Strike-Slip Fault Deformation and Its Control in Hydrocarbon Trapping in Ketaling Area, Jambi Subbasin, Indonesia

Aldis Ramadhan1, Alexis Badai Samudra1, Jaenudin1, Enik Puji Lestari1, Julian Saputro1, Sugiono1, Yosi Hirosiadi1, Indi Amrullah1

1Exploration Department of Pertamina EP, 16th Floor Standard Chartered Building, Jl. Prof. Dr. Satrio No. 164 Jakarta, 12950, Indonesia

Corresponding author: aldis.ramadhan@pertamina.com

Abstract. Geologically, Ketaling area consists of a local high considered as flexure margin of Tempino-Kenali Asam Deep in west part and graben in east part also known as East Ketaling Deep. Numerous proven plays were established in Ketaling area with reservoir in early Miocene carbonate and middle Miocene sand. This area underwent several major deformations. Faults are developed widely, yet their geometrical features and mechanisms of formation remained so far indistinct, which limited exploration activities. With new three-dimensional seismic data acquired in 2014, this area evidently interpreted as having strike-slip mechanism. The objective of this study is to examine characteristic of strike slip fault and its affect to hydrocarbon trapping in Ketaling Area. Structural pattern and characteristic of strike slip fault deformation was examined with integration of normal seismic with variance seismic attribute analysis and the mapping of Synrift to Postrift horizon. Seismic flattening on 2D seismic cross section with NW-SE direction is done to see the structural pattern related to horst (paleohigh) and graben. Typical flower structure, branching strike-slip fault system and normal fault in synrift sediment clearly showed in section. An echelon pattern identified from map view as the result of strike slip mechanism. Detail structural geology analysis show the normal fault development which has main border fault in the southern of Ketaling area dipping to the Southeast-East with NE-SW lineament. These faults related to rift system in Ketaling area. NW-SE folds with reactive NE-SW fault which act as hydrocarbon trapping in the shallow zone. This polyphase tectonic formed local graben, horst and inverted structure developed a good kitchen area (graben) and traps (horst, inverted structure). Subsequently, hydrocarbon accumulation potentials such as basement fractures, inverted synrift deposit and shallow zone are very interesting to explore in this area.

1. Introduction
Ketaling area is southeastern part of Jambi Sub-basin. NW-SE seismic cross-section reveals this area geologically consist of horst and graben that formed by paleogene tectonic event. Ketaling and Merang High represent horst whilst Sungai Gelam and East Ketaling Deep depict graben (Fig.1). In general, horst and graben in Jambi Sub-basin have northeast-southwest orientation as different to north-south trend in South Sumatera Basin [1].
Figure 1. Location Map of Ketaling Area.

Commonly in Jambi Sub-basin, there is no carbonate facies sediment exists yet Ketaling area is unique due to the presence of Middle Miocene carbonate caused by decreasing sediment input southwards. In the west part, this area also experienced the uplift of the Sembilang High as a result of Plio-pleistocene compressional event. This compressional event led to hundreds to thousands feet amount of erosion during the last few millions ago. Furthermore, this tectonic event formed northwest-southeast trending folds that proved to be hydrocarbon-bearing structure (Fig.2).

Figure 2. Structural Trend of Ketaling Area.

2. Data and Method
While Global positioning System have been used in many previous studies analysis [2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13], this study utilize seismic data for further analysis. The structural characterization both geometry and style in this paper was interpreted using New 3D seismic acquired in 2014. The seismic quality is fair to good. The shallow zone shows high amplitude area with much faults shadow effect the seismic quality, whilst the deeper zone shows low amplitude area.

The Mapping of fault and Syn to Post Rift horizon was conducted to examine structural pattern and characteristic of strike slip fault in this area [14]. Moreover, variance attribute analysis was conducted for better analysis and refined interpretation. Seismic flattening with NW-SE direction is done to see the structural pattern related to horst and graben as well as knowing rifting-inversion history of Ketaling area from Early Miocene to Present time (Fig.3).
3. Result and Discussion

3.1. A subsection
Seismic interpretation from new 3D seismic (Fig. 4) reveals that the Ketaling Area shows several strike slip features. NW-SE seismic cross section indicates NE-SW main border fault with synthetic and antithetic dipping direction, branching strike slip fault system, positive structural inversion in Post Rift, and typical flower structure features. Whilst SW-NE indicates inverted Syn Rift Deposit, typical flower structure features and development of normal faults in the basement-rift sediment. Flower Structure in this area characterized by relatively planar with high fault-dip angle.

Figure 3. NW-SE Flattening through Gelam-Ketaling-Merang Area.

Figure 4. Structure interpretation and characterization in Ketaling area.
Variance seismic attribute is a tool to analyse structures such as faults or micro-faults in the 3D seismic data. This attribute indicates discontinuities in the neighbouring lithology and subsequently in the trace-to-trace variability they become detectable in 3D seismic volumes.

Variance seismic attribute in selected time slice (Fig.5) show Ketaling Area consist of two major NNE-SSW and NW-SE structural trend. NE-SW orientation was formed by transtensional system in Palaeogene yield main border fault with SE dipping. Subsequently, NW-SE structural trend as en echelon fold truncated with NE-SW fault triggered by transpersonal system in middle Miocene to Pliocene. NE-SW fault trend in shallow zone similar to fault trend which formed in Palaeogene hence it showed a reactive fault. This evidence denotes this area experienced polyphase deformation. Those fault features and pattern confirms strike slip mechanism exist in this area.

Figure 5. Time slice of variance seismic attributes in - 1550 ms (Basement), -1300 ms (TAF), and -600 ms (Intra ABF) show the changes of structural pattern from Eo-Oligocene to Pliocene time.

3.2. Hydrocarbon Trapping
Eo-Oligocene transtensional tectonic event in Ketaling Area formed graben and horst with NE-SW direction. The graben, Sungai Gelam and East Ketaling Deep, are becomes the kitchen area for Syn Rift organic-rich shale source rock. The Organic-rich sediment in kitchen area consider already mature with regional oil window maturity cut-off at 1700-1800 meter depth.

The horst, Ketaling High, is potential as hydrocarbon trapping especially in basement level. Based on seismic flattening, the Ketaling High was a paleo-high and this area also experienced polyphase deformation that allow for extensive fracture exist in basement level. Moreover, this area directly facing the East Ketaling graben hence increases the chance to be charged by kitchen. The mechanism would magnify geological change in basement level for hydrocarbon accumulation.

Inversion structure in Syn Rift deposit has potential to be home of hydrocarbon accumulation. This structure surrounded by mature source rock, due to its position in kitchen area, which directly charge to reservoir. In shallow zone, proven hydrocarbon trapping occurred mostly on the NW-SE fold follows the major structure trend (East Ketaling Field) formed by middle Miocene to Pliocene transpersonal tectonic event. In this area, the migration pathway through strike slip fault considers as effective mechanism to accumulate HC in the positive structure near the fault system. The existence of hydrocarbon accumulation (East Ketaling Field) proved that hydrocarbon has accumulated and petroleum system has been running in this area.
4. Conclusion

- Transtensional system in Ketaling area formed local graben as kitchen area, while horst developed as traps for hydrocarbon accumulation.
- Transpersonal system in middle Miocene to Pliocene yields NW-SE fold and reactivated NE-SW fault. The product of this system act as trap in sediment and potential fractured reservoir in basement.
- Integrated normal seismic and variance seismic attributes interpretation show polyphase deformation from transtensional system with NE-SW orientation to transpersonal system with NW-SE fold and reactivated NE-SW fault.
- The change of transtensional to transpersonal system adding the occasion of HC accumulation in Ketaling area.
- Strike slip fault consider as effective migration pathway to store HC in the positive structure near the fault system.
- The existence of hydrocarbon accumulation (East Ketaling Field) proved that hydrocarbon has accumulated and petroleum system has been running in this area.

References

[1] Purwaningsih, M.E.M., Mujihardi, B., Prasetya, L., Suseno, W.A., Sutadiwiria, Y., 2006. Structural Evolution of The Jambi Sub-basin : A Rotated Strike Slip Mechansism. Proceedings of International Geosciences Conference And Exhibition, Jakarta.

[2] Ito, T., Gunawan, E., Kimata, F., Tabei, T., Meilano, I., Agustan, Ohta, Y., Ismail, N., Nurdin, I. and Sugiyanto, D., 2016. Co-seismic offsets due to two earthquakes (Mw 6.1) along the Sumatran fault system derived from GNSS measurements. Earth, Planets and Space, 68(1), 1, DOI: 10.1186/s40623-016-0427-z.
[3] Anugrah, B., Meilano, I., Gunawan, E. and Efendi, J., 2015. Estimation of postseismic deformation parameters from continuous GPS data in northern Sumatra after the 2004 Sumatra-Andaman earthquake. Earthquake Science, 28(5-6), 347-352, DOI: 10.1007/s11589-015-0136-x.

[4] Alif, S. M., Meilano, I., Gunawan, E. and Efendi, J., 2016. Evidence of Postseismic Deformation Signal of the 2007 M8.5 Bengkulu Earthquake and the 2012 M8.6 Indian Ocean Earthquake in Southern Sumatra, Indonesia, Based on GPS Data. Journal of Applied Geodesy, 10(2), 103-108, DOI: 10.1515/jag-2015-0019.

[5] Ardika, M., Meilano, I. and Gunawan, E., 2015. Postseismic Deformation Parameters of the 2010 M7.8 Mentawai, Indonesia, Earthquake Inferred from Continuous GPS Observations. Asian Journal of Earth Sciences, 8, 127–133, DOI: 10.3923/ajes.2015.127.133.

[6] Ohkura, T., Tabei, T., Kimata, F., Bacolcol, T. C., Nakamura, Y., Luis, Jr., A. C., Pelicano, A., Jorgio, R., Tabigue, M., Abraham, M., Jorgio, E. and Gunawan, E., 2015. Plate Convergence and Block Motions in Mindanao Island, Philippine as Derived from Campaign GPS Observations (Special Issue on Enhancement of Earthquake and Volcano Monitoring and Effective Utilization of Disaster Mitigation Information in the Philippines). Journal of Disaster Research, 10(1), 59-66.

[7] Gunawan, E., Meilano, I., Abidin, H. Z., Hanifa, N. R. and Susilo, 2016. Investigation of the best coseismic fault model of the 2006 Java tsunami earthquake based on mechanisms of postseismic deformation. Journal of Asian Earth Sciences, 117, 64-72, DOI: 10.1016/j.jseaes.2015.12.003.

[8] Gunawan, E., Maulida, P., Meilano, I., Irsyam, M. and Efendi, J., 2016. Analysis of coseismic fault slip models of the 2012 Indian Ocean earthquake: Importance of GPS data for crustal deformation studies. Acta Geophysica, 64(6), 2136-2150, DOI: 10.1515/acgeo-2016-0106.

[9] Raharja, R., Gunawan, E., Meilano, I., Abidin, H. Z. and Efendi, J., 2016. Long aseismic slip duration of the 2006 Java tsunami earthquake based on GPS data. Earthquake Science, 29(5), 291-298, DOI: 10.1007/s11589-016-0167-y.

[10] Gunawan, E., Kholil, M. and Meilano, I., 2016. Splay-fault rupture during the 2014 Mw7.1 Molucca Sea, Indonesia, earthquake determined from GPS measurements. Physics of the Earth and Planetary Interiors, 259, 29-33, DOI: 10.1016/j.pepi.2016.08.009.

[11] Gunawan, E., Meilano, I., Hanifa, N. R. and Widiyantoro, S., 2017. Effect of coseismic and postseismic deformation on homogeneous and layered half-space and spherical analysis: Model simulation of the 2006 Java, Indonesia, tsunami earthquake. Journal of Applied Geodesy, DOI: 10.1515/jag-2017-0009.

[12] Pratama, C., Ito, T., Sasajima, R., Tabei, T., Kimata, F., Gunawan, E., Ohta, Y., Yamashina, T., Ismail, N., Nurdin, I., Sugiyanto, D., Muksin, U. and Meilano, I., 2017. Transient rheology of the oceanic asthenosphere following the 2012 Indian Ocean Earthquake inferred from geodetic data. Journal of Asian Earth Sciences, 147, 50-59, DOI: 10.1016/j.jseaes.2017.07.049.

[13] Gunawan, E., Ghosalba, F., Syauqi, Widiastomo, Y., Meilano, I., Hanifa, N. R., Daryono and Hidayat, S., 2017. Field Investigation of the November to December 2015 Earthquake Swarm in West Halmahera, Indonesia. Geotechnical and Geological Engineering, 35(1), 425-432, DOI: 10.1007/s10706-016-0117-4.

[14] Lan, X., Lu, X., Zhu, Y., Yu. H., 2015. The geometry and origin of strike-slip faults cutting the Tazhong low rise megaanticline (central uplift, Tarim Basin, China) and their control on hydrocarbon distribution in carbonate reservoirs”. Journal Of Natural Gas Science and Engineering no.22 p.633-645.