EXPLORATION GEOCHEMISTRY OF THE TARANAKI BASIN WITH EMPHASIS ON KORA

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Abstract

A new type of oil, not previously encountered in the Taranaki Basin has been found in the Kora structure. Geochemically, this oil is quite distinct from the other major oil types in the basin in that it does not contain evidence of significant contribution from either gymnosperms or angiosperms. The Kora oil is characterized by unusual concentrations of C_{30} desmethyl and C_{30} and C_{31} methyl steranes and by a heavy carbon isotopic composition. These and other geochemical characteristics derived from whole-oil and saturate fraction gas-chromatography and gas chromatography-mass spectrometry indicate that algal material deposited in a nearshore marine or transitional type of environment is the source for the Kora fluid.

The presence of biogdegraded hydrocarbons coupled with foraminiferal age dating of the seal on the Kora structure allows an approximation of the timing of oil emplacement. It is suggested that the oil was generated in the Taranaki Graben from a Cretaceous source facies which has not yet been penetrated, and migrated into the Kora structure along graben bounding faults approximately 2-4 Ma.

Introduction

Until recently, the hydrocarbons encountered in the Taranaki Basin in New Zealand have been attributable to primarily two nonmarine sources. Many have noted the geochemical characteristics of the oils and condensates that associate the Taranaki oils with land plant derived organic matter (e.g. Johnston *et al.*, 1988; Weston *et al.*, 1988; and Cook, 1987).

The primary sources for the Taranaki hydrocarbons include the coals of the Cretaceous Pakawau Formation and the Eocene Kapuni Group. The oils derived from the Pakawau Formation have geochemical characteristics, such as the presence of diterpanes, that indicate these coals are primarily derived from gymnosperm (conifer) type organic matter. This source seems to be most important in the southern offshore part of the Taranaki Basin (in house unpublished data and Czochanska *et al.*, 1988).

Oils generated from the Eocene Kapuni Group coals have geochemical characteristics, such as the presence of oleanane, suggesting they are derived from angiosperm (flowering plant) type organic matter. These oils occur mostly onshore, to the north of the primary occurrence of the oils generated from the Pakawau Formation coals. Not surprisingly, the distribution of the oils coincides closely with the distribution of the Kapuni Group coals (Harrison, 1979).

The drilling of the Kora structure in the offshore northern Taranaki Basin revealed an oil different from that generated from either the Kapuni Group or Pakawau Formation coals. This oil reflects significantly more marine influence than the other oils in the basin.

This paper describes the occurrence of hydrocarbons in the Kora wells and the age and characteristics of the depositional environment of their source as interpreted from their chemistry. Additionally, the location of the Kora source, timing of oil generation and migration, and migration pathways are discussed.

Geological Setting

The Kora structure is located in the northern part of the Taranaki Basin (Block PPL38447) in the Cape Egmont Fault Zone on the western margin of the North Taranaki Graben (Figure 1). The structure is associated with a Miocene age stratovolcano (Bergman *et al.*, 1991) that has been dated as 8-20 Ma (Tt-Pl stage). The section penetrated by the deepest of the Kora wells (Kora 4, 3500m) went from Pliocene-Holocene Giant Foresets to Eocene Kaiata Formation (Figure 2). Although not penetrated by any of the wells, the Cretaceous Pakawau Formation underlies the Kaiata Formation in the Kora area.

The original objective for the Kora structure was the Eocene Tangaroa Sandstone which was tested in Kora 1 and 4. Kora 2 and 3 tested only the Miocene volcanics which became an objective based on the findings in Kora 1.

Kora Geochemistry

The Kora 1 well (3421m T.D.) showed a trend of unusually high vitrinite reflectance values (Figure 3) in the lower part of the well from about 3000m to T.D. These data suggest, as was also confirmed from petrographic data for the Eocene Tangaroa Sandstone (3128-3241m), that the lower section of the well had been thermally altered by hydrothermal fluids associated with the Miocene volcanic event. During drilling, significant hydrocarbon shows were encountered in the Tangaroa sands and the Miocene volcanics. However, the Tangaroa yielded only minor hydrocarbons on testing, but the Miocene volcanics tested 1168 BOPD of 35°API gravity oil with a GOR of 435. There was no evidence of thermal alteration of the hydrocarbons from either the Eocene

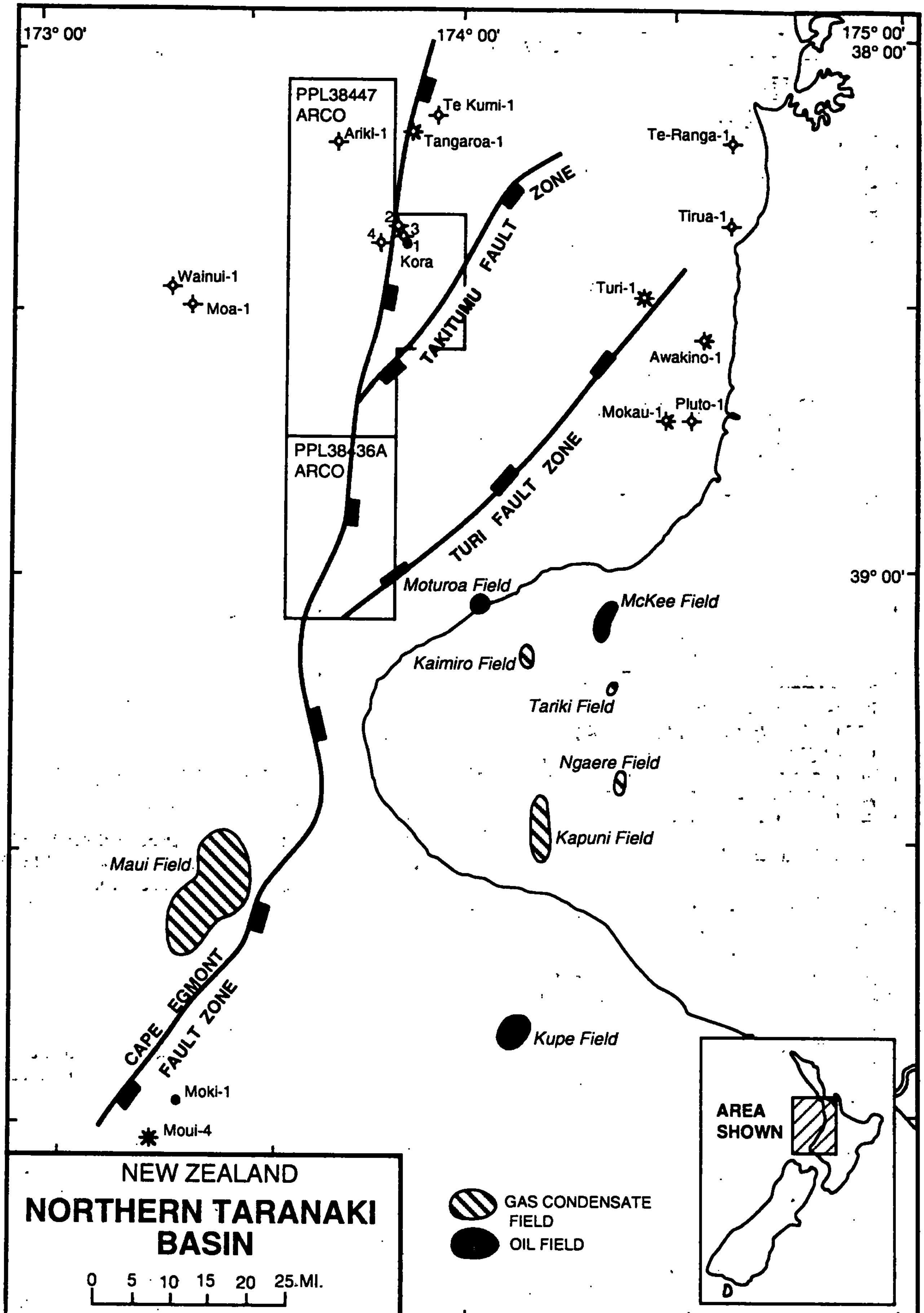

Figure 1: Location of Kora structure (Block PPL 38447) relative to the Cape Egmont Fault Zone and existing oil and gas production.

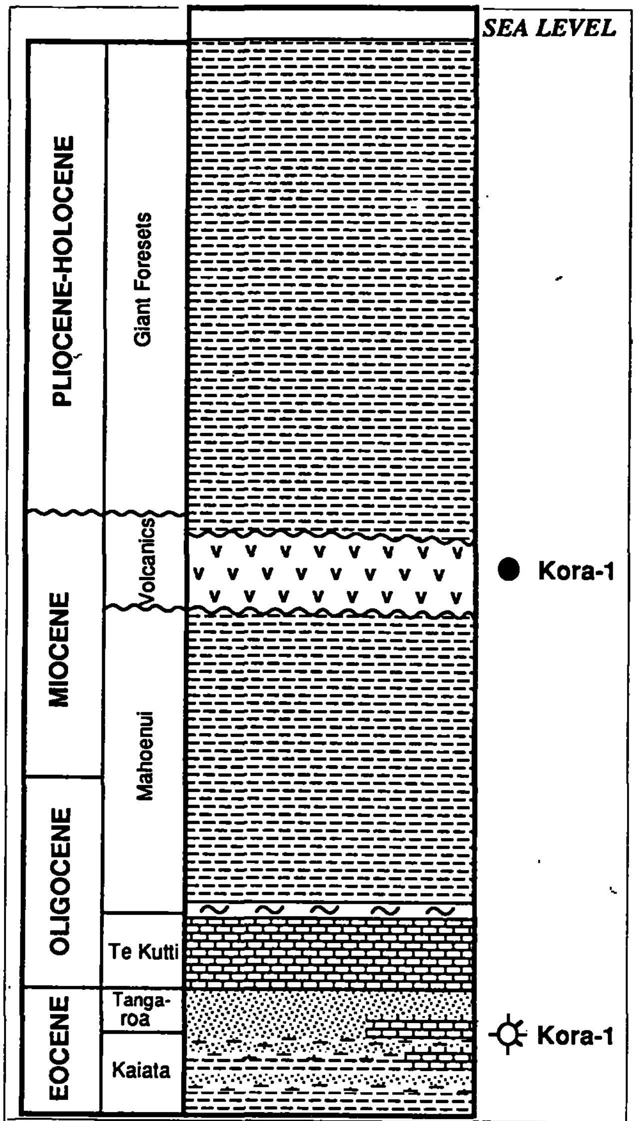

Figure 2: Kora generalised stratigraphy.

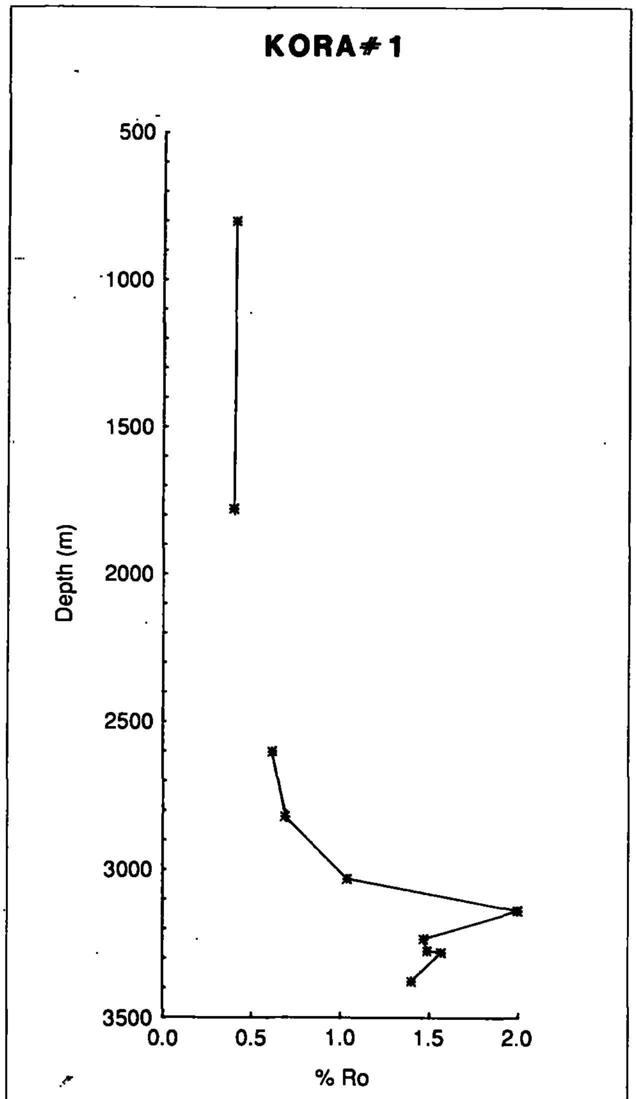

Figure 3: Profile of vitrinite reflectance with depth for the Kora 1 well showing the effects of hydrothermal fluids associated with the Miocene volcanic event.

or Miocene, indicating the Miocene volcanic activity had no direct thermal influence on the Kora 1 hydrocarbons as it had on the Tangaroa sandstone itself.

The analyses of the hydrocarbons from the two tests showed the oils were of the same type and therefore represented generation from only one source. Figure 4 shows the whole-oil chromatogram for the oil tested from the Miocene volcanics. Table 1 lists some of the general geochemical characteristics of the Kora 1 hydrocarbons. For comparison, data for oils generated from the two coaly sources in the Taranaki Basin have also been included in Table 1. More detailed characterisation of the Kora hydrocarbons was also made by examining the sterane and triterpane biomarkers. Figure 5 shows the m/z 191 and m/z 217 fragmentograms and Table 2 summarizes the GC-MS findings, again for both the Kora 1 oil as well as the other types of Taranaki Basin oils. The m/z 217 fragmentogram shows a very complex mixture of steranes in the Kora oil. A more detailed study and interpretation of the Kora biomarkers is beyond the scope of this study, but will be presented elsewhere.

The objective of Kora 2 and Kora 3 was the Miocene volcanics (Kora 2, 1656 m T.D. and Kora 3 1934 m T.D.). Neither well tested any hydrocarbons. However, the volcanics

	Kora	Tertiary Source Influence (Kapuni)	Cretaceous Source Influence (Pakawau)
API Gravity	35	——	——
Total Sulphur	0.24	<0.1%	<0.1%
Pristane/Phytane (ip19) : (ip20)	2.5	5-9	4-7
$\partial^{13}C$ Whole Oil	-22.9	-27 to -28	-26 to -27
$\partial^{13}C$ Saturates	-23.6	-27 to -28	-26 to -27
$\partial^{13}C$ Aromatics	-22.0	-27 to -28	-26 to -27

Table 1: Comparison of general geochemical characteristics for Taranaki Basin oils.

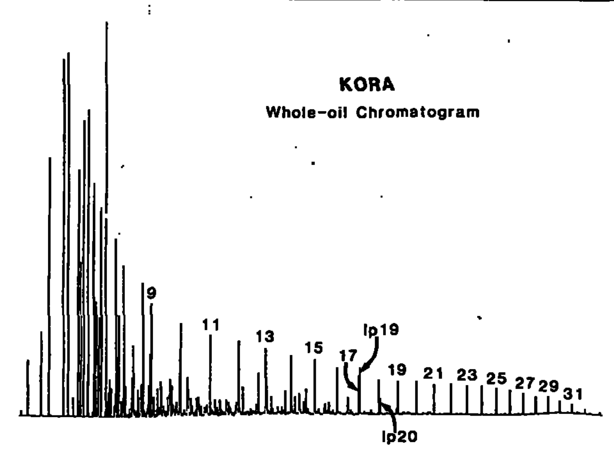

Figure 4: Whole-oil chromatogram for the Kora 1 oil tested from the Miocene volcanics (1784-1810m). Normal odd paraffins 9-31 are indicated. Ip19=pristane; Ip20=phytane.

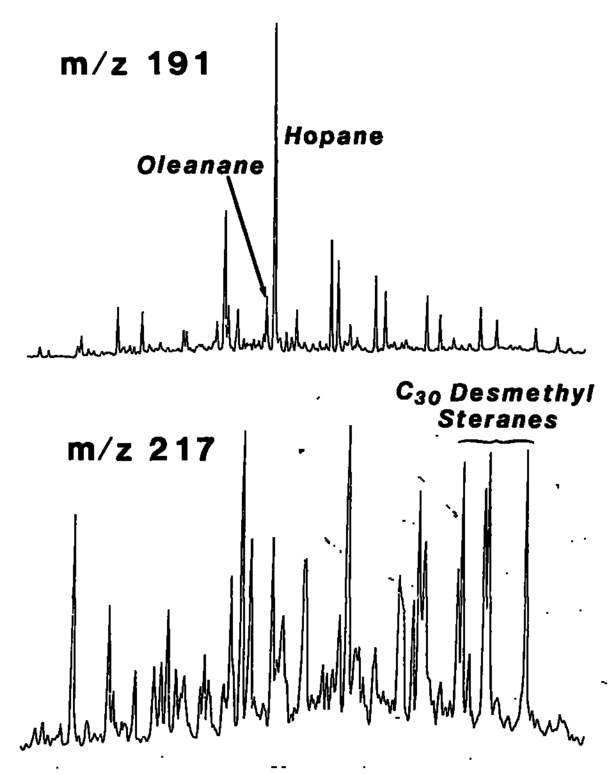

Figure 5: Kora Biomarkers. m/z 191 showing triterpanes; m/z 217 showing steranes.

in both wells were stained with biodegraded hydrocarbons that correlated with the oil from Kora 1, again indicating that a single source is responsible for the Kora hydrocarbons.

Kora 4 again tested the Eocene Tangaroa Sandstone as a primary objective (3500 m T.D.) with the Miocene volcanics as a secondary objective. Neither objective tested any hydrocarbons and no staining was found in any formation. The vitrinite reflectance profile for the well showed a normally increasing trend with depth with no anomalously high values. The highest Ro value for the well, 0.55%, occurred at 3473 m. There was also no petrographic indication that the Tangaroa Sandstone had been thermally altered as it had in Kora 1.

	Kora	Tertiary Source Influence (Kapuni)	Cretaceous Source Influence (Pakawau)
C_{30} desmethyl steranes	•		
Methyl steranes	•		
Abundant Isopimarane			•
Abundant Oleanane		•	
C_{29} Steranes Predominate	•	•	

Table 2: Comparison of Biomarker Characteristics for Taranaki Basin Oils.

Discussion

Kora Oil and Probable Source Geochemical Interpretation

As shown in the preceding section, the geochemistry of the Kora hydrocarbons is very distinct from the oils generated from the coaly Taranaki sources. The geochemical characteristics of the Kora hydrocarbons serve not only to distinguish them, but also to indicate something about the nature of the Kora source.

The Kora oil has not been generated from material that is strictly land derived. In fact, it reflects a significant influence of marine derived organic material. This is evidenced in part by the lack of the waxy compounds and the much lower pristane (ip19)/phytane (ip20) values as compared to the other Taranaki oils. Additionally, the Kora oil contains a significant abundance of C_{31} desmethyl steranes that have been associated with chrysophyte algae (Moldowan *et. al*, 1985 and Moldowan *et al.*, 1990) and therefore, used as definitive marine indicators.

Interestingly, the Kora oil also contains a moderate amount of the compound oleanane, a marker associated with angiosperms, which therefore indicates some influence of terrestrially derived material to its source. The presence of oleanane also places a constraint on the age of the Kora source. Angiosperms first began to evolve in the latest Cretaceous (Maastrichtian) and flourished in the Tertiary. Since the Kora oil contains oleanane the oldest the Kora source could be is Maastrichtian.

Finally, the Kora oil is characterised by a significantly heavier carbon isotopic composition relative to the other Taranaki oils. The significance of this other than serving to distinguish the Kora oil is not clear. However, studies on eutrophic lakes (McKenzie *et. al.*, 1989) suggest that algal blooms associated with a decrease in available CO_2 results in the organic matter becoming isotopically heavy as the system converts to bicarbonate utilisation. If this is related to the heavy isotopic signature of the Kora oil, it suggests the depositional environment of the source might have had limited circulation and possibly been fairly shallow water.

Summarising, these geochemical characteristics suggest a nearshore marine or perhaps estuarine transitional type of depositional environment for the Kora source. It had significant marine input with also some terrestrial influence and is probably Maastrichtian in age.

Timing of Entrapment of Kora Oil

Age dating of the Kora seal coupled with geochemistry was used to constrain the timing of entrapment of fluids in the Kora feature. Table 3 summarises the foraminferal age dating for the seal (Giant Foresets) in each well. These data indicate the seal is older at Kora 1 than at Kora 2 and 3. Further, the fact that the hydrocarbons in Kora 2 and 3 are biodegraded while those in Kora 1 are not, indicates the seal was not present, or at least not effective, when hydrocarbons moved into the volcanics at Kora 2 and 3 but was present when hydrocarbons moved in at the Kora 1 location. The relative age difference of the seals is also evident from seismic data.

Figure 6 is a structure map on the Miocene volcanics over the Kora feature showing the location of two seismic lines, 81-SY-03, an east west line through Kora 1, and AR88-M122 a northwest-trending line through Kora 2 and 3. Figure 7 shows line 81-SY-03 with wells 2, 3, and 4

	Kora 1	Kora 2	Kora 3	Kora 4
Age of Seal (Ma)	4	2.4	3.5	3-4
Depth (m)	1779-80	1274-1285	1774	1680-81
Top of Volcanics (m)	1781.2	1290	1776.	1684
Hydrocarbons in Volcanics	non-biodeg.	biodeg.	biodeg.	none

Table 3: Summary of seal characteristics and hydrocarbon occurrences in Kora wells.

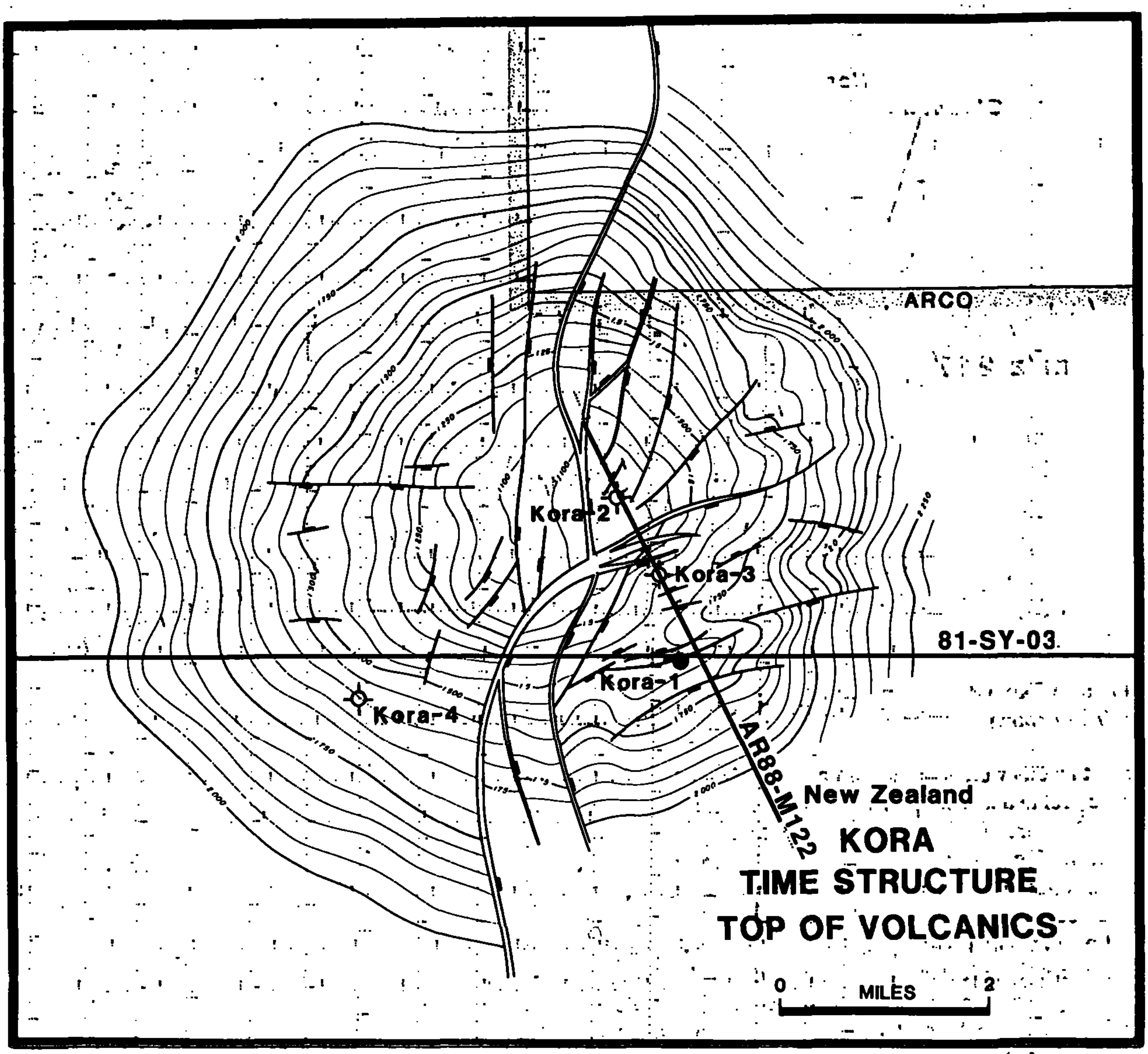

Figure 6: Structure map on the Miocene volcanics over the Kora feature, locating seismic lines 81-SY-03 and AR88-M122.

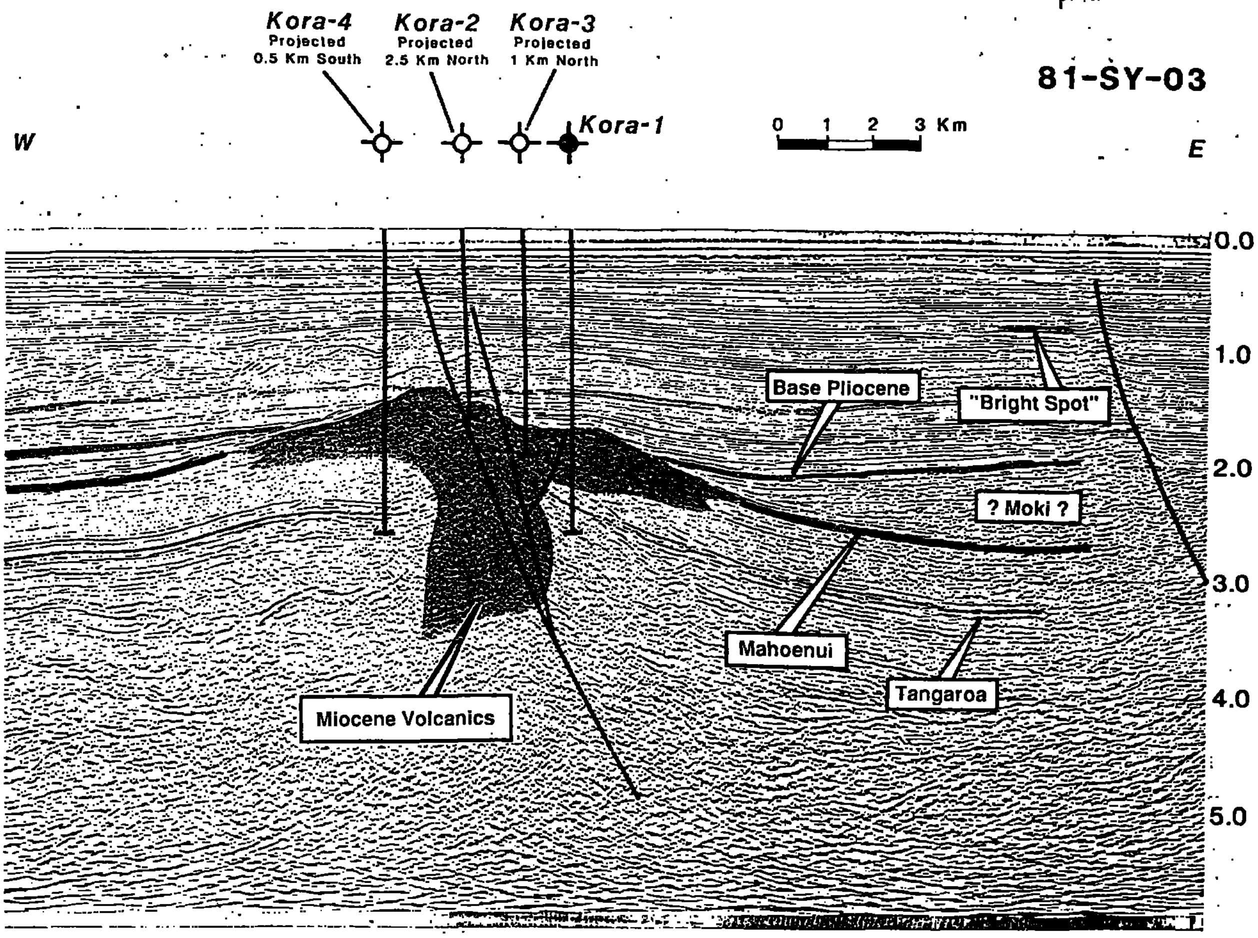

Figure 7: Interpreted seismic line 81-SY-03 with Kora 2, 3, and 4 projected.

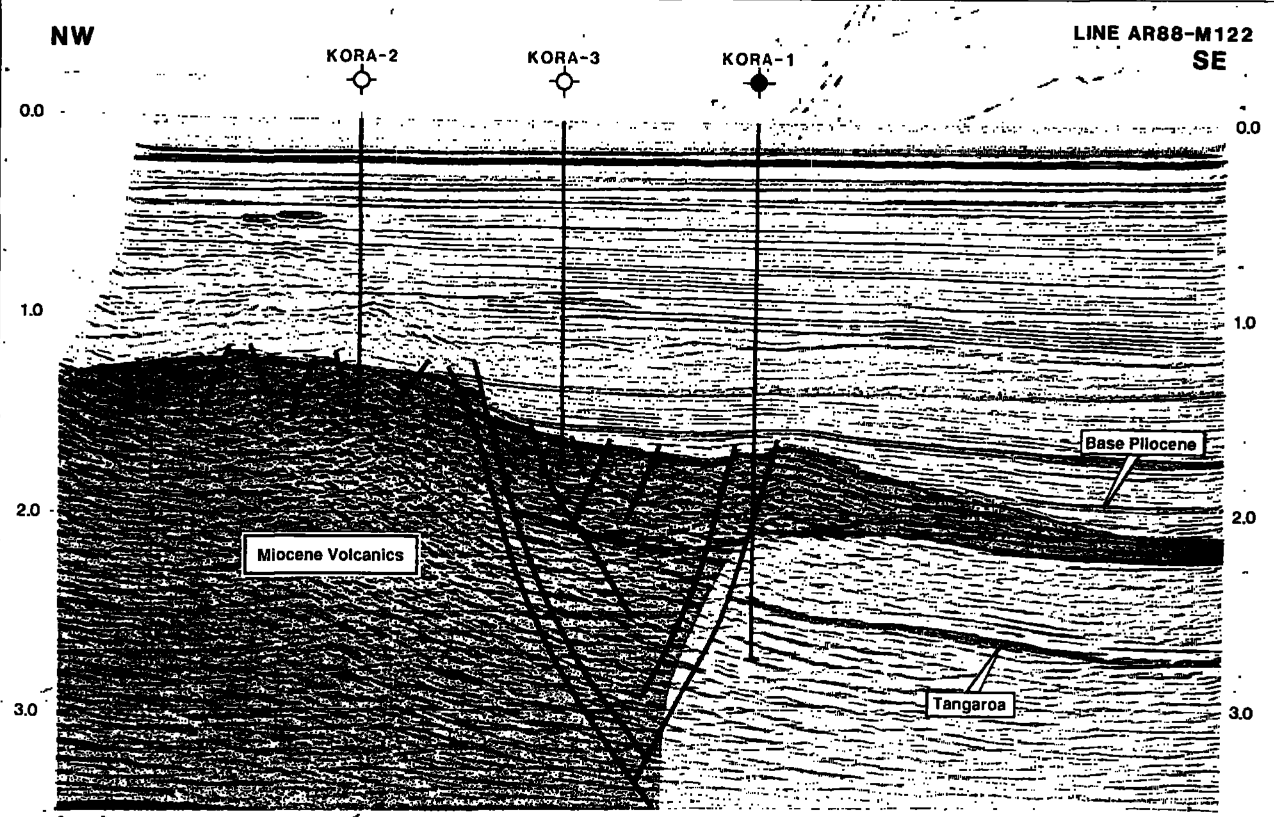

Figure 8: Interpreted seismic line AR88-M122 with Kora 1 projected.

projected onto it. The Base Pliocene (seal) reflector is indicated and below it are the Miocene volcanics. The age of the seal is younger at Kora 2 and 3 than it is at Kora 1. The other line, AR88-M122, is shown in Figure 8 with Kora 1 projected onto it. Again the younger age of the seal at Kora 2 and 3 compared with Kora 1 is evident.

The ages of the Kora seal (2.4-4 Ma) and the Miocene volcanics (8-20 Ma) and the fact that there is no evidence of thermal alteration of the hydrocarbons in the Tangaroa sands, constrains the timing of hydrocarbon entrapment at Kora. Using these data, an approximation of 2-4 Ma as the timing of entrapment was made. Additionally, molecular maturity parameters in the Kora oil indicate it was generated at an Ro equivalence of 0.95-1.0%. Using this information and the timing of hydrocarbon entrapment in the Kora structure, it is possible to postulate a burial reconstruction to approximate the depth of generation from the Kora source.

The burial history for the Kora 1 well was used as a general basis for reconstructing the depth of generation from the Kora source. Modifications made include elimination of the volcanics and thickening of the section in the Miocene and Pliocene. A geothermal gradient (derived from corrected bottom hole temperatures) of 2.85°C/100 m (1.57°F/100ft) was applied and held constant through time. Finally, it was assumed that the Kora source is Maastrichtian in age and has a Type II kerogen. The results of the modelling are summarised in Figures 9 and 10. Figure 9 is a burial history diagram mapped for vitrinite reflectance and contoured on temperature. The diagram indicates a burial depth of about 5000-6000 m (16400-19680 ft) is required to reach the Ro level (0.95%-1.0%) approximated for the Kora source at the time of generation of its oil. More specifically, Figure 10 shows a plot of Ro vs time for the Maastrichtian, the assumed age of the Kora source. A present day burial depth of 5200-5400m (17000-18000ft) is required for the Maastrichtian to reach an Ro of 0.95-1.0% at 3-3.5 Ma.

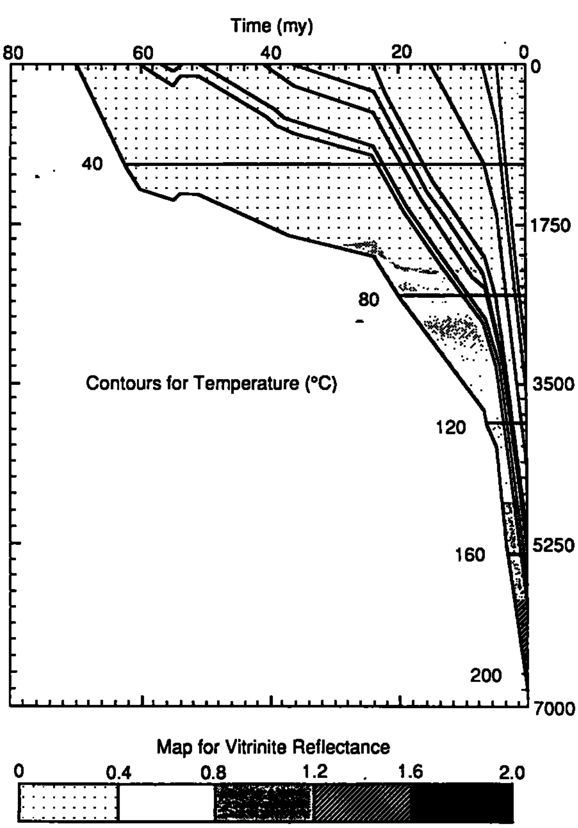

Figure 9: Burial history diagram mapped for vitrinite reflectance and contoured on temperature for a hypothetical Taranaki Graben well to simulate generation from the Kora source.

Kora Charge Area and Migration Pathway

Figure 11 shows structural trends and sediment thicknesses (shaded) in the northern part of the Taranaki Basin. The shaded area of 5000-10000 m of sediment thickness suggest that the Kora oil was generated to the east in the Taranaki Graben and moved into the Kora structure along graben bounding faults associated with the Cape Egmont Fault Zone. Faults are associated with Kora 1, 2, and 3 (Figures 7 and 8) all of which showed the presence of hydrocarbons. However, Kora 4 which was completely dry does not have communication with the fault zone which has served as a conduit for migration . It appears that not only sufficient burial depth for maturing the Kora source, but also association with the Cape Egmont Fault Zone was critical to charging the Kora structure.

Conclusions

(i) The Kora oil was generated from a source facies different from the other oils in the Taranaki Basin.

(ii) The Kora source organic facies was primarily marine chrysophyte algae. However, the depositional environment of this source facies was nearshore marine or transitional. The age of the source is no older than Maastrichtian.

(iii) Oil was trapped in the Kora structure approximately 2-4 Ma.

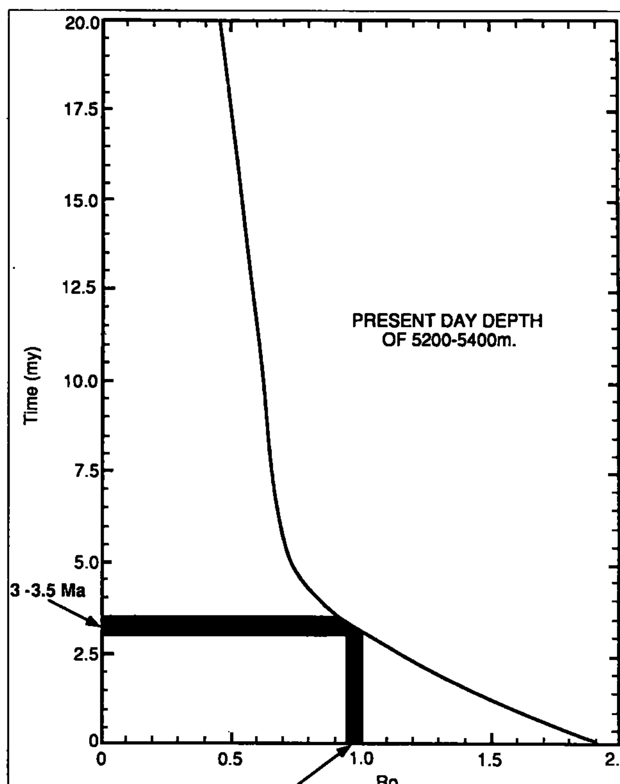

Figure 10: Plot of Ro versus time for the Maastrichtian resulting from the burial history modelling of the hypothetical Taranaki Graben well.

(iv) Kora oil was generated at an Ro(eq) of 0.95%-1.0%, corresponding to a present day burial depth of 5200-5400 m.

(v) The Kora oil was generated in the Taranaki Graben and migrated out along graben bounding faults.

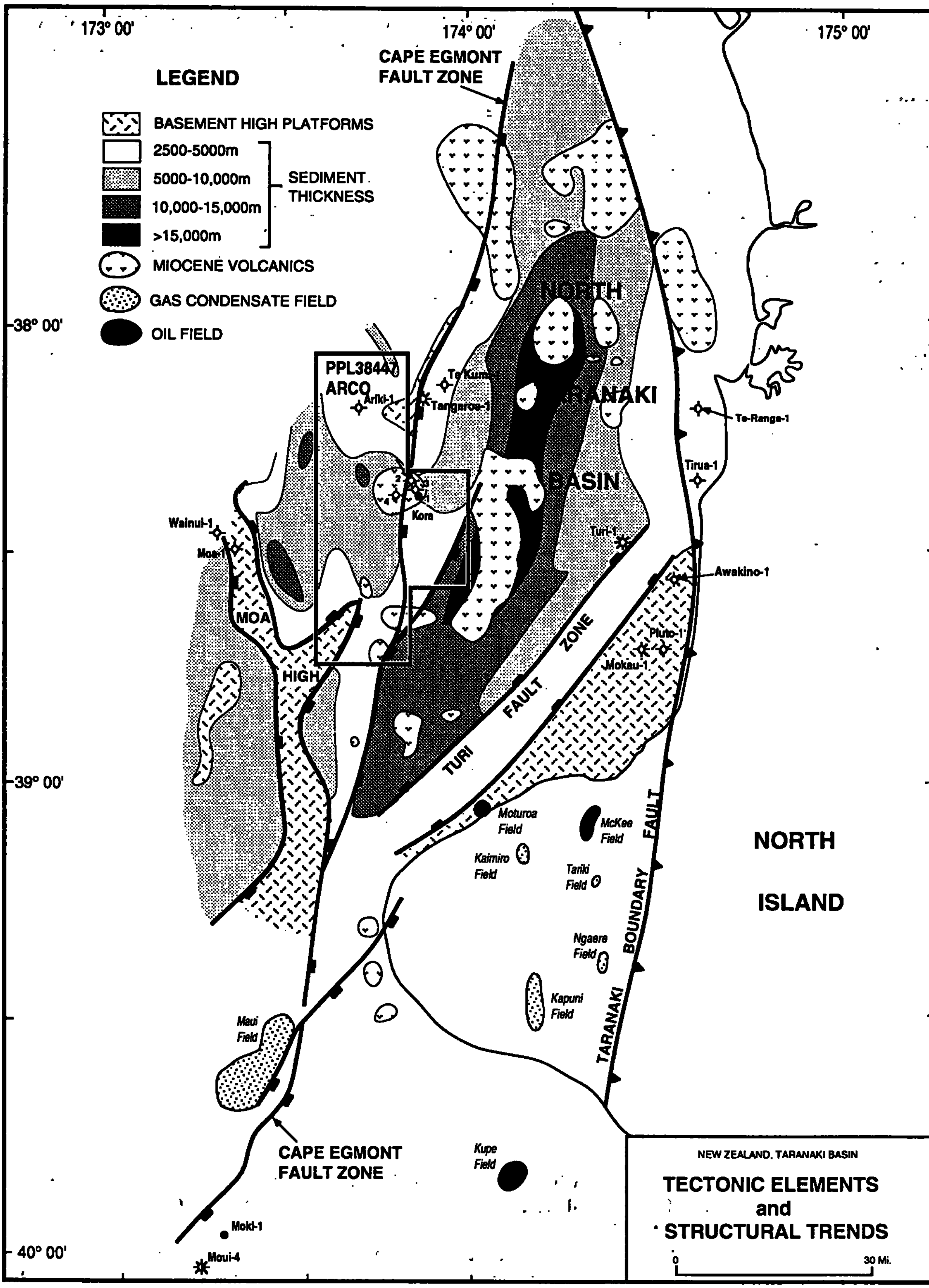

Figure 11: Map of the Northern Taranaki Basin showing structural trends and sediments thicknesses.

References

BERGMAN S., TALBOT J., & THOMPSON P., 1991: The Kora volanic feature, a Miocene andesite stratovolcano, northern Taranaki Basin, New Zealand: Geologic framework. This volume.

COOK R., 1987: The geology and geochemistry of the crude oils and source rocks of western New Zealand. PhD Thesis, Victoria University of Wellington, New Zealand.

CZOCHANSKA Z., GILBERT T., PHILP R., SHEPPARD C., WESTON R.J., WOOD T., & WOOLHOUSE A., 1988: Geochemical application of sterane and triterpane biomarkers to a description of oils from the Taranaki Basin in New Zealand. *Org. Geochem.*, 12, 123-135.

HARRISON J., 1979: Coal percentage and sandstone-shale ration maps, Kapuni Formation, Taranaki. N.Z. Geological Survey unpublished open-file Petroleum Report No. 745.

JOHNSTON J.H., COLLIER R., & CRAIG J., 1988: Oil-Source rock correlations in the Maui-4 oil exploration well, south Taranaki Basin. *Energy Explor. Exploit.* 6, 233-247.

MCKENZIE J., & HOLLANDER, D., 1989: Carbon cycling in Eutrophic Lakes: Models for carbon isotopic excursions in Middle Ordovician algal dominated (Gloeocapsomorpha) organic matter. Amer. Assoc. Pet. Geol. Abstract Annual Conference.

MOLDOWAN J.M., FAGO F., LEE C., JACOBSON S., WATT D., SLOUGUI N., JEGANATHAN A., & YOUNG D., 1990: Sedimentary 24-n propylcholestanes, molecular fossils diagnostic of marine algae. *Science* 247, 309-312.

MOLDOWAN J.M., SEIFERT W., & GALLEGOS E., 1985: Relationship between petroleum composition and depositional environment of petroleum source rocks. *Bull. Amer. Assoc. Pet. Geol.* 69, 1225-1268.

WESTON R.J., PHILP R., SHEPPARD C., AND WOOLHOUSE A., 1989: Sesquiterpanes, New Zealand. *Org. Geochem.* 14, 405-421.

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