J. SE Asian Appl. Geol., Jan–Jun 2012, Vol. 4(1), pp. 42–52

REGIONAL DEPOSITIONAL MODEL OF SOUTH MAKASSAR BASIN DEPOCENTER, MAKASSAR STRAIT, BASED ON SEISMIC FACIES

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Abstract

South Makassar Basin Depocenter (SMBD) is located in Southern Makassar Strait which has petroleum potential by the presence of oil and gas indications within the area based on Airborne Laser Fluorescence survey. However, detail studies within this area are not developed well. One of the studies which can be utilized for further discoveries of oil and gas field in SMBD is a study of depositional model using seismic facies method to maximize limited seismic and well data. Interpretation of depositional model in Eocene (syn-rift phase) was varied from alluvial plain and alluvial fan complex, continued gradually to platform. In Oligocene time (post-rift phase), massive transgression caused a major deepening in entire SMBD where the depositional environment changed to basinal plain. In early Miocene – recent interval (syn-orogenic phase), SMBD was relatively in stable condition at basinal plain environment. Lower Tanjung Sequence will be the most prolific petroleum play in SMBD due to its adequate source rock, reservoir rock and seal rock as well.

Keywords: *South Makassar basin, depositional model, seismic facies*

1 Introduction

Several hydrocarbon occurrences within and surrounding SMBD indicate potential discovery in the exploration point of view, such as seepages of hydrocarbons in the offshore Makassar Strait based Airborne Laser Fluorescence survey (MacGregor *et al*, 1991) and oil-gas seepages in onshore Sulawesi (Figure 1). Other informations surrounding study area also give potential hydrocarbon occurrences such as Makassar Straits-1 gas discovery, presence of oil in Pangkat-1X, existence of thermogenic gas in the Rubi Field and non-commercial gas discovery in Sultan-1 (Pireno and Darussalam, 2010). Hence, detailed studies of this area are required to be able to assist in finding new oil or gas fields. One of them is the study of depositional model based on seismic facies study to optimize limited 2D seismic data and exploration wells.

2 Geology and Tectonic Settings

South Makassar Basin is bounded by the Adang Fault Zone to the north and West Sulawesi Fold Belt (WSFB) to the east. Spermonde Platform limits this area to the south while Paternoster Platform becomes boundary to the west (Pireno and Darussalam, 2010).

Generally, tectonostratigraphy of study area can be associated with a typical basin in South Sulawesi which is divided into pre-rift, syn-rift, post-rift and syn-orogenic phase (Garrard *et al*, 1992). Syn-rift phase was related to extension phase, marked by the opening of the Makassar Strait (Guntoro, 1999) on around 42 million years ago or in Middle Eocene (Coffield *et al*, 1993). Middle – Late Eocene sediments

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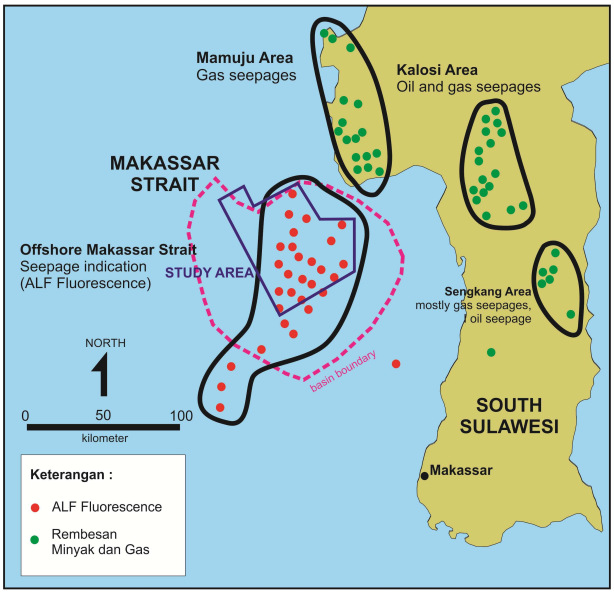

Figure 1: Location of Study area and distribution of seepage indication of ALF survey by MacGregor *et al* (1991) and onshore seepages.

filled the basin, equivalent to Toraja/Malawa Formation in several basins in South Sulawesi (Coffield *et al*, 1993). In Sebuku Basin (Offshore Kalimantan), this phase was represented by Lower Tanjung and Upper Tanjung Formation (Figure 2), commonly silisiclastic sediments which tend to be terrestrial origin and transitional environment in upper part (Pireno and Darussalam, 2010).

Post-rift phase was considered as phase of quiescence (Yulihanto, 2004), characterized by the cessation of the opening of the Makassar Strait, thermal cooling and sagging in the Early Oligocene or about 38 million years ago (Fraser *et al*, 1993). Post-rift sediments mainly consist of limestone with some sandstone, siltstone and mudstone in Oligocene – Early Miocene age. At Sengkang Sub-Basin and South Sulawesi, this sequence is represented by the Tonasa/Makale Formation (Coffield *et al*, 1993; Yulihanto, 2004; Figure 2). Berai Formation of Sebuku Basin is equivalent to Tonasa Formation which consists of coralline limestones on basement highs and on the edges of the basin (Pireno and Darussalam, 2010; Figure 2).

Syn-orogenic phase was a development of volcano-plutonic complex that occurred in the western Sulawesi (Coffield *et al*, 1993) due to collision stage in the beginning of time during Middle – Late Miocene between East Sulawesi and the Banggai-Sula microcontinent. It caused compressional phase in the Makassar Strait that formed WSFB. Syn-orogenic interval is divided into three, named Volcanic Camba Formation, Tacipi Formation and Walanae Formation. Equivalences in the Sebuku Basin are Lower Warukin, Upper Warukin and Dahor (Figure 2).

Based on well information, formation lithology as well as nomenclature in study area tends to have certain similarity with the regional stratigraphy of Sebuku Basin (Figure 2). Thus stratigraphy of Sebuku Basin will be used as reference of formation nomenclature in this study.

3 Methods

This study used 68 2D seismic data as well as three exploration wells (MAK-1, TT-1 and TT-2). Analysis of this study was carried out using SMT Kingdom 8.6 software and modules in Geological Engineering Department, Universitas Gadjah Mada. Quality of seismic data were checked and corrected such as navigation, mis-tie analysis and balance amplitude in SMT Kingdom 8.6. Next stage was Well Seismic Ties (WST) which can be performed in all wells using SynPAK. After finishing WST, each of facies markers were picked and extracted based on seismic facies method, such as reflection characteristics, internal reflection configurations, termination reflections, external shapes and geological structure analysis. In the last stage, depositional models were built on each sequence and then modeled to representative seismic cross-sections and maps using 2d/3dPAK and EarthPAK.

4 Depositional Model

Based on the seismic facies analysis, it concludes that there are several sequences in the SMBD which can be differentiated. These sequences are Lower Tanjung, Upper Tanjung, Berai, Lower Warukin and Upper Warukin. Characteristics of each sequence can be seen in Figure 3.

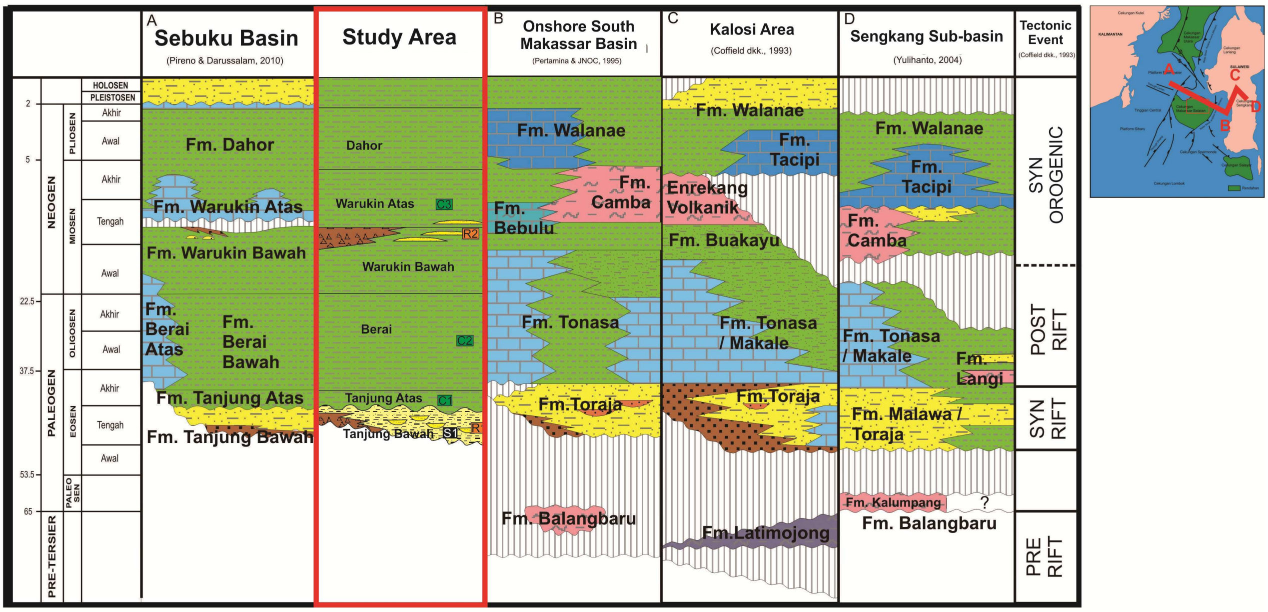

Figure 2: Stratigraphy column of South Makassar Basin Depocenter (red box) and surrounding area.

4.1 Lower Tanjung Sequence

In the pre-Middle Eocene, southern Kalimantan to Sulawesi western part was connected to each other. The process of rifting occurred during the Makassar Strait Middle Eocene, as deposition of Lower Tanjung, caused variations of non-marine and marine environment starting from fluvial, delta, shallow marine carbonate clastic to a deeper marine environment (Wilson and Moss, 1999).

Lower Tanjung shows typical of rifting sediments, which form terrestrial environment with two main facies, which are facies TB-B as alluvial plain complex (fluvial floodplains and meandering channels) on the hinge side of graben and facies TB-A as alluvial fan complex on the side of the graben fault (Figure 4).

Lacustrine deposits and coal layers are also expected to exist in the study area based on the indication of both at the bottom of the Graben Makassar (Pireno and Darussalam, 2010) adjacent to the MAK-1 wells. Rift succession continued to have transgression phase and deposition of vertical facies change towards transitional-transgressive shelf.

The pattern of alluvial fan is dependent on the relative position of major graben faults which have fairly complex direction. This phenomena is caused by existence of two main rift structures which are NE-SW of Taka Talu Fault Zone and NNW-SSE of Adang Fault Zone.

4.2 Upper Tanjung Sequence

Massive transgression in the end of rift phase (Late Eocene), probably caused by sudden subsidence, is responsible in changing the environment into marine as a deposition of Upper Tanjung. At this time, the influx of clastic material was reduced as well (Pireno and Darussalam, 2010).

The study area was dominated by facies TA-A as platform carbonates area (Figure 5). TT-1 and TT-2 bathymetry information in Lower Tanjung indicate neritic zone with calcareous shale and limestone intercalation which reflect the platform area.

Distribution of the platform facies (facies TA-A) as well as its limit were significantly influenced by rift structure, especially to the west, northwest and south of the SMBD. This evidence suggests that the rifting structure were still active at Upper Tanjung deposition.

4.3 Berai Sequence

In Oligocene time, rifting of Makassar Strait has stopped (Fraser *et al*, 1993) and has transformed

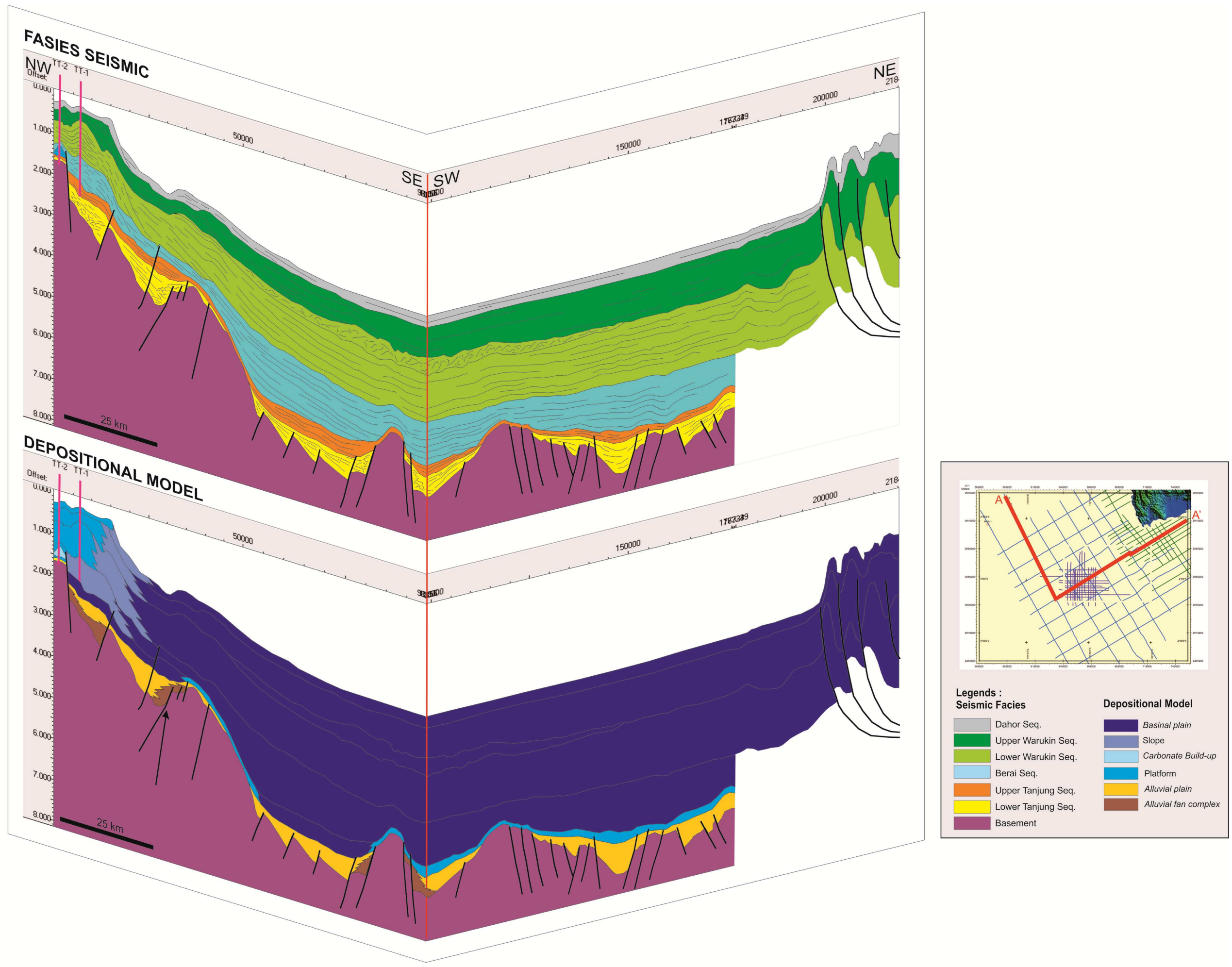

Figure 3: Composite cross-section of facies seismic (upper figure) and depositional model (lower figure).

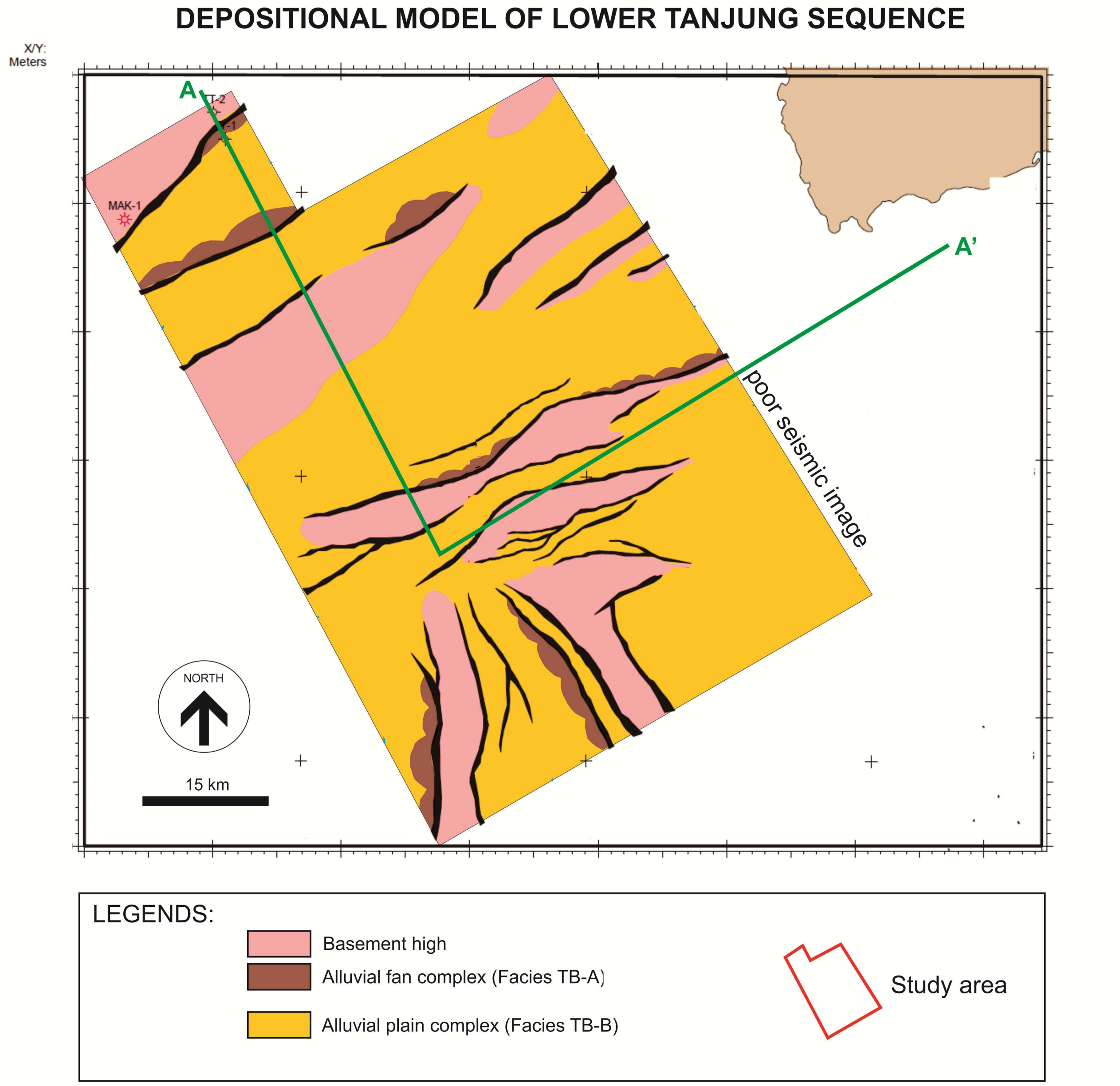

Figure 4: Depositional model of Lower Tanjung Sequence.

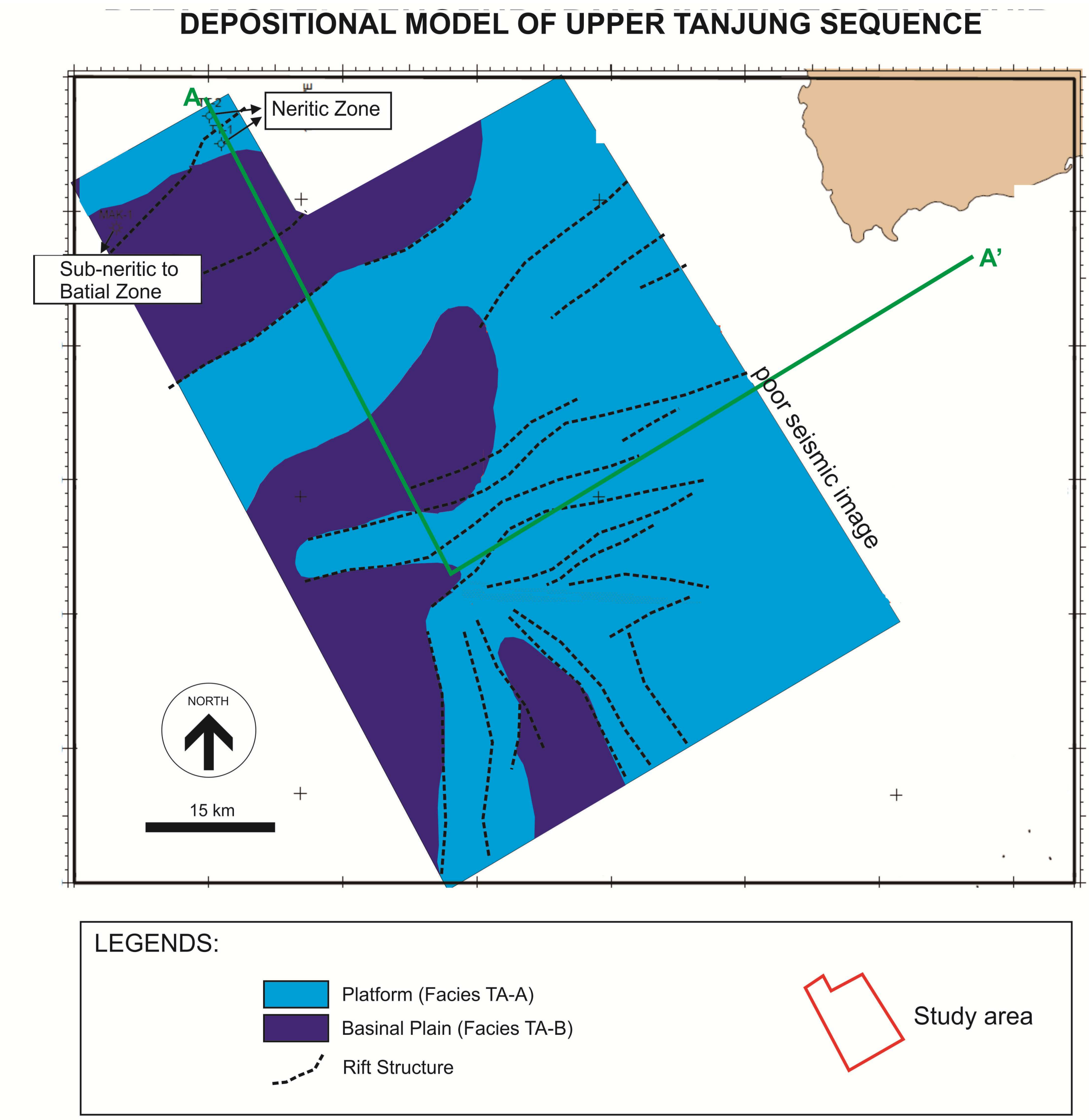

Figure 5: Depositional model of Upper Tanjung Sequence.

into a quiet phase (Yulihanto, 2004). This condition changed entire tectonostratigraphic phase of South Makassar Basin into the post-rift phase.

Transgressive phase caused deepening of this sequence, especially in SMBD. Depositional model of Berai Sequence (Figure 6) shows lateral changes (from NW to SE) in the environment from platform (facies B-A) and reef (facies B-B) to the slope (facies B-C), and basinal plain (facies B-D). Basinal plain mostly covers entire SMBD.

Intepretation of platform carbonates area is confirmed by the biostratigraphic record of TT-2 and MAK-1 which shows the development of limestone reef complex in neritic zone. TT-1 indicates limestone conglomerates of submarine slope area (sub-neritic).

4.4 Lower Warukin Sequence

Early Miocene was the beginning of syn-orogenic phase of volcano-plutonic complex occurrence in the western Sulawesi (Coffield *et al*, 1993). At this phase, Kalimantan also experienced early series of deltaic progradation (Moss and Chambers, 1999). In this interval, Lower Warukin were deposited in study area.

Depositional model of Lower Warukin Sequence at the age of Early - Middle Miocene was relatively similar to Berai Sequence, showing gradual facies changes from platform (facies WB-A) to the slope (facies WB-B) and basinal plain (facies WB-C) towards southeast (Figure 7). Basinal plain covers mostly the entire SMBD at this level.

Relative position of each facies are slightly prograde towards study area. This indicates that delta progradation of Kalimantan and the relative sea level drop affects the increasing supply of sediment to the basin. The presence of facies WB-D at the end of the Lower Warukin Sequence is interpreted as debris flow which is derived from Kalimantan (northwestern of study area) as a consequence of increasing sediment supply to the basinal area.

All well informations show that Lower Warukin Sequence consists of shale with limestone intercalation on neritic to sub-neritic bathymetry. This evidence is suitable to interpretation of platform area in those wells.

4.5 Upper Warukin Sequence

Late Miocene Upper Warukin Sequence was still part of the syn-orogenic phase (volcanism of West Sulawesi) and Kalimantan. Thus, depositional model was not significantly changed compare to Lower Warukin Sequence.

Upper Warukin Sequence indicates lateral facies changes from platform (facies WA-A) to the slope (facies WA-B) and basinal plain (facies WA-C) within SMBD or study area (Figure 8). This sequence exhibits slight progradation compared to the Lower Warukin. Three wells also indicate neritic to sub-neritic bathymetry which is correlable to the interpretation of platform in northwest of the study area.

5 Significance in Petroleum Exploration

Pireno and Darussalam (2010) informed that the Lower Tanjung is a proven source rock in MAK-1 well, consists of lacustrine shale and fluvio-deltaic shale. Indication of Lower Tanjung source rock in the SMBD can also be identified by the intepretation of alluvial plain complex environment. Development of alluvial plain complex in "sub-basins" within SMBD associated with rift structure is potential to form fluvial and lacustrine shale as prolific source rock.

Potential reservoir in SMBD is expected from Lower Tanjung Sequence as the meandering fluvial in the alluvial plain complex. This facies generally have strong amplitude, mostly local, possibly in form of isolated fluvial channel sandstones. Pireno & Darussalam (2010) also stated that the sandstones in the Lower Tanjung Sequence is potential reservoir and proven in the Barito Basin. Existence of Berai reef limestone reservoir in Paternoster (including in MAK-1) was not found within SMBD. SMBD is truly a deepest area of basin so that reef cannot have optimum growth in certain areas. Massive trangression at that time also decreased the possibilities of reef growth. Alternative reservoir inside of SMBD are basin floor fans in the Lower and Upper Warukin Sequence which

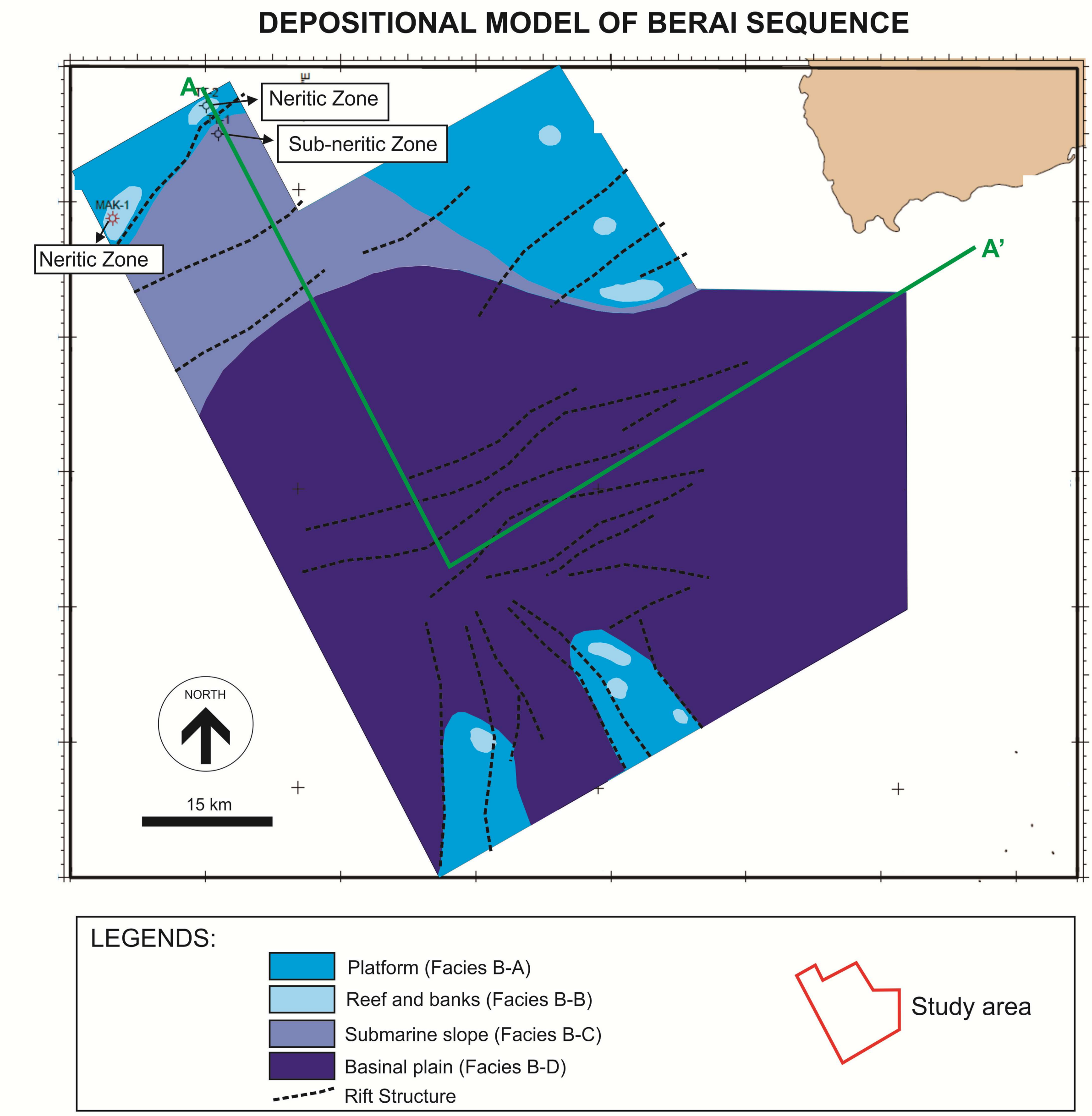

Figure 6: Depositional model of Berai Sequence.

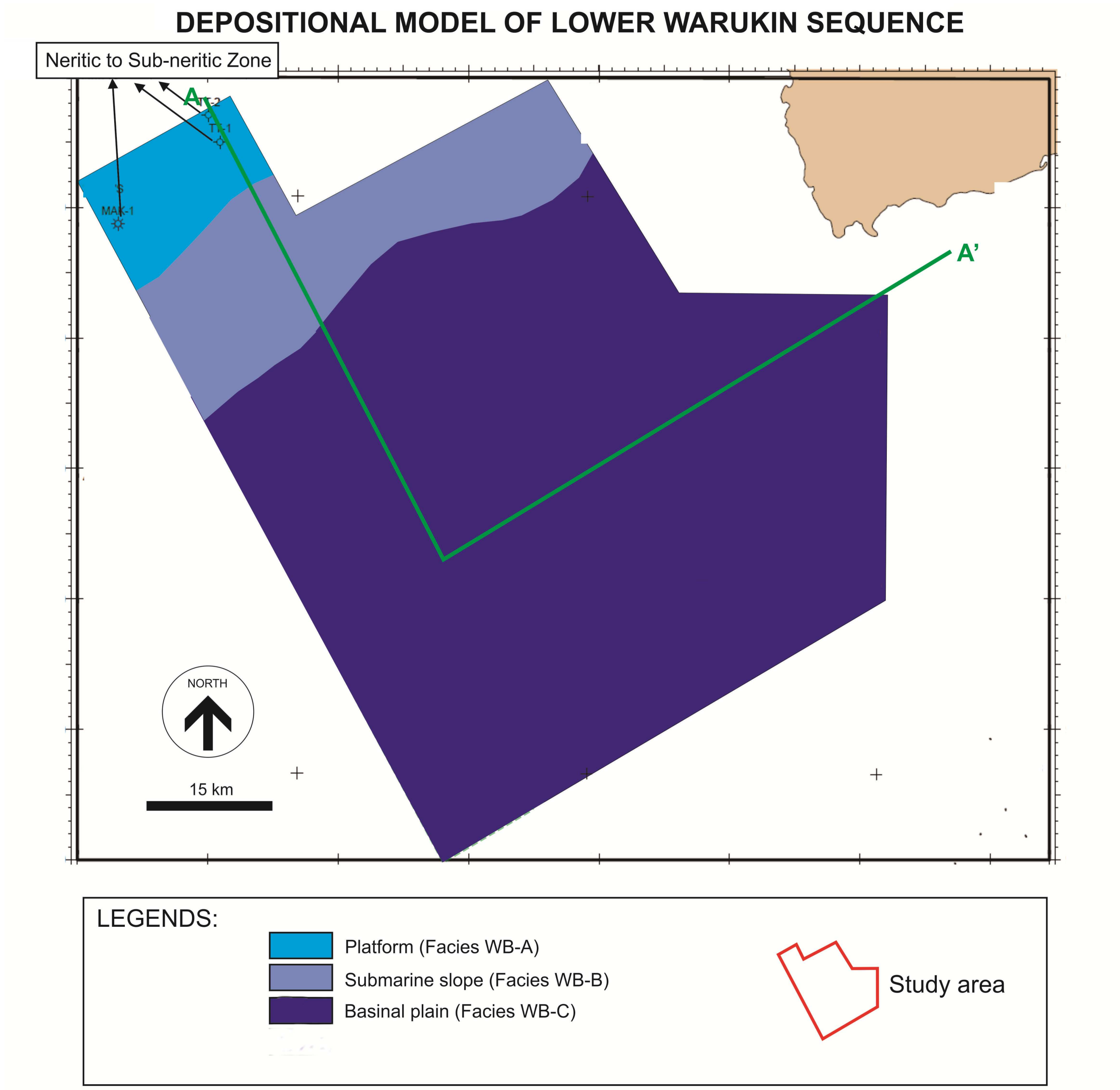

Figure 7: Depositional model of Lower Warukin Sequence.

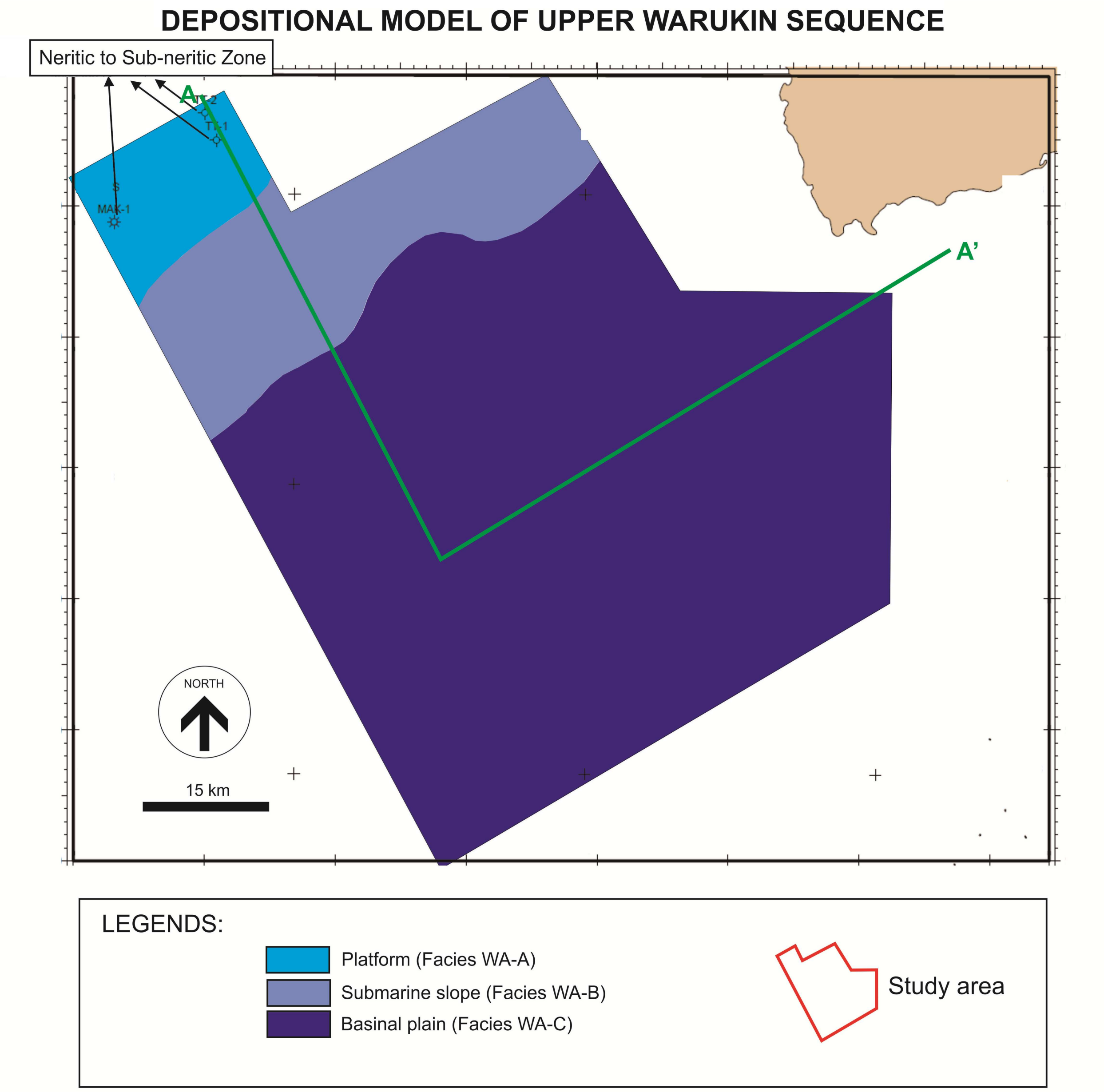

Figure 8: Depositional model of Upper Warukin Sequence.

generally exhibit mounded seismic with a high amplitude character.

Seal rocks are numerous and scattered in almost all sequences in the SMBD. Floodplain facies with low amplitude character on the Lower Tanjung Sequence can be very good for lateral seal to fluvial channel reservoir. Regional seal rocks can also be provided by basinal plain sediments of Berai, Lower and Upper Warukin Sequence which contain thick deep water hemipelagic shale. This typical shale shows seismic parallel configuration with low amplitude character.

6 Conclusion

First phase was the syn-rift that occurred in the Eocene with deposition of Lower and Upper Tanjung Sequence. The depositional model at that time was highly variable, in form of alluvial plain and alluvial fan complex, gradually changed into platform environment. The second phase was occurred in Oligocene time as a post-rift phase. This phase was the deposition of Berai Sequence. Rapid transgression occurred in this interval, forming a basinal plain environment in SMBD. In the Early Miocene time – recent, there was a regional syn-orogenic phase. However, SMBD was relatively stable and not affected so that the conditions remain in basinal plain environment.

Alluvial plain complex of Lower Tanjung Sequence is the most prolific petroleum play within SMBD. This sequence is expected to have adequate lacustrine and fluvio-deltaic source rock, fluvial channel reservoir rock and floodbasin shale as lateral and vertical seal rock. Additional play can be derived from basin floor fan reservoirs in Lower and Upper Warukin Sequence.

Acknowledgements

The authors are very grateful to Ditjen MIGAS and LKFT UGM for allowing to use seismic and well data as a Joint Study Research. Authors would also wish to thank to IHS Kingdom for SMT Kingdom 8.6 software donation for Universitas Gadjah Mada.

References

Cloke, I. R., Milsom, J., Blundell, D. J. B. (1999) Implications of gravity data from east Kalimantan and the Makassar Straits: A solution to the origin of the Makassar Straits?. Journal of Asian Earth Sciences. 17: 6–78.

Coffield, D. Q., Bergman, S. C., Garrard, R. A., Guritno, N., Robinson, N. M., Talbot, J. (1993) Tectonic and Stratigraphic Evolution of The Kalosi PSC Area and Associated Development of A Tertiary Petroleum System, South Sulawesi, Indonesia. Proceedings Indonesian Petroleum Association (IPA) 22: 679–706.

Fraser, T. H., Jackson, B. A., Barber, P. M., Baillie, P., Myers, K. (2003) The West Sulawesi Fold Belt and Other New Plays Within The North Makassar Straits - A Prospectivity Review. Proceedings Indonesian Petroleum Association (IPA) 27: IPA03-G-171.

Garrard, R. A., Nusatriyo G., and Coffield, D. Q. (1992) The Prospectivity of Early Tertiary Rift Sequences in the Neogene Foldbelts of South Sulawesi. Eastern Indonesian Exploration Symposium.

Guntoro, A. (1999) The formation of the Makassar Strait and the separation between SE Kalimantan and SW Sulawesi. Journal of Asian Earth Sciences 17: 79–98.

MacGregor, D. S., Thompson, M., Walker, N. S. (1991) Evaluation of an ALF Survey over the East Makassar Strait (unpublished).

Moss, S.J., dan Chambers, J.L.C. (1999) Depositional Modeling and Facies Architecture of Rift and Inversion Episodes in The Kutai Basin, Kalimantan, Indonesia. Proceedings Indonesian Petroleum Association (IPA) 27: IPA99-G-188.

Pireno, G. E. and Darussalam, D. N. (2010). Petroleum System Overview of The Sebuku Block and The Surrounding Area: Potential as A New Oil and Gas Province in South Makassar Basin, Makassar Straits. Proceedings Indonesian Petroleum Association (IPA) 34: IPA10-G-169.

Pertamina and JNOC (1995) Geological and Geophysical Study on South Makassar Area Eastern Indonesia (unpublished).

Wilson, M. E. J., Moss., S. J. (1999) Cenozoic Palaeogeographic Evolution of Sulawesi and Borneo, Journal of Palaeogeography, Palaeoclimatology, Palaeoecology. 145: 303–337.

Yulihanto, B. (2004) Hydrocarbon Play Analysis of The Bone Basin, South Sulawesi. Indonesian Petroleum Association (IPA) Proceedings, Deep Water and Frontier Exploration in Asia and Australasia Symposium. DFE04-OR-003.

