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Sterane and triterpane biomarker characteristics from oils and sediment extracts of the Middle-Upper Miocene sequences, Northern Sabah basin

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Abstract: Biomarker studies using oil samples and sediment extracts from wells located in the northern part of the Sabah Basin show that the organic matter source for the basin's hydrocarbon to be dominantly terrigenous, indicated by high triterpane/sterane ratios, the presence of compounds diagnostic of land-derived organic matter such as oleanane, and resins W, T and R, and the general predominance of C_{29} regular steranes over C_{27} and C_{28} components. The consistently similar mass fragmentograms of both m/z 191 and m/z 217 suggests that the oils and sediment extracts originated either from the same source rock or, more likely, from different source rocks with similar chemical compositions. The similarity of biomarker distributions in samples from different environments suggests that detrital plant components from similar higher land plant assemblages were redistributed by sedimentary/transport processes to various depositional settings. Petrographic studies of kerogen concentrates confirm the dominance of land-plant contribution and the general absence of marine organic matter even in the marine sediments.

For the oils, the 20S/(20S+20R)-sterane biomarker maturity ratios are lower than the equilibrium value of 0.55 and moretane/hopane ratios > 0.10. This supports the apparent retardation of the isomerisation process previously reported by Grantham (1986) to occur in Far Eastern Tertiary oils. The triterpane 22S/(22S+22R) ratio, on the other hand, appears to reflect the expected maturity levels of the oils. The majority of the extracted sediments are shown to be immature by pyrolysis T_{max}, vitrinite reflectance and kerogen elemental composition, indicating that the extracted hydrocarbons have migrated into the sediments from elsewhere. Therefore, biomarker maturity ratios from the extracts cannot be used to determine the true maturity levels of the sediments as the *in situ* biomarkers will have been mixed with those already present in the migrating hydrocarbons. Variations of biomarker maturity ratios with depth resemble those of the Production Index in all the studied wells, thus confirming the influence of non-indigenous residual hydrocarbons on the biomarker maturity ratios.

INTRODUCTION

The Sabah Basin is one of several petroliferous Tertiary basins located around the periphery of Borneo (Fig. 1). Identifying and mapping hydrocarbon source rocks in these basins have always been problematic, particularly in the case of offshore Sabah. This is despite the presence of many large hydrocarbon accumulations such as the highly productive Baram Delta, offshore Brunei and Sarawak, and the Samarang Field, offshore Sabah. Exploration activities in Sabah increased after the discoveries of the Tembungo and Erb West Fields in 1971 (Fig. 2). Other oil fields in the Sabah Basin include South Furious, St. Joseph, Barton, Kinabalu and the giant Samarang Field (230 million barrels of recoverable oil reserves; Scherer, 1980). Oils encountered are generally light (25-45°API) and waxy, with low sulphur contents. Their characteristics concur with land-derived organic matter as the source material (Jamil *et al.*, 1991; Abdul Jalil and Mohammad Jamaal, 1992; Anuar *et al.*, 1993; Azlina Anuar, 1994) with insignificant contributions from marine organic matter.

GEOLOGY OF THE SABAH BASIN

Structural Development

The Sabah Basin is a 350 km long and 140 km wide trench-associated Tertiary basin situated offshore Sabah. It elongates in a northeast-southwest direction and contains approximately 10 km thick of predominantly siliciclastic sediments (Levell, 1987). The opening of the South China Sea between 32–17 Ma (Middle Oligocene-Early Miocene) resulted in the collision of South China's micro-continental crust with Borneo in the Early

Miocene, forming a collision zone along the northwestern margin of Borneo. The resulting deformation and uplift of the Eocene-Oligocene Crocker Formation rejuvenated the Sabah landmass and formed an eroding provenance which provided the source of clastic infill for the offshore Sabah Basin during the Neogene. Four major tectonic provinces aligned parallel to each other (Fig. 3) were identified by Bol and van Hoorn (1980): the Palaeogene Foldbelt, Basement Faulting Zone, Extensional Zone and Thrust Zone.

Stratigraphic Framework

The stratigraphic framework of the Sabah Basin is defined by four major Tertiary sedimentary units informally known as Stages I, II, III and IV (Fig. 4). These units are seismically-defined by the correlation of nine regional unconformities and their correlative conformities (Bol and van Hoorn, 1980).

A pre-Middle Miocene phase of deep marine sedimentation constitutes sediments of Stages I, II and III. Stage III is currently regarded as the economic basement for hydrocarbon exploration. A mid-Middle Miocene and later phase of lower coastal plain to deep marine sedimentation represents the Stage IV sediments. A major regional unconformity, known as the Deep Regional Unconformity (DRU), separates the Stage IV sediments from those of the underlying Stage III. All commercial accumulations discovered to date are in the Middle Miocene and younger deposits of the Stage IV megasequence.

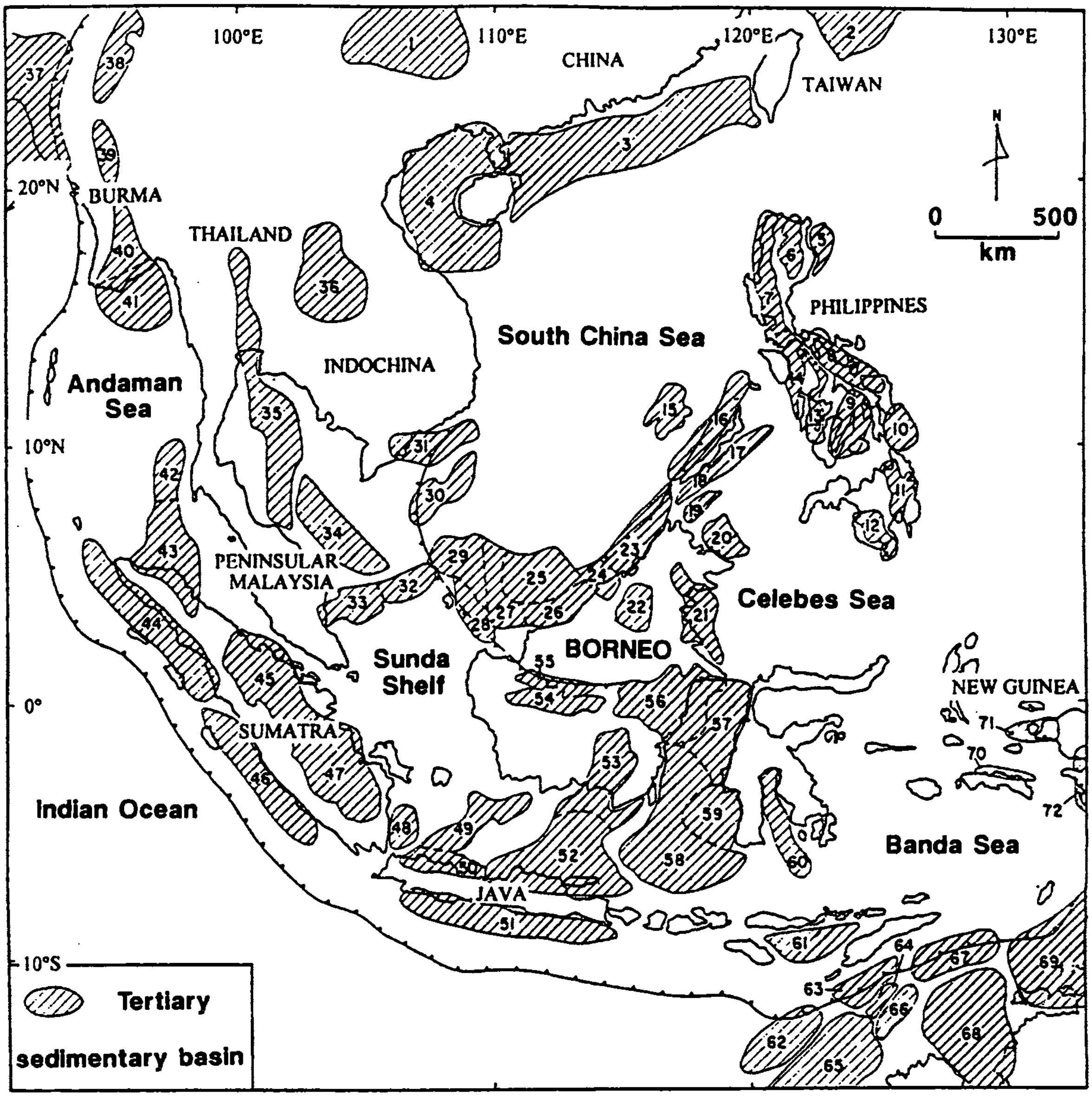


Figure 1. The Tertiary basins of Southeast Asia (after Hutchison, 1989). Listed are basins located around the periphery of Borneo: Bancauam (19), Sandakan (20), Tarakan (21), Sabah (23), Baram Delta (24), Central Luconia (25), Balingian (26), West Luconia (27), Sokong sub-basin (28), Northeast Natuna (29), Barito (53), Kutei (56), North Makassar (57) and Paternoster Platform (58).

Only a few hydrocarbon occurrences have been discovered in the pre-Stage IV deep-water deposits. The prospective Stage IV megasequence has been further subdivided into 7 stages, IVA–IVG, which are separated by seismically-defined unconformities and their correlative conformities in the deeper parts of the basin. These unconformities, formed as the result of several episodes of both local structural deformation and a regional tilting towards the northwest, provide the correlation framework for the Sabah Basin. They can be easily mapped on seismic sections in the inboard areas of the basin but become difficult to map in the outboard areas, especially in rapidly subsiding synclinal areas where subsidence rates of more than 500–1,000 m/Ma are common (Azim-Ibrahim, 1994) (Fig. 5).

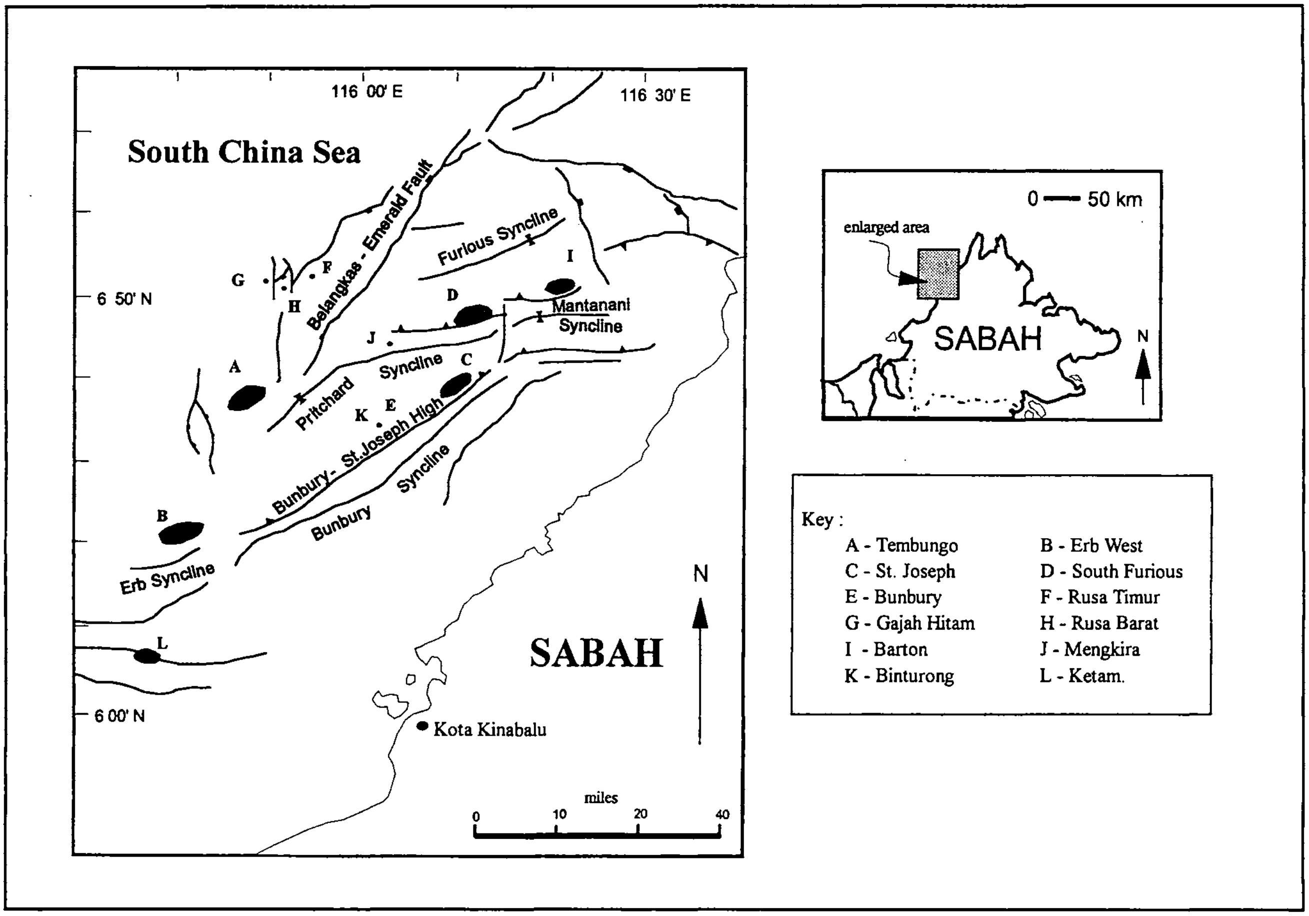


Figure 2. Oil fields and locations of exploration wells used in this study: Sabah Basin, Malaysia.

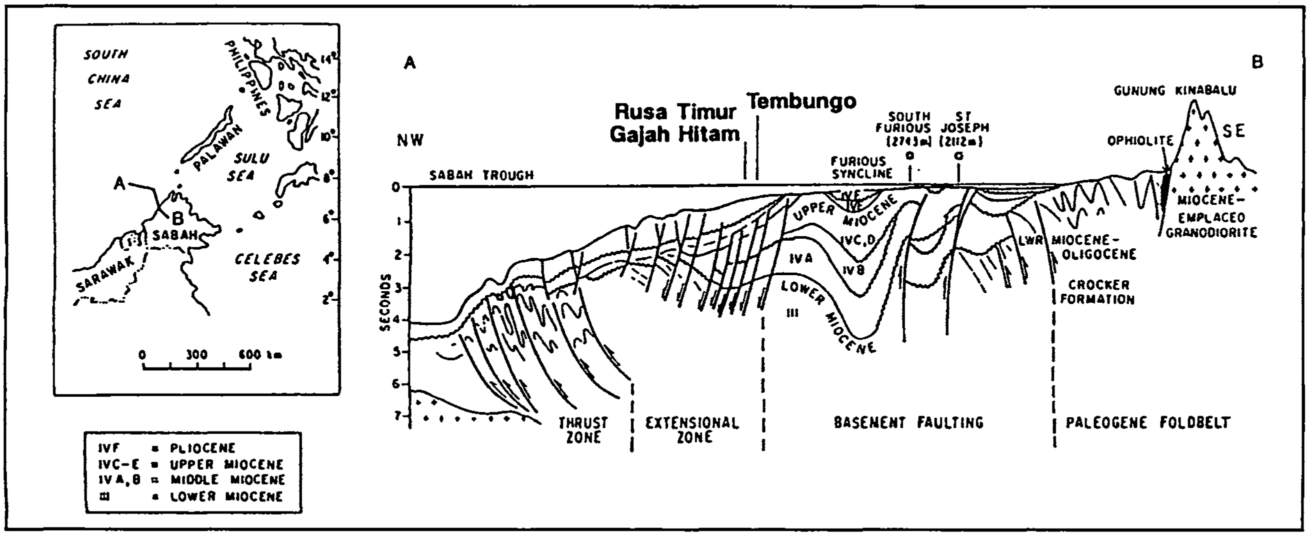


Figure 3. The four tectonic provinces of the Sabah Basin delineated by Bol and van Hoorn (1980).

THE BIOLOGICAL MARKER STUDY

Seven oil samples from different areas in the Sabah Basin (Fig. 2) — Rusa Timur, Tembungo, South Furious, Barton, St. Joseph, Erb West and Ketam — and twenty six sediment extracts from six wells were analysed using the GC-MS, monitoring for triterpanes (m/z 191) and steranes (m/z 217). Sediment extracts are considered to be non-indigenous hydrocarbons by the incompatibility of high Production Index values (> 0.2) with low pyrolysis T_{max} (< 440°C) and vitrinite reflectance values (< 0.50). Carbon Preference Index (CPI) values determined from two different methods (Bray and Evans, 1965; Louis, 1967) and Odd-Even Preference (OEP) values of Scalan and Smith (1970) vary between 1.0 –1.2, providing further evidence that the extracts are mature hydrocarbons which have stained the immature sediments during their migration from elsewhere.

The aims of this biomarker study are to determine the source of organic matter input, to determine the maturity levels of the oils and to observe the extent of influence of migrated hydrocarbons on maturity ratios determined from sediment extracts.

ANALYTICAL METHOD

For this study, the GC-MS facilities were made available by British Gas at their London Research Station. GC-MS analysis provides biomarker profiles which give information on organic matter source input, source environment and the maturity level of the analysed sample (Comet *et al.*, 1989; Thompson *et al.*, 1985). A Finnigan TSQ 70 triple quadrupole mass spectrometer, linked to a Varian capillary gas chromatograph was ran in SIM mode to monitor and measure the triterpanes (m/z 191) and steranes (m/z 217). The setup consisted of a 25 m x 0.22 mm internal diameter fused silica column coated with a cross bonded non-polar phase (CP-Sil 5CB). The temperature programme used being 50°C for 1 minute, then 5°C per minute until a maximum temperature of 320°C.

The TSQ 70 mass spectrometer was also operated in the GC-MSMS mode which allows the complete separation of complex hydrocarbons. The first quadrupole was set to jump molecular ions of the hopanoid class of triterpenoid hydrocarbons or steranes. Helium collision gas was introduced in the second quadrupole to fragment the molecular ion while the third quadrupole was set to monitor

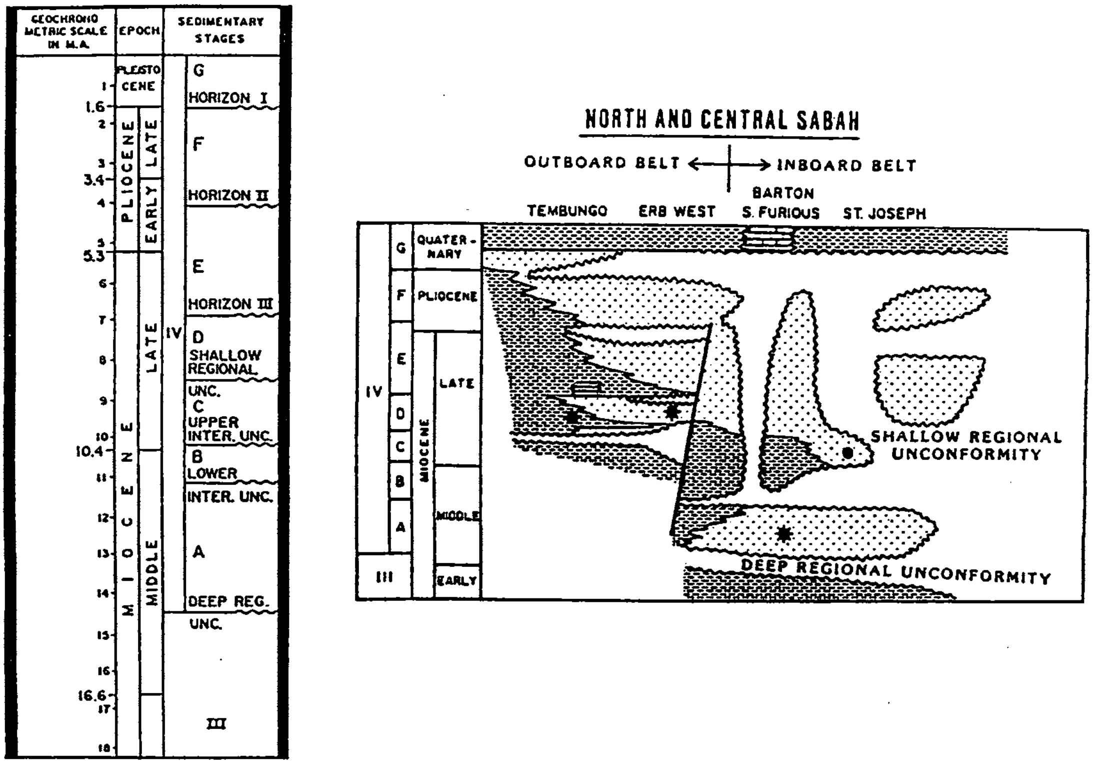


Figure 4. Chronostratigraphic framework of the Sabah Basin (after Johnson and Huong, 1991).

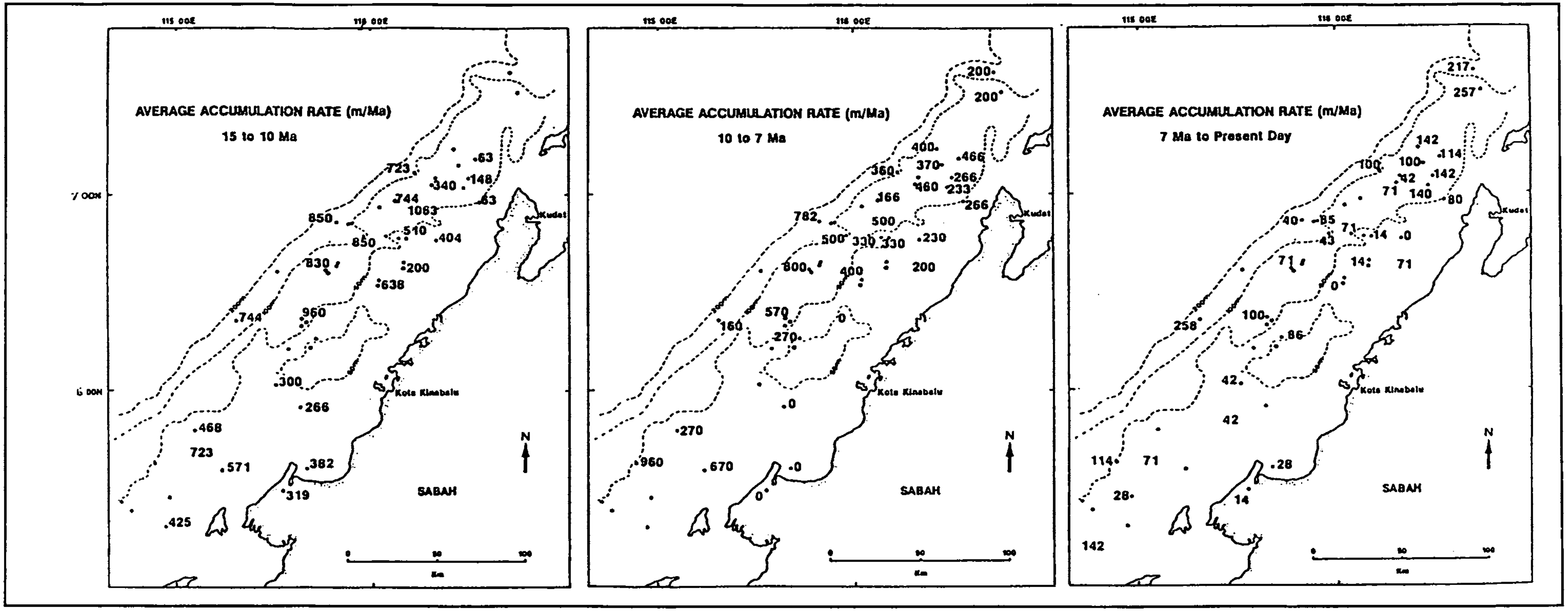


Figure 5. Average sediment accumulation rates in the Sabah Basin throughout the Neogene (Azim-Ibrahim, 1994).

the characteristic ion of hopanes (m/z 191) or steranes (m/z 217). The final reconstructed ion chromatogram (RIC) will consist entirely of hopane/sterane homologues. The main purpose of using this technique is to ascertain that the C_{32} 17α(H)21β(H)-hopane and C_{29} 5α(H)14α(H)17α(H)-sterane peaks used for calculating thermal maturity ratios are not affected by co-elution of other compounds which, if they are, will give erroneous biomarker maturity ratios. The equipment was set to monitor the following transitions: m/z 440–m/z 191 for the C_{32}-hopane, and m/z 372–m/z 217, m/z 386–m/z 217 and m/z 400–m/z 217 for C_{27}, C_{28} and C_{29}-steranes, respectively. Also monitored was m/z 412 for resin compounds as there were indications of resin peaks showing through the m/z 217 mass fragmentogram.

RESULTS AND DISCUSSION

Triterpane and sterane fingerprints of extracted hydrocarbons

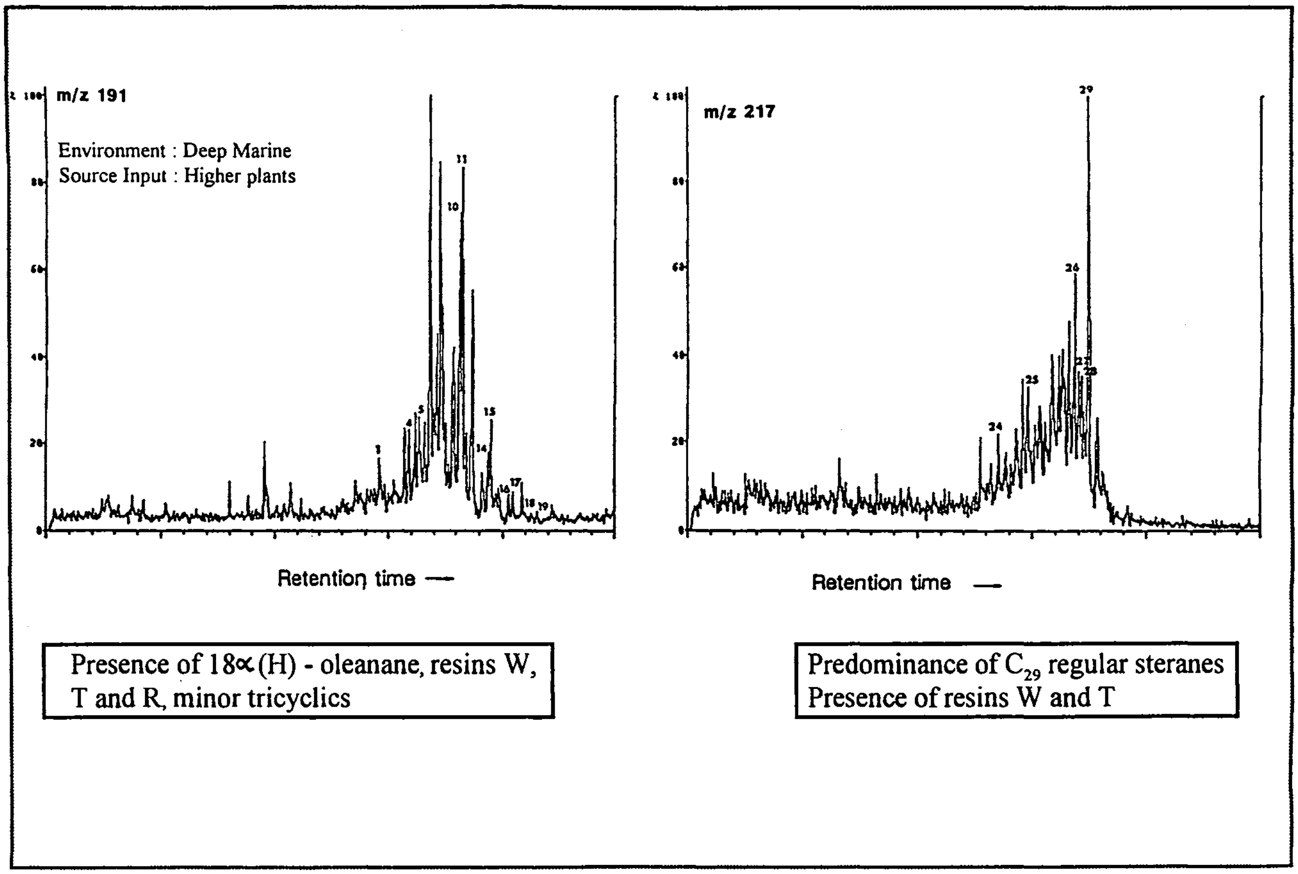
(a) Stage III

Sediments of Stage III penetrated in the South Furious area were deposited in a deep marine environment. The m/z 191 mass fragmentogram of a Stage III sediment extract from the South Furious displays characteristics typical of hydrocarbons sourced by land-derived organic matter (Fig. 6). Presence of 18α(H)-oleanane and resins W, T and R (a key to peak identities is given in Table 1) provide evidence for higher land plant input. Oleananes arise from the geological transformation of pentacyclic triterpenoids typical of higher plants (Ekweozor and Udo, 1988) and have been identified in rocks and oils from the Far East (Wang *et al.*, 1991), Southeast Asia (Grantham *et al.*, 1983; Jamil *et al.*, 1991; Anuar *et al.*, 1993; Azlina Anuar, 1994), Niger Delta (Nwachukwu and Chukwura, 1986) and Brazil (Mello *et al.*, 1988a, b). Resins W and T were identified by van Aarssen *et al.* (1990, 1992) as pentacyclic triterpanes known as bicadinanes, and are considered to be derived from dammar resins which originate from resin-producing tropical plants such as Dipterocarpaceae.

The m/z 217 mass fragmentogram also exhibits traits that point to input from higher land plants with the dominance of C_{29} regular steranes over the C_{27} and C_{28} species, and the presence of bicadinanes.

(b) Stage IVA

Stage IVA is represented by deltaic-lower coastal plain sediments in the South Furious area, and by bathyal sediments in the further offshore



Presence of 18α(H) - oleanane, resins W, T and R, minor tricyclics

Predominance of C_{29} regular steranes
Presence of resins W and T

Figure 6. Triterpane m/z 191 and sterane m/z 217 mass fragmentogram of South Furious Stage III sediment extract.

Table 1. Key to peak identity for triterpane m/z 191 and sterane m/z 217 mass fragmentograms.

Peak Number	Compound
Triterpane m/z 191 distribution	
1	Resin W (*cis-cis-trans* bicadinane)
2	Ts
3	Tm
4	Resin T (*trans-trans-trans* bicadinane)
5	Resin R
10	18α(H)-oleanane
11	C_{30} 17α(H)21β(H)-hopane
14	C_{31} 17α(H)21β(H)-homohopane, 22S
15	C_{31} 17α(H)21β(H)-homohopane, 22R
16	C_{32} 17α(H)21β(H)-bishomohopane, 22S
17	C_{32} 17α(H)21β(H)-bishomohopane, 22R
18	C_{33} 17α(H)21β(H)-trishomohopane, 22S
19	C_{33} 17α(H)21β(H)-trishomohopane, 22R
20	C_{34} 17α(H)21β(H)-tetrakishomohopane, 22S
21	C_{34} 17α(H)21β(H)-tetrakishomohopane, 22R
22	C_{35} 17α(H)21β(H)-pentakishomohopane, 22S
23	C_{35} 17α(H)21β(H)-pentakishomohopane, 22R
Sterane m/z 217 distribution	
Peak Number	**Compound**
24	Resin W (*cis-cis-trans* bicadinane)
25	Resin T (*trans-trans-trans* bicadinane)
26	C_{29} 5α(H)14α(H)17α(H)-cholestane, 20S
27	C_{29} 5α(H)14β(H)17β(H)-isocholestane, 20R
28	C_{29} 5α(H)14β(H)17β(H)-isocholestane, 22S
29	C_{29} 5α(H)14α(H)17α(H)-cholestane, 22R

Rusa Timur area. Comparing the m/z 191 mass fragmentograms from these two areas revealed similarities in the general compound distributions with the common presence of 18α(H)-oleanane, resins W, T and R, and the minor presence of tricyclics (Fig. 7). Minor differences do, however, occur such as the lower concentrations of Ts and Tm in the Rusa Timur sample. The presence of terrestrially-derived peaks in bathyal sediments, as seen in Rusa Timur, has also been documented in southern Nigerian basins where oleananes were found to be present in marine litho-units (Ekweozor and Udo, 1988). The resistance to biodegradation and low densities of the higher plant waxes and cuticles (Frewin *et al.*, 1993) are largely responsible for their preservation and incorporation into marine sediments. Figure 8 is the partial mass chromatograms for bicadinanes in the South Furious sample compared to those of van Aarssen *et al.* (1992), confirming the presence of bicadinanes.

The m/z 217 trace of the Rusa Timur sample closely resembles the South Furious sample, with the exception of slightly higher concentrations of the C_{29} 20R in Rusa Timur. Both contain rather high concentrations of resins W and T, and they also exhibit a predominance of C_{29} sterane over the C_{27} and C_{28} counterparts.

(c) Stage IVB

The sediments of this Stage were penetrated only in Rusa Timur where they are represented by deep marine shales. The m/z 191 distribution is shown in Figure 9, showing characteristics resembling those of the previous Stages with the 18α(H)-oleanane peak dominating the trace and the presence of minor tricyclics. The sterane m/z 217 trace is again comparable to the previous Stages, with C_{29} sterane in greater concentration than C_{27} and C_{28}, and the presence of resins W and T.

(d) Stage IVC

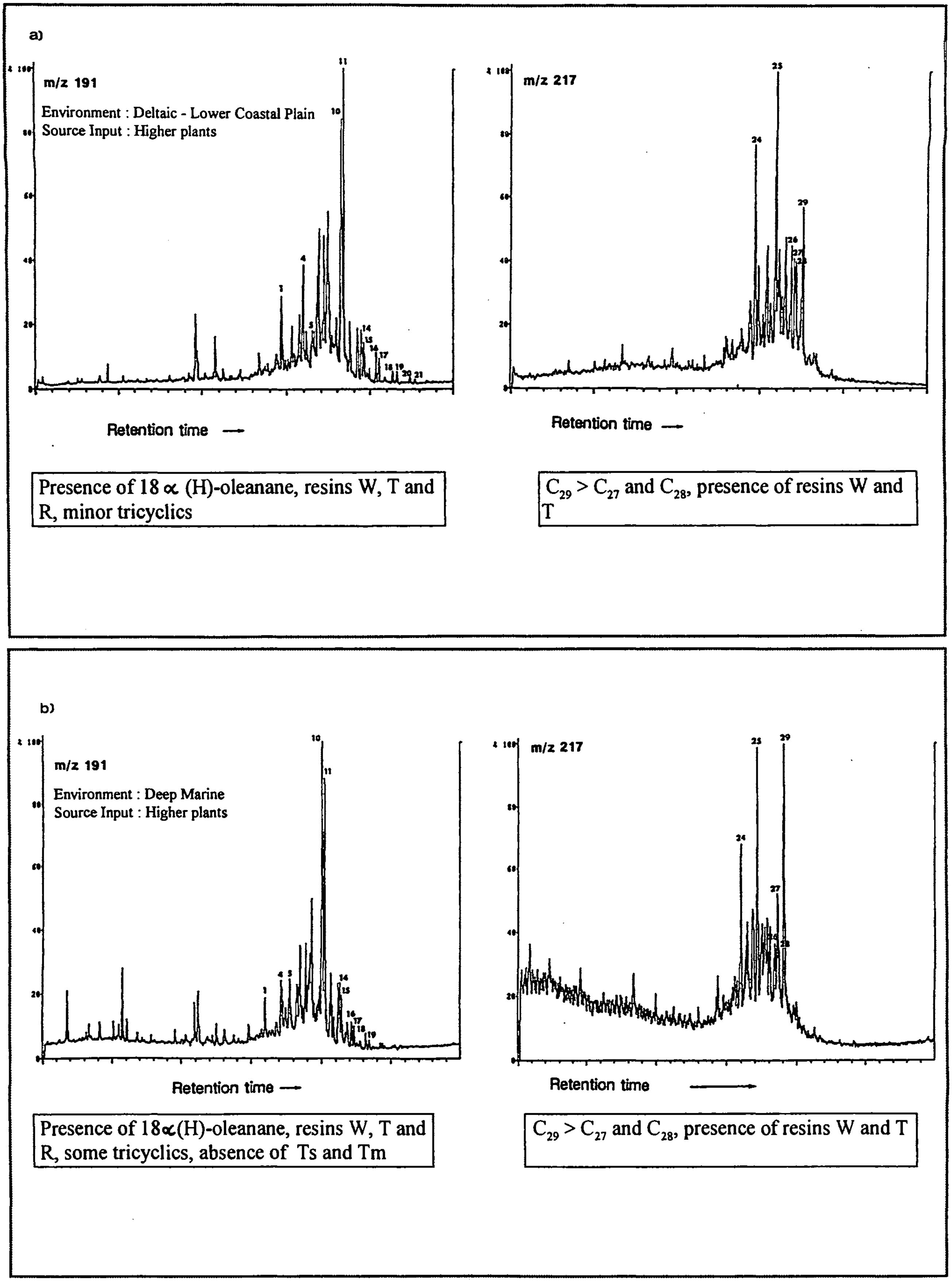
Stage IVC sediments were penetrated in the Tembungo, Rusa Timur and Gajah Hitam areas. The biomarker distribution of these deep marine sediments are generally comparable to each other (Fig. 10), with C_{30} hopane being dominant, similar relative abundances of the presence of 18α(H)-oleanane, resins W, T and R, and tricyclics in the m/z 191 trace. The m/z 217 mass fragmentograms exhibit the presence of resins W and T, and comparable C_{27}, C_{28} and C_{29} regular sterane distributions, indicating a possible mix between land-derived and marine source material.

(e) Stage IVD

C_{30} hopane is dominant in Stage IVD samples which were extracted from deep marine/bathyal sediments in the Rusa Timur and Tembungo areas. The usual suite of 18α(H)-oleanane, resins W, T and R and minor tricyclic peaks are present, with only one exception which is the sample from Rusa Timur where 18α(H)-oleanane is noticeably absent (Fig. 11), although it still displays resins T and R in the m/z 191 mass fragmentograms. The sterane distributions of the Stage IVD samples are all very similar to each other, with the C_{29} regular steranes predominating over the C_{27} and C_{28} species, and similar relative abundance of resins W and T.

Triterpane and sterane fingerprints of Sabah oils

The mass fragmentograms of the seven Sabah oils show very similar biomarker patterns, suggesting that they are likely to have been generated by the same source rocks or, more likely, by source rocks which are similar or comparable nature i.e. containing Type III, land-derived organic matter. All the oils have dominant 18α(H)-oleanane and C_{30} hopane peaks in the m/z 191 mass fragmentograms, and prominent resins W, T and R



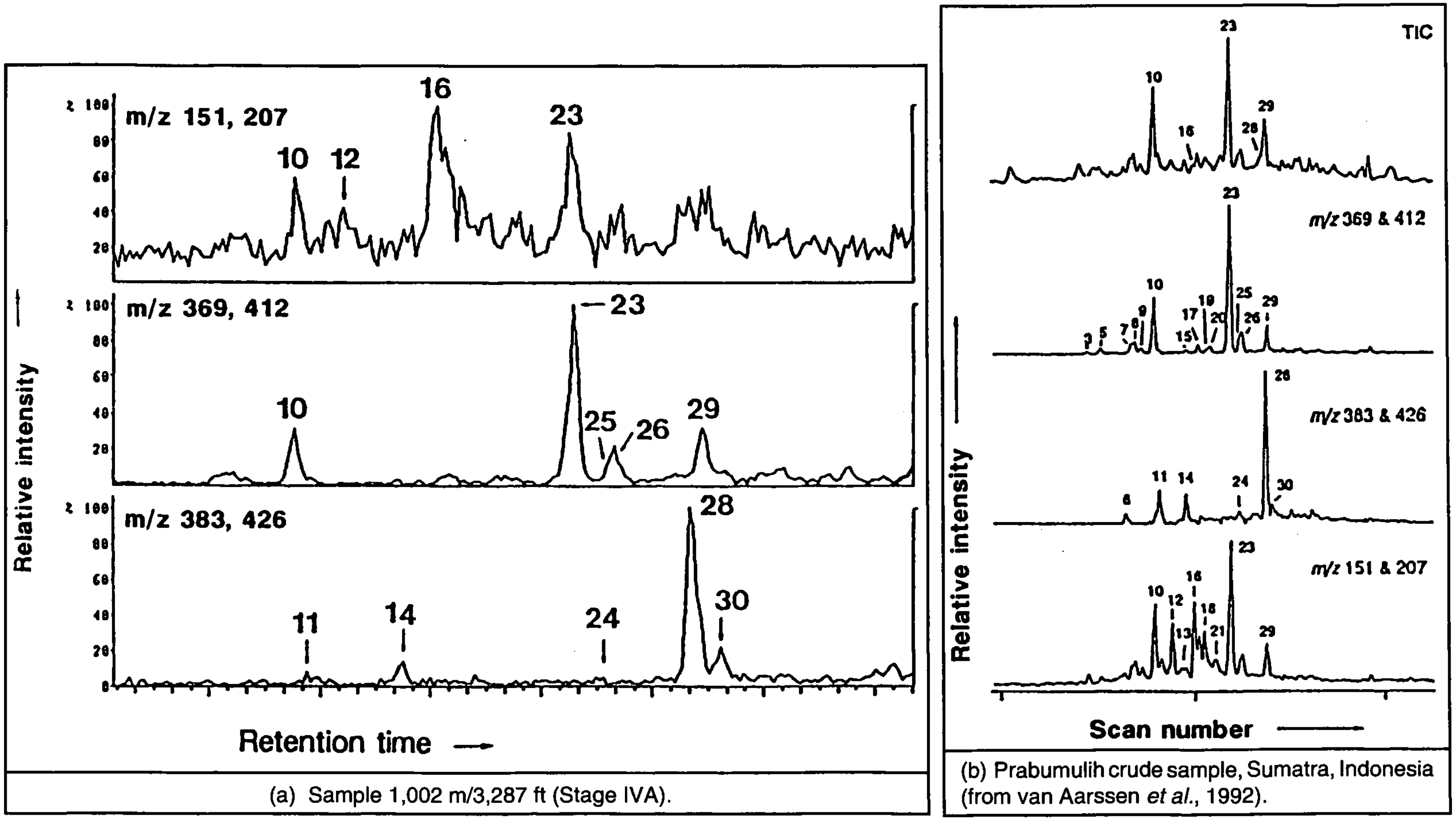
Presence of 18 α (H)-oleanane, resins W, T and R, minor tricyclics

$C_{29} > C_{27}$ and C_{28}, presence of resins W and T

Presence of 18α(H)-oleanane, resins W, T and R, some tricyclics, absence of Ts and Tm

$C_{29} > C_{27}$ and C_{28}, presence of resins W and T

Figure 7. Triterpane m/z 191 and sterane m/z 217 mass fragmentogram of (a) South Furious and (b) Rusa Timur Stage IVA sediment extracts.



(a) Sample 1,002 m/3,287 ft (Stage IVA).

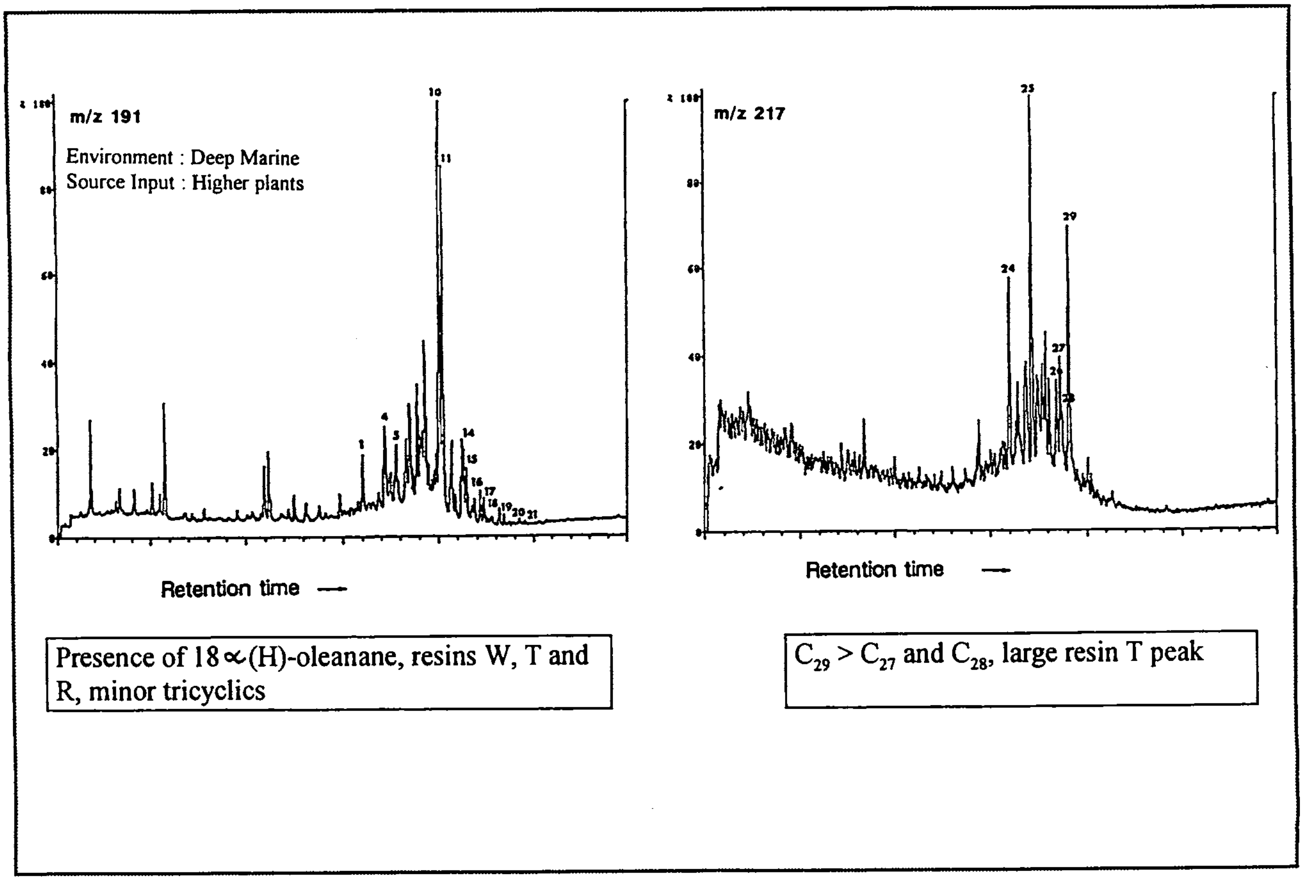
(b) Prabumulih crude sample, Sumatra, Indonesia (from van Aarssen *et al.*, 1992).

Figure 8. Comparison between the resulting partial mass chromatograms of m/z 151 and 207, indicating seco-bicadinanes, m/z 369 and 412, indicating bicadinanes, and m/z 383 and 426, indicating homobicadinanes of (a) South Furious Stage IVA extract sample and (b) van Aarssen *et al.*'s (1992) published data.

(Fig. 12). They exhibit a number of tricyclic triterpanes which are relatively more abundant than those present in all of the sediment extracts analysed. Tricyclic triterpanes were reported by Aquino Neto *et al.* (1983) to be present in oils derived from marine organic matter and that tricyclics have a microbial or algal origin. Tricyclics in the studied samples do not predominate over the regular and extended hopanes. In view of the setting, the presence of tricyclics may be an indication of marine organic matter input, albeit minor. Based on evidence from other organic geochemical analyses, these oils are more likely to have been generated from land-derived organic matter, with some input from bacteria and/or algae.

The m/z 217 mass fragmentograms are also very similar to each other although the Rusa Timur and Tembungo oils do display slight differences, in particular the relatively larger C_{29}-ββ peaks when compared to other oils. Bicadinanes W and T are also present in the oils, indicating contribution from terrestrial organic matter. The C_{29} regular steranes, however, do not show distinct dominance over the C_{27} and C_{28} counterparts; all three components being present in relatively comparable quantities. It is very likely that the sterane distributions reflect the source rocks' environment of deposition rather than the actual source input of the oils, which is considered to be primarily terrigenous organic matter transported into deltaic-paralic-marine environments by rivers and turbidity currents. However, oils produced from deltaic-lower coastal plain sediments can show minor marine indications, for example, those deposited in brackish-paralic settings where mixing of marine and fresh water occurs. Some marine algae may be washed in by the tide, creating a mix in the organic matter type with the terrigenous organic matter predominating. These conditions can occur in mangrove swamps, lagoons as well as in delta fronts.

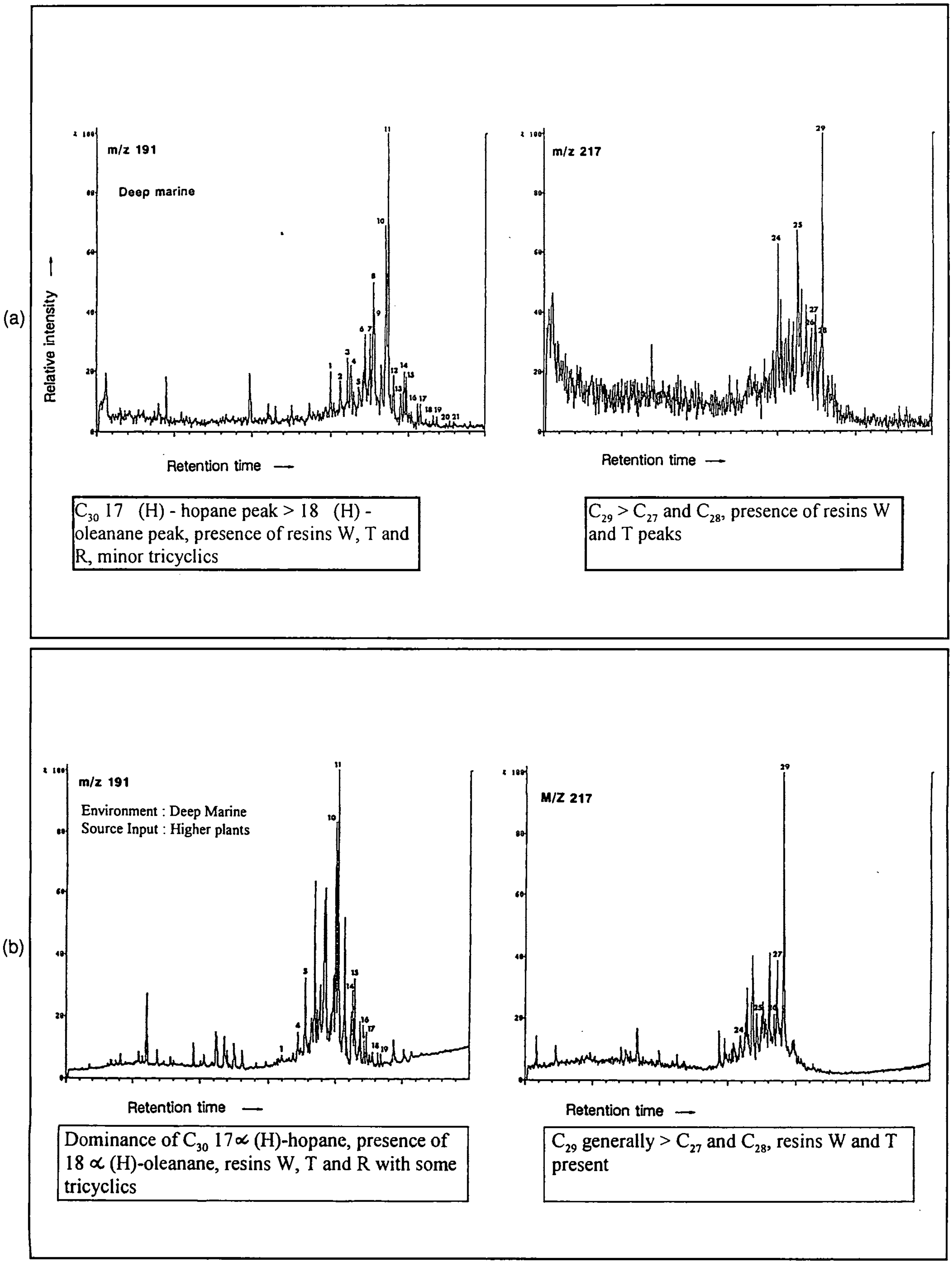
The C_{30} regular steranes are present in Rusa Timur and Tembungo oils in greater amounts than in the other oil samples studied. Moldowan *et al.* (1985) and Mello *et al.* (1988a, b) proposed that C_{30} regular steranes are only present in post-Silurian samples deposited in marine environments. If this is so, and there is presently little published material to prove otherwise, it would seem that Rusa Timur and Tembungo oils originate from terrestrial organic matter deposited in relatively more marine environments while the rest of the oils were derived from similar organic matter deposited in relatively less marine environments. This deduction seems to show a general agreement with the depositional palaeoenvironment of Stage IVA (Fig. 13). Oils from the 'inner belt' (South Furious, Barton, St.



Presence of 18∝(H)-oleanane, resins W, T and R, minor tricyclics

$C_{29} > C_{27}$ and C_{28}, large resin T peak

Figure 9. Triterpane m/z 191 and sterane m/z 217 mass fragmentogram of Rusa Timur Stage IVB sediment extract.



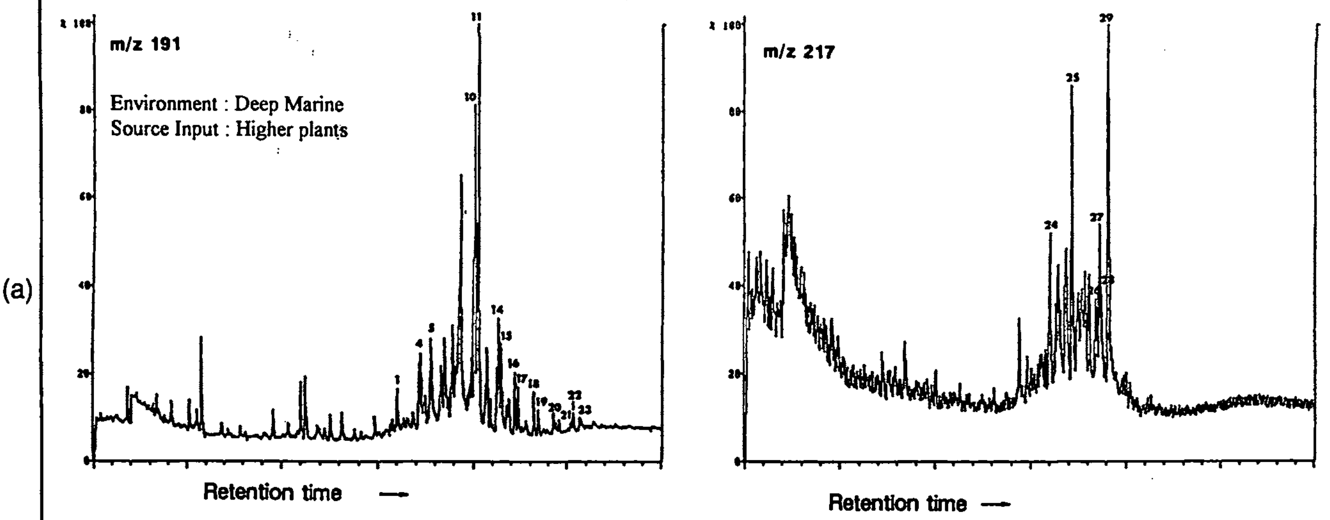
C_{30} 17 (H) - hopane peak > 18 (H) - oleanane peak, presence of resins W, T and R, minor tricyclics

$C_{29} > C_{27}$ and C_{28}, presence of resins W and T peaks

Dominance of C_{30} 17α (H)-hopane, presence of 18 α (H)-oleanane, resins W, T and R with some tricyclics

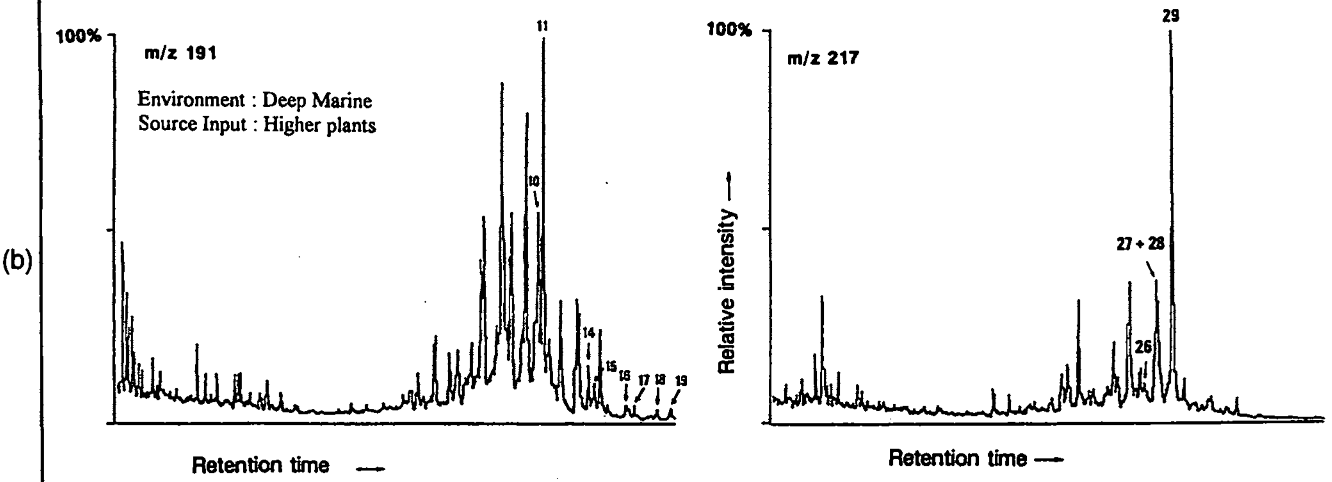
C_{29} generally > C_{27} and C_{28}, resins W and T present

Figure 10. Triterpane m/z 191 and sterane m/z 217 mass fragmentogram of (a) Rusa Timur and (b) Gajah Hitam Stage IVC sediment extracts.



Dominance of C_{30} 17α(H) - hopane and 18α(H) - oleanane peaks, presence of resins W, T and R with minor tricyclics

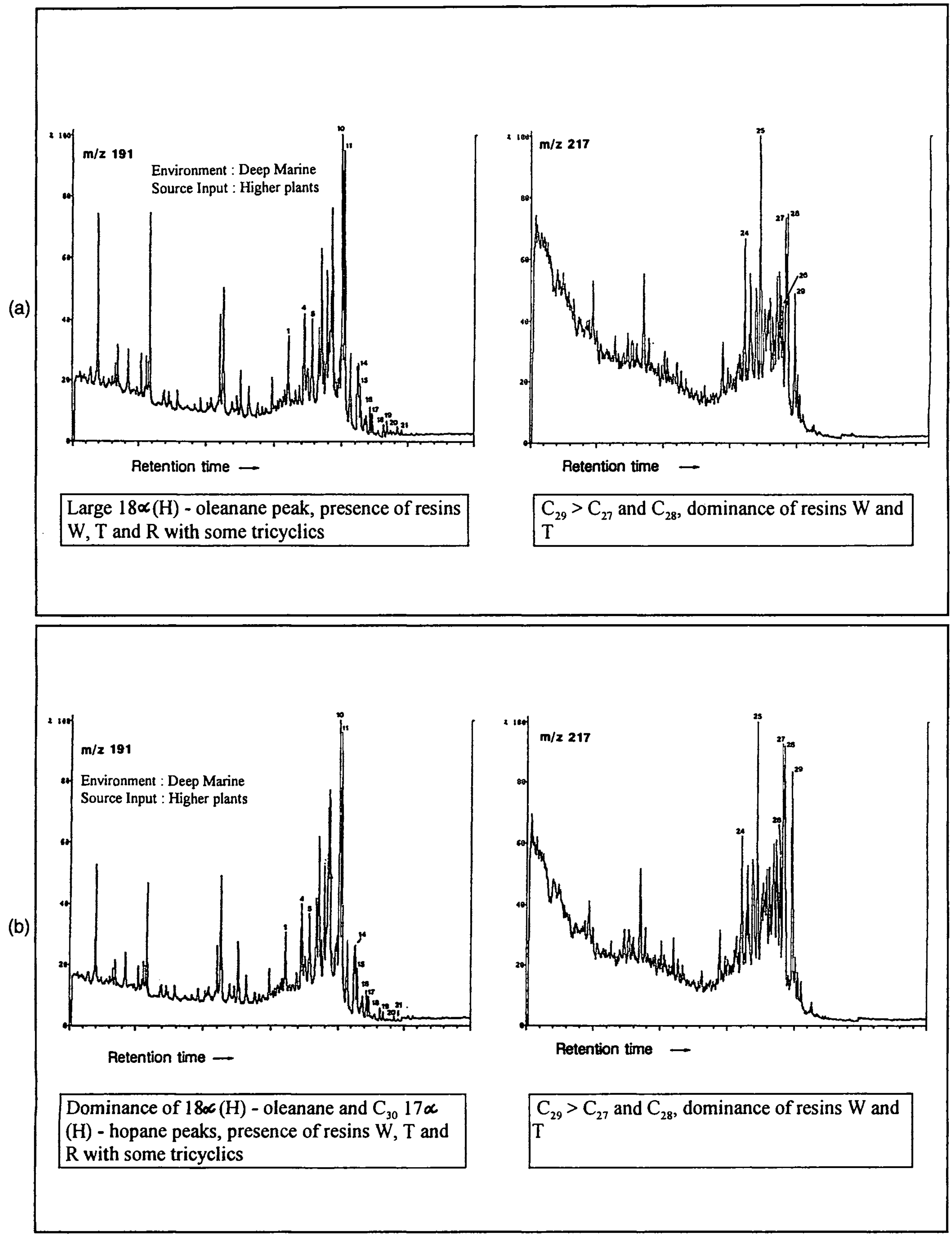
$C_{29} > C_{27}$ and C_{28}, presence of resins W and T



Dominant C_{30} 17α(H) - hopane peak, 18α(H) - oleanane present with minor tricyclics

$C_{29} > C_{27}$ and C_{28}, presence of resins W and T

Figure 11. Triterpane m/z 191 and sterane m/z 217 mass fragmentogram of (a) Rusa Timur and (b) Tembungo Stage IVD sediment extracts.



Large 18α(H) - oleanane peak, presence of resins W, T and R with some tricyclics

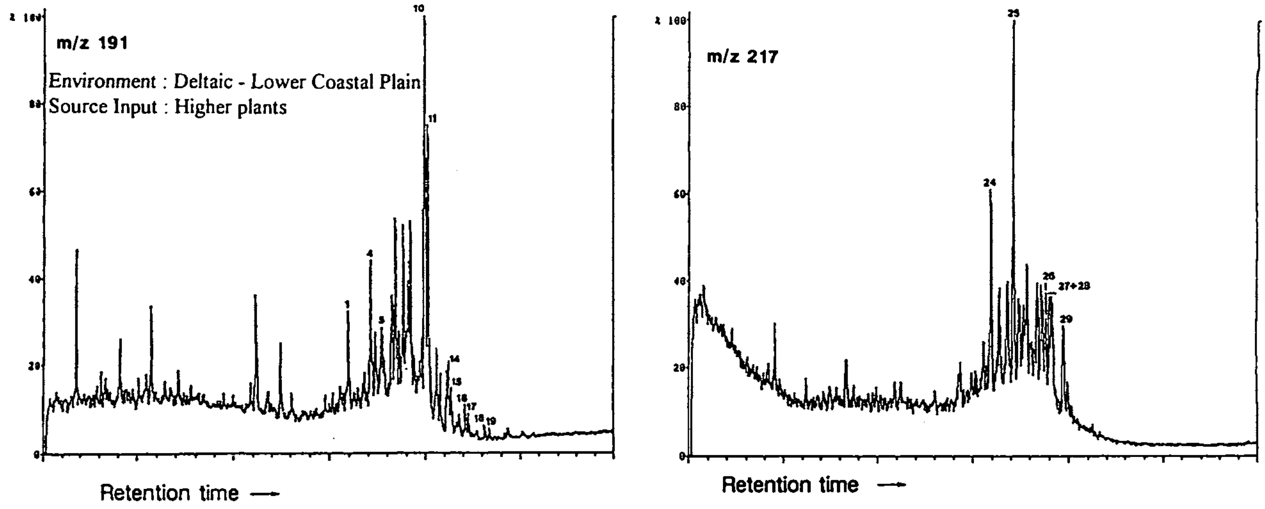
$C_{29} > C_{27}$ and C_{28}, dominance of resins W and T

Dominance of 18α(H) - oleanane and C_{30} 17α (H) - hopane peaks, presence of resins W, T and R with some tricyclics

$C_{29} > C_{27}$ and C_{28}, dominance of resins W and T

Figure 12. Triterpane m/z 191 and sterane m/z 217 mass fragmentogram of oils from (a) Rusa Timur, (b) Tembungo, (c) South Furious, (d) Barton, (e) Erb West, (f) St. Joseph and (g) Ketam.

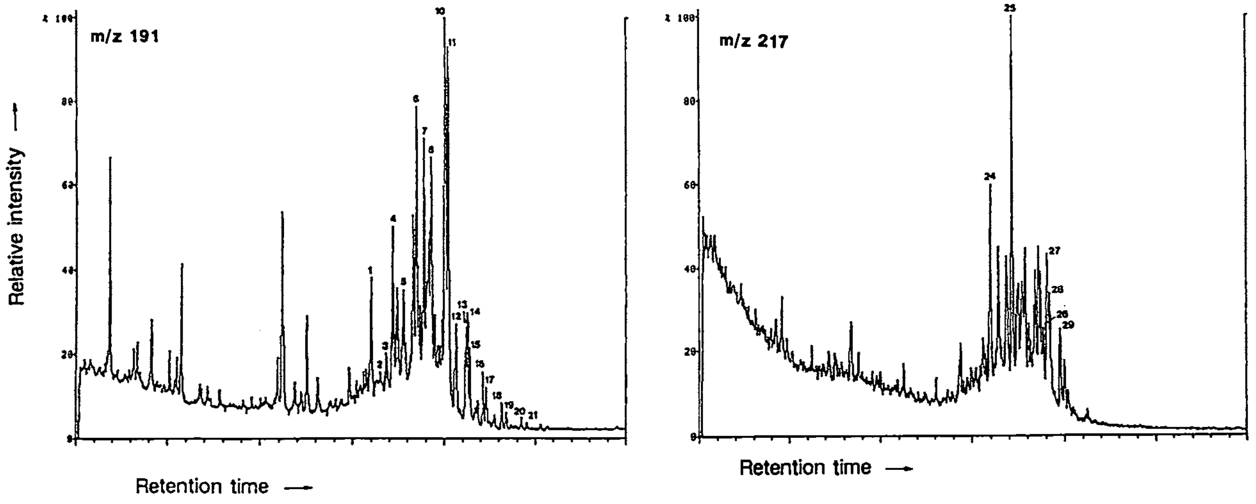
(c)



Large 18α(H) - oleanane and C_{30} 17α(H) - hopane peaks, presence of resins W, T and R with some tricyclics

C_{29} almost equivalent to C_{27} and C_{28}, dominance of resins W and T peaks

(d)

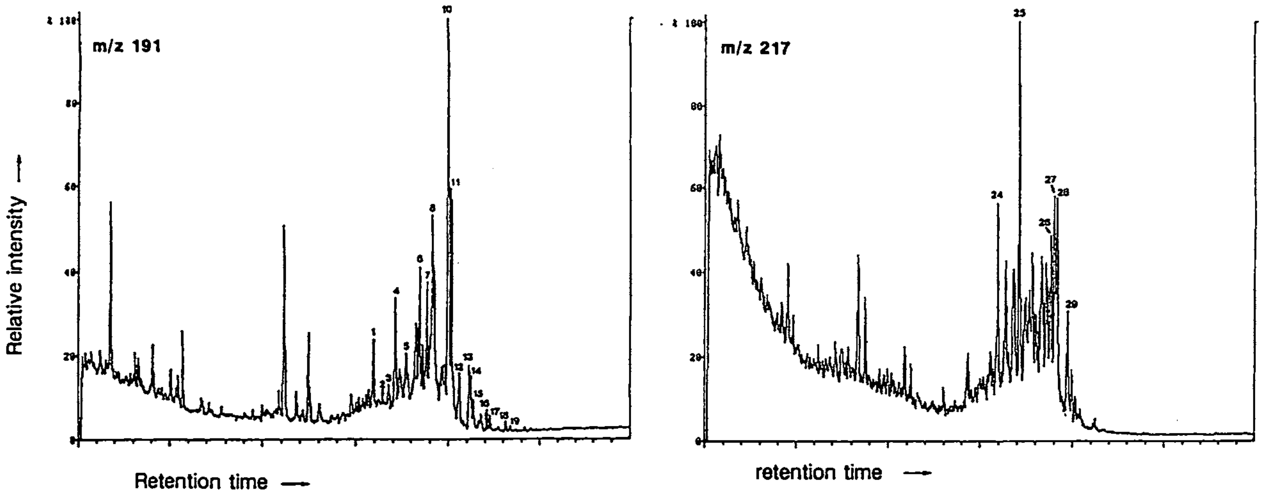


Large C_{30} 17α(H) - hopane and 18α(H) - oleanane peaks, presence of resins W, T and R, tricyclics

Comparable C_{29}, C_{27} and C_{28} peaks, dominance of resins W and T peaks

Figure 12 (cont'd). Triterpane m/z 191 and sterane m/z 217 mass fragmentogram of oils from (a) Rusa Timur, (b) Tembungo, (c) South Furious, (d) Barton, (e) Erb West, (f) St. Joseph and (g) Ketam.

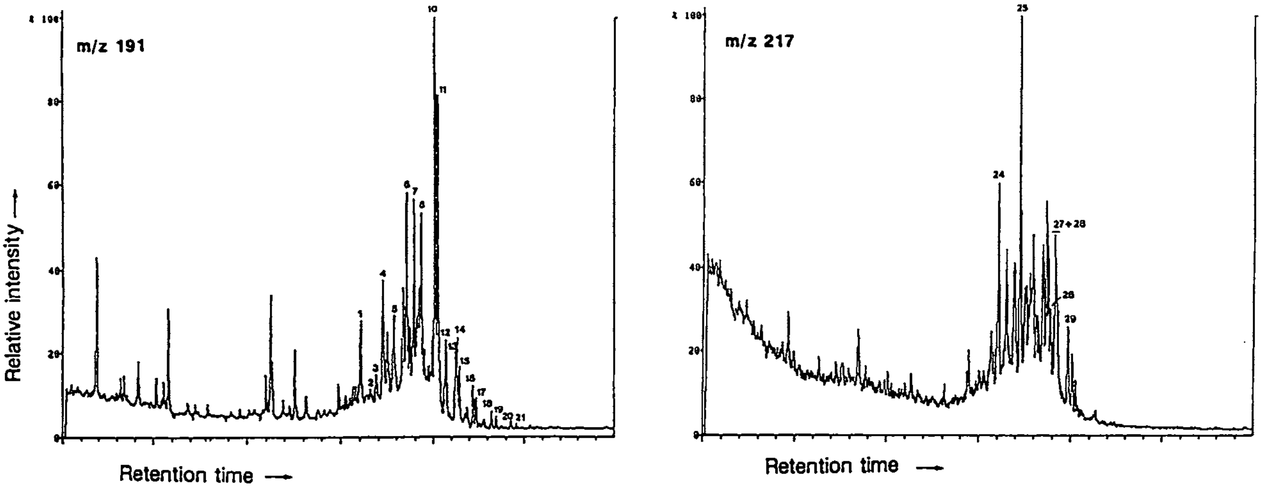
(e)



Large 18α(H) - oleanane peak, presence of resins W, T and R, tricyclics

C_{29} slightly larger than C_{27} and C_{28}, resins W and T peaks present

(f)



Large 18α(H) - oleanane peak, presence of resins W, T and R, tricyclics

C_{29} slightly larger than C_{27} and C_{28}, resins W and T peaks present

Figure 12 (cont'd). Triterpane m/z 191 and sterane m/z 217 mass fragmentogram of oils from (a) Rusa Timur, (b) Tembungo, (c) South Furious, (d) Barton, (e) Erb West, (f) St. Joseph and (g) Ketam.

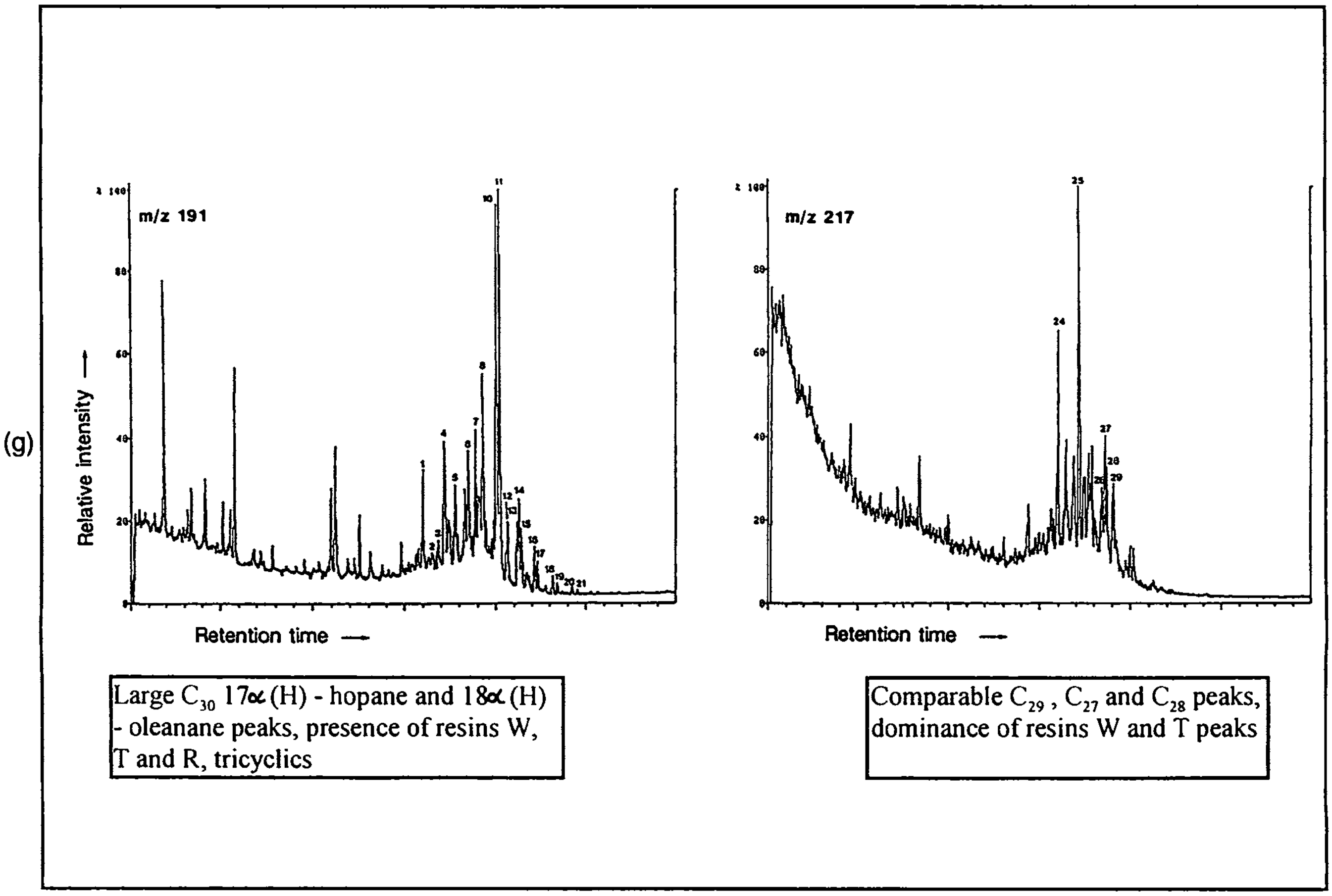
Joseph, Erb West and Ketam oils) originated from land-derived organic matter deposited in inner neritic/paralic/deltaic-lower coastal plain environments of Stage IVA while the two 'outer belt' oils (Rusa Timur and Tembungo oils) were produced by terrigenous organic matter deposited in predominantly bathyal environments.

It has been proposed that the triterpane/sterane ratio is an organic matter source indicator where oils generated from terrigenous organic matter commonly have high triterpane/sterane ratios, as in the Gippsland Basin (Philp and Gilbert, 1986), Mahakam Delta (Hoffman *et al.*, 1984) and some oils from the West and Central African rift system (Genik, 1993). Waples and Machihara (1991) expressed concern in the method of calculating this ratio because presently there is no uniformity over which hopanes and steranes are to be used for its calculation. In this study, triterpane/sterane ratios are calculated by taking the abundance ratio of the largest triterpane peak to the largest sterane peak. Table 2 gives the resulting triterpane/sterane ratio for the seven Sabah oils.

Table 2. Triterpane/sterane ratios of seven Sabah crude oil samples.

Sample	Triterpane/sterane ratio
Rusa Timur	3 : 1
Tembungo	3 : 1
Barton	5 : 1
St. Joseph	5 : 1
Erb West	5 : 1
South Furious	7 : 1
Ketam	8 : 1

The Sabah oils are classified as marine-paralic oils on Genik's (1993) hopane/sterane ratio comparative chart (Fig. 14) when it has been established from other organic geochemical methods that they were generated from land-derived organic matter. The lowest ratios are from Rusa Timur and Tembungo oils, which are from the deeper water areas of the basin compared to the rest of the oil samples. This is further evidence for the preservation of land-plant organic matter in more marine depositional environments, and concurs with the relatively higher C_{30} regular sterane



Large C_{30} 17α(H) - hopane and 18α(H) - oleanane peaks, presence of resins W, T and R, tricyclics

Comparable C_{29}, C_{27} and C_{28} peaks, dominance of resins W and T peaks

Figure 12 (cont'd). Triterpane m/z 191 and sterane m/z 217 mass fragmentogram of oils from (a) Rusa Timur, (b) Tembungo, (c) South Furious, (d) Barton, (e) Erb West, (f) St. Joseph and (g) Ketam.

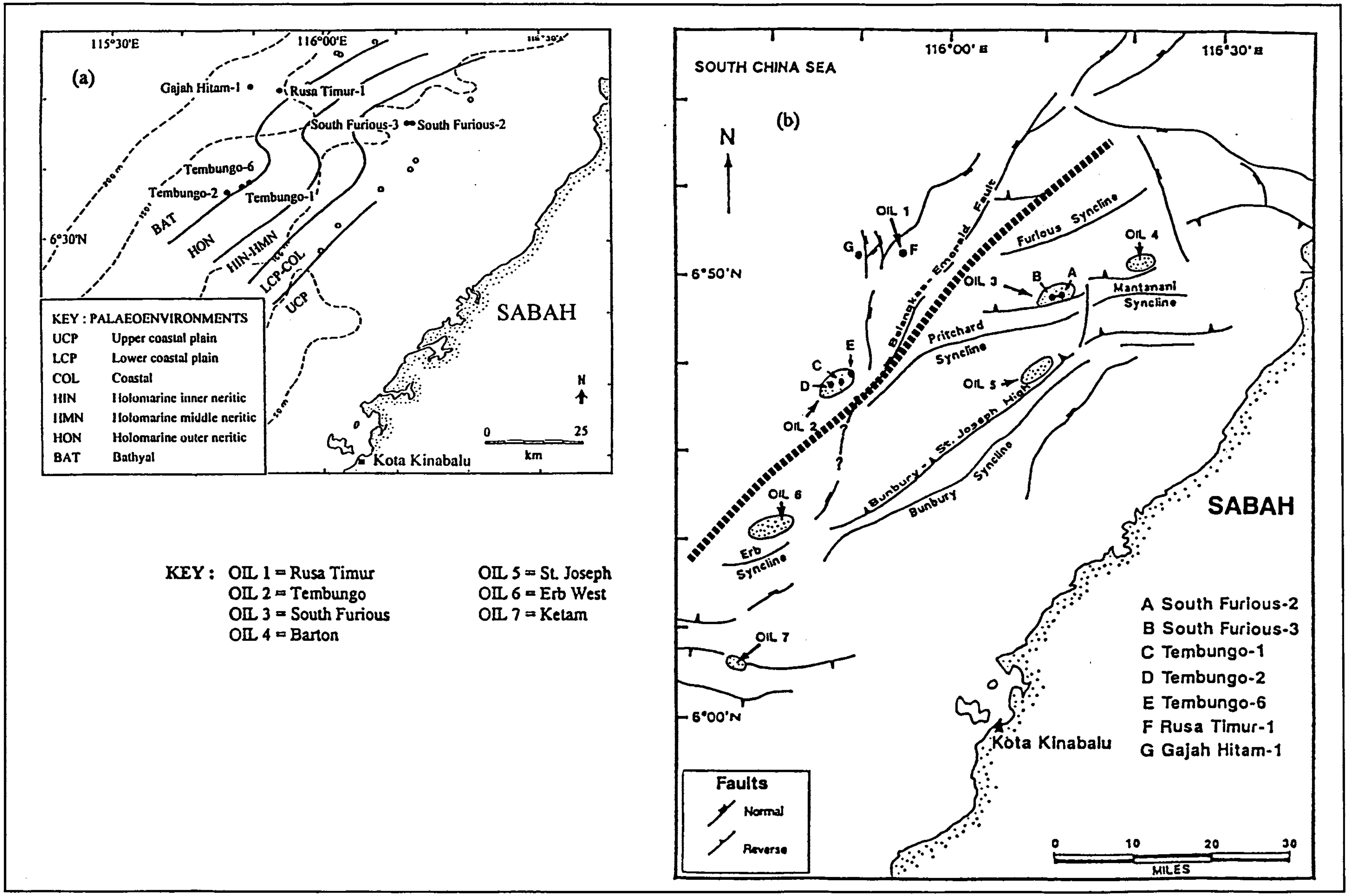


Figure 13. (a) Palaeoenvironment at the top of Stage IVA derived from PETRONAS in-house biostratigraphic reports, (b) the dividing line between the 'inner' and 'outer' oils based on triterpane/ sterane ratios. Rusa Timur and Tembungo oils are indicated to have been generated by land-derived organic matter deposited in deep-marine environments while the other oils were sourced by land-derived organic matter deposited in inner neritic/paralic/deltaic-lower coastal plain environments.

concentrations. Unfortunately, this seems to indicate that the triterpane/sterane ratio may be affected by depositional environment conditions when it is defined as a source indicator. The complex relationship between organic facies and the triterpane/sterane ratio (Waples and Machihara, 1991) may have been underestimated. It is also possible that differences in the resulting ratios are caused by the selection of different hopane and sterane peaks for the calculations. To enable the use of this ratio with more certainty, it is therefore necessary to conform to some sort of uniformity, or standardisation, for peak selection. This will eliminate result discrepancies caused by using different peaks and make the ratio universally applicable for comparing oils.

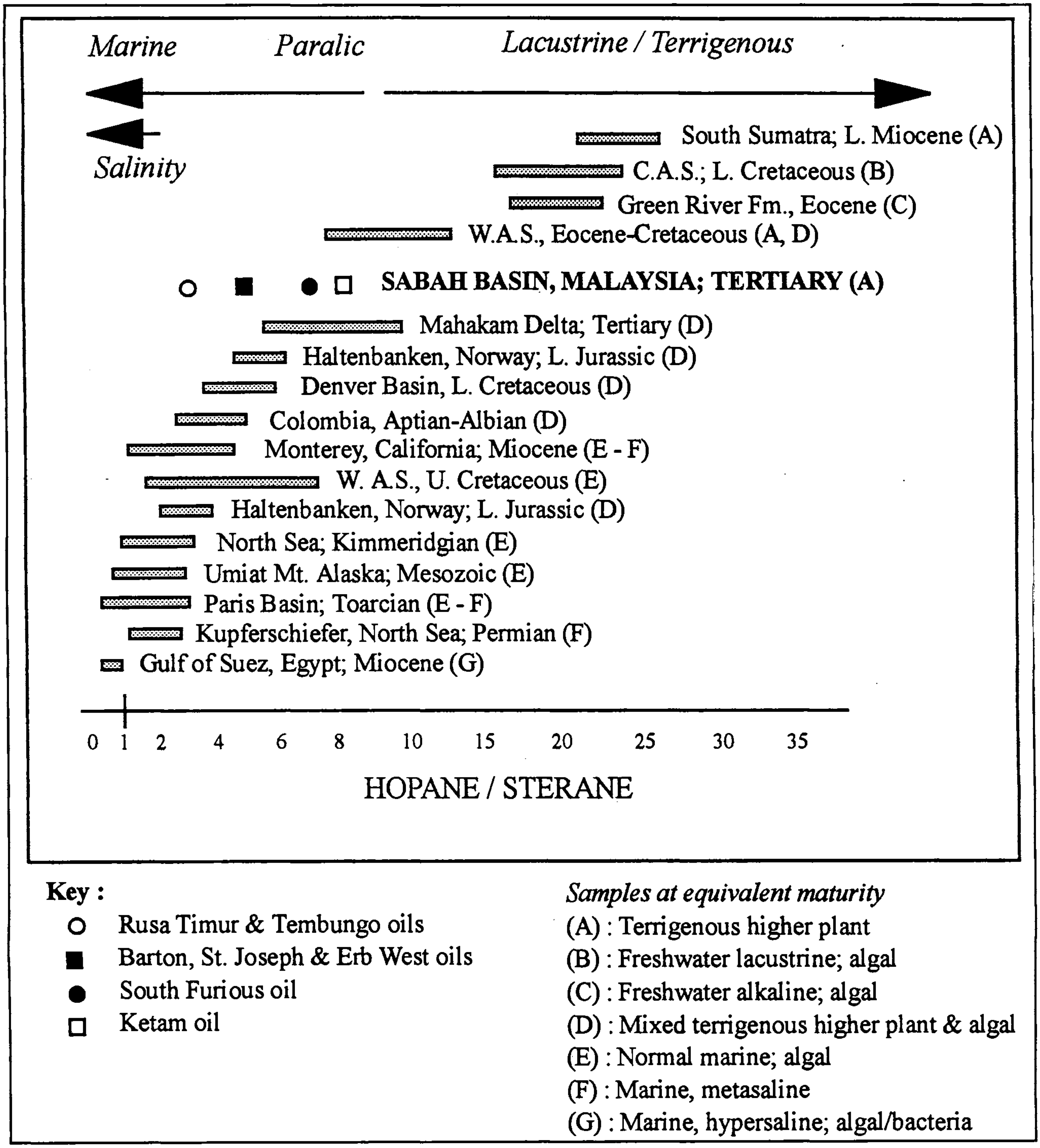


Figure 14. The Sabah Basin oils are classified as being sourced by marine-paralic kerogens based on Genik's (1993) triterpane/sterane ratio comparative chart.

MATURITY

Extracted hydrocarbons

Maturity ratios calculated from the sediment extracts cannot be used to determine the sediment maturity levels in this case due to the likely intermixing between biomarkers present in the residual migrated hydrocarbons and the *in situ* biomarkers. The sediments analysed were established to be immature by vitrinite reflectance and pyrolysis T_{max}. As such, the Production Index values can be used to indicate the extent of contamination by migrating hydrocarbons. Figure 15 shows that the 20S/(20S+20R)-sterane and 22S/(22S+22R)-triterpane ratios are highly correlatable with the Production Index values obtained from pyrolysis.

It is proposed here that if contamination by the migrating hydrocarbons is low, then the resulting biomarker ratios will be correspondingly low since the biomarkers present will be more representative of the immature sediments from which they were extracted. Conversely, if contamination by residual hydrocarbons is high, then the biomarker ratios will be correspondingly high, reflecting the maturity level already attained by the sediments that generated the hydrocarbons. Immature *in situ* biomarkers will be present, but in relatively smaller concentrations compared to when contamination is low. The maturity ratios fluctuate with increasing depth (Fig. 15), resulting in an overall decreasing trend with depth. Maturity is indicated to be highest in the shallower samples when they should naturally be the least mature. This trend is taken as an indication of the upward direction of hydrocarbon migration. The true sediment maturity will be the closest to the lowest ratio value obtained, where the effects of contamination from migrated hydrocarbons is minimal.

Oils

In general, the 20S/(20S+20R)-sterane ratios are < 0.55, the 22S/(22S+22R)-triterpane ratios are < 0.60, and the moretane/hopane ratios > 0.10 (Table 3). Study of Tertiary oils by Grantham (1986) revealed higher moretane/hopane ratios compared to those determined from older oils of similar maturities, with ratios ranging between 0.1–0.3 with values of 0.15–0.20 being common. Moretane/hopane values obtained from the oil samples in this study support the observations of Grantham (1986) with values ranging between 0.12–0.27.

Grantham (1986) also noted that the 20S/(20S+20R)-sterane ratios of the Tertiary oils appear to be retarded, not quite reaching the expected equilibrium value of 0.55. He underlined the significance of time in sterane isomerisation and proposed that the rapid sedimentation rates often experienced by young Tertiary basins may have influenced the chemical reactions of the biomarkers, resulting in retardation of the epimerisation process. Again, the 20S/(20S+20R)-sterane ratios of the Sabah Basin oils concur, with values much lower than the equilibrium value of 0.55 (range: 0.29–0.53). The 22S/(22S+22R)-triterpane ratios were calculated from the C_{32} hopane. Even though the ratios determined from the oils are less than the expected equilibrium value of 0.60, they are very close to it, ranging between 0.57–0.59. This perhaps suggests that the 22S/(22S+22R) ratio is unaffected by the yet unclear processes which caused the retardation of the sterane ratio. Unless retarded, most oils will fall in this range within the oil window. It is therefore proposed here that for Tertiary oils, the 22S/(22S+22R)-triterpane biomarker ratio is a relatively more reliable maturity indicator than the 20S/(20S+20R)-sterane and moretane/hopane biomarker ratios. The question as to why the triterpane ratio is unaffected remains to be answered. Future investigations may clarify the underlying reasons for the different behaviours of these biomarker ratios.

Table 3. Biomarker maturity ratios of seven Sabah crude oil samples.

Sample	Thermal Maturity Parameters		
	1 *	2	3
Rusa Timur	0.38	0.57	0.27
Tembungo	0.29	0.57	0.26
Barton	0.40	0.57	0.26
St. Joseph	0.45	0.59	0.25
Erb West	0.53	0.58	0.14
South Furious	0.39	0.59	0.25
Ketam	0.40	0.59	0.12

* **Key:**
1 Sterane 20S/(20S+20R)
2 Triterpane 22S/(22S+22R)
3 Moretane/C_{30}-hopane

CONCLUSIONS

The Sabah Basin source rocks are dominantly terrigenous in origin, deposited in generally oxic environments such as deltaic/peat swamps, brackish mangrove swamps and lagoons, as indicated by the high triterpane/sterane ratios, the presence of 18α(H)-oleanane, resins W, T and R, the general predominance of C_{29} regular steranes over the C_{27} and C_{28} counterparts and evidence from other organic geochemical analyses. Contribution from marine organic matter is essentially small, as indicated by the minor presence of C_{30} steranes, comparable C_{27}, C_{28} and C_{29} concentrations and lower hopane/sterane ratios in some samples. Consistently similar mass fragmentograms suggest that the oils and sediment extracts originated either from the same source rock or, more likely, from different source rocks with similar organic matter compositions. The relative similarity of biomarker distributions in samples from different palaeoenvironments suggest that components from similar types of higher land-plants were redistributed by sedimentary/transport processes to each depositional setting.

20S/(20S+20R)-sterane biomarker ratios of lower than the 0.55 equilibrium value and moretane/hopane ratios > 0.10 supports the retardation of isomerisation process previously suggested by Grantham (1986). Biomarker ratios from the extracts cannot be used to determine the true sediment maturity level as the *in situ* biomarkers are mixed with those present in the migrating hydrocarbons. Variations of biomarker maturity ratios with depth resemble those of the Production Index,

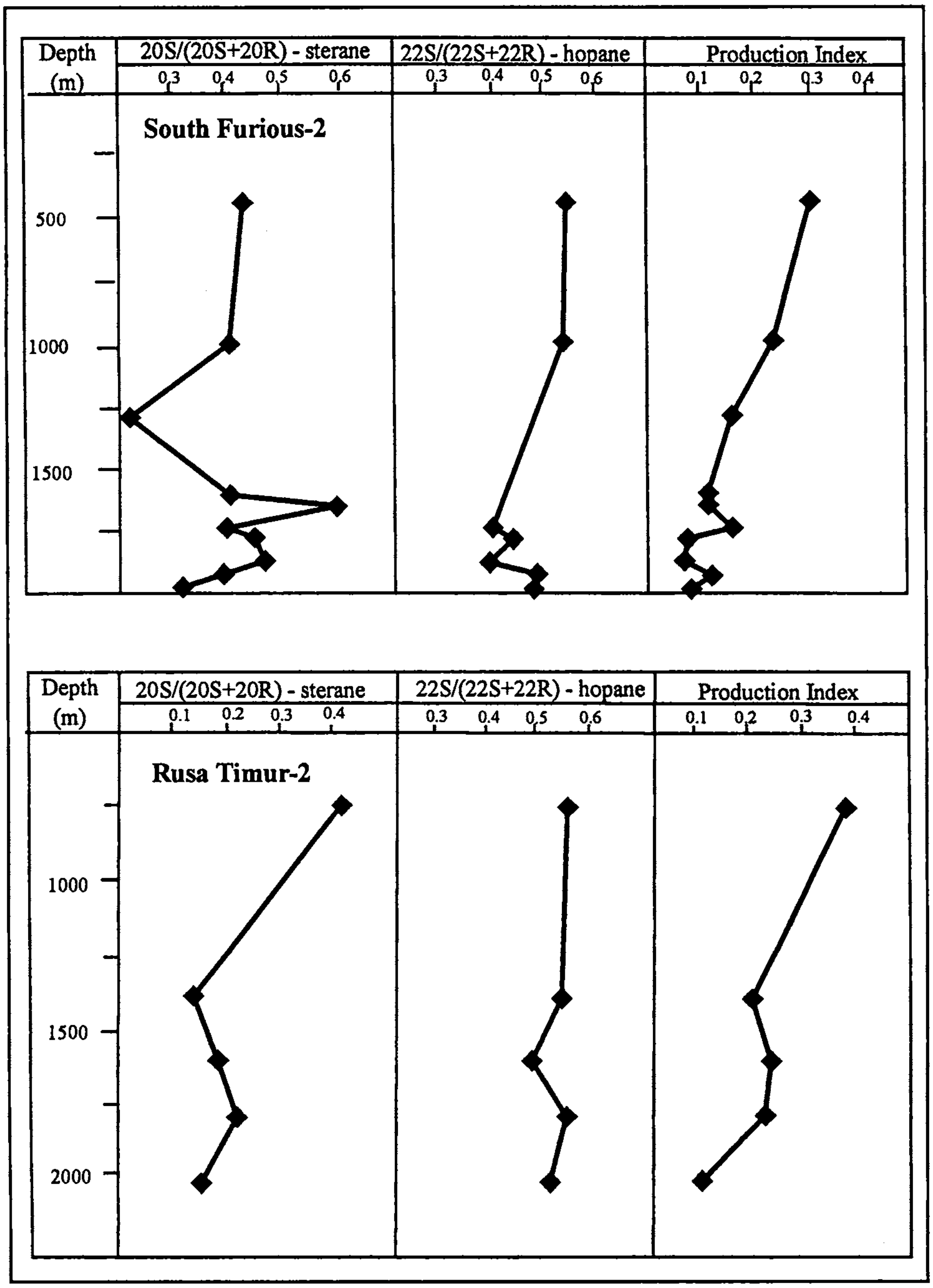


Figure 15. Both the 20S/(20S+20R)-sterane and 22S/(22S+22R)-hopane biomarker maturity ratios mimic the Production Index trend of decreasing with depth. This is taken as evidence for the effects of migrated hydrocarbons on the maturity ratios.

confirming the influence of non-indigenous residual hydrocarbons on the biomarker maturity ratios.

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