Sedimentology, Stratigraphy and Reservoir Quality in Outcrop Fluvial Sandstone, Khorat Group, Thailand

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Abstract

A more than 1000 m wide and 10-15 m thick outcrop succession was investigated for lithology, sedimentary structures, bed geometry, grain size and reservoir quality. There are 10 lithofacies that comprise single and multi-story sheet sands, lenticular point bar sands, crevasse splays and oxbow lakes. Wedge-shaped, massive sands were interpreted as levee and abandoned channel environments. All are part of a meandering river depositional system.
Three reservoir rock types, of poor to moderate quality, were interpreted from XRD and thin sections of four samples in combination with gamma ray logs across the outcrop. The best one is trough cross-bedded sub-arkose sandstones. The sandstones are in late middle diagenesis and compaction has significantly reduced porosity. Authigenic clays, sediment structures and bioturbation also decreased reservoir quality. Generally, the reservoirs are suitable for gas accumulation.

Keywords: Sedimentology, Reservoir quality, Khorat Group

1. Introduction

The sedimentology and stratigraphy of an exposure in the Sao Khua Formation of the Khorat Group in northeastern Thailand was evaluated with sedimentological observations, gamma-ray measurements, XRD and thin sections (Fig. 1). The objective was to develop a better understanding of the relationship between log shape and depositional environments in a fluvial system. In addition, sandstone reservoir quality was evaluated and ranked by shale volume from gamma-ray values, XRD analysis and thin section study.

Depositional environments

The interpretation of facies, architectural elements and bounding surfaces help to recognize the environments and sub-environments in outcrop. There are 9 facies that comprise 7 depositional environments, all of which are part of a meandering river depositional system (Fig. 2, Table 1). These are:

- An abandoned channel facies association that includes ripple lamination and flaser bedding in fine to medium-grain thin sandstones as well as laterally accreting planar, cross-bedded sandstone, mudstones, and massive

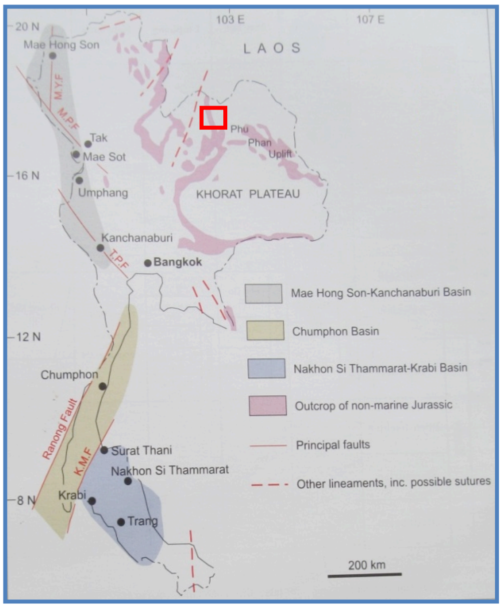

Figure 1. Location of the study area (red square) in northeastern Thailand (Ridd et al., 2011)

sand up to 3.5 m thick. The abandoned channel fill directly overlies an incised surface and is overlain by a thin black mudstone.

- Point-bar deposits are characterized mainly by trough cross-bedded, fine to medium grained sandstones with ripple and flaser bedded facies. Architectural elements of point bars include sheet sands, lateral and vertical sands.

- Sheet sands are longitudinal bars cut parallel to flow direction, the 1 – 1.5 m thick overbank mudstone deposit overlying this succession suggest a long period of flooding.

- Lateral accretion sands have a dip angle of 7-10 degree with thicknesses varying from 0.5 – 2.5m. The dominance of ripple lamination and flaser-bedding in very fine to fine-grained sandstone suggests that the sediments were deposited in low energy conditions. The sands pinch-out in one direction and are tangential to the channel base. The amalgamation of multiple sand bodies creates a lateral accretion unit. Channel width is estimated to have been about 300 m. One margin has a gentle slope while the other is steeper.

- Vertically accreted sand contains a series of small lenticular sand bodies that overlap one another, creating a vertical accretion succession. Gravel deposits with convex-up bases occur in some sand bodies, suggesting that the vertical accretion sand was the result of successively abandoned channels.

- Crevasse splay sediments contain stratified, cross-bedded gravel with mud clasts at the base overlain by horizontal, fine-grained sandstone, with low angle while trough cross-bedding, fine to medium-grained sandstone facies often occur at the top. Sand bodies are lenticular and between 0.2 and 1 m thick.

- Horizontal, fine grain sandstone and mudstones interbedded with wedge-shaped sandstones is interpreted as levee deposits. They include stacked fining upward beds 0.5-0.7 m thick, each of which records a flooding event.

- Oxbow lake sediments consist of horizontal laminated and bioturbated sandstone plus black mudstone. The sands are mainly very fine to fine grain and highly bioturbated. Oxbow lake deposits extend laterally for 1 km in two different places.

- Floodplain deposits are 0.5 – 2 m thick brown structureless mudstone that contain a lot of carbonate nodules, indicating a semi-arid environment.

Table 1. Facies associations, architectural elements and depositional environments

Architectural elements	Facies association	Interpretation
Massive sand (Single-story channel)	• Planar, cross-bedding sandstone (Spc) • Ripple lamination and flaser-bedding, very fine to fine-grained sandstone (Srf) • Horizontal, very fine-grained sandstone (Shvf)	Abandoned channel \Channel fill
Wedge – shaped sand (Levee)	• Horizontal, very fine-grained sandstone (Shvf) • Mudstones (Md)	Levee\Overbank
Sheet sand (Single-story channel)	• Trough and cross-bedding, fine to medium-grained sandstone (Stc) • Horizontal, fine-grained sandstone (Shf) • Mudstones (Md)	Point-bar\Channel fill
Lenticular sand (Multi-story channel)	• Gravel stratified cross-bedding and clasts supported (Gp) • Horizontal, fine-grained sandstone (Shf) • Trough and cross-bedding, fine to medium-grained sandstone (Stc)	Crevasse splay \Overbank
Lateral accretion sand (Single-story channel)	• Gravel stratified cross-beds and clasts supported (Gp) • Ripple lamination and flaser-bedding, very fine to fine-grained sandstone (Srf) • Interbedded sandstones and mudstones (Sim) • Mudstones (Md)	Point-bar\Channel fill
Oxbow lake deposits	• Horizontal lamination and bioturbated sandstone (Shb) • Mudstones (Md)	Oxbow lake deposits
Vertical accretion sand (Multi-story channel)	• Gravel stratified cross-beds and clasts supported (Gp) • Trough and cross-bedding, fine to medium-grained sandstone (Stc) • Mudstones (Md)	Point-bar \Channel fill

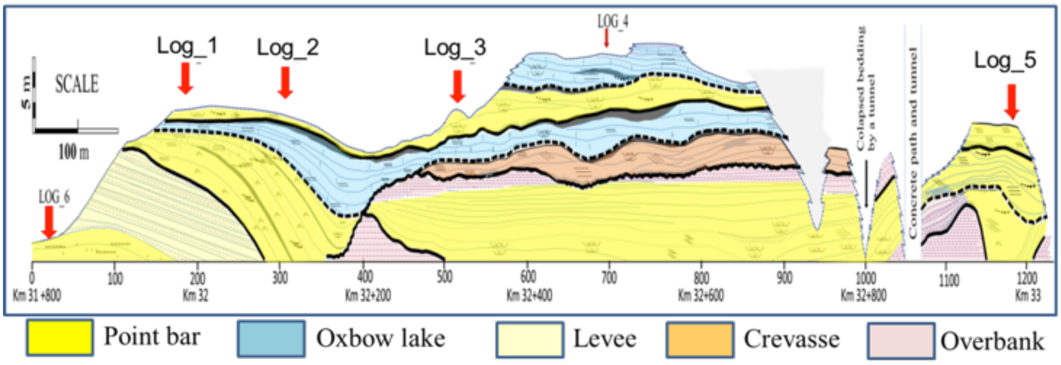

Figure 2. Depositional environments in the study area

Gramma log response to depositional environments

Log responses vary significantly from the same depositional environment. Gamma ray measurements indicate that point bar sand bodies can have bell-shaped, funnel-shaped or cylinder-shaped log curves while oxbow lake successions are dominantly funnel-shaped, crevasse splays have both bell and funnel-shaped responses, levee deposits generate small bell-shaped curves and abandoned channels generally have cylindrical or zig-zag curves.

Reservoir quality

Mineral identification and sandstone classification.

The most important minerals are quartz, feldspar, mica, kaolinite, chlorite, smectite and carbonates. Generally, all the sandstones are very fine to medium in grain size visual pore space varies from 41 to 55 μm in diameter, while detrital clay matrix is estimated at less than 15% and carbonate cement and authigenic clays fill pore space. One sandstone sample is a sub-arkose sandstone group, another is an arkose sandstone and two are lithic arkoses based on Folk's (1974) classification.

Reservoir quality from spectral gamma ray data

The statistics indicate that shale\clay volume varies considerably in different sand bodies. Levee sands contain the largest amount of K (2.4%) and Th (16 ppm) and have the highest Gr values (80-90), while all those values are lowest in point bar sandstones.

Shale volume was estimated from the Gr logs, with Gr min and Gr max values assigned as 35 nGyh-1 for sand and 110 nGyh-1 for shale based on measured data. Shale volume was calculated with a linear equation and the highest average shale volume is in levee deposits (about 64%) while the lowest (about 18%) is in point bar deposits. Sample Q-1-XRD is coarse-grained in thin section but recorded high Gr (75-90 nGyh-1), high K (3-4%) and high Th (12-15 ppm) values as a result of abundant feldspar and muscovite.

Reservoir evaluation

The low and moderate compositional and textural maturity in samples Q-1-XRD, Q-2-XRD and Q-3-XRD suggests that that sediments were deposited near their source, but the highly mature point bar sandstones in Q-4-XRD are homogeneous and probably were deposited far from their source and may have experienced several cycles of sedimentation.

Point bar and crevasse splay sands have moderate reservoir quality, which is the best in the study area. Abandoned channel sands and oxbow lake sands are poor reservoirs while levee sands are considered very poor reservoirs.

Discussion

Depositional environment

Furisch (in Heggemann et al., 1994) suggested there is some estuarine to brackish water influence in the upper part of the Sao Khua Formation based on the identification of the fresh water bivalve Trigonioides sp and the brackish water bivalve Eomiodon sp. However, similar to the findings of Racey (1996) on the Sao Khua Formation of the Khorat Group, this study indicates that the depositional environment was a meandering river system. Most of the sediments were deposited in low energy conditions with ENE to WSW flow directions.

Log response to depositional environment

Traditionally, point bar deposits in a meandering river are associated with fining- upward, or bell-shaped, log Gr patterns (Rider, 1990). However, the measured Gr log patterns are considerably more variable as cylinder-shaped, funnel-shaped and bell-shaped curves all occur in point bar successions. This is because facies architecture, bioturbation and mineralogy is variable within different sand bodies deposited in the same environment.

Factors impacting reservoir quality

The present study indicates that Sao Khua Formation sandstones have very poor to moderate reservoir quality. Racey (1996) found slightly better reservoir quality in the same formation in the central and western Khorat Plateau where compositional and textural maturities were somewhat higher. The textures and mineralogical composition from XRD and thin section petrography suggest that sediments underwent late middle diagenesis. According to Taylor's model 1974 (in Serra, 1989), it is interpreted that Sao Khua Formation was buried to a depth of about 3000 m and has 10% total porosity.

The detrital clay contnent is quite low (3-4% according to Racey, 1996), suggesting that primary porosity could be high. However, the high volume of authigenic clay, such as kaolinite, chlorite (5-20%), resulting from feldspar alteration under high temperature during middle diagenesis significantly reduced the number of pores and pore throat size.

In addition, the single-story sands that are the dominant architectural element suggests poor vertical connectivity between sand bodies. Bioturbation destroyed sedimentary structures and introduced clays from surrounding shales so that the impact of bioturbation was to decrease both porosity and permeability. Also, mud drapes and flasers act as baffles, further reducing permeability.

Uncertainties from outcrop measurements

The relationship between K and Th can be used to predict the presence of dispersed authigenic clays by applying cross-plots in Interactive Petrophysics (IP) software. However, authigenic clays cannot be distinguished in the outcrop potassium and thorium data on a K\Th cross-plot as most points plot in the mixed layer clay area. In comparison with the XRD results, the measured values of potassium and thorium are not consistent and are, therefore, less reliable, probably because the outcrop experienced significant surface weathering that further altered mineralogical composition.

Conclusions

This study came to the following conclusions:

a) The Sao Khua Formation was deposited by a meandering river system.

b) Gamma ray log patterns are not necessarily indicative of sub-environments in fluvial meandering systems.

c) Reservoir quality is very poor to moderate with low porosity. These sandstones have potential for gas accumulation.

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