Petroleum potential of New Zealand's deepwater basins

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Abstract

The New Zealand Exclusive Economic Zone (EEZ) contains at least six large deepwater basins (Figure 1): the head of the New Caledonia Basin, the Raukumara Basin, the Pegasus Basin, the head of the Bounty Trough, the Great South Basin and the Solander Trough. Structural styles vary from rift basins through strike-slip dominated basins to major accretionary prisms. Source rocks encountered 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 these basins may one day be prolific hydrocarbon producers.

The petroleum histories of most of these basins began with the Late Cretaceous break-up of Gondwana and the formation of rift basins. In onshore New Zealand and on the continental shelf, many of the source rocks for the productive Taranaki Basin 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 Neogene saw the formation of the present plate boundary and the emergence of New Zealand in response to plate collision. Many of the more spectacular structures in the New Zealand sedimentary basins were formed during the Neogene. Meanwhile, the deepwater basins away from the plate margin continued a quieter development. Some inversion did occur, 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.

Introduction

Scientific papers are usually about the results generated during research, but this paper is speculative and intended to help stimulate more thorough work in the deepwater regions of the New Zealand Exclusive Economic Zone (EEZ). Preliminary results presented here are firstly from the reconnaissance surveys of the EEZ carried out by the Institute of Geological and Nuclear Sciences (GNS) and its founder organisations. These were the New Zealand Geological Survey and more importantly, Geophysics Division of the Department of Scientific and Industrial Research (DSIR) and then DSIR Geology and Geophysics. The reconnaissance surveys were accomplished with a tiny budget and small and obsolete seismic systems and other geophysical instruments held together mainly by Kiwi ingenuity.

One of the most important results of these reconnaissance surveys was that the geographical extents of the sedimentary basins of the EEZ became largely known. The mainly single-fold seismic data had revealed the locations of the sedimentary basins but gave clues only to the upper part of the sedimentary succession. The sedimentary thicknesses, structure and evolution of the basins were largely matters for speculation.

An added dimension was provided by a few deep seismic lines, shot to study deep crustal structure. The first of these was a line acquired jointly by the United States Geological Survey (USGS) and DSIR across the East Coast accretionary prism. Then followed two lines across Taranaki, one from the Bay of Plenty as far as the Pacific ocean crust to the east and one from Cook Strait to the Chatham Rise. The South Island Geophysical Traverse (SIGHT) acquired lines from both sides of South Island and across the Solander Basin from Stewart Island to the Australian ocean crust. Finally, one line, owned jointly by the Australian Geological Survey Organisation (AGSO) and Land Information New Zealand (LINZ) from the Taranaki shelf along the axis of the New Caledonia Basin. All of these 2D seismic lines were shot with large air gun arrays up to 5000 cubic inches on long streamers up to 5000 m and were recorded to at least 12 seconds and generally to 16.

Nearly every one of these seismic lines showed new and sometimes surprising information on the deepwater sedimentary basins within New Zealand's EEZ. The rest of this paper describes some of these results.

Raukumara Basin

The Cretaceous and Tertiary sediments of the northern Coast of the Raukumara Peninsula mark the margin of the Raukumara Basin (Kingma, 1965) and its extent can be partially gauged from gravity data (Davy, 1995) which shows

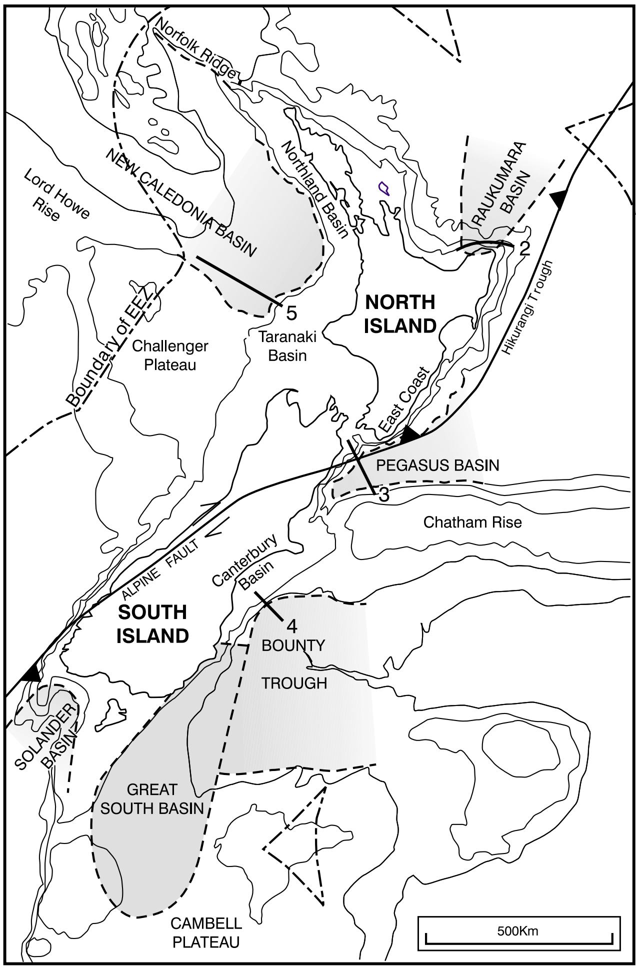

Figure 1: Deepwater basins of the New Zealand EEZ showing the main bathymetric features. The EEZ boundary is a short-long dashed line, and bathymetry at 500, 1000 and 2000 m is show. The present plate boundary is shown as are the sedimentary basins that are the subjects of this paper.

a 160 milligal low extending offshore to the north. Using single-fold seismic reflection and sono-buoy refraction data, Gillies and Davey (1986) showed that the Raukumara Basin covers atl east 20,000 km^2 (and perhaps as much as 60,000) with a thickness of at least 4000 m of sediments. In 1990, a 250 km long seismic profile was acquired from the Bay of Plenty, across the northern end of the Raukumara Peninsula (Figure 2), though the accretionary prism and on to the subducting Pacific plate (Davey, Henrys and Lodolo, 1995). This profile was recorded to 16 seconds two-way time (TWT) and it shows layered sedimentary reflectors to approximately 8 seconds TWT or 13 km in the Raukumara Basin.

Although several unconformities are seen, few faults have been recognised and stratigraphy is largely unknown, although correlations with onshore section suggest that Cretaceous sediments probably occur at depth and are overlain by a great thickness of Tertiary sediments. Despite a complex tectonic history, few structures are observed on this line, apart from large-scale basin sag and several relatively recent faults.

Petroleum source rocks of Cretaceous and Paleocene ages may be present and the subsequent marine history of the region may have supplied sandstones as reservoirs. Traps are more problematical and may be stratigraphic for the most part, although the single line is not definitive, and there may be more traditional structural traps in other parts of the basin.

Pegasus Basin

The angle between the East Coast accretionary wedge and the Chatham Rise is filled with approximately 4 seconds of Neogene sediments, which overlie a Cretaceous and Paleogene succession (Barnes and others, 1998). Although several single and low-fold seismic profiles had been acquired from the area, it was not until 1991, when a seismic line, shot as part of a program to investigate deep crustal structure, imaged the great thickness of sediments (Field, Uruski and others, 1997).

The seismic line (Figure 3) crossed from Cook Strait to Mernoo Bank on the Chatham Rise to image a broad half-graben thinning to the southeast. This basin occupies the transition zone where the motion of the obliquely subducting Pacific Plate is transformed to strike-slip faulting along the spine of the Southern Alps, the Alpine Fault.

The basin covers an area of at least 50,000 km^2 and probably contains all of the ingredients for petroleum generation and trapping. Source rocks of Cretaceous and Paleocene ages are probably present at a depth likely to generate hydrocarbons. Thrusting is transmitted from the subducting plate to the overlying sediments, forming rollover anticlines. Two large structures are seen; a back-thrust formed a landward-verging anticline below the shelf terrace in the northwest and an anticline underlies the northwestern edge of the Hikurangi Channel in the centre of the basin. Much of the Neogene sediment is likely to be turbiditic and sandstones should be common.

A prominent bottom-simulating reflector is visible along much of this section and amplitude anomalies are present below it, suggesting that the gas-hydrate layer acts as a cap rock trapping hydrocarbons in reservoir beds below.

Head of Bounty Trough

The possible existence of a thick sedimentary sequence in the head of the Bounty Trough is based on the geography of the Bounty Trough itself and on several seismic lines that image nearly 4 seconds TWT of sedimentary rocks below the Canterbury Slope (Figure 4). The geographical argument is that plate reconstructions invariably align the Bounty Trough with the New Caledonia Basin, known to contain large thicknesses of sedimentary rocks and the relatively flat seabed. The Bounty Channel system, easily seen in the bathymetry (Figure 1), is a distriburtary system that suggests some thickness of sedimentary deposits.

Davy (1993) reviewed the current knowledge of the Bounty Trough and he observed more than 3 seconds TWT of sedimentary fill below the Canterbury slope on single-channel seismic lines, some of them very old. This rift basin, with an

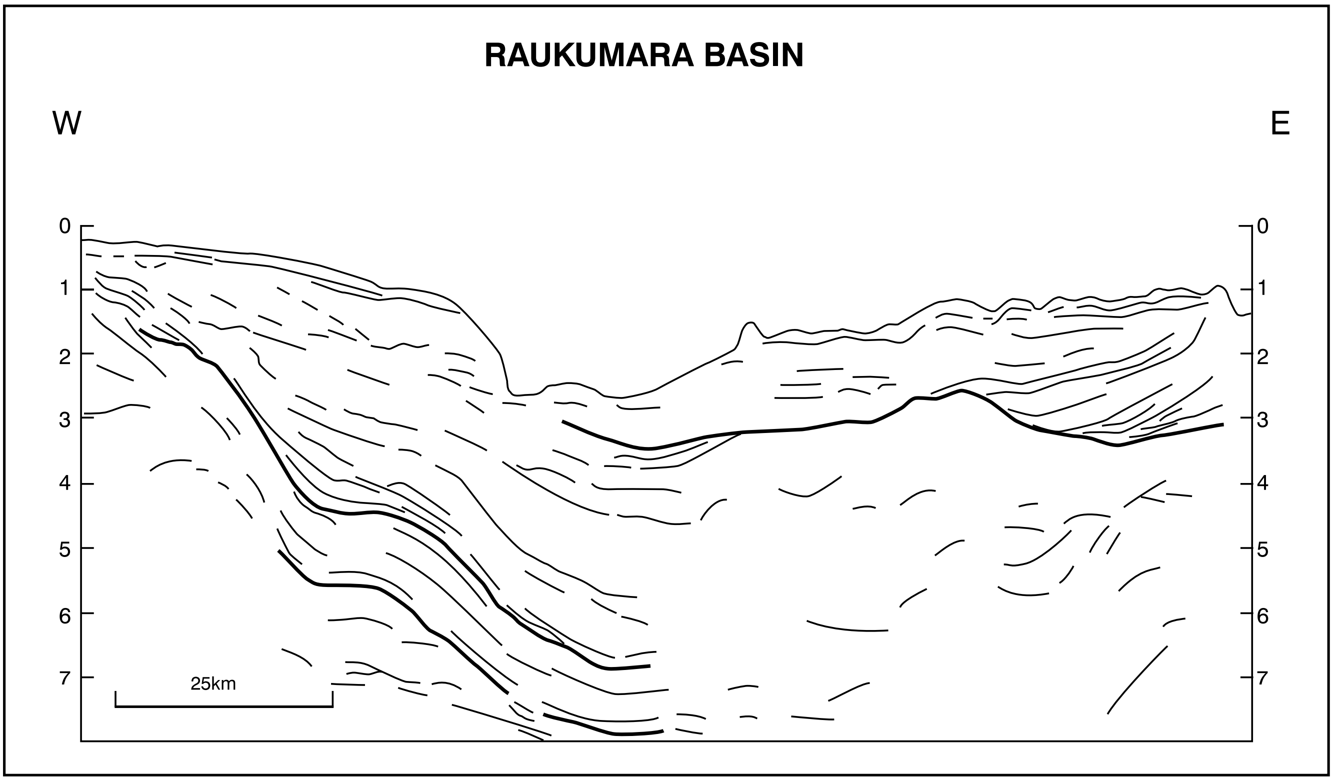

Figure 2: Line drawing of a vertically exaggerated, 130 km long seismic section across the Raukumara Basin. Davey and other (1995) calculated a total depth of 13,000 m to the lowermost bold reflector at nearly 8 seconds TWT near the centre of the section. The geology of this basin is largely unknown, but such large sedimentary successions have great potential for hydrocarbon exploration. For location, see Figure 1.

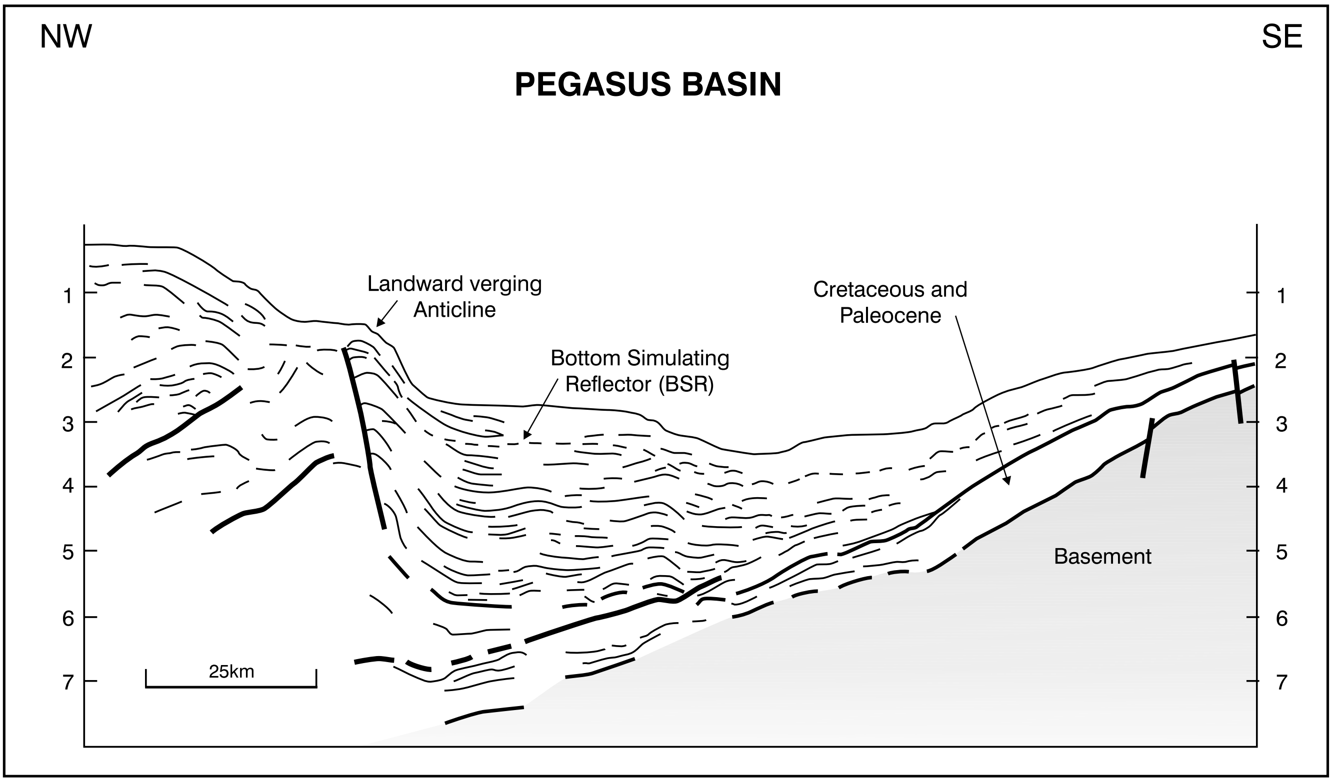

Figure 3: Line drawing of seismic line across the Pegasus Basin. This seismic line is approximately 170 km long and crosses the Pegasus Basin containing more than 5 seconds TWT of sedimentary reflectors. Structure is complex with a sole thrust exploiting a ramp formed by older rocks deposited on the Chatham Rise basement and forming several anticlines. One anticline verges landwards on a back trust. A bottom-simulating reflector (BSR) crosses much of the section at a depth of from 500 to 950 milliseconds below the seabed and in many places acts as an upper boundary to amplitude anomalies. These suggest the presence of hydrocarbons in traps capped by the gas-hydrate of the BSR. For location, see Figure 1.

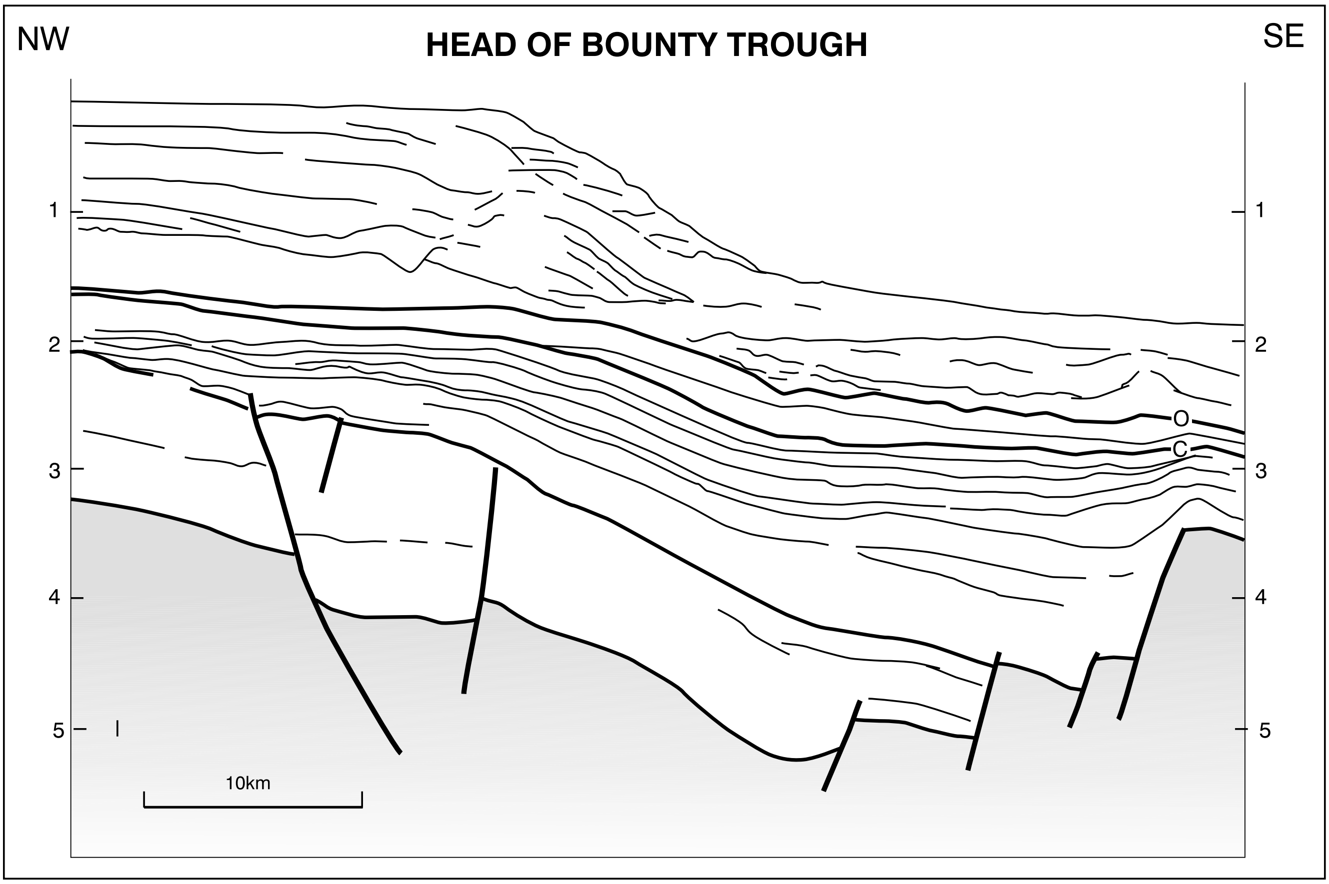

Figure 4: Line drawing of seismic line across the head of the Bounty Trough. More than 3 seconds TWT of sediments characterise the head of the Bounty Trough. The basement appears to be rifted with the large "Ben Reoch High" at the southeastern end of the line. C marks the top of the Cretaceous and O is the top Oligocene. For location, see Figure 1.

area of at least 100,000 km^2, is worthy of a closer look as rare high-fold, high-power seismic data reveals a greater thickness of sediments than are recognised on single-fold lines.

Great South Basin

The Great South Basin is one of the better known of New Zealand's deepwater basins having been explored during the 1970s and 1980s (Cook and others, 1999). More than 30,000 km of 2D seismic data was acquired from this basin (Figure 5) and eight wells were drilled between 1976 and 1984. Of these, four wells had shows of oil and gas. The basin covers an area of approximately 150,000 km^2 and water depths range from 500 to more than 1000 m. The Great South Basin contains more than 8000 m of sedimentary rock in places, of which the Tertiary accounts for up to 2500 m.

The Great South Basin is essentially a Cretaceous rift basin and source rocks include Cretaceous coal measures and Paleocene black marine shale. Reservoirs are likely to be sandstones of various ages and range from coastal plain sands of lowermost Cretaceous to fan sands of Tertiary ages. Traps are generally those associated with a rift basin, such as fault and drape structures, although the northwest part of the basin was affected by Tertiary shortening and some anticlines were formed by this later tectonism. Petroleum potential for this basin is excellent with known generation and a drill stem test of Kawau-1A that yielded 6.8 mmcf per day of gas with some condensate. Sutherland (2000, this volume) covers the Great South Basin more fully.

Solander Basin

The Solander Basin is the offshore extension of the Western Southland basins. The offshore has been explored lightly with some 4000 km of 2D seismic data and two wells, Parara-1, drilled in 1976 and Solander-1 drilled in 1986. Parara-1 encountered "dead" oil in the target Eocene sandstones, but Solander-1 was dry.

Earlier authors (Turnbull, Uruski and others, 1993) suggested that the offshore basin extends into deeper water, but until recently, little data was available. A seismic line, again acquired for deep crustal studies extends from south of Stewart Island and across the deepwater Solander Basin to the Puysegur Ridge accretionary prism and beyond to the Pacific Plate ocean crust. This line was interpreted and published by Melhuish and others (1999).

The Solander Basin was initiated as a rift basin during the Cretaceous break-up of Gondwana. Extensional faulting was renewed in the Eocene, probably as a result of transtensional strike-slip faulting. As the pole of rotation of the Pacific Plate with respect to the Australian Plate moved southwards, the transtensional movement gradually went through pure strike slip and eventually, in the mid-Oligocene, to transpressional. At this time several splays started riding up

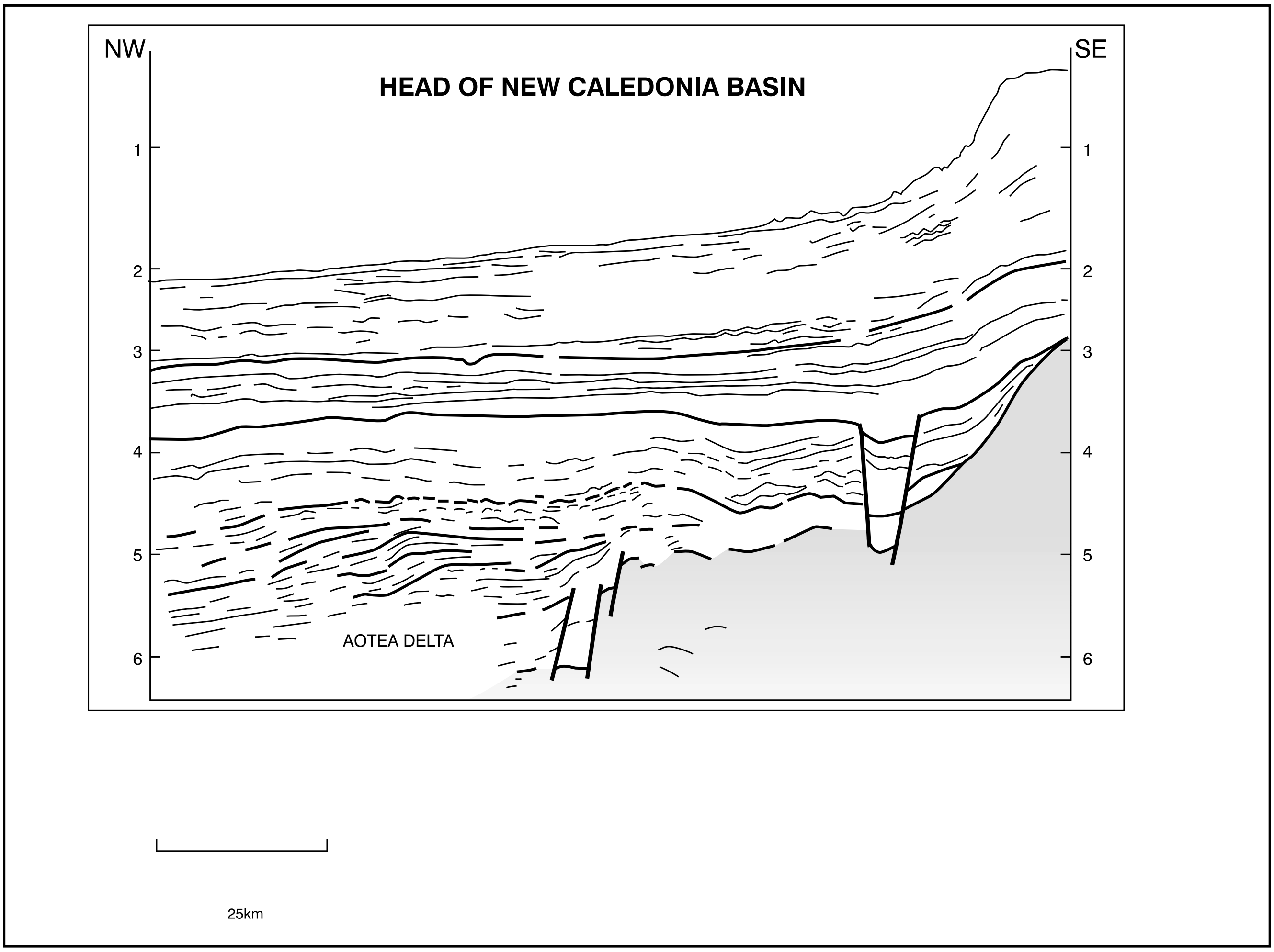

Figure 5: Line drawing of seismic line along the axis of the head of the New Caledonia Basin. This section is 210 km long and runs northwest from the Taranaki shelf edge. The well Wainui-1 was drilled near the shelf edge, penetrating the top Oligocene reflector near 2 seconds and a thin Cretaceous unit overlying granitic basement near 3 seconds. The basement is faulted and some of the faults extend into the Paleogene section. Seismic velocities show that the succession below the top Cretaceous reflector is at least 5000 m thick in the northwestern half of the section. The unit about 5 seconds TWT progrades and is topped by a broken high-amplitude unit. It is interpreted here as a delta. Equivalents of this thick basal unit are not recognised elsewhere in New Zealand although Conoco have reported an a similar section in Northland. For location, see Figure 1.

the main strike-slip fault becoming the large basement thrust ridges of the present-day Takitimu Mountains and Hump Ridge.

Deposition during the Cretaceous was terrestrial and included lacustrine deltaic units and coal measures. No Paleocene rocks are known, but there remains a possibility that Paleocene black shales may be present as they are in the Great South Basin, Campbell Island, the East Coast and Northland basins. A marine transgression characterises the Eocene and marine sediments were deposited during the Oligocene. A carbon-rich lacustrine unit was deposited near the present-day shore and was produced as an oil shale during world war one. Neogene units include limestones and both calcareous and clastic turbidites. Tectonic uplift resulted in a relative lowering of sea level from the late Miocene onwards. During the Pliocene, several volcanic bodies were extruded to the seabed and the most recent is Solander Island, a Pleistocene volcano.

All of the conditions for petroleum generation and trapping are present in this basin which covers an area of more than 40,000 km^2. Source rocks include the Cretaceous coals and lacustrine deposits, a possible Paleocene black shale and Late Eocene to early Oligocene Lacustrine units. Reservoirs are likely to be sandstones of terrestrial to deep marine units and marine mudstones are common and a likely regional seal. Structures include drape over rift blocks and many spectacular anticlines formed by the Neogene transpressional regime.

Head of the New Caledonia Basin

The Taranaki Basin is still New Zealand's only producing basin, but beyond the Taranaki shelf edge lies the New Caledonia Basin, a bathymetric depression that extends some 2000 km to New Caledonia. The New Caledonia Basin is more than 150 km wide and lies between the Lord Howe Rise and the Norfolk Ridge. The head of the New Caledonia Basin lies west of the Taranaki Basin and is completely within the New Zealand EEZ. In its centre is the large Aotea Seamount which lies approximately 100 km northwest of the Taranaki shelf edge.

A small volume of industry seismic data was acquired from the region in the 1970s and the forerunner organisations of GNS acquired a single-channel seismic survey in 1989. Uruski and Wood (1991) showed that sedimentary reflectors were apparent as far as could be imaged with their single channel system and suggested that basement might lie considerably deeper than 3 seconds TWT.

In 1997, after a survey to delineate the New Zealand claim for Legal Continental Shelf, the AGSO vessel Rig Seismic acquired a single 1000 km-long seismic line. The line shot along the axis of the New Caledonia Basin from the Wainui-1 well on the Taranaki shelf edge to DSDP well 206, more than 1000 km away. The deepwater Taranaki Basin sector of this line is characterised by very thick Cretaceous, and possibly older, sediments. The basement is faulted, suggesting that the New Caledonia Basin originated, like so many of New Zealand's basins, as a rift basin. From 4 to 5 seconds TWT is a prograding unit which, considering its scale, is probably a growing marine shelf which appears to overlie the earlier rift sediments. A unit above the ancient shelf is of a broken, coaly character and a mounded body closer inshore is associated with an amplitude anomaly.

This basin, covering an area of approximately 150,000 km^2, is probably the most attractive of New Zealand's deepwater basins. The age of the early sediments is unknown, but if they were of Albian to Turonian age, they would be in a good setting to include rich, black marine shales such as comprise nearly 30% of the source for the world's known oil deposits. Paleocene black shales may also be present as in Northland. Much of the overlying succession can be broken down into unconformity-bounded, generally marine sequences with possible large excised valleys. A large variety of reservoir rocks are possible, including terrestrial and marginal marine sandstones and seabed fans.

From this single line structures appear to be large, up to 30 km across. Large stratigraphic traps are also possible. Thermal modelling (see Stagpoole and others, 2000, this volume) suggests that large quantities of oil may have been generated in this basin.

Conclusions

1. The total area of the six basins discussed here, with more than 3000 m of sedimentary rock and within the 2000 m isobath, amounts to 550,000 km^2 or 15% of the area of New Zealand's EEZ.
2. The minimum volume of sedimentary rock in these basins is 1.2 million cubic kilometres.
3. In addition to these six basins there are other basins, less well-known, for example, part of the Reinga Basin (Herzer and others, 1997) is within the New Zealand EEZ and a basin has recently been discovered to the north of Northland.
4. Using figures derived from GNS thermal modelling in Taranaki, the deepwater basins within New Zealand's EEZ are capable of generating at least 24x10^{12} barrels of oil.
5. How much remains trapped and available for discovery?

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