

Basin Modelling at the Songkhla Basin (Gulf of Thailand) or: How Many Source Rocks Do I Have?*

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Abstract

The Songkhla basin is located in the western Gulf of Thailand, 15 km offshore east of the town of Songkhla. It covers an area of some 2,500km² and contains several oil producing fields. Songkhla is one of the Tertiary rift basins formed in the Gulf of Thailand between 40-20 Ma. It is an asymmetric basin controlled by NNW-SSE faults, which developed mainly in its western side, and it is filled by an assumed Eocene-Miocene continental sequence. The oil producing intervals are fluvial and alluvial sandstones of Eocene, Lower Oligocene and Lower Miocene age. Lower Oligocene lacustrine shales are the supposed source rocks of the basin. The hypothesis of an effective Miocene source is not certain at present day, and we favor the existence of a single main source rock interval at Songkhla: the Lower Oligocene organic-rich lacustrine shales. This is supported by both geochemical data and basin models. The recommendations which arose from this work were; 1) more wells in the basin should be sampled in order to complete the geochemical data set, 2) additional scenarios in basin models should be created in order to improve the understanding of source rock distribution and maturation in the Songkhla Basin, and 3) an eye must be kept for %Ro values, and alternative ways should be found to evaluate thermal maturity. The aim of this work was using the in-house data currently available to re-evaluate the presence, geochemistry and maturity of the known and potential source rock intervals of the Songkhla Basin.

Introduction

The Songkhla basin is located in the western Gulf of Thailand, 15 km offshore east of the town of Songkhla ([Figure 1](#)). It covers an area of some 2,500km² and contains several oil producing fields. Songkhla is one of the Tertiary rift basins formed in the Gulf of Thailand between 40-20 Ma. It is an asymmetric basin controlled by NNW-SSE faults, which developed mainly in its western side, and it is filled by an assumed Eocene-Miocene continental sequence ([Figure 2B](#)). The oil producing intervals are fluvial and alluvial sandstones of Eocene, Lower Oligocene and Lower Miocene age. Lower Oligocene lacustrine shales are the supposed source rocks of the basin, but the potential of the Lower Miocene is also considered in this work. The aim of this work was, using the in-house data currently available, to re-evaluate the presence, geochemistry and maturity of the known and potential source rock intervals of the Songkhla Basin.

Stratigraphy

The sequence at Songkhla is exclusively continental. This is supported by sedimentology, paleogeographic reconstructions, palynomorph analyses, and the recurrent present of ostracods, gastropods, and coal fragments. The Eocene is comprised of fluvial-alluvial tight sandstones, siltstones, red claystones and conglomerates. The Oligocene contains lacustrine dark-grey claystones, with interbedded siltstones and thin sandstone intervals that may correspond to hyperpycnal flows and fluvial episodes, respectively. Additionally, there are two distinctive lacustrine carbonatic events, which are clearly distinguishable in the seismic. The Miocene is comprised by fine to coarse sandstones, green-to-reddish claystones, with coal seams and loose sands, which are most abundant towards the top of the sequence. Depositional environments moved from fluvial with lacustrine episodes towards a lower coastal plain, as marine influence increased. Marine conditions settled after the Pliocene marine transgression, about 5 Ma (Morley and Westaway, 2006). The Eocene-Lower Miocene sequence is clearly syn-tectonic, as it significantly thickens out eastwards in the seismic, away from the main fault (Figure 2A). The rest of the Miocene sequence and recent sediments are post-rift and correspond to the sag phase, blanketing the previous sediments across the basin (Figure 2A).

Source Rock Characterization; Lower Oligocene and Lower Miocene

The Lower Oligocene shales have been assumed the main source rock in Songkhla. The Miocene, which are proved hydrocarbon sources in other basins in the Gulf of Thailand (Bishop, 2002), might have source rock potential, but its role as generating interval in Songkhla is still debated. Miocene source rocks were proposed to explain migration into certain apparently isolated reservoirs. The greenish clays and coals in the Lower Miocene have been suggested as additional source rocks sourcing the accumulations in the basin.

According to the existing data, the Lower Oligocene shales are the main source rock in Songkhla. They are dark grey to black syn-rift lacustrine shales with thin siltstone laminae (Figure 3) and pyrite microlaminations. These shales are oil-prone and have a fair-to-good quality with TOCs between 1-7%, where organic richness concentrates between 7500-9500 ft (Figure 4A), and an average HI of 400 mg HC/g TOC (Figure 4B). Organic matter is probably a mixture between lacustrine algae and terrestrial plants. These shales were deposited at the bottom of relatively deep lakes below the wave base, where autochthonous organic matter, mostly algae, precipitated and preserved under anoxic conditions. Rivers, during floods in rainy seasons (the area has remained in tropical latitudes since the Early Tertiary) likely brought to the system considerable amounts of reworked continental debris, which can be seen now as coal fragments. This mixture generated the HI/OI distribution, which can be seen in Figure 4B and 4C. Isotopic analyses and biomarkers of crude oils also suggest a lacustrine source (Figure 4D).

There are some geochemical evidences for a Lower Miocene source rock, but in general, the source potential of the Lower Miocene cannot be well characterized with the available data. The more detailed geochemical analyses penetrate only a thin section of the Lower Miocene in one of the wells, in which the organic richness reported is fair (see definition Peters et al. 1993), on average <0.5%. In addition, reddish, oxidized shales, not compatible with preserved organic matter that required forming a good source rock, can be seen in core images at Lower Miocene depths. Additionally, there are no ROCK-EVAL data for the Lower Miocene.

Petroleum Systems Modelling

1D and 3D basin models were created with the available well and seismic data in order to understand the maturation history of the potential source rock intervals at the Songkhla Basin. Paleo heat flow is generated using the McKenzie model (1978) for crustal stretching, with a rifting event extending from 40 to 14 Ma. Sediment-water interface temperatures are estimated from the paleo water depth and the latitude of the basin (Wygrala, 1989). The kinetics used to obtain source rock transformation ratios and hydrocarbon generation was Behar et al. (1997), for Type I organic matter. Temperatures from MDTs and RFTs and vitrinite reflectance values are used as calibration data.

Petroleum systems models have shown that vitrinite reflectance (%Ro) is not a good proxy for maturity in the Songkhla Basin. The basin has several oil-producing fields and therefore, regardless of how much, the source rock is mature and has generated oil. If we consider reliable the vitrinite reflectance results obtained in the geochemical evaluations performed at several wells in the basin, then we would have to calibrate the models by shifting down the heatflow more than 15-20 mW/m² (Figure 5A and 5B) as compared to a temperature-calibrated model. This would result in exceedingly cold models in which the oil window is too deep at most locations for the source rocks to generate any significant oil, and in this scenario, the models would not explain the presence of hydrocarbons in the basin (Figure 5A and 5B). Therefore, we consider %Ro as an invalid proxy for thermal maturity in the basin. Vitrinite reflectance suppression is an explanation for this (Waples, 1994), since it has been repeatedly reported in nearby basins such as Malay (Petersen et al., 2009). These type of vitrinitic material has a higher than average hydrogen content; they are per-hydrous vitrinites, and they are more resistive to heating during burial. Therefore, they reach lower reflectance values than 'normal' vitrinites would, yielding lower maturities. This can explain the existence of such low values in the Songkhla basin. Consequently, bottom-hole temperatures are preferred as calibration data for basin models, and we recommend that alternative methods of evaluating maturity should be applied at Songkhla and at other basins experiencing similar issues with %Ro. As a very broad note, %Ro suppression is a phenomenon that seems to affect vitrinitic material especially in tropical and subtropical basins. Perhaps the structure of the plants native to these areas has evolved to contain more water, being this the cause of their higher hydrogen content, and their resistance to burial heating.

According to temperature-calibrated 1D and 3D petroleum system models, the Oligocene lacustrine source rocks are mature in the centre of the basin (Figure 6A), and they entered the oil window in the Late Oligocene-Middle Miocene (Figure 6B). Even the temperature-calibrated basin models support hardly a sufficiently cooked Miocene source rock that have generated the discovered resources.

Conclusion

The hypothesis of an effective Miocene source is not certain at present day, and we favour the existence of a single main source rock interval at Songkhla: the Lower Oligocene organic-rich lacustrine shales. This is supported by both geochemical data and basin models. The recommendations which arose from this work were; 1) more wells in the basin should be sampled in order to complete the geochemical data set, 2) additional scenarios in basin models should be created in order to improve the understanding of source rock distribution and maturation in the Songkhla Basin, and 3) an eye must be kept for %Ro values, and alternative ways should be found to evaluate thermal maturity.

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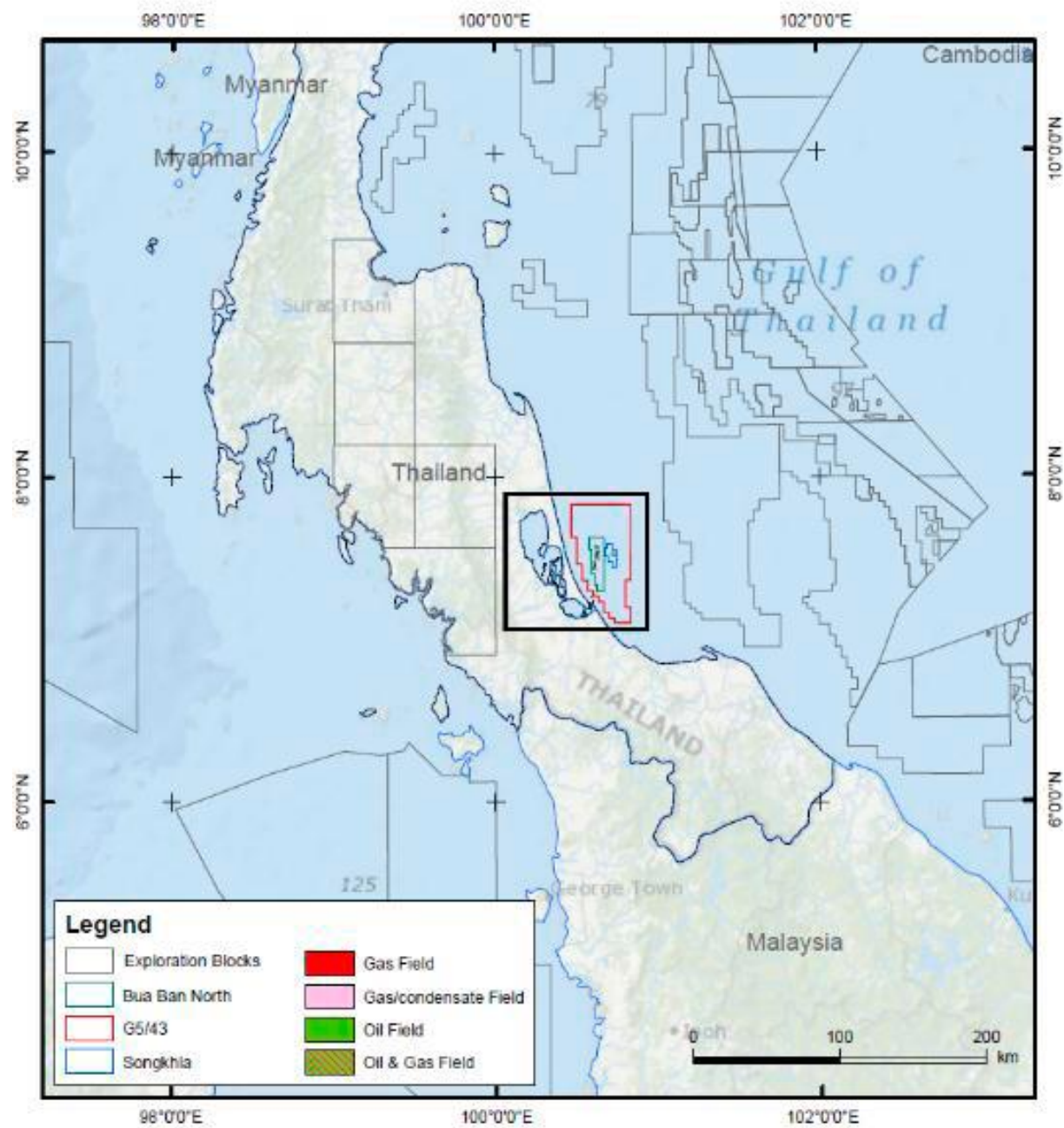


Figure 1. Location of the Songkhla basin.

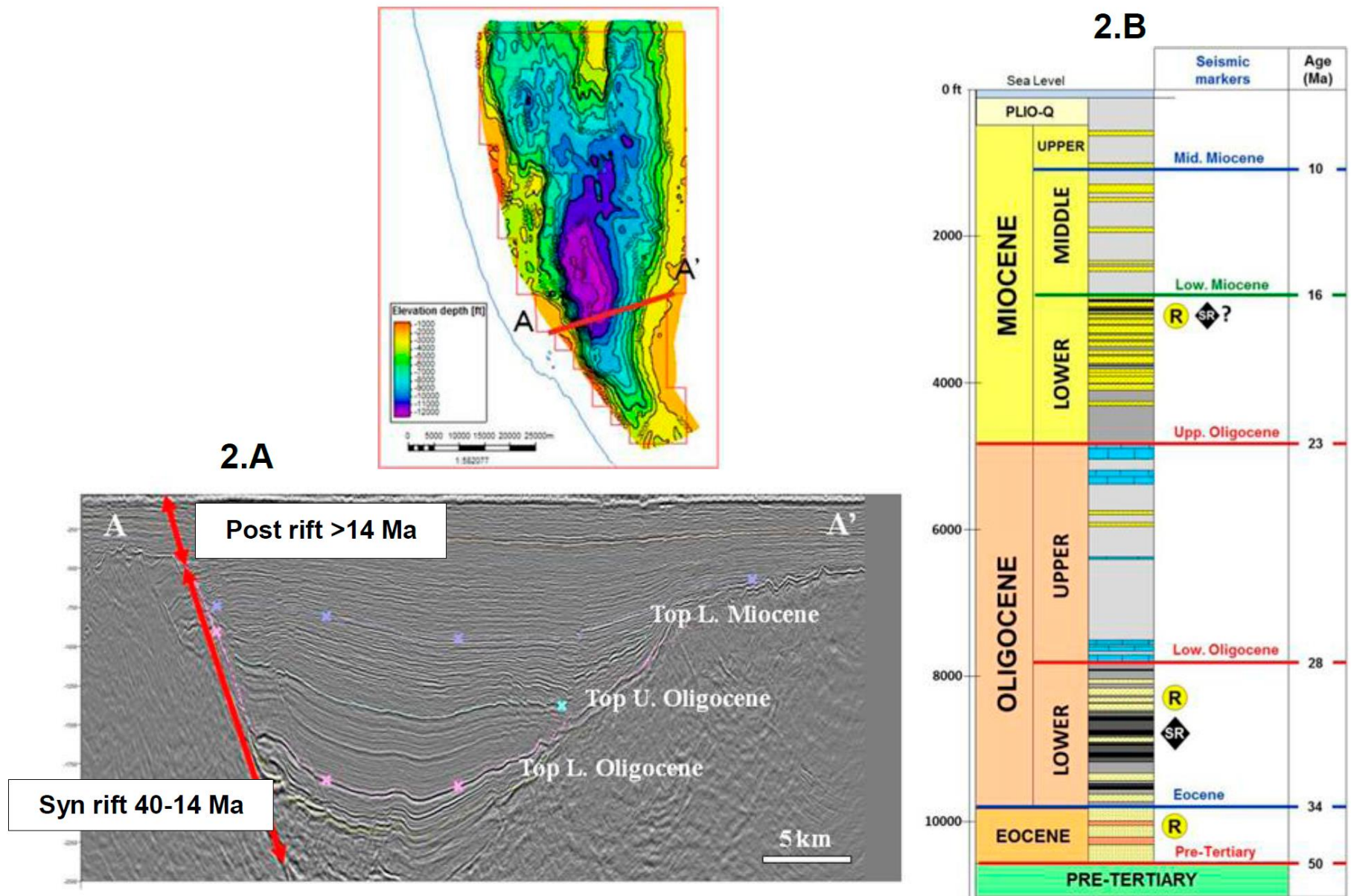


Figure 2. A) SW-NE seismic cross section across the Songkhla basin. The map above is a basement depth map showing the seismic line location. B) Songkhla basin generalised stratigraphic column.

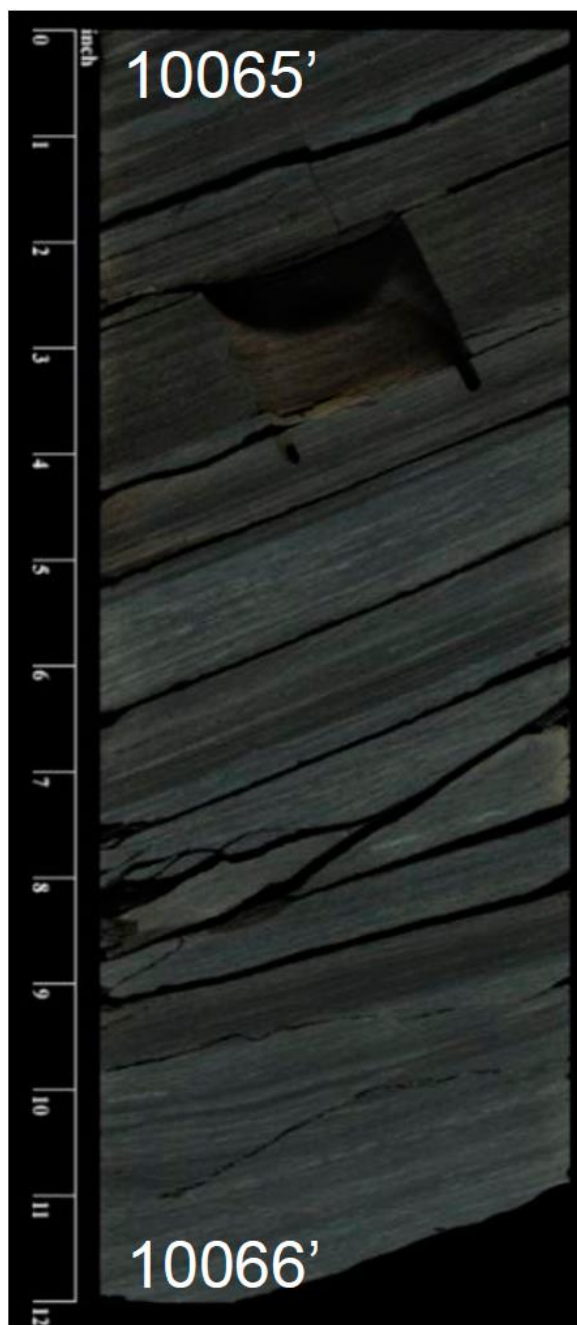


Figure 3. Laminated dark grey lacustrine shales. Lower Oligocene at a well in the Songkhla basin.

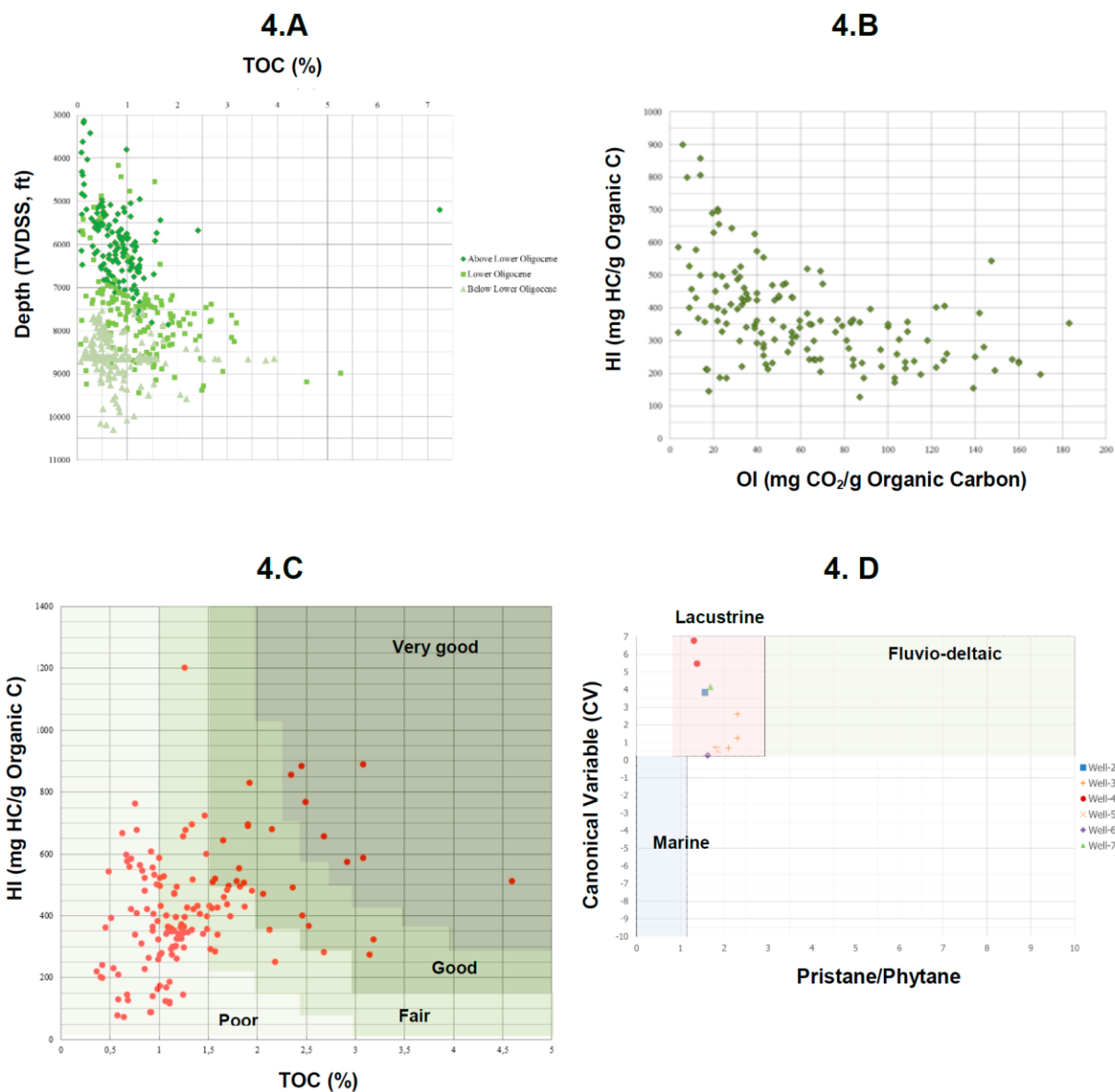


Figure 4. A) TOC distribution versus depth in nine wells of the Songkhla Basin. The sampled interval comprises Lower Miocene, Oligocene, and Eocene. B) HI/OI distribution in six wells. Data belongs only to the Oligocene and Eocene sections. C) HI vs. TOC and grades of source rock quality (after Tommeras and Mann, 2008) for Lower Oligocene samples in six wells. Data point distribution shows fair-to-good quality source rocks. D) CV (Sofer, 1984) vs. Pristane/Phytane ratios for crude oil samples in six wells, which show a clear affinity of the oils with lacustrine source rocks.

5.A

5.B

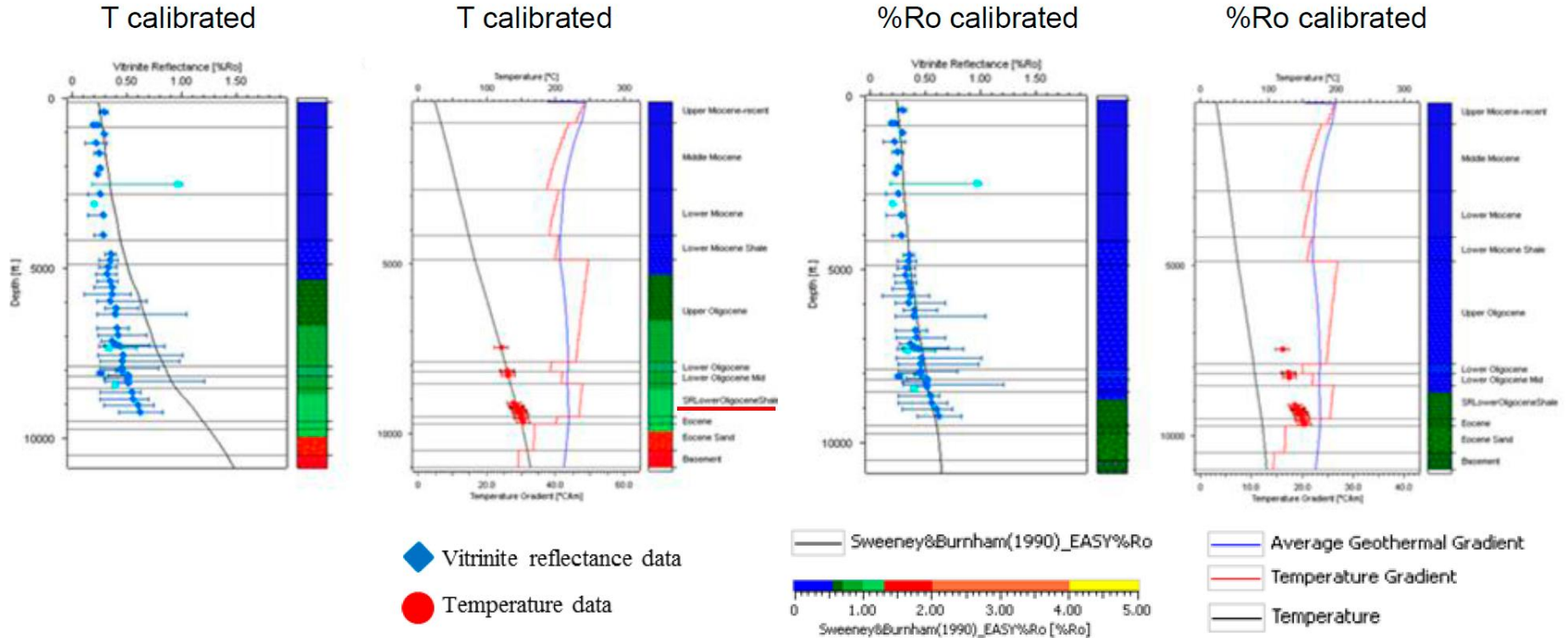
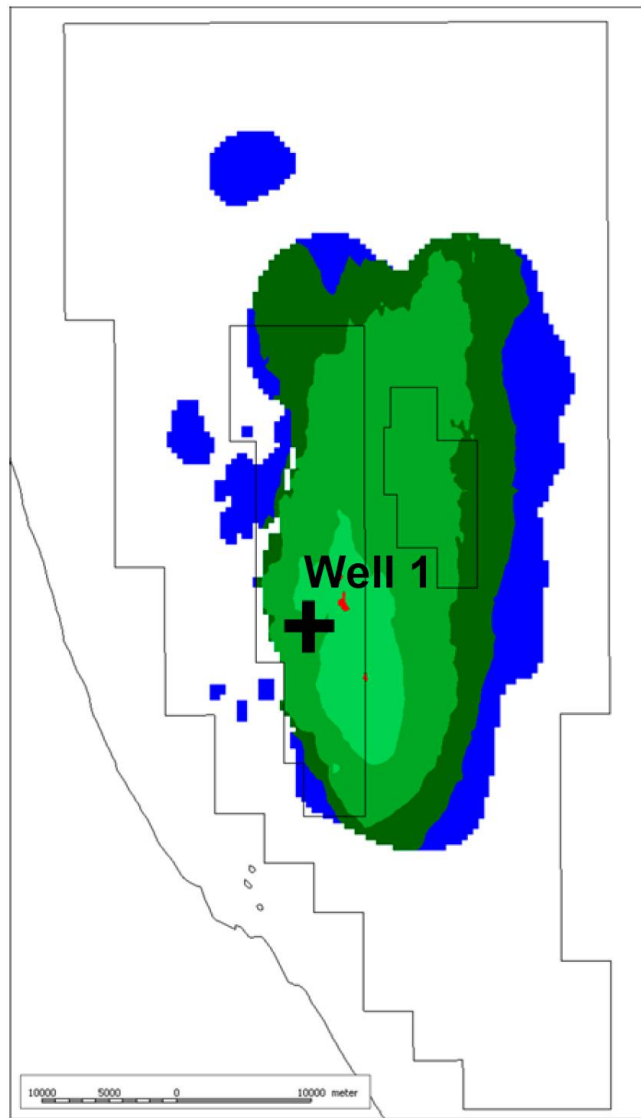


Figure 5. A) Well-11 (location in Figure 6A) Vitrite reflectance and temperature models adjusted to fit temperature data. B) Models calibrated to fit vitrite reflectance data. Note that in the first source rocks (underlined) are well in the oil window, while in the second, the oil window is deeper and source rocks barely cross it. Dots represent real data, whilst lines represent the evolution of VR, T, T gradient, and average geothermal gradient predicted by the model.

6. A



6. B

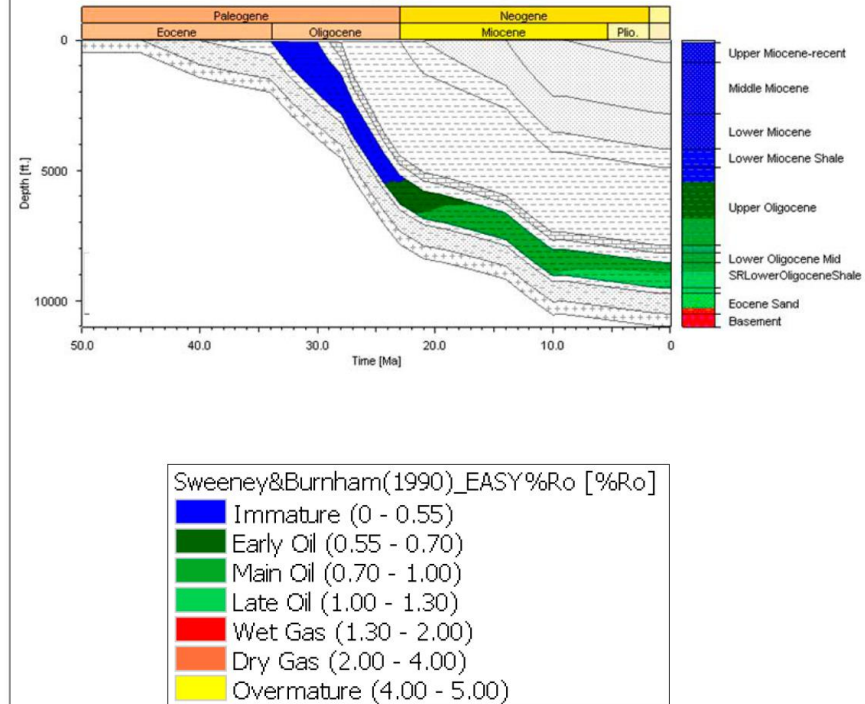


Figure 6. A) Lower Oligocene source rock present day maturity map in a temperature calibrated model. The lacustrine shales represented here are late oil-mature towards the SW of the basin, where they are now in the late oil window. The black cross indicates the Well-1 position. This well is situated close to the modelled source kitchen. B) Burial history at the Well-1 location (indicated in 6.A). Source rocks enter the oil window in the Late Oligocene, and therefore it is expected that, in areas far away from the Oligocene depocentre, the entrance in the oil window occurred much later.