

WHAT IS THE SOURCE OF TARANAKI BASIN OILS? GEOCHEMICAL BIOMARKERS SUGGEST IT IS THE VERY DEEP COALS AND SHALES

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The geochemical sterane and hopane biomarkers, which can be extracted from oils/condensates and source rocks, provide important information on oil-source rock correlations, levels of maturation of the oils and potential/probable source rocks, and a tentative indication of migration of the oil.

Over recent years we have characterised these biomarkers in suites of coals and shales of the respective Kapuni Group and Pakawau Formation and, where available, in produced hydrocarbons onshore and offshore wells in the Taranaki Basin.

The results of this study have shown unequivocally that although the oils are usually reservoirised in the mid to upper sands of the Kapuni Group, they have in fact been sourced from coals and also probably shales much lower in the sequence, at depths greater than about three kilometres, but in the Taranaki Basin it seems that this oil is retained in the coal and shale matrices and is not released until much greater depths and correspondingly increased levels of maturation. The oil then migrates upwards to the present reservoir, which also suggests that appropriate porosity and permeability must have been established to enable such migration to have taken place.

INTRODUCTION

The Taranaki Basin, located on the western margin of New Zealand, contains a sequence of Upper Cretaceous to Recent sediments lying largely offshore and partly onshore. It provides the only source of commercial hydrocarbons in New Zealand. The onshore Kapuni gas-condensate field was discovered in 1958 and in 1969 the larger offshore Maui gas-condensate field was discovered (McBeath, 1977). Since then a number of other smaller fields have been found near the eastern side of the Basin (for example the McKee, Kaimiro, Stratford, Waihapa fields). The potential hydrocarbon source rocks are considered to be the terrestrial coals and shales of the Paleocene-Eocene Kapuni Group, which is a thick sequence of coastal plain fluviomarine sandstones, siltstones, mudstones and coals, and of the similar underlying Late Cretaceous Pakawau Group. The oils and gas condensates are generally reservoirised in the upper sequences of the Kapuni Group (Pilaar and Wakefield, 1978; Palmer, 1985; Cook, 1987; Johnston *et al.*, 1988).

Geochemical biomarkers are organic molecules, often complex, which undergo structural and/or compositional changes during the process of petroleum formation from precursor biomass. The steranes, triterpanes and diterpanes are the best characterised biomarkers and those most commonly used. They can provide information on maturity

levels of oils/condensates and possible source rocks, oil-oil and oil-source rock correlations, the likelihood of migration and the extent of biodegradation of the oils/condensates. The various structures, isomerisation chemistry and respective interconversions of these hopane triterpane and sterane biomarkers are now well known, as are the ratios used to assess maturity. Also particular biomarkers such as the diterpanes, can be used to denote source characteristics. Current gas chromatography-mass spectrometry (gc-ms) methods allow routine analysis of the steranes, triterpanes and diterpanes which are now recognised as occurring ubiquitously in organic sediments and petroleum (e.g. see Seifert and Moldowan, 1978, 1979, 1981, Mackenzie *et al.*, 1980, 1981, 1982; Philp, 1985; Philp and Gilbert, 1982, 1986, 1987; Czochanska *et al.*, 1988; Johnston *et al.*, 1988, 1989).

Czochanska *et al.* (1988) studied sterane and terpane biomarker distributions in twenty-five oils from the Taranaki Basin. They showed the oils to be of terrestrial origin and approximately the same thermal maturity. Moreover, incomplete isomerisation of moretanes to hopanes and steranes to $\beta\beta$ steranes was observed, which is characteristic of oils derived from Tertiary sediments that have been subjected to relatively high temperatures (Grantham, 1986).

Johnston *et al.* (1988) characterised the hopane and sterane biomarkers from a selection of coals spanning the Kapuni

and Pakawau Groups of the Maui-4 well, and from the produced oil. This initial study showed that although the oil was reservoirised in the Upper Kapuni Group sediments, the maturity level of the oil was much greater than that of the adjacent coals. Also, even though the maturity level of the coals increased with increasing depth as expected, the maturity of the oil was still slightly greater than that of the deepest Pakawau Group coal (3894 m) encountered in the well (TD 3920 m). This was followed by a more detailed study of this well in which maturity levels and source characteristics of a greater number of coals and also shales, together with the oil, were characterised using hopane, sterane and diterpane biomarkers (Collier and Johnston, 1989). This confirmed the earlier conclusion that the Maui-4 oil was sourced from sediments with a maturity equivalent to that of sediments now lying at depths of 4100 m or deeper. The coals, shales and oils showed a predominance of the diterpane isopimarane, indicative of a conifer source and possibly kauri, but the selective concentrations of the minor diterpane components of the coals/shales within the well did not match those of the oil in detail. However, the overall diterpane similarity does indicate that a combination of such coals lying slightly deeper within the Basin could be the source.

Collier and Johnston (1989) also investigated coals, shales and condensate from the Kapuni-8 well (TD 4080) which encountered only Kapuni Group sediments and did not reach the deeper Pakawau Group. Again even the deepest coals/shales of this well were significantly less mature than the maturity level of the condensate and a generation depth of 4400-4900 m was suggested. As the diterpane distributions in Kapuni-8 coals and shales are quite different from that of the condensate, Collier and Johnston (1989) suggested that the source for the condensate was located elsewhere in the basin at this greater depth, and that the condensate had migrated to its present reservoir. The same conclusion was reached from a similar study of material from the Stratford-1 and Kaimiro-1, Mangaheva-1 and McKee-1 wells (Johnston *et al.*, 1989).

These biomarker studies of Taranaki Basin rocks (Johnston *et al.*, 1988, 1989; Collier and Johnston, 1989) therefore, collectively suggest that the oils and condensates, which are reservoirised in the Upper Kapuni Group sediments, were generated much deeper within the basin, at depths below those of the total depths of the respective wells studied. It was therefore necessary to carry out a biomarker study of coals and shales from sediments deeper within the basin and hence the Kapuni Deep-1 well, TD=5664 m, was selected for this purpose.

SAMPLES AND METHODS

The Kapuni Deep-1 well located in the onshore Kapuni field (e.g. see Johnston *et al.*, 1988) was drilled in 1984 to a total depth of 5664 m. The Kapuni Group was encountered between 3243-5664 m and was subdivided into four cycles (A-D) (Table 1 and Fig. 1). Cycles C and D contain the reservoir sandstones of the Kapuni Field and have been penetrated by all Kapuni Field exploration and production wells. Cycle B has been partially penetrated by many of these wells but only the Kapuni Deep-1 well has fully penetrated this sequence and also 1111 m of Cycle A. Both Cycles A and B contain coals and shales, with a 337 m sequence of coals at the top of Cycle A being the deepest

coals encountered in this well (S.B.P.T. 1984). Vitrinite reflectance values within the Kapuni Group ranged from 0.62 ± 0.05 (3445.50 m) to 0.77 ± 0.07 (4720.23 m) (Raine and Lowery, 1984).

A selection of coal and shale samples were taken over the 3420-4972 m interval (Fig. 1, Tables 1 and 5). The 3420 m coal is from Cycle D in the Kapuni Group and probably represents the Kap-20 coal (a distinct feature and marker on seismic reflection profiles of the area). The 3845 m sample is from a 47 m coal/sandstone band (3843-3890 m) of the upper Cycle B sequence. The 4426 m shale is from the lower part of Cycle B where the siltstones grade into dark shale (4418-4553 m). The samples from 4558-4800 m are from the coal/shale sequences of the upper part of Cycle A. The deepest sample (4972 m) is a shale from the uppermost part of a massive coastal sandstone which extends from 4890 m to at least 5664 m (TD). This sandstone sequence was not sampled because the well logs indicated very little organic matter and thus no prospective source rocks.

The biomarker fractions were extracted and characterised by gas chromatography-mass spectrometry (gc-ms) methods according to the experimental procedures outlined by Johnston *et al.*, (1988) and Collier and Johnston (1989). The

Depth (m bdf)	Formation	Age
10-175	Egmont Volcanics	Quaternary
175-1799	Tangahoe Formation	Pleistocene
400-1799	Matemateaonga Formation	Upper Miocene-Pleistocene
1799-1946	Urenui Formation	Upper Miocene
1946-2045	Waikiekie Formation	Middle Miocene
2045-2415	Mokau Formation	Middle Miocene
2415-3243	Mahoenui Formation	Lower Miocene-Oligocene
3243-5664	Kapuni Group	Lower Palaeocene-Palaeocene
3243-3548	Cycle D K3A reservoir (3524-3548 m) Kap-20 Coal (3391-3401 m) K1C sandstones (3376-3391 m)	
3548-3843	Cycle C K3E reservoir (3616-3771 m GWC)	
3843-4553	Cycle B (3843-3890 m, interbedded sandstones and coal) (3980-4418 m, mainly sandstones) (4418-4553 m, siltstones grade into dark shale)	
4553-5664	Cycle A (4553-4890 m, coal bearing, hydrocarbon indications) (4890-5664+ m, below last coal, massive coastal sandstone with low porosity) (Good oil shows between 5446 and 5520 m, core shows oil staining in fractures associated with a fault zone)	

From S.B.P.T. (1984).

Table 1: The stratigraphy of the Kapuni Deep-1 well with reference to Fig. 1.

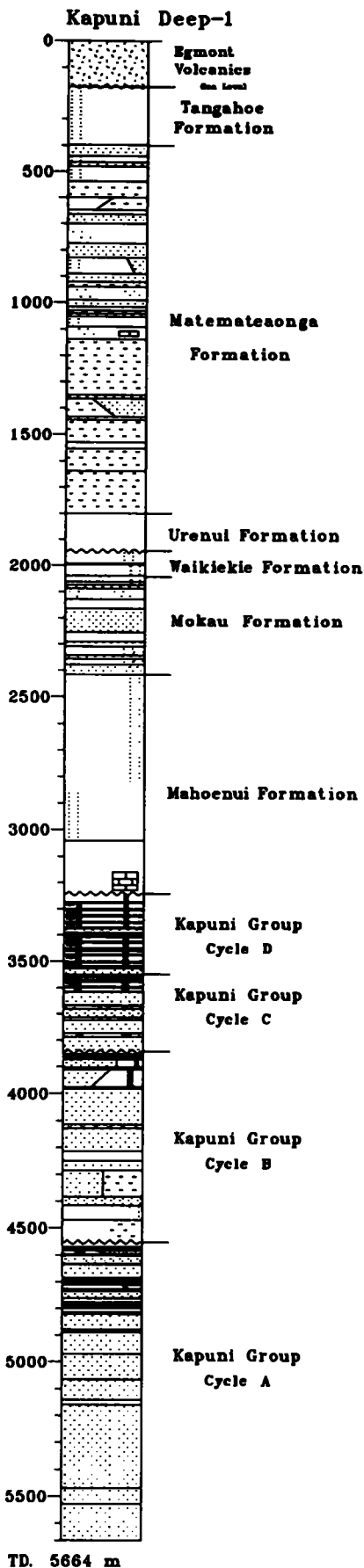


Fig. 1: Stratigraphic column for the Kapuni Deep-1 well showing the stratigraphy of the Kapuni Field.

steranes were characterised from the m/z 217 and 218 ion chromatograms, the hopane triterpanes from the m/z 191 and the diterpanes from m/z 123 ion chromatograms (Figs. 2, 3 and 5). The respective peak assignments for the sterane,

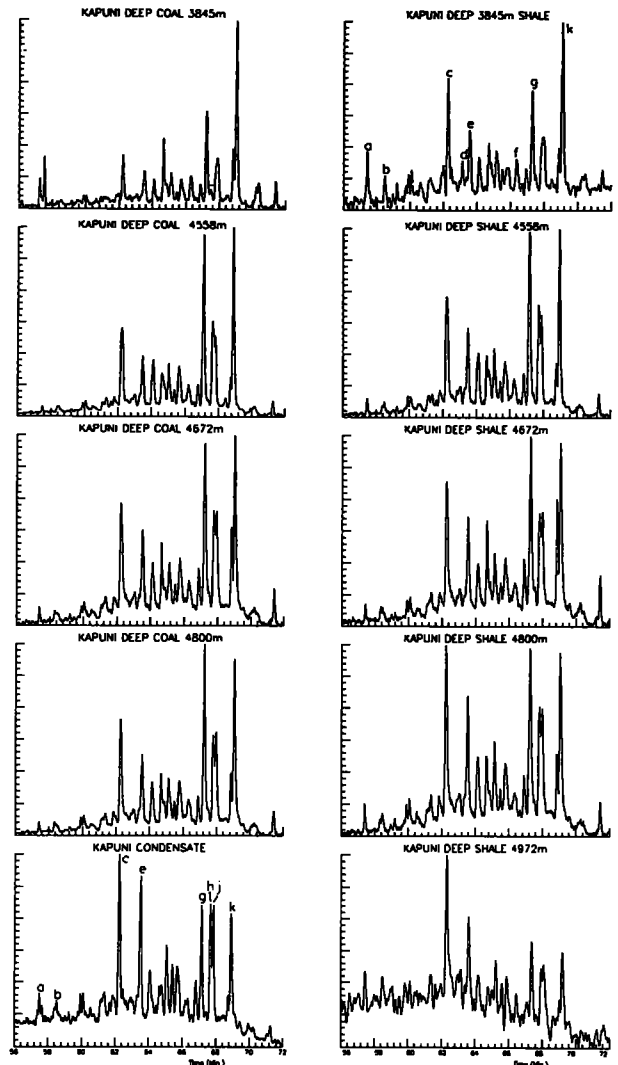


Fig. 2: Representative sterane m/z 217 ion chromatograms for the Kapuni Deep-1 well.

a	13 β (H),17 α (H)-diacholestane (20S)
b	13 β (H),17 α (H)-diacholestane (20R)
c	24-ethyl-13 β (H),17 α (H)-diacholestane (20S)
d	24-ethyl-13 β (H),17 α (H)-diacholestane (20R)
e	5 α (H),14 α (H),17 α (H)-cholestane (20R)
f	24-methyl-5 α (H),14 α (H),17 α (H)-cholestane (20R)
g	24-ethyl-5 α (H),14 α (H),17 α (H)-cholestane (20S)
h	24-ethyl-5 α (H),14 β (H),17 β (H)-cholestane (20R)
i	24-ethyl-5 β (H),14 α (H),17 α -cholestane
j	24-ethyl-5 α (H),14 β (H),17 β (H)-cholestane (20S)
k	24-ethyl-5 α (H),14 α (H),17 α (H)-cholestane (20R)

Table 2: Identification of the steranes in the m/z 217 ion chromatograms in Fig. 2.

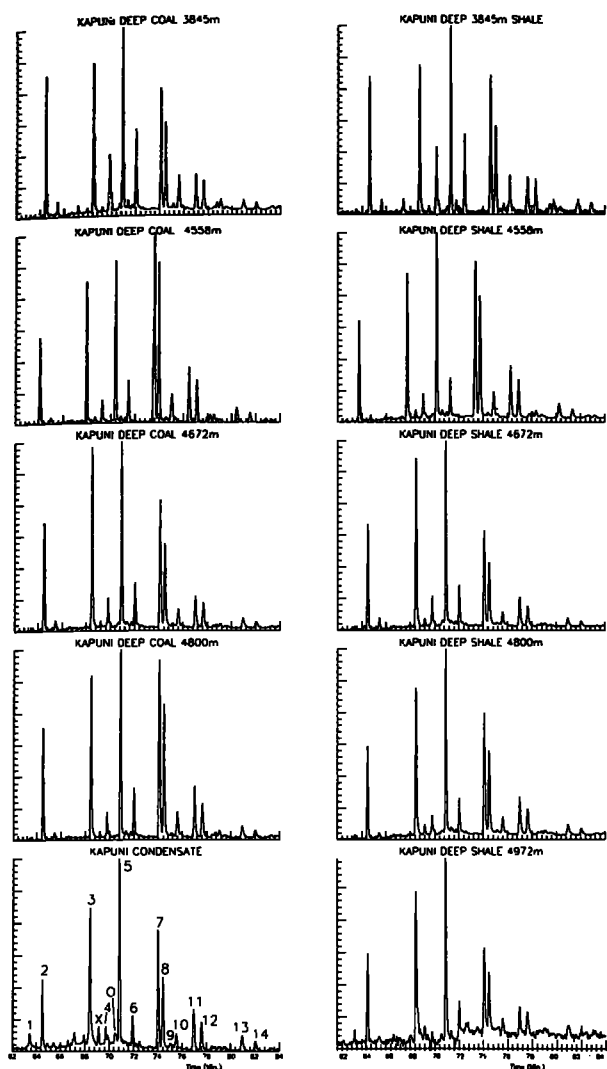


Fig. 3: Representative triterpane m/z 191 ion chromatograms for the Kapuni Deep-1 well.

triterpane and diterpane components are given in Tables 2, 3 and 5. The calculated values of the commonly used sterane and triterpane maturity ratios are given in Table 4.

RESULTS AND DISCUSSION

Maturity of the Kapuni Deep Sediments

Maturity ratios calculated from the sterane and triterpane distributions for the 3420 m coal and 3845 m coal and shale are similar to those measured on samples from the nearby Kapuni-8 well at comparable depth (Collier and Johnston, 1989), indicating very little difference in burial history between the two wells in this field.

The 22R epimerisation of C_{32} hopanes (22S/22R+22S) is approximately 60% (isomerisation equilibrium) for all samples except for that in the 3420 m coal which is marginally lower (52%) (Table 4). The C_{30} moretane/hopane ratios (Table 4, Fig. 4) show a scatter about a trend that generally decreases with depth. However, the C_{31}/C_{30} hopane ratios show greater variation, especially between 4429-4576 m which is probably related to source characteristics. The 20R epimerisation of C_{29} steranes (20S/20R+20S) increases from 24% in the 3420 m coal to approximately 50% for coals and shales below about 4500 m (Table 4). This epimerisation

1	(Ts) C_{27} 18 α (H) trisnorhopane
2	(Tm) C_{27} 17 α (H) trisnorhopane
3	C_{29} 17 α (H),21 β (H) norhopane
X	Unidentified C_{30} triterpane
4	C_{29} 17 β (H),21 α (H) normoretane
O	C_{30} 18 α (H)-Oleanane
5	C_{30} 17 α (H),21 β (H) hopane
6	C_{30} 17 β (H),21 α (H) moretane
7	C_{31} 17 α (H),21 β (H),22S homohopane
8	C_{31} 17 α (H),21 β (H),22R homohopane
9	C_{31} 17 β (H),21 α (H),22S homomoretane
10	C_{31} 17 β (H),21 α (H),22R homohopane
11	C_{32} 17 α (H),21 β (H),22S bishomohopane
12	C_{32} 17 α (H),21 β (H),22R bishomohopane
13	C_{33} 17 α (H),21 β (H),22S trishomohopane
14	C_{33} 17 α (H),21 β (H),22R trishomohopane

Table 3: Identification of the triterpanes in m/z 191 ion chromatograms in Fig. 3.

reaction usually approaches a steady state at about 50% (Mackenzie et al., 1982). The scatter in values around 50% is arising from errors in the peak integration due to a small shoulder peak on the trailing edge of the 20S peak (Figs. 2 and 4). Visual inspection of the peak heights confirm a value of 50% for this epimerisation ratio. The extent of sterane isomerisation (%BB) shows a generally increasing trend with depth although some scatter is observed, which may again represent experimental error. The value for this ratio at 4972 m (49%) is significantly displaced from the general trend and may result from matrix effects, such as an increased isomerisation rate due to acid clay catalysis (Table 4, Fig. 4).

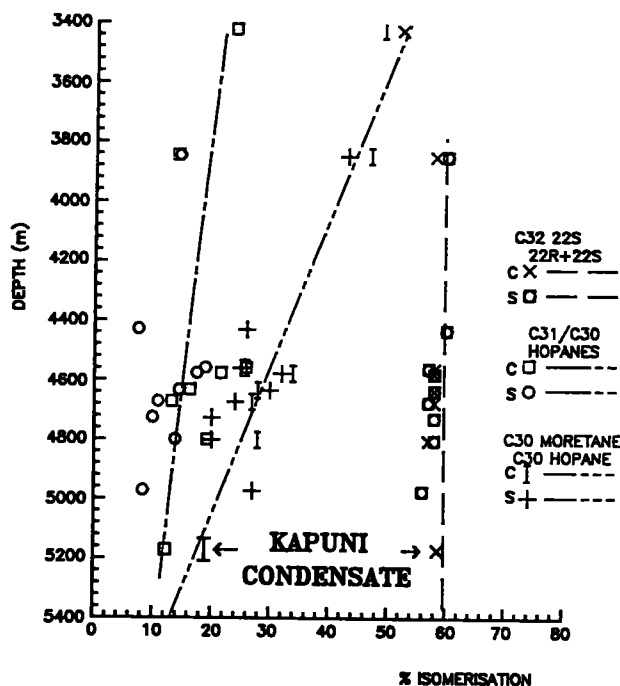
These depth-related maturity trends (Fig. 4) indicate that the Kapuni condensate was formed from source rocks of slightly greater maturity than the deepest samples studied here. Extrapolation of the moretane/hopane ratio indicates condensate generation at a present depth between 4800-5200 m and for the C_{31}/C_{30} hopane ratio a depth of about 5100 m. The sterane isomerisation ratio (%BB) indicates a slightly deeper source, namely between 5100-5700 m. Hence an equivalent generation depth of 5000-5500 m (in terms of the present position of the Kapuni Deep-1 rocks) is proposed for the source rock of the Kapuni condensate.

Hayward (1987) found that sediments in the Kapuni field had undergone about 600 m of uplift from maximum burial depth. This therefore indicates a burial depth of 5.6-6.1 km for the source rock of the Kapuni condensate.

Source characteristics of the Kapuni Deep sediments

The sterane distributions (Fig. 2) show that the relative abundances of the C_{27} steranes with respect to the C_{29} steranes are low (<15%) in all the deeper coals and shales,

a) HOPANES



b) STERANES

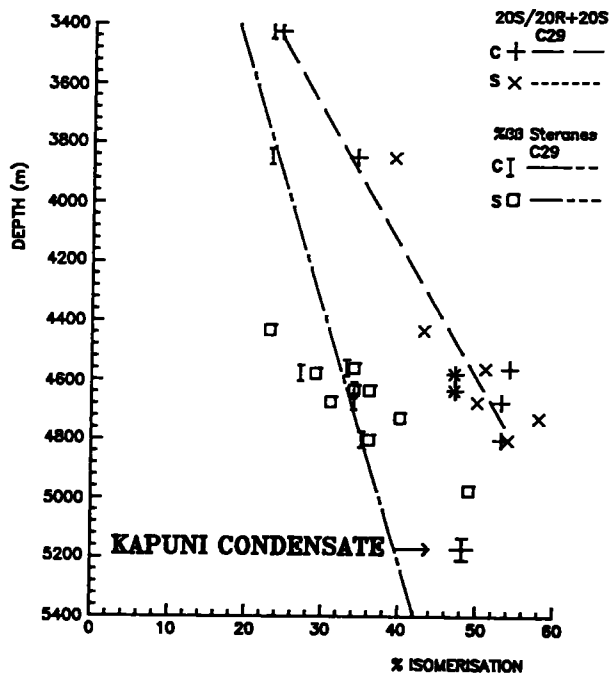


Fig. 4: Maturity vs depth relationships for the hopanes and steranes for the Kapuni Deep-1 well.

Sample	Hopanes			C ₂₉ Steranes	
	C ₃₂ 22S 22R+22S (%)	C ₃₀ Moretane Hopane (%)	C ₃₁ C ₃₀ (%)	20S 20R+20S (%)	BB Steranes (%)
Kapuni Condensate	58	19	118	48	48
3420 m Coal	52	49	236	24	(23)*
3845 m Coal	58	47	139	34	(23)
3845 m Shale	60	43	143	39	(29)
4429 m Shale	60	26	74	43	23
4558 m Coal	58	26	259	54	33
4558 m Shale	57	25	189	51	34
4576 m Coal	58	34	216	47	27
4576 m Shale	58	32	174	47	29
4633 m Coal	58	28	163	47	34
4633 m Shale	58	30	144	47	34
4672 m Coal	58	27	132	53	34
4672 m Shale	57	24	108	50	31
4726 m Shale	58	20	99	58	40
4800 m Coal	57	28	192	53	35
4800 m Shale	58	20	138	54	36
4972 m Shale*	56	27	83	58	49

*Figures in parentheses indicate the presence of β steranes which makes these data unreliable.

*The results for this 4972 m shale fraction may be unreliable due to the relatively low concentrations of the sterane and triterpane biomarkers.

Table 4: Sterane and triterpane maturity ratios.

and only slightly greater (≈30%) in the 3845 and 4429 m shales. This indicates a predominantly terrestrial input for all coals and shales with a possible marine influence in the

3845 and 4429 m shales, which is consistent with the gradual marine transgression that occurred during the Oligocene (King and Robinson, 1988).

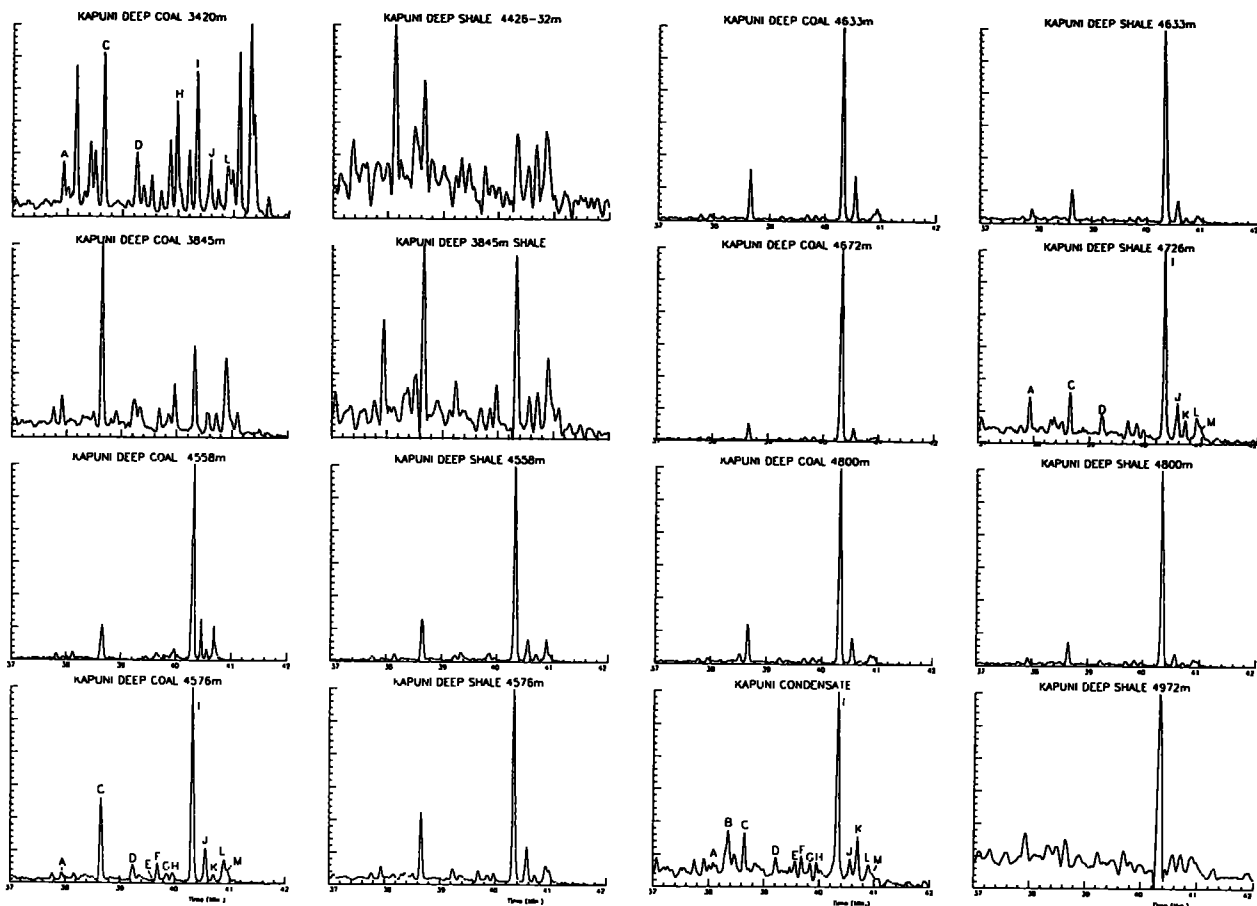


Fig. 5: Representative diterpane m/z 123 ion chromatograms for the Kapuni Deep-1 well.

Diterpanes	M/W'
A Unidentified C_{19} tricyclane	262
B 8 β (H)-Labdane(?)	278
and other unidentified (C_{20} tricyclane ?)	276
C 4 β (H)-19-norisopimarane	262
D Unidentified C_{19} ticyclic terpane	276
E Rimuane	276
F Unidentified (C_{20} tetracyclane ?)	274?
G Unidentified C_{20} tricyclane	276
H <i>ent</i> -Beyerane	274
I Isopimarane	276
J 16 β (H)-Phyllocladane	274
K Unidentified	276
L 16 β (H)-Kaurane	274
and coeluting unidentified C_{20} tricyclane	276
M 16 β (H)-Kaurane, 16 (H)-phyllocladane(?)	274
and another unidentified compound	276

Table 5: Identification of the diterpanes in the m/z 123 ion chromatograms in Fig. 5.

In addition to the regular hopanes and moretanes there are minor concentrations of other triterpanes in some m/z 191 ion chromatograms (Fig. 3). 18 (H)-oleanane (immediately preceding C_{30} hopane) and compound X (unidentified C_{30} pentacyclic triterpane of Philp and Gilbert, 1986) are both present in the Kapuni condensate, as are various C_{29} and C_{30} triterpanes eluting from 66-70 min. 18 (H)-oleanane is

essentially absent from the deeper coal samples (4558-4972 m) which indicates a minor difference between these coals and the condensate source. Philp and Gilbert (1986) attributed the presence of compound X in samples from the Gippsland Basin, which is similar to the Taranaki Basin, to a unique terrestrial source. This compound is present in all of the samples analysed here, although in lower concentrations for the less mature samples, which is consistent with the trend observed in Maui-4 samples (Collier and Johnston, 1989).

The diterpane compositions of shallower Kapuni Deep-1 coals and shales (Fig. 5, 3420-4429 m) show a relatively complicated array of diterpanes. The norisopimarane/isopimarane ratio is greater than or equal to one. This contrasts with the Kapuni condensate which has a predominance of isopimarane (Fig. 5), (Weston et al., 1989). However, the diterpanes present here are generally also present in the condensate, with the exception of the components eluting after 41 min. which could be related to the marine Oligocene transgression.

The deeper coal and shale samples (4558-4972 m, Fig. 5) all show a predominance of isopimarane. Comparison of the less abundant diterpanes eluting after isopimarane (J-M) shows 16 β (H)-phyllocladane (J) is present in all of the samples but it is always more abundant than diterpane K. However, diterpane K is more abundant in the condensate (Table 5, Fig. 5). Diterpanes L and M are present in most samples. The 4558 m, 4576 m and 4726 m coals and shales

have similar relative abundances of the L and M diterpanes to that of 16B(H)-phylocladane which in turn is similar to the condensate. These samples also have similar diterpanes, to the Kapuni condensate, eluting between norisopimarane and isopimarane. However in the region preceding norisopimarane, both coals and shales at 4558 and 4576 m have very low concentrations of diterpanes while the 4726 m shale shows similar compounds to the condensate but in different relative abundances.

The diterpane distributions of the condensate are therefore most similar to those of the Kapuni Deep coals and shales from 4558, 4576 and 4726 m. However the diterpane biomarker distributions are very specific and as the match between these coals and shales and the condensate is not an exact one, it is concluded that the condensate originates from a composite terrestrial source with characteristics similar but not identical to these coals and shales.

The biomarker maturity indicators suggest that Kapuni condensate was generated about 500 m deeper than the 4558-4726 m coals and shales (to reach the observed maturity level). Therefore taking account of the diterpane and maturity information it appears that the source rocks for the Kapuni Condensate are likely to lie within an extension of the Cycle A Kapuni Group (Fig. 1).

Implications for exploration of the Taranaki Basin and other New Zealand basins

This study indicates that oil generation in the Taranaki Basin from the middle Eocene Kapuni Group sediments (Kapuni Deep-1) requires a burial depth of at least 5.6-6.1 km. The older late Cretaceous Pakawau Group sediments require maximum burial of about 5 km (Johnston et al., 1988). Such a deep source for the hydrocarbons indicates that deeper reservoirs may contain hydrocarbons if sufficient porosity and permeability are present in a trapping situation. Present studies indicate that such porosity and permeability may in fact be preserved or enhanced at levels down to the depth of hydrocarbon generation (Collen and Newman, 1989). Also, the distance between the probable deep source rocks and the shallower upper Kapuni Group sandstone reservoirs indicates that the secondary migration from the source rock to the reservoir is important in the accumulation of petroleum to form a commercial hydrocarbon field (Collen, 1988).

The depths of maximum burial required to reach maturity sufficient for hydrocarbon generation are about 5 and 6 km for the Pakawau and Kapuni Groups respectively. Hence, in other New Zealand sedimentary basins, with possible source rocks of similar age, lithology and comparable heat flow, a maximum burial of 5-6 km would be required. Thus basins which have maximum burial depths of less than 5 km and do not contain pre-Cretaceous sediments have poor hydrocarbon generation potential unless they contain significantly different source rocks. Younger Cenozoic basins would require greater maximum burial depths of 6 km or more. These basins may be uplifted by later tectonic activity (for example, in the Taranaki Graben this may be 500-1000 m, and this should be taken into account).

Cook (1987) suggested that coals rather than shales were more likely to be the hydrocarbon source rocks in the Taranaki Basin and that coals with a high hydrogen index had the highest generation potential.

The diterpane biomarkers indicate coniferous forests have contributed significantly to the source rocks of the Kapuni condensate. The predominance of isopimarane in the Kapuni condensate may indicate that a particular environment (including a particular variety or assemblage of conifers) has a higher potential to generate hydrocarbons. The presence of these diterpanes in other sediments may also indicate particularly good source potential. Shanmugam (1985) described both fossil and geological evidence which suggests that coals in the Latrobe Group, Gippsland Basin, Australia, formed from a lowland coniferous forest with a raised peat bog setting. Such forests are thought to have been widespread in New Zealand during the Cretaceous (Fleming 1979).

Oil-source rock correlations and maturity trends for the Maui-4 well indicate that the deep Pakawau Group coals and shales are very similar to the Maui-4 oil (Johnston et al., 1988) and that the source of this oil lies in slightly deeper Pakawau Group sediments. Kapuni Deep-1 sediments of the deep Kapuni Group (Cycle A) have similar biomarker distributions to those deep Maui-4 samples and the Kapuni condensate, thereby indicating that the source of the condensate is likely to lie in the deep Kapuni Group sediments on the flanks of the structure or below the total depth of the Kapuni Deep-1 well. The location of oil shows in the Kapuni Deep-1 well between 5466 and 5664 m confirms at least some contribution from a deep source and hence the possibility of deeper reservoirs for oil produced by the deep Kapuni Group and Pakawau Group source rocks should be considered. These reservoirs could be located in deep sandstones such as those encountered in the Kapuni Deep-1 well. Thus, such deeper reservoirs may become exploration targets of the future.

It therefore appears that in the South Taranaki Basin the hydrocarbons are sourced from Kapuni and/or Pakawau Group sediments deep within the basin and this factor should be considered along with possible migration pathways when assessing the potential of exploration target structures for drilling.

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