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DEPOSITIONAL ENVIRONMENT OF THE LAN KRABU FORMATION IN SIRIKIT OIL FIELD, PHITSANULOK BASIN, THAILAND

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Abstract

The study was conducted to better understand the depositional environment of the Lan Krabu Formation in the Sirikit Oil Field of Phitsanulok Basin in order to improve the reservoir prediction, development of Sirikit Oil Field and new play exploration. Ten Lan Krabu Formation conventional cores from seven wells and log data from forty-five wells were integrated to interpret the depositional environment and establish the paleogeographic model of the Upper and Lower Lan Krabu Formation. The depositional environments were identified as freshwater lake, lacustrine/delta, alluvial plain with fluvial channels, and alluvial fan. There is not much difference in environment between the Lower and Upper Lan Krabu Formation, except the geographic boundary of each facies. The key evidence indicating non-marine environments and freshwater lakes area is Viviparidae gastropods and freshwater bivalves. The clastic sediment supply was mainly from the east and northeast to the west where the freshwater lake developed in the basin center.

Keywords: : Lan Krabu Formation, Sirikit Oil Field, Phitsanulok Basin, Depositional Environment, Conventional Core, Lithofacies

1. Introduction

The Sirikit Oil Field, the largest onshore field in Thailand, is located in Phitsanulok Basin. The main production is in the Sirikit main area which has been operated by PTTEP for more than 30 years. It is not only a production area but also there is an exploration area with new plays (Figure 1).

The Lan Krabu Formation, which is the main reservoir target in the field, is subdivided into the D, K, L, and M units (Figure 2). The study objective to better understand facies and depositional environments of the Lan Krabu Formation away from the field. The study focused mainly on the K and L units of the Lan Krabu Formation (LKU-K and LKU-L units) based on an integration of conventional core and wireline data to interpret the depositional environment and establish a paleogeographic model.

Ten Lan Krabu Formation conventional cores from seven wells and forty-five well logs data were used for this study (Figure 1). Support information included a regional interpreted seismic section across the study area.

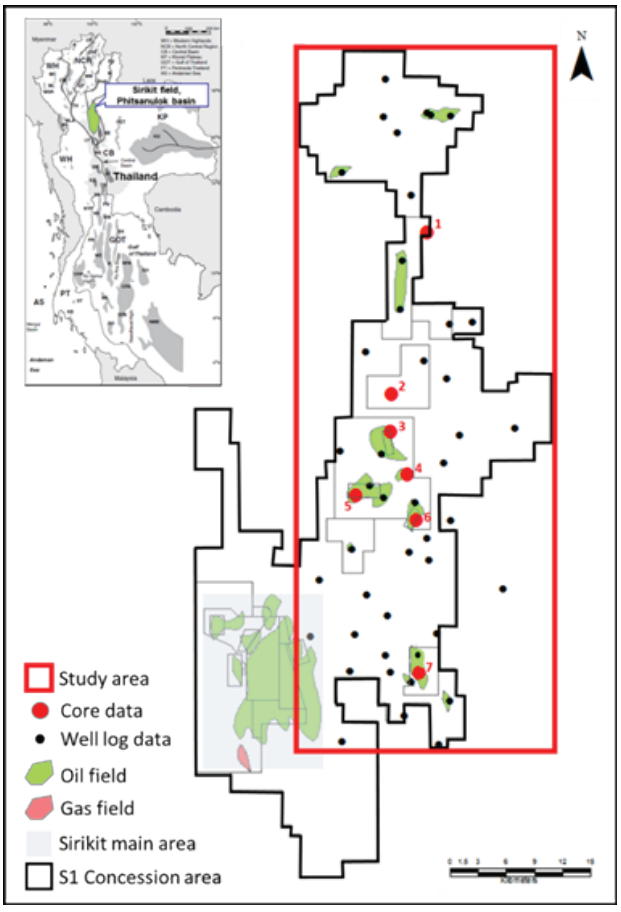

Figure 1: Well locations in Sirikit Oil Field, Phitsanulok basin, Thailand. The red well numbers are well locations with core data; OSN-01 to OSN-07, from north to south, respectively.

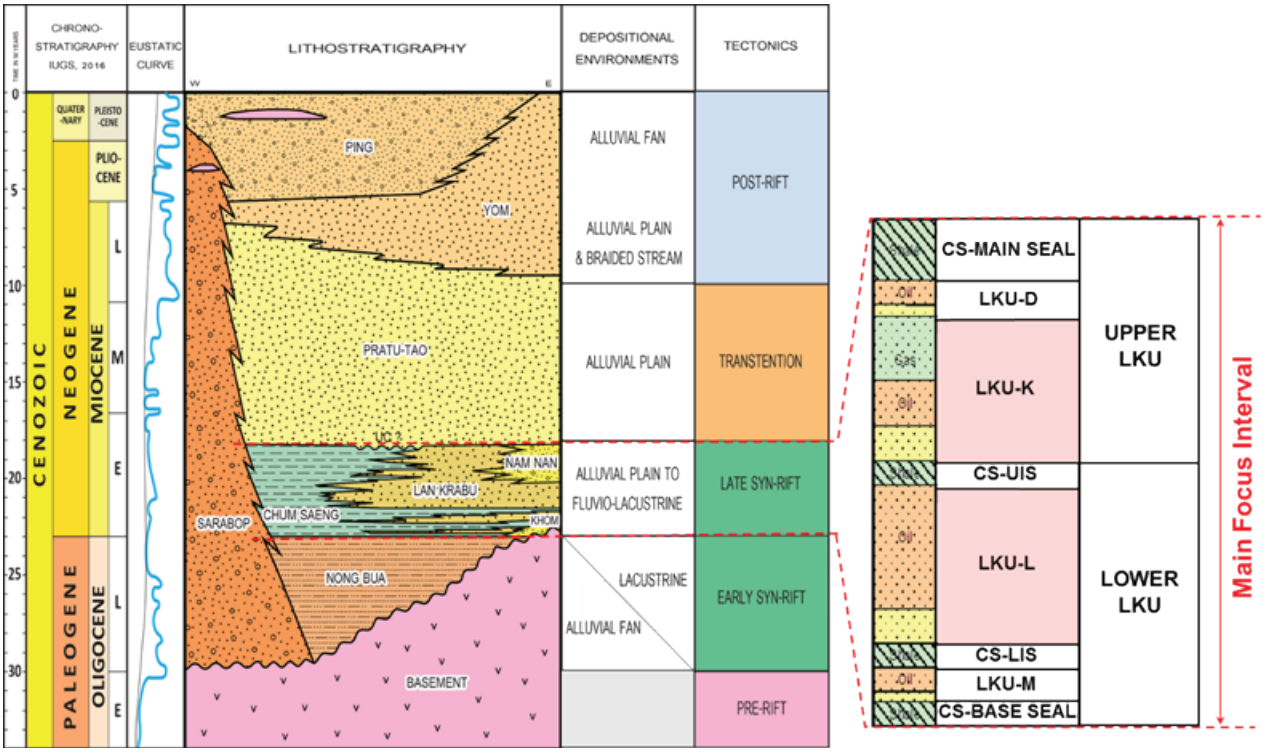

Figure 2: Regional stratigraphic column of Phitsanulok Basin (Modified after Knox and Wakefield, 1983)

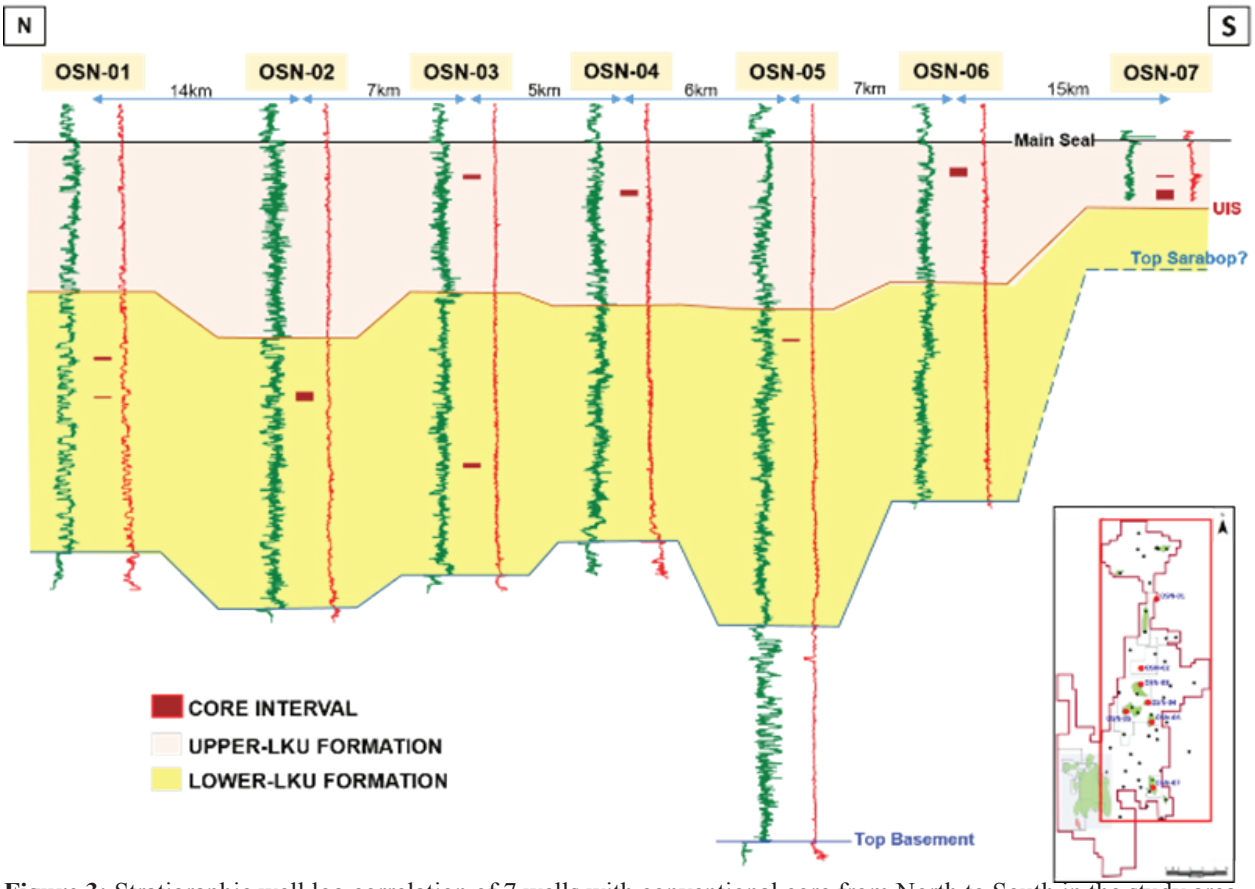

Figure 3: Stratigraphic well log correlation of 7 wells with conventional core from North to South in the study area

2. Core Interpretation

The Lan Krabu Formation cores from seven wells were selected for lithofacies and depositional environment interpretation (Figure 1). Those cores are mainly in the LKU-K and LKU-L units which are the focus intervals. For this study, the Lan Krabu Formation was divided to two main intervals, the Upper-LKU and Lower-LKU Formation. This separation is based on a preliminary correlation of the Upper Intermediate Shale (UIS) (Figure 3).

A) Upper-LKU Formation

There are five Upper-LKU conventional cores from the four wells; OSN-03, OSN-04, OSN-06, and OSN-07 (Figure 3). Seven lithofacies were identified from these cores, which are described and interpreted below.

(1) Shale-laminated Sandstone; Sl

The Sl lithofacies is very fine to medium sandstone with laminated shale that is present in all wells (Figure 4). The lamination is mainly parallel lamination with interlaminate cross-lamination. There also are mud drapes and some siderite. The thickness of this facies is 0.3-2.5 m. There are no grain size trends, except in OSN-03 core 1 that has coarsening-upward sandstone.

The coarsening-upward succession with fine-grain sandstone and shale-lamination are related to mouthbar sand deposition. In addition, a cross-lamination with some mud drapes associated with fluctuating energy by waves from the lacustrine influence.

Based on the sedimentary structure, grain size trends and sand thickness, this lithofacies is interpreted as delta plain mouthbar for coarsening-upward sandstone and shoreline sand nearby lacustrine environment.

(2) Mollusk fossil fragment sandstone; Sf

The Sf lithofacies is fine to medium sandstone with mollusk fossil fragments that are present in well OSN-07 (Figure 5). There are abundant gastropods fossils and rare bivalves (Figure 5A). The fossils are fragments preserved within sandstone along the sand bedding, which could be inferred to be transported fossils from a nearby area; such as a lake, lagoon, or swamp.

There also is minor shale lamination and siderite.

Based on the mollusk fossil fragments and fine grain size sediment, this lithofacies is interpreted as a shoreline sand associated with an embayment or marginal lacustrine environment.

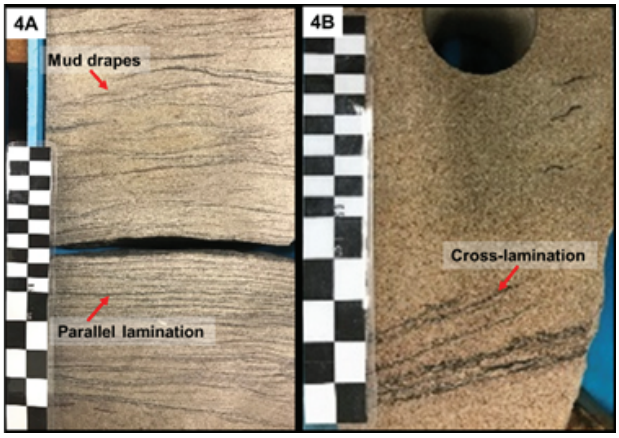

Figure 4: Sl lithofacies of the Upper-LKU Formation; 4A has parallel lamination and mud drapes, and 4B illustrates cross-lamination

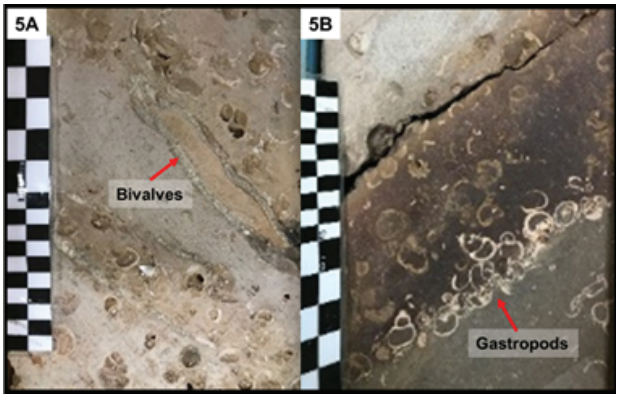

Figure 5: Sf lithofacies of the Upper-LKU Formation with mollusk fossil fragments of gastropods and bivalves; 5A freshwater bivalves with gastropod fragments. 5B Viviparidae gastropod fragments.

(3) Siltstone with shale lamination; Zm

The Zm lithofacies is siltstone to very fine sandstone with shale lamination. Bioturbation is observed. This facies is present in well OSN-06 (Figure 6). This facies is underlain by lacustrine mudstone.

Based on the lithology and sedimentary structure, this lithofacies is interpreted as shoreline environment.

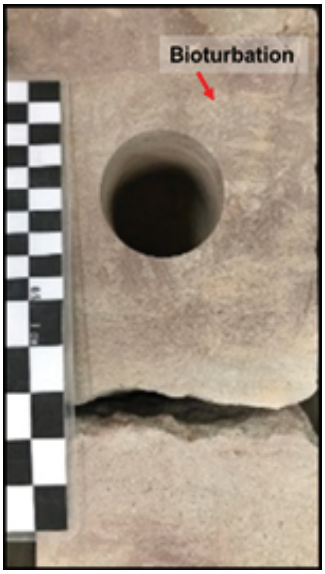

Figure 6: Zm lithofacies of the Upper-LKU Formation is siltstone to very fine sandstone with shale lamination and bioturbation from well OSN-06.

(4) Bioturbated Shale; Mb

The Mb lithofacies is medium to dark grey shale, and admixtures of silt with heavy bioturbation. The vertical burrows are recognized as contact of shale-siltstone or shale-sandstone. There are a few siderite bands. This facies is present in well OSN-03, OSN-04 and OSN-05 (Figure 7).

Based on the heavy bioturbation of very fine-grain sediment, this lithofacies is interpreted as delta plain associated with shoreline sand to marginal lacustrine.

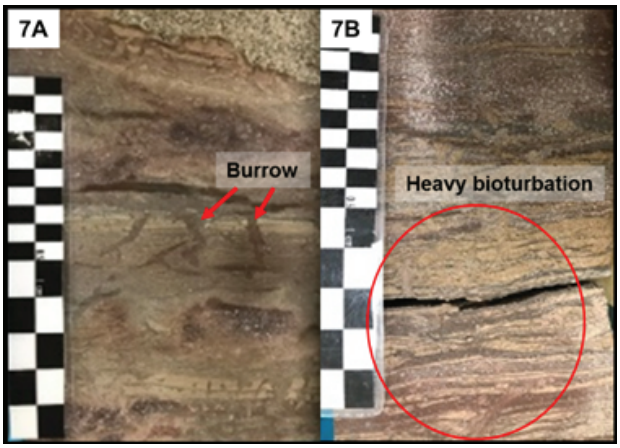

Figure 7: Mb lithofacies of the Upper-LKU Formation; 7A shows burrow that can indicate the contact of shale and sandstone. 7B heavy bioturbation with some burrows

(5) Mollusk fossil Shale; Mf

The Mf lithofacies is medium to dark grey shale with abundant gastropods. This facies is present in well OSN-04 and OSN-07 (Figure 8). The gastropod mollusks belong to the family of Viviparidae. The thickness is about 0.1-0.3 m. Based on the gastropod fossils which indicate a freshwater environment, this lithofacies is interpreted as a freshwater lacustrine environment.

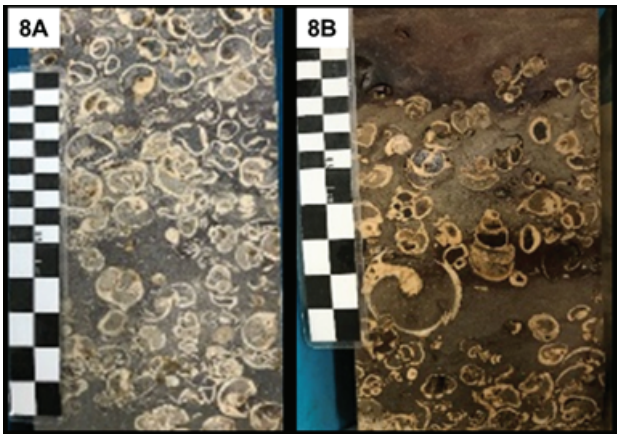

Figure 8: Mf lithofacies of the Upper-LKU Formation; 8A and 8B have abundant mollusk fossils of Viviparidae gastropods in shale that infers in-situ deposition.

(6) Massive shale; Mm

The Mm lithofacies is light to dark grey or dark olive grey homogenous shale with siderite band/nodules. There are no sedimentary structures, some carbonaceous content and minor siltstone. This facies is present in well OSN-03, OSN-06 and OSN-07 (Figure 9).

This lithofacies is interpreted as lacustrine. The mior siltstones could indicate a lacustrine with minor fluvial influence or a shoreline sand association depending on the overlying and underlying facies.

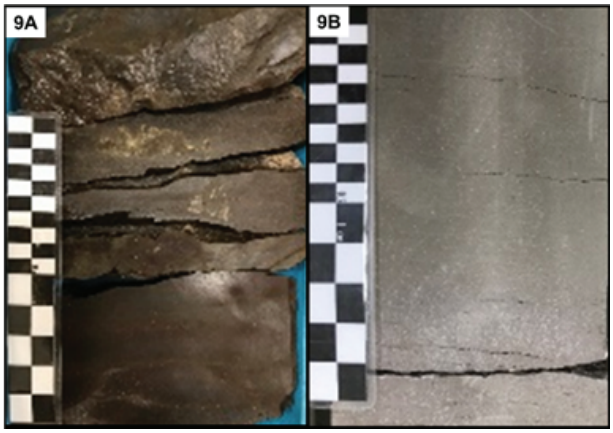

Figure 9: Mm lithofacies of the Upper-LKU Formation dark olive grey (9A) and light to dark grey (9B) massive homogeneous shale

(7) Carbonaceous Shale; Mc

The Mc lithofacies is dark grey to black carbonaceous shale. This facies is present in well OSN-07 (Figure 10). Abundant organic material was observed. It is normally associated with coal. The thickness of carbonaceous shale is less than 0.3 m.

Based on the high organic material and over-underlying facies association, this lithofacies from well OSN-07 is interpreted as a highly carbonaceous shale in an embayment or lacustrine environment with shoreline sand association.

Figure 10: Mc lithofacies of the Upper-LKU Formation is a carbonaceous shale

B) Lower-LKU Formation

There are five Lower-LKU conventional cores from the four wells; OSN-01, OSN-02, OSN-03, and OSN-05 (Figure 3). Five lithofacies were identified from these cores, which are described and interpreted below.

(1) Shale-laminated Sandstone; Sl The Sl lithofacies is very fine to medium sandstone with shale lamination that is present in all wells (Figure 11). The lamination is mainly parallel lamination (Figure 11A) with interlaminated cross-lamination (Figure 11B). Mud drapes and some siderite occur locally. The thickness of this facies from core is different in each well. It varies from 0.3 m to 8 m. Thin sands (about 0.3-2 m) do not have grain size trends. However, there is fining-upward sandstone in the thick sands (4 m and 8 m) of well OSN-01 and OSN-02.

Based on the sedimentary structures, grain size trend and sand thickness, this lithofacies is interpreted as a fluvial channel or fluvial pointbar. For the thin sand, it is interpreted as crevasse splay/levee or shoreline sand depend on over-underlying facies.

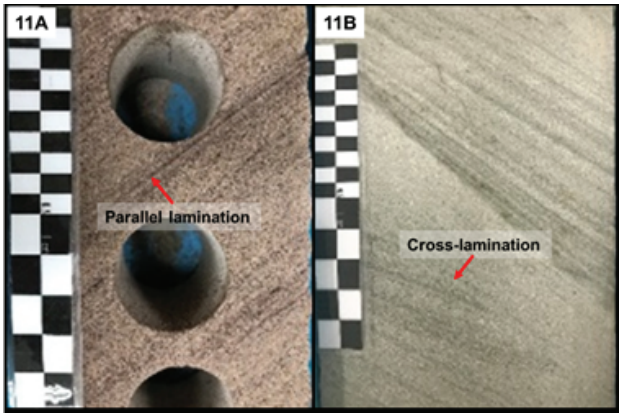

Figure 11: Sl lithofacies of the Lower-LKU Formation has parallel lamination (11A), cross-lamination (11B)

(2) Coarse-grain Sandstone; Sx

The Sx lithofacies is medium to very coarse grain sandstone with some shale lamination in well OSN-01 (Figure 12). Coarse grain rip-up clasts are common. The grains are angular to sub-rounded. The thickness of this facies from OSN-01 core is about 4 m. Fining-upward sandstone is observed.

Based on the sedimentary structures, grain size and sand thickness, this lithofacies is interpreted as a fluvial channel environment. Grain size and grain roundness indicate it is near the source of sediment, so it may be interpreted as a fluvial braided channel or alluvial plain.

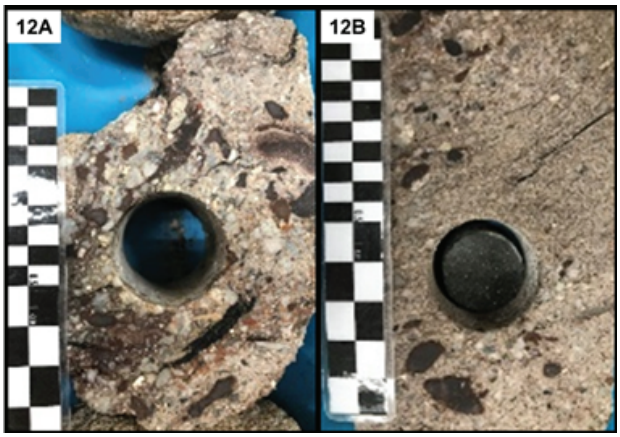

Figure 12: Sx lithofacies of the Lower-LKU Formation is coarse to very coarse-grain sandstone.

(3) Mottled Shale; Mr

The Mr lithofacies is reddish-pale greenish grey mottled shale with rootlets and minor bioturbation. There are some organic clasts/coalified wood. This facies is present in OSN-01, OSN-02, and OSN-03 (Figure 13). The thickness of mottled shale varies from about 1 m to 8 m. Also, there are some carbonaceous and siltstone laminae, and some siderite nodule.

Based on the mottling and rootlets, this lithofacies is interpreted as floodplain with landplants and oxidized shale.

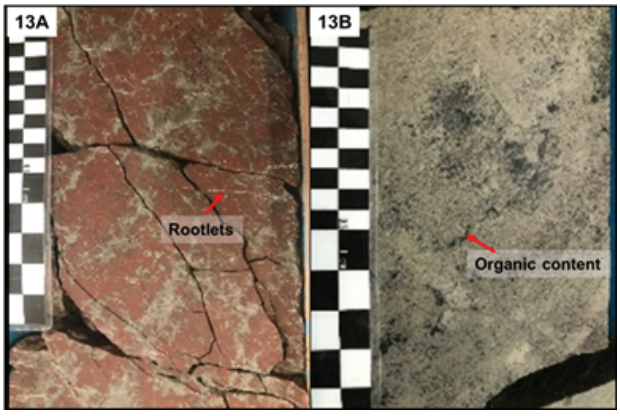

Figure 13: Mr lithofacies of the Lower-LKU Formation is mottled shale with rootlets (13A and 13B).

(4) Massive shale; Mm

The Mm lithofacies is greenish grey to dark grey shale with siderite band/nodules. There is some carbonaceous content and minor siltstone. This facies is present in OSN-03 and OSN-05 (Figure 14).

Based on the homogenous shale with no sedimentary structures, this lithofacies is interpreted as lacustrine. The minor siltstones indicate it could be marginal lacustrine with minor fluvial influence. The over-underlying shoreline sand facies association indicates a marginal lacustrine and shoreline environment.

(5) Carbonaceous Shale; Mc

The Mc lithofacies is dark grey to black carbonaceous shale. This facies is present in OSN-02, and OSN-03 (Figure 15). The high organic material was observed. The thickness of carbonaceous shale is thin, less than 0.3 m. Based on the organic material, this lithofacies is interpreted as a swamp on a floodplain or carbonaceous shale in a lacustrine environment. These interpretations depend on the overlying and underlying facies.

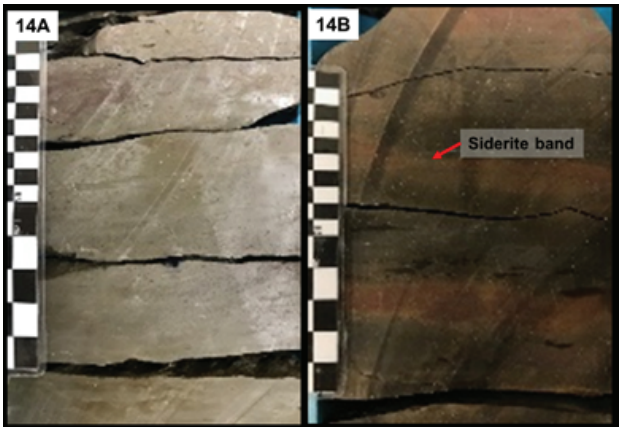

Figure 14: Mm lithofacies of the Lower-LKU Formation is pale to dark grey massive homogeneous shale.

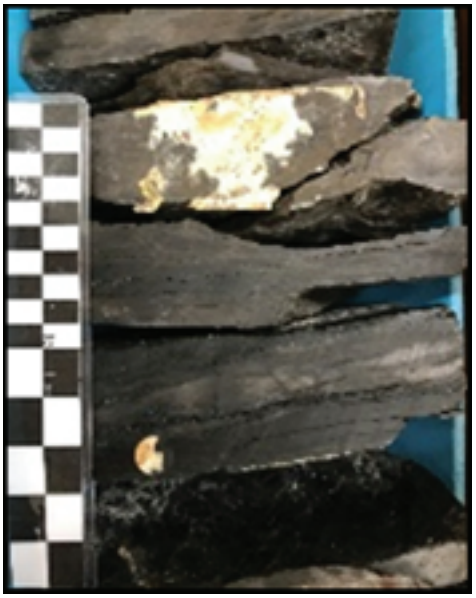

Figure 15: Mc lithofacies of the Lower-LKU Formation is highly carbonaceous shale.

3. Well Log Analysis

A) Core to well log correlation

The stratigraphic successions of ten conventional cores were constructed and integrated with the gamma ray wireline log in order to recognize the log pattern and the lithofacies of each depositional environment. The interpretation was described by formation and well location from north to south of the study area, respectively.

- Upper-LKU formation

(1) OSN-03 core 1

The overall lithology is massive shale and bioturbated shale with coarsening-upward sandstone and thin-bed sandstone. The thin-bed sandstone is about 20-40 cm thick with parallel and cross-lamination that overlies the lacustrine shale. At the upper part of the core, it was followed by 2 meters of coarsening-upward sandstone with parallel and cross-lamination, interbedded with burrowed and bioturbated shale. The gamma log pattern corresponds to the core lithology. It was recorded as a funnel shaped coarsening-upward mouthbar sand interval. The shaly sandstone and silty shale could not be separated on the gamma ray log because of the resolution limit of the tool.

Based on this succession, this cored interval is interpreted as a lacustrine-delta environment, including massive marginal lacustrine shale with shoreline sandstone and mouthbar sandstone with bioturbated shale of the delta plain environment.

(2) OSN-04

The overall lithology is bioturbated shale and mollusk fossil shale interbedded with parallel- and cross-laminated sandstone. The shale facies of this core is bioturbated with gastropod mollusks, and some siderite. The thickness varies from 0.5 m to 2 m. In addition, the gastropods are both fragmented and well-preserved Viviparidae. The sandstone has parallel and cross-lamination with some mud drapes that could indicate wave influence in a lake. For this core, the gamma log value range 50 – 90 API is narrow which corresponds to the fine-grained sandstone to silty shale from core interpretation.

Based on this succession, this core interval is interpreted as deposited in a freshwater marginal lacustrine to shoreline environment. The gastropods indicate a non-marine environment, the well-preserved gastropods infer in-situ deposition and the fragments infer nearby transportation.

(3) OSN-06

The lower part of this core is about 14 meters of massive shale followed by thin layers of siltstone and very fine to fine grained sandstone with minor lamination at the upper section. The gamma log is around 100 API, indicating shale.

Based on this succession, this core interval is interpreted as a lacustrine environment overlain by silt to very fine grain sandstone from a shoreline environment.

(4) OSN-07

The overall lithology is fine grain sandstone with lamination and mollusk fossils, and shale with some mollusk fragments. Most of the lithology of this core is very fine to medium grain sandstone with interbedded silty shale. The parallel lamination, cross-lamination, mud drape, with bivalves and gastropods fragments in the sandstone indicates a lacustrine shoreline environment.

Based on this succession, this core interval is interpreted as deposition on a lacustrine shoreline. The well is located near a paleo-basement high with a fluvial-delta environment. The fossil fragments indicate transportation and reworking of fluvial-lacustrine sediment.

According to all core and wireline log interpretations, the overall environment of deposition of the Upper-LKU Formation is a lacustrine-delta and shoreline environment in the center (OSN-03, 04, 06) and southern part (OSN-07) of the study area.

- Lower-LKU Formation

(1) OSN-01

The overall lithology is coarse to very coarse-grain sandstone and mottled shale with bioturbation and rootlets. At the lower part of the core, a coarse to very coarse-grain sandstone is about 4 m thick with parallel and cross-lamination that is overlain by mottled floodplain shale. The gamma log pattern corresponds with the core lithology. It has the blocky shape of a fluvial channel sand.

Based on this succession, this core interval is interpreted as a proximal alluvial plain with fluvial channel. The grain size of the sandstone is the key evidence for of the proximal alluvial plain interpretation.

(2) OSN-02

The overall lithology is mottled shale with bioturbation and rootlets interbedded with laminated sandstone facies and a minor organic shale. At the bottom part of the core, a fining-upward sandstone around 8 m thick sand with parallel and cross-lamination structure was identified as a fluvial pointbar. In addition, there are thin beds of organic shale interbedded with the sandstone. It is overlain by bioturbated and rooted mottled shale with thin beds of sandstone. The gamma log pattern corresponds to the core lithology. It has the bell shape of a fining-upward fluvial pointbar. The thin beds of organic shale cannot be detected on wireline.

Based on this succession, this core interval is interpreted as a deposition on a fluvial system, including fluvial pointbar, swamp, crevasse splay, levee, and floodplain.

(3) OSN-03 core 2

The overall lithology is massive shale and bioturbated shale with thin-bed sandstone. The thin-bed sandstone is parallel and cross-laminated and interbedded with the massive lacustrine shale. It was followed by the bioturbated floodplain shale occur in the upper part of the core. The thin bed sandstone could not be resolved on the gamma ray log.

Based on this succession, this core interval is interpreted as a deposition on a lacustrine-delta environment, including massive marginal lacustrine shale with thin beds of shoreline sandstone

(4) OSN-05

The overall lithology is massive shale with thin sandstones. The thin-bed sandstone is parallel laminated. The gamma log pattern corresponds to the core lithology. This core is interpreted as a deposition on a lacustrine-delta environment, including massive marginal lacustrine shale overlain by shoreline sandstone.

According to all core and wireline log interpretations, the overall environment of deposition of Lower-LKU Formation is increasingly landward to the northeast. The coarse to very coarse-grain fluvial channel with floodplain occurs at the northeast area (OSN-01) and finer grained fluvial sandstone of the southwest (OSN-02). In the center, a lacustrine-delta and shoreline environment were interpreted from OSN-03 and OSN-5.

B) Well to Well Correlation

Well to well correlation of LKU Formation across the study area is illustrated based on the Chum Saeng Main Seal regional marker, which suggests a widespread distribution of lacustrine shale. The correlation sections were correlated across the study area in order to identify the boundary of each depositional environment.

The north-south correlation panel (Figure 16) indicates that the basement high areas are at the northern and southern part of the study area. Thus, the section is thinner to the north and south, which is displayed at OSN-11, OSN-39, OSN-41, and OSN-07. The coarser grain size sediment is in the north compared with the center (OSN-02, 03, 04, and 06)

Based on the three west-east correlation panels (Figures 17-19), the thickness of LKU Formation increasing and grain size fines to the west. Therefore, basinward is in the western part of the study area, whereas the source of sediment is mainly from the east and northeast.

4. Depositional Environment Model

The lithofacies from core interpretation and well log characterization and correlation across the study were taken into account to identify the depositional environment model. This study area is located on the passive margin of the Phitsanulok non-marine basin surrounded by pre-Teriary basement to the east and northeast of the basin. The basin depocenter is in the west. Thus, the related environments of these two provinces are freshwater lake, lacustrine delta, alluvial plain with fluvial channel, and alluvial fan.

The models were constructed and divided into two main key stages; Upper-LKU Formation (Figure 20) and Lower-LKU Formation (Figure 21) that were in the late syn-rift phase and early syn-rift phase, respectively. The two stages are not significantly different. The freshwater lake is in the west with clastic

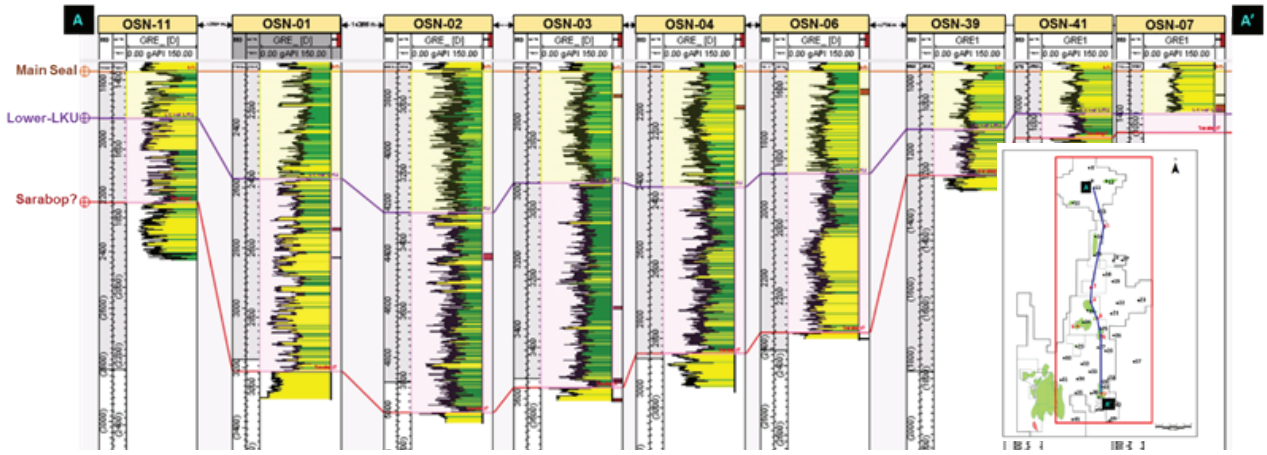

Figure 16: Regional North to South well correlation panel of the study area demonstrating the thinner section in the north (OSN-11) and south (OSN-39, 42, and 07) study area. The main seal marker, Chum Saeng shale, to Sarabop marker is correlated as the Lan Krabu Formation. The thinner section is due to paleo-basement highs. The blocky coarse-grained sandstone at OSN-11 and OSN-01 corresponds to alluvial fan and alluvial plain environment. In the center (OSN-02, 03, 04, and 06) have a funnel shape of bar sands. These log patterns were identified on a lacustrine-delta transitional environment. Moreover, the southern part (OSN-39, 42, and 07) is both funnel shaped and bell shaped that were interpreted as a fluvio-delta environment.

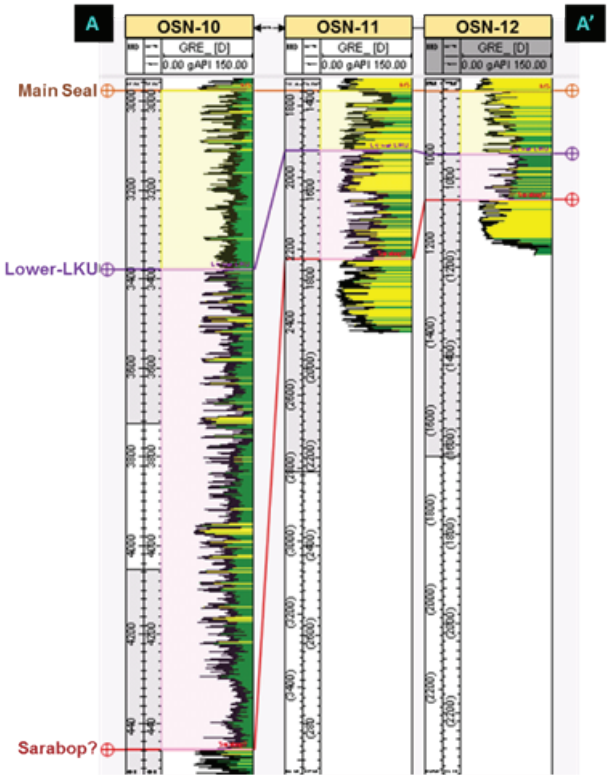

Figure 17: Southwest to northeast well correlation panel at the northern part of the study area with very thick lacustrine shale at OSN-10 and a thinner section of alluvial plain/ alluvial fan in the northeast (OSN-11, 12)

sediment supply mainly from the east and northeast alluvial fan and alluvial plain environments. The sediment grades from coarser to finer grain from the east-northeast to the west that correspond to a transition from alluvial fan to alluvial plain, the fluvial channel and flood-plain, and finally lacustrine-delta and shoreline environments.

The available core data in the center and southern part (Well OSN-02 to OSN-7) which were interpreted as transitional environments with a more proximal fluvial environment in the north (Well OSN-01). Coarse sand with a blocky pattern of gamma ray log is related to alluvial fans. Fining-upward successions indicate fluvial channel and alluvial plain environments. Also, the coarsening-upward succession indicates the transitional zone of delta plain and mouthbar.The lake succession is typically shale with thin sand beds (Boggs, 2006).

Figures 20-21 illustrate the paleogeography of the Upper and Lower Lan Krabu Formation. The lake level was higher during deposition of the Lower-LKU Formation then the Upper-LKU Formation on the shoreline shifted landward. The lacustrine-delta transitional area is larger in the Upper-LKU Formation because of lower slopes on the passive margin in the late syn-rift phase.

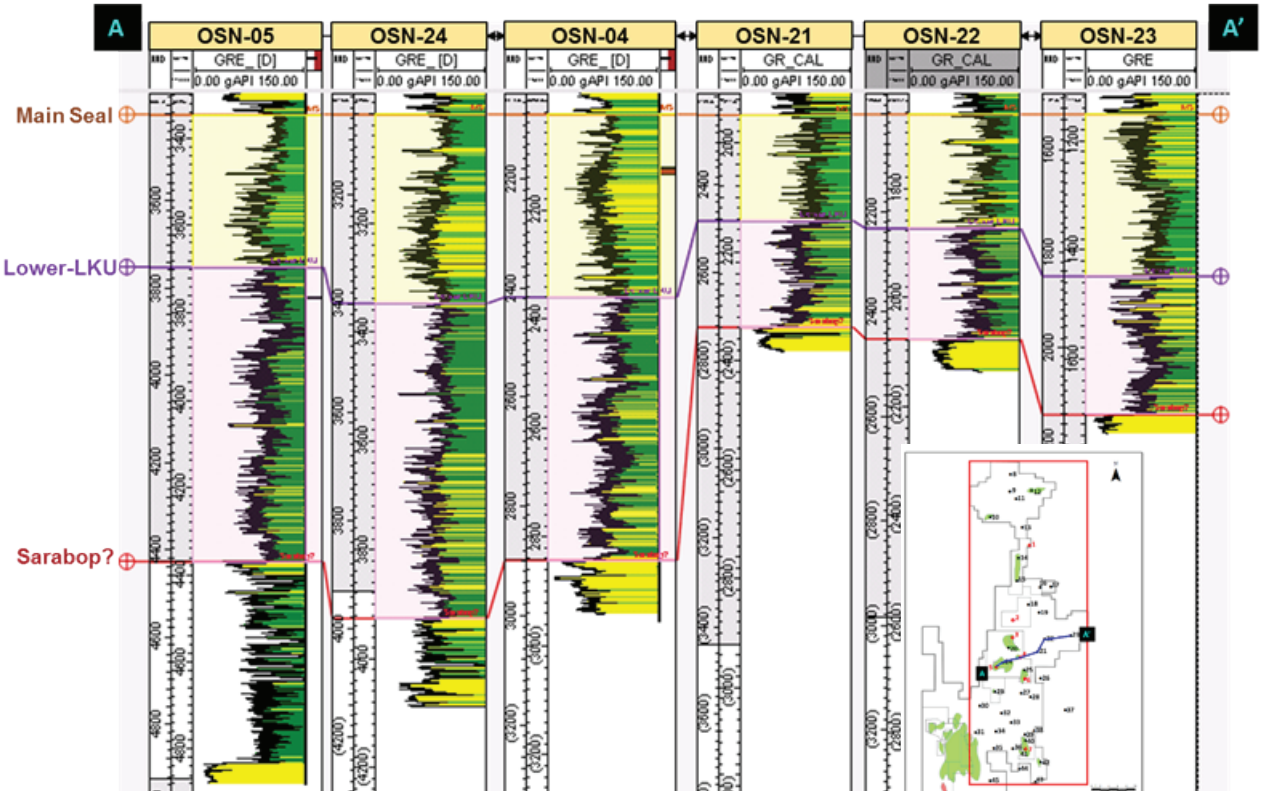

Figure 18: West to east well correlation panel at the center of the study area with the thinner section to the east (OSN-21 to 23) due to a paleo high and thickening to the west (OSN-05, 24, 04). The overall gamma log pattern is funnel shaped and symmetric, which is interpreted as a transitional environment.

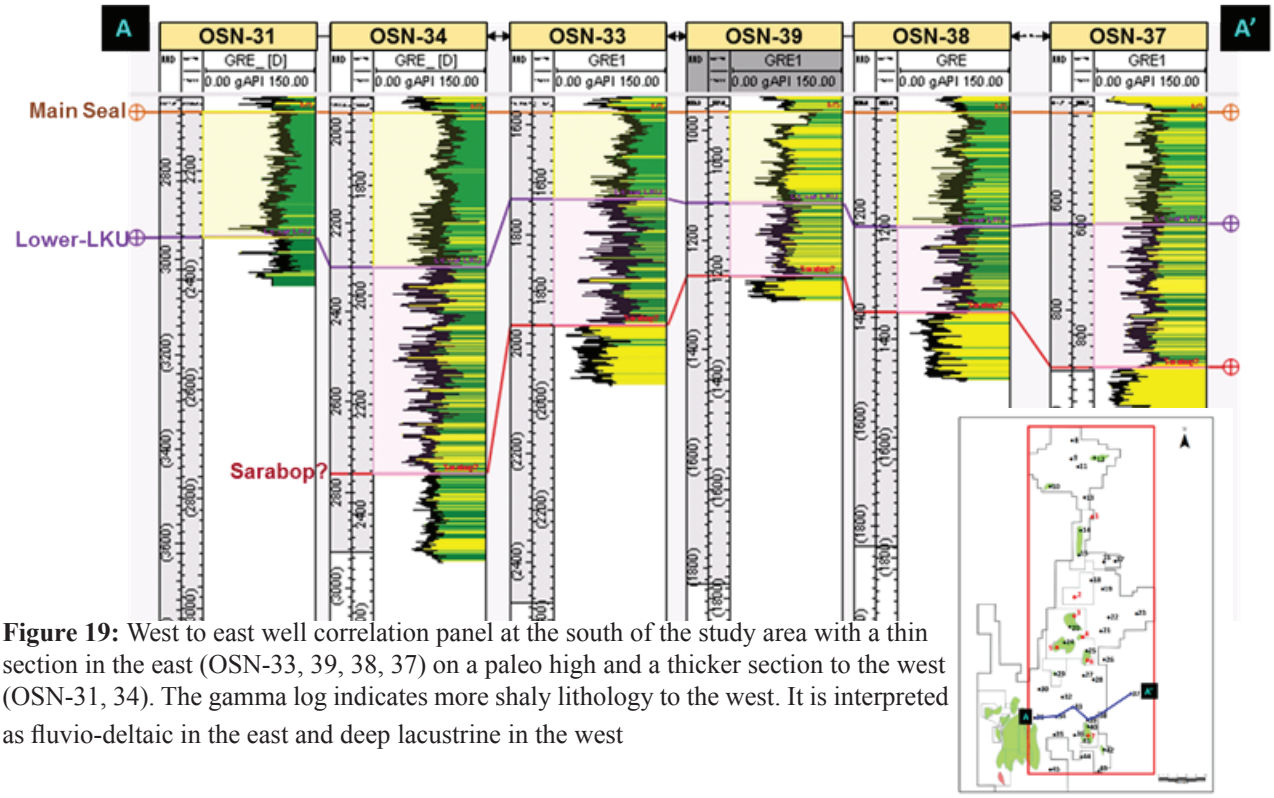

Figure 19: West to east well correlation panel at the south of the study area with a thin section in the east (OSN-33, 39, 38, 37) on a paleo high and a thicker section to the west (OSN-31, 34). The gamma log indicates more shaly lithology to the west. It is interpreted as fluvio-deltaic in the east and deep lacustrine in the west

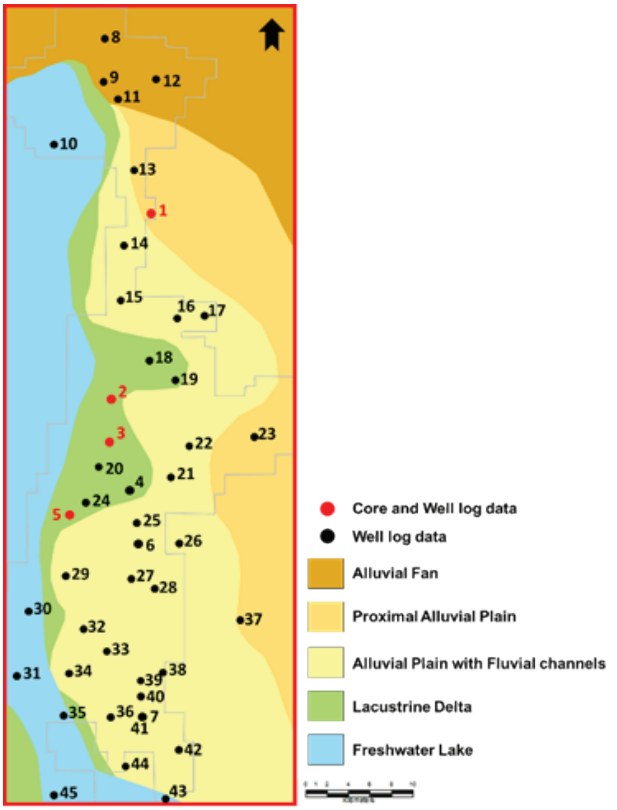

Figure 20: Paleogeographic model of the Lower Lan Krabu Formation in the study area including freshwater lake, lacustrine delta, alluvial plain with fluvial channels, proximal alluvial plain, and alluvial fan facies. The interpretation is based on conventional core and well log data

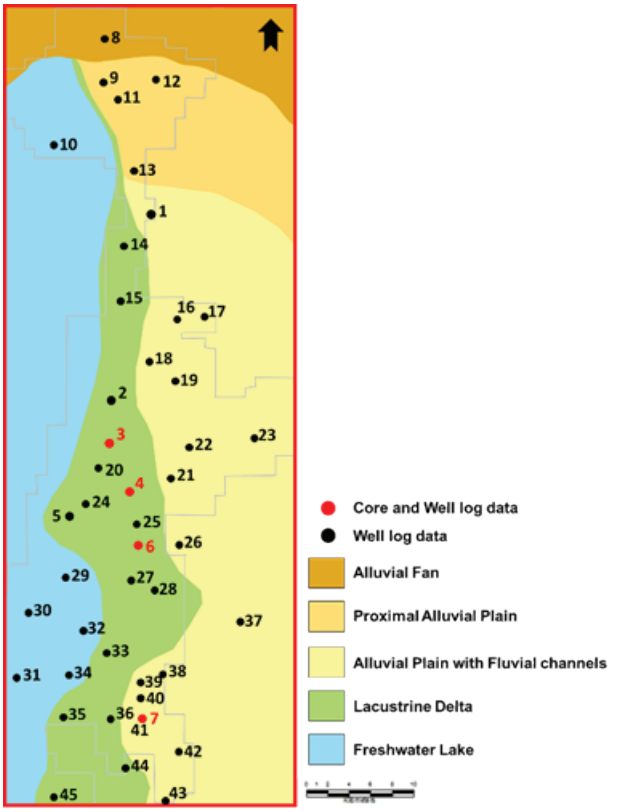

Figure 21: Paleogeographic model of the Upper Lan Krabu Formation in the study area including freshwater lake, lacustrine delta, alluvial plain with fluvial channels, proximal alluvial plain, and alluvial fan facies. The interpretation is based on conventional core and well log data.

5. Discussion

In the literature, palaeogeographic reconstructions of the fluvio-deltaic Lan Krabu Formation deposition is prograding from the north to lacustrine Chum Saeng Formation deposition to the south (Morley and Racey, 2011). The previous interpretation is based on borehole data and seismic data which defined that the basin depocenter (represented by lacustrine Chum Saeng Formation) was located at the southern part in the early Miocene period and associated with initial displacement on the Western Boundary Fault. The sediment supply and channel direction were mainly from north to south.

However, integrated with more conventional core and wireline log information, and regional seismic in this study, a different interpretation is necessary to explain the direction of sediment supply, channel orientation, and paleogeographic model. The western boundary fault is the key main fault in this rift basin and the basin configuration (supported by a regional seismic cross-section) of Phitsanulok Basin in the late Oligocene to early Miocene syn-rift phase is constructed with the basin depocenter in the center part of the basin (the western part of the study area). Thus, the active and passive margins of this basin are separated by the western boundary fault. This indicates that the study area is in the passive margin. It was interpreted that the alluvial and fluvio-deltaic clastic sediment in the passive margin was deposited from the east to the lake in the depocenter in the western part of the study area. Additionally, the northeastern and eastern part of the basin is surrounded by pre-Tertiary basement paleo-highs that were the main source of clastic sediment supply. It could be inferred that channel orientation was mainly east-west and northeast-southwest.

For petroleum applications, the shale

succession of the freshwater lake environment in the Upper and Lower Lan Krabu Formation has high potential as a source rock. The Lan Krabu Formation fluvial channel and/or pointbar sand and distributary channel and/or mouthbar sands are the best reservoir potential in the study area.

6. Conclusions

Conventional core and wireline log data in Sirikit Oil Field, Phitsanulok Basin were integrated to interpret the lithofacies and their depositional environments. The main conclusions are;

1) The depositional environment of the Lower and Upper Lan Krabu Formation in the study area are freshwater lake, lacustrine-delta environment, alluvial plain with fluvial channel, and alluvial fan environment.

2) Viviparidae gastropods and freshwater bivalves support a non-marine environment and freshwater lake interpretation.

3) Gamma ray pattern corresponds to cored lithology, however, wireline sampling rate cannot capture the lithology of thin intervals.

4) The clastic sediment supply of this study area is mainly from the east and northeast via alluvial fan and alluvial plain to fluvio-deltaic environments. The sediment deposited in the west is a thick shale succession in a freshwater lake that developed in the basin center.

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