

Tertiary Sarawak Basin Origin: A Small Step in Demystifying the Ambiguity*

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Abstract

The Sarawak Basin is one of the most prolific hydrocarbon bearing basins in South East Asia. However, extensive debates and hypotheses concerning its origin have perplexed the Asian scientific community for long. The quest for revealing the birth of this basin is an amalgamation of various data and studies. Subsidence history can throw light on the tectonic origin of a basin. This research work attempts to contribute a fundamental step to paving the way for solving the mysteries of the basin's origin. The objective of generating a tectonic subsidence plot from offshore well data is met by primarily calculating density, initial porosity, Athy's factor, paleo-water depth and eustatic sea level in order to perform a 1D Airy backstripping which eliminates effects of sediment compaction, water and sediment loading. Results obtained from the analysis using the above-mentioned factors, observe variations from previous works conducted on tectonic subsidence and the origin of Sarawak basin. The results from wells distributed within offshore Sarawak Basin observe tectonic activity with rapid subsidence initially and a gradual decrease in subsidence rate with time, indicative of a rift origin following the McKenzie model.

Introduction

Among hydrocarbon-bearing basins in Southeast Asia, offshore Sarawak emerges as one of the sedimentary basins with huge potential due to geologically favorable conditions. The basin hosting number of oil and gas fields lies on the southwestern part

of the South China Sea marginal basin. Although the major tectonic elements and fault zones along with the age and geometry of spreading of the South China Sea is reasonably well established (Cullen 2010; Cullen, 2014; Lee and Laver, 1995; Hall, 1996; Pubellier et al., 2005; Taylor and Hayes, 1983; Briais et al., 1993; Barckhausen and Roeser, 2004) ([Figure 1](#)), the geological and structural complexity of the basin is a topic of continuous debate among researchers. Extensive debates and hypotheses concerning its origin have perplexed the masses resulting in the onset of various evolutionary models over time.

The present day tectonic elements of southeast Asia were shaped by complex extensional and compressional interactions during the Cenozoic Era involving three tectonic plates (continental Philippine tectonic plate to the Northeast, the oceanic Indian-continental Australian tectonic plate to the South and Southwest and oceanic Pacific tectonic plate to the East) (Sandal, 1996). Sarawak basin located in NW Borneo forms the southern margin of the Oligocene-Recent South China Sea Basin unconformably overlying the Rajang Group, and the tectonic origin of this basin is still being debated. The deep-water areas of the basin have not been extensively studied after the review by Madon in 1999 (Madon, 1999). The Sarawak margin has a 300 km wide shelf and water depths ranging from 200 m to above 2000 m ([Figure 2](#)). The basin is underlain by more than 12 km of Tertiary siliciclastic and carbonate sediments (Madon et al., 2013; Doust, 1981). The Sarawak margin is divided into various tectonostratigraphic provinces. The Oligocene - Recent strata of offshore Sarawak is subdivided into eight regressive sedimentary cycles by Shell (Madon, 1999).

Geohistory analysis isolates tectonic processes contributing to basin formation. Unraveling the geological history of a basin in order to decipher the tectonic evolution can be achieved by quantitative subsidence analysis (Hinte, 1978). This research work attempts to contribute a fundamental step to paving the way for solving the mysteries of Sarawak basin's origin. The objective of generating a tectonic subsidence plot from published offshore well data (Mat-Zin, 1996) is met by primarily calculating density (ρ_c), initial porosity, depth coefficient Athy's factor (c), paleo water depth and eustatic sea level in order to perform a 1D Airy backstripping which eliminates effects of sediment compaction, water and sediment loading. Standard backstripping techniques of stratigraphic sections allows for calculation of basement subsidence rates and uplift history, incorporating an Airy model for isostasy to correct for sediment and water loading. The subsidence graph of a sedimentary basin may throw light on the origin of the basin by using trends in subsidence patterns and rate of subsidence over time. The McKenzie model (McKenzie, 1978) tabulates various types of origins of sedimentary basins based on their subsidence rates and patterns of subsidence.

Subsidence Analysis of Sarawak Basin

Quantitative subsidence analysis of Sarawak basin has been carried out on published well data (Mat-Zin) utilizing Backstrip software, version 3.5 (Cordozo, 2014). Mechanical properties such as density (ρ_c), initial porosity (Φ_0) and depth coefficient/Athy's factor (c) of the stratigraphic units were extracted using lithology mixing module of Schlumberger PetroMod version 2011.1. Total tectonic subsidence comprises of syn-rift (Cycle I), late syn-rift (Cycle II) and post-rift (Cycle III - Recent) sediments. Observations from subsidence analysis conducted on offshore wells located in the Sarawak Basin are as follows:

Well S1: This well located closest to Borneo coast in shallow depths of ~70 m ([Figure 2](#)) has all the sedimentary cycles preserved until recent sediments (Cycle I-VII). Basin initiation commenced with the deposition of syn-rift sediments during Priabonian (Eocene ~37 Ma) until Langhian (Miocene ~16 Ma). Tectonism for a time interval of 21 Ma played a vital role in basin evolution as rapid basement subsidence of ~1.742 km can be observed from the calculated tectonic subsidence plot of Well S1 ([Figure 3](#)). From the end of syn-rift deposition until recent sediments, a slow subsidence of ~0.314 km is observed. Two phases of uplift are noticed in the plot with variable rates of uplift (first phase slower than second phase). The first phase from Langhian (Miocene ~16 Ma) until Tortonian (Miocene ~11 Ma) and the second phase from Zanclean (Pliocene ~5.2 Ma) until Piacenzian (Pliocene ~3 Ma).

Well S2: This well located in shallow water of ~80 m ([Figure 2](#)) has all sedimentary cycles preserved except Cycle II. Initial rapid subsidence of ~1 km of syn-rift sediments can be observed during the first 15 Ma of basin initiation (37 Ma - 22 Ma) from the subsidence graph ([Figure 3](#)). The basin subsided at a slower rate of ~0.303 km from the end of syn-rift deposition until recent sediments. Two phases of uplift (first phase slower than second phase) are observed during the same time of uplift indicated in Well S1.

Well S3: This well located at water depths of ~200 m has all the sedimentary cycles preserved. Initial rapid subsidence of ~2.931 km of syn-rift sediments can be observed during the first 21 Ma of basin initiation (37 Ma - 16 Ma) from the subsidence graph ([Figure 3](#)). From the end of syn-rift deposition until recent sediments, a slow subsidence of ~1.38 km for a time period of 16 Ma can be seen. No uplift phases can be observed from the graph.

Well S4: This well located at water depths of ~180 m has all the sedimentary cycles preserved. Initial rapid subsidence of ~2.966 km of syn-rift sediments can be observed during the first 21 Ma of basin initiation from the subsidence graph ([Figure 3](#)).

From the end of syn-rift deposition until recent sediments, a slow subsidence of ~0.742 km for a time period of 16 Ma can be seen. One phase of uplift during the Langhian (Miocene ~16 Ma) until Tortonian (Miocene ~11 Ma) time can be observed.

Well S5: This is the deepest well used in this study, located at water depths of ~400 m has all sedimentary cycles preserved except Cycle IV. Initial rapid subsidence of ~2.123 km can be observed during the first 21 Ma of basin initiation from the subsidence graph ([Figure 3](#)). From the end of syn-rift deposition until recent sediments, a post-rift subsidence of ~2.046 km for a time period of 16 Ma can be seen. No uplift phases can be observed in this well.

Well S6: This well is located in water depth of ~120 m, has all the sedimentary cycles preserved. Initial rapid subsidence of ~1.252 km of syn-rift sediments can be observed during the first 21 Ma of basin initiation from the subsidence graph ([Figure 3](#)). From the end of syn-rift deposition until recent sediments, a slower subsidence of ~0.563 km for a time period of 16 Ma can be seen. One phase of uplift during the Zanclean (Pliocene ~5.2 Ma) until Piacenzian (Pliocene ~3 Ma) time can be observed in the graph.

Well S7: This well is located in water depth of ~130 m, has all the sedimentary cycles preserved. Initial rapid subsidence of ~2.529 km of syn-rift sediments can be observed during the first 21 Ma of basin initiation from the subsidence graph ([Figure 3](#)). From the end of syn-rift deposition until recent sediments, a slower subsidence of ~0.86 km for a time period of 16 Ma can be observed. One phase of uplift during the Zanclean (Pliocene ~5.2 Ma) until Piacenzian (Pliocene ~3 Ma) time can be observed in the graph.

Conclusions

Results obtained from the analysis, observe variations from previous works conducted on tectonic subsidence and the origin of Sarawak basin. Results from wells distributed within offshore Sarawak Basin observe tectonic activity with rapid subsidence initially and a gradual decrease in subsidence rate with time, indicative of a rift origin following the McKenzie model. Upon comparing the subsidence plots of wells studied ([Figure 3](#)), inferences can be made regarding the limit of zones having varying rates of rapid subsidence. Wells located in deep water (S3, S4 and S5) shows rapid subsidence starting from basin initiation until Pleistocene with no phases of uplift. Wells located in shallow depth (S1, S2, S6 and S7) shows rapid subsidence rate, however, lesser as compared to the wells located in the deeper region. Two phases of uplift with varying rates are observed in the shallow depth wells. Comparing uplift amplitude, according to well locations, a NS trend is noticed, from the deep-water zone indicating no uplift in the north to the shallow water zone indicating uplift towards the south. Following these observations, it may be

possible to find evidences and traces of these uplift episodes further south, onshore continental Borneo, which will hold further clues to demystify the ambiguity revolving around the origin of Sarawak Basin.

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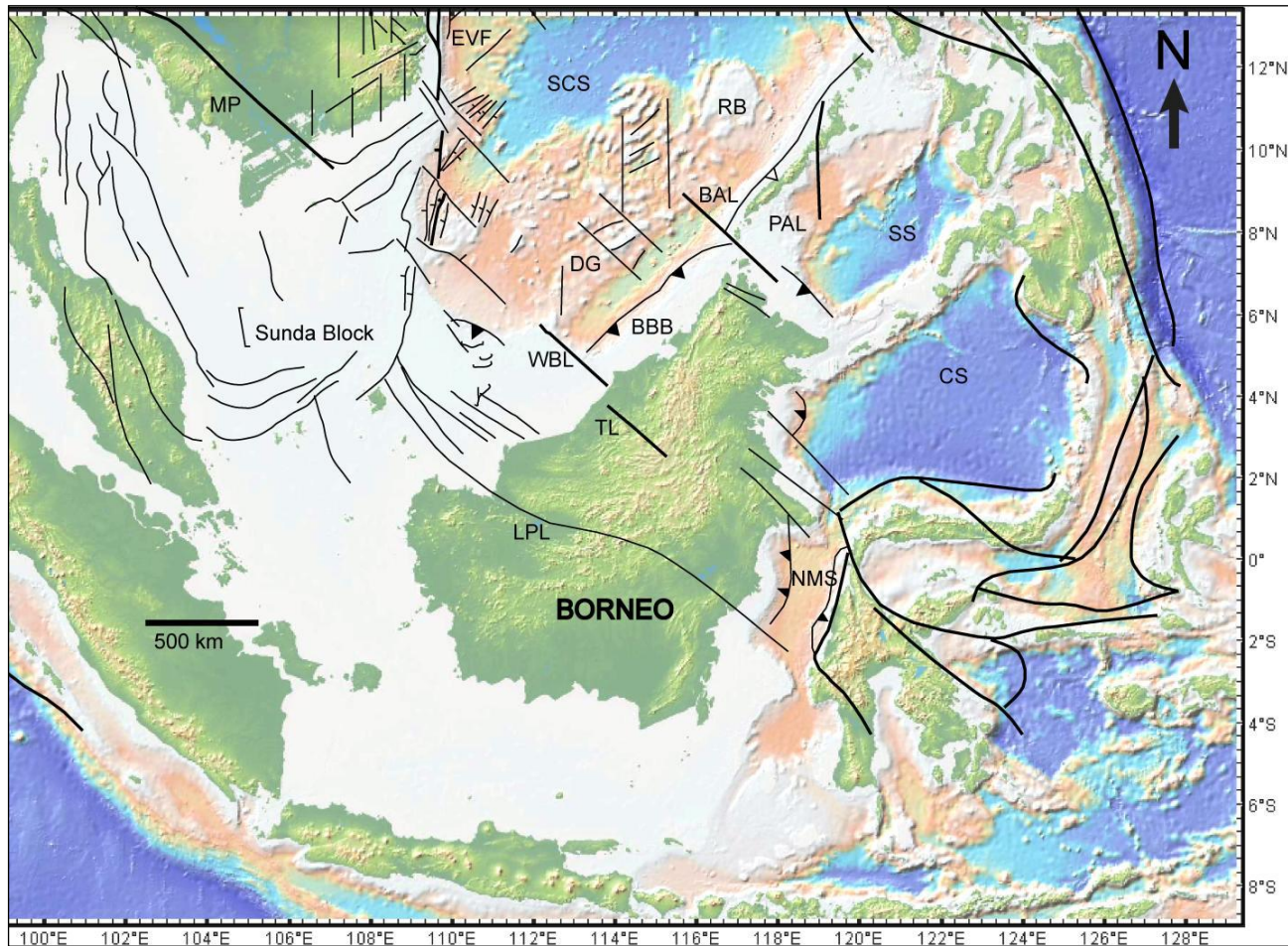


Figure 1. Regional setting map, BBB, Baram Balabac Basin; BAL, Balabac Line; CS, Celebes Sea; DG, Dangerous Grounds; EVF, East Vietnam Fault Zone; LPL, Lupar Line; MP, Mae Ping Fault zone; NMS, North Makassar Straits; PAL, Palawan; RB, Reed Bank; SCS, South China Sea; SS, Sulu Sea; TL, Tinjar Line; WBL, West Baram Line. Solid black lines show faults and fault relays (Modified after Cullen, 2010).

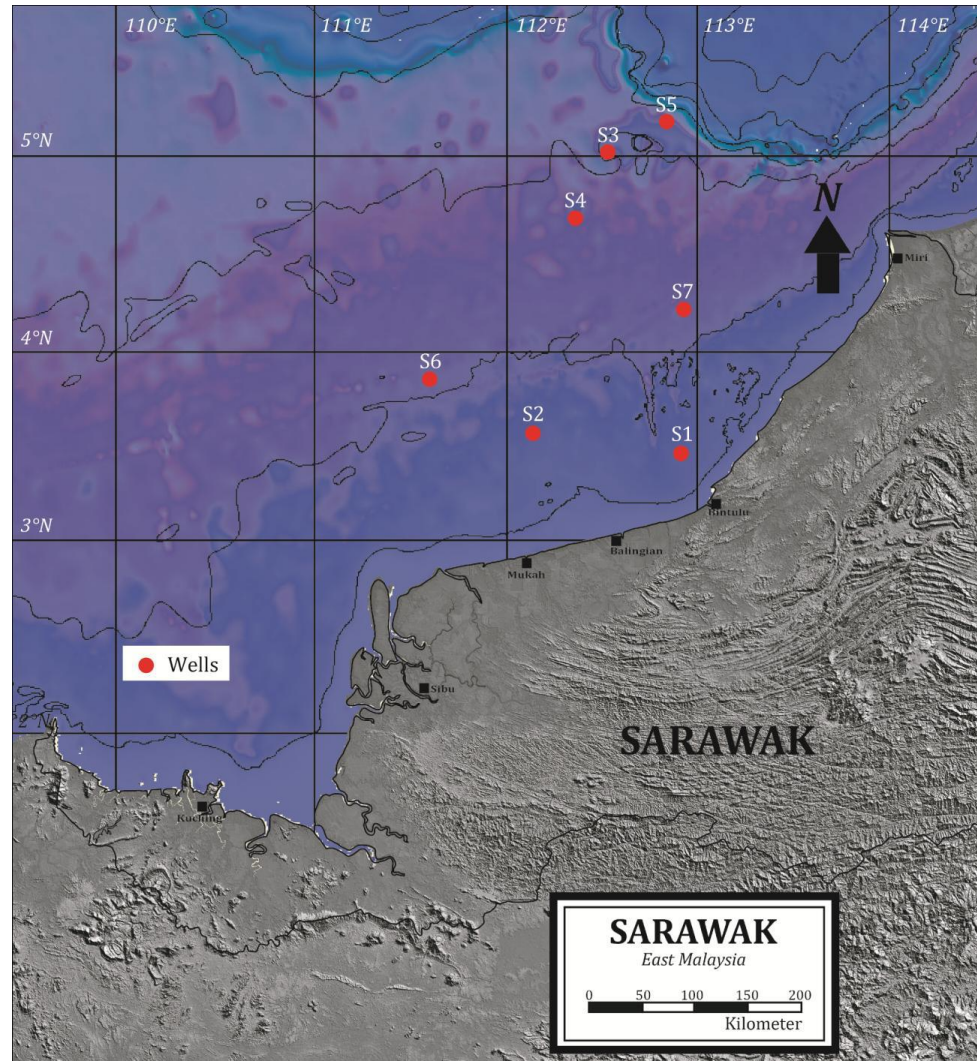


Figure 2. Map showing location of wells in offshore Sarawak and bathymetry with isobath lines ranging from 20-2,000 m depth (Modified after Mat-Zin, 1996).

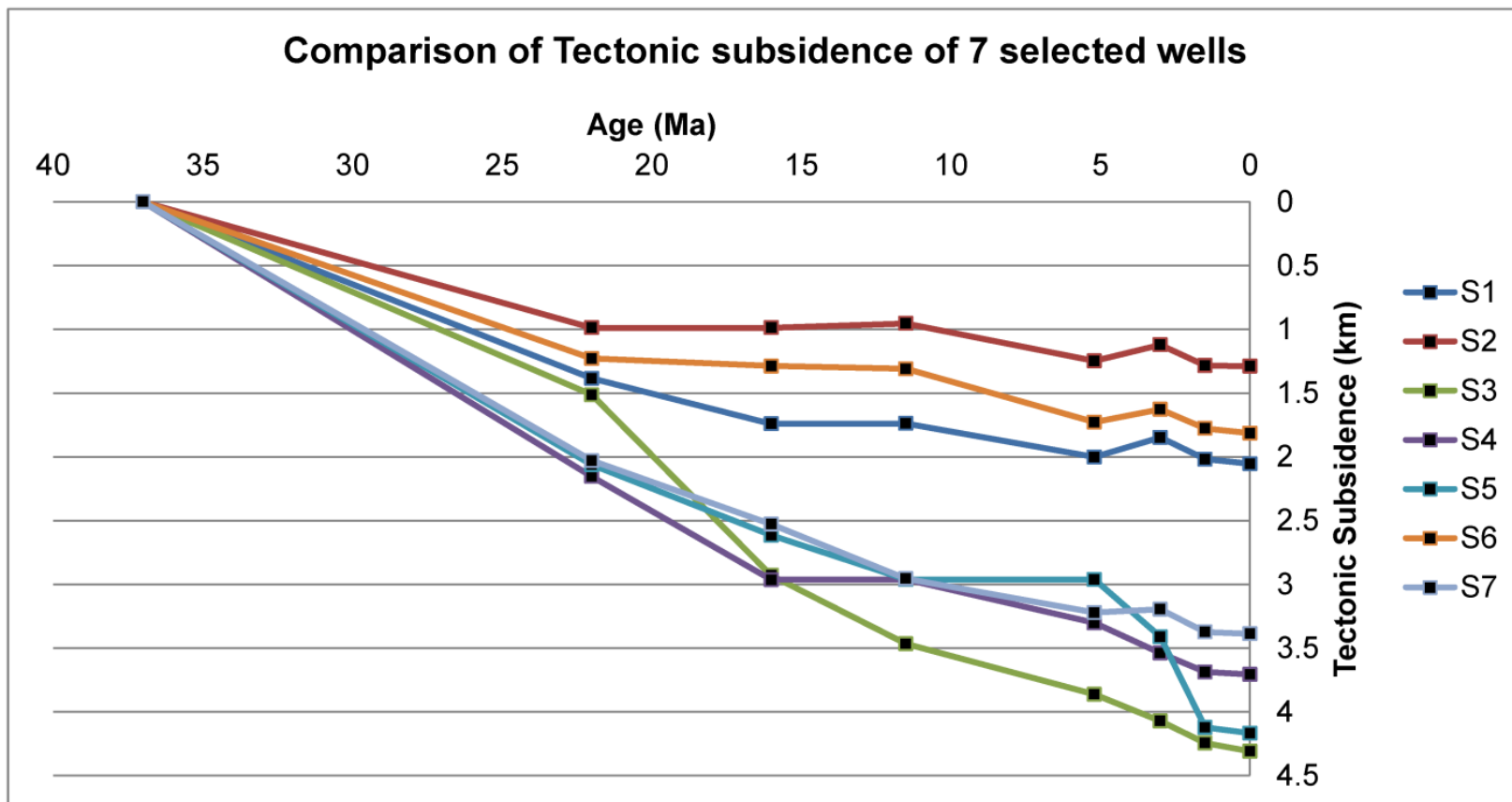


Figure 3. Comparison of tectonic subsidence plots of selected wells from offshore Sarawak used in this study.