Geochemical Characteristic of Crude Oils in Musi Platform, South Palembang Sub-Basin, South Sumatra Basin

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Abstrak - Platform Musi terletak di Subcekungan Palembang Selatan, Cekungan Sumatra Selatan, dibatasi oleh Palung Pigi di bagian utara, Graben Saung Naga di bagian selatan, dan Benakat Gulley di bagian timur. Pada Platform Musi terdapat beberapa lapangan minyak yang telah ditemukan, dan sebagian besar masih berproduksi hingga saat ini. Variasi jenis minyak bumi ditemukan pada sumur TG-1, TG-13, TG-10, TG-4, TG-7, TG-5, TG-2, dan TG-11. Kedekatan lokasi antar sumur tersebut mengindikasikan bahwa minyak-minyak ini kemungkinan berasal dari sumber batuan induk (source rock) yang sama. Analisis minyak bumi dilakukan melalui analisis geokimiawi, yang meliputi kromatografi cair, kromatografi gas, serta kromatografi gas–spektrometri massa (GC–MS). Analisis dilakukan terhadap 21 sampel untuk isotop karbon dan 23 sampel untuk biomarker. Korelasi antar minyak bumi dilakukan dengan menginterpretasikan data isotop karbon dan biomarker tersebut. Berdasarkan hasil analisis geokimia terhadap sampel minyak mentah, menggunakan metode analisis isotop karbon, minyak pada daerah penelitian dapat diklasifikasikan ke dalam dua kelompok utama, yaitu light saturates dan heavy saturates. Minyak dengan tipe light saturates hanya ditemukan pada sumur TG-9, TG-8, TG-7, TG-10, dan TG-13, sedangkan sumur lainnya mengandung heavy saturates. Selanjutnya, hasil penelitian menunjukkan bahwa terdapat tiga famili minyak bumi pada daerah studi, yaitu famili lacustrine, lacustrine–estuarine, dan shallow marine. Famili minyak lacustrine dicirikan oleh rasio C26/C25 (trisiklik terpan) lebih dari 1, rasio C31/C30 hopane kurang dari 0,25, nilai isotop karbon δ13C saturate antara -18,70 hingga -22,08, konsentrasi C28 sterana tinggi, serta konsentrasi diasterana rendah. Famili minyak lacustrine–estuarine memiliki rasio C26/C25 (trisiklik terpan) lebih dari 1, rasio C31/C30 hopane kurang dari 0,25, nilai isotop karbon δ13C saturate antara -24,24 hingga -29,1, konsentrasi C29 sterana tinggi, dan konsentrasi diasterana rendah. Famili minyak laut dangkal (shallow marine) ditandai oleh rasio C26/C25 (trisiklik terpan) kurang dari 1, rasio C31/C30 hopane lebih dari 0,25, nilai isotop karbon δ13C saturate antara -18,8 hingga -23,7, serta konsentrasi C27 sterana dan diasterana tinggi.

Kata kunci: Biomarker, Famili minyak, Lacustrine, Lakustrin–estuarin, Laut dangkal.

Abstract *- Musi Platform located in South Palembang Subbasin, South Sumatra Basin, bounded by Pigi Trough at the north, Saung Naga Graben at the south, and Benakat Gulley at the east. In Musi Platform, there are several oil fields that have been discovered and most of them remain produce oil to this day. Oil type variation discovered in the TG-1 – TG-13 – TG-10 – TG-4 - TG-7 - TG-5 – TG-2 – TG-11 wells. Location of their wells close to each other leads to assumption that they come from same kitchen. Oil analyses were conducted by geochemical analysis including liquid chromatography, gas chromatography, and gas chromatography-mass spectrometry analysis. Oil analysis included 21 samples for carbon isotope and 23 samples for biomarkers. Correlation of crude oil to crude oil, was done by interpreting carbon isotope and biomarkers data. Based on geochemical analysis of crude oil samples, using carbon isotope analysis, oils at research area could be divided into two groups: light saturates and heavy saturates. The light saturates were only found in TG-9, TG-8, TG-7, TG-10, and TG-13 wells, while another well contained heavy saturates. Furthermore, it can be concluded that there are three (3) oil families in the study area, i.e. lacustrine, lacustrine-estuarine, and shallow marine oil families. Lacustrine oil family show* C_{26}/C_{25} *(tricyclic terpane) ratio is more than 1, ratio of* C_{31}/C_{30} *hopane is smaller than 0.25, carbon isotope* $\delta^{13}C$ *saturates value is -18.70 to -22.08, high* C_{28} *sterane concentration, low diasterane concentration. Lacustrine-estuarine oil family show ratio of* C_{26}/C_{25} *(tricyclic terpane) is more than 1, ratio of* C_{31}/C_{30} *hopane is smaller than 0.25, value of carbon isotope* $\delta^{13}C$ *saturates -24.24 to -29.1, high* C_{29} *sterane concentration, low diasterane concentration. Shallow marine oil family show ratio of* C_{26}/C_{25} *(tricyclic terpane) is less than 1,* C_{31}/C_{30} *hopane ratio is greater than 0.25, carbon isotope* ^{13}C *saturates value is -18.8 to -23.7, high* C_{27} *sterane and diasterane concentration.*

Keywords: *Biomarker, Oil family, Lacustrine, Lacustrine – estuarine, Shallow marine.*

INTRODUCTION

Musi Platform located in South Palembang Subbasin, South Sumatra Basin, bounded by Pigi Trough at the north, Saung Naga Graben at the south, and Benakat Gulley at the east. Musi Platform is a structural element in the South Sumatra Basin, which makes it an important targets for future exploration activities. In the South Sumatra Basin, oil and gas are produced from several reservoirs such as the Talangakar Sands, Baturaja Limestone, and Palembang Sands, as well as fractures in the Pre-Tertiary Basement. Hydrocarbon source rocks are believed to be Paleogene lacustrine shales of the Lahat/Lemat Formation and fluvio-deltaic to marginal marine Talangakar Shales and Coals (Rashid et al., 1998; Ryacudu 2008).

Various geochemical methods have been applied to analysis oils and provide information about sources and geological conditions including stable isotopes, gas chromatography, and gas chromatography-mass spectrometry (Robinson, 1987; Suseno et al., 1992; ten Haven and Schiefelbein, 1995; Rashid et al., 1998; Bishop, 2001; Peters et al., 2005; Syaifudin et al., 2015; Syaifudin, 2016; Sabra 2021; Sutadiwiria et al., 2022; and Syaifudin and Subroto, 2024). In addition, literature contains various interpretations of how isotopic compositions of oils can be related to organic matter and depositional environments of their source rocks.

The carbon isotopic composition of the oil typically depends on the $d^{13}C$ value of the kerogen in the source rock from which it generated. The $d^{13}C$ value of kerogen depends on the type of organisms being preserved and on the condition of depositional environmental (Zhang and Huang, 2005). As a result, $\partial^{13}C$ values of oils are useful for determining oil–oil and oil– source rock correlations and in conjunction with other geochemical properties, it can show the possible age and depositional environment of source rocks (Zhang and Huang, 2005; Peters et al., 2005). Oils having a disparity larger than 3‰ generally do not have a genetic relationship (Peters et al., 2005; Cheng et al., 2013).

In Musi Platform, there are several oil fields have been discovered and most of them remain produced oil to this day. Oil type variation discovered in the TG-1 – TG-13 – TG-10 – TG-4 - TG-7 - TG-5 – TG-2 – TG-11 wells. Location of their wells close to each other leads to assumption that they come from same kitchen but this assumption is not reflected from their carbon isotope values. Based on the geochemical analysis of oils, it is found that carbon isotope of the oils above could also be divided into two groups: light saturates and heavy saturates. The light saturates have been found only in TG-9, TG-8, TG-7, TG-10, and TG-13 wells. Other wells contain heavy saturates (Figure 1).

Furthermore, it can be concluded that there are three (3) oil families in the research area. There are lacustrine, lacustrine - estuarine, and shallow marine oil families. Lacustrine oil family show ratio of C_{26}/C_{25} (tricyclic terpane) is more than 1, ratio of C_{31}/C_{30} hopane is smaller than 0.25, value of carbon isotope $\delta^{13}C$ saturates -18.70 to - 22.08, high C_{28} sterane concentration, low diasterane concentration. Lacustrine-estuarine oil family show ratio of C_{26}/C_{25} (tricyclic terpane) is more than 1, ratio of C_{31}/C_{30} hopane is smaller than 0.25, value of carbon isotope δ^{13} C saturates -24.24 to -29.1, high C_{29} sterane concentration, low diasterane concentration. Shallow marine oil family show ratio of C_{26}/C_{25} (tricyclic terpane) is less than 1, ratio of C_{31}/C_{30} hopane is greater than 0.25, value of carbon isotope ^{13} C saturates -18.8 to -23.7, high C_{27} sterane concentration, high diasterane concentration. The research area is located in Musi Platform, South Palembang Subbasin, South Sumatra Basin (Figure 2).

Regional Geology of South Sumatra Basin

Evolution of South Sumatra Basin started since Mesozoic (Pulunggono et al., 1992) as a back-arc basin. In Indonesia, back-arc basins are generally hydrocarbon prolific basins. The mechanism involved in the basin formation is generally rifting, forming a graben or half graben. This basin was formed in two phases, i.e., the rifting phase during Paleogene and the sagging in Neogene. Rifting phase is characterized by thinning of crust forming graben or half graben, whereas characteristic in the sagging phase is stable tectonic, and even a change into compression tectonic and finished with volcanic activities that are shown by the occurrence of tuff that appeared in the Air Benakat Formation.

The rifting phase was filled by the Lahat Group, comprised by Benakat and Lemat Formation. Benakat formation was sedimented in the central portions of the basin, in a fresh and brackish lacustrine environment, and has potential to be a good source rock. Lemat Formation was deposited in fluvial environment (Ryacudu, 2008). However, in the Jemakur-Tabuan Gaben, Lemat Formation is likely to have fluvio-deltaic environment. The sagging phase was filled with sediments from the Talangakar Formation (deltaic environment) up to the youngest formation, i.e., Kasai Formation (Figure 3).

METHODS AND MATERIALS

Analytical methods used in this study were capillary gas chromatograph (GC); a standard gravitational column chromatography for hydrocarbon fractionation and saturate GC-MS for biomarker determination. Whole oil sample was previously analyzed using a Fast GC to find alkanes distribution. Fingerprinting analysis of whole oil was carried out by using an Agilent 6890 N GC instrument coupled to a flame ionization detector (FID). The GC was fitted with a 10 m x 0.21mm i.d. DB-1 (J and W) fused-silica capillary column. Samples were injected using an Agilent 7673 auto sampler, with split/splitless mode injector.

For GCMS analysis, the oil samples were separated into saturated hydrocarbon, aromatic hydrocarbon, and non-hydrocarbon fraction (polar compounds) by preparative column chromatography. Isolation of branched and cyclic fraction from saturated hydrocarbons was carried out using a packed activated silicalite chromatographic column based on method described by West (1990). Then the branched and cyclic fractions were introduced to a GCMS instrument.

GC-MS analyses of saturate fraction was performed using an Agilent 6890 Gas Chromatograph (GC) coupled to an Agilent 5973 series Mass Selective Detector (MSD) – computer data system (chemstation). The GC was fitted with a 60 m x 0.25 mm i.d. DB- 5MS (J and W) fused-silica capillary column. Samples were injected using an Agilent 7673 auto sampler, with split/ splitless mode injector. The MS condition was ionization mode: electron impact (EI), EM voltage was 1980 Volt; electron energy was 70 eV and source temperature 250°C. Examination of fingerprint signatures for all the samples were based on pristane, phytane of whole oil chromatograms, triterpanes (m/z 191) and steranes (m/z 217) of saturated fractions.

RESULTS AND DISCUSSIONS

Characterization of Oils in The Musi Platform

In this research, data analysis consisted of biomarkers and stable isotopes. Biomarker data include Pr/nC_{17}, Ph/nC_{18}, Pr/Ph, $C_{27} – C_{28} – C_{29}$ sterane, total hopane/ total sterane (Table 1), $C_{19} – C_{26}$ tricyclic terpane (Table 2). While stable isotopes consist of carbon isotope $\delta^{13}C$ saturates and $\delta^{13}C$ aromatics (Table 1).

Based on carbon isotop and biomarker analysis, both qualitative and quantitative methods, oils in Musi Platform could be divided into 3 oil families :

1. Lacustrine oil family (TG-1 – TG-6 wells).
2. Lacustrine – estuarine oil family (TG-7 – TG-10 wells).
3. Shallow marine oil family (TG-11 – TG-14 wells).

Qualitative Methods

The comparison of qualitative biomarker characterization between lacustrine, lacustrine-estuarine, and shallow marine oil families of oil samples from Musi Platform (Figure 4).

Based on data of 29H and 30H (hopane) distribution, the pattern of 29H <30H indicate marine clastic sediment, while 29H > 30H is evaporates-carbonate sediment (Waples and Machihara, 1991; Peters and Moldowan, 1991; Peters and Moldowan, 1993; Peters et al., 2005; Xiangchun et al., 2013; Rabbani et al., 2014; Syaifudin et al., 2015; Wang et al., 2015; Syaifudin, 2016; Abdullah and Gezeery, 2016). Lacustrine and lacustrine-estuarine oil families show 29H < 30H (associated with clastic sediment), while shallow marine oil family show 29H > 30H, is evaporate-carbonate sediment (Figure 4).

From the homohopane distribution data (Figure 4), which decreased regularly from C_{31} to C_{35}, interpreted as depositional environment which associated with clastic (Waples and Machihara, 1991) or suggests an oxic to dysoxic depositional condition (Peters and Moldowan, 1991; Peters and Moldowan, 1993; Peters et al., 2005; El Diasty and Moldowan, 2012; Rabbani et al., 2014). High C_{35} homologues are commonly associated with marine carbonates or evaporites (Waples and Machihara, 1991), and sometimes with saline lacustrine deposits (Wang et al., 2015) or $C_{35}/C_{34} > 1$ indicates the source rock deposition under anoxic conditions or highly reducing depositional conditions (Peters and Moldowan, 1991; Peters and Moldowan, 1993; El Diasty and Moldowan, 2012; Peters et al., 2005; Rabbani et al., 2014). Oil families of lacustrine and lacustrine-estuarine show decreased regularly from C_{31} to C_{35}, interpreted depositional environment which associated with clastic or oxic to dysoxic depositional condition, while shallow marine oil family beside show decreased regularly from C_{31} to C_{35}, also show $C_{35}/C_{34} > 1$, is marine carbonates or evaporites or source rock deposition under anoxic condition or highly reducing depositional conditions (TG 11 well, Figure 4).

High diasterane concentrations relative to regular steranes, can be expected to occur in clay rich source rocks and their hydrocarbon derivatives (Peters et al., 2005; El Diasty and Moldowan, 2012; Xiangchun et al., 2013), and low ratios in oils indicate clay poor (Peters et al., 2005; Xiangchun et al., 2013), carbonate source rocks deposited under anoxic conditions (Hakimi et al., 2011). Oil families of lacustrie and lacustrine-estuarine show low diasterane and shallow marine oil family show high diasterane (Figure 4).

Tricyclic terpanes are used to correlate crude oils and source-rock extracts, predict source-rock characteristics, and evaluate the extent of thermal maturity and biodegradation (de Grande et al., 1993; Peters and Moldowan, 1993; Tao et al., 2015). Terrestrial is characterized by high C_{19} and C_{20} tricyclic terpanes (Peters and Moldowan, 1993, Zhang and Huang 2005; Peters et al., 2005; Hao et al., 2011; Rabbani et al., 2014; Tao et al., 2015; Wang et al., 2015). C_{23} tricyclic terpanes is often the dominant in crude oils of a marine source (Peters and Moldowan, 1993; Zhang and Huang, 2005; Tao et al., 2015). Lacustrine oil family samples show C_{23} tricyclic terpane are more abundant, lacustrine-estuarine oil family samples show C_{23} and also C_{19} tricyclic terpane dominant, and shallow marine oil family samples show C_{23} tricyclic terpane are more abundant (Figure 5).

Determination of lacustrine sediment using parameter C_{26}/C_{25} tricyclic terpane and C_{31} 22R/C_{30} hopane. Characteristics of lacustrine sediments show C_{26}/C_{25} (tricyclic terpane) ratio is greater than 1 (ten Haven and Schiefelbein, 1995; Peters et al., 2005; and Tao et al., 2015; Priyanto et al., 2023; Priyanto et al., 2024). The C_{31}R/C_{30} hopane ratio is used to distinguish between marine and lacustrine environments. This value is generally higher than 0.25 for marine environments and lower for lacustrine settings (Peters et al., 2005; Gulbay et al., 2012). It appears that lacustrine and lacustrine-estuarine oil families are derived from lacustrine sediments because high C_{26}/C_{25} tricyclic terpane and low C_{31} 22R/C_{30} hopane, while shallow marine oil family show low C_{26}/C_{25} tricyclic terpane and high C_{31} 22R/C_{30} hopane (Figure 4 and Figure 5), it is indicated derived from shallow marine sediment.

It is usually believed that C_{27} steranes derive mainly from phytoplankton and metazoa, whereas C_{29} steranes mainly originate from terrigenous higher plants (Huang and Meinschein, 1979; Moldowan et al., 1986; El Diasty and Moldowan, 2012; Gross et al., 2015; Ding et al., 2015). Oil family of shallow marine samples show that C_{27} is higher than C_{28} and C_{29}, it indicated that oil family of shallow marine samples derive mainly from shallow marine sediments (Figure 4).

Quantitative Methods

Biomarker and stable isotopes data of oils in the study area can be seen in Table 1. Pristane/phytane (Pr/Ph) ratios have been used to assess the redox potential of the depositional environment and source of organic matter (Didyk et al., 1978; Tissot and Welte, 1984; Zhang and Huang, 2005; Peters et al., 2005; Cheng et al., 2013 and Tao et al., 2015) or reflect the relationship between contributing organisms and the chemistry of the environment (Mello and Maxwell, 1990; Zhang and Huang, 2005). It is generally accepted that very low values of the pristane/phytane ratio (≤ 1) indicate anoxic conditions while high values (Pr/Ph > 3) are related to terrigenous organic matter input under less restricted conditions (Peters et al., 2005). From the cross plot of Pr/Ph – Pr/nC_{17}, as proposed by Robinson (1991) (Figure 6) shows all of the oil families in the study area are found in anoxic-suboxic, only one (1) sample from shallow marine oil family (TG-12 well) are in oxic terrestrial. Lacustrine oil family samples show more toward to algal/ bacterial than lacustrine-estuarine and shallow marine oil families of samples.

The cross plot of Pr/nC_{17} – Ph/nC_{18} as proposed by Connan and Cassou, 1980 (Figure 7), showed all of the oil families in the study area composed by mixed kerogen (humic and sapropelic kerogen), and only one (1) sample from lacustrine oil family (TG-4 well) are derived from humic kerogen. From this figure is also shown that lacustrine oil family samples look relatively more mature than the others (lacustrine-estuarine and shallow marine oil families (Figure 8).

The carbon isotopic composition of the oil typically depends on the d^{13}C value of the kerogen in the source rock from which it generated. The d^{13}C value of kerogen depends on the type of organisms being preserved and on the condition of depositional environmental (Zhang and Huang, 2005). As a result, ∂^{13}C values of oils are useful for determining oil–oil and oil– source rock correlations and in conjunction with other geochemical properties, it can show the possible age and depositional environment of source rocks (Chung et al., 1992 vide Zhang and Huang, 2005; Peters et al., 2005). Waples (1985) stated that on average, oils are about 2 ‰ more negative (lighter) than kerogens. Oils having a disparity larger than 3‰ generally do not have a genetic relationship (Peters et al., 2005; Cheng et al., 2013). From the cross plot of carbon isotope δ^{13}C saturates – δ^{13}C aromatics as proposed by Sofer

(1984) (Figure 8), and carbon isotope $\delta^{13}C$ saturates – Pr/Ph as proposed by Bishop (2001) (Figure 9), show that lacustrine, lacustrine-estuarine, and shallow marine oil families samples have carbon isotope $\delta^{13}C$ saturates values are (-18,7) – (-22,08); (-24.24) – (-29.10); and (-18,8) – (-23.7) respectively. All of the oil families in the study area are in anoxic-suboxic conditions, only one (1) sample from shallow marine oil family (TG-12 well) are in oxic condition.

From the sterane distribution curve of C_{27},C_{28}, dan C_{29} as proposed by Huang and Meinshein (1979) (Figure 10), shows lacustrine and lacustrine-estuarine oil families samples were found in estuarine or shallow lacustrine, and shallow marine oils family samples was found in open marine or deep lacustrine and in estuarine or shallow lacustrine.

Based on these data, lacustrine-estuarine oil family is interpreted initially been deposited in lacustrine environment, after that there was marine influence in Benakat Gully, so lacustrine environment turns into an estuary environment.

CONCLUSION

Based on carbon isotop and biomarker analysis, both qualitative and quantitative methods, oils in Musi Platform could be divided into lacustrine, lacustrine-estuarine, and shallow marine oil families.

Lacustrine oil family derived from lacustrine environment, with ratio of C_{26}/C_{25}(tricyclic terpane) is more than 1, C_{31}/C_{30} hopane ratio is smaller than 0.25, value of carbon isotope $\delta^{13}C$ saturates -18.70 to -22.08, high C_{28} sterane concentration, low diasterane concentration, derived from humic and sapropelic kerogen, anoxic-suboxic condition.

Lacustrine-estuarine oil family is interpreted initially deposited in lacustrine environment, afterthat there is marine influence and change to be estuarine environment. Ratio of C_{26}/C_{25} (tricyclic terpane) is more than 1, C_{31}/C_{30} hopane ratio is smaller than 0.25, value of carbon isotope δ^{13} C saturates -24.24 to -29.1, high C_{29} sterane concentration, low diasterane concentration, derived from humic and sapropelic kerogen, anoxic-suboxic condition.

Shallow marine oil family is derived from shallow marine environment, ratio of C_{26}/C_{25}(tricyclic terpane) is less than 1, C_{31}/C_{30} hopane ratio is greater than 0.25, value of carbon isotope ^{13} C saturates -18.8 to -23.7, high C_{27} sterane concentration, high diasterane concentration, derived from humic and sapropelic kerogen, anoxic-suboxic condition.

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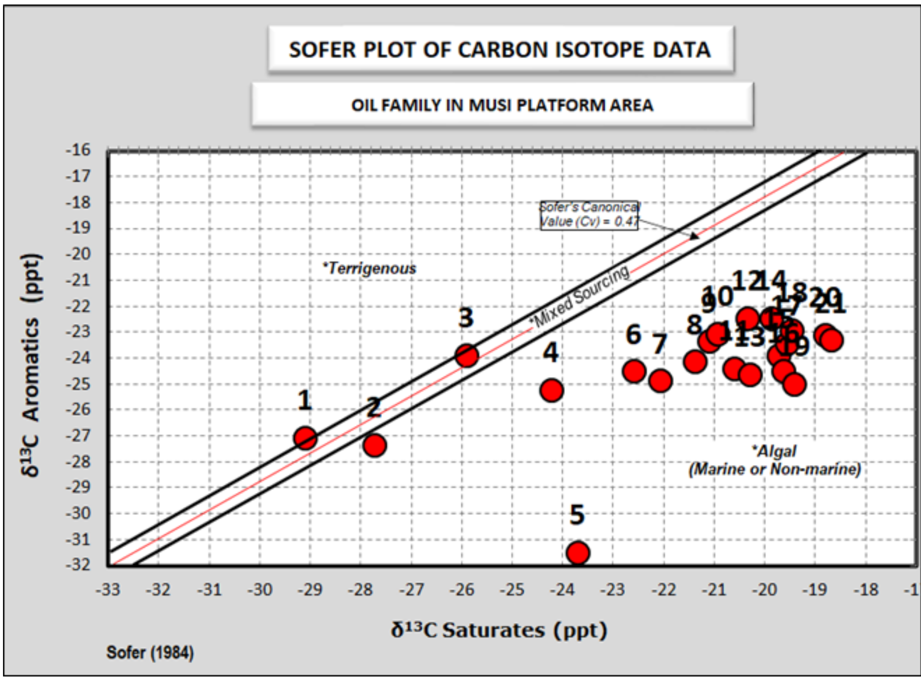
Table 1. Biomarker data of oils in the research area (Abbreviations: BRF= Baturaja Formation).

No	Wells	API Gravity	Sat	Arom	NSO+ Asph	Sat/Aro	wt % Sulphur	$\delta^{13}C$ arom	$\delta^{13}C$ sat	Ph/nC_{18}	Pr/nC_{17}	Pr/Ph	Tot Hop/ Tot Ster	C_{27}	C_{28}	C_{29}
1	TG-1-1, 3298-3311 ft, BRF	40.60	83	9	9	9.52	0.21	-23.43	-19.56	0.07	0.22	3.35	5.59	31.08	27.32	41.60
2	TG-1-2, 3312-3318 ft, BRF	41.20	86	11	4	8.14	0.48	-22.93	-19.47	0.07	0.21	3.52	3.61	30.85	33.33	35.82
3	TG-1-2, 3262-3273 ft, BRF	51.20	88	7	4	12.28	0.59	-23.32	-21.10	0.08	0.20	3.24	6.87	25.09	37.27	37.64
4	TG-1-3, 3590-3600 ft, BRF	–	52	5	43	9.77	–	-24.47	-19.64	0.12	0.32	2.84	2.84	–	–	–
5	TG-1-4, 3343 ft, BRF	42.80	–	–	–	9.52	0.20	–	–	0.07	0.21	3.53		–	–	–
6	TG-1-5, 3588-3599 ft, BRF	43.9	91	7	2	12.24	2.55	-22.44	-19.87	0.08	0.24	3.16	3.16	–	–	–
7	TG-1-6, 1574-1584 ft, BRF	39.60	90	3	7	33.48	0.40	-24.13	-21.39	0.08	0.23	2.99	7.82	33.18	35.43	31.39
8	TG-1-6, 3250-3260 ft, BRF	42.50	88	8	4	11.40	0.42	-23.90	-19.73	0.08	0.21	3.31	5.79	35.87	32.93	31.20
9	TG-1-7, BRF	43.90	71	8	21	9.13	–	-25.00	-19.43	0.18	0.41	2.64	2.64	–	–	–
10	TG-2, 4804-4814 ft, BRF	44.80	89.60	6.70	3.70	13.37	0.25	-24.87	-22.08	0.09	0.23	2.96	1.74	21.84	41.36	36.79
11	TG-3, 3157 ft, BRF	–	91.20	6.30	2.60	14.48	–	-22.46	-20.35	0.15	0.34	2.24	91.79	–	–	–
12	TG-4, 3224 - 3228 ft, BRF	45.00	87.20	7.60	5.20	11.47	0.09	-23.30	-18.70	0.08	0.56	2.17	6.90	–	–	–
13	TG-5-1, BRF	–	76.30	15.70	8.00	4.86	–	-24.60	-20.30	–	0.36	2.77	7.97	37.14	22.86	40.00
14	TG-5-2, 3226-3250 ft, BRF	43.70	87.70	7.00	5.30	12.53	0.05	-24.40	-20.60	–	0.35	3.21	7.97	23.90	38.30	37.80
15	TG-6, 5684-5700 ft, BRF	45.10	90.10	6.00	3.90	15.02	0.22	-23.03	-20.93	0.11	0.24	2.92	10.38	22.17	46.55	31.28
16	TG-7, 3220-3228 ft, BRF	37.90	81.10	11.90	7.00	6.82	–	-23.86	-25.91	0.24	0.65	2.99	8.88	26.70	23.30	50.00
17	TG-8, 3792-3802 ft, BRF	–	46	14	40	3.24	–	-27.35	-27.73	0.31	0.89	2.63	2.63	35.95	15.12	48.93
18	TG-9, BRF	28.80	75	6	19	11.64	0.05	-27.05	-29.10	0.93	0.94	1.27	6.27	15.93	17.85	66.21
19	TG-10, BRF	33.30	60.10	27.30	12.60	2.20	0.19	-25.20	-24.24	0.29	0.75	2.85	2.10	28.18	20.81	51.01
20	TG-11, Basement	54.80	80.20	18.30	1.50	4.40	0.04	-24.50	-22.60	–	–	–	–	33.30	21.90	44.80
21	TG-12, 4360-4390 ft, BRF	63.30	94.60	1.90	3.50	49.78	0.02	-23.10	-18.80	0.17	0.21	6.68	2.54	56.25	17.31	26.44
22	TG-13, 4533 ft, BRF	42.70	78.40	13.20	9.00	5.94	0.06	-31.50	-23.70	0.38	0.68	1.87	3.80	42.90	22.80	34.30
23	TG-14, 3000-3010 ft, BRF	46.80	72.70	21.50	5.80	3.38	0.01	–	–	0.37	0.64	2.09	5.79	48.50	21.20	30.30

Table 2. Tricyclic Terpane data of oils in the research area (Abbreviations: BRF= Baturaja Formation).

No	Oil Samples	Norm % Tricyclic Terpane							
		C_{19}	C_{20}	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}
1	TG-1-1,3298-3311 ft, BRF	8	15	18	2	23	19	7	8
2	TG-1-6, 1574-1584 ft, BRF	9	15	20	4	23	22	7	10
3	TG-2, 4804-4814 ft, BRF	6	13	13	8	22	19	8	11
4	TG-9, BRF	17	13	22	4	19	18	6	10
5	TG-7, 3220-3228 ft, BRF	11	9	19	4	19	19	7	12
6	TG-12, 4360-4390 ft, BRF	12	16	15	0	28	19	10	6
7	TG-14, 3000-3010 ft, BRF	13	17	11	0	29	17	12	8
8	TG-13, 4533 ft, BRF	6	11	13	0	41	17	12	7



No	Oil Samples
1	TG-9, BRF
2	TG-8, 3792-3802 ft, BRF
3	TG-7, 3220-3228 ft, BRF
4	TG-10, BRF
5	TG-13, 4533 ft, BRF
6	TG-11, kondensat
7	TG-2, 5318-5530 ft
8	TG-1-6, 1574-1584 ft, BRF
9	TG-1-2, 3262-3273 ft, BRF
10	TG-6, 5684-5700 ft, BRF
11	TG-5-2, 3226-3250 ft, BRF
12	TG-3, 3157 ft
13	TG-5-1, BRF
14	TG-1-5, 3588-3599 ft, BRF
15	TG-1-6, 3250-3260 ft, BRF
16	TG-1-3, 3590-3600 ft, BRF
17	TG-1-2, 3298-3311 ft, BRF
18	TG-1-2, 3312-3318 ft, BRF
19	TG-1-7, BRF
20	TG-12, 4360-4390 ft, BRF
21	TG-4, 3224 - 3228 ft, BRF

Figure 1. Cross plot of carbon isotope $\delta^{13}C$ saturates – aromatics of oils based Sofer (1984) in the research area (Abbreviations: BRF= Baturaja Formation).

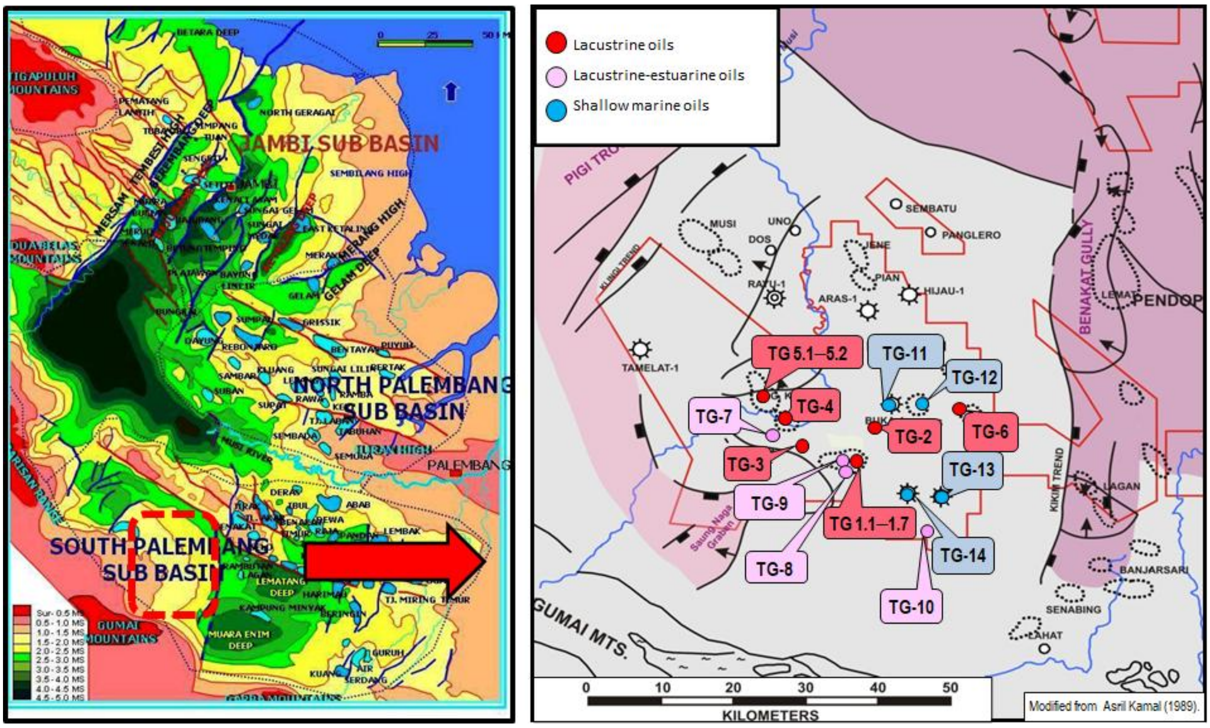


Figure 2. South Sumatra Basin (left) and location map of research area (right).

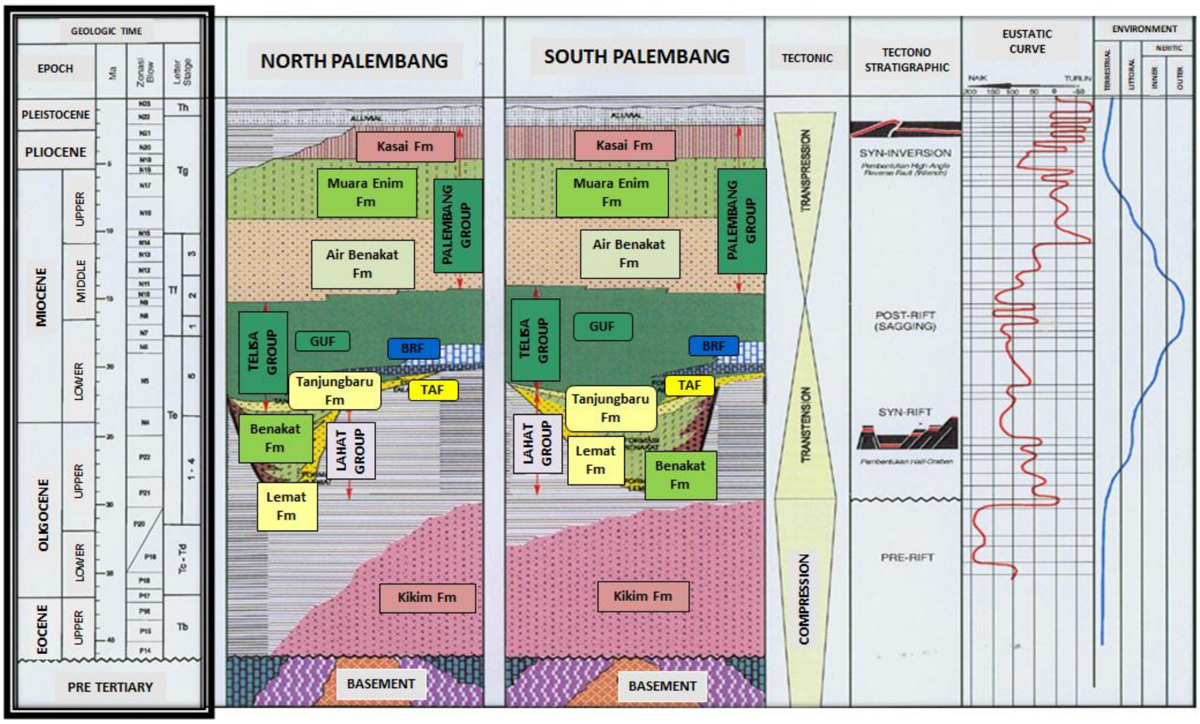


Figure 3. Regional stratigraphy of the South Sumatra Basin (modified from Ryacudu, 2008).

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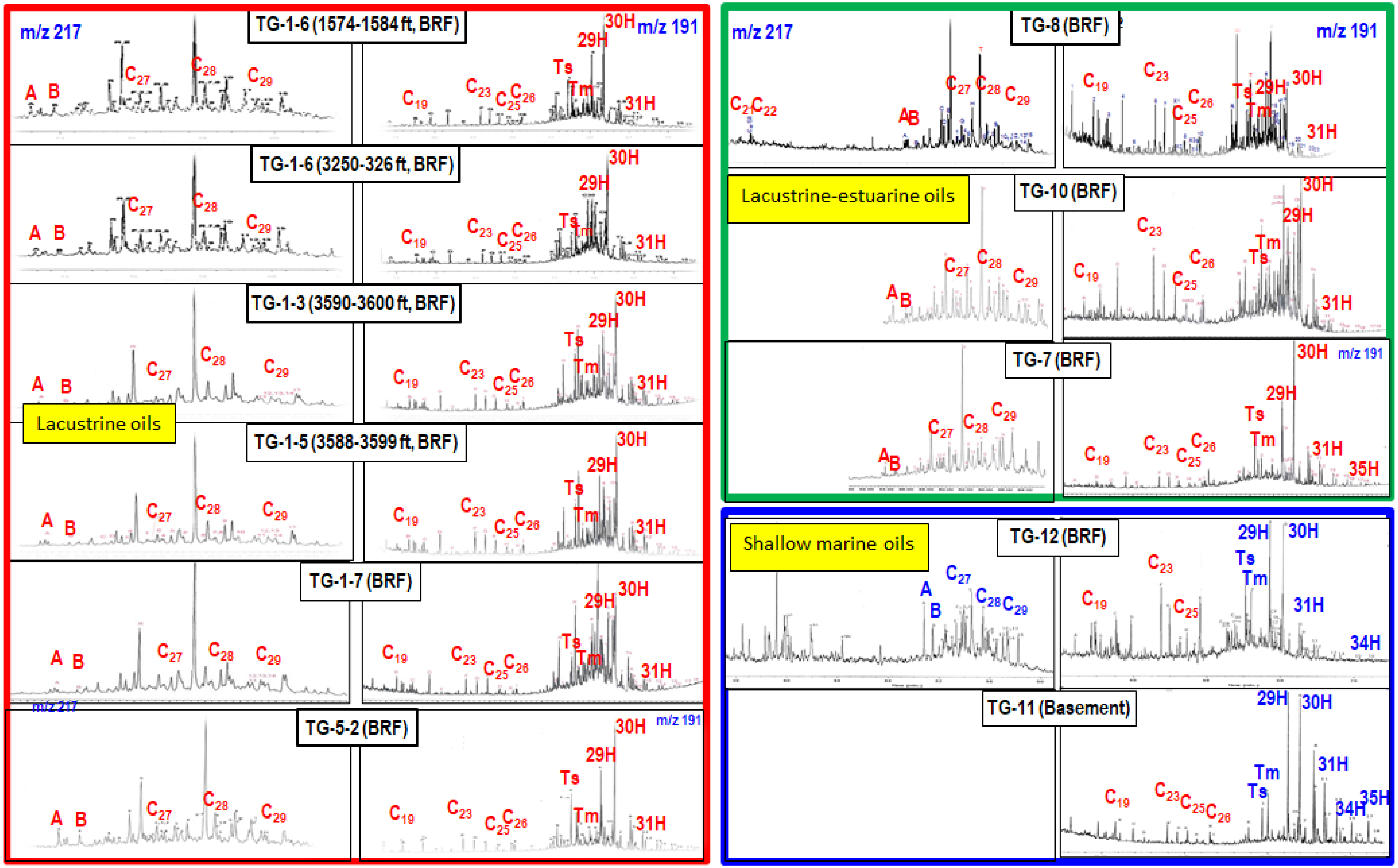

Figure 4. Comparison of biomarker characterization qualitatively between lacustrine, lacustrine-estuarine, and shallow marine oils (Abbreviations: BRF= Baturaja Formation).

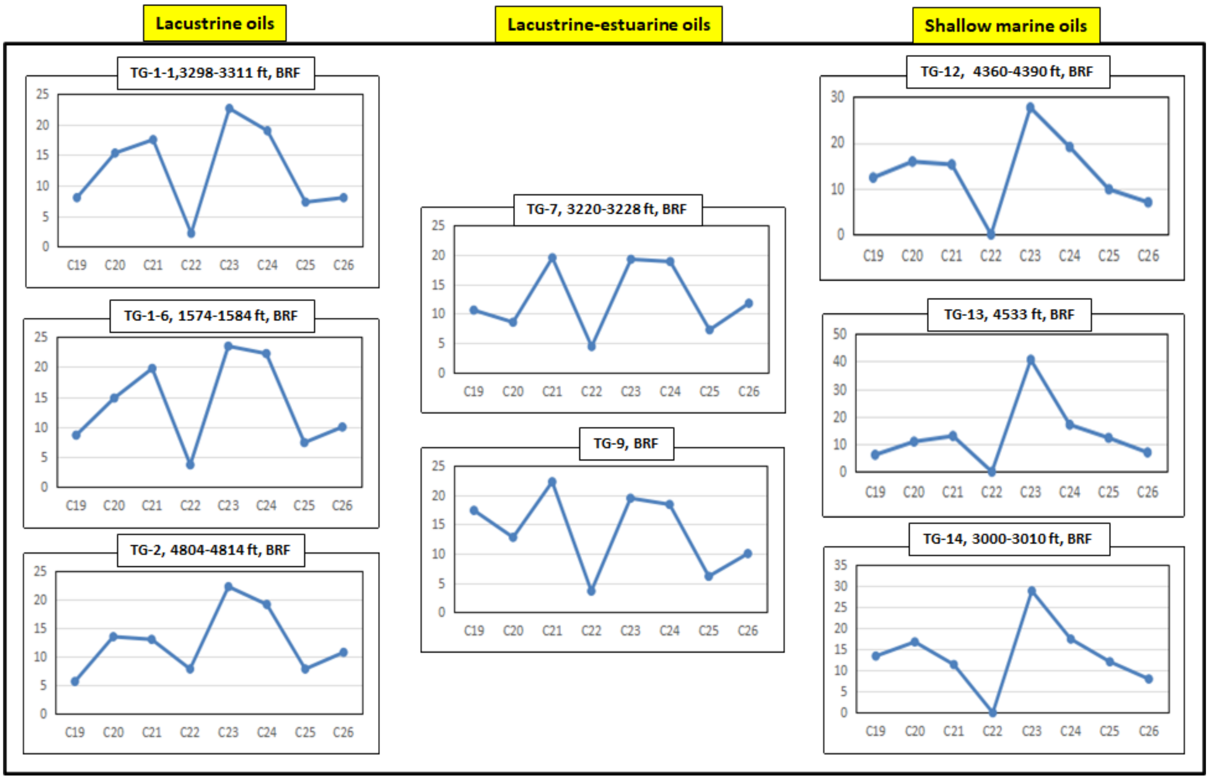

Figure 5. Distribution of $C_{19} – C_{26}$ (tricyclic terpane) of oils in in the research area (Abbreviations: BRF= Baturaja Formation).

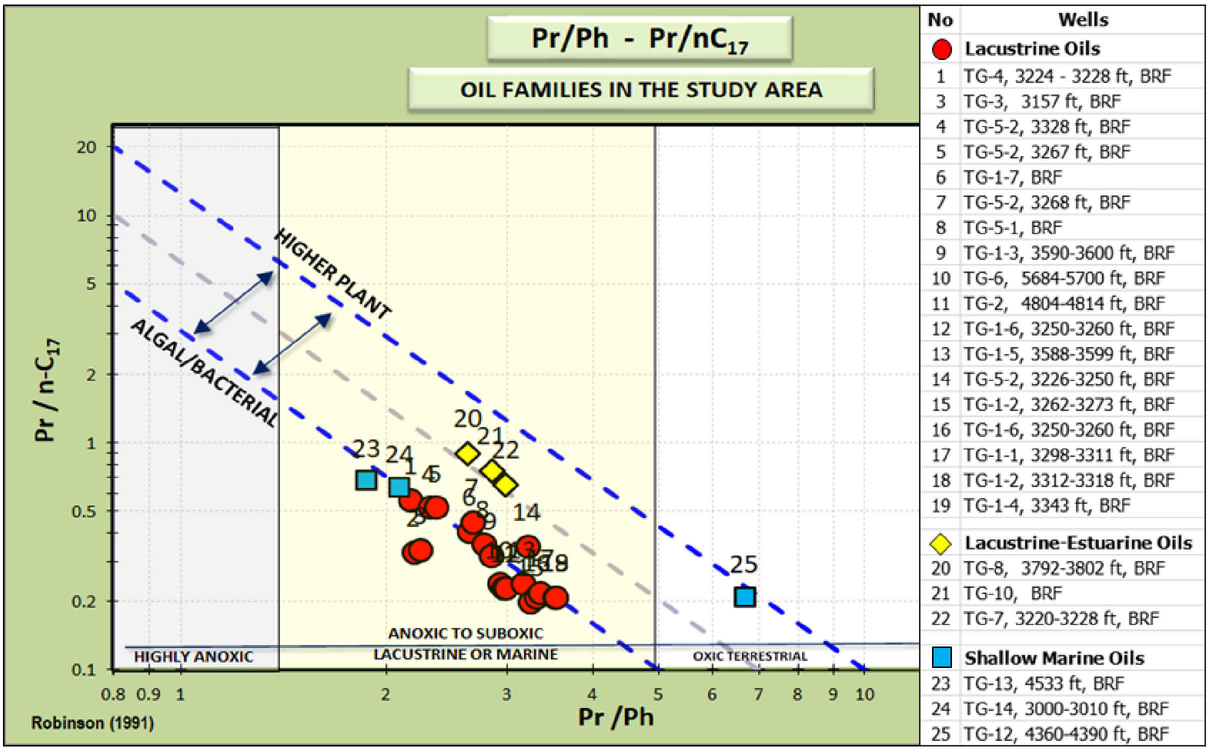

Figure 6. Cross plot of Pr/Ph – Pr/nC_{17} of lacustrine, lacustrine-estuarine, and shallow marine oils in the research area (Abbreviations: BRF= Baturaja Formation).

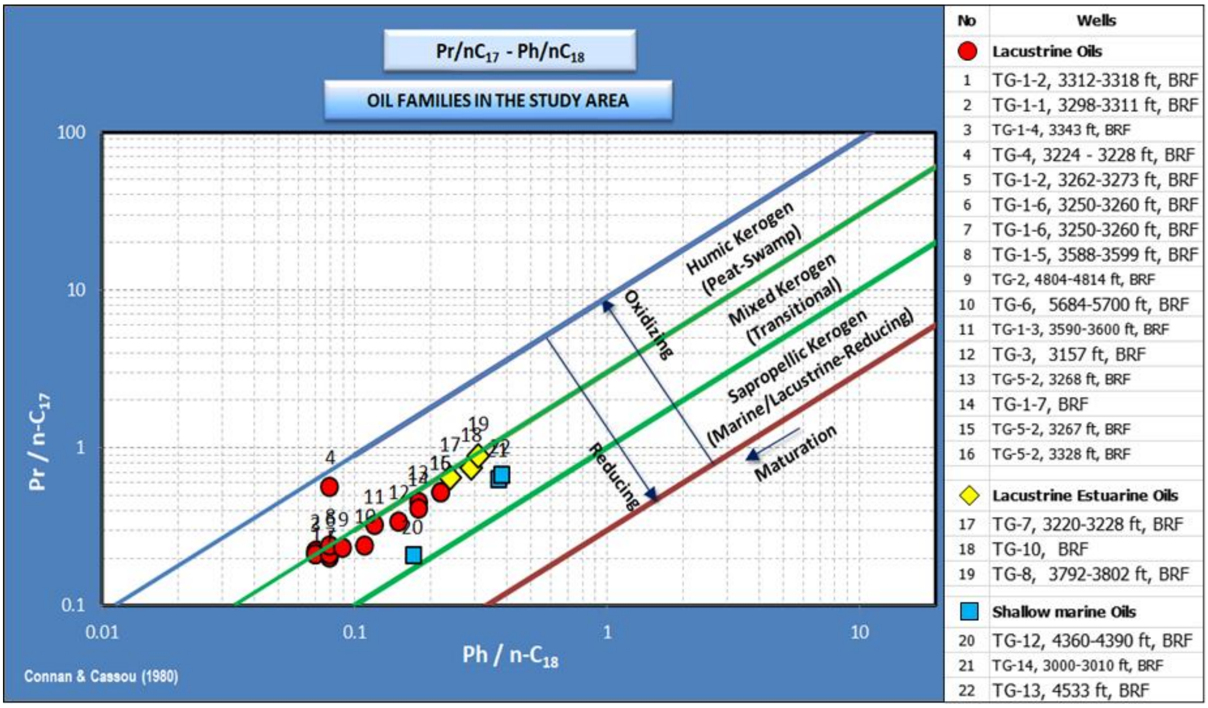

Figure 7. Cross plot of Pr/nC_{17} – Ph/nC_{18} of lacustrine, lacustrine-estuarine, and shallow marine oils in the research area (Abbreviations: BRF= Baturaja Formation).

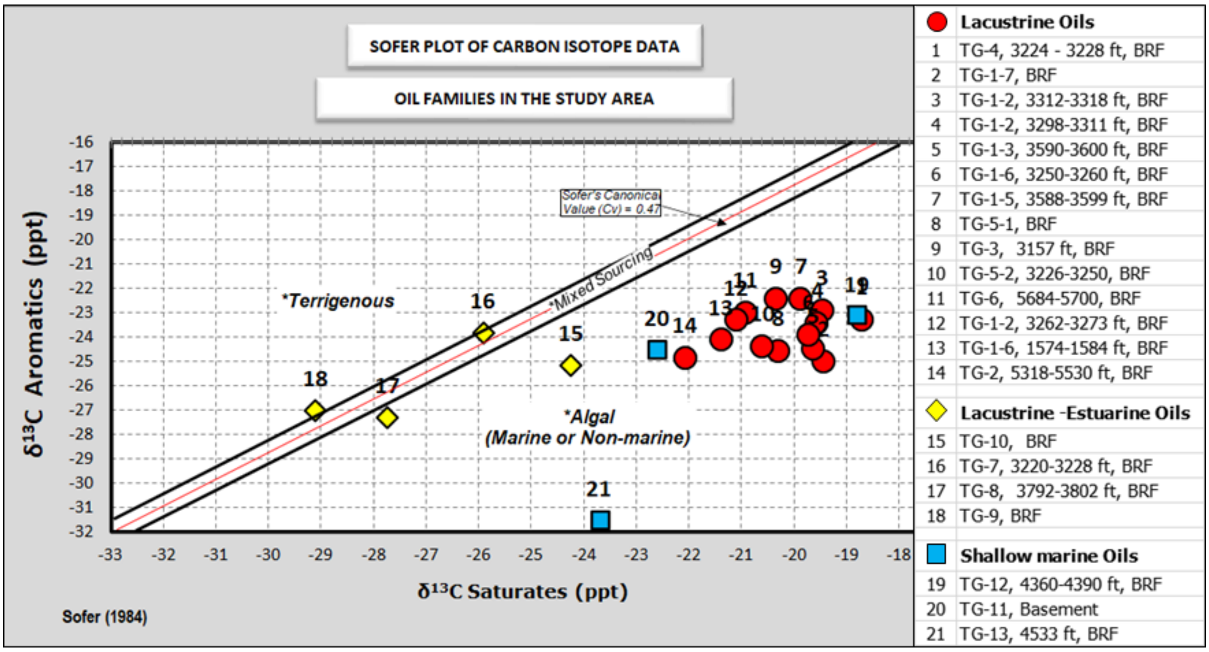

Figure 8. Cross plot of carbon isotope $\delta^{13}C$ saturates – $\delta^{13}C$ aromatics of lacustrine, lacustrine-estuarine, and shallow marine oils in the research area (Abbreviations: BRF= Baturaja Formation).

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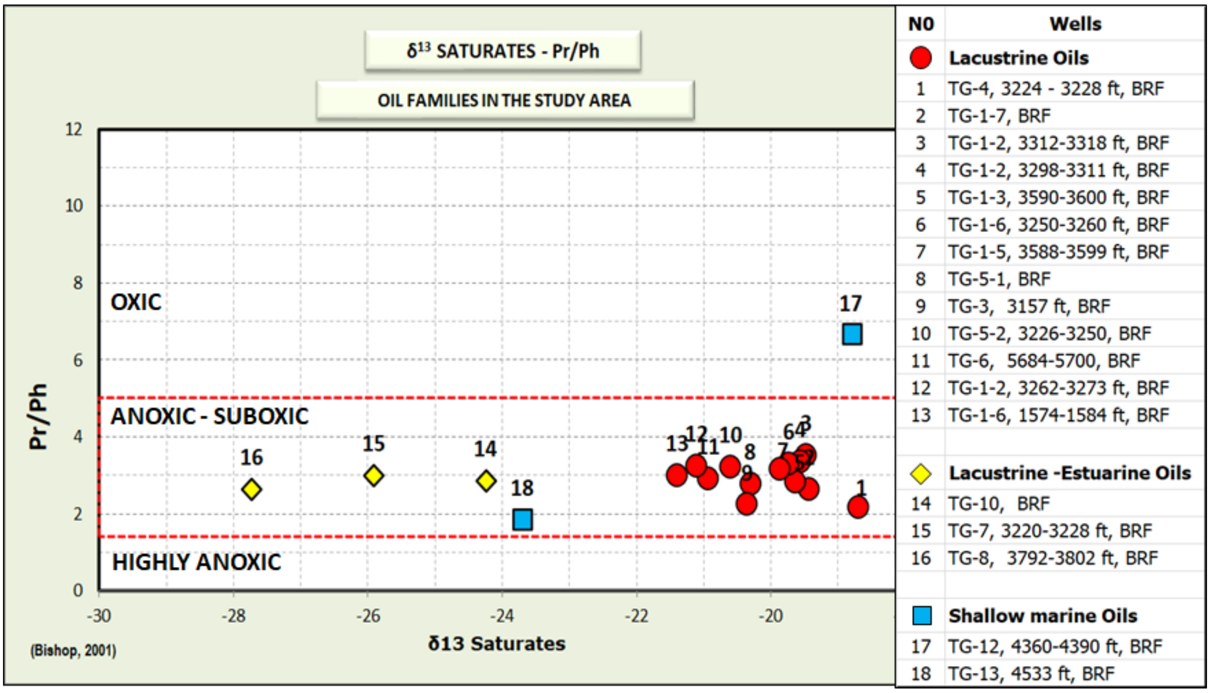

Figure 9. Cross plot of carbon isotope $\delta^{13}C$ saturates – Pr/Ph of lacustrine, lacustrine-estuarine, and shallow marine oils in the research area (Abbreviations: BRF= Baturaja Formation).

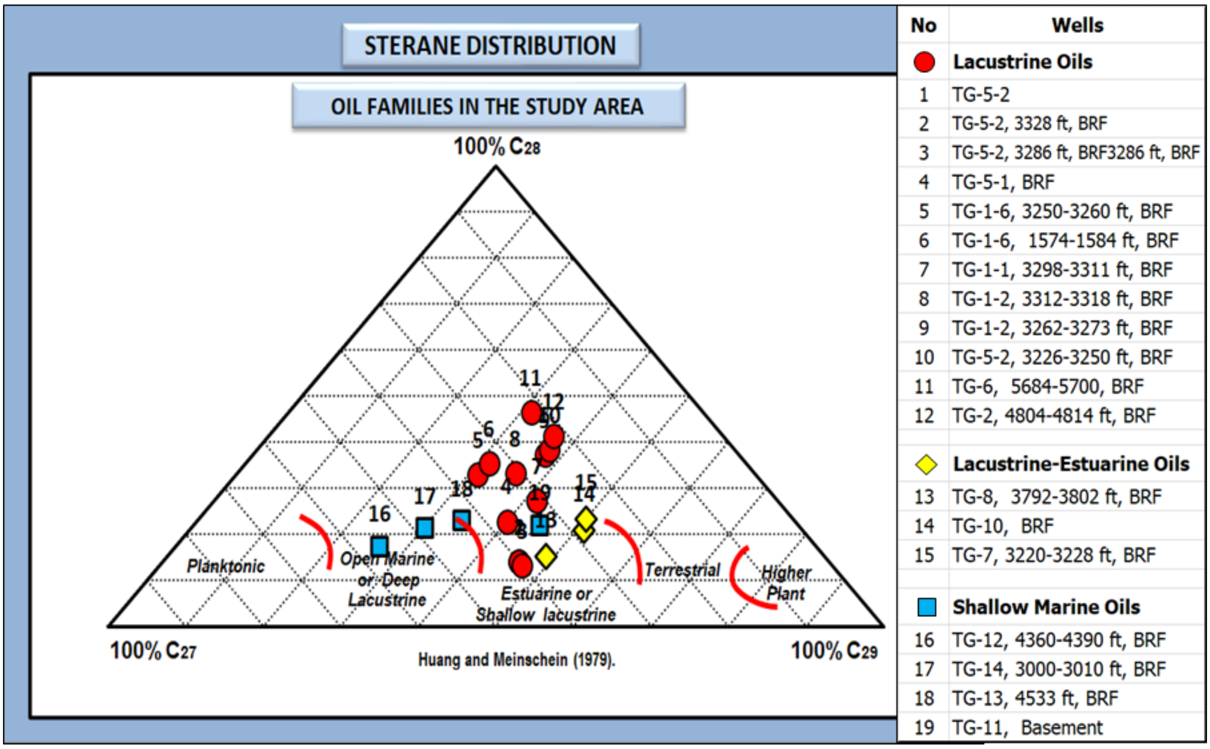

Figure 10. Sterane distribution C_{27}, C_{28}, and C_{29} of lacustrine, lacustrine-estuarine, and shallow marine oils in the research area (Abbreviations: BRF= Baturaja Formation).