LATE CRETACEOUS SOURCE ROCKS OF TARANAKI BASIN

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Abstract

Seismic reflection mapping, outcrop observations and petroleum exploration well data show that the late Cretaceous sedimentary sequence in the Taranaki Basin can be subdivided into two main stratigraphic units. The lower unit is early-rift sedimentation within a series of en-echelon sub-basins that formed along the Taranaki Rift. This lower late-Cretaceous unit is predominately organic-rich terrestrial coal-measures. Overlying this early-rift sequence is a more widespread transgressive sequence of latest Cretaceous age. This upper late-Cretaceous unit consists of two main sedimentary subdivisions: organic-poor marine rocks and laterally equivalent, organic-rich coastal-plain deposits.

Because the burial depth required to generate and expel hydrocarbons from these sediments within the Taranaki Basin may be quite deep (in excess of 5km) the dominant unit responsible for generating the basin's hydrocarbons is probably the lower late Cretaceous, early-rift coal measures.

Introduction

Taranaki Basin first formed as a failed rift during the late Cretaceous breakup of the Gondwana Continent. Thrasher (1990a) presented evidence that the Taranaki Rift was a sinistral-oblique transform which accommodated the opening of the New Caledonia Basin, by offsetting that basin's separation south into the Tasman Basin rift. Along this transform, oblique motion resulted in a series of en-echelon sub-basins. These sub-basins underlie parts of Taranaki Basin and may contain the organic rich sediments responsible for Taranaki's hydrocarbon accumulations. The oldest sediments encountered during exploration drilling in the basin are the middle Cretaceous (Clarence) age terrestrial to marginal marine sediments in the Te Ranga-1 well, in the northwest corner of the basin. The sedimentary context of these rocks (the "Taniwha Formation" of Shell BP and Todd, 1986) has not been determined, but a pre-rift or syn-rift origin is possible. They may have been deposited on the Gondwana continent prior to rifting. Alternatively, these rocks may be the first deposits within the rift, although there is no evidence of equivalent sediments in other wells penetrating the early-rift sequence in the basin.

The first widespread rocks deposited in Taranaki Rift sub-basins are late Cretaceous (Haumurian) terrestrial sediments (Raine, 1991 (in press)). These conglomerates, sandstones, carbonaceous shales, and thin coals were shown by Thrasher (1990b) to be the lowest units within the Pakawau Group, and to be overlain by regional transgressive sediments of latest Cretaceous age.The purpose of this present study is to examine the stratigraphy and distribution of the late Cretaceous rocks of Taranaki Basin to ascertain their potential to source hydrocarbons.

Late Cretaceous Stratigraphy of Northwest Nelson

The only place where the late Cretaceous rocks of Taranaki Basin are exposed in outcrop is the Pakawau region of Northwest Nelson. This outcrop area is structurally controlled by folding and uplift of strata along the Wakamarama Anticline. The simplified outcrop geology is shown on Figure 2. Cretaceous rocks in the outcrop area are contained within the Pakawau Group, while the overlying

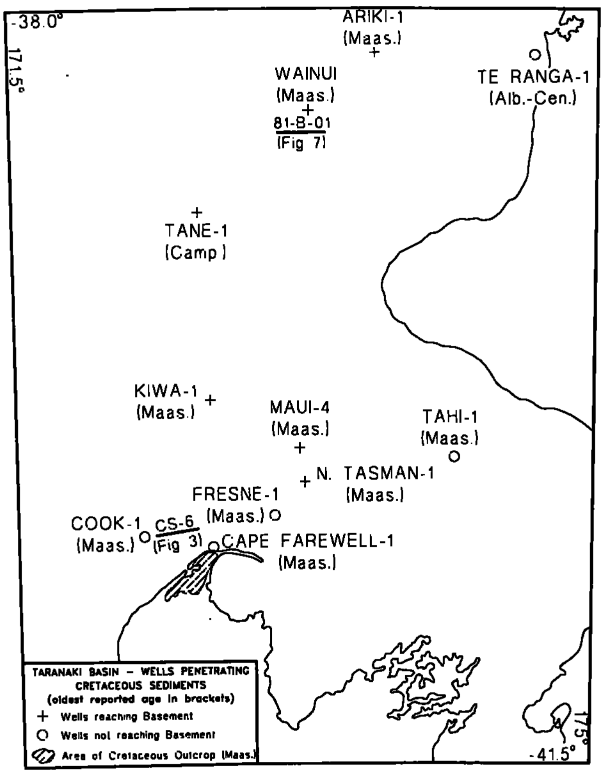

Figure 1: Location of petroleum exploration wells in the Taranaki Basin which encountered late Cretaceous rocks. Location of Figures 3 and 7 also shown.

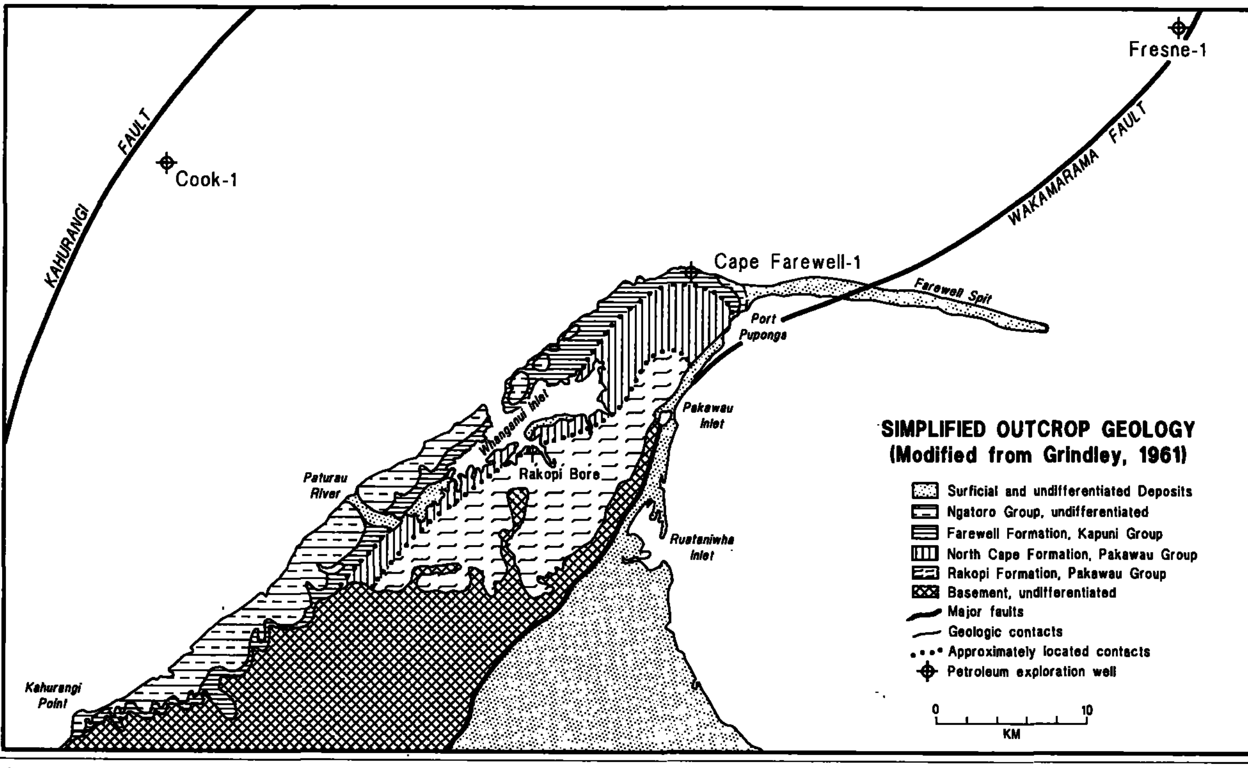

Figure 2: Simplified geology of Northwest Nelson, New Zealand.

Paleogene rocks were assigned by King (1988) to the Kapuni and Ngatoro groups.

The lowest formation of the Pakawau Group is the Otimataura Conglomerate (Bishop 1971). The distribution and thickness of this basal conglomerate is uncertain, but it is believed to be a fault-proximal deposit of limited lateral extent with a maximum thickness of a few hundred metres.

Overlying, and laterally equivalent to, the Otimataura Conglomerate is the informally-named Rakopi Formation of Thrasher (1990b). The Rakopi Formation is a coal-measure sequence of interbedded sandstone, carbonaceous siltstone and mudstone, and thin coal. The formation is more than 1500m thick and is believed to be wholly terrestrial.

The North Cape Formation (after Suggate, 1956) overlies the Rakopi Formation throughout the outcrop area. This formation is a thick (up to 500m) sequence of conglomerate, sandstone, and siltstone, with only minor coal. Titheridge (1977) considered the North Cape Formation to have been deposited in a braided stream environment, but recently acquired outcrop samples from near the base of the unit contain dinoflagellates of very latest Cretaceous age that indicate rapid sedimentation in a nearshore marine setting (Wilson 1991a). Sedimentary features consistent with shallow marine deposition can be observed in outcrop.

The Puponga Formation (Suggate 1956) is the uppermost formation of the Pakawau Group (as defined by King 1988). This thin (generally less than 100m) coal-bearing formation is probably restricted laterally to the area around the community of Puponga. Other coal measure sequences of latest Cretaceous age in Taranaki Basin, such as those in Fresne-1, have been correlated with the Puponga Formation by King (1988), but no lateral continuity can be demonstrated.

Within the outcrop area, the Pakawau Group is everywhere overlain by the Farewell Formation of the Kapuni Group. This terrestrial unit is composed of coarse sandstone and conglomerate, with minor siltstone and coal, and is up to 500m thick.

Seismic Reflection Mapping

Offshore from the outcrop area, seismic reflection data show that the late Cretaceous sequence can be subdivided into two main seismic facies: a lower facies characterized by high amplitude, often discontinuous, reflectors; and an upper unit characterized by a much more uniform, frequently near-reflection-free seismic signature. This separation of the late Cretaceous into two seismic reflection facies was noted by Thrasher (1988), who associated the lower unit with terrestrial sediments and the upper unit with marine sediments. Figure 3 is a portion of a seismic reflection profile offshore from the Pakawau Group outcrop area, illustrating the two distinct seismic facies.

Projection of stratal dips from the Pakawau Group outcrop, and the Cape Farewell-1 exploration well, to the offshore seismic reflection data confirms the seismic horizon which separates the two seismic facies illustrated on Figure 3 to be the contact between the terrestrial Rakopi Formation and the overlying North Cape Formation. The lower seismic facies is therefore correlated with the Rakopi Formation and the upper seismic facies with the North Cape Formation. Distinctive seismic reflection signatures for the basal Otimataura Conglomerate and the topmost Puponga Formation have not been recognised.

The seismic reflection horizon which in the Pakawau region separates the Rakopi and North Cape formations can be identified throughout much of the Taranaki Basin. This mid-late Cretaceous horizon is remarkably uniform, and is present in most of the sub-basins underlying Taranaki Basin. A regional interpretation of this reflector was presented by Thrasher (1991).

Seismic interpretation of the mid-late Cretaceous horizon allows the late Cretaceous syn-rift sequence to be subdivided into two units. Figures 4 and 5 are isopach maps of these two units, simplified from Thrasher (1991). The lower unit (Figure 4) consists of early-rift, terrestrial rocks of the Taniwha Formation, Otimataura Conglomerate, Rakopi Formation, and equivalents. The upper unit (Figure 5) represents a transgressive sequence with a major marine component.

Figure 4, the isopach map of the lower late-Cretaceous sedimentary unit, portrays the earliest history of the Taranaki Basin. The basin first formed as a series of fault-angle depressions on the downthrown side of normal faults. Sedimentation was terrestrial. These basins slowly expanded and infilled, until a major set of en echelon, but still separate, sub-basins was created. Basin fill was predominantly the Rakopi Formation and equivalent coal-bearing sediments.

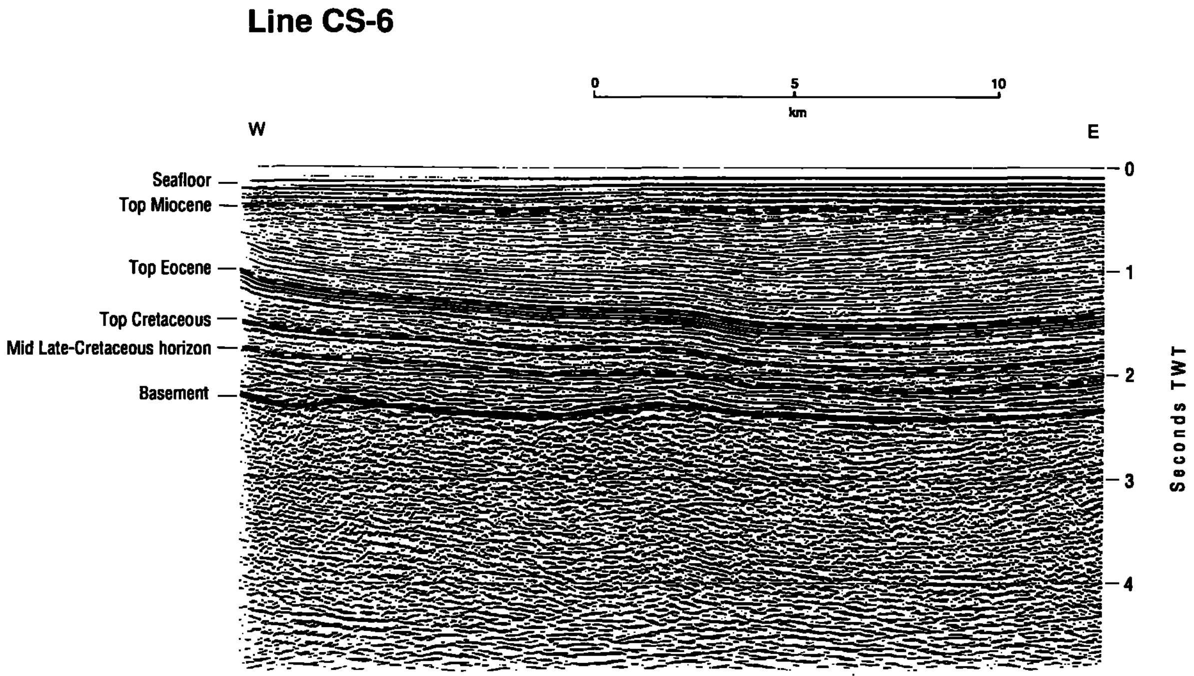

Figure 3: Portion of offshore seismic reflection profile CS-6, southwestern Taranaki Basin. From New Zealand Geological Survey PR 1170, GECO NZ, 1985.

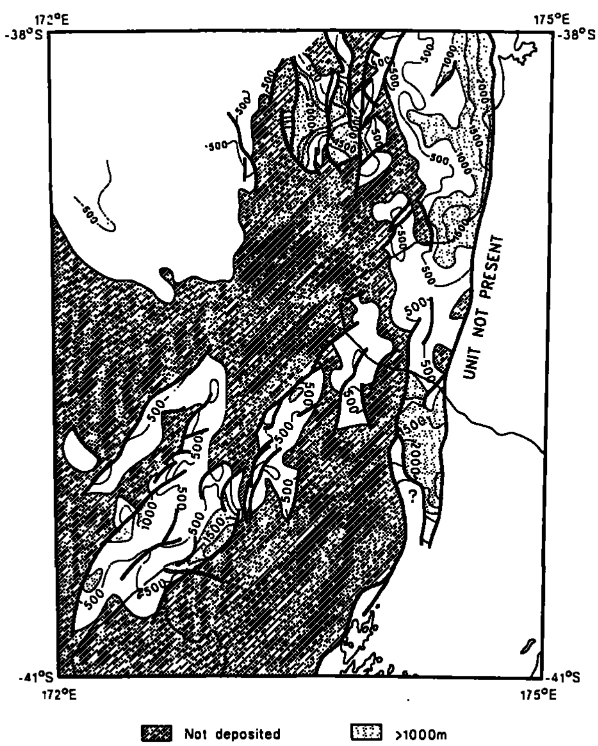

Figure 4: Isopach of lower late-Cretaceous sediments, Taranaki Basin.

Figure 5: Isopach of upper late Cretaceous sediments, Taranaki Basin.

The seismic reflection signature of high-amplitude, discontinuous reflectors is similar within all these sub-basins. A possible exception to this is the rocks of the Taniwha Formation, known only in the Te Ranga-1 well. The seismic signature of these rocks may have more lateral continuity than the subsequent late-Cretaceous coal-bearing rocks in the basin. Shell BP and Todd (1986) suggest the Taniwha Formation was deposited in a deltaic setting. The greater lateral continuity of seismic reflectors may be indicating the marine influence on the deposition of these rocks.

The Otimataura Conglomerate, known only from the Pakawau Region, cannot be distinguished on its seismic reflection character, but is not believed to be laterally extensive. Numerous small conglomeratic fans probably existed throughout the deposition of the terrestrial sediments, along the active fault scarps which controlled the sub-basins. These fans have been diagrammatically indicated on Figure 6, but their existence is only postulated.

The presence of throughgoing drainage during deposition within separate sub-basins cannot be verified, but given the swampy conditions which the coal-measure sedimentation implies, such drainage seems likely. The presence of lacustrine environments also seems likely. Major drainage was probably from highlands in the south, northwards towards the New Caledonia Basin. A schematic drawing of a proposed paleogeography near the end of separate subbasin sedimentation, but prior to the marine incursion which flooded these basins, is shown in Figure 6.

The horizon which separates the two late Cretaceous units essentially marks the end of sedimentation in confined sub-basins and the beginning of Taranaki as a single

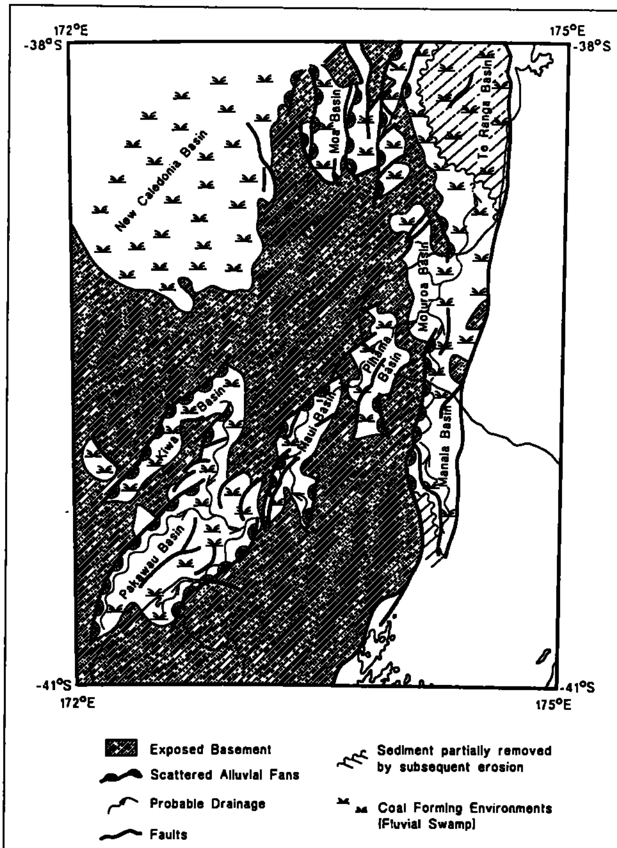

Figure 6: Paleogeography of Taranaki Basin during the end of lower late-Cretaceous sedimentation.

sedimentary basin. Whether this horizon is a time plane (an instant in geologic time) is unknown. Biostratigraphic subdivision of the Cretaceous sequences in the Taranaki Basin is not sufficiently refined to provide an answer at present. On seismic reflection data the horizon is remarkably uniform, and can be tied throughout the region as a stratigraphic horizon with the characteristics of a time plane. Correlation between sub-basins can be accomplished without undue difficulty. It is unlikely that the horizon is the same age everywhere. The possible southward propagation of the transgression, out of the New Caledonia Basin, means that the seismic horizon is likely to be older in the north than in the south.

Correlation with Petroleum Exploration Wells

Seven petroleum exploration wells in the Taranaki Basin have intercepted the mid-late Cretaceous seismic horizon. These wells are Cape Farewell-1, Cook-1, Fresne-1, Maui-4, Tahi-1, Tane-1 and Te Ranga-1. In Cook-1, Maui-4 and Tahi-1 the seismic horizon represents the contact between underlying Haumurian terrestrial sediments and overlying Haumurian marine sediments. The presence in Cook-1 of a thick (over 800m) sequence of latest Cretaceous marine sandstone has only recently been confirmed (Wilson 1991b). In the nearby Fresne-1 and Cape Farewell-1 wells, this same interval (the North Cape Formation) has some marine influence, but the extent and significance of that influence has not been established. In the Te Ranga-1 well the underlying sediments are the mid-Cretaceous "Taniwha Formation" rocks, with a thin veneer of latest Cretaceous marine sediments overlying.

In Tane-1 the regional horizon lies within a Haumurian terrestrial sequence. Seismic facies mapping in the vicinity of Tane-1 shows that the terrestrial, coal-bearing rocks above the mid-late Cretaceous horizon are laterally discontinuous to the north, and within a few tens of kilometres have been replaced by rocks with a marine seismic signature. The upper late-Cretaceous terrestrial rocks in the Tane-1 well are therefore considered to be coastal plain sediments associated with the latest Cretaceous marine transgression. Similar sediments, deposited in a coastal plain setting, were encountered in the Wainui-1 and North Tasman-1 wells, resting on basement. The uppermost Cretaceous sandstone unit in Tane-1 was deposited in a marine setting (Wilson 1988), but the full extent of marine influence in this well has not been determined. The presence of the thick (200m) marine sandstone at the very top of the Cretaceous sequence in Tane-1 indicates that the maximum marine transgression occurred very near the Cretaceous/Tertiary boundary.

Correlation of lithology with seismic reflection signature at well locations where the upper late-Cretaceous sedimentary sequence has been documented allows for particular facies to be mapped laterally using seismic reflection data. The simplest seismic-facies subdivision is to characterize the seismic signature as "marine" or "terrestrial" (including shoreline deposits). An example of such a correlation, tied to the Wainui-1 and Tane-1 wells, is illustrated in Figure 7. Using this technique, the paleogeography of the basin during the deposition of particular sedimentary units can be ascertained.

Figure 8 is a seismic-facies-derived paleogeographic map of this maximum flooding. On this map, much of the

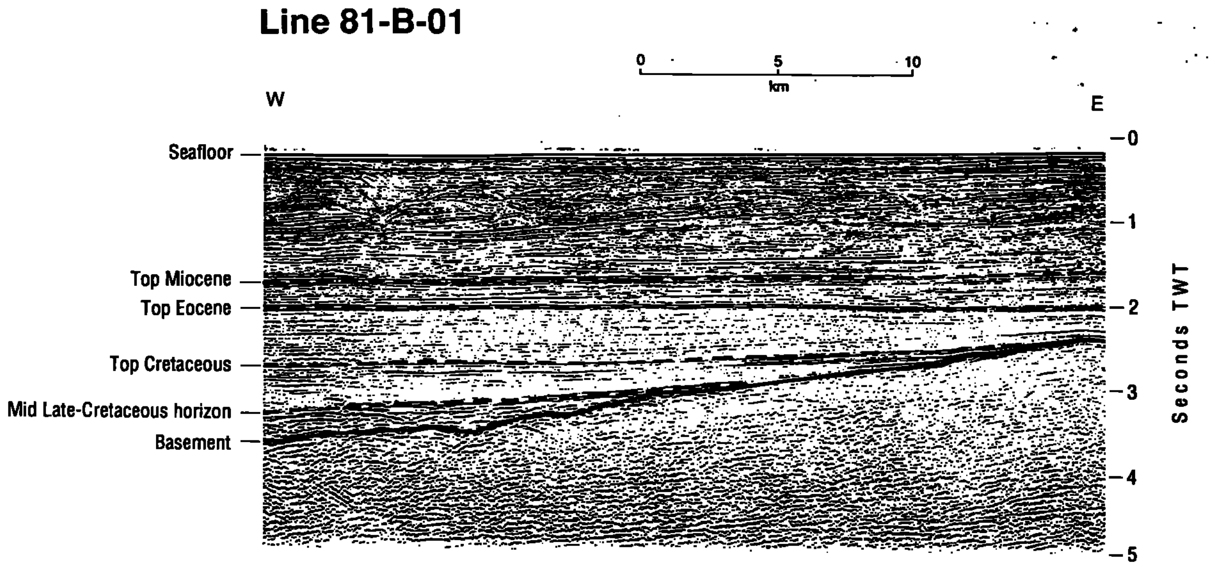

Figure 7: Portion of seismic reflection profile 81-B-01, near the Wainui-1 petroleum exploration well. On the left-hand side of the figure, the interval between the mid late-Cretaceous horizon and the top Cretaceous horizon illustrates the rather bland seismic character associated with marine sediments. Towards the right, near the basement pinchout of the unit, the amplitudes increase and the signature becomes that of the lower coastal plain/marginal marine facies. Profile from New Zealand Geological Survey PR 1018, Shell BP & Todd Oil Services, Ltd, 1982.

basin is shown as being subject to marine conditions, although large portions of the Western Platform were subaerial and experiencing coastal plain conditions.

Based on seismic facies mapping, it seems likely that the late Cretaceous sedimentary sequence over parts of the Western Platform is composed wholly of terrestrial, coal-bearing rocks. In contrast, much of the present Taranaki Graben is probably underlain by a wholly-marine upper late-Cretaceous sequence. The extent of the upper late-Cretaceous coal measures is limited, and mostly they are confined to the present Western Platform. Elsewhere upper late-Cretaceous coal measures are present only as coastal strips around the edges of the upper late-Cretaceous marine embayments.

Petroleum Source Rock Potential

Using the results of seismic reflection mapping, the late Cretaceous rocks of the Taranaki Basin can be subdivided into three major groups of sediments: the lower late-Cretaceous coal measures; the upper late-Cretaceous marine sediments; and the upper late-Cretaceous coal measures. The potential of these three groups to source hydrocarbons can be investigated using geochemical data from petroleum exploration wells.

The source-rock indicator most commonly available for petroleum exploration wells within the basin is total organic carbon (TOC). The TOC of a rock sample is the percent, by weight, of the sample which is composed of elemental carbon held within organic molecules. Many of the wells which have penetrated the late Cretaceous sequence in the Taranaki Basin, have had this rather simple indicator run on rock cuttings collected during drilling.

Often TOC is used to screen samples prior to conducting more sophisticated analytical techniques, such as Rock-Eval Pyrolysis. Because Rock-Eval Pyrolysis is only conducted on samples with TOC values in excess of 0.5%, the record of TOC measurements is much more complete than that of

Figure 8: Latest Cretaceous paleogeography of Taranaki Basin.

pyrolysis measurements, especially where organic richness is low. This completeness of record is the main reason for choosing TOC as the main indicator of source rock richness for this study.

TOC is only an approximate indicator of the ability of a sequence to generate hydrocarbons, and no firm guidelines are available to separate "good" source rocks from "poor" source rocks using TOC alone. A "high" TOC value from a rock sequence indicates that the rock may be able to source petroleum provided the thermodynamic conditions are appropriate for the particular type of organic material within the rock. On the other hand, a rock with "low" TOC is highly unlikely to be able to produce petroleum under any circumstances. Thus TOC alone cannot tell us which rocks can, or have, generated petroleum, but can indicate which rocks cannot be considered potential source rocks. A generally accepted cutoff, below which source potential is considered negligible to slight is 1.0% (Waples 1985). Above 1.0% potential is considered modest, and above 2.0% potential is considered good.

Table 1 shows the results of the large number of publicly available TOC measurements from late Cretaceous rocks in the basin. Note that both the upper and lower late-Cretaceous coal measures have very high TOC averages (10% and 9%). The variability in these rocks, as indicated by the standard deviation (14% and 11%), is also high. In contrast, the upper late-Cretaceous marine rocks have very low TOC values, with an average of only 0.4% and a standard deviation of 0.6%.

This relationship is clearly illustrated in the Maui-4 and Cook-1 wells. Figures 9 and 10 are graphs of TOC versus depth for the late Cretaceous to Paleocene section in these wells. The upper late-Cretaceous coal measures are not present. At the mid late-Cretaceous horizon, which separates the Rakopi Formation from the overlying Tahi/North Cape Formation, the average TOC values drop from about 5% in the Rakopi Formation to less than 1% in the Tahi Formation. The TOC values then slowly increase upwards and again exceed 5% in the terrestrial coal measures of the Kapuni Group.

	Upper Late-Cret. coal measures	Upper Late-Cret. marine clastics	Lower Late-Cret. coal measures
Average	10%	0.4%	9%
Std. dev.	14%	0.6%	11%
# wells	5	7	5
# samples	80	121	120
Maximum	59.3%	3.9%	52.1%
Minimum	0.26%	0.03%	0.03%
Formations	Puponga	Tahi/ North Cape	Rakopi

Table 1: Total organic carbon measurements from late Cretaceous rocks.

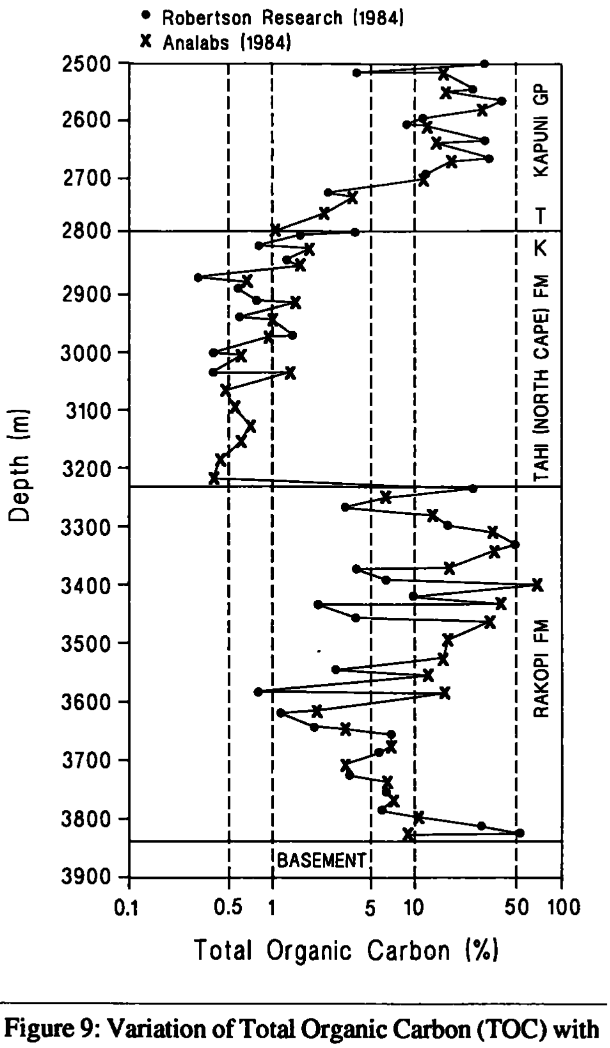

Figure 9: Variation of Total Organic Carbon (TOC) with depth for the Cretaceous and Paleocene section in the Maui-4 well.

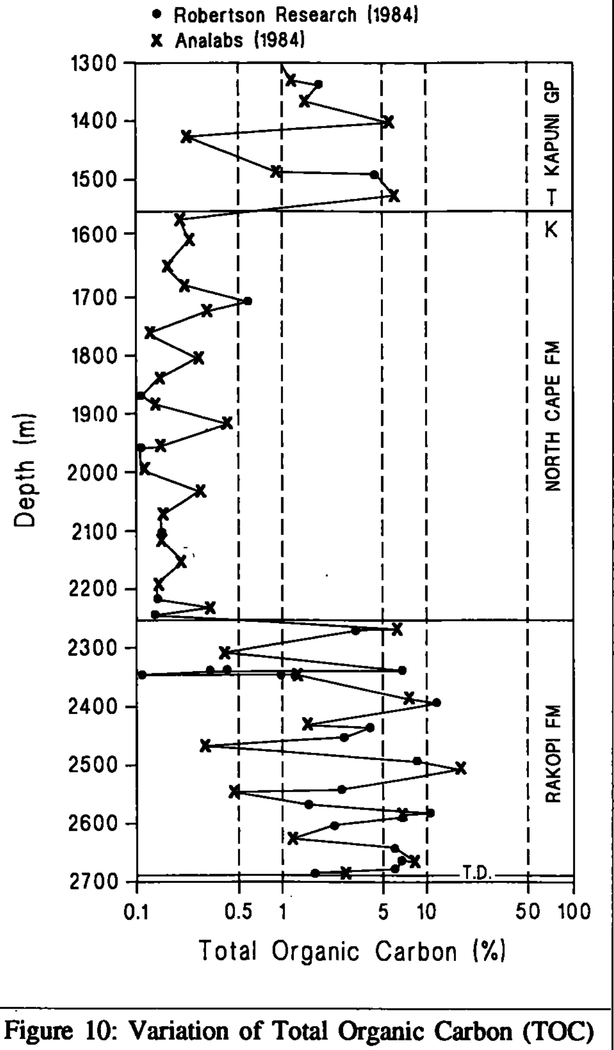

Figure 10: Variation of Total Organic Carbon (TOC) with depth for the Cretaceous and Paleocene section in the Cook-1 well.

The situation portrayed in these wells probably exists throughout much of the central portions of the basin. The organic-rich Rakopi Formation (lower late-Cretaceous) coal measures are separated from the organic-rich Kapuni Group (early Tertiary) coal measures by 500 to 1500 m of organic-poor marine transgressive sediments. In this central portion of the basin laterally discontinous organic-rich coastal plain deposits of upper late-Cretaceous age are also present around the edges of the marine embayments. However, the total volume of these deposits is probably small compared with the volume of the lower late-Cretaceous coal measures. When considering the source rock potential of the late Cretaceous Pakawau Group within the Taranaki Graben, the dominant unit is the lower late-Cretaceous coal measures.

Upper late-Cretaceous coal measures are much more extensive on the Western Platform. These coastal-plain sediments cover most of the Western Platform as a veneer, up to 500m thick.

One problem with the application of TOC measurements to characterise large volumes of rock is the bias introduced by sampling procedures. Often the organically richest intervals within a sequence are sampled for TOC analysis. The average TOC values shown on Table 1 may be indicative not of the organic content of the units as a whole, but of organic-rich intervals within the units. This bias is not of concern in units where the TOC values are low enough to discount any significant source-rock potential, but may be a problem where potential source rocks are indicated, especialy if volumetric estimates of hydrocarbon yield are being considered.

One other way of looking at the potential of a unit for sourcing hydrocarbons is to look at the relative abundance of lithologic constituents of the rock sequence. For the lower late-Cretaceous coal measures, the lithological logs are available for 8 wells, totaling 3963 m of penetrated section. The average lithologic abundance for this unit is:

Coarse lithologies (sand and conglomerate)	63%
Fine lithologies (mud, silt, shale, clay)	31%
Coal	6%

The coarse lithologies have essentially no input into the hydrocarbon source potential of the unit, as the coal and fine lithologies are likely to act as sources of organic carbon. If the lithologies reported as "coal" average about 50% TOC, and the fine lithologies are at most 5% TOC, then the total organic carbon content of a unit with the lithologic abundances reported above would be less than 5%. The average of all TOC measurements from this same unit is 9%. Even if the organic content of the unit is only 5%, it still must be considered a potential source rock, just not as rich as geochemical data alone might indicate.

Thermal Maturity

One major unresolved problem in our understanding of the source of hydrocarbons in the Taranaki Basin is the burial depth required for generation and expulsion in the basin. Many authors have indicated that the depth of burial in the Taranaki Basin is greater than that generally required for hydrocarbon generation. For example Cook (1987, 1988) suggests a depth greater than 5.5km for generation in Taranaki. Johnston and others (1990) give depths of 5 km for Pakawau Group sediments, and 6 km for Kapuni Group sediments to be the source of Taranaki's oil and gas.

If these inferred depths to generation are correct, then Kapuni Group sediments, which are rarely buried deeper then 5.5 km, may not be important in the provision of hydrocarbons. Even the upper late-Cretaceous coal measures of the Pakawau Group are rarely buried to depths great enough to generate hydrocarbons. For example the Western Platform, discussed in the previous section, does not include regions where the upper late-Cretaceous coal measures are buried deeply enough to constitute mature source rocks using a burial depth of 5 km.

Only the lower late-Cretaceous coal measures are routinely buried deeper than 5km. Given the distribution of these sediments, underlying or adjacent to the known hydrocarbon accumulations, and their substantial thickness, they seem the most probable source rocks for Taranaki Basin's hydrocarbons.

Conclusions

The traditional view of the late Cretaceous Pakawau Group as a thick sequence of organic-rich terrestrial coal measures must be revised. The Pakawau Group is subdivisable into distinct formations which vary greatly in their organic carbon content and therefore in their likelihood of generating hydrocarbons.

The first widespread sediments deposited within the Taranaki Rift were terrestrial coal measures, referred to here as the Rakopi Formation. These organic-rich sediments underly much of the present Taranaki Basin. They are deeply buried and may well be the source rocks for Taranaki's known hydrocarbon accumulations.

Overlying these lower late-Cretaceous coal measures is an upper late-Cretaceous trangressive sequence of marine and coastal plain sediments. The marine facies, generally referred to as the Tahi Formation and now shown to also include the North Cape Formation, are very poor in organic material. Although buried deeply, they are not likely to be significant in the generation of petroleum. They can be very sandy and may constitute a potential reservoir sequence.

The coastal plain sediments associated with this latest Cretaceous transgression are organic rich and could make very good source rocks if significant volumes of them were buried to substantial depths. This does not appear to be the case, however, as only the Western Platform portion of Taranaki Basin can be shown to have large volumes of these rocks. On the Western Platform they may not be buried to sufficient depths for hydrocarbon generation and explusion.

Conformably overlying the late Cretaceous sediments of the Taranaki Basin are widespread Paleogene terrestrial rocks of the Kapuni Group. Although often mentioned as a potential source rock for the Taranaki Basin hydrocarbons, they have not been shown to be definitely mature for generation and expulsion in any sampled sequence (for example Cook 1987; Johnston and others 1990). If presently available estimates for the overburden required to mature these sediments are correct, then the Paleogene rocks are in general not buried deeply enough to be significant in generating hydrocarbons.

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