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# Petroleum system modeling in the Songkhla basin, Gulf of Thailand

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## Abstract

The Songkhla Basin, located in the southwestern Gulf of Thailand and renowned for hydrocarbon exploration, contains petroleum source rocks within the Early Oligocene strata. This study developed a one-dimensional petroleum system model based on well data and seismic data. Findings show that hydrocarbon generation from the source rocks began in the Early Miocene, reaching significant transformation in the Middle Miocene, and continuing to the present day. Seismic data suggest that fault activity likely caused oil leakage, impacting current exploration viability. This research provides insights into the maturation history and potential for future hydrocarbon exploration in the Songkhla Basin.

**Keywords:** Petroleum System Modeling, 1D Modeling, Hydrocarbon Exploration, Source Rock Evaluation

## 1. Introduction

Petroleum system modeling is a technique used to represent the burial history of a sedimentary basin and the hydrocarbon process. The modeling examines and evaluates a petroleum system to determine if the necessary components for hydrocarbon generation and accumulation are present and aligned in time and space.

The Songkhla Basin (Figure 1) is a small, approximate area of 2,500 square kilometers, located in the southwestern Gulf of Thailand (GOT), and is significant for hydrocarbon exploration containing the Bua Ban Oil Field (Rivas et al., 2016). Unfortunately, exploration in this oil field basin has been unsuccessful and abandoned. The source rock maturation is suspected to be problematic in this basin. Thus, source rock modeling needs to be studied. The main source rock of this basin is in the Early Oligocene strata with an average total organic carbon (TOC) content of 1.5% by weight and an average Hydrogen Index (HI) of 500-800 mgHC/gTOC (Premier Oil Pacific Ltd., 1988). The vitrinite reflectance of the source rocks ranges from 0.45% to 0.77% (Premier Oil Pacific Ltd., 1988; Premier Oil Pacific Ltd., 1990).

The basin consists of sediments from the Eocene to the present day (Figure 2). Mixed lacustrine shales and fluvial-alluvial sandstones dominate the Eocene layer. The Early Oligocene section is characterized by lacustrine deposits comprising organic-rich shales and a few sandstones. The Late Oligocene to Early Miocene periods represents a basin dominated by lacustrine shales. The environment shifted from the Middle to Late Miocene to predominantly fluvial, sand-prone deposits. The Pliocene period was characterized by delta plain, marginal marine, and shallow marine environments (Phoosongsee and Morley, 2019; Do, 2014).

Kaewkor et al. (2015) interpreted three main phases in the basin's development: the Early Rift

Stage in the Eocene, characterized by numerous small extensional faults that established the basin's foundational structure; the Late Rift Stage from the Oligocene to Early Miocene, which focused on developing and maturing the major boundary fault system, leading to a half-graben morphology as smaller faults became inactive; and the Post-Rift Stage starting in the Middle Miocene, noted for reduced tectonic activity and continued subsidence that shaped the basin's current sedimentary architecture. The extensional faults in this basin affect sedimentary layers ranging from the Eocene to the Pliocene periods (Morley and Racey, 2011; Racey, 2011; Paramita, 2012; Kartikasari, 2021).

To enhance understanding of hydrocarbon maturation and destruction within the Songkhla Basin, this study aims to simulate a one-dimensional (1D) petroleum system model using PetroMod software, incorporating geochemical data, seismic data, well data, and other boundary conditions. The 1D petroleum system modeling is particularly valuable and widely used for the understanding of petroleum source rock maturity evolution.

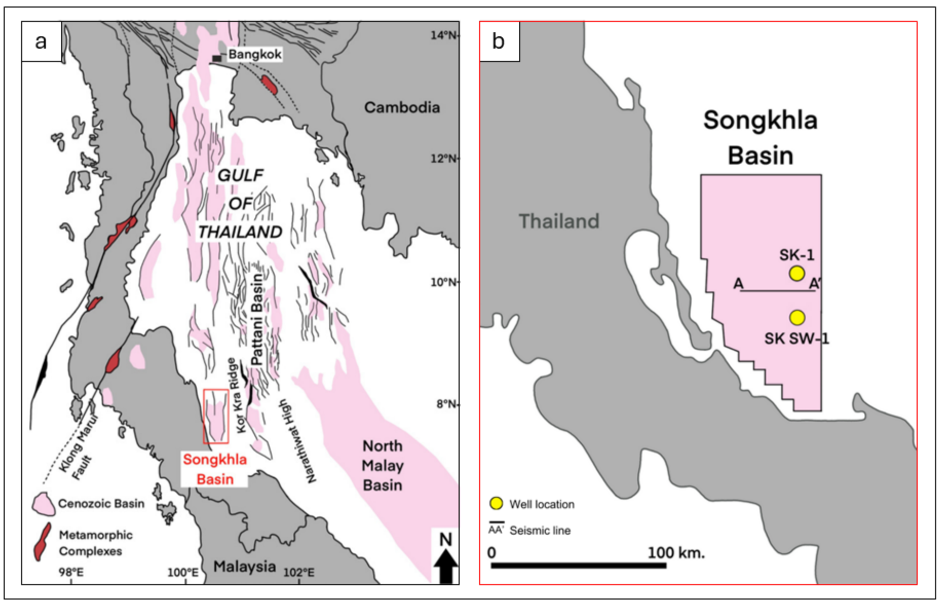


**Figure 1** (a) Simplified location map of the Songkhla Basin. The study area is displayed in the red rectangle. (b) Songkhla concession block with the Songkhla-1 (SK-1) and Songkhla Southwest-1 (SK SW-1) well locations and seismic line (modified after Phoosongsee and Morley, 2019).

## 2. Methodology

The research study was analyzed through geological analysis from exploration wells which drilled vertically, seismic data, mudlogging data, wireline data, and the final well report, The depth of data along to 8,675 feet (2,644 meters) in Songkhla-1 well and 9,152 feet (2,789 meters) in Songkhla Southwest-1 well (Figure 1b). The lithostratigraphic correlation and cutting description analysis were conducted based on the mud log data. These analyses were essential in defining the lithology, depositional environment, and facies variations within the Songkhla Basin.

To simulate source rock maturation (1D) modeling was utilized to replicate geological processes along a single vertical profile, typically representing a well or stratigraphic column. This approach focused on capturing vertical variations in geological properties over time. The modeling process involved reconstructing the geological history and properties at a specific location along a vertical axis, providing detailed insights into sedimentation rates, compaction, thermal history, and maturation of organic matter (Magoon and Dow, 1994).

In addition, 1D modeling captured changes in temperature, pressure, and fluid migration over geological time while assuming lateral homogeneity to concentrate exclusively on vertical variations. This method was primarily used for detailed well analysis, assessing source rock maturation, and serving as a basis for calibrating more complex models. The main inputs are stratigraphy, source rock properties, and lithology data (Table 1). Boundary conditions, which are the parameters of the related geological environment and factors, need to be defined carefully to make the simulations accurate and logically reasonable. The boundary conditions include paleo-water depth (PWD), sediment-water interface temperature (SWIT), and heat flow (HF).

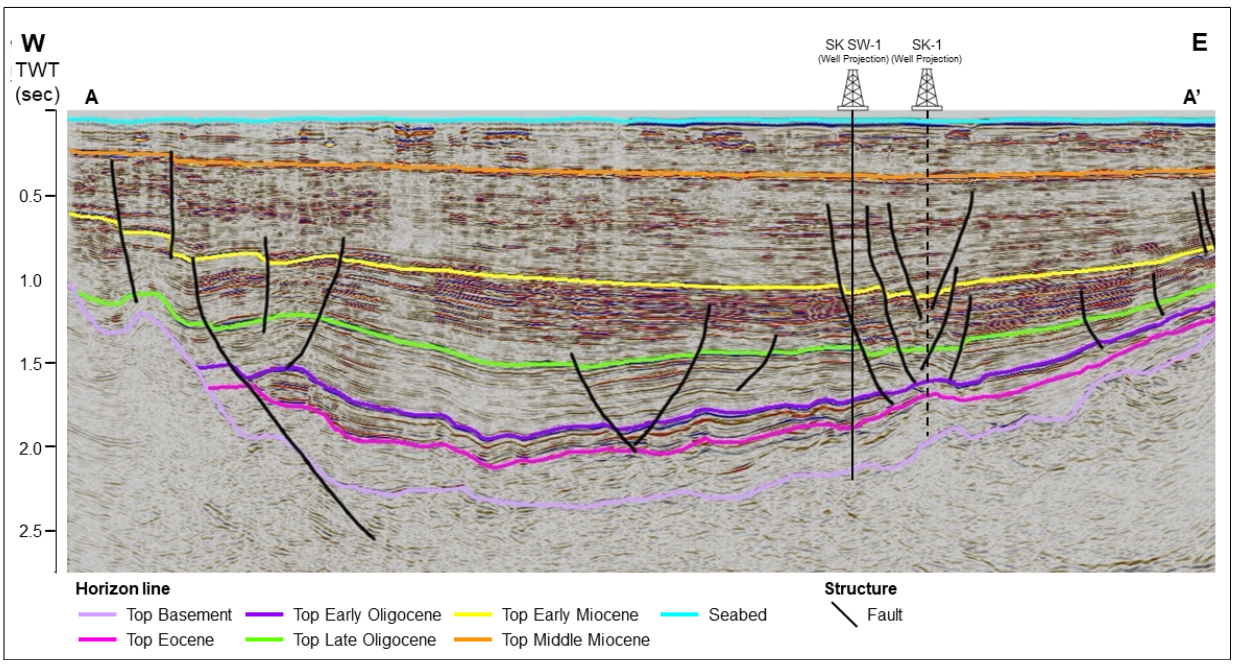


**Figure 2** Seismic profile from the study area shows faults and key horizons (see location in Figure 1).

| Layer | Top(ft.) | Base(ft.) | Thick(ft.) | Depo. From(Ma) | Depo. To(Ma) | Lithology | TOC(%) | Kerogen type | HI(mgHC/gTOC) |
|---|---|---|---|---|---|---|---|---|---|
| Recent-Late Miocene | 174 | 1316 | 1142 | 12 | 5 | Sandstone | | | |
| Middle Miocene | 1316 | 4021 | 2705 | 16 | 12 | Shale | | | |
| Early Miocene | 4021 | 6280 | 2259 | 23 | 16 | Shale | | | |
| Late Oligocene | 6280 | 7380 | 1100 | 28 | 23 | Shale | | | |
| Early Oligocene | 7380 | 7740 | 360 | 31 | 28 | Shale | | | |
| Early Oligocene(Source Rock) | 7740 | 7980 | 240 | 33 | 31 | Shale | 2.3 | Type I | 584 |
| Early Oligocene | 7980 | 8090 | 110 | 34 | 33 | Shale | | | |
| Eocene | 8090 | 8675 | 585 | 50 | 34 | Sandstone | | | |
| | | | | | 50 | | | | |

**Table 1** The main input parameter (stratigraphy, source rock properties, and lithology data) for 1D modeling.

## 3. Result and Discussion

From the simulation of 1D modeling, transformation ratio, maturation profile, expulsion graph, and generation mass oil graph are used for interpretation in this study.

The transformation ratio is the percentage of the kerogen in the source rock that has been converted to hydrocarbon. In Songkhla-1 the source rock started transformations at 0.55 %Ro in the Early Miocene (19.9 Ma) and critical moment at 50 % in the Middle Miocene (15.3 Ma). In the Late Miocene (10.6 Ma) transformation ratio stopped increasing and continued in recent years at 95 % (Figure 3a). In Songkhla Southwest-1 the source rock started transformations at 0.55 %Ro in the Early Miocene (19.74 Ma) and critical moment at 50 % in the Middle Miocene (15.2 Ma). In the Late Miocene (9.7 Ma) transformation ratio stopped increasing and continued in recent years at 95 % (Figure 3b).

In Songkhla-1, the source rock entered the early oil phase during the Early Miocene (19.9 Ma) and transitioned to the main oil phase in the Early Miocene (16.9 Ma). By the Middle Miocene (13.9 Ma), the petroleum source rock reached the late oil phase at a depth of 6,588 feet (2,008 meters) and remained in this phase up to the present day (Figure 4a). In Songkhla Southwest-1, the source rock entered the early oil phase at a depth of 4,076 feet (1,242 meters) during the Early Miocene (19.7 Ma) and progressed to the main oil phase at 5,071 feet (1,545 meters) in the Early Miocene (16.8 Ma). By the Middle Miocene (13.8 Ma), the petroleum source rock was in the late oil phase at a depth of 6,614 feet (2,016 meters) and continued in this phase to the present day (Figure 4b).

The expulsion graph of Songkhla-1 shows that the generation of oil expulsion began in the Early Miocene (16.8 Ma) and peaked in the Middle Miocene (14.4 Ma). The generation mass oil graph shows the total oil generated is 2.07 million metric tons (15.18 million barrels) in the Middle Miocene (12.15 Ma; Figure 5a and c). In Songkhla Southwest-1 the expulsion graph shows the generation of oil expulsion beginning in the Early Miocene (17.1 Ma) and peak expulsion in the Middle Miocene (14.5 Ma). The total oil generated is 3.73 million metric tons (27.35

million barrels) in the Middle Miocene (12.08 Ma; Figure 5b and d).

From the results of this study, the relation of the basin and the source rock maturation of Songkhla basin by burial history shows that both wells similarly entered the oil phase and same maturation. The source rock generated 1.15 and 2.1 million metric tons (8.43 million barrels and 15.39 million barrels) of oil at a 50 % transformation ratio from Songkhla-1 and Songkhla Southwest-1 respectively (Figure 3a and b). Total oil generated from source rock is 2.07 million metric tons (15.18 million barrels) and 3.73 million metric tons (27.35 million barrels) from Songkhla-1 and Songkhla Southwest-1 respectively (Figure 5c and d). When compared with other previous studies (e.g. Supriatna, 2011; Rivas et al., 2016) the source rock maturation in the Songkhla Basin from this study shows similar results as described below.

From previous studies by Supriatna (2011) and Rivas (2016), the result of Supriatna (2011) shows that the Early Oligocene source rock is oil-prone with maturity levels ranging from middle mature to mature. These findings are similar to our study results; however, the maturation of source rock is different. This study indicates the source rock is mature, while the study of Supriatna (2011) identifies it as middle mature and mature. In Rivas et al. (2016) the result shows that the Early Oligocene source rock entered the oil window at the Late Oligocene (24 Ma), whereas in this study, it entered in the Early Miocene. (19.9-19.7 Ma). In Rivas et al. (2016) study, the oil generation peak occurred in the Mid-late Miocene, which is close to our finding of a peak in the Middle Miocene. The total mass oil generated in Rivas et al. (2016) study is 367.2 million metric tons (2.7 billion barrels) which is significantly different from this result. To make the most accurate comparisons for this study, a comparison between results from this study and petroleum reports from oil and gas companies is used. Coastal Energy (2007) proves that probable oil reserves in the Songkhla Basin have 613,093 metric tons (4.5 million barrels) and recoverable oil reserves are 5.18 million metric tons (38 million barrels). The amount of oil from this study is more than proven probable oil reserves and less than recoverable oil reserves by Coastal Energy (2007).

Moreover, seismic interpretation shows that faults are cutting through productive reservoirs during the Oligocene to Miocene in the central part of the basin (Figure 2). This event occurred after the transformation ratio exceeded 50%, making it highly likely that these faults were the cause of oil leakage to the surface at the time that oil was generated, rendering the area unsuitable for exploration at present.

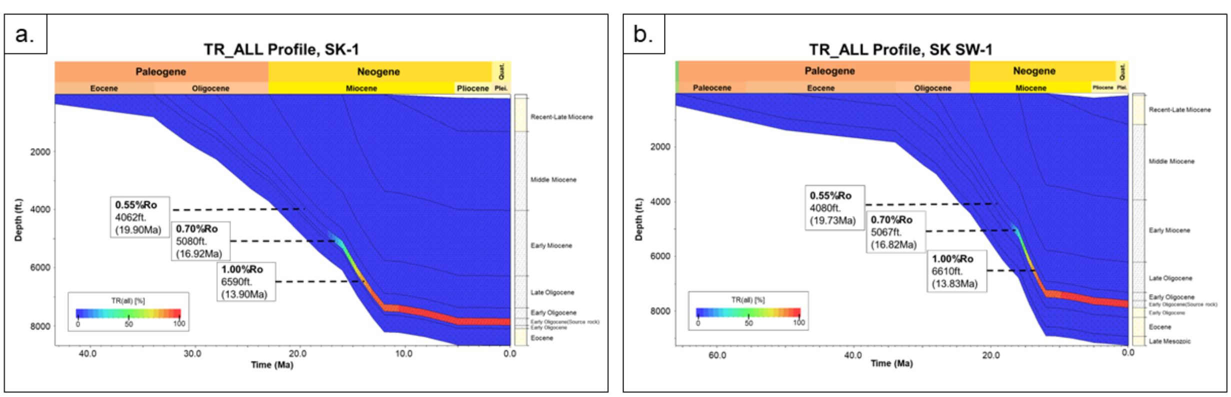


**Figure 3** (a) Transformation Ratio profile of Songkhla-1 (SK-1). (b) Transformation Ratio profile of Songkhla Southwest-1 (SK SW-1).

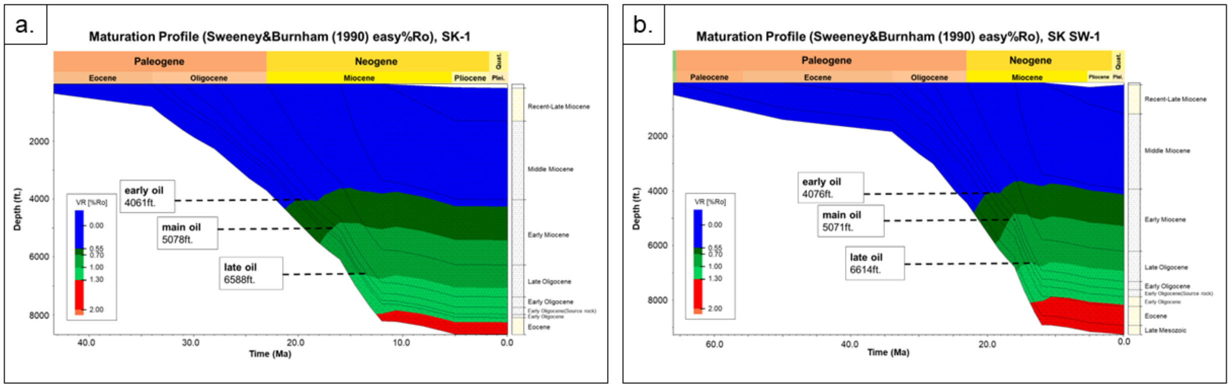


**Figure 4** (a) Maturation profile of Songkhla-1 (SK-1). (b) Maturation profile of Songkhla Southwest-1 (SK SW-1).

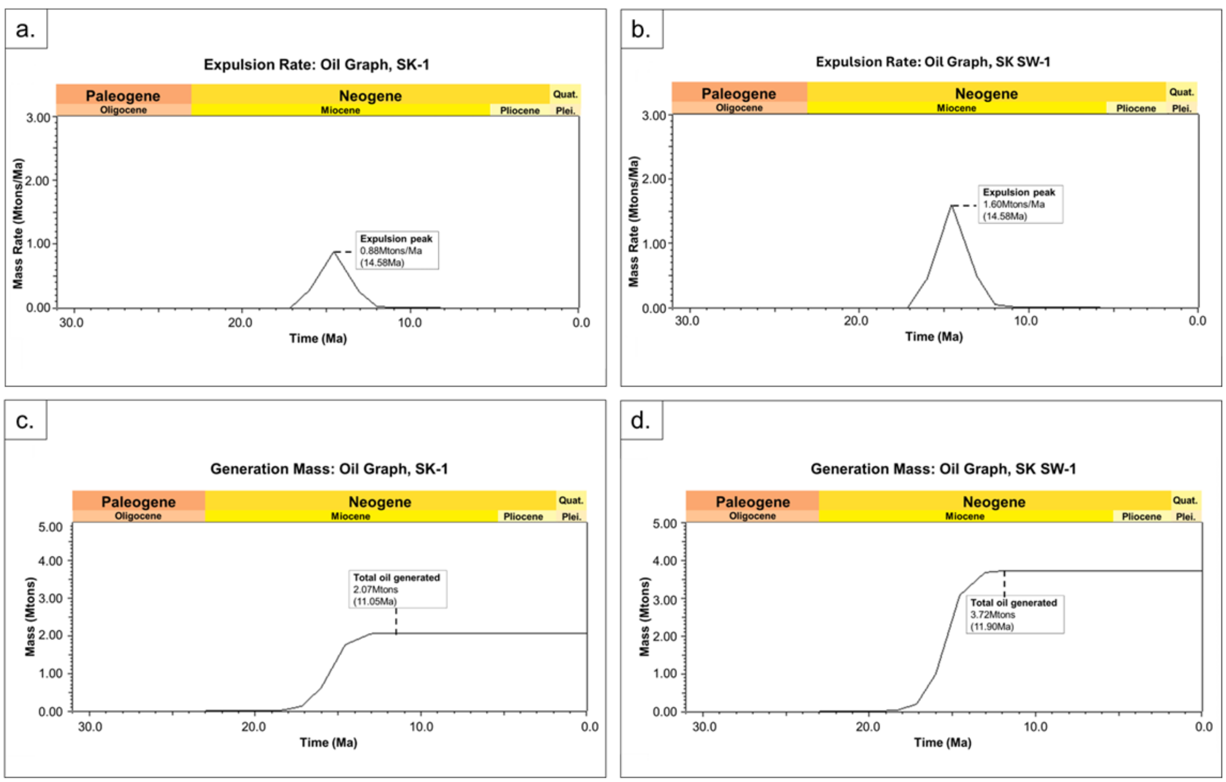


**Figure 5** (a) Expulsion Rate Oil graph of Songkhla-1 (SK-1). (b) Expulsion Rate Oil graph of Songkhla Southwest-1 (SK SW-1). (c) Generation Mass Oil graph of Songkhla-1 (SK-1). (d) Generation Mass Oil graph of Songkhla Southwest-1 (SK SW-1).

## 4. Conclusions

The study of the source rocks in the Songkhla Basin provides significant insights into the hydrocarbon maturation process. The research confirms that hydrocarbon generation began in the Early Miocene, progressed through the Middle Miocene, and continued to the present day. This process has resulted in substantial oil generation, with estimates of 15.18 million barrels in Songkhla-1 and 27.35 million barrels in Songkhla Southwest-1. However, seismic data indicate that fault activities have likely caused considerable oil leakage, particularly in the western region of the Songkhla Basin, where faulting has had the greatest impact on exploration viability. These findings underscore the importance of conducting detailed geological assessments, such as 2D modeling, to guide future hydrocarbon exploration and production strategies in the region.

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