The East Coast basin seismic sequence off Cape Runaway as an element of New Zealand's eastern petroleum system

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Abstract

Seismic line OGS-90 was shot from the Bay of Plenty to the continental margin east of the North Island of New Zealand. It shows a typical Cretaceous and Cenozoic East Coast Basin seismic sequence lying on strike with what has been considered to be the northern end of the basin in the East Cape area. The regional basement and, particularly, the basin's five main Albian to Pliocene stratigraphic units are defined on the section. The sequence is unique in that it has not undergone the uplift which created the adjacent Raukumara Peninsula, and is correspondingly more simply structured. All of the seismic parameters, which define the basin as a hydrocarbon province, are evident on the line. It shows the latest Cretaceous and Paleocene source rock interval within the regional oil generation zone. The basin's regional east dip directs migration paths towards the up-dip inner and outer shelf sandstones which characterises basin exposure around Koranga, rather than the deep-water turbidite systems previously targeted for oil exploration. OGS-90 extends the hydrocarbon potential of the East Coast Basin beyond its existing limits, and provides an insight into the petroleum potential of the western side of the East Coast Basin in the Raukumara Peninsula.

Introduction

A review of the petroleum geology of the New Zealand continental shelf and inner slope from eastern Northland Peninsula to eastern Bay of Plenty (Haskell 1999 a,b) shows two areas worth additional study. The most significant of these covers the eastern Bay of Plenty and adjacent offshore East Cape. Early, 1960s and 1970s, reconnaissance seismic in this area shows indications of one second two-way-time thick Neogene sequence related to the adjacent East Coast Basin. In 1990 the Research Vessel Explorer shot seismic line OGS 90 across Bay of Plenty, East Cape and out to the continental margin using standard industrial acquisition parameters (figure 1). The line (figure 2) was designed and used by the Institute of Geological and Nuclear Sciences Ltd (GNS) to interpret the offshore Taupo Volcanic Zone and the interface of the Australian and Pacific Plates.

The line runs north of the Cape Runaway - East Cape area of the Raukumara Peninsula, location of the Matakaoa Volcanics and traditional northern end of the East Coast Basin. This part of the line is on strike with the northern basin, and is dominated by a six second two way time (seconds) thick seismic sequence. The sequence occupies the inner part of a major gravity low which extends the basin to the north north east, and is considered to comprise Miocene sequence. This may well be further offshore, but the inner element on OGS-90 is here correlated with the prospective and extensively licensed East Coast Basin (figure 1).

This correlation is primarily based on recognition of seismic segments relating to established sedimentary systems, tectonic regimes and, particularly, unconformities spanning the Cretaceous, Tertiary and Quaternary. These segments are expressed on- and offshore seismic and in outcrop around the northern East Coast Basin and can be defined in its two deep wells, Petrocorp Rere-1 and Aquitaine BP Shell and Todd Opoutama-1. Interval velocity correlation across the section provides evidence of package continuity, particularly at basement level, and helps differentiate packages. As well the offshore basin falls into two geographic elements east and west of a basin high, which models the distribution of Cretaceous sequence across the basin margin at Koranga in the west-central Raukumara Peninsula (figure 1).

The seismic section shows all of the features of the basin which define it as a hydrocarbon province, though the orientation is towards western, shallow marine inner and outer shelf sandstone systems as possible reservoirs. This objective differs from the eastern basin floor sequences targeted by most exploration programmes to present. The offshore line provides a seismic model of the western margin of the basin that parallels the structural and sedimentological systems developed onshore, and exposed near Koranga. The offshore area, though, has not undergone the uplift and relatively modest structuring which affects the Raukumara Peninsula. OGS-90 therefore provides both conformation and insights into the western margin of the petroleum province, and both areas are reviewed in detail below.

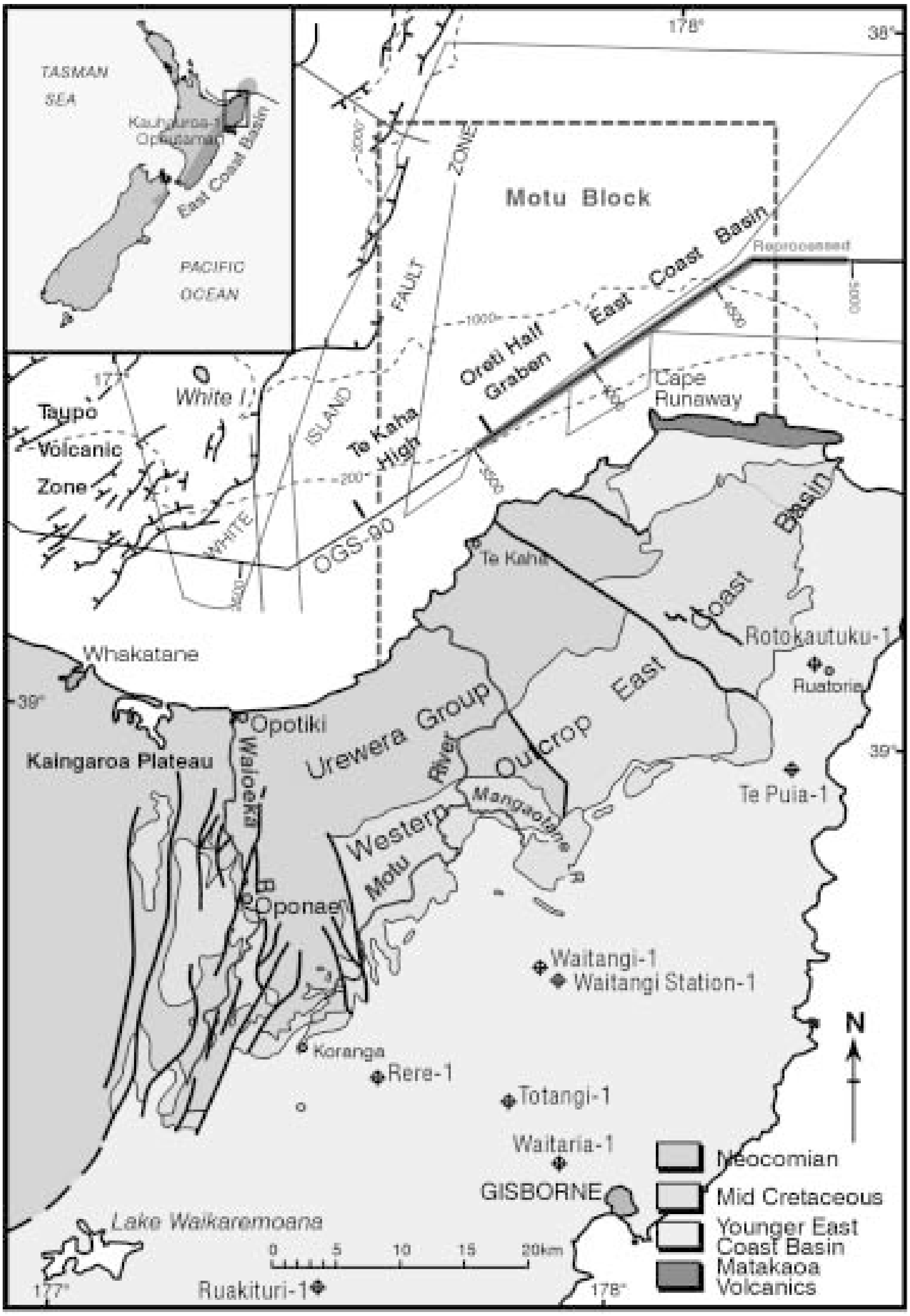

Figure 1: Location map.

The East Coast Basin sequence on OGS-90, as interpreted here, thins against a basement ridge, here termed the Waihau high. To its immediate west is a prominent half-graben, the Oreti Half graben.

Data base

The first seismic collected here was single to 3-fold data shot by Gulf, Mobil and Magellan. The later OGS-90 line was moderately well processed with respect to the 1-5 sec sequence noted above, but showed the basin margin and tectonic elements sought by GNS.

Thirty kilometres of the line, covering the immediate basin margin and, particularly, the then main objective, a major western half-graben within the Motu Block containing the sequence noted in the reconnaissance seismic, was reprocessed. This provided a significantly better interpretation base, and a further 35 km across the western basin margin and deep sequence noted above was also reprocessed.

Geological setting

The western element of Poverty Bay's geology is the Taupo Volcanic Zone (TVZ), a complex of Quaternary volcanics and

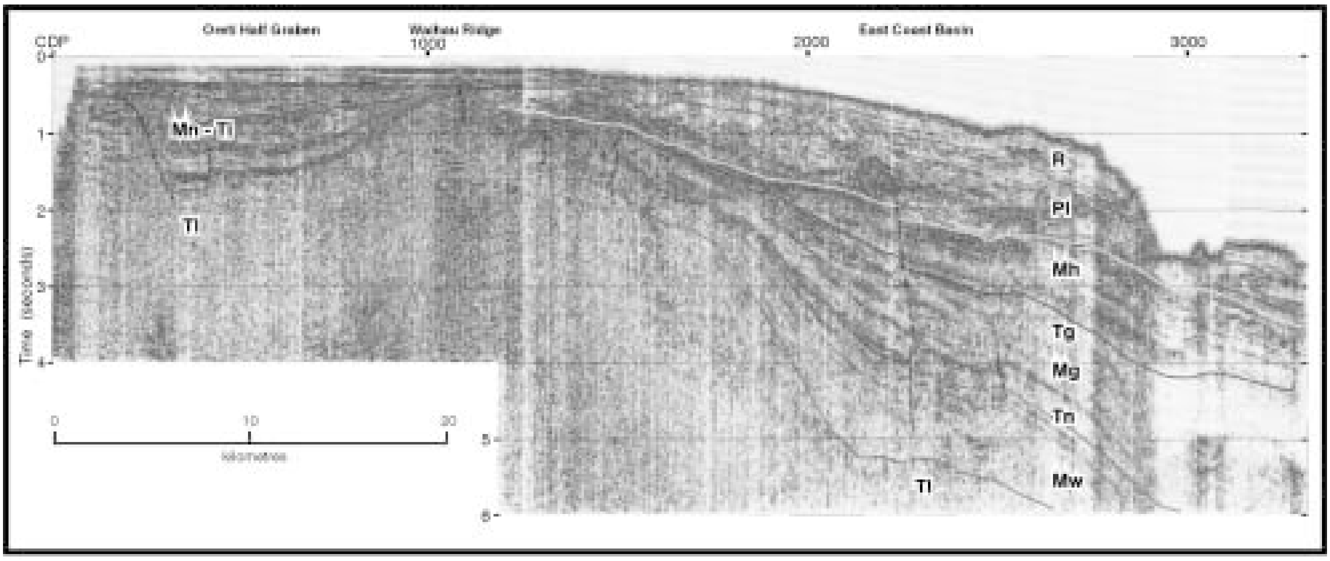

Figure 2: Reprocessed part of OGS-90. Tl: Torlesse Terrane, Mw: Matawai Group, Tn: Tinui Group, Mg: Mangatu Group, Tg: Tolaga Group, Mh: Mangaheia Group; Pl: Pleistocene, R: Recent.

volcanic outwash overlying faulted basement. The eastern margin of the zone is the White Island fault, which separates the complex from the Kaingaroa Plateau. The plateau comprises dominantly Jurassic Torlesse Terrane basement, largely overlain by volcanic outwash up to two kilometres thick. Basement rises eastwards through an onshore fault complex into the western Raukumara Peninsula and its associated ranges though ash is still widespread in the area (figure 1).

East Coast Basin history

Regional basement over the North Island of New Zealand is the Permian to Neocomian Torlesse Terrane. The Torlesse Terrane deposition onshore in this area represents the last phases of activity on Gondwana's convergent margin and is largely Neocomian. It is termed Urewera Group here, partly following Moore, Francis and Mazengarb (1984). The subsequent East Coast Basin Albian to Oligocene sequence is dominated by sedimentary activity on a passive margin system. Initially this margin related to Gondwana, and remained in place until break-up in the Santonian. Subsequent activity related to the to the New Zealand sub-continental margin. Sedimentation rates and tectonic activity in the early mid Cretaceous were relatively high, probably reflecting the geographic proximity of Gondwana. These rates decreased through the later Cretaceous and Paleogene. Simultaneously carbonate deposition increased, becoming prominent in the early Eocene. The process continued to the extent that clastic sedimentation virtually ceased in the Oligocene. The resulting limestone deposition is widespread across the sub-continent, comprising the Weber Limestone in the East Coast Basin.

Convergence began again in the Miocene, setting up sedimentation along the lines of the earlier depositional systems. This developed as distinctive, and separate, Miocene and Pliocene systems, though the depositional axis migrated eastwards early in the period.

In regional terms the basin sequence falls into pre-breakup Matawai Group, breakup to Paleocene Tinui Group, then Mungatu Group to the onset of convergence, with Tolaga and Maungahaia Groups following in the remaining Neogene (figure 3).

Regional geology

The Albian and later Cretaceous parts of the basin onshore in the Motu Block are developed in two related, but geologically distinct geographic units. The early parts of the main basin sequence are exposed around Koranga, where they comprise relatively thin and more proximal elements of the basin's depositional systems. These thicken rapidly eastwards into the basin. West of Koranga, essentially across the geographic axis of the Raukumara Ranges, which core the peninsula, a further series of Albian to Maastrichtian beds are exposed in the western tributaries of the Waioeka River south of Whakatane and Opotiki. These beds are similar to the more easterly Cretaceous, and, from the Albian, are essentially flat lying (figure 1).

Urewera Group

The Torlesse Terrane is a generally submetamorphic grade greywacke sequence that comprises basement to the North Island. In and around Motu Block, though, it is consistently younger and of lower rank than it's generally Triassic and Jurassic aged extensions to the south west and west.

BP geologists, Stoneley, Russell and Haw (1958) and Moore (1961), worked from Lake Waikaremoana (figure 1) to Koranga and described the later Neocomian Taitai sandstone and Mokoiwi mudstone units there as part of, or overlying the "greywacke", Torlesse Terrane basement.

Mazengarb (1993) discusses conventional Torlesse Terrane and East Coast Basin relationships, but noted that its more north and easterly Urewera Group outcrops include Albian dinoflagelates. He considered that sedimentation there can be at least locally continuous between the Urewera Group and the basal East Coast Basin sequence. This may be more general than proposed by Mazengarb. The Petrocorp Rere-1

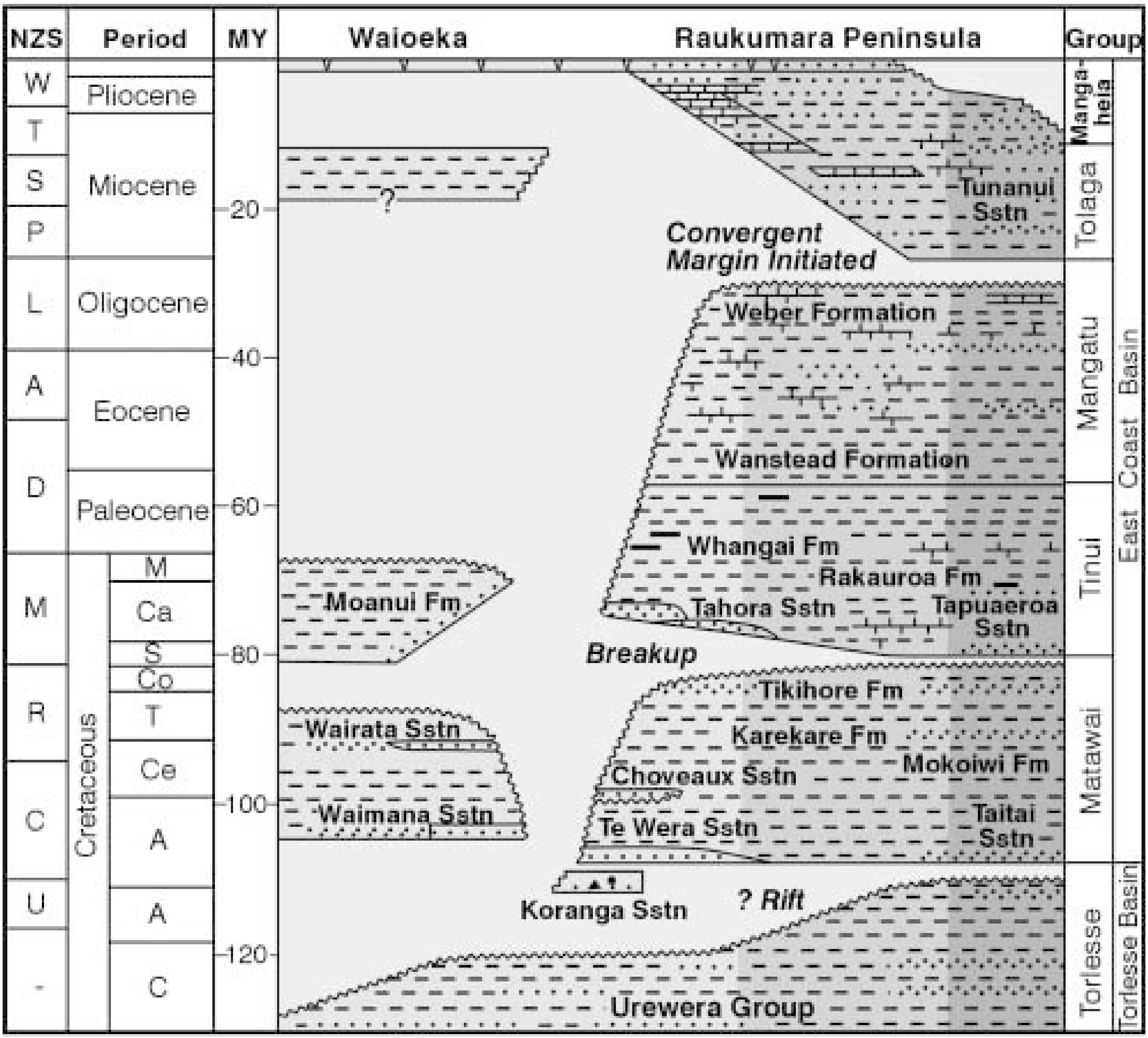

Figure 3: Regional chronostratigraphy of the northern East Coast Basin.

well was proposed to intersect Albian Te Wera sandstone resting on basement. Instead it drilled an essentially continuous mid Cretaceous sequence of what was correlated with Karekare siltstone extending into the Aptian (de Bock et al., 1986). This was thought to be the result of thickening of the siltstone unit, and the well was considered to have reached total depth (4352m) without reaching either Te Wera sandstone or basement. Using Masengarb's thesis, the well entered Torlesse Terrane, but was in a very young Urewera Group interval. This interval probably underlies Karekare siltstone with very little, if any, unconformity.

Koranga Sandstone

The Aptian Koranga sandstone (Speden, 1975), the oldest East Coast Basin unit, unconformably overlies Urewera group at Koranga (figure 1). It comprises channel-fill conglomerates, fine to very fine sandstones and occasional conglomerate and breccia beds. Shell and plant fragments are common at the base of these beds, and near the top of the siltstones which overlie them.

Stanley et al.'s and Moore's Mokoiwi and Taitai formations, mapped immediately beyond the basin margin as Urewera Group, are the last phases of Torlesse deposition, and Speden's stratigraphicly isolated Koranga sandstone the first element of western East Coast Basin deposition. This contrasts with the situation in Rere-1, but is compatible with it on a regional scale.

Matawai Group

The Albian to Santonian and early Campanian Matawai group at Koranga includes basal Albian Te Wera sandstone, a continental shelf unit that unconformably overlies both Urewera Group, and Koranga sandstone (figure 3). It is 91.5 - 183 m thick (Speden, 1975), though 500 m intervals are developed to the north east, further into the basin. The overlying Albian to late Coniacian Karekare formation siltstones are widespread and dominant in this western part of the basin. Other sandstones occur as lenses in the Karekare formation, such as the 16 m thick Choveaux sandstone, also developed near Koranga. These are largely confined to the western side of the East Coast Basin, and represent shelf deposition on erosion surfaces developed by intermittent marine regressions. These disconformities include a locally prominent mid Turonian break between the Clarence and Raukumara Series

The Matawai Group rock sequence west of Koranga, in the headwaters of Waioeka River west of Oponae (figure 1) is not well known.

Mazengarb's Waimana sandstone covers the oldest (late Albian) interval of these beds. Both he and Moore (1961) measured some 120 m of the unit, which comprises locally steeply dipping, fine to medium-grained greenish wacke sandstone, including patches of conglomerate and grit and breccia and scattered invertebrate fossils (Speden, 1975). Speden noted carbonaceous siltstone interbeds along with large scale cross-bedding in the unit and proposed an inner shelf environment of deposition, though Mazengarb considered it to be from "further offshore". The Waimana sandstone grades up to Karekare formation siltstone (figure 3).

An exotic unit, the Oponae melange, a late Albian olistostrome, is developed within this sequence. It both overlies, and again grades to, Karekare siltstone.

The Turonian Wairata sandstone outcrop caps hills and dip slopes in the same area. It was mapped by Speden (1975) at up to 250 m thick, and comprises a flat-lying, very fine and moderately sorted sandstone. It is an inner shelf transgressive unit and is again set within Karekare formation (Mazengarb, 1993). Much of the western Santonian sequence was eroded away in the later part of the Campanian as breakup occurred, which limits exposure towards the basin margin.

Tinui Group

The Campanian Tahora sandstone is developed in a relatively irregular lensoidal sequence deposited with the subsequent transgression over the eroded Karekare formation in the Koranga area. Moore (1961) mapped a 300-450 m thick massive late Campanian shelf sandstone in Anini River, 20 km south west of Koranga. This unit, and a like element, a 30-60 m sequence of fine-grained and moderately sorted sandstones mapped north and south of Lake Waikaremoana by Stoneley et al. are correlated with the Tahora sandstone.

West of Koranga the equivalent Moanui formation is a flat lying, 500 m thick siltstone and very fine sandstone unit set on a basal conglomerate and resting on Karekare formation. The interval includes thin sandstone bands, and lenses of conglomerate, breccia and pebbly sandstone. The base of the unit originates in the early Turonian and extends to the basal Coniacian. Again it is of shallow water, inner shelf, origin, though upper, and finer, elements are deeper.

The sandstones are overlain by, and pass eastward to, fine-grained Rakauroa formation, then, to the east, the Whangai formation mudstones in kilometre scale thickness. The upper part of the Whangai formation comprises moderately carbonaceous mudstone, which essentially passes up to Waipawa Black Shale in the early Paleocene. These two units provide the main source rocks for the basin.

Mangatu Group

Subsequent late Paleocene and early Eocene rocks are generally fine-grained, and from the late Eocene become progressively more calcareous, commonly comprising marls and limestones in the Oligocene. These intervals comprise elements of the regional Wanstead formation and Weber limestone respectively.

Tolaga Group

Proximal early Miocene rocks are developed in the western basin sequence, but the main sequences are developed to the east. The Miocene sequences which provide reservoir systems in the Wairoa area, and reservoir potential in more northerly drilling are part of the Miocene basin floor depositional system.

Mangaheia Group

The Pliocene routinely includes porous coquinas and inshore sandstones in coastal deposition systems through the basin.

Corelation of OGS-90 line sequence

The earliest and simplest correlation across OGS-90 is Torlesse Terrane basement.

The western part of OGS 90 shows the tectonics of the Taupo Volcanic zone with volcanoclastic sequence set on a 3500 m/sec interval velocity Torlesse Terrane basement, which is well, if recently, structured. This high velocity basement carries east under the 25 km wide Oreti Half Graben and crosses the Waihau Ridge, then plunges eastwards. It increases in interval velocity as it deepens, reaching 6000 m/s at 4 seconds, or 5200 metres, at SP 2910, and beyond. Notably Davey considers the ridge to be volcanic.

As noted above, this basement configuration parallels the Cretaceous geographic and geological situation across the Koranga Saddle.

The East Coast Basin's main stratigraphic intervals are well known on seismic lines across the basin.

Rere-1 well was drilled on Petrocorp GIS 84-05 in 1986 (figures 1,4), and provides well and seismic control adjacent to Koranga. The well sequence came in on seismic depth, but the main objective Albian sandstone sequence was missing.

Even so, using the analysis set out above, the Rere-1 well was on depth with respect to time stratigraphic, if not lithological, prognosis.

This well result shows that the seismic marker picked as basement in corresponds to the near conformable top of the Torlesse Terrane and the base of the East Coast Basin sequence. The break-up unconformity at the top of the Matawai Group is also prominent, defining an equivalent seismic sequence which comprises simple, well organised and common internal reflectors. The late Cenomanian Clarence to Raukumara series interface was picked by Petrocorp (figure 4).

Using this model, the break-up unconformity and Top Matawai Group marker on OGS-90 is picked at the first main unconformity above basement. This tops a seismic package with good definition, and a main internal reflector corresponding to the late Cenomanian series interface. The amount of Matawai Group missing in the seismic unconformity increases westwards along the line as would be expected between Rere-1 and outcrop at Koranga.

The late Oligocene limestone provides a seismic marker, which is widespread over the sub-continent. It is typically present on GIS 84-05 where it is the top of the Weber limestone as drilled in Rere-1. It is also prominent on Asia Pacific Oil 89-01 shot west of Gisborne, as I showed in 1994 (figure 4). The corresponding horizon is picked at the succeeding break on OGS-90 (figure 2). The Tinui and Mangatu Groups thin onto the Waihau high

The succeeding Miocene occurs as a well-defined unit with prominent seismicity on- and offshore eastern Raukumara Peninsula. The remainder of 89-01 is Miocene, and is similar to the penultimate unit immediately offshore on BP L-1, which characteristically onlaps gently westwards.

The Pliocene on- and offshore Gisborne is also developed as a well-defined unit, which onlaps much more strongly westward across the Miocene.

Petroleum geology of East Coast Basin

Source rock systems

The principal source rock systems developed in the basin are late Maastrichtian and Paleocene, respectively the eastern Porangahau facies of the Whangai shale, and the overlying Waipawa Black shale. Both are widespread within the East Coast Basin, and the latter is also present in wells in Canterbury and Taranaki Basins. However fair total organic carbon (TOC) values of 0.5-1% are common in middle and remaining late Cretaceous beds. These relate to plant debris commonly present in bedding plains of shelf and turbidite sequence.

Sources characteristic of the marine Whangai formation and Waipawa Black Sale dominate geochemistry of oil seeps, stains and shows from the Raukumara Peninsula (Rogers, Ollen, Johnston and Elgar, 1999). Killops (1996) reports a possible Karekare formation source for an oil stain Oponae which has geochemical relationships with Albian lower coastal plain source rocks of Canterbury Basin (Haskell, 1999a). Of twenty seven TOC values taken from the Karekare formation, 5 are in the 0.6 - 1% or fair range, with 2 at 1.1% and 4.1% in the good and excellent categories. The latter is from a sandstone unit.

Of 16 samples of the western Rakauroa formation and upper Calcareous members in the Raukumara Peninsula, 7 have in the poor category and 9 are fair.

These Karekare and Rakauroa unit values have been used to generate the potential for a high volume, low TOC source

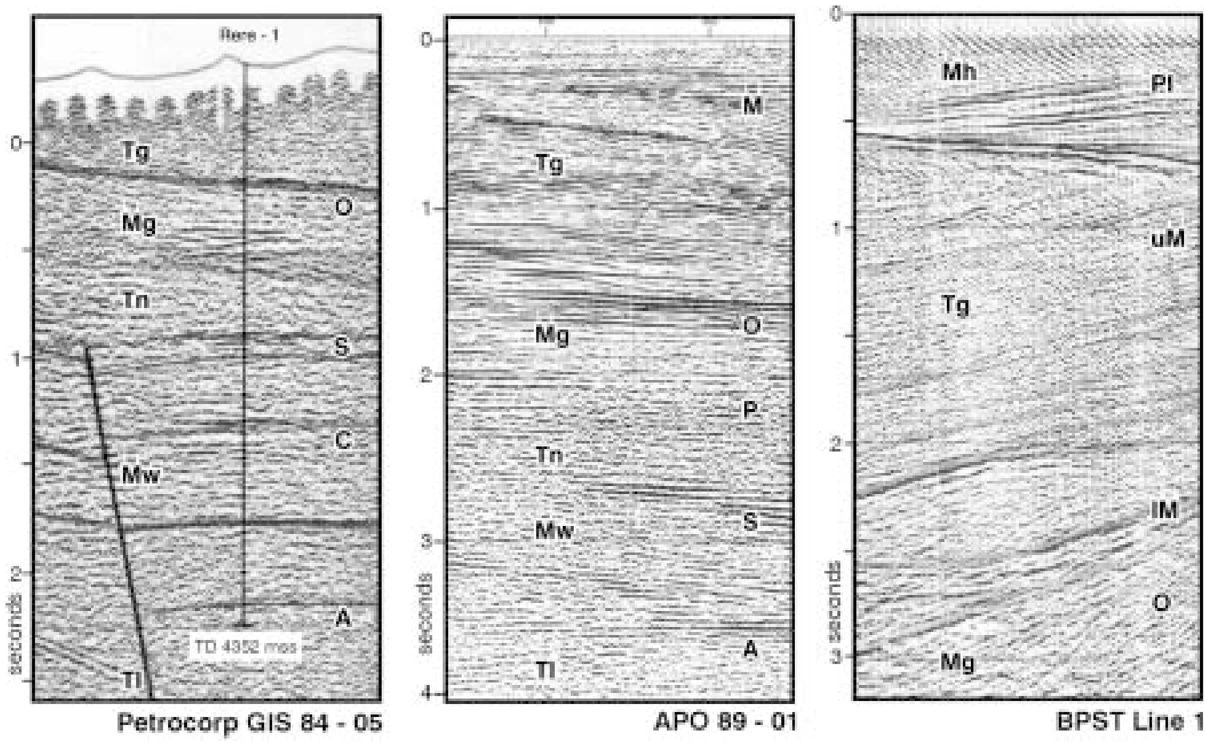

Figure 4: Parts of Raukumara Peninsula seismic lines Petrocorp GIS 84-05, APO 89-1 and BP L-1. Annotation as for figure 2 above, with A: Aptian, C: Cenomanian; S: Santonian ; P: Paleocene; O: Oligocene; M: Miocene.

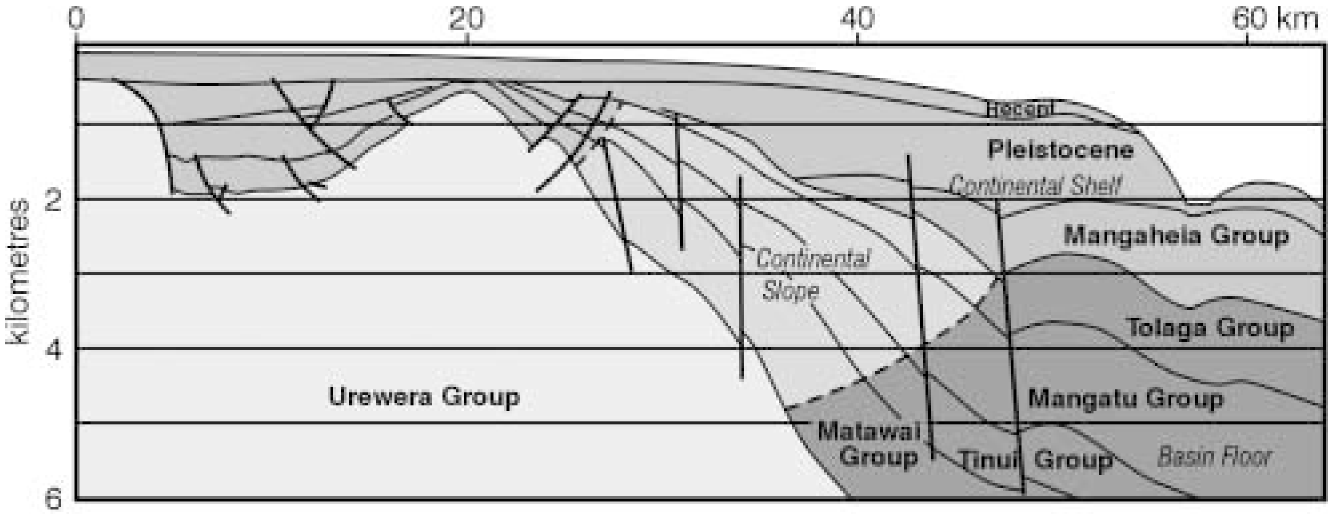

Figure 5: Schematic depth conversion of line OGS-90.

rocks system in the Matawai and Tinui Groups, (Haskell, 1995, and as discussed by Funnell et al., 2002.

The late Maastrichtian and Paleocene Waipawa Black shale unit is relatively restricted in outcrop in the Raukumara Peninsula, with most sampling from central eastern and eastern areas. One sample, taken near Koranga, has TOC of 8.1%, with remainder having a 0.7 - 12.3% TOC range, averaging 4.2%.

Thermal regime and maturation levels

The maximum depth of burial for the onshore Raukumara Peninsula sequence was generally achieved in the late Miocene.

The regional geothermal gradient is 23^0C km^{-1} based on the more significant wells in the region (Landmark, 1989), which places the oil window in the 3.7 - 5.9 km depth range. Using this model, de Bock et al. (1986) place the oil window towards the Rere area at between 3 and 4.5 km, where one kilometre or more of Miocene rocks have been recently eroded off. A single Ro value of 0.97%, correlated with the bottom of the oil window, was determined at 3552 m in Rere-1, though up to 2 km of Miocene was eroded from the drill site area.

The Rere-1 example is supported by results from Opoutama-1 where successive Ro values measured from Coniacian and Turonian sequence from 2719, 3197 and 3655 metres were 0.68%, 0.62% and 0.72%. The Opoutama-1 Miocene sequence is intact, though 1 km of uplift occurred in the Pleistocene (Furnell in Field and Uruski et al., 1997).

Reservoir rocks

The principal geological controls on sandstone distribution on this western side of the basin are the inner and middle shelf systems, and their migration essentially westwards, across Albian to Cenomanian and early Maastrichtian unconformities. Little work has been done on reservoir properties of these sandstone systems, but the basis for reservoir development is present.

Summarising Cretaceous continental shelf sandstone parameters mapped near the western side of the basin, as noted above:

Sandstone	Age	Thickness	Character
Koranga	Aptian	200 metres	Thick interbeds in Mudstone
Te Wera	Albian	91-183 m	Conglomerate, breccia grit, fine sandstone
Choveaux	Cenomanian	16 m	Fine to coarse
Waimana	Cenomanian	120 m	Fine to medium
Moanui	Turonian	60-240 m	Medium, silty, with coarse layers
Wairata	Turonian	100-250 m	Fine to medium
Tahora	Campanian	10-150 m	Medium, well sorted

Liming (1984) noted porosities of 7-10% and permeabilities of less than 1mD in the Koranga sandstone, and equivalent values of 8% and 0.7mD in the Te Wera sandstone. Moore (1961) showed that a Turonian to Coniacian sandstone, probably equivalent to the Wairata sandstone, sampled north of Lake Waikaremoana had reservoir properties of:

Sample Locality	Porosity to Air (%)	Permeability to Air (mD)
Hope's Plateau	16.89	0.05
Whakaretu Stream	24.87	Cracked
Upper Anini River Basin	13.76	0.05
Upper Anini River Basin	9.02	0.05
Winding Creek	7.94	0.05
Bicorrugatus Creek	5.1	0.05
Bicorrugatus Creek	6.3	0.05
Bicorrugatus Creek	2.4	0.05

Little work has been done on reservoir properties of other shelf sandstones.

Conclusions

The East Coast Basin system expressed on OGS-90 east of the Waihau high includes all of the elements of the basins seismic sequence developed on- and offshore to the south, which relate directly to the regions major stratigraphic units. The parts of these sequences which define the basin as a hydrocarbon province can be positioned on the seismic line, and indicate that the prospective shown there is at least equivalent to the adjacent onshore area.

Along the western margin of the basin the successive sedimentary systems from mid Aptian to early Miocene stack on each other, as shown by the concentration of shelf sandstone in the proximity of Koranga. The structure of the basin on OGS-90 indicates sedimentation there will parallel this, and that both the stacking and basin margin concentration is a regional feature, as does the presence of Cenomanian sandstone high on the present basin margin in Te Horo-1, 90 km to the south west.

Using the same model, sandstones occur as finite elements of an other-wise dominantly fine grained sequence. As a result seals would be common where outer shelf and slope Karekare formation or Rakauroa member siltstones and mudstones onlap the sandstones.

These fine-grained formations also provide high volume - low TOC source rocks, though these would tend towards gas expulsion rather than oil. However, the main source lies within the upper Tinui Group upper Whangai formation and Waipawa Black Shale Group, at top Cretaceous and Paleogene levels. Again, given the basins universal eastward dip, these would be presently becoming mature, and expelling oil at 3.4 km depth. Given the continuous rotation of the block, they have probably done so since early Miocene.

East-west structural closure is present in most Cenozoic units, and on a smaller scale, in up-dip Cretaceous sequence.

The lateral extent of the basin in this area is not known. The sequence does as noted above not appear on the various older reconnaissance lines in the area. The line, though, is set on the south side of a major gravity low. The low extends north north east into deep water, and may show a major extension of the basin.

Acknowledgements

Line OGS-90 was made available to the study, and reprocessed, by IGNS. My colleagues assisted in the projects preparation. Ian Wylie bird-dogged the processing, and Debbie Cowman and Bridget Carthew undertook the papers preparation. Clyde Bennett and Roger Gregg, of the Ministry of Economic Development assisted with the development of the project.

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