An Improved Geochemical and Biomarker Tracing to Determine a Migration Pathway and Reservoir Compartmentalization: A Case Study in Tangai-Sukananti Field, Talang Akar Formation, South Sumatera Basin, Indonesia

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ABSTRACT

A comprehensive geochemical study of oils and source rocks in Tangai-Sukananti Field was conducted in order to establish oil-oil and oil-source rock correlations. The methodology used in this study is geochemical inversion. Analyses consisted source rock evaluation, stable carbon isotope analysis and biomarker analyses in oils and source rock extracts samples. The TOC analysis of all structures show that most of the samples are fair-excellent source rocks. All samples show mixed oil and gas prone (type 2 kerogen). Maturity indicator such as Tmax (426 - 450° C) values suggest that the samples are in the early maturity stage. Biomarker analyses of oil samples revealed that only one oil group exist. The oils appear to originate from fluvial deltaic shale source rocks that deposited under oxic conditions as shown by high Pr/Ph ratios (>3), low Homohopane Index and the presence of Oleanane. Cross plot of stable carbon isotope values of saturate and aromatic fractions clearly showed oils and source rock extracts clustered in the same area which suggests mix environment between algae and terrestrial origin. Age related biomarker parameters showed these oils to be derived from a source rock younger than Cretaceous which points to the Talang Akar Formation. The results of this research show that Tangai-Sukananti Field was charged by the Talang Akar shale source rock. Maturity parameter observation by using Methylphenanthrene Index (MPI) from aromatic Methylphenanthrene (m/z 192), Phenanthrene (m/z 178) and cross plot of Ts (Ts+Tm) vs Moretane-Hopane ratio suggests southward migration of oil from progressively maturing source rock. The reservoir continuity indicated by production data and the same biomarker and carbon isotope characteristic of the oils found in the B structure. The understanding of migration pathway and reservoir compartmentalization significantly improves the new perspective of development strategy in Tangai-Sukananti Field.

INTRODUCTION

Tangai-Sukananti oilfield is located in South Sumatera Basin, approximately 80 kilometers southwest of Palembang City, Indonesia (Figure 1). The area is covered mostly by local plantation. Geologically, the oilfiled is situated in the eastern part of South Palembang Sub-Basin. Lithologically the reservoir consists of sandstones and shale with high pour point oil.

STRATIGRAPHY

Referring to regional stratigraphy in South Sumatera Basin (Ginger & Fielding, 2005), three (3) source rocks exist in this area:

1. Lemat/Lahat Formation.

The Lemat/Lahat Formation of Eocene-Oligocene age is described by Todd et al. (1997) as a lacustrine to paralic source rock. Some wells in the Bentayan field have penetrated shales with TOC values in the range 1 to 3% and are interpreted to be class C algal oil source rocks (Pepper and Corvi, 1995) deposited in a shallow lacustrine environment.

2. Talang Akar Formation

The Talang Akar Formation is believed to be the dominant source of commercial hydrocarbons in the South Sumatra Basin. Talang Akar intervals drilled at the graben margins contain only poor quality gas prone source rocks whilst both paralic shales and coal horizons have significant source rock quality in thicker sections within the Central Palembang Sub Basin, the Benakat Gully (Sarjono and Sarjito, 1989; Kamal, 1999; Argakoesoemah and Kamal, 2004).

3. Gumai Formation

Source potential is locally found in Gumai Formation marine shales, generally towards the base of the section close to the maximum flooding surface for the basin as a whole. These source rocks, although immature where penetrated, would form effective source kitchens if present in the deepest parts of the Central Palembang Depression and Lematang Deep.

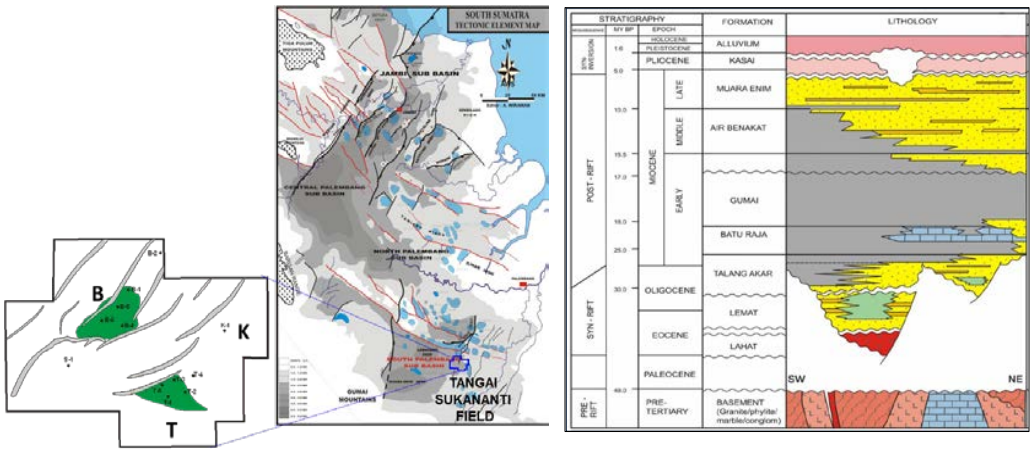

Figure 1. Location map and stratigraphic column of South Sumatera Basin (Ginger & Fielding/ 2005)

DATA AND METHODOLOGY

The data available for this study are 5 (five) wells. There are 3 (three) wells in B structure (B-1, B-3, B-5), 1 (one) in T structure (T-1) and 1 (one) in K structure (K-1) (Figure 2). Source rock extracts were taken from equivalent source rock (Talang Akar Formation) from the existing wells. This study used geochemical inversion method to determine the source from oil properties (Bissada et al., 1992). This study compares the parameters of oil with another oil & with source rock extracts. Source rock evaluation, carbon isotope analysis and biomarker analyses were perfomed as part of this study. The discussion of the aforementioned studies will be addressed sequentially as follows: (1) Source Rock Evaluation, (2) Source Rock Facies, (3) Age Related Biomarker, (4) Organic Matter Input, (5) Maturity Parameter, (6) Oil-Oil Correlation, (7) Oil-Classification, (8) Oil-Source Correlation, (9) Implication for Migration Pathway, (10) Implication for Reservoir Compartmentalization.

RESULTS & DISCUSSIONS

Source Rock Evaluation

Source rock data is available from 3 (three) different structures: B structure (B-1), T structure (T-1), K structure (K-1). The TOC analysis of all taken samples within each structures show that most of the samples are fair-excellent source rocks (Peters and Cassa, 1994). All samples appear to be mixed oil and gas prone (type 2 kerogen) (Espitalie et al. 1985). Maturity indicator such as Tmax (426 - 450° C) values suggest that the samples are in the early mature stage (Figure 2).

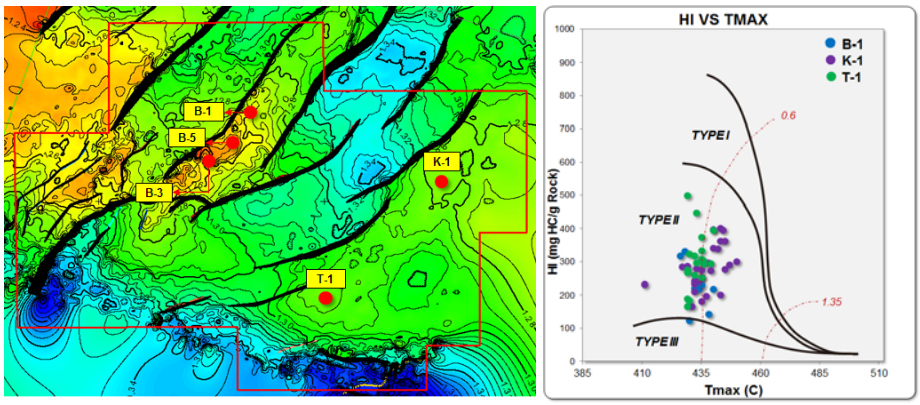

Figure 2. Source rock evaluation from 3 (three) different structures appear to be mixed oil and gas prone (type 2 kerogen)

Source Rock Facies

Coastal classification was used to find out the depositional environment in transition area (Boyd et al., 1992). Vertical succession of all wells show typical deepening upward and fining upward succesion. These data show that the sediment packages were deposited under the transgression regime. Conventional core data from B-5 well was examined to determine depositional environment from Talang Akar Formation. The core consist of fining upward sandstone, light grey, medium-coarse sand, rounded-subrounded, contain shale strict, rock fragment, carbonaceous lamination, cross bedding,

wavy lamination which indicates the process of tidal dominated (Figure 3). All parameters analyzed show that the depositional environment is Tide Dominated Estuary.

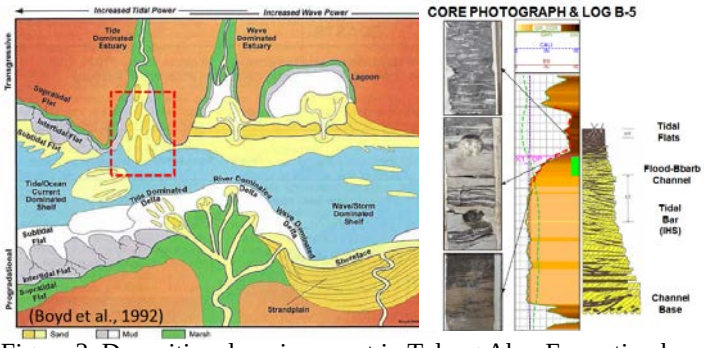

Figure 3. Depositional environment in Talang Akar Formation based on core analysis in B-5 well (Boyd et al., 1992)

Carbon isotope ratio in this study was measured for oils and source rock extracts and then plotted on a sofer diagram (Sofer 1984) as shown in Figure 4a. The data plot of saturate and aromatic fractions of the oils and source rock extracts shows similarities with average ratios of all samples are -29.0‰ and - 27.6 ‰, respectively. The carbon isotope ratio suggests all the oils and source rock extracts were derived from the same organic facies. The data is in intermediate range and falls within the same cluster. This analysis is consistent with the generation from a mixed terrestrial/algal organic facies. The result supports the interpretation of mix/transition depositional environment from conventional core data. High Pr/Ph (>3.0) indicates terrigenous organic matter input under oxic conditions (Peters and Moldowan, 1993). The Pr/Ph ratio for all samples oil and source rock extracts show a ratio greater than 3. The results of the Pr/Ph ratio plot show all the data are in the same cluster, terrigenous type 3 (peat & swamp) (Figure 4b). The Gas Chromatogram (GC) data for the oils and source rock extracts are typical of Indonesian oils sourced from fluvio-deltaic shales and coals containing mainly terrestrial input (Robinson, 1987) (Satyana 2016).

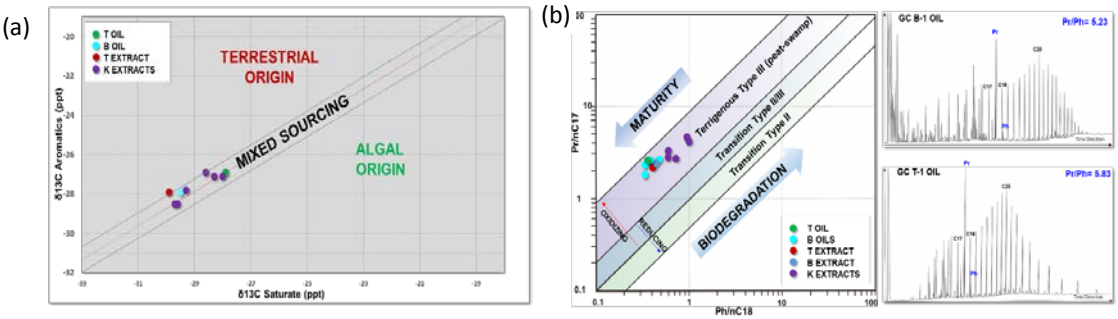

Figure 4. (a) The carbon isotope ratio suggests mixed environment between algae and terrestrial origin (sofer, 1984). (b) The Pr / Ph ratio indicates terrigenous type 3 (peat & swamp)

Distributions of C31-C35 homohopanes were used to infer redox conditions during deposition of the source rock (Peters and Moldowan, 2005). Figure 5 shows distribution of all samples with regular decrease of homohopanes from C31-C35 that associated with clastic environments (Waples &

Machihara , 1991) and more oxidizing conditions. The source rock and oil relationship was implied by similarity of homohopane distributions.

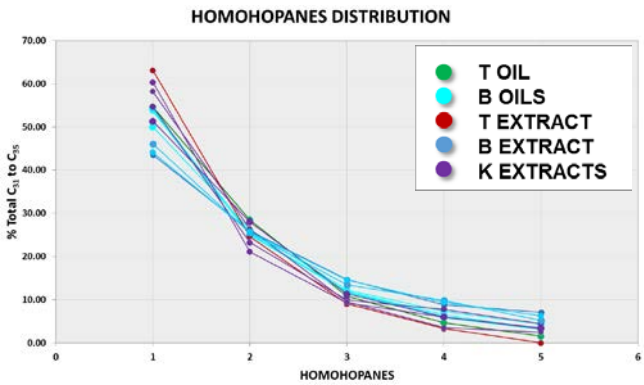

Figure 5. Distribution homohopanes with regular decrease of homohopanes from C31-C35

Age Related Biomarker

Oleanane, originated from angiosperm plant/flowering plant that grows in Late Cretaceous age is very important in correlation of oil & source rock, especially in determining whether the oil comes from younger or older source rock. Olenanae ratio higher than 20% suggest that the source rocks younger than Cretaceous (Moldowan et al. 1994). The age of the oil is determined by plotting the Oleanane index from ratio of Oleanane/(Oleanane + Hopane). Figure 6 shows the abundance of Oleonane in all oils indicating that the oils are derived from source rocks younger than the Cretaceous age.

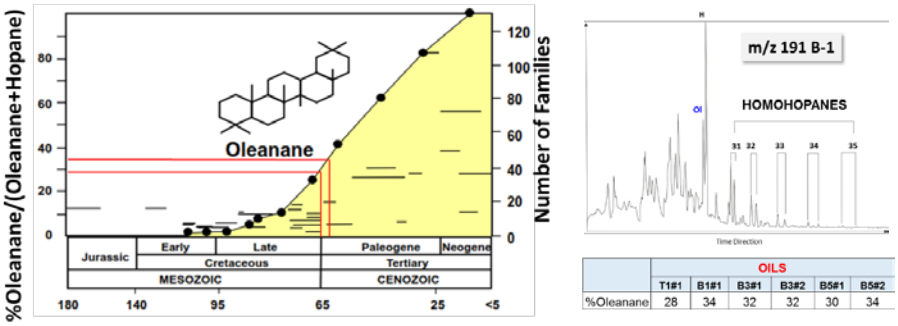

Figure 6. The method used to determine the age of the oil by using the Oleanane index obtained from the ratio of Oleanane/(Oleanane + Hopane) (Moldowan et al., 1994).

Organic Matter Input

Ternary diagram is commonly used to display basic data of Sterane distribution (Huang and Meinschein 1979). Sterane distributions display subequal proportion of C27, C28 and C29 which indicates mix organic matter input. Based on the ternary diagram, 3 (three) components of sterane distribution are slightly the same so the other biomarker parameters are used to confirm the condition of the environment & organic matter input. Oleanane was used to confirm the condition of the environment & organic matter

input. The presence of Oleanane in all oils supports mixed environments between marine and terrestrial organic matter input as shown in Figure 7.

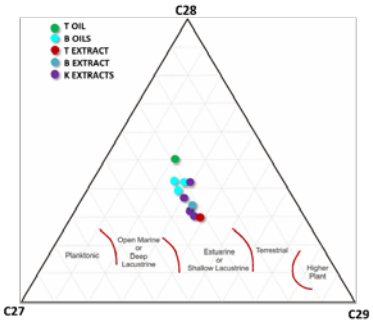

Figure 7. Ternary diagram of Sterane distribution indicates mix organic matter input. (Huang and Meinschein 1979)

Maturity Parameter

Maturity related parameters, such as Ts/(Ts+Tm), Moretane/Hopane and Aromatic Methylphenanthrene (MP) of oils and source rock extracts were applied to reveal maturity of oils in Tangai Sukananti Field. Maturity from the Methylphenanthrene Index (MPI) can be derived from calculated vitrinite reflectance (Rc). MPI is measured using Phenanthrene (m/z 178) and Methylphenanthrene (m/z 192) biomarker (Radke and Welte, 1983) (Satyana 2009).

MPI = 1.5 x (2-MP+3-MP) / P+1-MP+9-MP

Where P=Phenanthrene and MP = Methylphenanthrene.

The equation below is used to calculate vitrinite reflectance (Rc):

Rc = 0.6 MPI + 0.4 (%) (Equation for maturity window between 0.65 – 1.35%) Rc = -0.60 MPI + 2.30 (Equation For the maturity window between 1.35 – 2%)

The maturity parameter based on cross plot of Ts (Ts+Tm) vs Moretane-Hopane shows that B-3 is more mature than B-1 and B-5. The result of Methylphenanthrene Index also shows maturity increases from B-1 to B-3 consistently as shown in Figure 8.

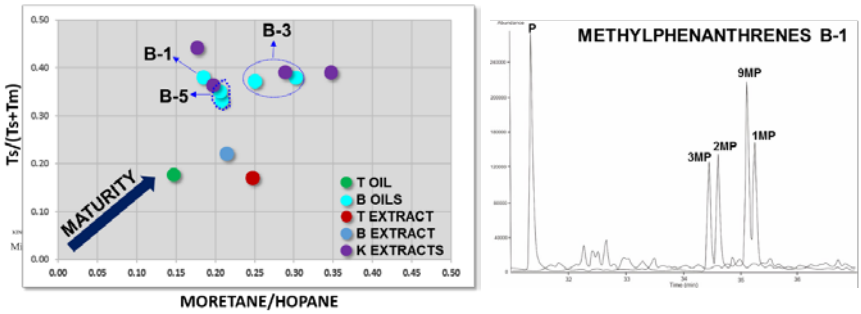

Figure 8. Maturity parameter based on plot of Ts-Tm vs Moretane-Hopane and MPI showing maturity is increasing from B-1 to B-3.

Oil-Oil Correlation

Oil-oil correlation in this study was performed by comparing molecular parameters such as GC, m/z 191, m/z 217 and carbon isotope to determine the genetic relationship. Figure 9 shows the method for correlation using pattern matching and cross plot analysis of biomarker variables. Based on GC data, oil from B and T structure comes from organic matter with the same characteristics. GC oil shows a high Pr/Ph ratio (>1) which indicates terrigenous organic matter input under oxic conditions. Data m/z 191 also shows the same pattern of extended Homohopane. From all existing oil samples in B and T structure, it can be concluded that the oils are correlatable, tertiary, fluvio deltaic and shale source rock.

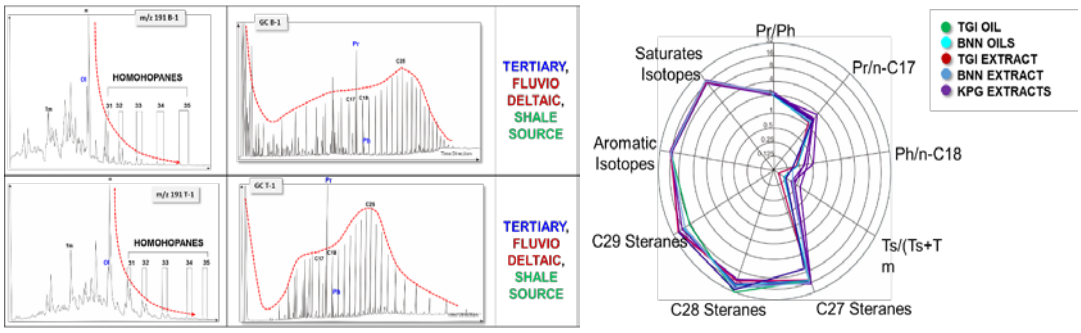

Figure 9. Oil-oil and oil-source correlation showing positive correlation

Oil-Classification

The results of the analysis of all parameters show only 1 (one) oil family exist from the oil samples taken in B & T structure. The analysed oils using Pepper and Corvi (1995) classification, show that oils derived from terrestrial Type D/E kerogens. Type D/E kerogens is characterized by terrigenous, non-marine, waxy, higher plant cuticle, resin, low sulfur, with depositional environment coastal plain in mesozoic and younger.

Oil-Source Correlation

The purpose of oil-source correlation is to find out where the oil comes from. Due to the absence of samples from source rock in the kitchen area, the biomarker extraction from the equivalent source rocks were taken from the existing well. Biomarkers provide specific and unique information, even though oil migrates over long distances, the oils showing little or no change in structure from their parent organic molecules and their original source rock (Peters and Moldowan, 1993; Hunt, 1996). In this study, oil-source correlation was performed by comparing all parameters using star diagram as shown in Figure 9. A visual comparison of biomarkers distribution shows close similarities between

the oils and source rock extracts. This indicates oil generated from the same or very similar source rocks. The relatively minor differences in biomarker between the oils and source rock extracts may reflect organic facies variation rather than generation from a distinctly different source rock unit. Variation exists in the Ts & Tm parameter due to differences in the level of maturity in all samples. In conclusion, based on correlation of oils and source rock extracts data including carbon isotope, molecular properties and depositional environment of South Sumatera Basin, it is considered that Talang Akar shales is the main source of the oils. Hydrocarbons in the B and T structure are charged from Talang Akar Formation.

Implication for Migration Pathway

Oils, if derived from a single source rock, but the result of different phases of charge representing different source rock maturity levels. The reservoir was receiving hydrocarbons from the source rock at progressively increasing maturity levels. The finding of maturity data shows that oil maturity increases from B-1 to B-3. This plot is also supported by the increasing trend of GOR data from B-1 to B-3. The blue arrow in Figure 10 shows southward migration of oil from progressively maturing source rock.

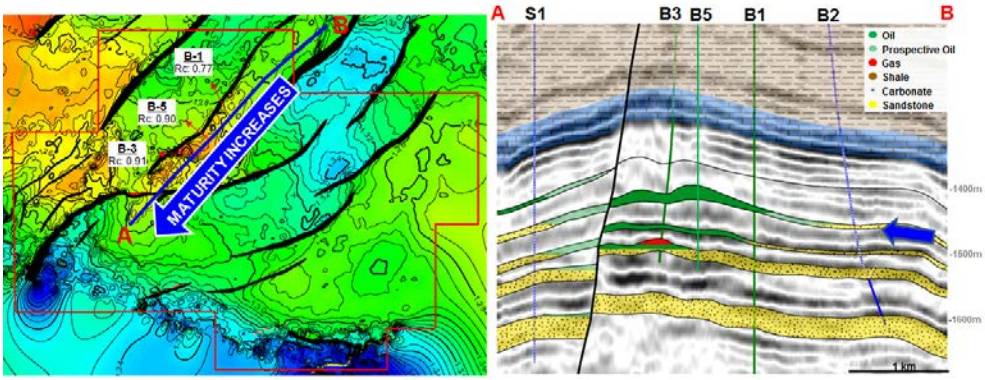

Figure 10. Southward migration of oil from progressively maturing source rock

Implication for Reservoir Compartmentalization

Star diagram shows the same oil characteristics between B-1, B-3 and B-5 well. In reservoirs without compartments/ boundaries, the filling history tends to be the same, therefore the reservoirs will have the same biomarkers and carbon isotope characteristics from oils found in 1 (one) structure. Oil migrates from north to south and charging to B-1, B-5 and B-3 through the same carrier bed. The star diagram suggests communication between B-1, B-3 and B-5 as shown in Figure 9. The result of this analysis is also supported by production data between well B-1 and B-5 when interference test was carried out. When B-1 was turned off, after several days it was observed a change in production trend from well B-5, so that it could be concluded that both wells are interconnected. This integrated method confirms no reservoir compartment in B structure.

CONCLUSIONS

- Biomarker data indicate that the B and T oils were derived from shale source rock with a mix sourcing from terrestrial and algal, mix terrigenous and marine organic matter contribution deposited in deltaic environment under oxic conditions in Tertiary age.

- The characteristics of these oils are consistent with their sourcing from the Talang Akar source rocks.
- The finding of maturity data suggests southward migration of oil from progressively maturing source rock.
- The same oil characteristics between B-1, B-3 and B-5 well suggests communication between those wells.

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REFERENCES

Argakoesoemah, R. M. I. and Kamal, A., 2004. Ancient Talang Akar Deepwater Sediments in South Sumatra Basin: A New Exploration Play: Indonesian Petroleum Association, Proceedings, Deepwater and Frontier Exploration In Asia & Australasia Symposium, p. 251-268.

Bissada, K.K., Elrod, L.W., Darnell, L.M., Szymczyk, H.M. and Trostle, J.L., 1992. Geochemical inversion – a modern approach to inferring source rock identity from characteristics of accumulated oil and gas, Proceedings Indonesian Petroleum Association (IPA), 23rd Annual Convention, p. 165-199.

Boyd, R., Dalrymple, R., Zaitlin, B.A., 1992. Classification of Clastic Coastal Depositional Environments. Sediment. Geol. 80, 139–150.

Espitalie, J., Deroo, G., and Marquis, F., 1985: Rock-Eval Pyrolysis and its Application. Inst. Fr. Petrol. Preprint, 33578: 72.

Ginger, D. and Fielding, K., 2005. The Petroleum Systems and Future Potential of the South Sumatra Basin, Proceedings Indonesian Petroleum Association Thirtieth Annual Convention & Exhibition, Jakarta, Indonesia.

Huang, W.Y. and Meinschein, W.G., 1979. Sterols as Ecological Indicators. Geochimica et Cosmochimica Acta, 43, p. 739-745.

Hunt, J.M., 1996, Petroleum Geochemistry and Geology, 2nd ed., W.H. Freeman and Company, New York.

Moldowan, J. M., Dahl, J., Huizinga, J., Fago, F. J., Hickey, L. J., Peakman, T. M., and Taylor, D. W., 1994, The Molecular Fossil Record of Oleanane and its Relation to Angiospermae: Science, v. 265, p. 768-771

Pepper A. S. and Corvi P.J., 1995. Simple Kinetic Models of Petroleum Formation Part 1: Oil and Gas Generation from Kerogen. Marine and Petroluem Geology Volume 12 No. 3, p. 291-319.

Peters, K.E., Cassa, M.R., 1994. Applied Source Rock Geochemistry. In: Magoon L.B., Dow, W.G. (Eds.), The Petroleum System—From Source to Trap. American Association of Petroleum Geologists Memoir 60, pp. 93–117.

Sarjono, S. and Sardjito, 1989. Hydrocarbon Source Rock Indentification in the South Palembang Sub Basin: Proceedings Indonesian Petroleum Association, 18th Annual Convention, p. 427-467.

Peters, K.E. and Moldowan, J.M., 1993, The Biomarker Guide: Interpreting Molecular Fossils in Petroleum and Ancient Sediments, Prentice-Hall, Inc., Englewood Cliffs.

Peters, K.E., Walters, C.C. and Moldowan, J.M., 2005, The Biomarker Guide, Second Edition, Vol. I & II, Cambridge University Press, Cambridge.

Radke, M. and Welte, D.H., 1983, The methylphenanthrene index (MPI) : A Maturity Parameter Based on Aromatic Hydrocarbons, in Bjoroy M. et al., eds, Advance in Organic Geochemistry, John Wiley and Sons, New York, p. 504-512.

Robinson, K.M., 1987, An Overview of Source Rocks and Oils in Indonesia, Proceedings Indonesian Petroleum Association, 16th Annual Convention, 97-122.

Sarjono, S. dan Sardjito. 1989. Hydrocarbon Source Rock Identification In The South Palembang Sub-Basin. Proceedings Indonesian Petroleum Association, 18th Annual Convention, October 1989.

Satyana, A.H., 2009, Emergence of New Petroleum System in the Mature Salawati Basin: keys from geochemical biomarkers, Proceedings of the Indonesian Petroleum Association, 33rd Annual Convention & Exhibition.

Satyana, A.H., 2016b, The power of oil biomarkers for regional tectonic studies: How the Molecular Fossils Imply Exploration Ventures – Cases from Indonesia, Proceedings of the Indonesian Petroleum Association, 40th Annual Convention & Exhibition.

Sofer, Z., 1984. Stable carbon isotope compositions of crude oils: application to source depositional environments and petroleum alteration. Bull. AAPG, 68, p. 31-49.

Todd, S.P., Dunn, M.E. and Barwise, A.J.G., 1997. Characterising Petroleum Charge Systems in the Tertiary of SE Asia from Fraser, A.J., Matthews, S.J. and Murphy, R.W., eds., 1997, Petroleum Geology of Southeast Asia, Geological Society Special Publication No. 126, p. 49-76.

Waples, D. W., Machihara, T. Biomarkers for Geologists: A Pratical Guide to the Application of Steranes and Triterpanes in Petroleum Geology. AAPG Methods in Exploration, 9. 1991.