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GEOCHEMICAL ASSESSMENT OF LATE PALEOGENE SYNRIFT SOURCE ROCKS IN THE SOUTH SUMATRA BASIN

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ABSTRACT: The potential of Late Paleogene synrift source rocks in generating hydrocarbons within the South Sumatra basin has been evaluated using geochemical and pyrolytic techniques. The samples were collected from the outcropping shales of different layers constituting the Upper Oligocene Talang Akar Formation. Results of TOC analysis reveal minor quantities of organic carbons, indicating poor to fair potential source rocks. The S_2/S_3 ratios indicate two apparent kerogen types. The majority of the samples is type III kerogen; however, there appears minor type IV kerogen, implying the oxydized organic matter and no expulsion. The S_1+S_2 measurement of all the pyrolysed rocks, except one sample LP 12A, yields less than 1 mg HC/g rock, supporting the proposed scenario of little potential to generate hydrocarbons. Evaluation of hydrogen and oxygen indices confirms a gas prone source, but all the shales analyzed, disregarding one sample LP 18, provide a direct evidence that the rock section is immature to early mature to expel oil. Important notes can be made that the early stage of organic maturation might have occurred due to heating, as a result of deeper burial during Miocene time prior to the subsequent uplift in response to the Plio-Pleistocene orogeny.

Keywords: Geochemistry, Outcrops, Pyrolysis, Source Rock, Thermal Maturity

1. INTRODUCTION

The organic geochemical study reported in the present paper aimed to evaluate potential source rocks, and to assess thermal maturity of the rock succession in the Paleogene South Sumatra basin. Tectonically, the study area lies in the South Palembang subbasin, situated around the southern part of South Sumatra basin (Fig. 1). The initial subsidence of the basinal area has commonly been attributed to extensional forces occurred in the southwestern margin of Sundaland during the Late Eocene [1]. Several workers have suggested that an early episode of depression began in the Early Tertiary as rifts, in which the synrift clastic materials accummulated in a terrestrial environment [2]-[3].

The synrift sedimentation in the basin continued as the rifting event proceeded, and the shoreline migrated landward because of the occurring transgression during Late Oligocene-early Middle Miocene times. This transgressive phase resulted in successively from lower to upper units the Talang Akar Formation, the Baturaja Formation, and the Gumai Formation. At this time, the basin was mostly under the influence of tensional stresses responsible for widening the depocenter area. In the late Middle Miocene a transgressive event in the basinal area ceased, the sea level dropped, a regressive regime commenced, and the region was predominantly controlled by compressive strain fields for the rest of Tertiary times. This regime formed consecutively the Air Benakat Formation, the Muara Enim Formation, and the Kasai Formation (Fig. 2). In the Plio-Pleistocene, the whole sedimentary successions of the region were uplifted due mainly to orogeny. The late Tertiary orogenic event is considered to be the latest tectonic deformation that has been responsible for the present geologic configuration of the Paleogene South Sumatra basin. A particular interest of the present study is the Talang Akar Formation. This work has employed conventional geochemical analyses and pyrolysis measurements for the sampled sections.

2. METHODS

Organic geochemistry is an important tool to identify the quality of prospective source rocks with respect to hydrocarbon generation [5]-[6]. The present study has employed the widely used geochemical technique to determine total organic carbon (TOC wt. %), and pyrolysis measurements to gain the values of hydrogen index (HI mg HC/g C), oxygen index (OI mg CO_2/g C), and maximum temperature (T_{max} ºC). In interpretation of the TOC data, this study implements the accepted geochemical model [7], suggesting that the TOC content of 1.0 wt. % is the lower limit for identifying hydrocarbon expulsion from source rocks.

The measurement of pyrolytic contents utilizes Rock-Eval instrument to calculate the following parameters:

- Hydrogen Index (HI) = (S_2/TOC) x 100 (mg HC/g C)
- Oxygen Index (OI) = (S_3/TOC) x 100 (mg CO_2/g C)
- Hydrocarbon type (HT) = S2/S3 (mg HC/g rock)
- Production Index (PI) = $S_1/(S_1+S_2)$

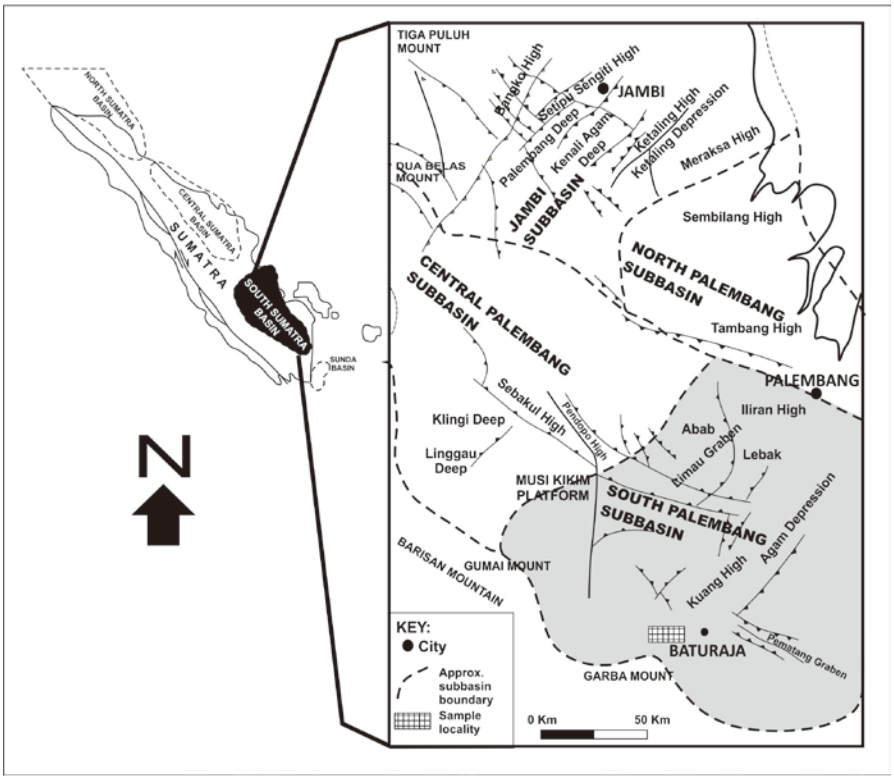
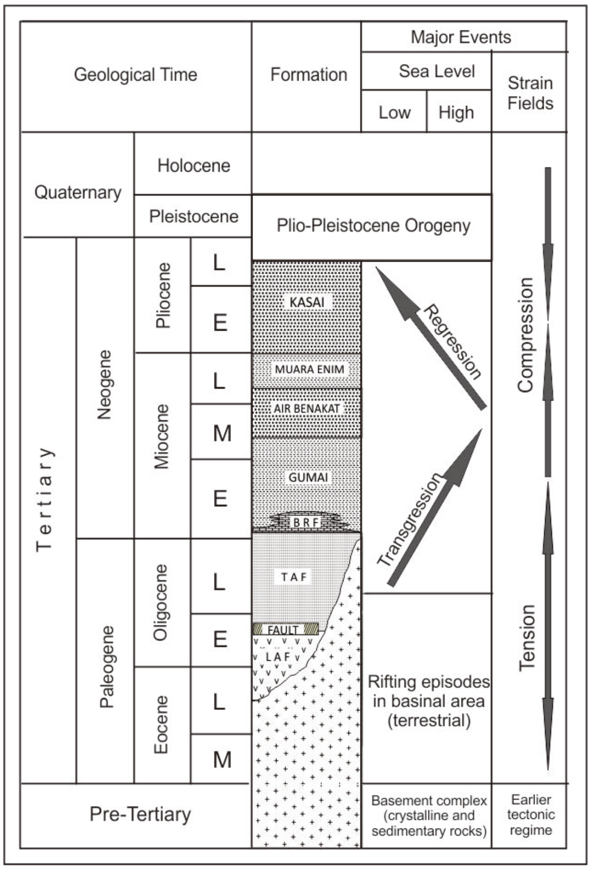


Fig. 1 Main structural features in the Paleogene South Sumatra basin. The study area is situated in the South Palembang subbasin (modified from [4])



LAF: Lahat Formation; TAF: Talang Akar Formation;
BRF: Baturaja Formation

Fig. 2 Generalized stratigraphy of South Sumatra basin

Determination of hydrocarbon types follows the accepted values [5]. According to this author, the HT value of less than 2.5 mg HC/g rock is defined as dry gas, ranging from 2.5 to 5.0 mg HC/g rock is classified as wet gas, and higher than 5.0 mg HC/g rock is considered as oil. The sum of S_1+S_2 components define genetic potential for hydrocarbon yield due principally to heating, hence the given values suggest the amount of total hydrocarbons. In this respect, S_1 represents the amount of free hydrocarbons (mg HC/g rock) released by volatilization at elevated temperatures, whereas S_2 is the value of HC quantity (mg HC/g rock) resulted from further heating of kerogen during experimental work. Assessment for total potential of source rock refers to as the published classifications [7] as follows:

- values of less than 2.0 mg HC/g rock are classified as little potential for oil generation, possibly some potential for gas prone
- values ranging from 2.0 to 6.0 mg HC/g rock are considered to be moderate or fair source potential
- values of higher than 6.0 mg HC/g rock are typical indicators of good to excellent source potential

In order to assess thermal maturity of the source section, the present study used T_{max} data and PI values, and compared the resulted interpretations to the previously reported models cited elsewhere in many published works [7]. This study has also compiled the geological data available, such as regional geology and stratigraphy to support interpretations of geochemical data and pyrolytic parameters.

3. SAMPLE DETAILS

Varieties of strata constituting the Upper Oligocene Talang Akar Formation have been observed in the studied region. Nine rock specimens were collected from this section, particularly from exposures along Lengkayap river (LP 04, LP 11, LP 12A, LP 12B, 24, and LP 25) and Napalan river (LP 16, LP 17, and LP 18). Fig. 3 shows the locality of shale outcrops sampled for geochemical analyses discussed in this article. The outcrops were investigated based mainly on lithologic and sedimentologic characteristics. Shales in the Talang Akar sequence are commonly silty or sandy and coaly, and these rocks are mostly brown and gray. Details of the rock samples such as locality, stratigraphic age, stratigraphic unit, and types of lithology are displayed in Table 1.

Table 1 Sample details showing locality, stratigraphic age, stratigraphic unit, and lithology

Sample No.	Locality			Stratigraphic Age	Stratigraphic Unit	Lithology
	River	Longitude (ºE)	Latitude (ºS)			
LP 04	Lengkayap	104º 05' 54.9"	4º 19' 48.7"	Upper Oligocene	Talang Akar Formation	Brown shale
LP 11	Lengkayap	104º 06' 04.9"	4º 19' 52.9"			Gray shale
LP 12A	Lengkayap	104º 06' 07.3"	4º 19' 52.2"			Brown shale
LP12B	Lengkayap	104º 06' 07.3"	4º 19' 52.2"			Gray shale
LP 16	Napalan	104º 06' 54.9"	4º 22' 47.5"			Brown shale
LP17	Napalan	104º 06' 57.5"	4º 22' 37.5"			Gray shale
LP18	Napalan	104º 06' 57.0"	4º 22' 35.3"			Gray shale
LP 24	Lengkayap	104º 05' 26.5"	4º 19' 45.3"			Brown shale
LP 25	Lengkayap	104º 05' 26.2"	4º 19' 45.6"			Brown shale

4. GENERAL GEOLOGY

The study area is situated in the South Palembang subbasin, which is one of four subbasins within the Paleogene South Sumatra basin (Fig. 1). The basin has long been recognized as one of hydrocarbon producing basins in Sumatra. The island of Sumatra is part of Sundaland located in the southwestern portion of SE Asian continent. The tectonic evolution of the region during Tertiary times has been discussed in many published works [1], [8]-[9]. The more recent overview of the development of Sundaland from the Late Palaeozoic to the Late Mesozoic has also been presented [10]. However, discussion in details the regional tectonics of this landmass is beyond the main aims of the present study.

Regional geology of the South Sumatra basin has been presented elsewhere, and commonly discussed on the basis of a wide variety of views. The basin is an asymmetric depocenter, bounded by the Barisan Mountains to the southwest, the Sunda platform to the northeast, the Tigapuluh Mountains to the northwest, and the Lampung High to the southeast [2]. It has generally been acknowledged that subsidence in basinal area was initiated by tensional stresses occurring in the southwestern margin of Sundaland during Late Oligocene to Early Miocene times [3], [11].

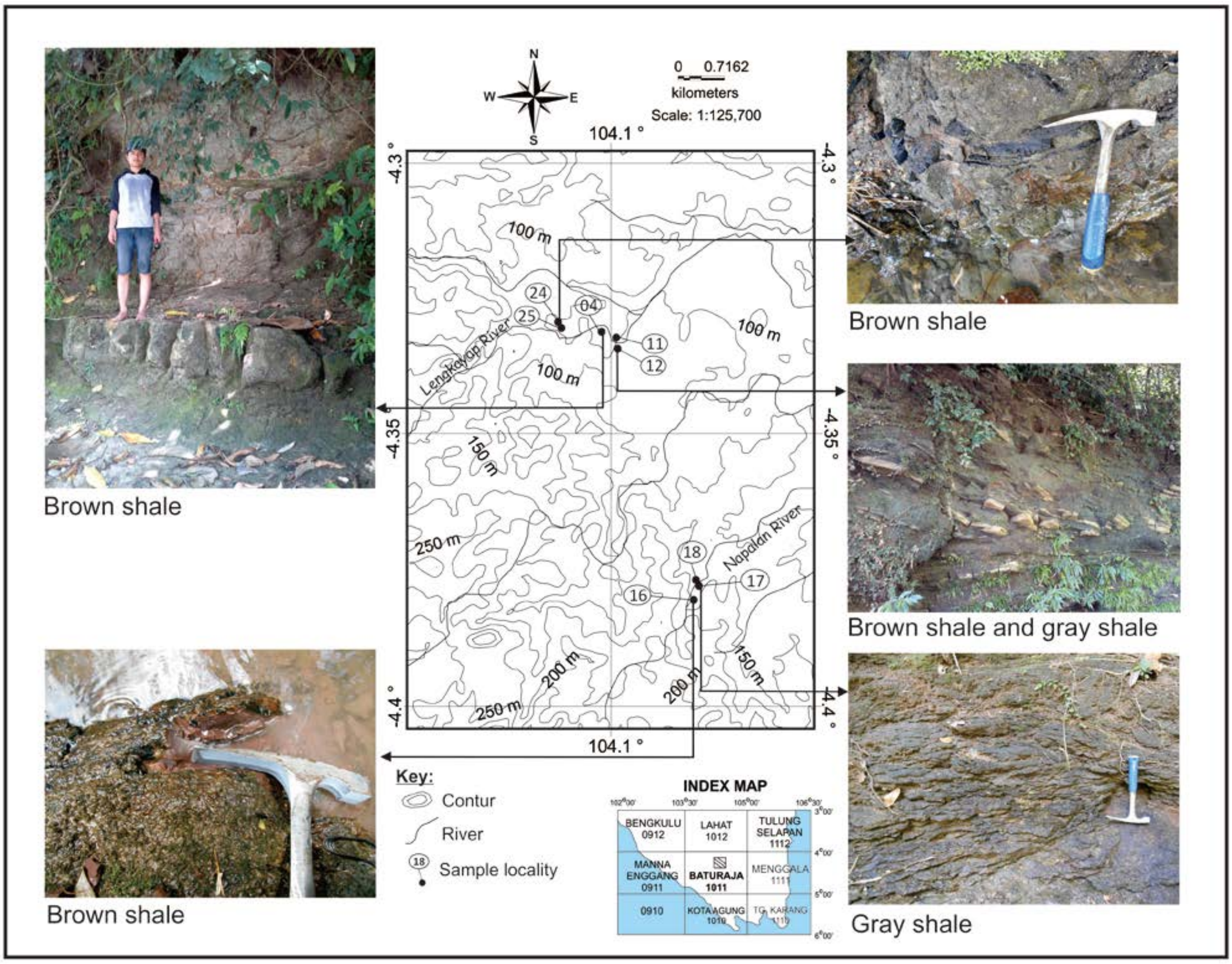


Fig. 3 A topographic map showing the locality of shale beds collected for geochemical analyses. Also shown are the sample numbers and some outcrop photographs

The tension is considered to have been responsible for the commencement of rifting in a back-arc setting. The back-arc basins extending along the eastern section of the island, namely North Sumatra basin, Central Sumatra basin, and South Sumatra basin, were formed during the Late Eocene or at ~40 Ma [1]. There were at least three stages of rifting within the basinal area [12]. These authors suggest that the early-, middle-, and late-rift episodes were followed respectively by the deposition of predominantly non-marine sediments, deep and broad lacustrine clastics, and coarse clastic fluvio-deltaic facies. In the case of Talang Akar Formation, the deposition of rock sequence commenced during the early rift stage in the Late Oligocene. The generalised stratigraphic column of the basin has been presented elsewhere by various workers [2], [13]-[16].

In terms of a regional structural setting, the basin comprises at least two main components. These include (1) half graben, horst, and faulted blocks involving the Mesozoic basement [2], [17], and (2) the NW-SE trending structures and depression to the northeast. The structures in the region were broadly resulted from the Late Neogene Barisan orogeny due to oblique convergence between the Indo-Autralian and Eurasian plates [2]-[3], [11], [17]. These structural features, especially folds and faults appear to have controlled a general pattern of stratigraphic exposures, involving both the pre-Tertiary basement sequence and the Tertiary sedimentary cover [3]. The basement exposures occur particularly in areas of block faulting, whereas the overlying successions tend to follow the regional strike of anticlinoria.

5. RESULTS AND INTERPRETATIONS

A number of selected outcrops of the Upper Oligocene Talang Akar Formation have been analyzed to obtain organic geochemical data and pyrolysis values. Results of the present analysis were compared with those of the published work [18] in order to better understand geochemistry of the source system throughout the region. Table 2 shows the analytical results of geochemical analysis and pyrolysis measurements of the rock samples.

Table 2 Geochemical and pyrolysis analytical results from the sampled rock sequence

Sample No.	TOC	S_1	S_2	S_3	HI	OI	TP (S_1+S_2)	HT (S_2/S_3)	PI S_1/(S_1+S_2)	OM
LP 04	0,11	0,06	0,09	0,06	81,52	54,35	0,15	1,50	0,40	421
LP 11	0,90	0,06	1,04	0,62	115,57	68,90	1,10	1,68	0,06	415
LP 12A	0,61	0,04	0,31	0,75	51,01	123,42	0,35	0,41	0,11	417
LP12B	0,81	0,05	0,46	0,52	56,83	64,25	0,51	0,89	0,10	412
LP 16	0,08	0,02	0,05	0,04	61,65	49,32	0,07	1,25	0,29	380
LP17	1,55	0,03	0,10	0,25	6,44	16,09	0,13	0,40	0,23	407
LP18	1,16	0,04	0,07	0,17	6,06	14,72	0,11	0,41	0,36	514
LP 24	1,00	0,06	0,74	0,86	73,79	85,75	0,80	0,86	0,08	396
LP 25	1,04	0,06	0,91	0,72	87,37	69,12	0,97	1,26	0,06	411

TOC: total organic carbon (wt. %); S_1: amount of free hydrocarbon (mg HC/g rock); S_2: amount of hydrocarbon from heating (mg HC/g rock); S_3: organic carbon dioxide; HI: hydrogen index [(S_2/TOC)x100] (mg HC/g C); OI: oxygen index [(S_3/TOC)x100] (mg CO_2/g C); TP: total potential (mg HC/g rock); HT: hydrocarbon type (mg HC/g rock); PI: production index; OM: organic maturity or T_{max} (ºC).

TOC values range from 0.08 to 1.55 wt. %, and a median content of 0.81 wt. %. Of these, five rocks LP 04, LP 11, LP 12A, LP 12B, and LP 16 yielded TOC content of less than 1.0 wt. %, and four samples LP 17, LP 18, LP 24, and LP 25 resulted in TOC content of more than 1.0 wt. %. These values do not vary significantly, suggesting that the source section is poor to good in quality. This interpretation is principally to follow the previously proposed geochemical models [5], [7], [19]-[20]. It has also been reported that the source facies of Talang Akar unit in Kuang area has poor to fair potential, whereas the rock sequence in Limau area has good potential [18].

The apparently low TOC content is likely to determine a minor quantity of organic carbons in the source beds. In contrast to marine black shales, in which the organic matter is commonly abundant [21], all of the shales studied are mostly light to medium brown and gray, implying a general lack of organic component. This may be a direct reflection of terrestrial environment, where the silty or sandy shales of the Talang Akar Formation accummulated. The previously published studies have also reported that the oil source rocks for the majority of back-arc basins in the western region of Indonesia were deposited in fluvio-deltaic environments [22]-[23]. In addition, it has been confirmed that oils in Sumatra were generated from terrestrial-rich marsh or swamp coals and coaly shales [24]. The more recent studies suggest that the Paleogene South Sumatra basin has terrestrial source rocks, consisting mainly of carbonaceous shales and coals [12].

There are two kerogen types based on the S_2/S_3 ratios. The majority of samples yielded the S_2/S_3 values of equal to or more than 1.0 mg HC/g rock, suggesting type III kerogen, whereas the minority of rocks resulted in less than 1.0 mg HC/g rock, indicating type IV kerogen. The later type of kerogen is also supported by the HI values of less than 50 mg HC/g C derived particularly from samples LP 17 and 18. Type IV kerogen is more likely negligible with respect to expulsion, and it is commonly resulted from other kerogen types that have been reworked or oxidized [6]. Evaluation of total potential of hydrocarbon generation relies principally on the measurement of pyrolytic yield (S_1+S_2). The pyrolyzed rock samples resulted in low values, ranging from 0.07 to 1.10 mg HC/g rock and a median value of 0.96 mg HC/g rock. Therefore, the data provide a direct evidence of little or no potential for source rocks to expel oil. This interpretation is consistent with the results of previous studies [7], [18].

Hydrogen indices range from 6 to 116 mg HC/g C, and average 60 mg HC/g C. All but one sample LP 11 yielded HI values of less than 100 mg HC/g C (Table 2). Organic facies with low HI values (<300 mg HC/g C) and low S_2/S_3 ratios is referred to as gas prone [25]. The present values are identical with the existing pyrolytic data [18]. Hence, the HI data confirm a gas prone source in the Talang Akar unit. Given the low HI values, there existed the effects of weathering on source rocks [26]. In this case, the Talang Akar succession may have undergone any surface weathering since the commencement of basin inversion following the Late Neogene orogeny [11]. Oxygen indices range from 15 to 123 mg CO_2/g C, and average 61 mg CO_2/g C. Several samples yielded S_2 ≥0.4 mg HC/g rock, suggesting that the formation has reliable HI and OI indices and an organic composition characterized by the type III variety of kerogen. Fig. 4 displays the HI vs OI plot constructed on the basis of the Talang Akar pyrolytic data, confirming a strong indication of gas prone and type III kerogen.

Excluding LP 18, the eight of nine samples yielded T_{max} ranging from 380º to 421ºC, suggesting that the source beds are immature to expel oil. In oppose to the T_{max} data [18], the values here are considerably low. According to these authors, the Talang Akar section in

Limau area is mature with T_{max} values of 436º-450ºC, while that exposed in Kuang area is early mature with T_{max} values of 425º-433ºC. The source rocks with T_{max} less than 435ºC are immature, T_{max} between 435º and 465ºC may result in oils, and T_{max} higher than 465ºC enable to generate gases [5]. Based on this category, the Talang Akar shales are mostly immature. Fig. 5 shows the HI vs T_{max} values of the Talang Akar samples, which indicates that the eight of nine samples are immature, whereas one specimen with an extremely high T_{max} yield is apparently odd and thus disregarded in the interpretation of the resulted data.

However, coal-bearing sequence such as the studied formation is able to expel liquid hydrocarbon at T_{max} above 360ºC [27]. In this regard, the present data suggest that the Talang Akar section is oil-prone generation, implying that the rock unit has possibly entered the top zone of maturation. This interpretation agrees with the result of studies on the low rank coal of the South Sumatra basin [28], suggesting that the T_{max} value of the coal bearing source rock has reached approximately the upper limit of oil generating window. To compile the existing and present data, the Late Paleogene source section in the basin appears to be well constrained geochemically as poor to good yield in generating liquid hydrocarbons (Table 3).

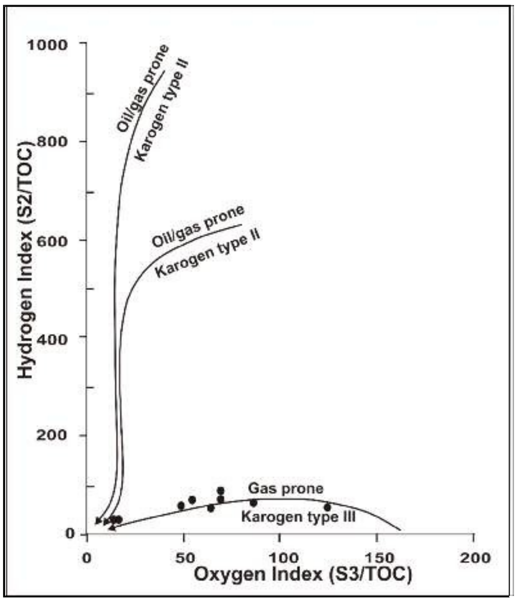


Fig. 4 Modified van Krevelen diagram showing the HI vs OI plot based on the Talang Akar pyrolytic data, indicating that the source section is gas prone and type III kerogen

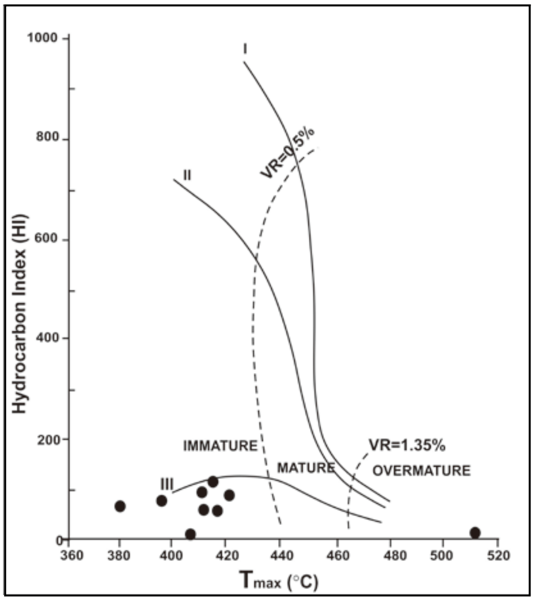


Fig. 5 Diagram showing the HI vs Tmax yield of the Talang Akar samples. Also shown are the range of thermal maturities based on the accepted vitrinite reflectance (VR) values (dashed line). One sample in the right extremity (T_{max} 514ºC) is unlikely and considered here as an erroneous T_{max} yield

Table 3 Comparison of experimental results between the previously reported geochemistry of well rocks and the present geochemical analysis of outcrops

Parameters	Area within the South Palembang subbasin				Interpretations
	Well rocks (1)		Outcrops (2)		
	Limau	Kuang	Napalan River	Lengkayap River	
TOC (wt. %)	1.5-8.0	0.3-0.9	0.08-1.55	0.11-1.04	(1) fair to good potential, and early mature to mature [18]. (2) poor to fair potential, and disregarding the T_{max} value of 514ºC, the present study suggests immature based on the existing classification [5], and early mature following the other model [27].
S_1 (mg HC/g rock)	0.5-2.1	0.1-0.5	0.02-0.04	0.04-0.06	
S_2 (mg HC/g rock)	1.5-8.0	0.2-4.0	0.05-0.10	0.09-1.04	
T_{max} (ºC)	436-450	425-433	380-514	396-421	

In a regional context, the proposed scenario is also consistent with the result of fission track study conducted in the adjacent Sunda basin [29]. This author suggests that the Late Paleogene Talang Akar source section has been exposed to the zone of thermal annealing, which is coincident with the top of oil window [30]. In the South Sumatra basin, the thick Miocene overburden seems to have provided the necessary burial depth for organic maturity in the shale beds. In addition, several workers suggest that the upward emplacement of dioritic and granitic magmas underneath the sedimentary cover was somehow responsible for the paleo-high heat flow in the basin [31]-[32]. The heat influx might permit significant heating favourable for an early stage of maturation.

It seems interesting that one sample TP 18 yielded the T_{max} value of 514ºC, suggesting that the sequence is overmature (Fig. 5). The appearence of such a very high temperature is unlikely, and discordant with the existing analytical results of thermal maturity observation and their corresponding interpretations [18], [23]-[24]. More importantly, the overmature level as suggested by the one sample only obviously disagrees with independent thermal maturity constraints such as vitrinite reflectance (VR) measurements. The VR data derived from the Talang Akar well samples indicate that the maturity degree of the source sequence ranges from immature (VR = 0.3-0.4%) to mature (VR = 0.45-0.94%) [18]. Thus, it is technically sound to disregard the T_{max} yield of this particular sample in the interpretation of organic maturity data, and this single value is considered here as a result of incorrect T_{max} readings, but the possible causes of the technical false remain uncertain.

6. CONCLUSIONS

On the basis of the above discussion, the present geochemical study draws some concluding remarks as follows:

1. The Late Paleogene Talang Akar shales contain lack of organic carbons based on the TOC data and the S_1+S_2 values, suggesting poor to fair potential source rocks for generating a significant amount of oils.
2. The HI/OI ratio of all the rock samples analysed suggests that the source sequence is gas prone or type III kerogen.
3. The source rocks are attributed to differences in thermal maturity ranging from immature to early mature with respect to oil expulsion.
4. The succession has been subjected to the zone of early mature, principally caused by heating via deeper burial as a result of the Early Neogene deposition.

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