DOI: https://doi.org/10.31315/jigp.v13i1.17079 *e-ISSN 2987-100X*

Characteristics and Correlation of Source Rocks and Oils at Jemakur-Tabuan Graben, South Sumatra Basin

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Abstract - There are differences of argument for determining an oil family at South Sumatra Basin. The first opinion argues that oils were generated from source rocks that were deposited in fluvio-deltaic, shallow marine, and lacustrine environments. In other hand, there is also opinion argues that there are no evidence of source rocks or oils with lacustrine characteristic. The research area is in the Jemakur-Tabuan Graben, which is considered as syn-rift basin and it is expected to find source rock with fluvio-deltaic, shallow marine, and lacustrine deposit characteristic. The source rocks and crude oils characterizations were conducted by geochemical analysis, including liquid chromatography, gas chromatography, and gas chromatography-mass spectrometry analysis. The source rocks samples were taken from Lemat and Talangakar Formations. Carbon isotope and biomarker analyses were done on the 15 and 14 source rock samples, respectively. Crude oil characterisation was performed in Jemakur-Tabuan Graben, which consist of 15 and 16 samples for carbon isotope and biomarker analyses, respectively. Furthermore, correlation between source rock and crude oil, as well as crude oil to crude oil, was carried out by interpreting the carbon isotope and biomarker data. Geochemical analysis concluded that there is an oil family with lacustrine characteristic in the research area. However, the oil was not generated from source rock of Lemat and Talangakar formations. Source rocks of Lemat and Talangakar Formations show the characteristic of deltaic deposits. There is no correlation between the source rocks (Lemat and Talangakar Formations) and crude oils in Jemakur-Tabuan Graben. The lacustrine source rocks in the research area (as evidenced by the presence of lacustrine oil) was interpreted from source rock of Benakat Formation.

Keywords: differences of argument, lacustrine characteristics, deltaic deposits.

INTRODUCTION

Geochemical studies of source rocks and oils in South Sumatra Basin have been reported by Robinson (1987); Suseno *et al*. (1992); ten Haven and Schiefelbein (1995); Rashid *et al*. (1998); Ginger and Fielding (2005); Doust and Sumner (2007); Doust and Noble (2008); Noble *et al*. (2009); Syaifudin *et al*. (2015); Syaifudin (2016); Syaifudin and Subroto (2024). Carbon isotopic composition of oil is typically dependent upon the $\delta^{13}C$ value of the kerogen in the source rock from which it was generated. The $\delta^{13}C$ value of kerogen depends, in turn, on the types of organisms preserved and depositional environmental conditions (Zhang and Huang, 2005). Consequently, $\delta^{13}C$ values of oils are useful for determining oil – oil and oil – source rock correlations and, in conjunction with other geochemical properties, can indicate the possible age and depositional environment of source rocks (Zhang and Huang, 2005).

Biological markers can be measured in both crude oils and extracts of petroleum source rocks. These will assist petroleum geologists to interpret the characteristics of petroleum source rocks, in case only oil sample is available. Biomarkers are also useful because they can provide valuable information on the organic matter of the source rock, environmental conditions during its deposition and burial (diagenetic) history, thermal maturity experienced by rock or oil (catagenesis), degree of biodegradation, and the age. Different depositional environments are characterized by different assemblages of organisms and their biomarkers (Peters *et al*., 2005).

In the South Sumatra Basin, there are differences in argument among geochemists in determining oil family. The first argument is based on only oil samples analysis (ten Haven and Schiefelbein, 1995; Ginger and Fielding, 2005; Noble *et al*., 2009; and Rashid *et al*., 1998; Doust and Noble, 2008; Doust and Sumner, 2007) which concluded that oils in this area were generated from fluvio-deltaic, shallow marine and lacustrine source rock. The second argument used source rock and oil samples analysis (Robinson, 1987 and Suseno *et al*., 1992) which argues that no source rock and oil with lacustrine characteristic were found in this area (Table 1).

This research was conducted to investigate characteristic of oils and source rocks in research area. It focused on discovering the successful combination of isotopic and biomarker indicators to analyze comprehensively

geochemical characteristics including organic material origin and depositional environment of source rocks of Lemat and Talangakar Formations and oils in this area.
The research area is located in Jemakur-Tabuan Graben as part of North Palembang Sub Basin, South Sumatra Basin. Figure 1 shows the location of research area and summary of the oils and source rock geochemical data in Jemakur-Tabuan Graben. 15 source rock samples were taken from Lemat and Talangakar Formations, while 16 crude oil samples were obtained from Jemakur-Tabuan Graben.

METHODS AND MATERIALS

The source rock analyses consist of carbon isotope measurement in 15 samples and biomarker analysis in 14 samples. The oil analysis comprises carbon isotope measurement in 15 samples and biomarker analysis in 16 samples.
Oil and rock samples were prepared using an extraction and liquid chromatography to obtain the saturated hydrocarbon. The hydrocarbon extract was carefully evaporated then transferred to sample vial. Isolation of branched and cyclic fraction from saturated hydrocarbon was done using a packed activated molecular sieve to trap *n*-alkane. Some preparation for the samples were conducted before doing laboratory analysis (GC and GC-MS analysis). Three steps preparation for oil sample are: 1) oil separation from water or other contaminant using DCM, 2) deasphaltene of oil sample to know amount of asphaltene that consisted in oil and also to remove asphaltene from oil before sample are injected to GC-MS, 3) liquid chromatography of oil sample using column to separate saturate, aromatic, and NSO fraction. In this process, each fraction was weighted to know the composition of oil sample. Rock sample was cleaned up from contaminant by washing with water, dried in oven and crushed into fine size. Then, bitumen extraction was performed by using soxhlet extractor and DCM to extract bitumen/free hydrocarbon in the rock. The result of bitumen extraction can be prepared for deasphaltenes and liquid chromatography like oil sample preparation did.

Gas Chromatography (GC) and Gas Chromatography Mass Spectrometry (GC-MS).

Oil and bitumen extract were analyzed by Gas Chromatography (GC) with Agilent 6890N GC instrument coupled to a flame ionization detector (FID) with a 20 m x 0.21 mm i.d. DB-1 (J and W) fused-silica capillary column and Agilent 7673 auto sampler (split/splitless mode injector). Sample (0.1µL) was injected into the GC then through a column. In column, the temperature rises gradually. The oven temperature was programmed from 35ºC to 325ºC. In this process, samples run into separation compounds (static phase and mobile phase) then evaporated and mixed with helium gas toward the detector (FID). The result was recorded in the computer. The GC analysis result is a fingerprint, which records the normal alkanes and isoprene. That result can be used for biomarker interpretation.

After fractionation, GC-MS analysis was performed on the saturates and aromatic fractions from oil and rock-bitumen. GC-MS system performs: 1) compound separation by gas chromatography, 2) transfer separated compound to the ionizing chamber of the mass spectrometer, 3) ionization, 4) mass analysis, 5) detection of the ions by electron multiplier, 6) acquisition processing and display of the data by computer. In this research, GC-MS analysis used an Agilent 6890 Gas Chromatograph (GC) coupled to an Agilent 5973 series Mass Selective Detector (MSD) – computer data system (Chemstation) with a 60 m x 0.25 mm i.d. DB-5 (J and W) fused-silica capillary column and Agilent 7673 auto sampler (split/splitless mode injector). The result of this analysis is mass fragmentograms (ex. m/z 217 for steranes and m/z 191 for terpanes) used for biomarker interpretation.

Characterization will be categorized based on qualitative and quantitative data. Qualitative data consist of evaluation based on mass-fragmentograms, whereas quantitative data consists of a series of cross-plots, eg. cross plot of carbon isotope $\delta^{13}C$ saturates – aromatics, distribution of C_{27}–C_{28}–C_{29} sterane, Pr/nC_{17}–Ph/nC_{18}, Pr/Ph–Pr/nC_{17}, carbon isotope $\delta^{13}C$ saturates–Pr/Ph, Pr/Ph–total hopane/total sterane and ratio of C_{26}/C_{25} (tricyclic) terpanes and C_{31} 22R/C_{30} hopane.

Regional Geology

Evolution of South Sumatra Basin was 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 Formations. 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 2).

Petroleum System

The Benakat and Lemat Formations of the Lahat Group appear to be the source of lacustrine and fluvial oils, respectively. The deltaic oils seem to be generated from sorce rock of Talang Akar Formation. Oils in the South Sumatra Basin were trapped in structural and stratigraphic traps. Oils accumulated in the Lemat, Talangakar and Palembang Formations are mainly found in structural traps. However, a few fields are known to have stratigraphic entrapments. The oils in the Baturaja limestone are mostly found in stratigraphic traps, only a few are found in structural traps.

Several reservoirs have been proven in sandstones of Lemat, Talangakar, Palembang and Telisa Formations as well as limestones of Baturaja formation and fractures of the Pre-Tertiary Basement. The Telisa Formation usually acts as a regional seal (Figure 3). Intra-formational seals are found in the Lemat, Talangakar, Lower Palembang and Middle Palembang Formations. In Exspan's areas, it is believed that hydrocarbons started to be generated at around 12.5 mybp. Since then, early oil migration occurred and accumulated in the paleo traps/structures. Around 2.8 mybp, the Plio-Pleistocene orogeny modified the paleo structures where oil spilled to the present-day traps (Rashid *et al*., 1998).

RESULTS AND DISCUSSIONS

Correlation of Source Rocks and Oils in Jemakur-Tabuan Graben

In this research, data analysis consists of biomarkers and stable isotope composition. Biomarker data include total hopane/total sterane, Pr/nC_{17}, Ph/nC_{18}, Pr/Ph, C_{27}, C_{28}, C_{29} steranes (Table 2) and tricyclic terpanes (Table 3). Stable isotope data covers both saturates and aromatics fraction (Table 2).

Qualitative Methods

Figure 4 is the comparison of qualitative biomarker characterization between source rocks of Lemat and Talangakar Formations, and crude oil samples from Jemakur-Tabuan Graben.

Based on data of 29H and 30H (hopane) distribution, the pattern of 29H < 30H indicate marine clastic sediments, while 29H > 30H suggests evaporates-carbonate sediment (Zumberge, 1984; Price *et al*., 1987; Waples and Machihara, 1991; Peters and Moldowan, 1991; Peters and Moldowan, 1993; Peters *et al*., 2005; Syaifudin *et al*., 2015; Wang *et al.*, 2015; Syaifudin, 2016; Sabra, 2021). Source rocks of Lemat and Talangakar Formations reveal both marine clastic sediments and evaporate-carbonate sediments as indicated by the patterns of 29H and 30H hopanes (Figure 4). Based on the pattern, crude oil samples could be interpreted to originate from marine clastic sediments.

The homohopane distribution indicates regular decrease pattern from C31 to C35 for both source rock and oil samples as shown in Figure 4. Such indication infers depositional environments associated with clastic (Waples and Machihara, 1991) or more oxidizing conditions (Peters and Moldowan, 1993; Peters *et al*., 2005; and Hakimi *et al*., 2011).

Tricyclic terpanes commonly used to correlate crude oils and source-rock extracts, defined source-rock characteristics, and evaluate the extent of thermal maturity and biodegradation (Peters and Moldowan, 1993; Peters *et al*., 2005; Tao *et al*., 2015; Chen *et al*, 2024). Terrestrial input 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; Tao *et al*., 2015; Wang *et al*., 2015). C_{23} tricyclic terpanes is often the dominant biomarkers in crude oils generated from marine source rocks (Peters and Moldowan, 1993; Zhang and Huang, 2005; Peters *et al*., 2005; Hakimi *et al*., 2011; Tao *et al*., 2015; Sutadiwiria *et al*., 2022). Crude oil samples show The C19 tricyclic terpanes (TT) is generally more abundant than the C23 TT. Meanwhile in the source rocks extracts, the C19 TT is consistently less abundant than the C23 TT. Based on Peters *et al*. (2005), such TT distribution implicates that the source rocks were likely deposited in marine environments, while the oil samples might originate from terrestrial source (Figure 5).

The crude oil samples reveal that trisnorneohopane (Ts) is more abundant than trisnorhopane (Tm) (Ts > Tm), while the source rocks samples show lower Ts than Tm (Ts<Tm) (Figure 4). This suggests that the crude oils were generated from source rocks which are more mature (Seifer and Moldowan, 1978; Waples and Machihara, 1991; Peter *et al*., 2005).

Lacustrine sediment is commonly interpreted using ratios of C_{26}/C_{25} tricyclic terpanes and C_{31} 22R/C_{30} hopanes. Lacustrine sediments generally show the C_{26}/C_{25} tricyclic terpanes ratio of 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; Syaifudin and Subroto, 2024). The $C_{31}R/C_{30}$ hopanes ratio is used to distinguish between marine and lacustrine environments. This value is generally higher than 0.25 for marine environments and lower than 0.25 for lacustrine settings (Peters *et al*., 2005, Gulbay *et al*., 2012; Syaifudin and Subroto, 2024). It appears that crude oil samples in Jemakur-Tabuan Graben were generated from lacustrine sediments because they show high C_{26}/C_{25} tricyclic terpanes (Figure 5) and low C_{31} 22R/C_{30} hopanes (Figure 4). Meanwhile, source rock samples of Lemat and Talangakar Formations might be deposited in marine environments as indicated by low C_{26}/C_{25} tricyclic terpanes ratio (Figure 5) and high C_{31} 22R/C_{30} hopanes ratio (Figure 4).

Quantitative Methods

Pristane/phytane (Pr/Ph) ratios has been used to assess the redox potential of the depositional environment and source of organic matter (Tissot and Welte, 1984; Zhang and Huang, 2005; Peters *et al*., 2005; Hao *et al*., 2011; Hakimi *et al*., 2011; 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).

The cross plot of Pr/Ph – Pr/nC17 as proposed by Robinson (1991), indicates that most of the source rocks samples are related to oxic and terrestrial environments (Figure 6). The crude oil ratios appear in the anoxic – suboxic environments. This leads to interpretation that the organic matter of source rocks is likely dominated by higher plants, while that of the oils is dominated by algal/ bacterial origin.

The relative abundance of steranes to hopanes has been used to determine organic matter composition. High sterane/hopane ratios appear to be related to aquatic algae (Jiamo *et al*., 1990; El Diasty and Moldowan, 2012), whereas low sterane/ hopane ratios correspond to a terrigenous and/ or microorganism reworked organic matter source (Tissot and Welte, 1984; Jiamo *et al*., 1990; Robinson, 1991; Peters and Moldowan, 1993; El Diasty and Moldowan, 2012).

The cross plot of Pr/Ph – hopane/sterane as shown in Figure 7 demonstrates that most of studied source rock samples were influenced by highly oxidising and terrestrial environments. The crude oil samples appear to be influenced by terrestrial material in anoxic-suboxic conditions. In general, this interpretation is in agreement with that of pristane and phytane indicators.

The cross plot of Pr/nC_{17} – Ph/nC_{18} as proposed by Connan and Cassou (1980) (Figure 8), shows that source rocks samples of Lemat Formation are composed by humic kerogen, while those of Talangakar Formation consists of humic and mixed kerogen (humic and mostly sapropelic kerogen). Crude oil samples seem to be generated from humic and mixed kerogen and the plot also indicates that crude oil samples were generated from relatively more mature source rocks than the studied source rocks samples (Figure 8).

Waples (1985) stated that on the average, the $\delta^{13}C$ of oils are about 2 ‰ more negative (lighter) than that of kerogens. Oils having a disparity of the value larger than 3‰ generally do not have a genetic relationship (Peters *et al*., 2005). The cross plots of carbon isotope $\delta^{13}C$ of saturated vs aromatic fractions as proposed by Sofer (1984) (Figure 9) and carbon isotope $\delta^{13}C$ of saturated fraction – Pr/Ph as proposed by Bishop (2001) (Figure 10) suggest that source rock samples of Lemat and Talangakar Formations are related to mostly oxic conditions in marine settings (see Figure 7). Based on the plots, the crude oil samples are interpreted to be related with anoxic-suboxic conditions in terrestrial environment.

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; El Diasty and Moldowan, 2012; Ding *et al*., 2015; Sutadiwiria, 2022). The sterane distribution diagram of C_{27}, C_{28}, dan C_{29} (Figure 11) shows that source rocks of Lemat Formation were deposited in estuarine to terrestrial environments, while those of Talangakar Formation were deposited in open marine, estuarine to terrestrial environments. Most of the crude oil samples are related to shallow lacustrine environments. Crude oil samples (TG-11 and Geo-3) do not have correlation with source rocks of Lemat and Talangakar Formations. This is because TG-11 and Geo-3 samples are indicative for anoxic-suboxic environments and dominated by organic matter derived from algae (Figure 6). Besides that the crude oils were generated from more mature source rocks than the existing studied source rocks of Lemat and Talangakar Formations (see Figure 8).

Doust and Sumner (2007) and Doust and Noble (2008) stated that early synrift stage (typically Eocene to Oligocene) related with the period of rift graben formation and following period of maximum subsidence. Most of depositions were limited to early-formed half-grabens. During the syn-rift period, most of the grabens were filled with a sequence of alluvial and lacustrine to deltaic sediments, while during the latest synrift these were filled with an increasingly transgressive sediments. Ryacudu (2008) stated that the synrift sequence, Lahat Group, consists of Lemat and Benakat Formations with interfingering stratigraphic relationship. The main element of Lemat Formation comprises coarse clastic rock (sandstone) with Tuff Members and Conglomerate Members. Sandstone of Lemat Formation was deposited in fluvial environment, while conglomerates are interpreted as alluvial fan deposits. The Benakat Formation is dominated by fine clastic rock (shale) deposited in the lake system (lacustrine).

Based on these data, Lemat Formation is interpreted to have estuarine to terrestrial characteristics and Talangakar Formation is interpreted to have open marine, estuarine to terrestrial characteristics. Crude oils from Jemakur-Tabuan Graben are interpreted as being derived from the shallow lacustrine and terrestrial environments and does not have a correlation with source rocks from Lemat or Talangakar Formations in research area. Crude oils from Jemakur-Tabuan Graben are thus interpreted to originate from source rock of Benakat Formation.

CONCLUSIONS

Using combination of isotopic and biomarker indicators to analyze geochemical characteristics, we can conclude that source rocks of Lemat and Talangakar Formations in the Jemakur – Tabuan Graben were not deposited in lacustrine environments, as the value of C_{26}/C_{25} tricyclic terpanes ratio is smaller than 1. Source rocks of Lemat and Talangakar Formations consist of humic kerogen dominated by higher plants and largely influenced by terrestrial material on high oxic conditions. Based on tricyclic terpanes data, source rocks of Lemat and Talangakar Formations show delta and marine settings. Source rocks of Lemat and Talangakar Formations were interpreted to have deltaic characteristics.

Crude oils in the Jemakur – Tabuan Graben are interpreted to be derived from a shallow lacustrine sedimentary rocks because of the higher ratio of C_{26}/C_{25} tricyclic terpanes (>1) and low C_{31} 22R/C_{30} hopanes. Their source rocks mostly consist of mixing kerogen, and are dominated by algae-derived organic matter, relatively more mature than the existing studied source rocks, and related to terrestrial input on anoxic-suboxic conditions.

As conclusion, there is an oil family with lacustrine characteristics in the research area but it was not generated from source rock of Lemat and Talangakar Formations. Their source rocks might be part of the Benakat Formation.

ACKNOWLEDGEMENTS

We would like to thank the management of Directorate General of Oil and Gas and Medco EP for their permission to publish this paper.

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Table 1. Comparison of oil families and analysis performed on the source rocks and oils from some researchers.

No	Researchers	Research area	Source Rock Analysis						Oil Analysis				Correlation		Oil Family
			TOC	Pyrolisis	Maturity	GC	GC-MS	Carbon Isotope	Bulk Composition	GC	GC-MS	Carbon Isotope	Oil-Oil	Source rock-Oil	
1	Robinson (1987)	South Sumatra Basin	✓	✓	–	✓	–	–	✓	✓	✓	✓	✓	✓	Fluvio-deltaic
2	Suseno et.al. (1992)	South Palembang Subbasin	✓	✓	✓	✓	✓	–	–	✓	✓	–	✓	✓	Fluvio-deltaic and shallow marine
3	ten Haven and Schiefelbein (1995)	South Sumatra Basin	–	–	–	–	–	–	✓	✓	✓	✓	✓	–	Lacustrine, deltaic and resinitic.
4	Ginger and Fielding (2005)	South Sumatra Basin	–	–	–	–	–	–	–	✓	–	✓	✓	–	Lacustrine, fluvio-deltaic, and terrigeneous
5	Noble et al. (2009)	South Sumatra Basin	–	–	–	–	–	–	Using data of oil family from Robinson (1987), ten Haven and Schiefelbein (1995), Schiefelbein et al. (1997), and Peters et al. (1999)				✓	–	Lacustine and deltaic
6	Rashid et al. (1998)	Musi Platform and Palembang High	–	–	–	–	–	–	–	✓	✓	–	✓	–	Lacustrine, marine, terrestrial (deltaic-marine, fluvio-deltaic and resinitic/oleanane
7	Sarjono and Sardjito (1989)	South Palembang Subbasin	✓	✓	✓	–	–	–	–	–	–	–	–	–	–

p-ISSN 2356-024X
e-ISSN 2987-100X

Table 2. Biomarker data of source rocks and oil families in the research area. (Abbreviations: LAF= Lemat Formation; TAF = Talangakar Formation; BRF = Baturaja Formation; GUF= Gumai Formation).

No	Source Rocks (LAF)	Tot Hop/ Tot Ster	Pr/nC_{17}	Ph/nC_{18}	Pr/Ph	C_{27}	C_{28}	C_{29}	$\delta^{13}C$ sats	$\delta^{13}C$ aroms
1	Geo-1, 3560 ft, LAF	3.95	13.00	0.90	8.67	39.44	7.04	53.52	-28.92	-27.88
2	Geo-2, 2700 ft, LAF	5.57	2.80	0.71	5.80	18.36	19.06	62.58	-29.12	-27.79
3	Geo-3, 2600 ft, LAF	7.60	2.67	0.60	6.89	16.21	22.09	61.70	-29.12	-27.72
4	Geo-4, 1400 ft, LAF	1.52	6.55	-	2.43	37.02	24.63	38.35	-30.10	-28.82
5	Geo-4, 1390-1400 ft, LAF	9.66	9.92	0.73	10.82	23.41	11.64	64.95	-28.02	-26.92
6	Geo-5, 2775 ft, LAF	10.32	12.63	1.88	9.54	15.05	24.12	60.83	-27.69	-25.99
7	Geo-6, 3775 ft, LAF	5.16	4.02	1.03	6.44	12.15	18.99	68.86	-29.43	-27.69
No	**Source Rocks (TAF)**	**Tot Hop/ Tot Ster**	**Pr/nC_{17}**	**Ph/nC_{18}**	**Pr/Ph**	**C_{27}**	**C_{28}**	**C_{29}**	**$\delta^{13}C$ sats**	**$\delta^{13}C$ aroms**
8	Geo-2, 2638 ft, TAF	2.49	2.13	0.92	3.21	25.33	26.58	48.09	-28.82	-26.76
9	Geo-3, 2488 ft, TAF	24.95	8.36	1.03	11.65	2.94	15.87	81.19	-27.62	-26.46
10	Geo-4, 1160 ft, TAF	8.06	2.67	0.60	6.89	2.89	6.98	90.13	-30.52	-28.62
11	Geo-5, 2340 ft, TAF	4.07	1.70	0.51	5.83	28.13	29.73	42.14	-28.50	-27.78
12	Geo-5, 2420 ft, TAF	11.35	14.71	0.89	12.88	18.04	19.07	62.89	-	-
13	Geo-6, 3565 ft, TAF	7.23	4.57	1.03	7.10	10.89	19.57	69.54	-28.66	-26.23
14	Geo-7, 3340 ft, TAF	1.43	12.15	1.38	7.18	49.81	19.16	31.03	-29.97	-27.26
15	Geo-7, 3470 ft, TAF	2.41	7.14	0.87	5.77	42.17	18.37	39.46	-25.81	-27.07
No	**Oils Family**	**Tot Hop/ Tot Ster**	**Pr/nC_{17}**	**Ph/nC_{18}**	**Pr/Ph**	**C_{27}**	**C_{28}**	**C_{29}**	**$\delta^{13}C$ sats**	**$\delta^{13}C$ aroms**
1	TG-1, 2667-2698 ft, BRF	14.13	0.49	0.27	2.69	32.73	23.63	43.64	-28.70	-27.40
2	TG-2, 2552-2562 ft, TAF	12.67	0.82	0.28	2.68	39.29	21.43	39.28	-28.70	-27.70
3	TG-3, 2847-2913 ft, TAF	10.67	0.79	0.35	2.47	36.40	21.20	42.40	-28.60	-27.50
4	TG-4, 3431-3440 ft, LAF	13.80	0.83	0.30	2.67	33.33	18.51	48.10	-28.90	-27.70
5	TG-4	14.22	0.47	0.14	3.53	25.09	20.58	54.33	-28.47	-27.69
6	TG-5, 2290-2321 ft, TAF	5.75	1.72	0.42	2.97	34.38	28.13	37.50	-28.70	-27.30
7	TG-6, kondensat, BRF	45.69	-	-	1.00	35.92	25.71	38.37	-	-
8	TG-7, 2763 ft	11.44	0.79	0.21	3.98	34.91	21.00	44.09	-29.66	-28.00
9	TG-8, 5318-5330 ft, BRF	11.19	0.98	0.24	4.87	29.01	25.09	45.30	-29.03	-27.83
10	TG-9, 3050 ft, BRF	-	-	-	-	28.49	25.79	45.72	-28.78	-27.74
11	TG-9, 3056 ft, BRF	-	-	-	-	28.30	26.85	44.85	-28.75	-27.69
12	TG-10, 2779 ft, BRF	-	0.99	0.26	4.99				-29.70	-27.70
13	TG-11, 2174-2184 ft, GUF	-	0.50	0.15	3.61	20.71	19.70	59.59	-29.27	-27.36
14	TG-12, 1095-1105 ft, TAF	-	-	-	-	34.00	18.90	47.20	-28.60	-27.60
15	Geo-2	11.61	0.43	0.15	3.37	30.83	28.50	40.67	-29.42	-27.91
16	Geo-3	10.72	0.42	0.12	3.74	20.00	22.76	57.24	-27.18	-26.28

DOI: https://doi.org/10.31315/jigp.v13i1.17079
e-ISSN 2987-100X

Table 3. Tricyclic terpanes data of oils and source rocks of Lemat and Talangakar Formations in the research area. (Abbreviations: LAF= Lemat Formation; TAF = Talangakar Formation).

Oils	Norm % Tricyclic Terpane							
	C_{19}	C_{20}	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}
TG-4	17.81	12.83	19.09	7.43	18.30	18.11	6.42	8.00
Geo-2	23.61	13.32	18.10	5.75	16.97	16.41	5.83	8.00
Geo-3	26.83	13.82	18.28	6.51	15.12	14.75	4.71	7.00
Source Rocks	**Norm % Tricyclic Terpane**							
	C_{19}	C_{20}	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}
Geo-2 (2,700 ft, LAF)	11.50	14.29	20.93	5.23	26.33	15.16	6.55	4.60
Geo-4 (1,400 ft, LAF)	10.72	11.66	23.25	5.11	29.26	14.78	5.22	3.56
Geo-3 (2600 ft, LAF)	13.18	9.49	25.36	4.59	26.63	14.69	6.05	4.21
Geo-2 (2,638 ft, TAF)	9.93	6.93	25.23	5.12	28.42	17.57	6.81	5.70
Geo-5 (2,340 ft, TAF)	5.12	10.90	21.30	2.60	34.46	18.16	7.45	6.20
Geo-4 (1160 ft, TAF)	14.34	10.37	22.49	6.40	24.92	15.73	5.75	3.60

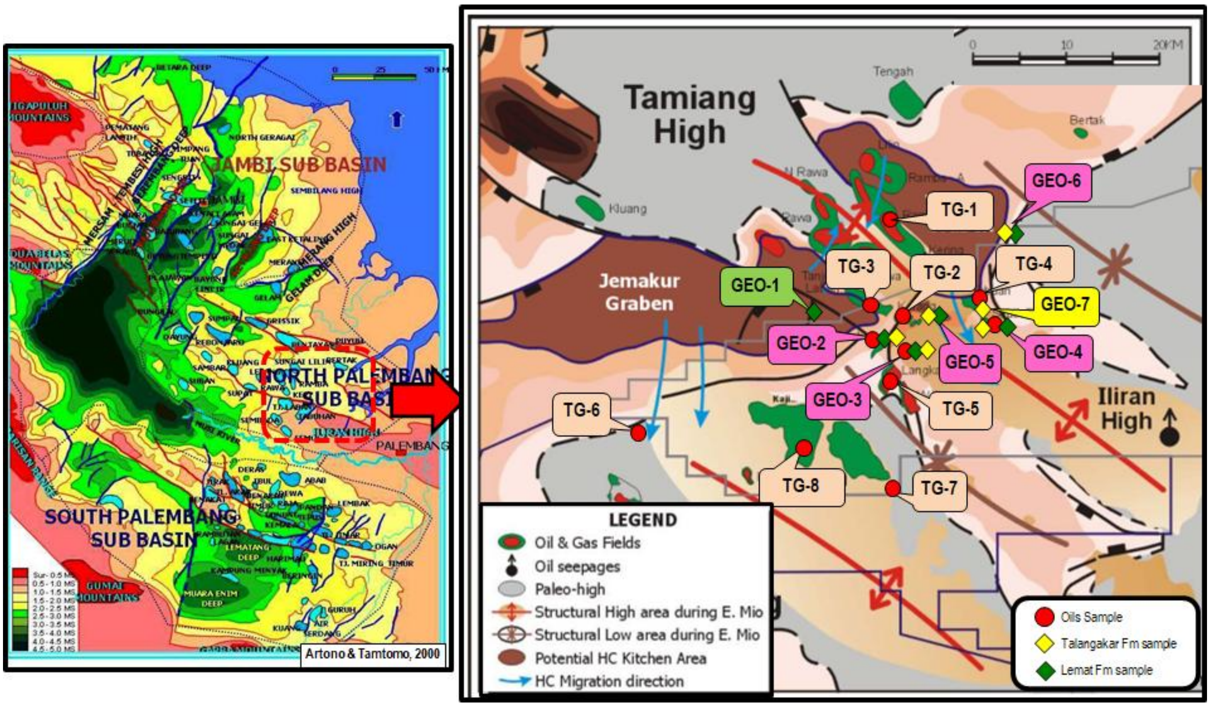

Figure 1. South Sumatra Basin (A) (modified Artono and Tamtomo, 2000) and location of study area and Paleogene geographic map showing potential hydrocarbon kitchen areas in the Jemakur and Tabuan Grabens superimposed with regional structural elements during the Early Miocene (B) (modified from Firmansyah *et al*., 2007).

p-ISSN 2356-024X
e-ISSN 2987-100X

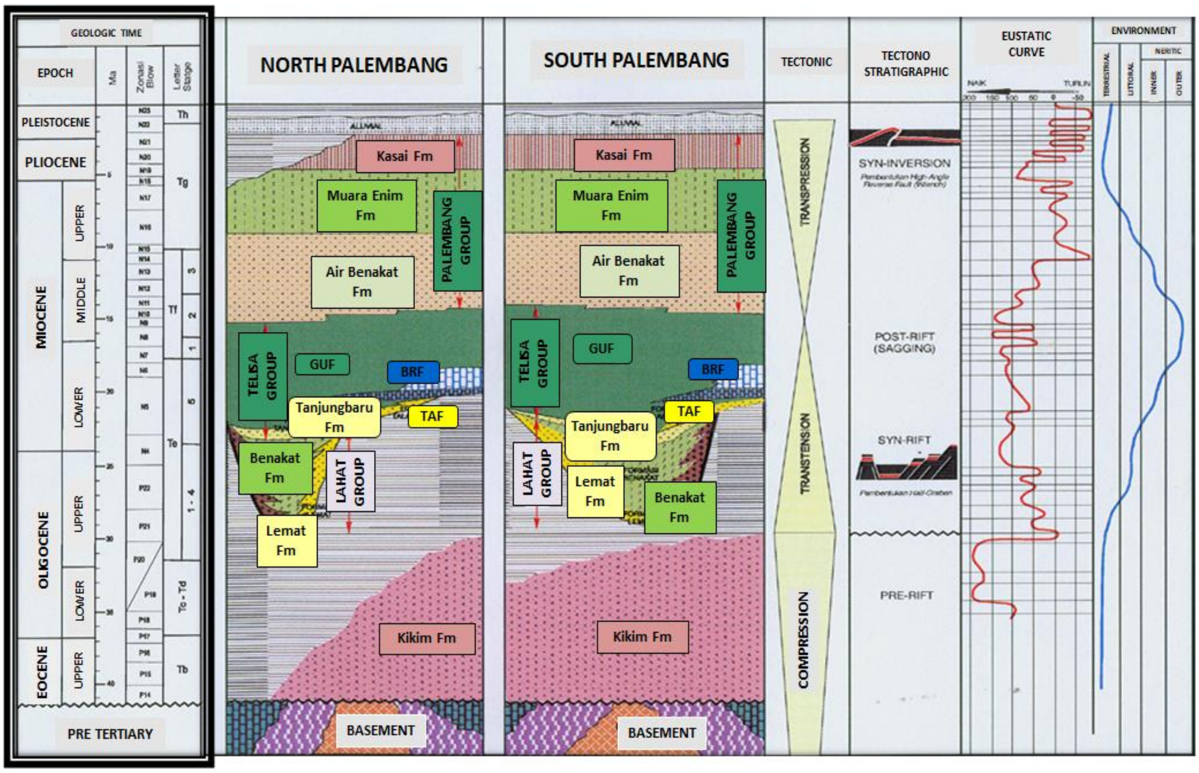

Figure 2. Regional stratigraphy of the South Sumatra Basin (modified from Ryacudu, 2008).

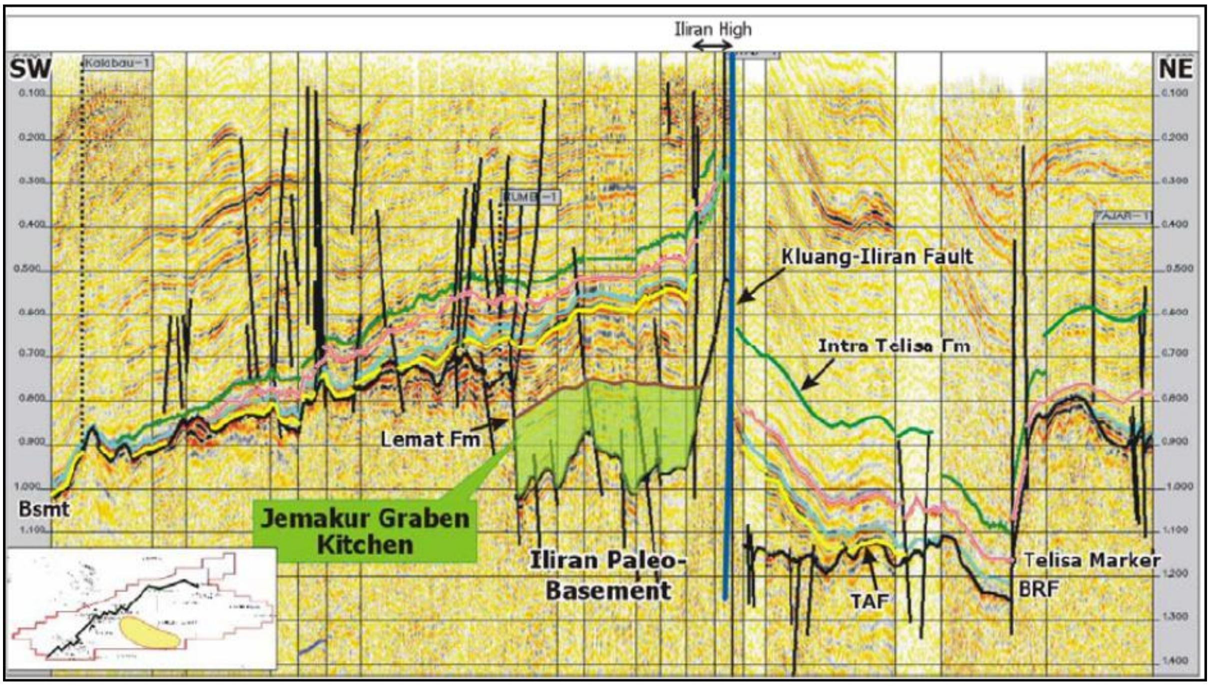

Figure 3. Regional seismic line in the Palembang High area showing the present day Jemakur Graben where the Lemat Formation lacustrine source facies was deposited. (Abbreviations: TAF= Talangakar Formation; BRF= Baturaja Formation) (Firmansyah et al., 2007).

 p-ISSN 2356-024X
e-ISSN 2987-100X

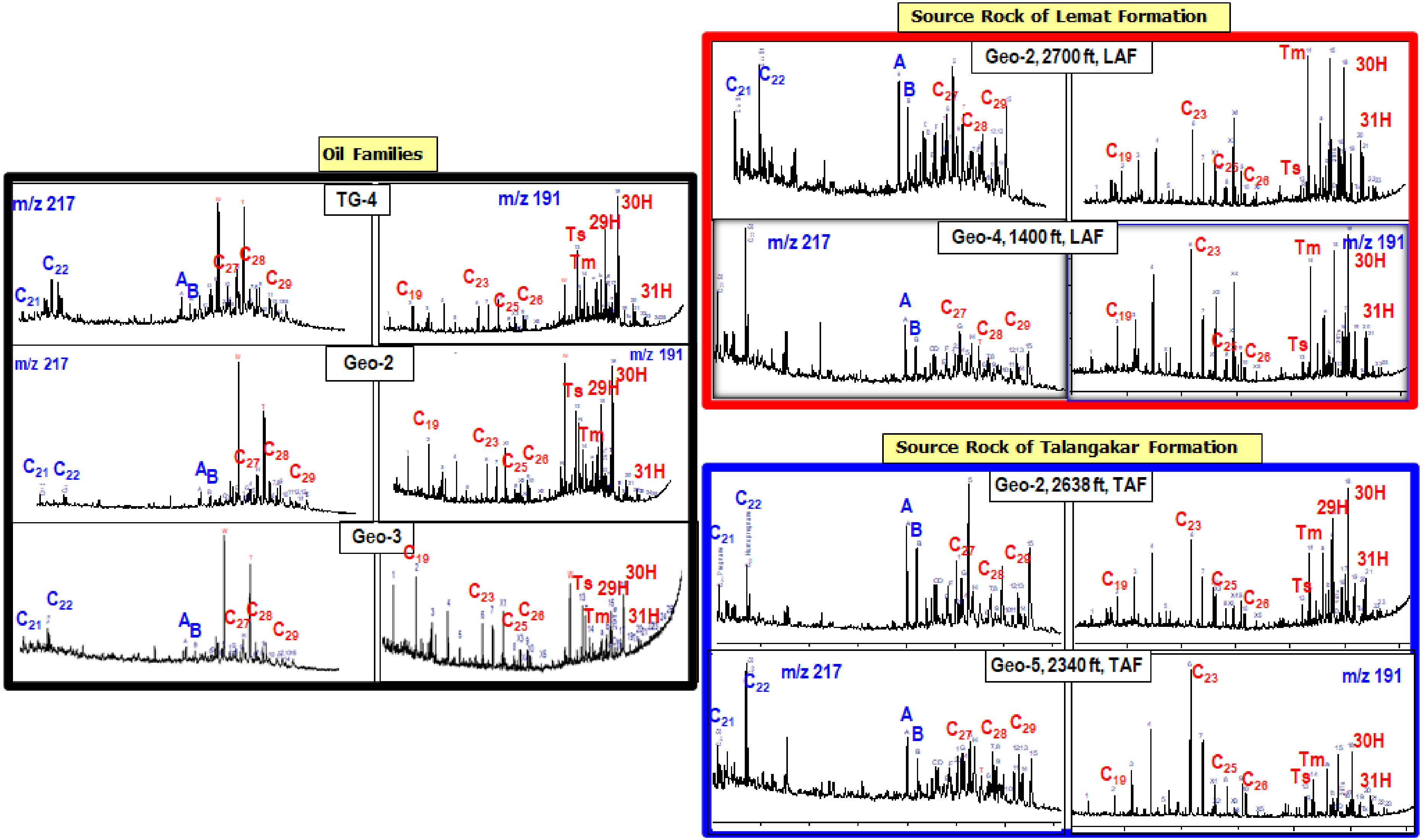

Figure 4. Comparison of biomarker characterization qualitatively between crude oils and source rocks of Lemat (LAF) and Talangakar Formations (TAF) in the research area.

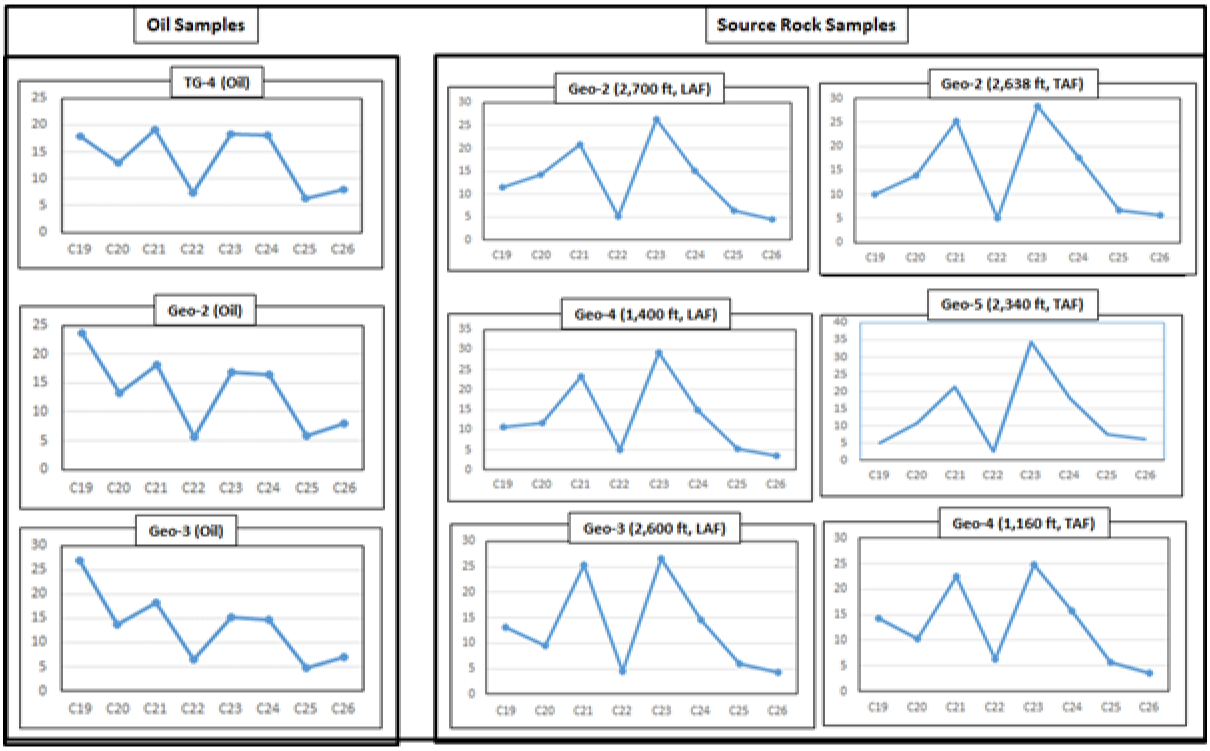

Figure 5. Distribution of tricyclic terpane of oils and source rocks of Lemat (LAF) and Talangakar Formations (TAF), in the research area.

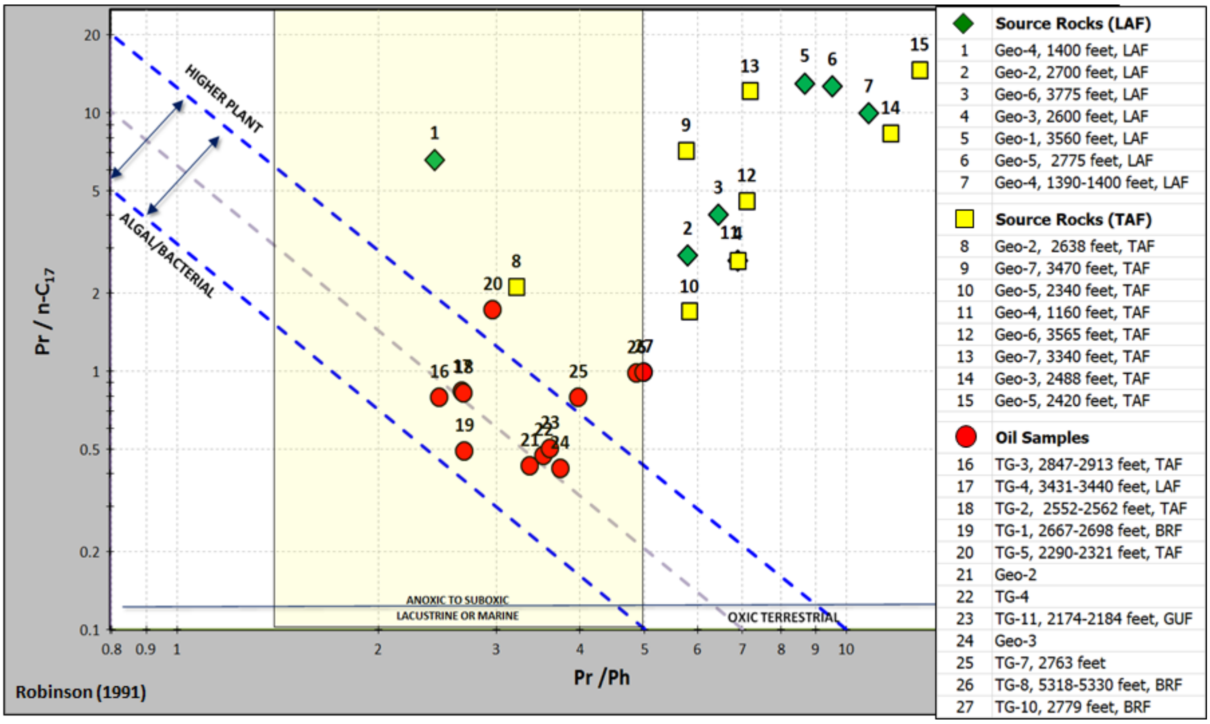

Figure 6. Cross plot of Pr/Ph – Pr/nC$_{17}$, based on Robinson, 1991, source rocks of Lemat (LAF) and Talangakar Formations (TAF), and oils in in the research area.

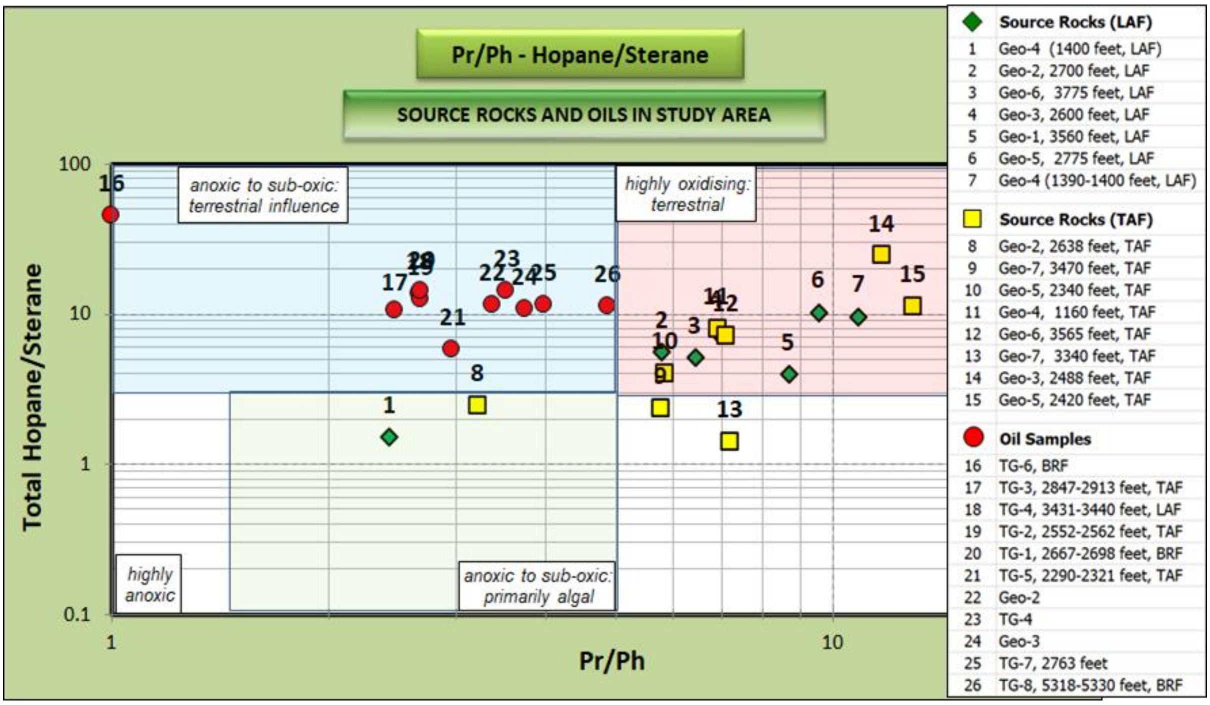

Figure 7. Cross plot of Pr/Ph – hopane/sterane, based on Robinson, 1991, source rocks of Lemat (LAF) and Talangakar Formations (TAF), and oils in the research area.

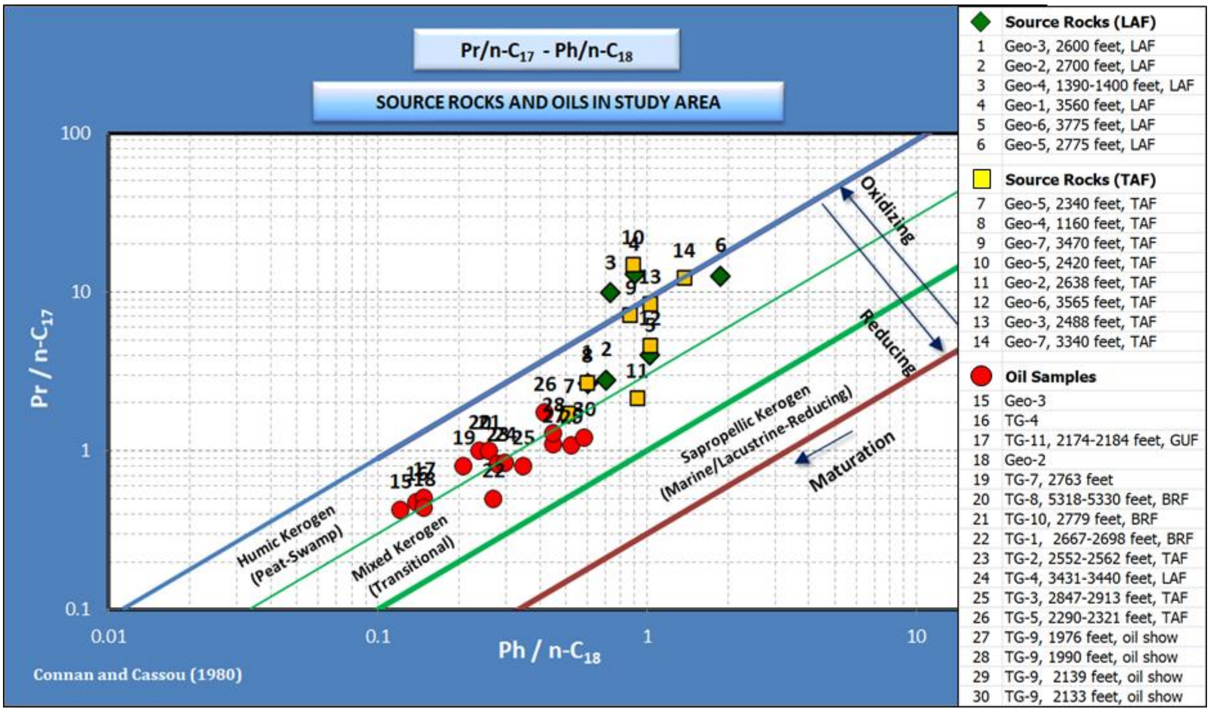

Figure 8. Cross plot of Pr/nC_{17} – Ph/nC_{18}, based on Connan and Cassou, 1980, source rocks of Lemat (LAF) and Talangakar Formations (TAF), and oils in the research area.

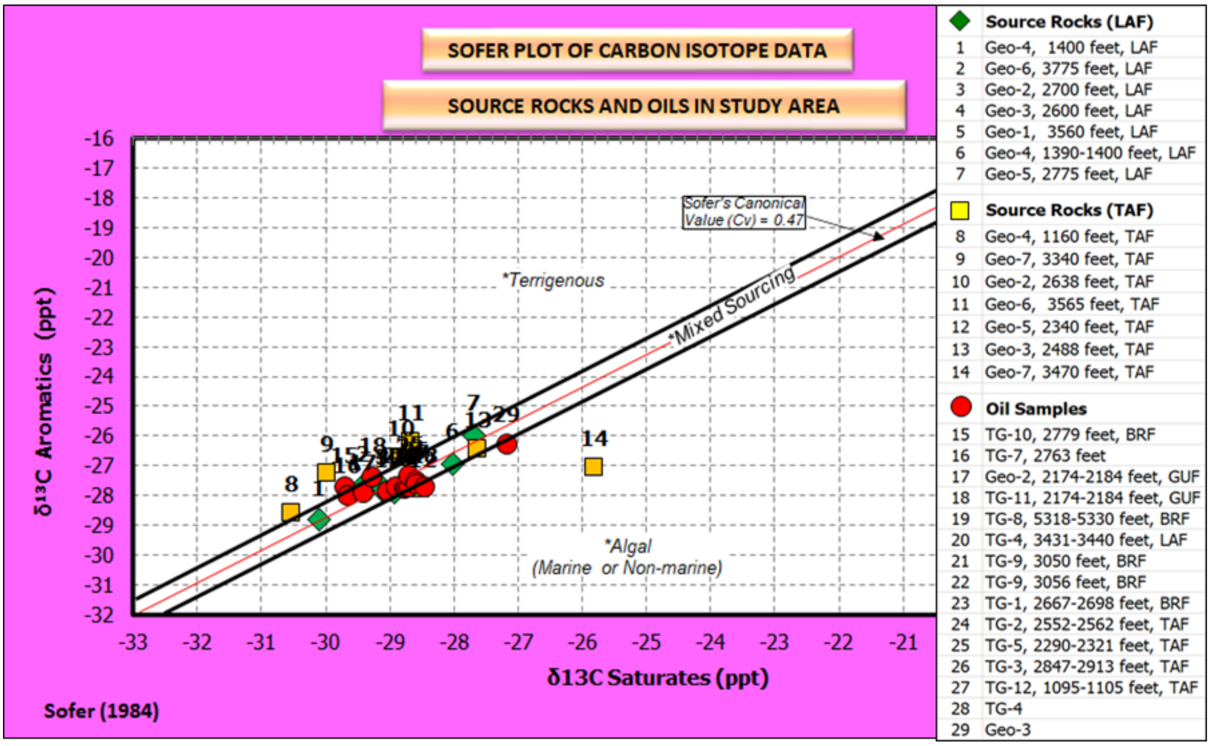

Figure 9. Cross plot of carbon isotope δ^{13}C saturates – δ^{13}C aromatics based on Sofer, 1984, source rocks of Lemat (LAF) and Talangakar Formations (TAF), and oils in the research area.

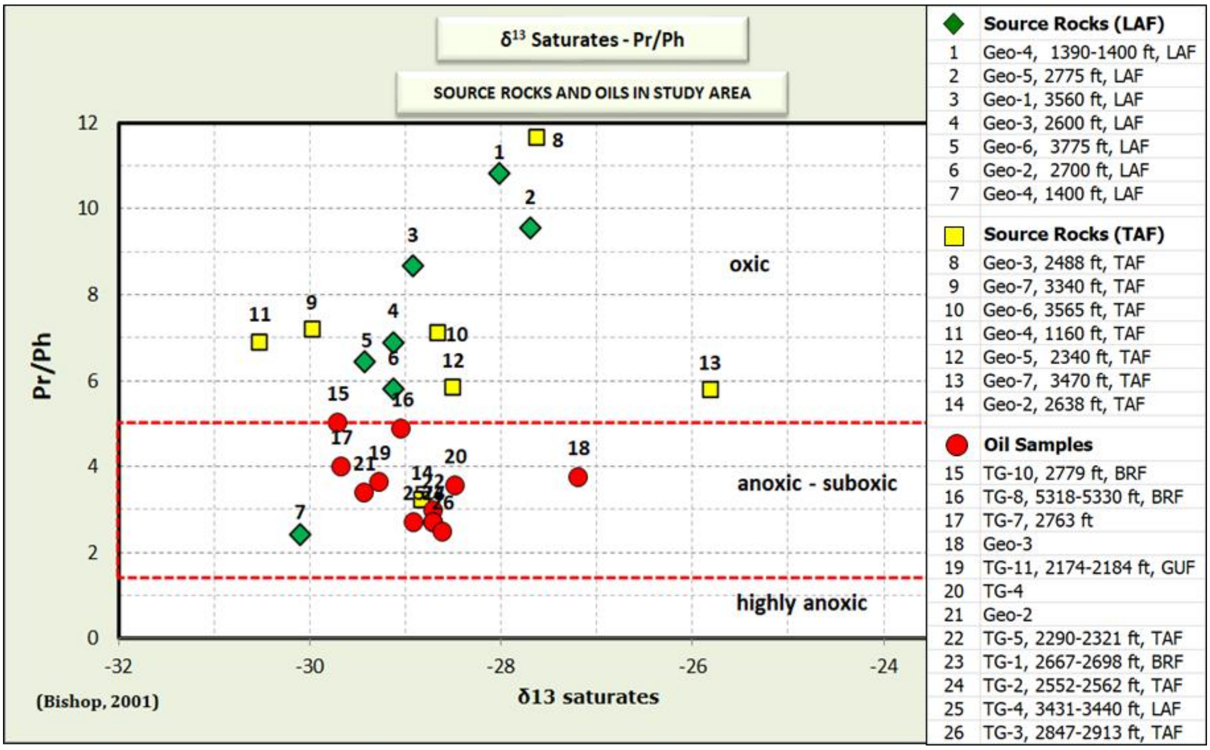

Figure 10. Cross plot of carbon isotope δ^{13}C saturates – Pr/Ph, based on Bishop, 2001, source rocks of Lemat (LAF) and Talangakar Formations (TAF), and oils in the research area.

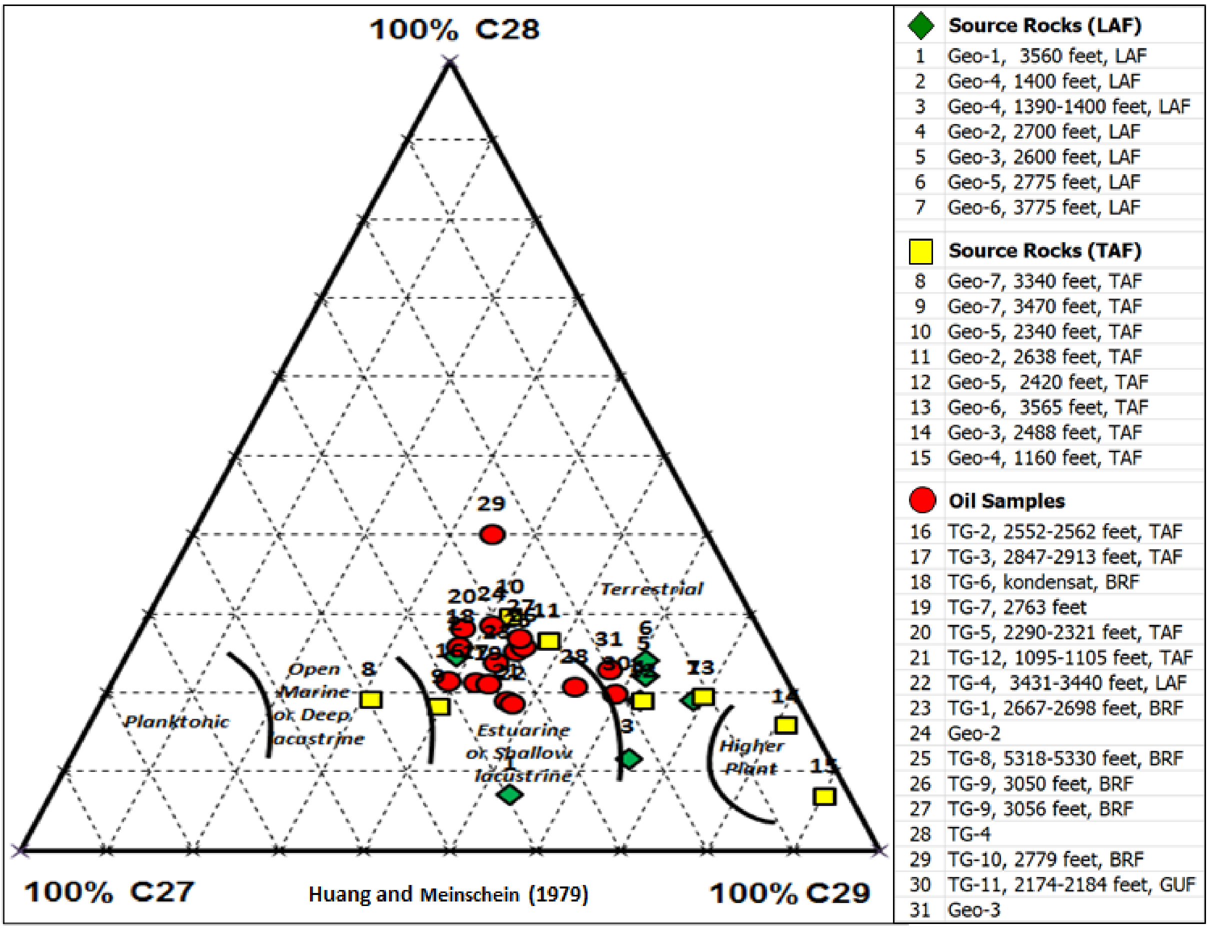

Figure 11. Cross plot of sterane distribution C_{27}, C_{28}, and C_{29} based on Huang and Meinschein, 1979, source rocks of Lemat (LAF) and Talangakar Formations (TAF), and oils in the research area.