Formation, and Pha Dua Formation. The Saraburi Group sits unconformably on Devonian-Early Carboniferous sandstone, mudstone, limestone, basalt, evaporates, and coal of the Ban Sa Ngao and Dok Du Formations, Nong Dok Bua Formation, and Pak Chom Formation. It is conformably overlain by a basal conglomerate and fine red sandstone of the Middle to Late Triassic Kuchinarai Group, exposed in Loei-Phetchabun Foldbelt (LPF) in the center of the Loei Syncline.

The study area focuses on three Formations consisting of Nong Dok Bua Formation, Wang Saphung Formation, and Huai Hin Lat Formation (Fig. 2).

Nong Dok Bua Formation deposited in Lower Carboniferous (early) with lithology consists of conglomerate, sandstone, calcareous sandstone, shale, siltstone, chert, quartzite, mudstone, tuff, limestone, dolomite, and slate. This formation as a part of the study area with lithologies has argillaceous shale and argillaceous mudstone.

Wang Saphung Formation deposited in Upper Carboniferous (late)-Early Permian, with predominantly a siliciclastic succession

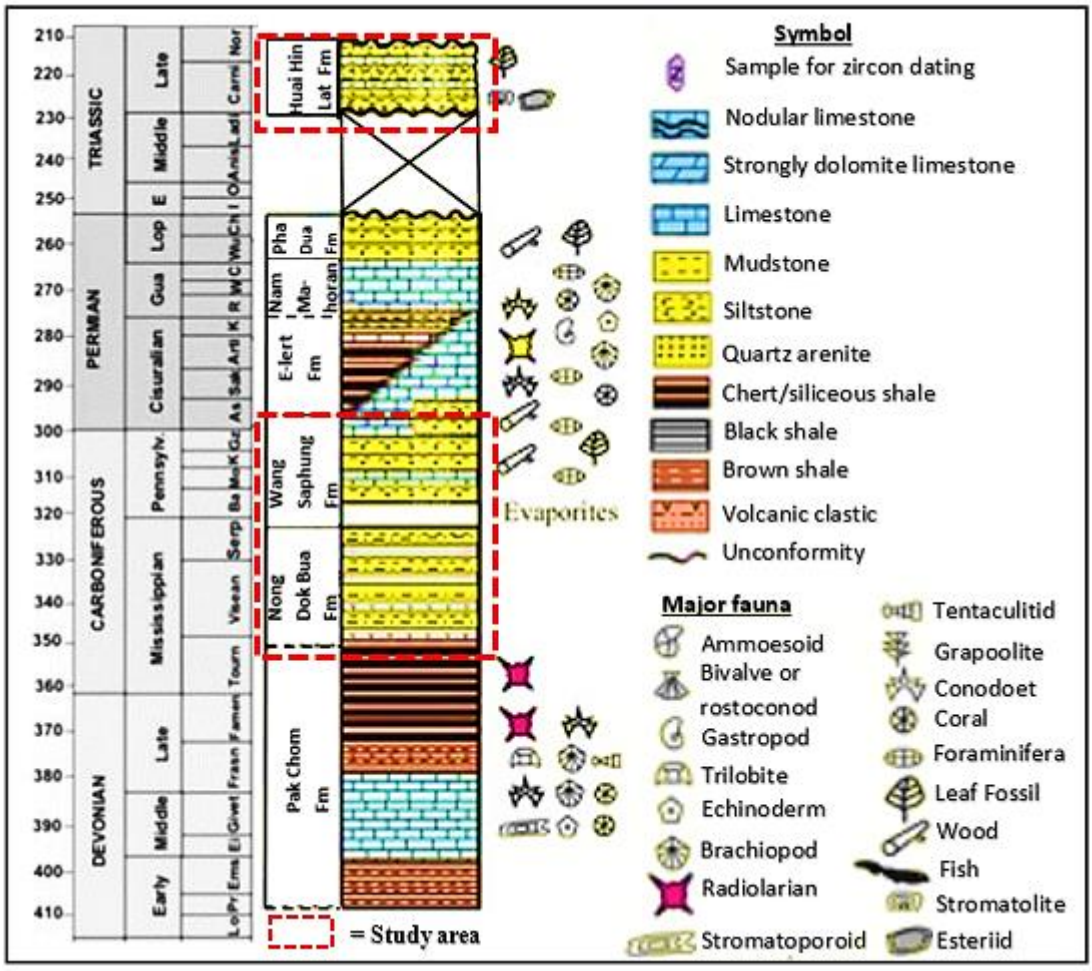

Figure 2. The stratigraphy of the study area part of Loei-Phetchabun Fold Belt with focuses in Nong Dok Bua Formation, Wang Saphung Formation, and Huai Hin Lat Formation (Burret, 2014).

composed of dark grey siltstone with local impure to clean limestone lens (Charoenpravat et al., 1984). The limestone contains common ooids, ungdarellid algae, beresellid algae, corals, brachiopods, foraminifera and crinoids (Fontaine et al., 1991). Phylloid algae and Tubiphytes became more common during the Late Carboniferous (Chuvashov and Riding, 1984), equivalent in subsurface with Si That Formation. This formation as a part of the study area with calcareous mudstone dominantly.

Huai Hin Lat Formation deposited from Late Triassic non-marine. The Formation distributed along the western margin of the Khorat Plateau and extended through the Khorat basin in the subsurface (Booth, 1998; Booth and Sattayarak, 2011). The depositional environment of the Huai Hin Lat Formation is broadly interpreted to have been a fluvial and lacustrine setting during the extension and half-graben development (Chonglakmani and Sattayarak, 1978). The Huai Hin Lat Formation consists of various lithologies which are characterized by different siliciclastic grain size.

The Huai Hin Lat Formation has two major units which are the lower and upper sequences. The lower sequence consists of the Pho Hai Member and the Sam Khaen Conglomerate Member where the Pho Hai member is characterized by the volcanic rocks including tuff, rhyolite, agglomerate, andesite, and some interlayers of sandstone and conglomerate; The Sam Khaen Conglomerate Member, considered to be a lateral equivalent unit of the Pho Hai Member, contains predominantly conglomerate with some intercalations of limestone beds, and normally found interfingering with sandstone and shale.

The upper sequences have the Dat Fa Member, the Phu Hi Member, and the I Mo Member. The Dat Fa Member consists of calcareous, carbonaceous shale, and argillaceous limestone with fossils; the Phu Hi Member consists of sandstone, shale, and argillaceous limestone with some conglomerate; the I Mo Member consists of volcanic rocks interbedded with shale, sandstone, and limestone.

3. Materials and methods

Field geological observations to obtain data which are rock description and geochemical analysis. The stratigraphic sections are used to interpret depositional environment in the study area. The geochemical analysis can determine a petroleum source rock potential. The geochemical analysis uses rock samples from outcrops. The rock samples are cut using a rough grinding (jaw crusher) and then using disc mill to obtain pulverization or powder. Rocks powders will be analyzed in for total organic carbon (TOC), rock-eval pyrolysis, and soxhlet extraction (aromatic and NSO compound). The results of the geochemical analysis are used to provide quality, quantity, maturity, and depositional paleo-environment of the rock samples.

4. Results

4.1 Stratigraphic section

The outcrops samples in the study areas are described in detail. Rock name classification is based on lithological differences in each Formation of the study area. Commonly, the lithology of the rock samples consists of calcareous mudstone, argillaceous mudstone, coal-shale, calcilutite, calcarenite, and argillaceous shale. Stratigraphic sections are described and consists of Amphoe Nam Nao (ANN), Grand Canyon Nam Nao (GCNN), and Amphoe Mueang Loei (AML). No section data in Amphoe Lom Sak (ALS) and Amphoe Pak Chom (APC).

4.1.1 Amphoe Nam Nao (ANN)

The total bed thickness is approximately 19 meters (Fig. 3). This study has facies association consisting of calcareous mudstone dominated facies association (FA1) with a total of bed thickness is 8.5 meters. It is composed of interbedded calcareous mudstone and calcareous siltstone facies (F5) with calcareous components. Texture gradation occurs between silts to very fine sand grained. This facies association is encountered in the lower part from 0 to 8.5 m. This facies association apparently occurs in the low energy, low-density, suspension deposited or traction where

lamination present, and tranquil setting. The FA1 is bounded by an erosional surface at the top of the facies association which changes into a coal-shale dominated facies association.

Coal-shale dominated facies association (FA2) with a total of bed thickness approximately 5.6 meters. This association is composed of interbedded coal and siltstone facies (F2) and coal-shale facies (F4) with silica contents that occur in this facies association. Texture gradation between clay to very fine sand grained. This facies association is encountered in the middle part from 8.5 to 14.1 m. deposited in low-high energy from a suspension of silt and low to high density. The coal-shale facies (F4) are more dominant and sometimes found the plant or wood fragments. The interbedded coal and siltstone facies (F2), normally encountered on the top and bottom of F4. The FA2 is bounded by an erosional surface between the top and bottom of the facies association. At the top which changes into sandstone dominated facies association and at the bottom is loading contact facies association by mudstone dominated. Commonly, this location started depositing in lower or deep lacustrine-floodplain or levees.

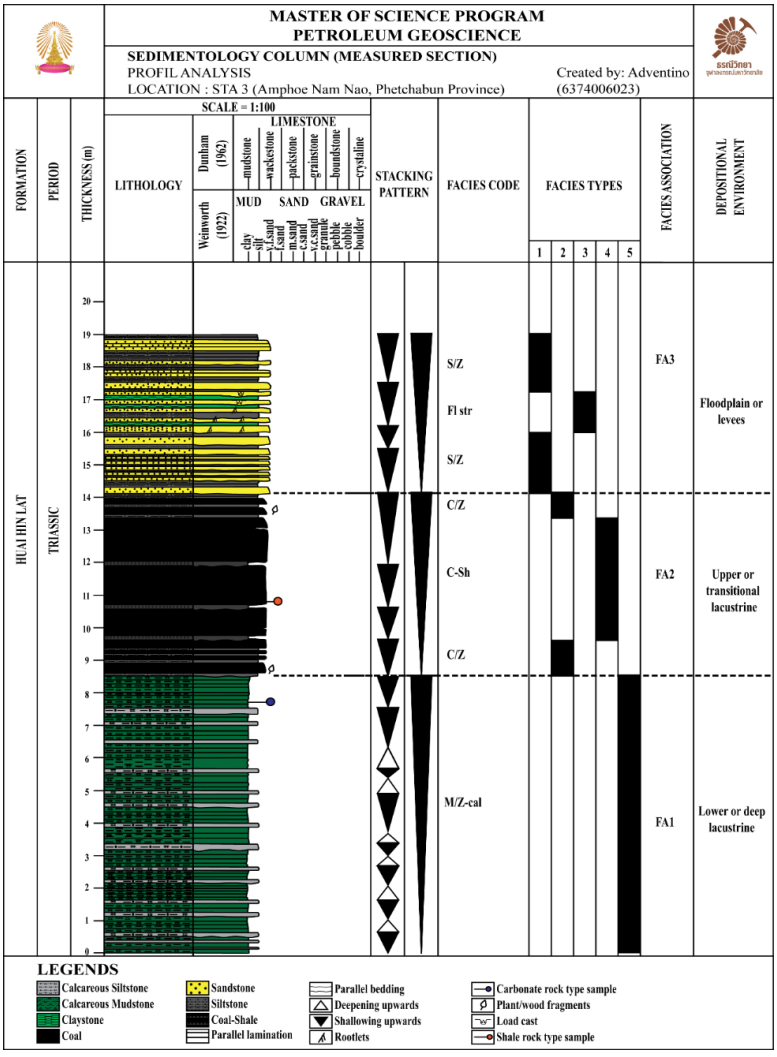

Figure 3. Measured section interpretation of Amphoe Nam Nao (ANN) part of Huai Hin Lat Formation.

Sandstone-dominated facies association (FA3) have a total of bed thickness approximately 5.6 meters. This association is composed of interbedded coal and siltstone (F2) and coal-shale (F4) with silica contents that occur in this facies association. Texture gradation is between clay to very fine sand grained. This facies association is encountered in the middle part from 8.5 to 14.1 m. Deposited in low-high energy from a suspension of silt and low to high density are occurred in these facies association. The coal-shale facies (F4) are more dominant and sometimes found the plant or wood fragments. The interbedded coal and siltstone facies (F2) normally encountered on the top and bottom of F4. The FA2 is bounded by an erosional surface between the top and bottom of the facies association. At the top which changes into sandstone dominated facies association and at the bottom is loading contact facies association by mudstone dominated.

4.1.2 Grand Canyon Nam Nao (GCNN)

The total bed thickness is approximately 9.6 meters. Facies association is calcareous mudstone composed of interlaminated calcareous mudstone, calcareous siltstone, and calcareous sandstone (F1), interbedded calcareous mudstone and calcareous siltstone (F2), structured calcareous sandstone (F3), and structureless calcareous mudstone (F4). Texture gradation is between clay to very fine sand-grained. This facies association has calcareous sandstone intercalations or thin layers and was founded at the bottom and top of the section. Sometimes, stromatolites and burrow structure were found in sand layers deposited in low to moderate energy with low-high density, suspension of mud deposited, and tranquil setting and or traction setting where laminations present (Fig. 4). Generally, depositional environment in this study is shallow or lacustrine

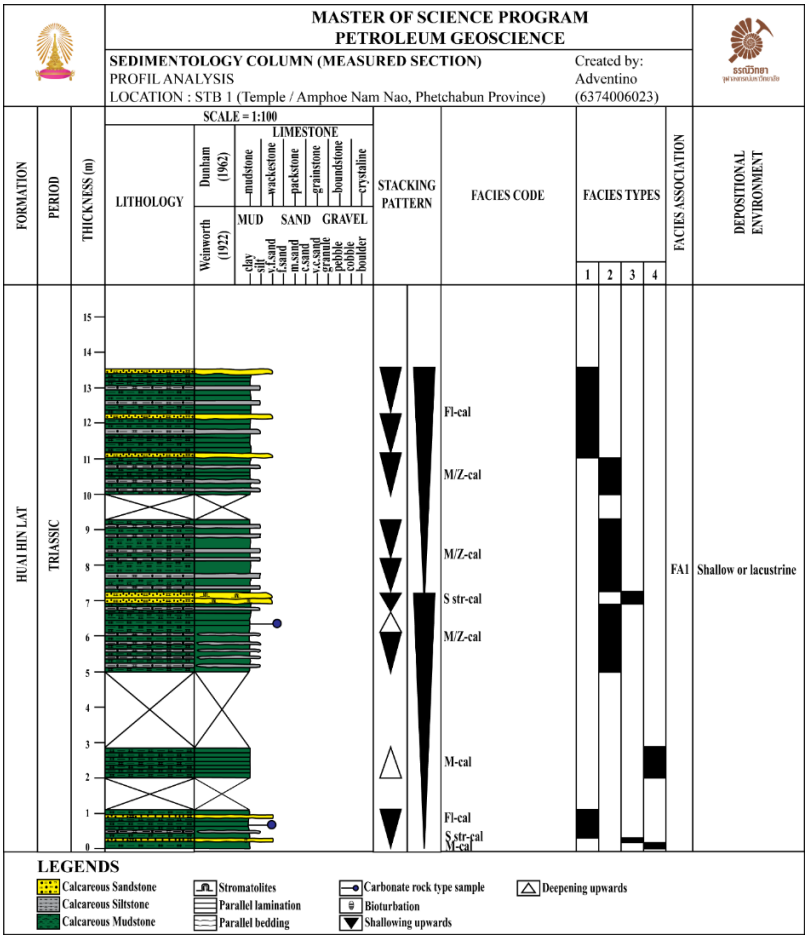

Figure 4. Measured section interpretation of Grand Canyon Nam Nao (GCNN) part of Huai Hin Lat Formation.

4.1.3 Amphoe Mueang Loei (AML)

The total bed thickness approximately 13.5 meters. This facies association consists of wackestone-packstone dominated facies association (FA1) with a total of bed thickness of 4.8 meters. This association composes of wackestone (F3) and packstone (F4). Texture gradation occurs between very fine to medium sand grained. This facies association is encountered in the lower part of the section from 0 to 3.7 m and 5 to 6.1 m. deposited in high energy and high density. Organism structures such as burrows and abundant fossils occurred in this facies association.

Calcareous mudstone is dominated facies association (FA2) with a total bed thickness of approximately 8.7 meters. This association is composed of interbedded calcareous mudstone and calcareous siltstone (F1) and structured calcareous mudstone (F2). Texture gradation started from clay to silt. This facies association is founded in the middle of the section from 7 to 9.7 m and 10.6 to 16.6 m deposited in low energy, low density, suspension of mud deposited and or traction setting where lamination present. According to the stratigraphic section, the depositional environment in this study area should be foreslope-back reef lagoon (Fig. 5).

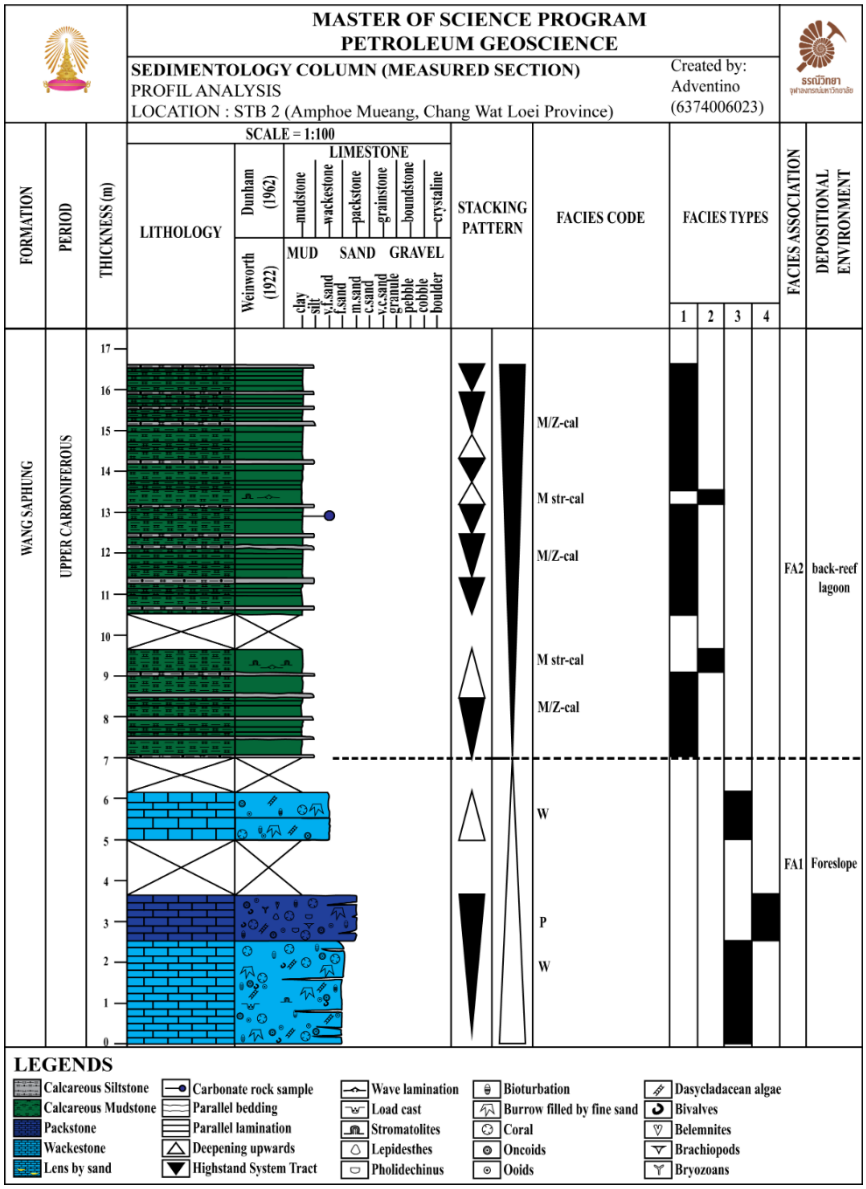

Figure 5. Measured section interpretation of Amphoe Mueang Loei part of Wang Saphung Formation.

Table 1. Geochemical data of the rock samples from the study area.

Sample ID	TOC	S1	S2	PY	S3 CO2	S3 CO	Tmax	HI	OI	PI	EOM (ppm)
HHA-1	0.56	0.01	0.05	0.06	0.47	0.02	598	9	84	0.17	140
HHA-2	0.83	0.01	0.03	0.04	0.59	0.03	501	4	71	0.25	120
HHA-3	0.22	0.01	0.04	0.05	0.35	0.01	487	18	159	0.20	120
HHA-4	0.40	0.01	0.06	0.07	0.21	0.01	505	15	53	0.14	120
HHB-1	0.91	0.04	0.12	0.16	0.36	0.01	580	13	40	0.25	120
HHB-2	2.10	0.03	0.23	0.26	0.49	0.03	580	11	23	0.12	160
HHB-3	18.41	0.03	8.34	8.37	0.8	0.32	527	45	4	0.00	2939
HHB-4	20.17	0.05	6.7	6.75	0.47	0.27	525	33	2	0.01	4127
HHC-1	0.93	0.02	0.06	0.08	1.91	0.05	600	6	205	0.25	200

HHC-2	1.60	0.03	0.13	0.16	0.83	0.06	598	8	52	0.19	196
HHC-3	1.75	0.03	0.1	0.13	1.18	0.07	592	6	67	0.23	120
HHC-4	1.39	0.03	0.12	0.15	1.12	0.06	594	9	81	0.20	100
WSP-1	0.08	0.01	0.02	0.03	0.37	0	484	25	463	0.33	100
WSP-2	0.04	0.01	0.04	0.05	0.29	0.01	430	100	725	0.20	100
WSP-3	0.11	0.01	0.03	0.04	0.07	0.01	440	27	64	0.25	120
NDB-1	0.03	0.01	0.01	0.02	0.14	0.01	425	33	467	0.50	80
NDB-2	0.24	0.03	0.03	0.06	0.27	0.04	485	13	113	0.50	80
NDB-3	0.05	0.02	0.05	0.07	0.09	0.01	428	100	180	0.29	60

Table 2. Total organic carbon content and name rocks samples

Formation	Sample ID	Name rocks samples	TOC (% wt.)	Source rock capacity	Rock type classification
Huai Hin Lat Fm	HHA-1	Calcareous mudstone	0.56	Good	Carbonate rock
	HHA-2	Calcareous mudstone	0.83	Good	
	HHA-3	Calcareous mudstone	0.22	Fair	
	HHA-4	Argillaceous mudstone	0.40	Fair	
	HHB-1	Calcareous mudstone	0.91	Good	
	HHB-2	Coal-shale	2.10	Very Good	Shale
	HHB-3	Coal-shale	18.41	Excellent	
	HHB-4	Calcareous mudstone	20.17	Excellent	Carbonate rock
	HHC-1	Calcareous mudstone	0.93	Good	
	HHC-2	Argillaceous mudstone	1.60	Very Good	
	HHC-3	Calcilutite	1.75	Very Good	
	HHC-4	Calcarenite	1.39	Very Good	
Wang Saphung Fm	WSP-1	Calcareous mudstone	0.08	Poor	
	WSP-2	Calcareous mudstone	0.04	Poor	
	WSP-3	Calcareous mudstone	0.11	Poor	
Nong Dok Bua Fm	NDB-1	Argillaceous shale	0.03	Poor	Shale
	NDB-2	Argillaceous mudstone	0.24	Poor	
	NDB-3	Argillaceous mudstone	0.05	Poor	

4.2 Quantity of organic carbon

Eighteen samples from the study areas are collected for quantity analysis. The results are used to compare with Peter and Cassa (1994) classification for determining rock type (Table 1)

4.2.1 TOC and EOM

The source potential in this study with carbonate rock and shale shows a small range of TOC of 0.22 wt.% (fair capacity) and the high value of TOC of 20.17 wt.% (excellent capacity). Generally, the Huai Hin Lat Formation has fair to excellent as a capacity of source rock potential but the Wang Saphung Formation and Nong Dok Bua Formation have a poor capacity as source rock potential in the study area (Table 2). The pulverized rock samples from the study area were used for EOM or bitumen analysis and combined saturate hydrocarbon as n-alkane, aromatic hydrocarbon, and hetero-aromatic hydrocarbon that has properties to give a petroleum potential in commercial production.

The bitumen contents of pulverized rock from eighteen samples can be extracted in range of 60 ppm (small range) to 4127 ppm (high value). The highest content appears on the coal-shale sample (HHB-3) with the value of 2939 ppm and in sample of carbonate rock (HHB-4)

with the value of 4127 ppm. The comparison of results between TOC and EOM based on Peters and Cassa classification (Fig. 6).

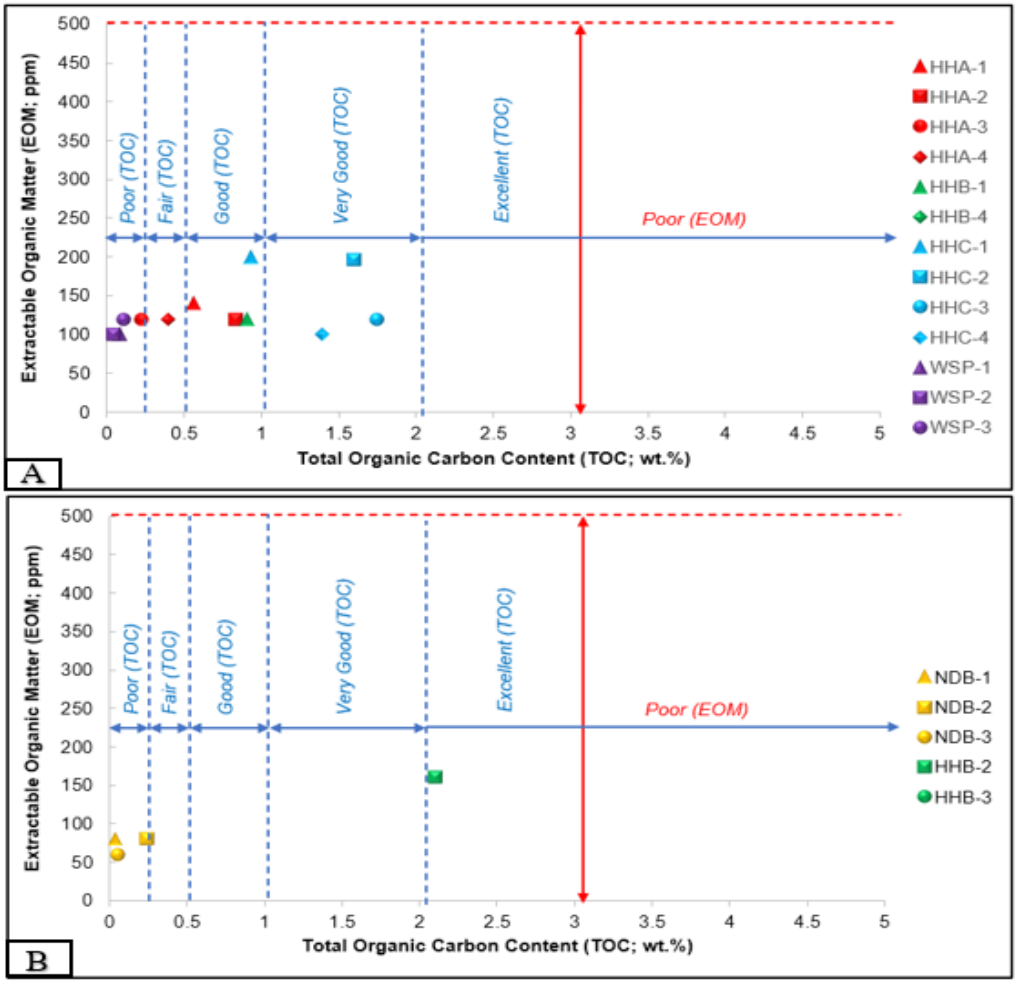

Figure 6. Diagram shows the results of the study area. **(A)** Relationship between TOC and EOM of carbonate samples, **(B)** Relationship between TOC and EOM of shale samples

4.2.2 Genetic potential

Genetic potential or potential yield shows that the total of hydrocarbon can be generated and remain in source rock by summation of free hydrocarbon (S1) and hydrocarbon cracking process of kerogen (S2). Based on the results of genetic potential using Peters and Cassa classification, the study area has two genetic potentials with a high value of 8.37 mg HC/g in HHB-3 and 6.75 mg HC/g in HHB-4. High S2 shows that the potential of organic material in rock can be turned into petroleum by going through the kerogen cracking process. Moreover, the other locations in Wang Saphung Formation and Nong Dok Bua Formation have poor genetic potential status.

4.3 Quality of organic carbon

The condition of type organic matter is interpreted by using the pyrolysis parameter and TOC contents, then plot HI and OI in Van Krevelen diagram. High HI shows the deposition under anoxic conditions while high OI contents are oxidized organic matter. The high value of HI indicates the source rock is dominated by oil, and high OI shows the source rock dominated by gas.

Generally, the study area has a source rock that is dominated by gas, in some places found inert or dry gas (Fig. 8a)

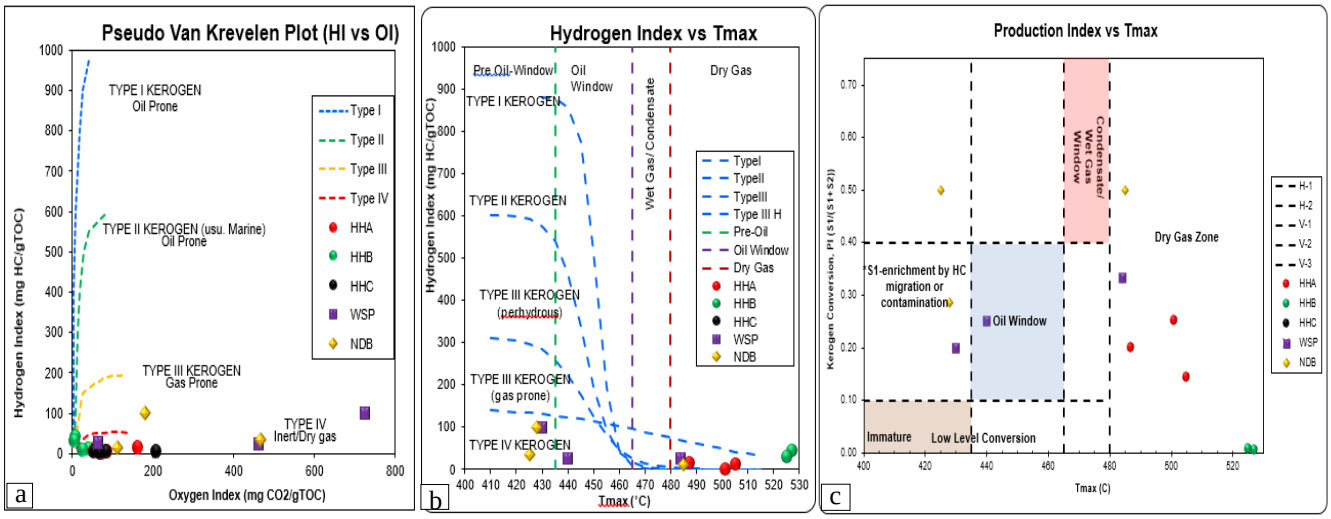

Figure 8. The cross plots show a quality and maturity level of the study area. **(A)** Van Krevelen diagram shows the quality of organic carbon consisting of cross plots HI and OI for kerogen type. **(B)** Cross plot shows the Hydrogen vs Tmax in the study area. **(C)** Cross plot shows the Produciton Index vs Tmax which is a part of maturity level

4.4 Maturation level

This parameter determining the maturity level of the source rock. The recorded Tmax is strongly influenced by the type of organic matter. The burial pressure, heat, and time are important factors to decompose organic matter into oil and gas. The cross plot between HI and Tmax (Fig. 8b) shows the maturity level in the study area starting from immature and over mature. The immature level is located in Nong Dok Bua Formation since it has a temperature of 425°-428°C. The Wang Saphung Formation is a top oil window and the over mature level is located in Huai Hin Lat Formation. The cross plot of PI and Tmax shows that samples in the study area is in dry gas zones (Fig. 8c).

5. Discussion

The TOC contents are variable from approximately 0.02 to 0.99 wt% which can be classified as a poor to fair potential source rock (Phujareanchaiwon et al., 2021), 0.2 to 5.76% can be classified as a poor to very good organic (Racey, 2011), and 1.9 to 10.09% from black shales and coaly shales is very good to excellent (Arsairai et al., 2016, 2020).

This research shows values from 0.03-20.17% from coaly-shale and carbonate rock which can be classified as poor-excellent potential source rock and coincides to previous studies. The deposition of organic-rich rocks in lacustrine environment is dominantly controlled by the relation of production, destruction, and dilution (Bohacs et al., 2000). The evidence of depositional in the study area consisting of HI and OI of Van Krevelen diagram shows that a source rock is dominated by gas, in someplace found inert or dry gas. Comparing with the stratigraphic sections, the depositional environment in Amphoe Nam Nao (ANN) and Grand Canyon Nam Nao (GCNN) part of Huai Hin Lat Formation is lacustrine-floodplain or levees and then the Amphue Mueang Loei

(AML) part of Wang Saphung Formation deposited in foreslope-backreef or lagoon. No section data in Amphoe Lom Sak part of Huai Hin Lat Formation and Amphoe Pak Chom part of Nong Dok Bua Formation.

6. Conclusions

The studied outcrops of the Huai Hin Lat Formation, Wang Saphung Formation, and Nong Dok Bua Formation are investigated in detail to stratigraphic section, quantity, quality, and maturity of organic carbon.

According to petroleum potential source rock assessment , Huai Hin Lat Formation is potential source rock but Wang Saphung Formation and Nong Dok Bua Formation part of this study area reveal non-potential petroleum source rock.

The TOC shows values from 0.03-20.17% from coaly-shale and carbonate rock which suggests poor to excellent potential source rock. The EOM shows that Huai Hin Lat Formation has fair-excellent as a capacity of source rock potential but the Wang Saphung and Nong Dok Bua Formations have a poor capacity as source rock potential. The study area has two genetic potentials with a high value of 8.37 mg HC/g in HHB-3 and 6.75 mg HC/g in HHB-4. The quality of the study area has a source rock that is dominated by gas, in some places found inert or dry gas. For the maturity level started from immature and over mature. The immature level is located in Nong Dok Bua Formation since it has a temperature of 425^{o}-428^{o}C. The Wang Saphung Formation is a top oil window and the over mature level is located in Huai Hin Lat Formation. The cross plot of PI and Tmax shows that samples in the study area are in dry gas zones. The depositional environment of this research shows that the Huai Hin Lat Formation was deposited in lacustrine-floodpalin or levees , while the Wang Saphung Formation was deposited in foreslope-backreef or lagoon.

7. Acknowledgements

The author would like to thank the Petroleum Geoscience Program for funding this research project and Dr. Thasinee as a reviewer of BEST journal.

8. References

Arsairai, B., Wannakomol, A., Feng, Q., and Chonglakmani, C. (2016). Paleoproductivity and paleoredox condition of the Huai Hin Lat Formation in northeastern Thailand. J. Earth Sci. 27, 350–364. doi: 10.1007/s12583-016- 0666-8.

Bohacs, K. M., Carroll, A. R., Neal, J. E., and Mankiewicz, P. J. (2000). “Lake-basin type, source potential, and hydrocarbon character: an integrated sequence stratigraphic-geochemical framework,” in Lake Basins Through Space and Time, eds E. H. Gierlowski-Kordesch and K. R. Kelts (Tulsa, OK: AAPG).

Booth, J. E., and Sattayarak, N. (2011). “Subsurface carboniferous – cretaceous geology of northeast Thailand,” in The Geology of Thailand, eds M. F. Ridd, A. J. Barber, and M. J. Crow (London: Geological Society of London), 185–222. doi: 10.1144/goth.9.

Booth, J. E. (1998). “The Khorat Plateau of NE Thailand-exploration history and hydrocarbon potential,” in Proceedings of the 1998 SEAPEX Exploration Conference, Singapore, 169–202.

Burrett C., Zaw K., Meffre S., et al. The Configuration of Greater Gondwana-Evidence from LA ICPMS, U-Pb Geochronology of Detrital Zircons from the Palaeozoic and Mesozoic of Southeast Asia and China. Gondwana Research, 2014, 26(1):3151. DOI:10.1016/j.gr.2013.05.020

Chantong, W. 2007. Carbonate reservoir in the Khorat Plateau. in Proceedings of DMF Technical Forum. pp. 55-76.

Charoenpravat, A., Phuanda, J. & Maneenai, D. (1987) Geological map scale 1:50,000 sheets Amphoe Mae Tha (4945-3), Ban Bo Kaeo(4944-1), and Changwat Phrae(5045-3). Geol. Surv. Div., DMR (unpubl., in Thai).

Chonglakmani, C., and Sattayarak, N. (1978). “Straigraphy of the Huai Hin Lat Formation (Upper Triassic) in northeastern Thailand,” in Proceedings on the Third Conference on

Geology and Mineral Resources of Southeast Asia, Bangkok, 739–762.

Chuvashov, B., Riding, R. (1984) Principal floras of Palaeozoic marine calcareous algae. Palaeontology. 1984, Vol 27, Num 3, pp 487-500; illustration; ref:3p Coden Pontad, ISSN 0031-0239.

Phujareanchaiwon C, Chenrai P and Laitrakull K (2021) Interpretation and Reconstruction of Depositional Environment and Petroleum Source Rock Using Outcrop Gamma-ray Log Spectrometry From the Huai Hin Lat Formation, Thailand. Front. Earth Sci. 9:638862. doi: 10.3389/feart.2021.638862.

Mouret, C. 1994. Geological history of northeastern Thailand since the Carboniferous. Relations with Indochina and Carboniferous to Early Cenozoic evolution model. Proceedings of the International Symposium on Stratigraphic Correlation of Southeast Asia. Department of Mineral Resources, Bangkok, 245–252.

Racey, A. (2011). “Petroleum geology,” in The Geology of Thailand, eds M. F. Ridd, A. J. Barber, and M. J. Crow (London: Geological Society of London), 351–392.

Ueno, K., Charoentitirat, T., 2011, Carboniferous and Permian. In: Ridd, M. F., Barber, A. J., Crow, M.J. (Eds.), The Geology of Thailand, pp. 71-136-28. The Geological Society of London.