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Possible source for the Tembungo oils: evidences from biomarker fingerprints

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Abstract: The Tembungo field located offshore Sabah is a highly faulted anticlinal structure where oil and gas accumulations occur in different fault blocks. This paper discusses source rock potential, characteristics of Tembungo oils, and oil – oil and oil – source rock correlations between oils and source rocks from Tembungo and adjacent fields.

The shales of the Tembungo wells have poor to fair source rock potentials mainly of Type III gas-prone organic matter and minor contributions from Type II oil-prone organic matter. Maturity data show that the organic matter in the Tembungo well sections are immature.

The Tembungo crude oils from the different fault blocks are genetically similar, paraffinic, contain low sulphur and wax, and have moderate API gravity. The presence of C_{24}– tetracyclic terpanes, oleananes, C_{30}– resin triterpanes and predominance of C_{29}– steranes in all the samples suggest that the oils are derived from source rocks of terrigenous origin containing different mixtures of land-plant organic matter including resins. GC and GCMS analyses indicate that the crude oils produced from the same fault block have similar biomarker distributions but some variations occur in oils from different fault blocks. These variations are interpreted as due to the effect of migration and biodegradation whereby each fault block has a separate fluid system and there is no or very little intermixing between them.

Oil – oil correlation indicates that the oils in the study area have similar biomarker fingerprints and could have been generated from the same source rock type containing abundant terrigenous organic matter.

INTRODUCTION

Tembungo field is located offshore Sabah, about 75 km NNW of Kota Kinabalu (Fig. 1). The field is a highly faulted anticlinal structure (15 km x 5 km) trending NE-SW where oil and gas accumulations in the different fault blocks are controlled by the N-S trending fault system (Fig. 2). The main hydrocarbon accumulations occur in the Tembungo reservoir turbidite sands of upper Miocene (Fig. 3).

Geochemical studies have so far failed to identify the exact source rock which could have generated the commercial quantities of oils in the Sabah basin. The source rock intervals in the area are lean in organic matter but are sufficient in quantity. This study describes the application of geochemical approach particularly in the use of biomarkers in characterising crude oils and source rocks from the Sabah basin. It is hoped that the present study would be able to throw some light

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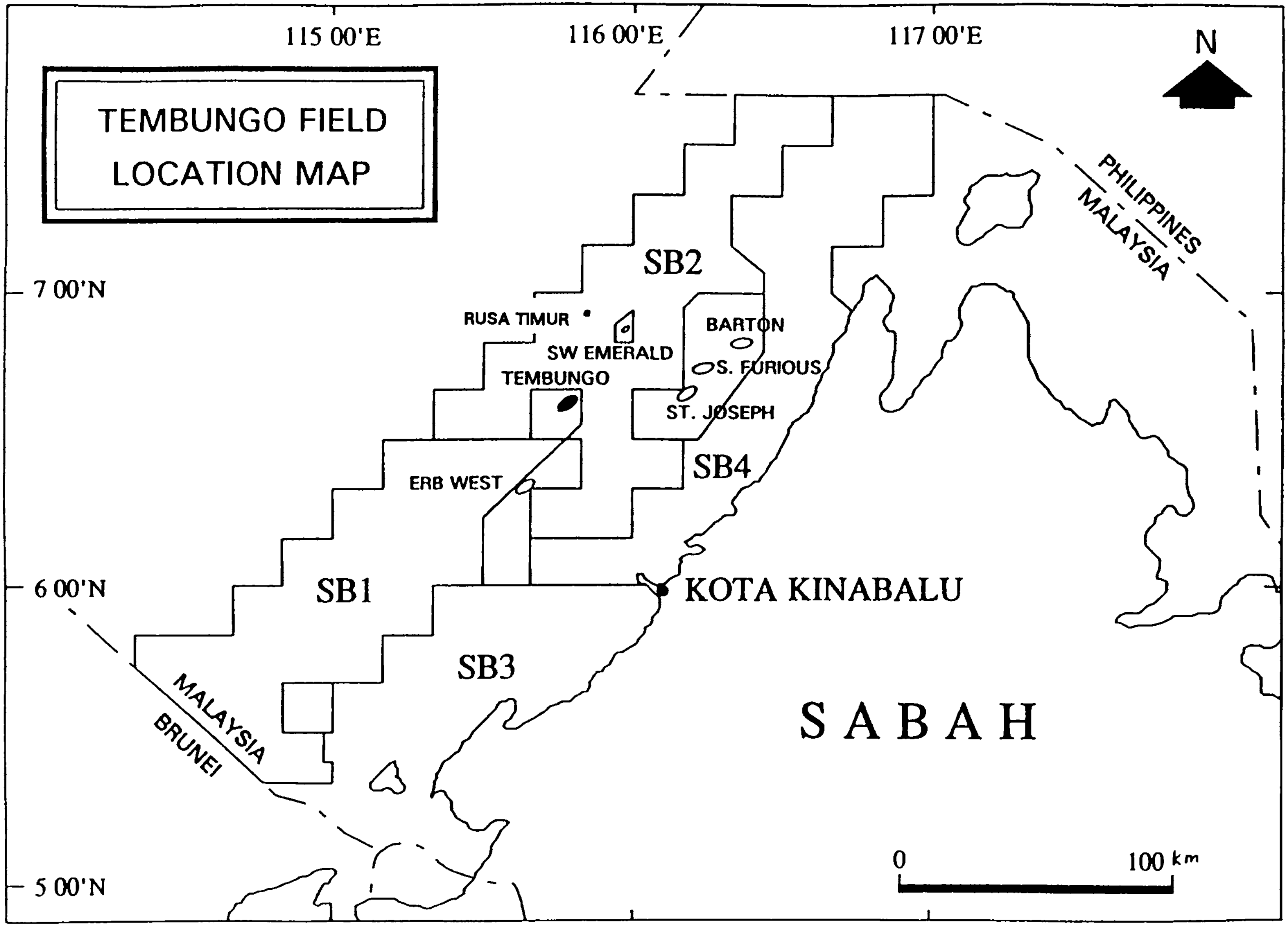

Figure 1: Location map of Tembungo field.

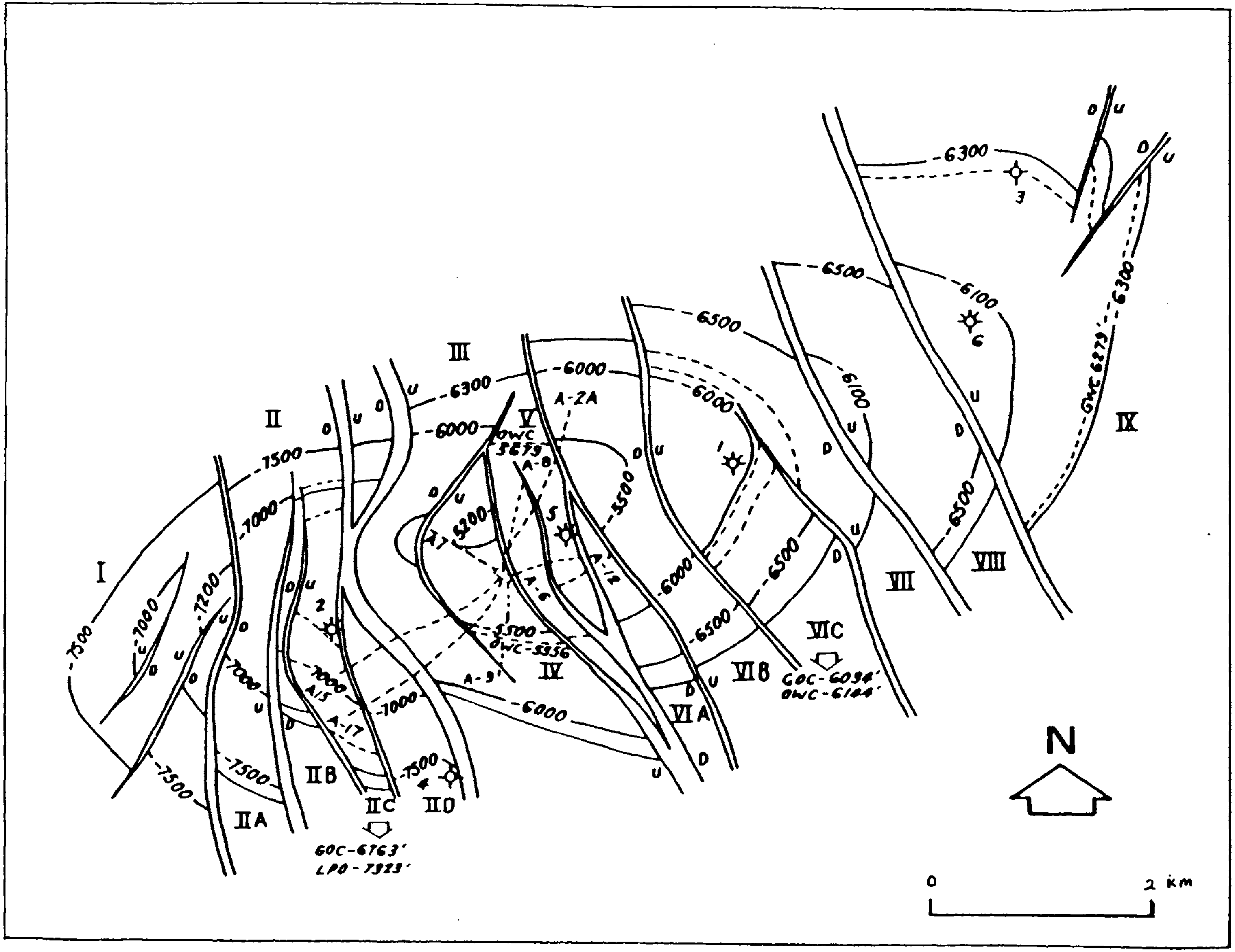

Figure 2: Structural map of Tembungo field.

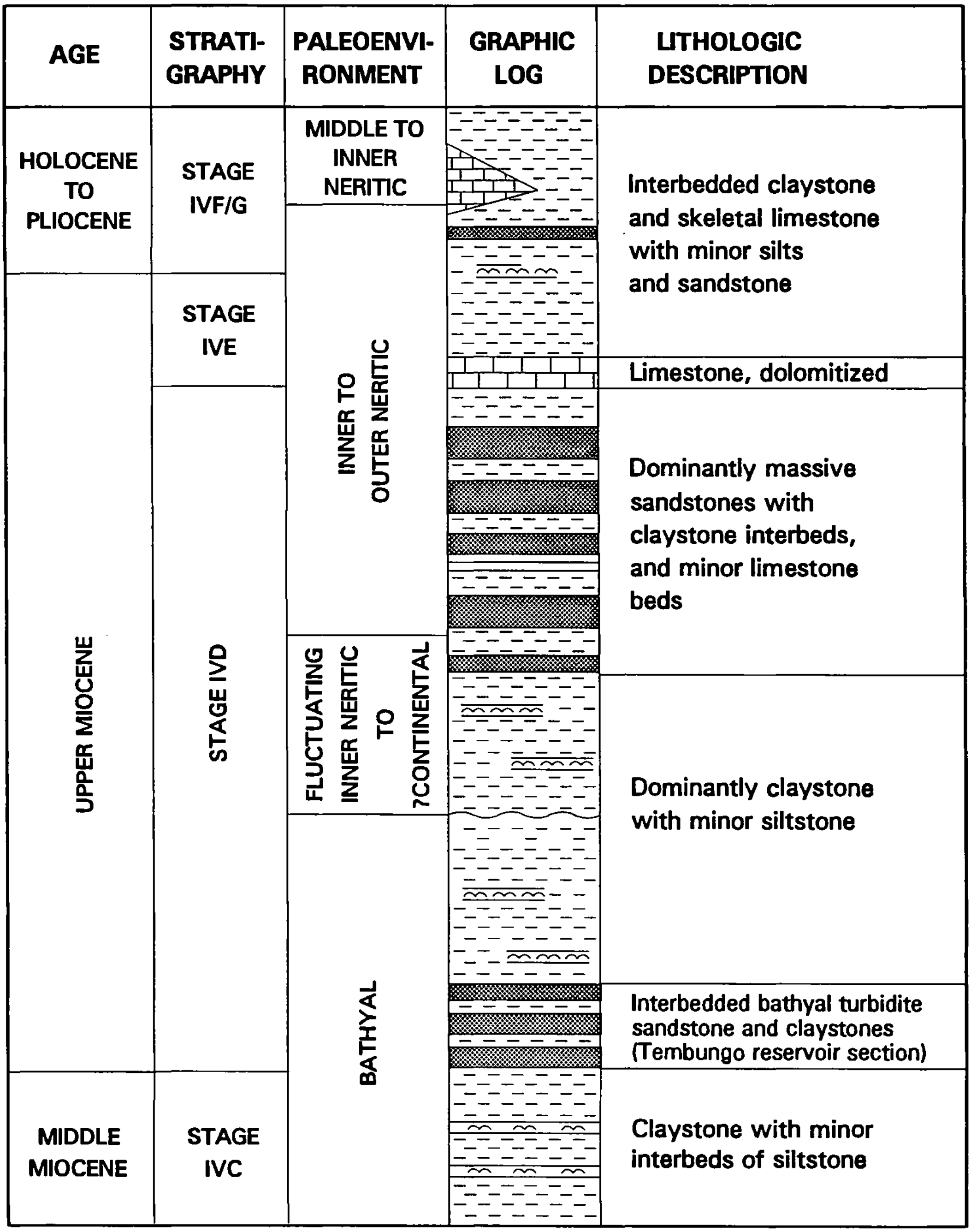

Figure 3: Generalised lithostratigraphy of Tembungo field.

on the possible source for the Tembungo and other oils in the vicinity of Tembungo field.

Methodology

For the purpose of this study, ditch-cuttings, cores and crude oils from Tembungo and adjacent fields were analysed. Seven crude oil samples were sampled from four different fault blocks of the Tembungo field and another four were from adjacent fields. Ditch-cuttings and cores were analysed using Rock-Eval pyrolyser and Leco TOC equipment to determine the source rock potential. Selected potential source rocks were soxhlet extracted and fractionated using liquid column chromatography (LCC). The saturated fraction was further analysed using gas chromatography (GC) and gas chromatography – mass spectrometry (GCMS). Crude oil samples were analysed for physical properties and also fractionated using LCC. Carbon isotope analysis was carried on the saturated and aromatic fractions, whilst GC and GCMS on the saturates.

Genetic similarities of the Tembungo crude oils were determined using bulk properties and compositions, carbon isotopes, light hydrocarbon and C_{12+} alkane distributions, and steranes (m/z 217) and triterpanes (m/z 191) distributions. Correlations between oils and source rock extracts from Tembungo and adjacent fields were carried out using m/z 191 fragmentrograms of triterpanes.

RESULTS AND DISCUSSION

Source Rock Potential

The results show that in general, all the shale sections of the Tembungo wells contain poor to fair quantities of pyrolysable kerogen (S_2) with low to average total organic carbon (TOC) contents. Hydrogen indices are generally less than 200. Plot of hydrogen index (HI) versus Tmax of the samples (Fig. 4) shows that the shales of the Tembungo field contain mainly Type III gas-prone organic matter with minor contributions from Type II oil-prone organic matter.

The coals on the other hand, contain high quantities of pyrolysable kerogen (S_2 = 5.0 to 100 mg HC/g rock) with high TOC (28.3 to 55.4 wt. %) contents. However, HI versus Tmax plot indicates that most of the coals are mainly of Type III humic organic matter.

Thermal maturity based on vitrinite reflectance shows that the organic matter in the Tembungo wells at total depth (TD) are immature. This is supported by Tmax data from Rock-Eval pyrolysis (Fig. 4).

Genetic Similarities of Tembungo Oils

The genetic similarities of seven Tembungo oils sampled from the different fault blocks (Fig. 2) were studied using bulk properties and compositions, carbon isotopes, gas chromatography (GC), and gas chromatography – mass spectrometry (GCMS). The GC and GCMS techniques were used to compare and contrast the distribution of the n-alkanes / isoprenoids and steranes / triterpanes respectively present in the samples.

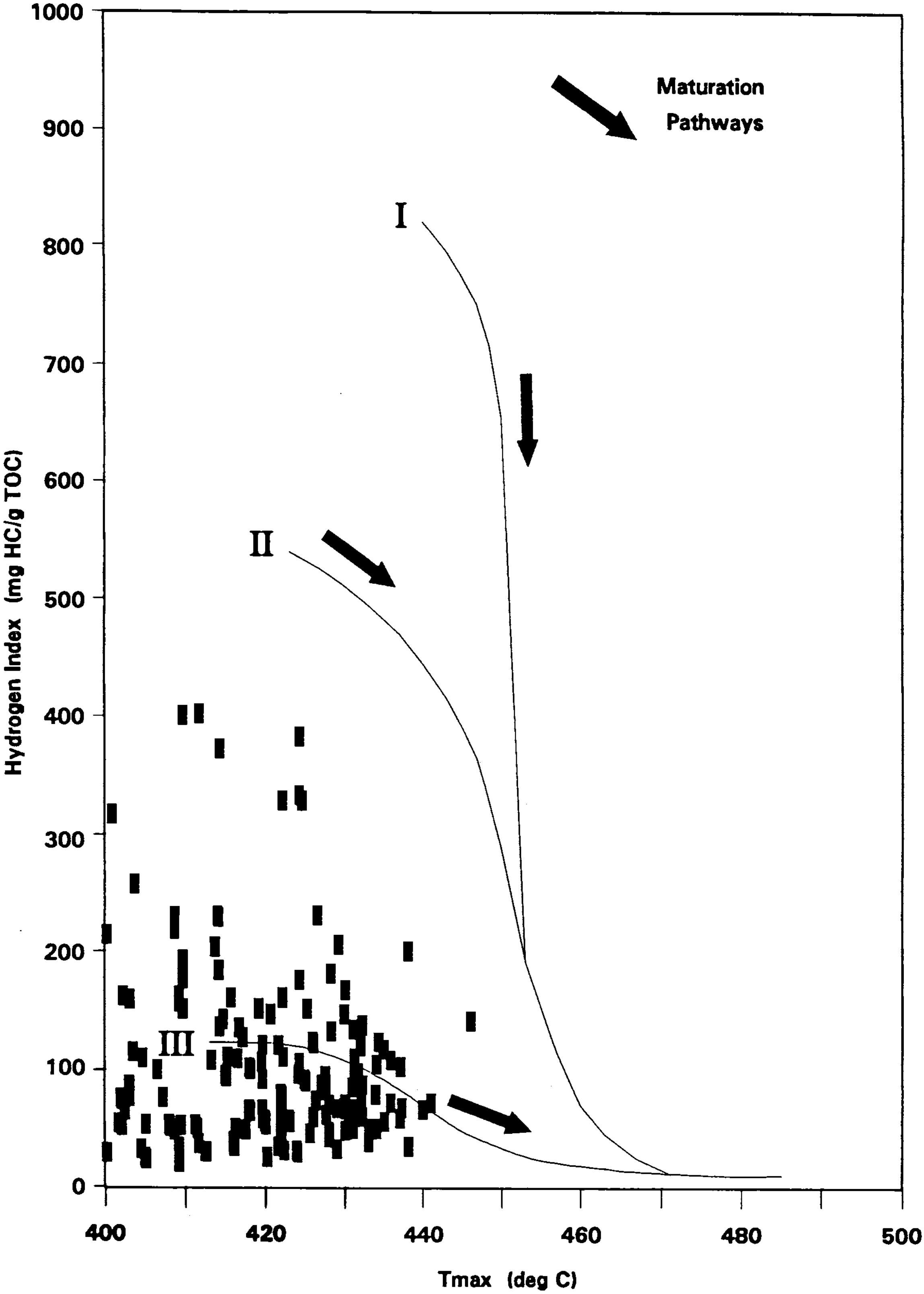

Figure 4: Plot of hydrogen index versus Tmax for Tembungo rock samples.

Bulk Properties and Compositions

Bulk properties and compositions (Tables 1 and 2) indicate that the Tembungo crude oils are genetically the same. They are paraffinic with high proportions of saturated hydrocarbon fractions (71 to 89%), moderate API gravities (35 to 38°), low sulphur (0.05 to 0.07%) and wax (1.7 to 6.2%) contents, and pour points ranging from –3 to 0°C (with the exceptions of samples A-15 and A-17 with values of 21°C and 15°C respectively). This may be explained by the relatively higher wax contents of the two samples. The low sulphur content is typical of oils derived from terrigenous origin. The close clustering of points in a plot of carbon isotope ratios of saturate and aromatic fractions (Fig. 5) supports the above suggestion that the Tembungo crude oils are of the same origin.

Light Hydrocarbon Distributions

The genetic similarities of the Tembungo oils is also shown by the distribution of C_7 light hydrocarbon fraction (<150°C) of the Tembungo crudes (Fig. 6). The clustering of points representing the Tembungo oils from the different fault blocks indicate that they are genetically similar.

Table 1: Bulk properties of Tembungo oils.

Sample	Pour point (°C)	API gravity (at 15°C)	Sulphur content (wt %)	Wax content (wt %)
Tembungo A–1	-3	35.87	0.06	3.26
Tembungo A–6	0	34.53	0.06	2.07
Tembungo A–8	-3	36.59	0.05	2.73
Tembungo A–9	-3	34.67	0.07	1.97
Tembungo A–12	-3	36.77	0.05	1.71
Tembungo A–15	21	35.34	0.06	6.22
Tembungo A–17	15	38.04	0.05	3.39

Table 2: Composition, isoprenoid ratios and Carbon Preference Index of Tembungo crudes.

Sample	Sat %	Aro %	NSO %	Polar %	Pr/ Ph	Pr/ nC_{17}	Ph/ nC_{18}	CPI 24–34
A-1	79.9	2.2	11.1	6.8	4.05	1.73	0.33	1.09
A-6	80.5	1.8	8.5	9.2	3.57	2.02	0.38	1.13
A-8	83.4	2.1	11.6	2.9	3.71	1.59	0.33	1.09
A-9	89.1	1.9	8.9	0.1	3.96	1.80	0.35	1.06
A-12	70.9	2.3	11.4	15.4	4.27	1.34	0.29	1.09
A-15	85.3	2.5	11.9	0.3	4.95	1.12	0.24	1.13
A-17	77.4	4.7	8.5	9.4	4.00	1.28	0.32	1.08

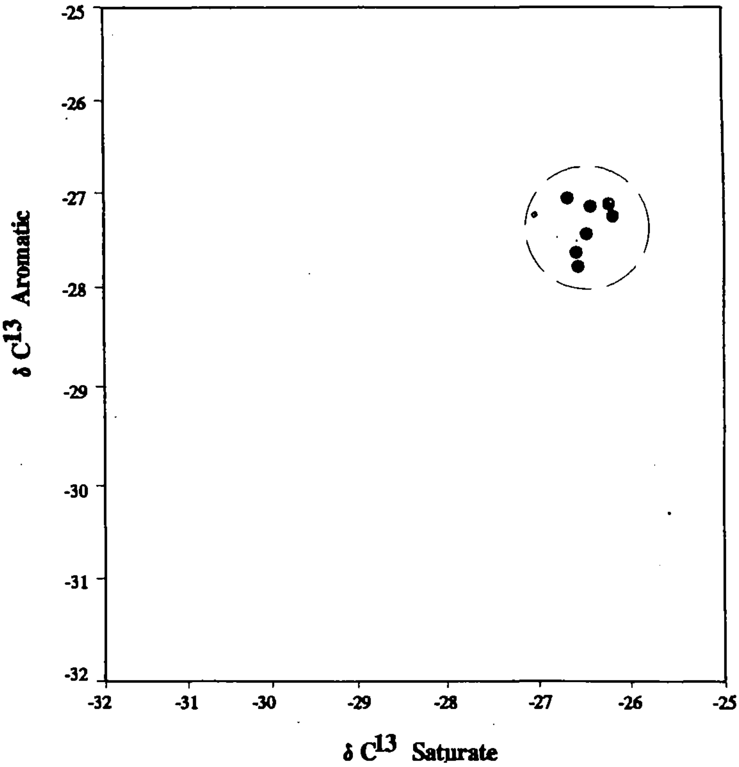

Figure 5: Carbon isotope ratios of C_{15+} saturates and aromatics of Tembungo oils.

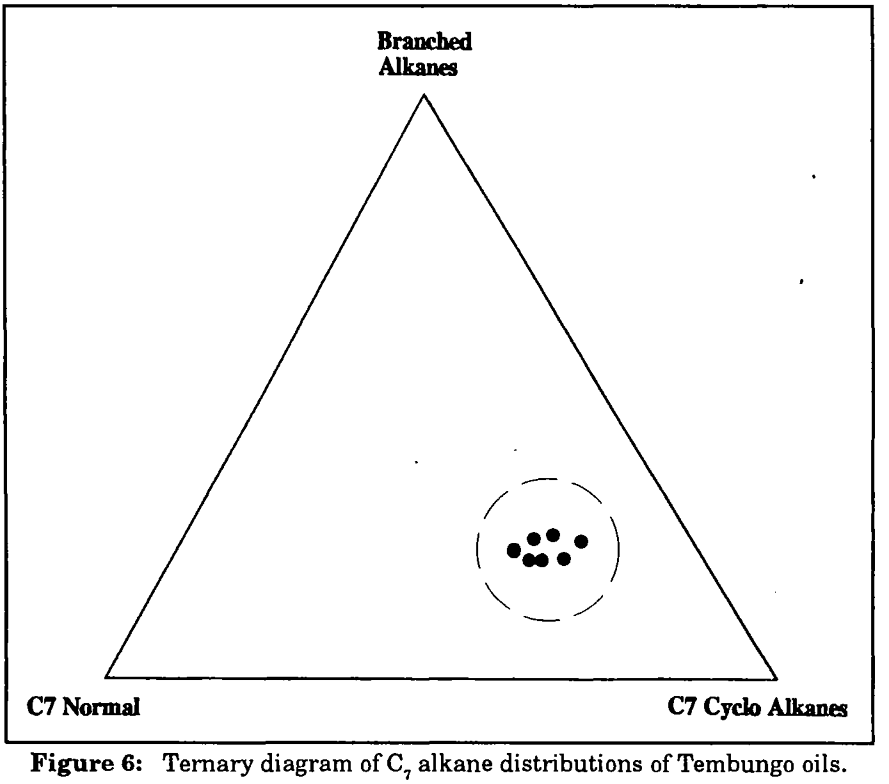

Figure 6: Ternary diagram of C_7 alkane distributions of Tembungo oils.

C_{12+} Alkane Distributions

The gas chromatograms of the saturated hydrocarbons of the Tembungo crudes as shown in Figure 7 are generally the same indicating genetic similarities. They show unimodal n-alkane distributions ranging from nC_{12} to nC_{35} with maxima in the nC_{17} region. The slightly higher concentrations of the nC_{20+} n-alkanes in samples A15 and A17 show that they are slightly waxy. This is also shown by the slightly higher wax contents and pour points of the two samples (Table 1).

Pristane / phytane and pristane / nC_{17} ratios for all the samples with values ranging from 3.7 to 5.0 and 1.1 to 2.0 respectively are considered high, indicating that the source rocks for the crude oils were probably deposited in a peat swamp environment which may later be eroded and deposited elsewhere (marine setting). Carbon preference indices (CPI) of the crude oils ranging from 1.06 to 1.13 show that the oils are mature (Table 2).

Sterane And Triterpane Distributions

The mass fragmentograms of the steranes and triterpanes of the Tembungo crude oils produced from the different fault blocks are shown in Figures 8 and 9. The distributions of the steranes and triterpanes of all the crudes are again very similar indicating that they were probably generated from the same source rock type. The m/z 191 shows a series of hopanes ranging from C_{27} to C_{33}. The absence or very low concentrations of C_{34} and C_{35} extended hopanes is not uncommon in oils derived from terrigenous origin in offshore Sabah and Sarawak.

In addition to the ubiquitous hopanes, m/z 191 also shows presence of 18α(H)– and 18β(H) – oleananes, resin triterpanes (W, T and R), C_{24}-tetracyclics and some unknown C_{30}– pentacyclic triterpanes. In all the samples, 18α(H) – oleanane is present in relatively high concentrations (oleanane index: 0.56 to 0.90) indicating a high input of land-plant-derived triterpenoid precursor into the source rocks. Oleanane Index is a measure of the relative concentration of 18α(H) – oleanane against $C_{30}\alpha\beta$ – hopane. The significance of oleanane is that it is believed to be derived from angiosperm which is only present in Late Cretaceous and Tertiary source rocks and crude oils (Philp and Gilbert, 1986). The presence of oleananes and resin triterpanes in all the samples suggests that the crude oils are derived from source rocks of terrigenous origin containing mixtures of different types of land-plant organic matter including resins. The presence of oleanane has not only been reported in oils from Southeast Asia (Grantham, *et. al.*, 1983; Hoffmann, *et. al.*, 1984), but also in Tertiary Niger delta (Ekweozor *et. al.*, 1979a; 1979b) and Taranaki basin, New Zealand (Czochanska *et. al.*, 1988).

The sterane and diasterane peaks in all the samples as shown by m/z 217 are not prominent. This is due to the relatively high concentrations of the resin triterpanes (W and T) compared to the steranes as shown by the two most prominent peaks (see Fig. 9). Plot of C_{27}–, C_{28}– and C_{29}– αααR steranes shows that the Tembungo oils are genetically similar and derived from source rocks containing abundant terrigenous organic matter (Fig. 10).

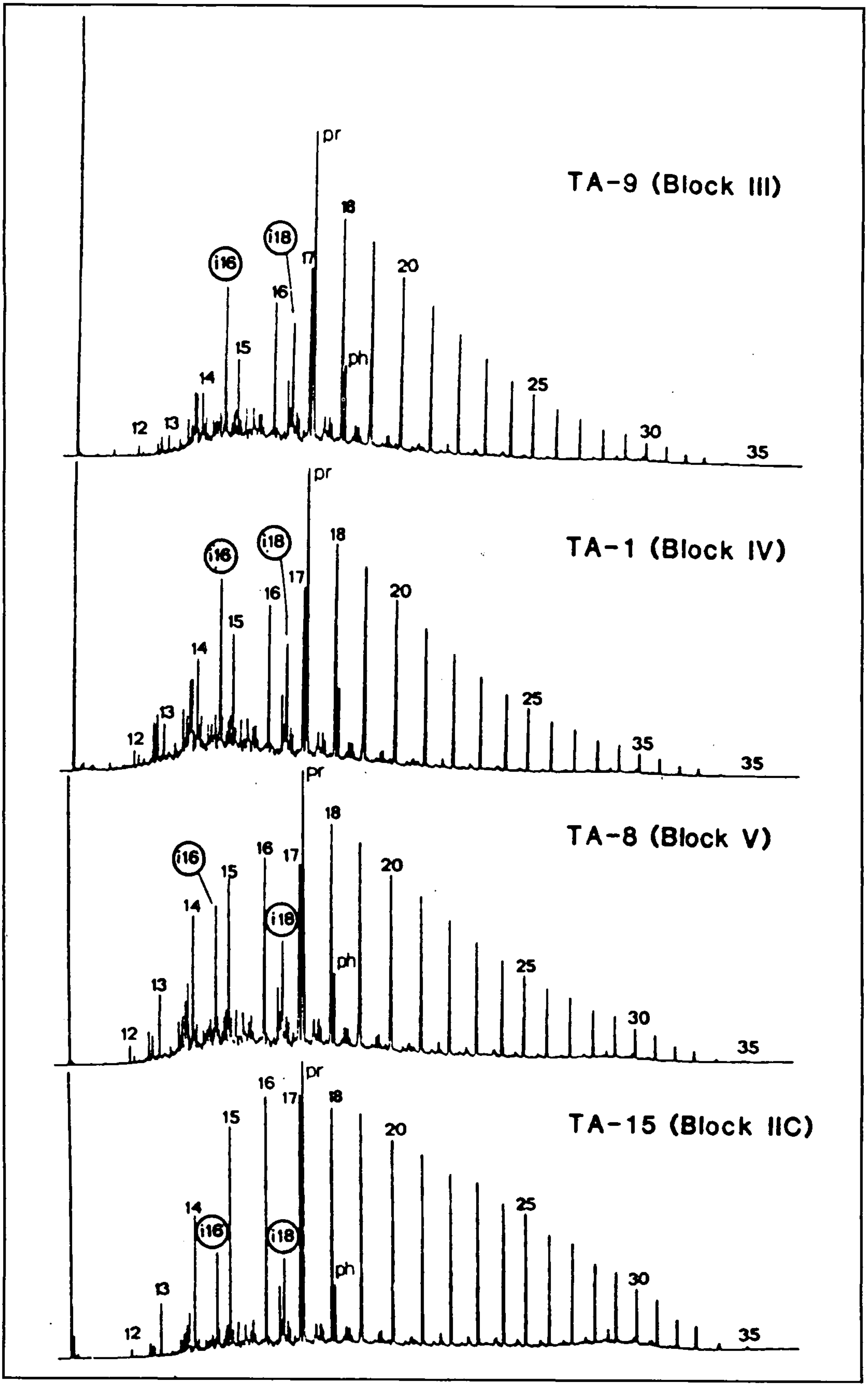

Figure 7: Gas chromatograms of C_{12+} saturate fraction of selected Tembungo oils. Numbers indicate n-alkanes, and isoprenoids, pr=pristine, ph=phytane.

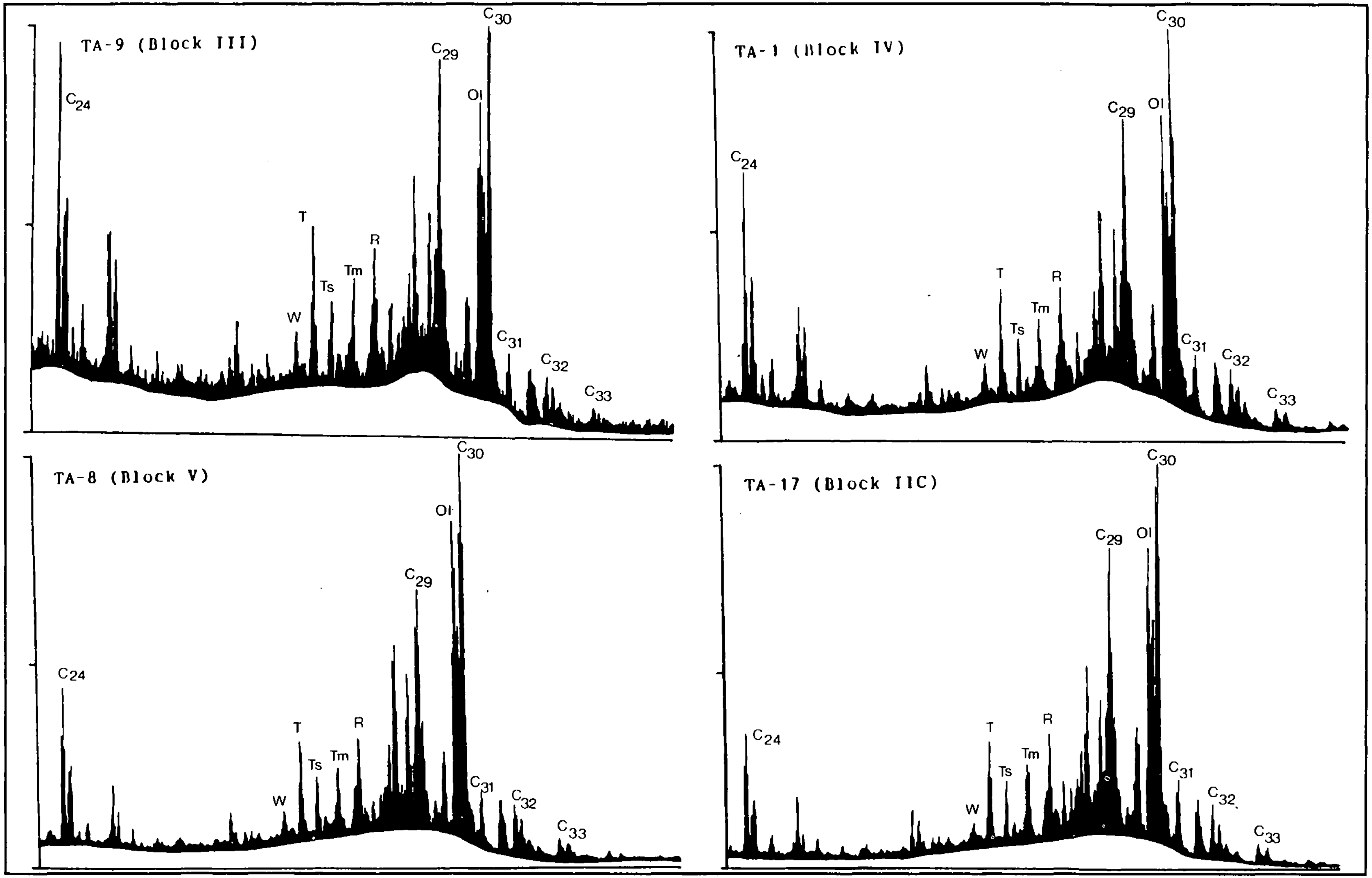

Figure 8: Mass fragmentograms (m/z 191) of triterpanes of selected Tembungo oils.

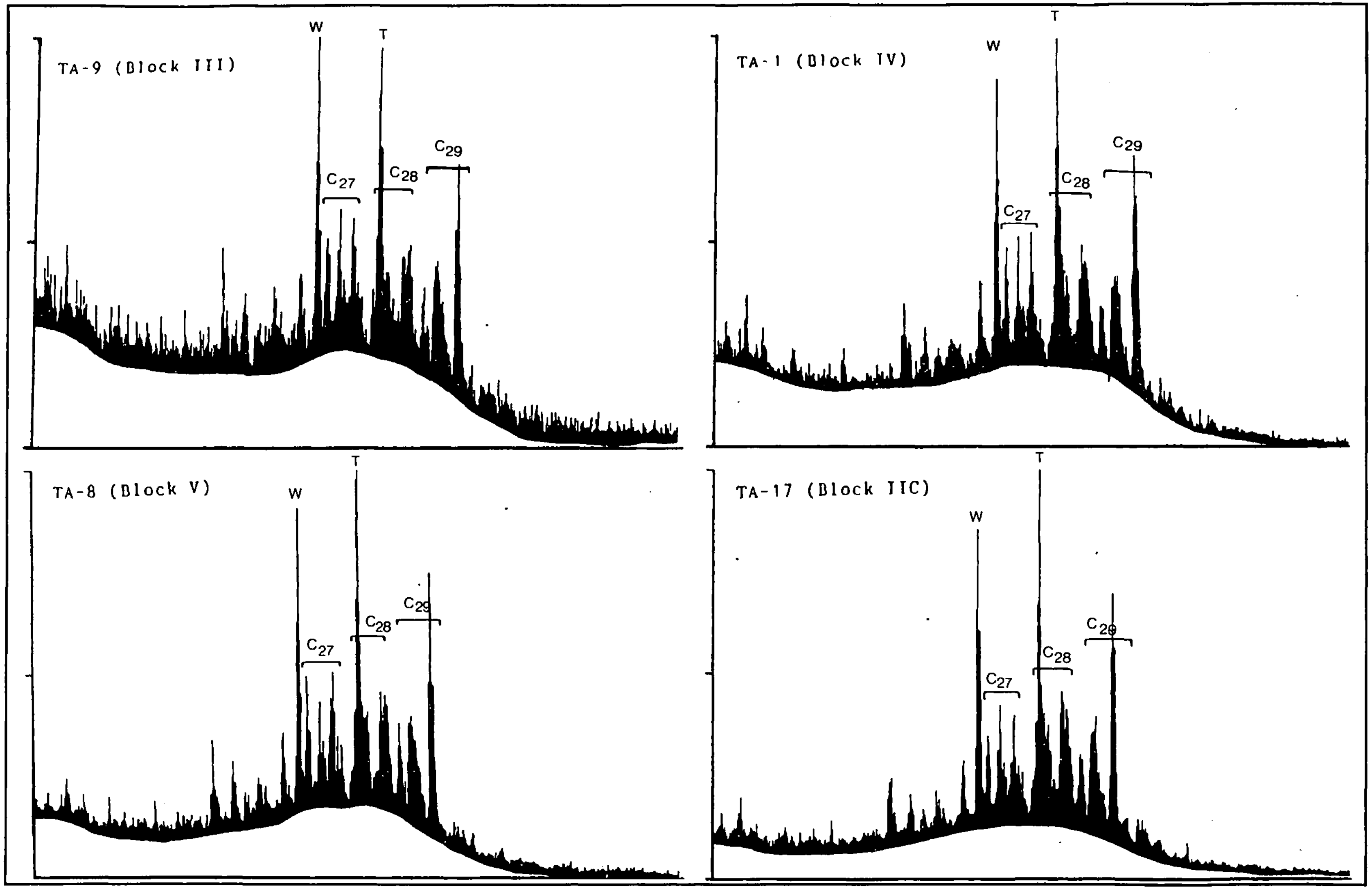

Figure 9: Mass fragmentograms (m/z 217) of steranes of selected Tembungo oils.

Biodegradation / Migration of Tembungo Oils

Alteration processes such as biodegradation and water washing occurring in the reservoir can be studied by the distributions of light hydrocarbons and C_{12+} hydrocarbons fractions. The lower the concentrations of n-alkanes with respect to iso-alkanes or cyclic-alkanes, the higher the degree of biodegradation. The distribution of these hydrocarbons as indicated by the relative concentrations of n-alkanes (nC_{14}, nC_{15}, nC_{16} and nC_{17}) over iso-alkanes (iC_{16}, iC_{18} and iC_{19}) show that all the Tembungo crudes analysed are found to be very slightly biodegraded (Table 3). But it is of interest to note that the degree of biodegradation of the crudes in one fault block is similar but differs from that of another block. This may be explained by the fact that each block has a separate fluid system and there is no or very little intermixing between them.

The effect of migration of the crude oils can also be studied by biomarker distributions. Migration of crude oils from source rock through carrier bed to reservoir causes loss of heavier hydrocarbons relative to lighter hydrocarbons. The magnitude of loss reflects the distance of migration covered. The ratio of $(C_{21} + C_{22})/(C_{28} + C_{29})$ n-alkanes for the crude oils shows that the distance of migration of the crudes in one fault block is similar but different from that of another block (Table 3). This observation is also shown by the ratio of C_{24}– tetracyclic / C_{30}– hopane.

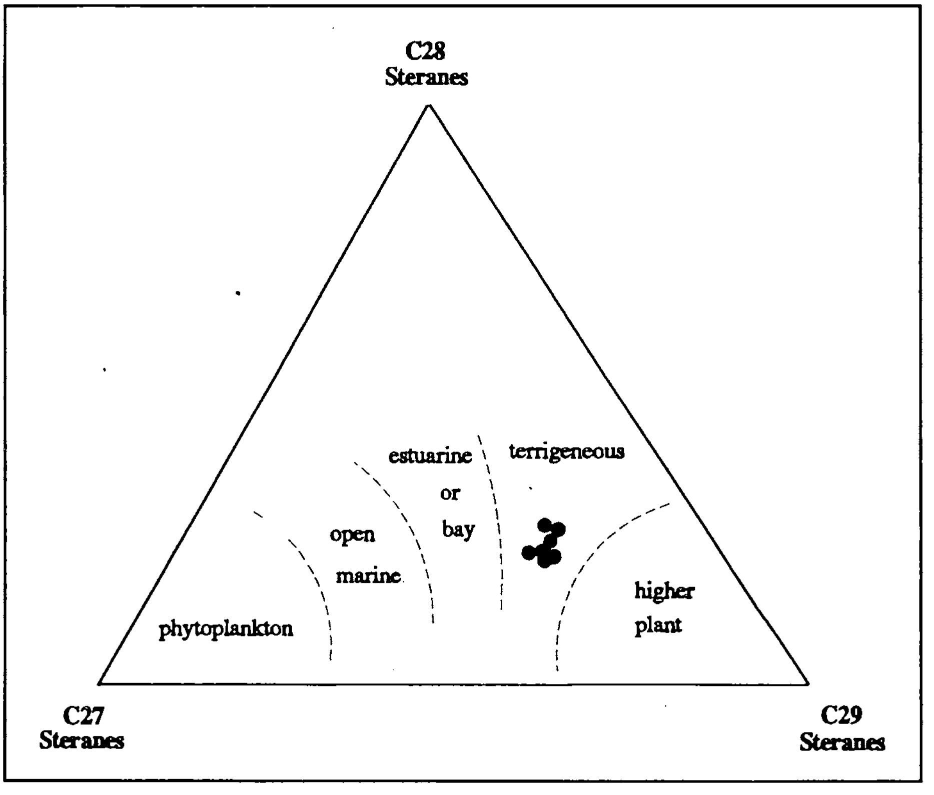

Figure 10: Ternary diagram of sterane distribution of Tembungo oils (Huang and Meinschein, 1979).

Table 3: Biodegradation and migration of Tembungo crudes: C_{12+} alkane distribution.

Block	Sample	Normal/Iso-alkane Ratios						
		nC_{14}/iC_{16}	nC_{15}/iC_{16}	nC_{16}/iC_{18}	nC_{17}/iC_{18}	nC_{17}/iC_{19}	$C_{21}+C_{22}/C_{28}+C_{29}$	C_{24}–Tetra/C_{30}–Hopane
III	TA-9	0.33	0.52	1.19	1.50	0.54	4.74	0.86
IV	TA-1	0.52	0.66	1.36	1.53	0.57	4.06	0.60
	TA-6	0.61	0.69	1.37	1.32	0.53	3.88	0.54
V	TA-8	0.97	1.19	1.86	1.76	0.65	3.36	0.41
	TA-12	1.03	1.29	2.10	2.16	0.74	3.62	0.42
IIC	TA-15	1.39	1.74	2.45	2.33	0.91	2.41	0.33
	TA-17	1.37	1.69	2.52	2.17	0.78	2.23	0.33

Oil - Oil and Oil - Source Rock Correlation

In an attempt to determine the source for the Tembungo oil, a number of oils and source rock extracts from various stratigraphic intervals from nearby fields were analysed using gas chromatograph – mass spectrometer (GCMS) to study their biomarker distributions. To correlate the Tembungo oil with other oils in the vicinity of the Tembungo field, the distribution of triterpanes were used. Figure 11 shows that the fingerprints of oils from wells A, B, C and D are very identical to that of Tembungo, indicating that all the oils could have been generated from the same source rock type containing abundant terrigenous organic matter.

In determining the source rock for the Tembungo oil and other oils in the vicinity of the Tembungo area, source rock extracts from Stages IVA, IVB, IVC, upper and lower part of IVD, and IVE were analysed. Again the distributions of the triterpanes were used in the correlation studies. The m/z 191 mass fragmentograms of the triterpanes (Fig. 12) show that the Stages IVA and IVB extracts are very identical to that of the Tembungo oil fingerprint, whilst the rest are totally different. The Stages IVA and IVB, and the Tembungo oil have high concentrations of oleananes, C_{30} – resin triterpanes and C_{24} – tetracyclics, and very low concentration or absence of C_{34} and C_{35} extended hopanes. This implies that the source for the Tembungo oil and oils from adjacent fields are most probably from Stages IVA and IVB sediments. The Stages IVE, upper part of IVD, and IVC are different with respect to the absence of or very low concentrations of oleananes and resin triterpanes. Tricylics, a marine source indicator, are observed to occur in significant amount. The lower part of Stage IVD extract has a rather unusual biomarker fingerprint with the unknown peak 'X' occurring as the base peak followed by C_{29}–hopane. The oleanane and C_{30} resin triterpanes are present at a lower concentrations compared to the Tembungo oil.

CONCLUSION

The shales of the Tembungo wells have poor to fair source rock potentials, of mainly Type III gas-prone organic matter with minor contributions from Type II oil-prone organic matter.

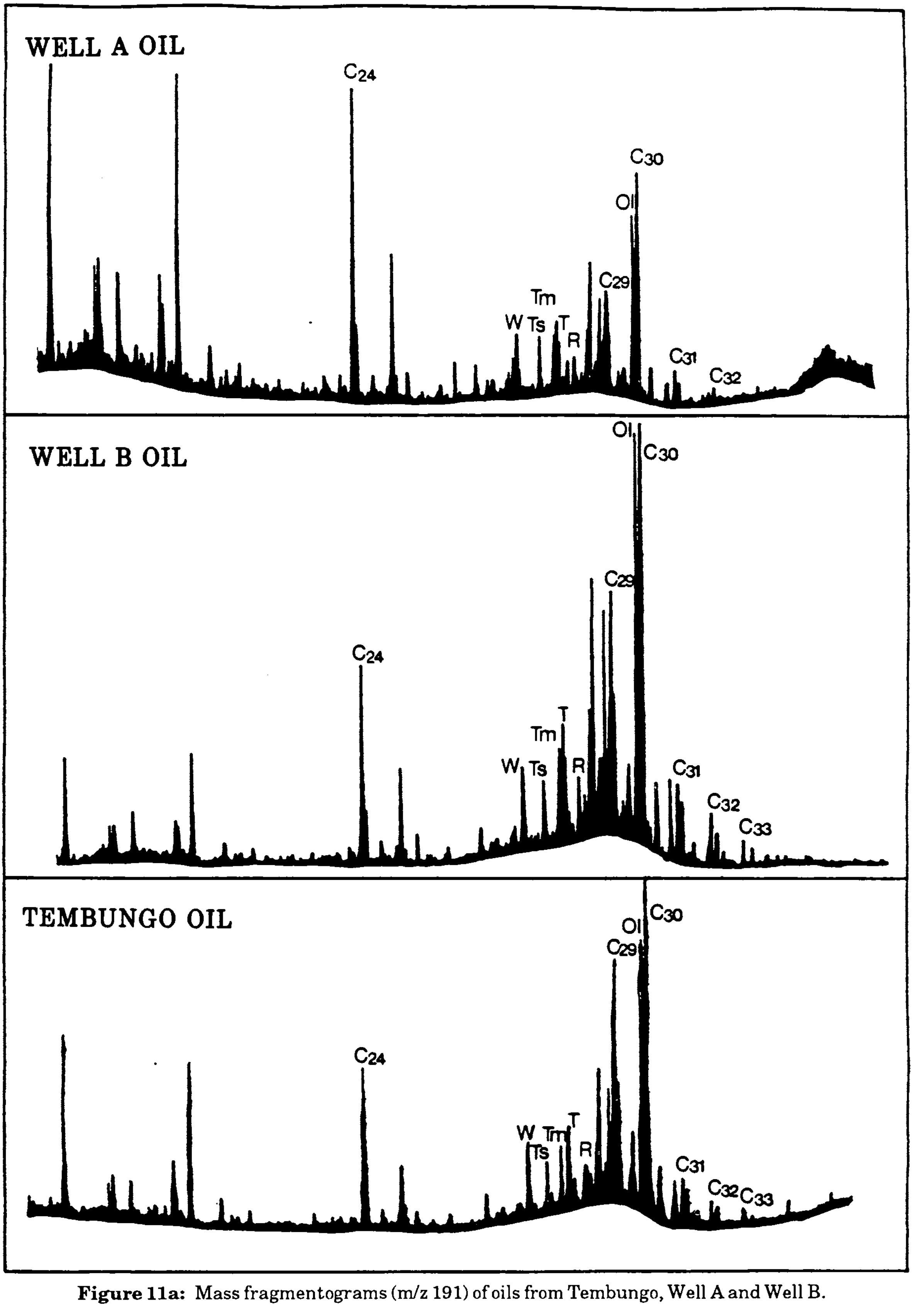

Figure 11a: Mass fragmentograms (m/z 191) of oils from Tembungo, Well A and Well B.

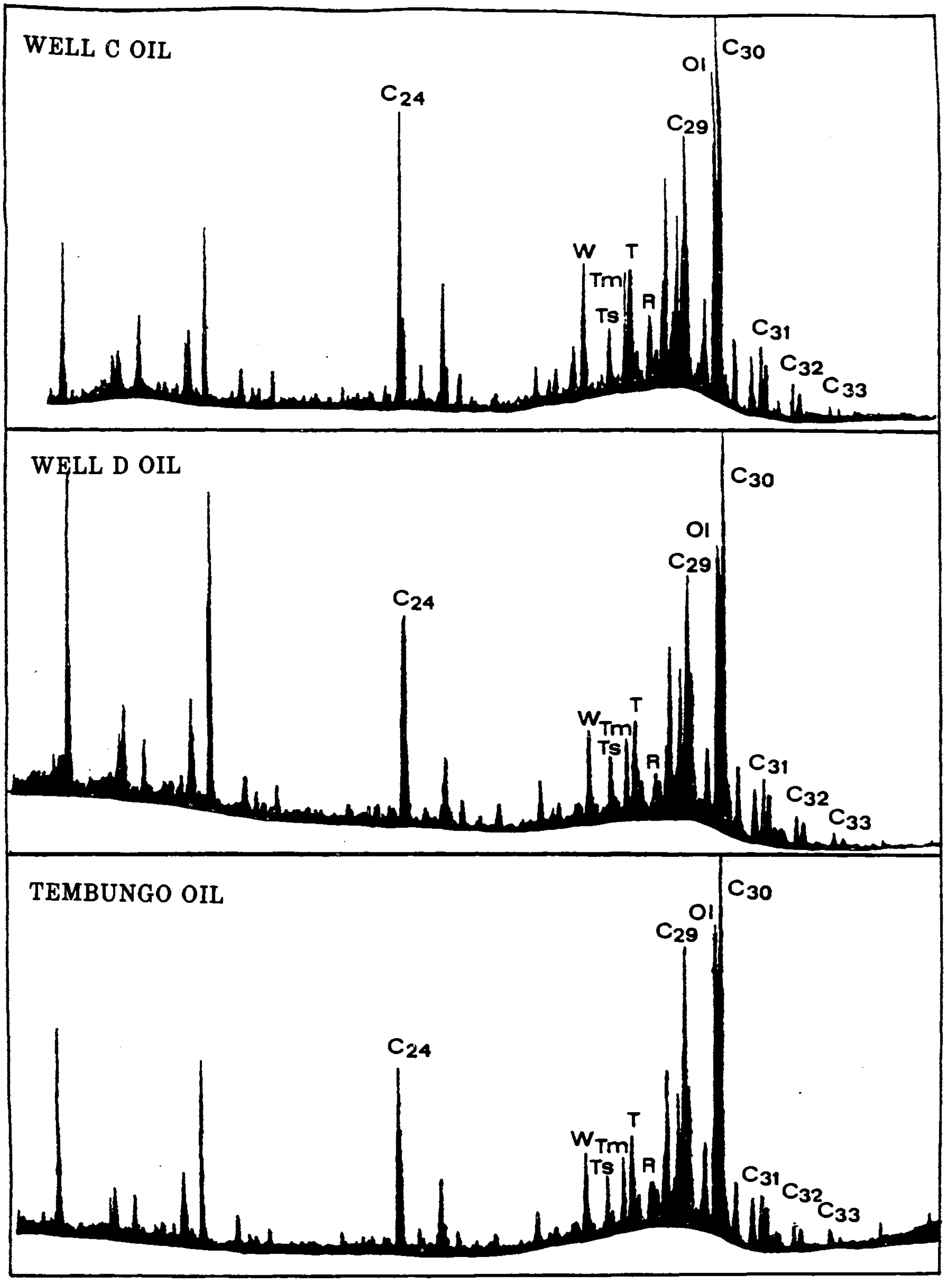

Figure 11b: Mass fragmentograms (m/z 191) of oils from Tembungo, Well C and Well D.

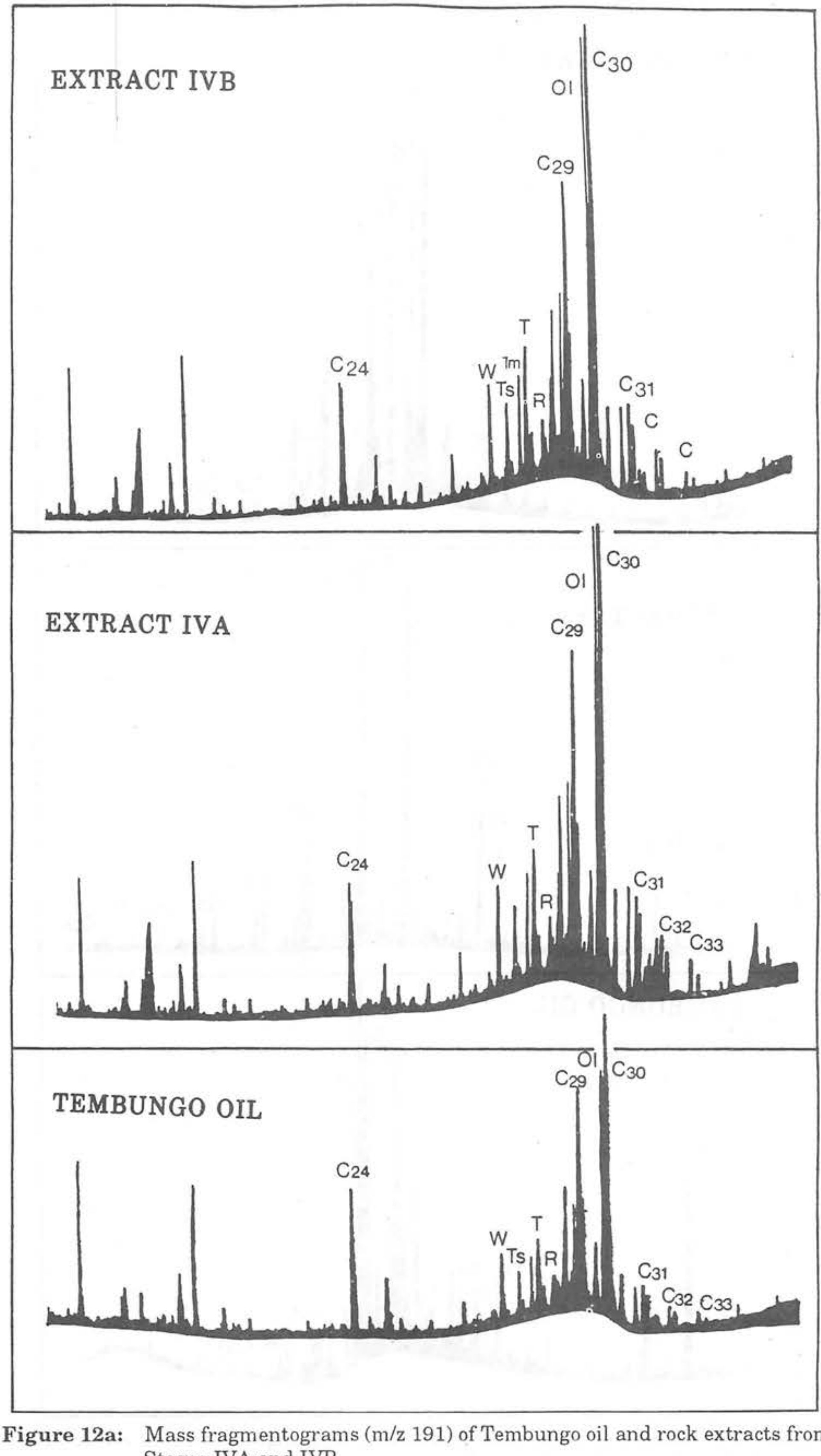

Figure 12a: Mass fragmentograms (m/z 191) of Tembungo oil and rock extracts from Stages IVA and IVB.

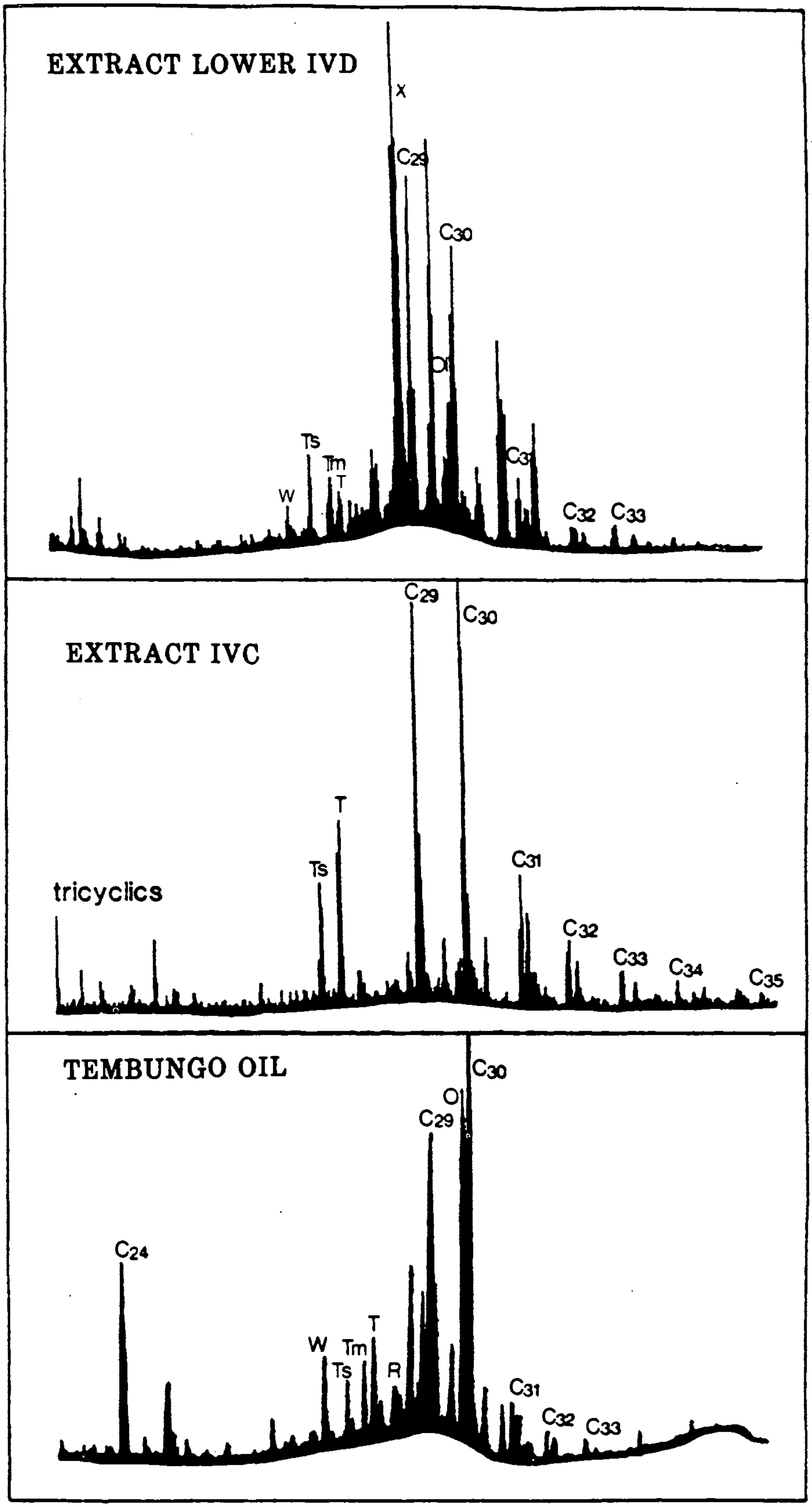

Figure 12b: Mass fragmentograms (m/z 191) of Tembungo oil and rock extracts from Stages IVC and lower IVD.

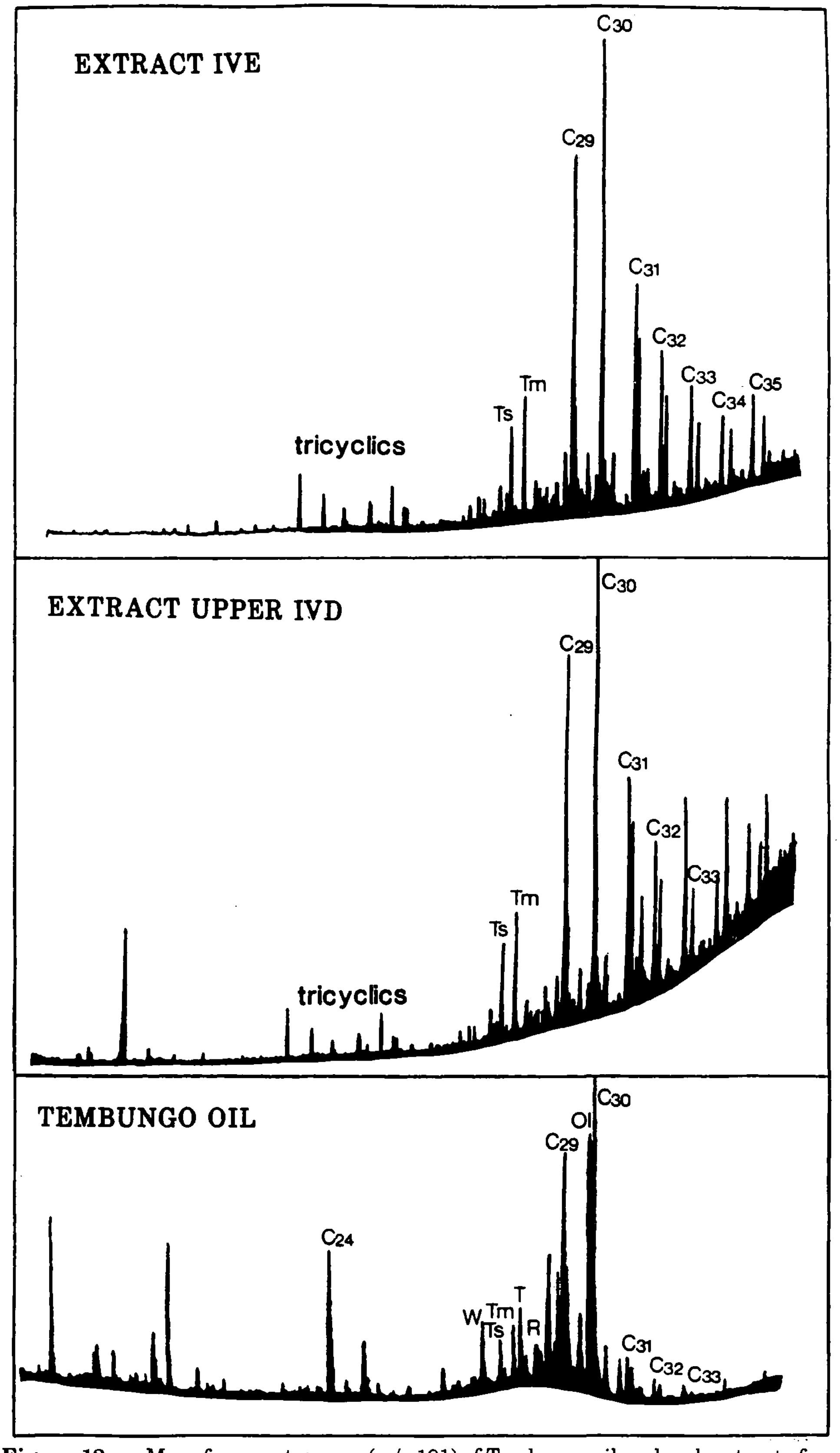

Figure 12c: Mass fragmentograms (m/z 191) of Tembungo oil and rock extracts from Stages upper IVD and IVE.

Bulk properties and compositions, carbon isotopes and biomarker distributions show that the crude oils of the Tembungo field are genetically similar, paraffinic and probably generated from the same source rock of terrigenous origin containing mixtures of different types of land-plant organic matter including resins.

The effects of biodegradation and migration of the Tembungo crude oils in one fault block is the same but differs from that of another block.

The Tembungo oil and other oils in the vicinity of Tembungo field are of the same family and were probably generated from the same source rock type containing abundant terrigenous organic matter. The most likely source for these oils are Stages IVA and IVB sediments.

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