Different Types of Organic-Rich Geological Markers in Surat, Central-North of Pattani Basin, Gulf of Thailand

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Abstract

The lower to middle Miocene organic-rich sediment in the Surat area, central Pattani Basin, Gulf of Thailand has been studied using conventional core with the integration of wireline and petrographical data. The results suggest three types of organic-rich sediments, which are non-marine coaly mudstone, marginal marine coaly mudstone, and estuarine shale. Non-marine coaly mudstone is indistinguishable from floodplain sediments on wireline due to their similar characteristics. Marginal marine coaly mudstone with abundant pyrite nodules has low density, and high gamma well-log characteristics and a widespread distribution. Thin estuarine shale is difficult to distinguish on wireline only, however; associated marginal marine coal with low resistivity and high gamma shale can be recognized and correlated. The other associated facies in the succession are interpreted as dominantly fluvial deposits with tidal influence. The recognition of estuarine shale suggests that major marine transgressions occurred in the lower and middle Miocene. The presence of a thin transgressive section indicates the low basinal slope of the Miocene of Pattani Basin allowed the marine shoreline to migrate to the central-north of the basin. The evidence of marine incursions provides a better understanding of the lower to middle Miocene stratigraphic framework in the Surat area and Pattani Basin, and it is an important controlling factor for possibly tide-influenced fluvial sand reservoirs in the southern area.

Key Words: Organic-rich, Geological marker, Marginal marine, Surat, Pattani basin

1. Introduction

Organic-rich sediments have been used as markers for well correlation in Pattani Basin, Gulf of Thailand, as they have a widespread deposition. However, the markers are normally defined on wireline data only and follow the type logs.

This study will define the lower to middle Miocene organic-rich sediments in the Surat area, which is located in central part of Pattani Basin (Figure 1). In order to improve the understanding of organic-rich sediments and expand their stratigraphic relationships northward, conventional core data, petrography and wireline data were used to define lithofacies and depositional environments. Other associated facies were examined to improve the understanding of the stratigraphic framework. Interpretation and correlation of organic-rich strata in wells without cores were used to investigate their geographical geographical distribution and stratigraphic relationships.

The data set consists of conventional core, wireline, and petrographic data acquired by Chevron Thailand Exploration and Production, Ltd. The conventional cores and petrographic data are from SU-I, SU-II, SU-III, and SU-IV (Figure 1). Wireline data come from 66 wells in the Surat area and consists of gamma, resistivity, neutron, density, and transit time. Four of the wells with conventional core also have spectral gamma logs.

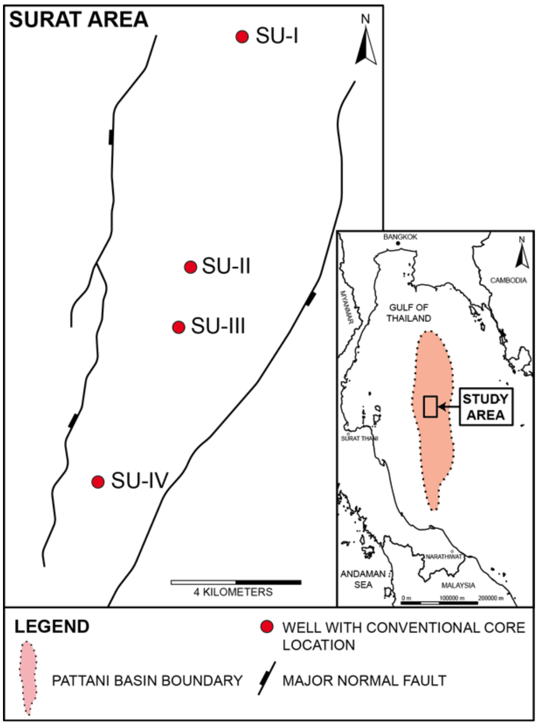

Figure 1. The Surat study area is located in the central part of the Pattani Basin, Gulf of Thailand, with the location of the wells used in the study.

2. Facies Analysis

Organic-rich sediment is the focus of this study. Stratigraphic units were divided into two groups, organic-rich facies and other associated facies. The facies analysis is based on core description and interpretation including petrographic data and wireline logs.

2.1 Organic-rich Facies

2.1.1 Coaly Mudstone

The coaly mudstone facies is medium to dark gray mudstone. Thickness ranges from 0.5 ft (0.15 m) to 2 ft (0.61 m). Sedimentary structures include mainly indistinct stratification. Lower and upper contacts are typically gradational with greenish-reddish gray siltstone. Coaly plant remains and coal are common. Yellowish pyrite nodules and layers are rare (Figure 2A).

The well-log characteristics of coaly mudstone facies are poorly distinguished, because beds are thinner than wireline resolution and adjacent strata have similar petrophysical properties, although, it typically has slightly different characteristics from underlying and overlying floodplain deposits. This facies is recognized by moderately low density and high transit time.

The presence of indistinct stratification, coaly plant remains and the relationship with surrounding floodplain deposits suggests a poorly drained, waterlogged soil, and good preservation, which is interpreted as a swampy area on a floodplain. The slightly lower density than adjacent floodplain strata also suggests small amounts of plant material and a high proportion of fine clastics introduced into relatively shallow swamps during floods.

2.1.2 Coaly Mudstone with Nodular Pyrite

The coaly mudstone with nodular pyrite facies has similar characteristics to the coaly mudstone facies. It is characterized by interbedded medium to dark gray mudstone and dark gray to black coal. However, coal beds are thicker and typically contain more abundant nodular pyrite than the coaly mudstone facies (Figure 2B). Thickness ranges from 1 ft (0.30 m) to 3.5 ft (1.07 m). Sedimentary structures include mainly indistinct stratification and minor thin (<0.3 cm) parallel lamination. Lower contacts are gradational with gray siltstone delta plain. Upper contacts are gradational with coarsening-upward estuarine sand or gray siltstone delta plain.

The well-log characteristics of coaly mudstone with nodular pyrite are used to differentiate the two types of coaly mudstone. It is recognized by high gamma and 'spike curves' of transit time. Gamma ray is high (177-240 API) with high proportion of uranium (8.00-15.10 ppm).

The lithology of coaly mudstone facies suggests good preservation in a swampy area. However, coaly mudstone with higher sulfur content or pyritization indicates deposition under periodic influence of marine environment (McCabe, 1984). Stratigraphic proximity to overlying coarsening-upward estuarine sand or adjacent delta plain also supports a marine influenced environment. Thus, the coaly mudstone with nodular pyrite facies is interpreted as deposition in a marginal marine environment.

The 'spike curves' of transit time suggest a higher proportion of low-density coal compared to coaly mudstone facies, as does the thicker coal beds. High uranium content is also indication of marine influence as uranium was removed from seawater and mixed with fine clastics (Choy, 1994).

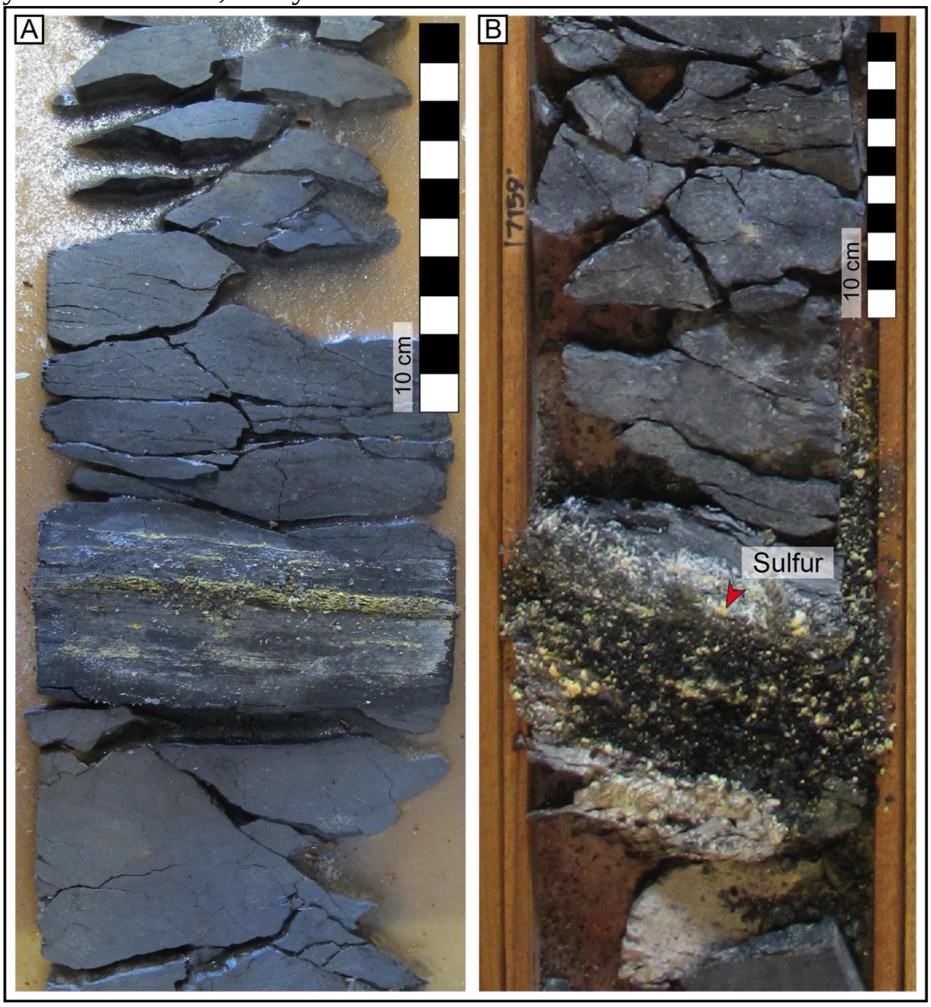

Figure 2. Core photographs of A) coaly mudstone B) coaly mudstone with nodular pyrite.

2.1.3 Laminated Clayey Siltstone

The laminated clayey siltstone facies is composed of clayey siltstone, coal and coaly mudstone. It typically tends to coarsen-upward into the overlying facies. Thickness ranges from 2 ft (0.61 m) to 16.4 ft (5.00 m). Sedimentary structures include mainly thin (<0.3 cm) to thick (0.3-1 cm) parallel lamination (Figure 3A). There are interbeds coal and coaly mudstone with indistinct stratification, which are more common in the lower part of facies (Figure 3B). Thin (1-3 cm) fine-grained sandstone to sandy siltston

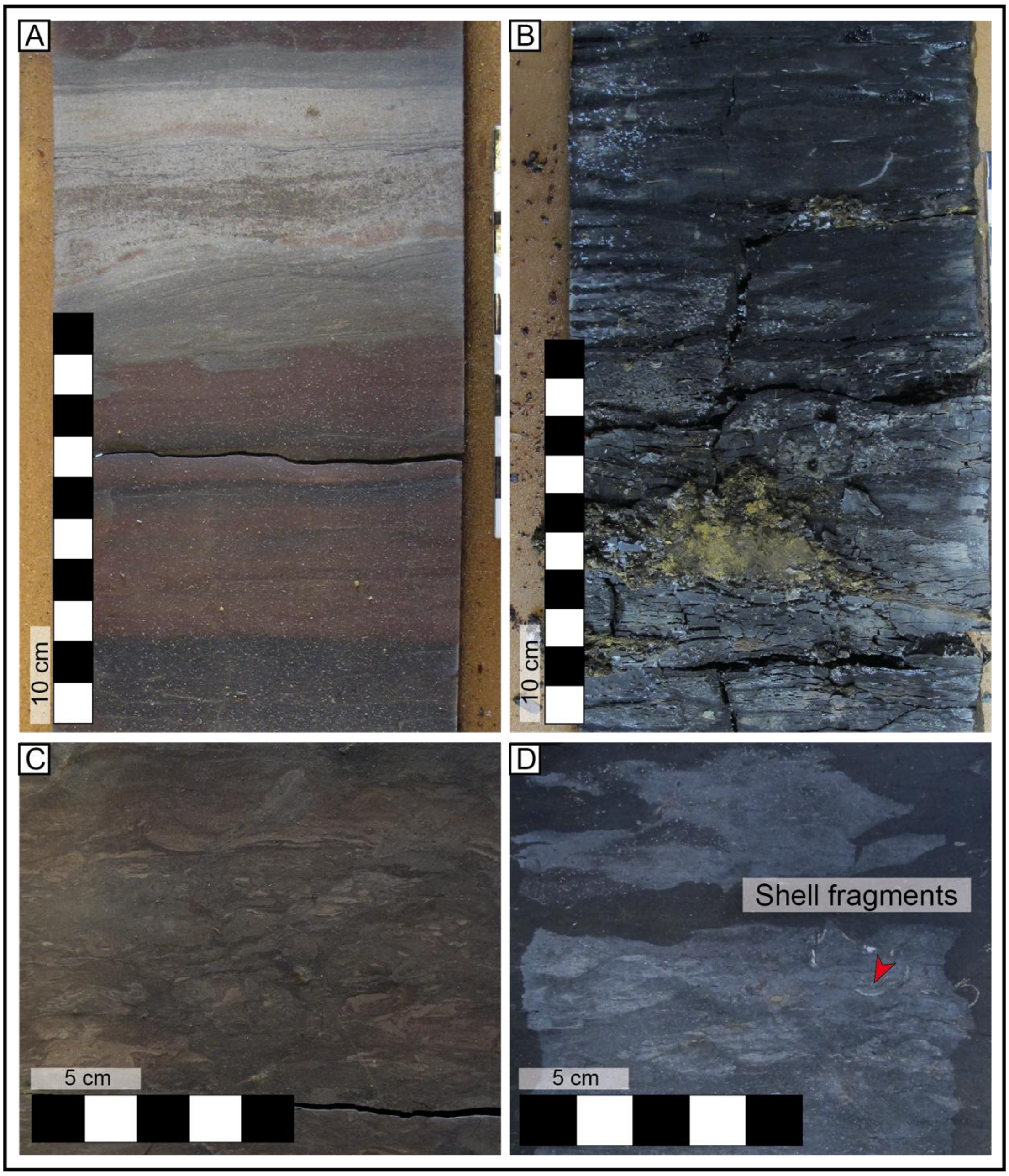

Figure 3. Laminated clayey siltstone facies core photograph A) laminated beds with thin beds of fine-grained sediment. B) Interbeds of coaly mudstone that are common near the base of the facies. C) The formation has abundant burrows, and D) shell fragments locally.

beds are present in some intervals with thin (<0.3 cm) mud drapes (Figure 3A). Lower contacts are typically sharp with the underlying greenish-reddish gray siltstone. Upper contacts are gradational into overlying coarsening-upward interlaminated sandstone and siltstone. Calcareous foraminifera, *Amonia sp.*, are present in thin section (Jones, 1991). Compressed leaf, woody peat, and shell fragments (Figure 3D) are present locally. Burrows are common near the top of the facies (Figure 3C) and tend to be abundant in overlying coarsening-upward interlaminated sandstone and siltstone. Siderite, calcite and pyrite are also present.

The well-log characteristics of laminated clayey siltstone facies are typically recognized by high gamma, low resistivity and slightly increasing upward density. Gamma is typically high (180-270 API) with high proportion of uranium (5.00-21.10 ppm). The well-log signature of this facies is difficult to distinguish from floodplain, however; the characteristic high transit time of marginal marine coal may be present near the base of shale sections.

The dark gray color, thin lamination and preserved plant remains suggest subaqueous deposition and coalification. The occurrence of *Amonia sp.*, an inner neritic to brackish water form, indicates marine influence, as does the presence of abundant burrows. The sharp bases may represent depositional hiatuses between the laminated clayey siltstone facies and underlying floodplain facies. The gradational relationships into overlying coarsening-upward interlaminated sandstone and siltstone facies suggest progradational sand onto estuarine deposits. Based on the lithology, stratigraphic relationships between underlying and overlying facies, and fossils in thin section, the laminated clayey siltstone facies is interpreted as an estuarine deposit.

The high uranium content and low thorium to uranium ratios are an indication of marine influence as uranium was removed from seawater and mixed with fine clastics (Choy, 1994, Adam and Weaver, 1958), which are typical of the laminated clayey siltstone facies. The low resistivity points to a high seawater content in the pore water. The characteristic increasing density upward is related to the common occurrence of coal beds near the base of the facies, which suggests the abundant organic material, burial, and coalification. The lower gamma in some intervals is related to the presence of thin beds of fine-grained sediment, which occasionally prograde into an estuary during flooding events.

2.2 Associated Facies

There are six associated facies, including conglomerate, cross-bedded sandstone, interlaminated sandstone and siltstone, greenish-reddish gray siltstone, and interbedded sandstone and clayey siltstone that are interpreted as part of fluvial successions. The other associated facies is coarsening-upward interlaminated sandstone and siltstone, which is interpreted as estuarine sand deposits.

3. Correlation and Mapping

Three types of organic-rich sediment have been correlated using wireline log from 66 wells in the Surat area. Isopach maps were generated based on the stratigraphic correlation and overlain on a middle Miocene structure map, which represents the regional structure during deposition of the organic-rich sediments in lower Miocene and middle Miocene.

3.1 Lower Miocene

Marginal marine coaly mudstone-5 and estuarine shale-5 have been selected to represent the organic-rich distribution in the lower Miocene.

3.1.1 Marginal Marine Coaly Mudstone

The isopach map of marginal marine coaly mudstone indicates widespread deposition, which suggests marine transgression across almost all of the Surat area in the lower Miocene (Figure 4). The likely boundary is illustrated in Figure 4.

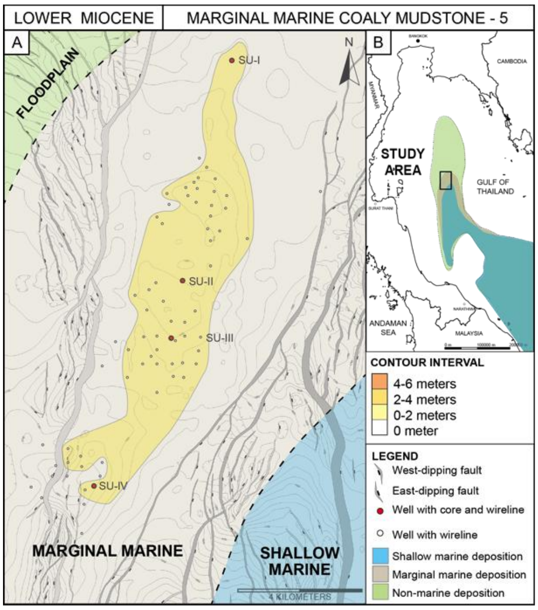

Figure 4. A) The isopach map of marginal marine coaly mudstone-5 with Depositional trends in the lower Miocene. B) The likely boundary in Pattani Basin (from Morley and Westaway, 2006).

3.1.2 Estuarine Shale

The isopach map of estuarine shale suggests widespread deposition in all areas (Figure 5). This also suggests a marine transgressive event that occurred in the lower Miocene. The likely boundary is illustrated in Figure 5.

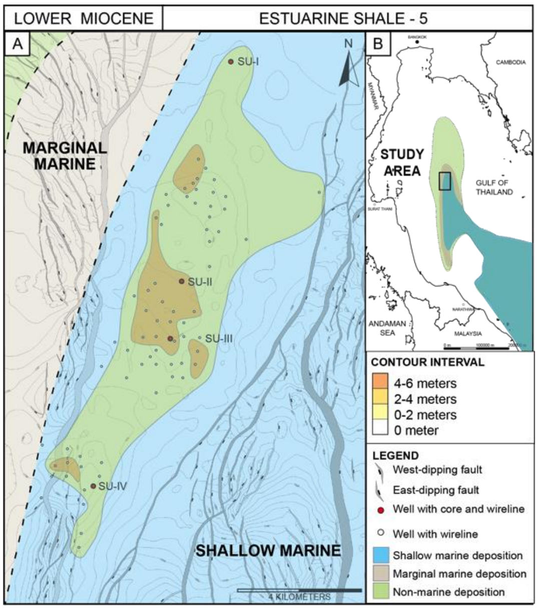

Figure 5. A) The isopach map of estuarine shale-5 with the likely depositional trends in the lower Miocene. B) The likely boundary in Pattani Basin (from Morley and Westaway, 2006).

3.2 Middle Miocene

Non-marine coaly mudstone-6, marginal marine coaly mudstone-1, and estuarine shale 2 have been selected to represent the likely distribution of organic-rich facies in the middle Miocene interval.

Non-marine coaly mudstone-6 and marginal marine coaly mudstone-1 are nearly stratigraphically equivalent. The isopach maps of the two types of organic-rich facies are overlain on the same structural map in order to interpret the likely boundary between non-marine and marginal marine deposition in the middle Miocene.

3.2.1 Non-Marine Coaly Mudstone

The isopach map of non-marine coaly mudstone suggests the lateral extent of floodplain swamp deposits (Figure 6). The facies is mainly located in the north, which also suggests non-marine deposition northern part of the Surat area. However, the isopach map is based on well-log characteristics and correlation reliability. The indistinct well-log characteristics of non-marine coaly mudstone may cause an underestimation of its extent because it has similar characteristics to the floodplain facies.

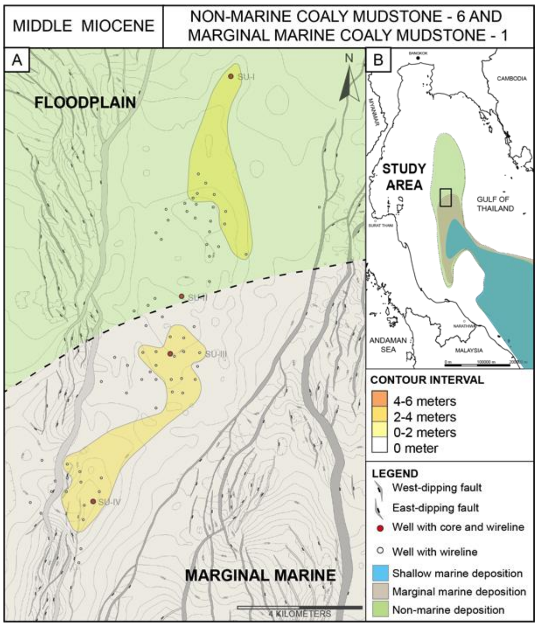

Figure 6. A) The isopach map of non-marine coaly mudstone-6 and marginal marine coaly mudstone-1 with the likely depositional trend in the middle Miocene. B) The likely boundary in Pattani Basin (from Morley and Westaway, 2006).

3.2.2 Marginal Marine Coaly Mudstone

The isopach map of marginal marine coaly mudstone suggests it is mainly located in the southern middle part of the Surat area (Figure 6). This suggests that the shoreline was located in the middle part of the area at that time.

The integration of non-marine coaly mudstone and marginal marine coaly mudstone suggests gradually increasing sea level and landward shoreline migration in the middle Miocene. The interpreted boundary is illustrated in Figure 6.

3.2.3 Estuarine Shale

The isopach map of estuarine shale suggests a wide distribution across the Surat area (Figure 7). Thickness tends to increase to the northeast, which may suggest marine influence further to the north. The interpreted boundary between marginal marine and shallow marine is illustrated in Figure 7.

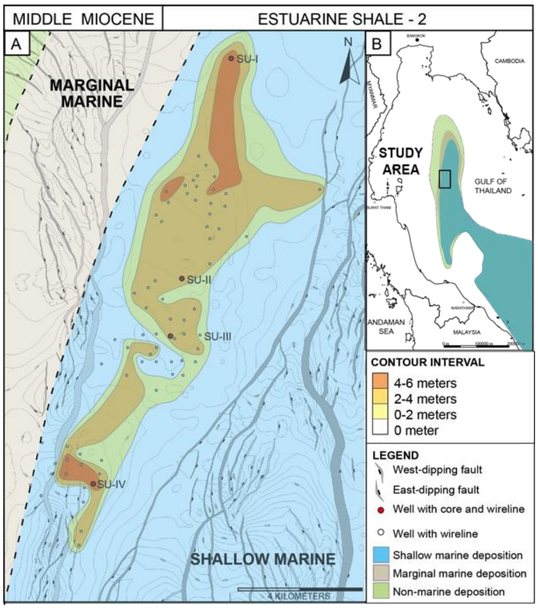

Figure 7. A) The isopach map of estuarine shale-2 with the likely depositional trend in the middle Miocene. B) The likely boundary in Pattani Basin (from Morley and Westaway, 2006).

5. Discussion

Marginal marine coaly mudstone is a good well correlation marker in the Surat area and provides high confidence for correlating the same stratigraphic interval through nearby areas. It is expected to thin northward while a relatively thick section is expected southward. However, because depositional environments vary laterally, some marginal marine coaly mudstone in Surat probably correlate to estuarine or marine shale in the same chronostratigraphic unit. Therefore, using marginal marine coaly mudstone wireline correlation may not be applicable on a regional scale.

Important outcome of the core study is the ability to identify estuarine shale, which is not normally from wireline data only. The difficulty of recognizing thin transgressive successions may cause an underestimation of marine influence outside the cored intervals in the Surat area and other parts of Pattani Basin. For qualitative identification, the integration of palynology and petrographic data are also useful.

The recognition of estuarine shale in the Surat area indicates shallow marine conditions influenced the central Pattani Basin during the lower and middle Miocene. The stratigraphic section in the Surat area is considerably thinner over the horst, which has been an area with a localized low subsidence rate (Crossley, 1990). The thin transgressive shale section is expected to be thicker in the eastern graben, southern area, and possibly in the western graben.

The presence of estuarine shale in the northernmost Surat well suggests the low basin allowed marine influence to penetrate at least that far north. Common relatively fine-grained sediments with a low proportion of cobbles and coarser-grain sizes in the associated fluvial facies suggests low gradient fluvial meanderbelts. The deposition of marine shale in this low-slope basin may have occurred across the entire basin during shoreline migration to the north. The narrow connection between the Narathiwath Ridge and the Narathiwath High to the North Malay Basin also implies shallow marine conditions throughout the Pattani Basin during highstands in the lower and middle Miocene. The palynology and the presence of relatively thick marine intervals in the southern Pailin area (Narapan, 2015) also support the development of shallow marine in the southern Pattani Basin.

The recognition of estuarine shale also impacts future exploration and development planning in order to predict reservoir characteristics and possibly reservoir connectivity in Pattani Basin as the lower to middle Miocene fluvial sandstone is considered to be the main hydrocarbon reservoir. More marine influence in sandstone reservoirs is expected laterally south and southeastward. Reservoir sands probably are thinner with elongate and narrow geometries as fluvial-deltaic deposits are expected in proximity to marine environments. Also, higher clay contents and finer-grained sands are expected, which will reduce reservoir porosity and permeability. As the estuarine shale has a high clay content, it may be a regional seal in the Surat area.

6. Conclusion

Conventional core, wireline log, and petrophysical data in the Surat area were examined to determine the different types of organic-rich sediment and corresponding depositional environment. The following conclusions summarize the findings of this study:

1) There are three types of organic-rich sediments, non-marine coaly mudstone, marginal marine coaly mudstone, and estuarine shale.

2) Marginal marine coaly mudstone is a good correlation marker in the Surat area due to its distinct well-log characteristics and widespread distribution.

3) Estuarine shale is difficult to recognize from wireline, however, the association of marginal marine coal near the base of estuarine shale can be used for well correlation.

4) Non-marine coaly mudstone has indistinct well-log characteristics and is similar to floodplain deposits.

5) Using wireline only may cause an underestimation of non-marine and estuarine intervals.

6) The associated facies are interpreted as part of a fluvial succession with tidal influence.

7) The overall stratigraphy is interpreted as dominantly fluvial with occasional marine transgressions. Transgressive events occurred in the lower Miocene and middle Miocene.

7. Acknowledgements

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