Petroleum systems of the deepwater Taranaki Basin, New Zealand

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Abstract

The New Zealand Exclusive Economic Zone (EEZ) contains at least six large deepwater basins. Structural styles vary from rift basins through strike-slip dominated basins to major accretionary prisms. Source rocks include coal measures, black marine shales and lacustrine facies. Sedimentary thicknesses, heat flow studies and basin modelling supported by production and numerous seeps in the shelf and onshore, suggest that there is significant untested petroleum prospectivity. In particular, the head of the New Caledonia Basin contains thick sediments and, being adjacent to the Northland Basin and Taranaki, New Zealand's only producing petroleum basin, is believed to be most attractive for exploration.

The petroleum histories of these basins began with Late Cretaceous rifting associated with break-up of Gondwana. In onshore and nearshore New Zealand, many potential source rocks were deposited at this time. The earliest sediments to be deposited were commonly fluvial, lacustrine, deltaic and nearshore facies with an increasing marine influence as the region foundered through the Paleogene. The lateral equivalents of the Cretaceous coaly facies of the Taranaki shelf appear to be deltaic in Deepwater Taranaki. These deltaic units may contain significant finely disseminated kerogen, as do other deltas around the world. The region was a 150 km-wide seaway, closed at its southeastern end by the foundering New Zealand landmass, to the northeast by the Norfolk Ridge and to the southwest by Challenger Plateau. Anoxic conditions may have developed in this restricted seaway, resulting in formation of rich source rocks.

As in much of New Zealand, the Paleogene succession was generally thin in the deepwater basins. Minor inversion may have occurred during this time in the Deepwater Taranaki Basin. The Neogene saw the formation of the present plate boundary and the emergence of New Zealand in response to plate collision. Meanwhile, the deepwater basins away from the plate margin continued a quieter development. Some inversion occurred, but not to the extent of the nearshore and onshore regions. This relatively gentle structural evolution increases the likelihood of discovering large hydrocarbon fields in unbreached structural traps.

During 2001, a 6200 km 2D seismic survey was acquired by TGS-NOPEC from the Deepwater Taranaki Basin. This paper discusses the preliminary results of that reconnaissance survey.

Introduction

The New Zealand mini-continent is actually a long triangular block of crust extending some 4000 km from the Coral Sea in the north to the sub-Antarctic Islands in the south (Fig. 1). At its widest point, the mini-continent is approximately 2000 km across giving a total area of some 4,000,000 km^2, or nearly half the size of the Australian continent. The total land area of New Zealand and New Caledonia combined is approximately 500,000 km^2. About 87.5% of the New Zealand mini-continent therefore lies below sealevel. Of the total mini-continent, approximately 50% lies in New Zealand's Exclusive Economic Zone (EEZ) with 30% in Australia's and 20% to France via New Caledonia.

In 1987, a survey aboard the New Zealand government's research vessel Rapuhia outlined the broad structure of New Zealand's part of the New Caledonia Basin (Uruski and Wood, 1991). The low power, single-fold survey showed sedimentary section as far as the seabed multiple, leaving researchers to speculate on total sediment thickness and geological history of the basin. Work on the basin then had to wait until 1997.

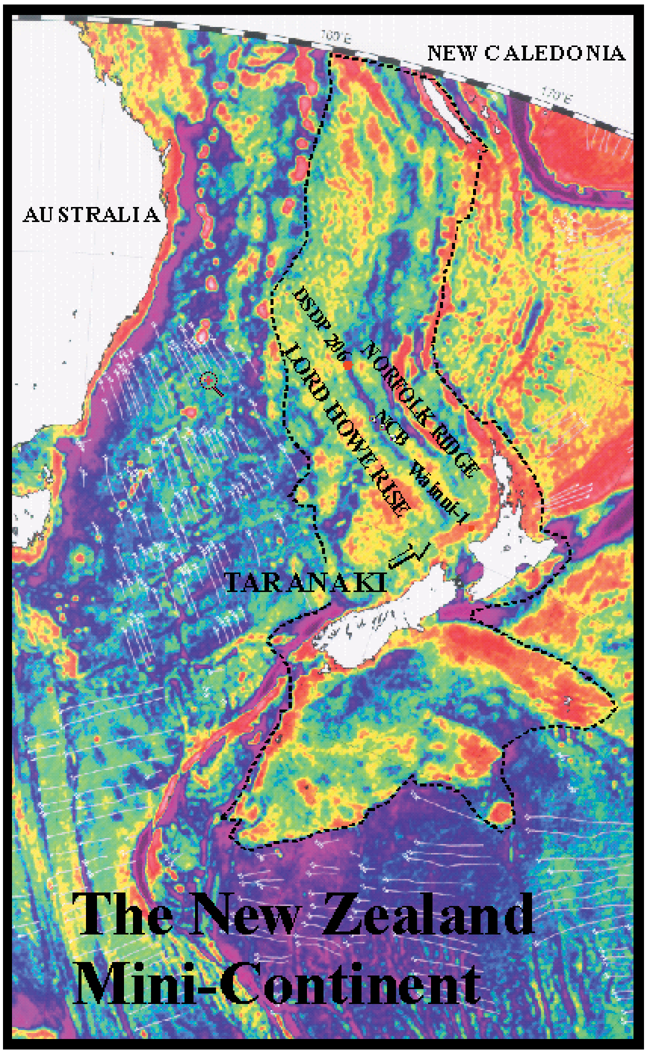

Figure 1: Gravity anomalies of the New Zealand region. Lambert conformal conic projection. The extent of the New Zealand mini-continent is shown by the dashed black outline. **NCB** is the New Caledonia Basin. The locations of wells Wainui-1 and DSDP 206 are shown. Map after Sutherland (1996).

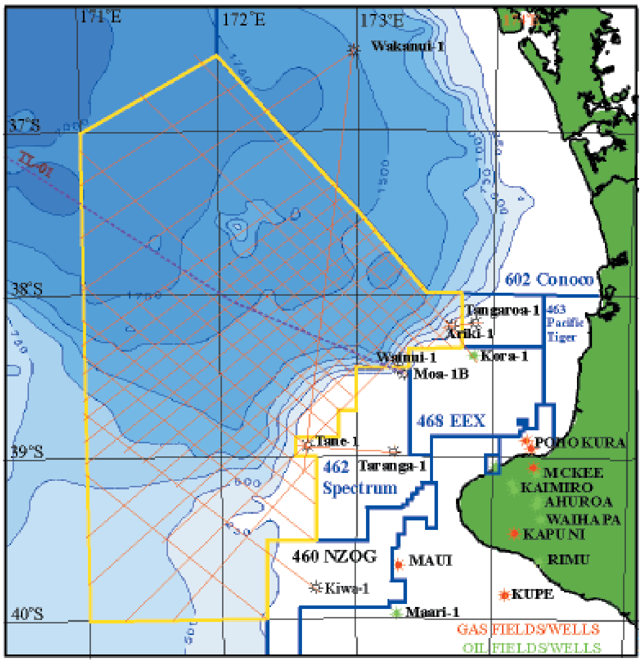

Figure 2: Deepwater Taranaki Basin. The yellow polygon is Petroleum Prospecting Permit 38467 with survey tracks in red. The earlier seismic line TL-01 is marked as are the wells the survey will be tied to. Adjacent exploration licenses and their operators are shown in blue and discovery wells are coloured green or red for oil and gas respectively.

In that year, as an adjunct to a joint Australia and New Zealand project, a single 1000 km seismic line was acquired. Line TL-01, owned jointly by Geoscience Australia (formerly AGSO) and Land Information New Zealand (LINZ) started from the Wainui-1 well near the Taranaki shelf edge and ran along the axis of the New Caledonia Basin to finish at DSDP well 206 (Fig. 1). This paper is concerned with the New Zealand end of the New Caledonia Basin, in particular, the part adjacent to New Zealand's only producing basin to date, Taranaki. The Deepwater Taranaki Basin (Fig. 2) extends from the shelf edge, at depths of approximately 200 m to water depths of 1800 metres some 200 km to the northwest. In March 2001, TGS-NOPEC acquired Petroleum Prospecting Permit (PPP) 38 476 over an area of approximately 60,000 km^2, entirely within New Zealand's EEZ, in order to acquire a 7000 km non-exclusive 2D seismic survey.

TGS-NOPEC and the Institute of Geological and Nuclear Sciences (GNS) planned the 2D reconnaissance survey of the Deepwater Taranaki Basin on a basic 10 km grid over much of the PPP. In water depths beyond 1500 m and in the southern sector of the area the grid is much wider. In the latter region, known sedimentary section amounts to only 2 seconds or so, although a thicker section is suspected to lie below a volcanic layer. The survey is timed to coordinate with a block release by the New Zealand government in mid-2002. The vessel "Polar Duke" was chosen to acquire the data. Nine wells near the Taranaki shelf edge and in the adjacent Northland Basin are tied by the survey, which started in April 2001. Although poor weather conditions were common, survey specifications were not relaxed and a total of 6208 km of high-quality data was acquired by mid-April 2001 when the survey was stopped due to the vessel's commitments. The data package was then processed by Western-Geco in Perth to pre-stack time migration and early results are very encouraging.

Origin of the New Caledonia Basin

Before the break-up of Gondwana, the New Zealand mini-continent formed the seaboard margin of the super-continent (Fig. 3). The ancient Pacific plate was being subducted below the super-continent's margin, putting the New Caledonia Basin in the location that would be occupied by a back-arc basin. The structural origin therefore may have been as a back-arc basin, perhaps in the Jurassic or earlier. Late Cretaceous rifting was widespread in the New Zealand region, with very few parts unaffected. It is highly likely that the New Caledonia Basin too was subject to Late Cretaceous rifting and, if the basin did not already exist, it must have been initiated at this time.

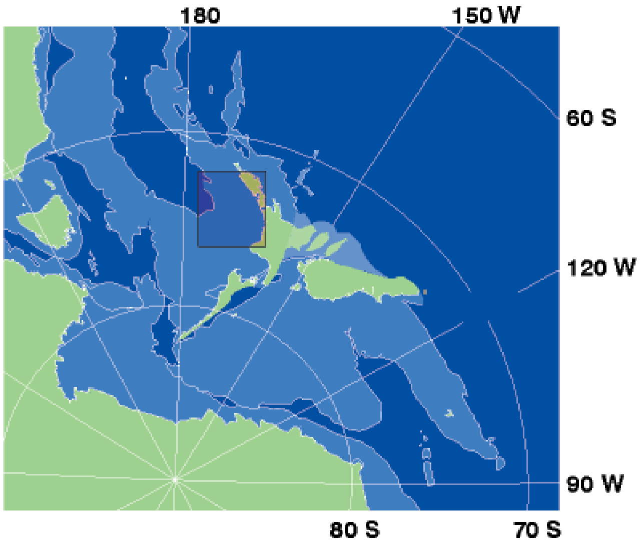

Figure 3: Shows the configuration of the New Zealand mini-continent 100 million years ago. The Taranaki area is highlighted.

The petroleum geology of most of New Zealand's basins is considered to have begun in the Late Cretaceous as the New Zealand mini-continent was rifted first from Antarctica and then from Australia. Many source rocks were deposited at that time in coal basins, particularly in the Taranaki region (King and Thrasher, 1996). Following rifting and ocean spreading, the New Zealand landmass gradually subsided, until, in the Oligocene, very little remained above sea level. Consequently, New Zealand's sedimentary record, though complete through the Paleogene, is generally very thin. However, rich potential source rocks were deposited around the New Zealand region during the Paleogene, as were reservoir units for the major Taranaki fields such as Maui, Kapuni and Pohokura.

The present plate boundary was initiated at the end of the Paleogene and is complex. It includes southwestward subduction of the Pacific Plate below North Island, northeastward subduction of the Australian Plate below the southern end of South Island and a 600 km long strike slip boundary offsetting the two trenches and causing gradual convergence of the two systems. Abundant sealing mudstone, reservoir sandstones and limestones of many facies were deposited during the Neogene. In addition, the complex tectonics of the developing plate boundary formed many structures capable of receiving charge from the maturing source rocks.

Satellite gravity

The satellite gravity map of the region (Fig. 1) shows a variety of features. A large high trends northeast-southwest along the Taranaki Shelf. This area is known to contain approximately 5000 m of sedimentary section and a typically rifted granitic basement. The high is generated by the 2000 to 3000 m thick Pliocene to Recent prograding basin margin succession, called the Giant Foresets Formation. The strength of the Taranaki crust has maintained the shelf sediments out of isostatic equilibrium, thus masking the signature of the thick low-density sediments of the region. The adjacent Deepwater Taranaki Basin is broadly outlined by a set of linear northwest-southeast trending anomalies. Highs follow the trends of the Norfolk Ridge and the Lord Howe Rise, which together form the opposing flanks of the broad New Caledonia Basin. The bathymetric axis of the basin is also occupied by a broad high, which represents either the effects of near-surface mantle material below thinned crust or a southeastern prolongation of the West Norfolk Ridge into the area. In the first case, the gravity high masks the low density contribution of a thick accumulation of sediments.

Deepwater Taranaki

The Deepwater Taranaki Basin is defined as the extension of the Taranaki Basin from the shelf edge to the 2000 m isobath. Line TL-01 (Fig. 4) runs from Wainui-1 on the Taranaki shelf edge along the axis of the New Caledonia Basin. Considering the unpromisingly high gravity anomaly along the axis of the New Caledonia Basin, the Deepwater Taranaki segment came as a pleasant surprise. Basement is poorly imaged at approximately 8 seconds two-way time (twt). Using stacking velocities, this gives a total depth to basement of approximately 11.5 km, or a total sediment thickness of 9000 m in a water depth of 1500 m.

Following the distinctive top Cretaceous reflector into the basin from the Wainui-1 well, it became apparent that the Cretaceous, and possibly older, succession is about 5000 m thick. This figure is equivalent to the average total sediment thickness of the onshore and shallow water Taranaki Basin.

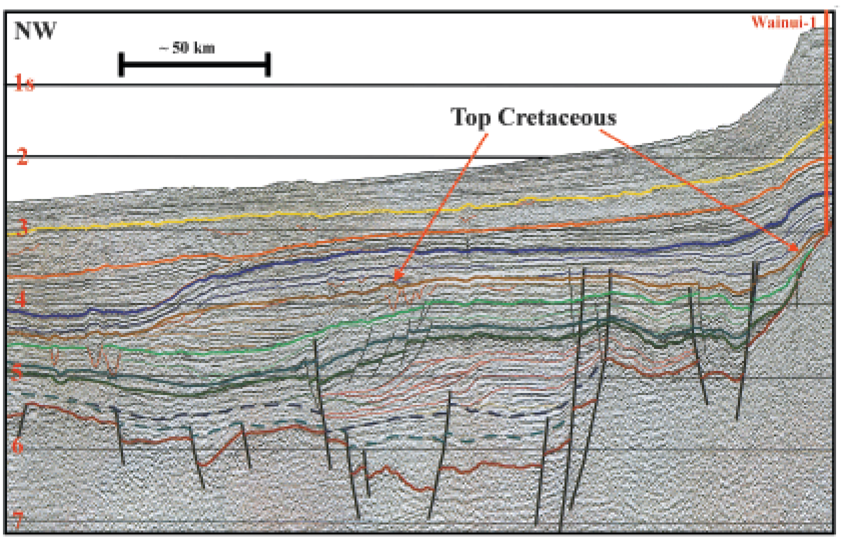

Figure 4: Part of seismic line TL-01 across the Deepwater Taranaki Basin. The Wainui-1 well at the edge of the Taranaki Shelf is indicated at the right hand end. Reflectors tied to the well are; top Miocene (yellow), Top Middle Miocene (orange), near Top Oligocene (dark blue), Top Cretaceous (brown). Other reflectors are believed to be of Cretaceous age, although older units are not precluded.

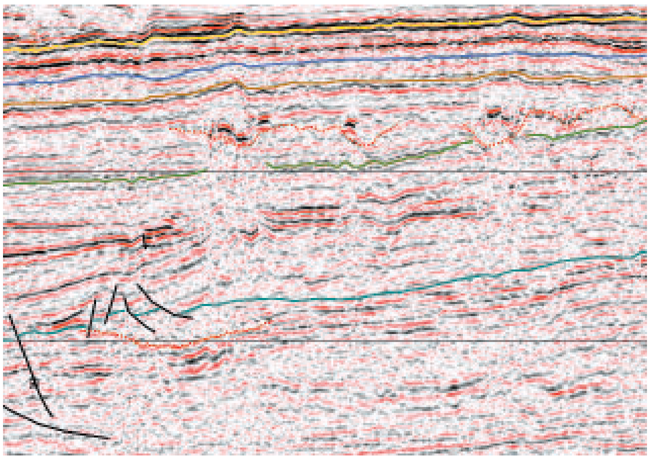

Figure 5: Panel from seismic line TL-01 showing the prograding facies interpreted as a delta, overlying blocky coal measure facies and the later shingled units. The panel is approximately 50 km long.

Sequence stratigraphy of the Cretaceous Section

The basal unit (Fig. 5) of the Cretaceous section is a mounded, but otherwise characterless unit that is poorly imaged. Above this unit is a sequence prograding apparently to the northwestward, away from the New Zealand landmass and along the axis of the New Caledonia Basin. The topset unit of the later part of the sequence consists of high amplitude, blocky and discontinuous reflectors typical of coaly facies seen elsewhere in Taranaki. The prograding unit is interpreted here as a delta approximately 100 km long and 2000 m thick.

Seawards of the delta are deeper water sediments that may contain black shales. The reasoning for this is that a probable coaly delta had been distributing sediments into a restricted seaway, possibly as long ago as the Jurassic, but definitely during part of the Late Cretaceous, both periods when rich source rocks were deposited around the world.

Overlying the early delta are thin shingled units (Fig. 5) that may have recorded episodic rapid transgressions that forced the delta to build from further to the southeast. A second transgression eventually truncated the new delta, leaving only the delta front sands in place. These rapid transgressions may have been tectonic in origin.

The remaining Late Cretaceous section is the thick lateral equivalent of the thin unit tested by the Wainui-1 well. A marine influence was suggested for the Late Cretaceous, coal-measure sediments in the well (SBPT, 1982). The recognition of turbidite fans within the latest Cretaceous of the Deepwater Taranaki Basin gives confidence in the interpretation of this unit as a marine succession.

In many basins surrounding New Zealand, black marine shale of Paleocene age is recognised. In particular, it has been recognized and mapped in the adjacent Northland Basin (Isaac and others, 1994). It is highly likely that it is present also in the Deepwater Taranaki Basin. Where this unit is mature, it may be expelling oil to be trapped in possible overlying sandstones of Eocene age. These marine equivalents of the Kapuni Group form the reservoirs for the Kapuni field and the giant Maui field that has been the mainstay of the New Zealand petroleum industry for many years.

Petroleum systems

Two possible petroleum systems are envisaged. The older is the Late Cretaceous system sourced by the early delta and its possible offshore time equivalent black shales. Petroleum was generated from these sources in the center of the basin during the latest Cretaceous and Paleogene. Near the flanks of the basin, where crustal thicknesses are greater, heat flow is lower and the units may be shallower, generation and expulsion would have been delayed. Reservoirs are expected to be Late Cretaceous turbidite fans or, possibly shoreface or delta front sands. At least one turbidite mound displays a high amplitude seismic anomaly (Fig. 5).

In the younger of the two petroleum systems the Paleogene system, petroleum may have been generated from the Paleocene black shale to migrate into the overlying Eocene sands. These are also expected to be turbidite fans, the seaward equivalents of the terrestrial Kapuni reservoirs of nearshore Taranaki. Some evidence is emerging of minor inversion, possible in the Eocene. This event may have provided a late heat pulse that may have brought more of the system into the oil window.

Oil or gas?

Following the discovery of the onshore Kapuni gas and condensate field in the 1950s and the giant Maui gas and condensate field in the 1970s, the industry tended to the belief that Taranaki is gas prone and it has therefore not been a popular exploration venue. Several lines of evidence suggest that the Deepwater Taranaki Basin should be oil prone rather than gas prone. The first is that the shallow water and onshore basin is now seen as more oil prone than previously. This is due to an oil trend in the onshore overthrust zone, the Kaimiro and Ngatoro oilfields in northern onshore Taranaki, the recent offshore discoveries of an oil leg in the Maui field, the Maari discovery in 1999 and the more recent Rimu discovery in 2000. Even the new Pohokura gas field has a significant condensate content in that the volumes of condensate alone may be great enough to cover the cost of field development.

The second line of reasoning is based on the seismic stratigraphy outlined above. The increased marine influence implied by the delta interpretation and the known oil-proneness of deltas around the world increases confidence that the Deepwater Taranaki Basin is oil prone. In addition, the inferred restricted seaway increases the chances of widespread organic rich shales being deposited.

Finally, we have the age of the early delta. From Wainui-1 we know that the delta lies in the lower part of the Cretaceous and possibly older succession. More than half of the known oil accumulations in the world were sourced from rocks deposited during the Jurassic and Cretaceous.

New data

Having based the entire argument so far on one seismic line, TL-01, the question arises as to how far the new data either confirms those arguments or otherwise. First, does the new data confirm the thickness of the Late Cretaceous depocentre and how extensive is it? Second, is there further evidence to support interpretation of the seismic facies described above and finally, what does the new data have to say about petroleum potential and the presence or absence of petroleum systems? Although it is early in the interpretation phase, it is possible to say that an extensive, thick depocentre does indeed exist and that all of the features described on line TL-01 are confirmed by the new data. Some panels from the new data will be shown at the conference and all of the data is available for viewing at TGS-NOPEC offices in Perth, Houston and London.

Petroleum potential assessments

Three methods have been used to calculate volumes of petroleum that may have been generated and trapped in the Deepwater Taranaki Basin, each of these is a rough estimate based on several assumptions and estimates. These include heat flow history, nature and history of the source rocks and rates of burial.

The first method is based on area and average generation figures. The assumptions made here are that the source rocks are similar to those in the neashore and onshore Taranaki Basin and therefore give a lower limit as we believe the source rocks in Deepwater Taranaki Basin to be more oil prone and probably richer. Workers at GNS have calculated the average petroleum generation potential of the 80,000 km^2 shallow water and onshore Taranaki Basin to be approximately 22 million barrels per square kilometre (Funnell, pers. com.). This includes regions with no source rock and where sediment cover is too thin for generation to occur and is limited to Cretaceous source rocks. If this figure is applied to the 60,000 square kilometres of the Deepwater Taranaki Basin, a total of 1,320 billion barrels may have been generated. If 1% of this is trapped, there may be 13 billion barrels of oil awaiting discovery.

The second method is based on volumes of source rock units. We recognise two potential source rocks in the Deepwater Taranaki Basin; the early delta and marine mudstone of a similar age. In considering the early delta as a potential source rock, it is known to be approximately 100 km long. From gravity modelling (Wood and Woodward, 2001, in press) it appears that the early delta may be 100 km across. If we assume, it is 2000 m thick on average, it has a total volume of 20,000 cubic kilometres. Assuming an average ToC of 2% the total volume of organic carbon is 400 cubic kilometres. If 25% of this is transformed to oil, a total of 100 cubic kilometres of oil may have been generated from the delta facies. Assuming 1% of the oil generated is trapped, there may be 1 x 10^9 cubic metres, or 6 billion barrels of oil waiting to be discovered. However, there are potential black marine shales for which similar calculations may be made. Although, at this time we do not know the total extent of these facies, or if they are mature, we expect that they cover much of the 60,000 km^2 of the survey area and may add a considerable contribution to the total oil generated and trapped.

The third method addresses bulk volumes. Wood and Woodward (2001) estimated that approximately 35,000 cubic kilometres of rock is mature for oil at the present day within the Deepwater Taranaki Basin. Funnell (2001) estimates that source rocks in the nearshore and onshore Taranaki Basin have yielded 220 million barrels of oil equivalent (BOE) for every cubic kilometre. Assuming the same productivity, Deepwater Taranaki could have generated some 7,700 billion BOE.

The end result of all of this calculation, admittedly on very little data and making sweeping assumptions, is that a very large volume of oil may have been generated in the basin. The general lack of Neogene tectonic activity further suggests that the basin should be relatively efficient at trapping the petroleum generated. We hazard a guess that the Deepwater Taranaki Basin may contain as much as 20 billion barrels of trapped oil.

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