Old data, new opportunities in New Zealand's West Coast basins

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Abstract

For the last 15 years, depressed oil prices have moved exploration efforts away from frontier basins. In the current setting of OPEC solidarity and political instability in producing countries, it is time to take a fresh look at under-explored basins in favorable geologic environments, especially those in politically stable areas.

New Zealand's West Coast basins share similarities in source and reservoir systems with the Gippsland Basin of Australia. Satellite altimetry maps delineate the rift basin geometry of the Tasman Rift System, which created the environment for deposition of source and reservoir rocks of the productive Gippsland and Taranaki basins, as well as the West Coast basins.

Although seismic lines in most of the West Coast basins are sparse and thirty years old, modern reprocessing reveals much more geological information than the originals, including areas where the rift sediments are deeply buried. Thermal maturation models indicate that rift sediments are in the oil expulsion window in one of these basins. Soil gas samples taken directly onshore of one basin confirm that hydrocarbons are seeping to the surface.

Gravity models contain uncertainties that leave room for a significant wedge of rift sediment. With few exceptions, the old seismic data do not image primary events below the rift unconformity reflection. They do, however, indicate multiple, stacked basin-axis turbidite sand accumulations directly above the hydrocarbon kitchen. The remaining unanswered question is whether rift sediments are present in large enough volumes to charge giant traps. The current evidence includes:

- extensive occurrences of thermally mature source rocks onshore
- absence of a major geologic discontinuity between the onshore and the offshore sub-basins
- oil and gas seeping to the surface in numerous places onshore
- absence of negative evidence on seismic and gravity data and offshore wells.

Thomasson International Ventures believes that the offshore South Westland basins have promise for world-class giant oilfields.

Introduction

Limited budgets, fluctuating prices, and attractive acquisition economics dominated exploration strategies of the last fifteen years. In this setting, New Zealand's West Coast basins were not competitive with South America and the Middle East. Exploration was more and more focused on proven productive basins. Now, in the present climate of OPEC solidarity and Middle East political instability and nationalism, competition is rising for new frontier exploration opportunities. It is once more important to take a close look what is not known about long-dormant, under-evaluated areas, especially in politically stable regions.

During the last ten years, New Zealand has stimulated exploration in non-producing areas by attracting independents simply by providing four critical elements:

- workable terms for securing exploration permits with very attractive tax structures

- an organized information system including a world-class geological survey, and exploration data acquired by past Permit holders made available for the cost of reproduction
- a large continental margin and tectonic foreland geologic settings
- geologically attractive, under-explored basins.

The Acceptable Frontier Offer and New Zealand's tax and royalty scheme are known to be among the best in the world. The exploration database managed by the Ministry of Economic Development is a valuable national resource. Even thirty-year-old seismic data can reveal areas of interest.

The Taranaki Basin, the Gippsland Basin, and the West Coast basins of South Island share similar source and reservoir rocks, referred to by the authors as the Tasman Rift Sequence. Mobil Oil, Esso Exploration, and Gulf Oil acquired seismic data along the West Coast following the late 1960's discoveries in the Gippsland Basin, and Maui Field in the Taranaki Basin. No basins as large as Taranaki were imaged on the surveys and only Esso followed up with more detail. Several wells were drilled, but without success. Offshore gravity maps (Figures 1 and3) reveal several sub-basins along the West Coast, and show that the offshore wells were drilled on rift horsts between sub-basins. On each tested horst block, the rift sequence is absent or very thin. Original processing of old seismic data does not image the rift sequence in sub-basins where it has been buried deeply enough to reach thermal maturity. Gravity models neither prove nor disprove the existence of the rift sequence in the sub-basins. Yet there are faint primary reflections beneath the rift unconformity that appear similar to those seen on Taranaki Basin data of the dame vintage. Oil and gas seeps and soil gas samples taken in onshore South Westland prove that the rift sequence is expelling hydrocarbons in several areas along the western South Island.

What is not known is whether the rift sequence is present in large enough volumes to charge Maui-size traps that are visible immediately above the interpreted mature source rock. Yet to believe that the source volumes are very small would require a major tectonic discontinuity between observed extensive source rock volumes onshore and the offshore sub-basins. We believe that modern seismic data will lead to discoveries of world-class reserves in this large, untested, and very attractive region.

New Zealand is well positioned for an increase in exploration by virtue of its attractive political and geological setting, coupled with its virtually unexplored, large continental shelf. Existing gravity and seismic data, plus a few scattered wells are inadequate to define structural and stratigraphic features within the very favorable regional tectonic setting. The South Westland basins have the added attractiveness of being in the same rifted continental margin that contains the productive Gippsland and Taranaki basins. Reprocessing existing gravity and seismic data, and re-examining it in the light of more recent published studies, coupled with new fieldwork, demonstrates that the old data can reveal potential for major accumulations.

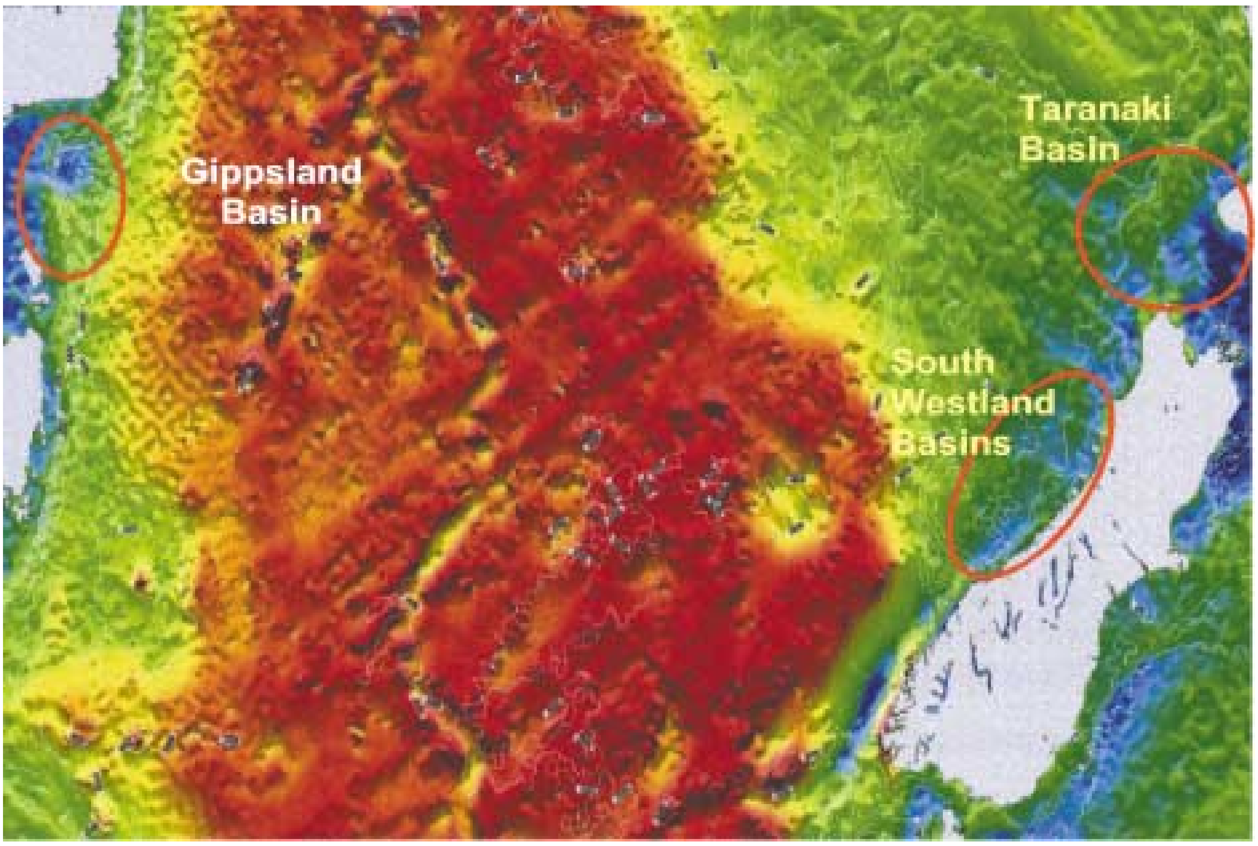

Figure 1: Tasman Rift Satellite Gravity Map

Interlude: 1975-2000

During the last ten years, New Zealand has stimulated exploration by supplying two critical elements:

- workable terms for securing exploration permits with favorable tax and royalty rates
- an organized information system including a world-class geological survey, and exploration data acquired by past Permit holders made available for the cost of reproduction.

New Zealand's tax structure, royalty and regulatory regimes have been rated among the ten most favorable in the world. The Acceptable Frontier Offer program makes it possible for independent exploration companies to benefit from doing preliminary studies in areas with excellent potential. By carrying out relatively inexpensive gravity and seismic reprocessing, as well as geochemical and petrographic studies, it is possible to define promising frontier areas and retain a production interest that justifies the costs and risks of years of research.

The Crown Minerals exploration database is a valuable national resource. Thirty-year-old seismic data has special properties that may conceal features of interest to the explorationist. Because of limited receiver offset and sensitivity, low energy sources, with the original processing and displays, much stratigraphic and even structural information is not visible, or improperly imaged. This contributed to misconceptions of the prospectivity of some highly prospective unexplored areas.

In addition, New Zealand offers a geologic setting that includes two of the most productive geological settings in the world: the outer continental shelf, and tectonic forelands. Ninety-five percent of the giant oilfields worldwide exist in these two settings. For these to coexist in a highly under-explored setting cannot be ignored for long.

Mobil Oil, Esso Exploration, and Gulf Oil acquired seismic data along the West Coast following discoveries in Gippsland and Taranaki in the late 1960s. No basins as large as the Taranaki or Gippsland were imaged on the surveys and only Esso followed up with more detail along the northern portion of the West Coast. Several wells were drilled during the following decade, but without success. Although academic geological field studies were carried out in the twenty intervening years by several New Zealand universities and the Institute for Geological and Nuclear Sciences, virtually no petroleum exploration has taken place in offshore South Westland during the interlude.

Tectonic setting of the South Westland basins

During the Late Cretaceous to Eocene, the Taranaki Basin, the Gippsland Basin, and the South Westland basins were part of the same continental margin undergoing rift faulting and crustal thinning. Satellite gravity maps of the Tasman Sea (Figure 1) clearly show the spreading center, transform faults, the continental slope, and most importantly, rift grabens oriented sub-parallel to the spreading center. Oceanic crust is shaded darkest, low gravity anomalies within the continental crust are lighter, and the continental margin is lightest. Sedimentary basins along the West Coast of South Island are visible as lighter areas.

Due to their shared history, the sedimentary basins have important similarities in source and reservoir rocks, referred to by the authors as the Tasman Rift Sequence (Figure 2). The similarity of the Late Cretaceous to Eocene rift section in these areas contrasts with the differences in the post- drift breakup Miocene to Recent section. Beginning in Miocene time, the West Coast basins went into a strongly compressional regime due to the formation of the Pacific-Australian plate boundary, expressed by the Alpine Fault on the South Island.

Applying the Bouguer correction to satellite free-air gravity maps increases the definition of low-gravity anomalies along the West Coast, which may indicate either Cretaceous-Eocene rift grabens or compressional basins formed since the Miocene (Figure 3). This interpretation also shows the offshore wells to have been drilled on gravity highs. On each tested horst block, the rift sequence is absent or very thin (Figure 4). This has contributed to the perception that the Rift Sequence is absent over most of the South Westland basins offshore. Yet the rift sequence exposed in outcrops along the West Coast at Paringa (between Haast and Harihari) indicates an estimated 3000 meters thickness immediately onshore. A map of the rift sequence in the South Westland onshore basins (Figure 5) shows that the sequence is both thick and extensive, and produces numerous oil seeps and shows in wells. There is no major geologic boundary between the rift sequence onshore, and the offshore basins: all the exposures and well penetrations are west of the Alpine Fault plate boundary.

1970s seismic data

Seismic data acquired in the early 1970s does not image the rift sequence in most areas. Hydrophone maximum offsets were 2000 meters, one third of today's, airgun volumes were 500 cubic inches (now 1500 to 1800 cu in) and pressures were 500 psi, also one third of current values. Each of these parameters directly influences acoustic penetration and resolution. Data processing methods at the time did not include crooked-line or 3D corrections, or many of the noise suppression and signal enhancement procedures available today. In addition, displays of the data were limited to variable-area "wiggle-trace" displays that were not capable of showing subtleties in amplitude, phase and frequency.

Figure 6 is the original display of one of these lines. The rift unconformity at the base of Miocene can be reliably mapped and tied to offshore wells, although a small uncertainty cannot be removed due to lack of velocity surveys in nearby offshore wells. The Plio-Miocene boundary can also be mapped over most of the area. However, the rift sequence is not easily identified. In most of the areas where the

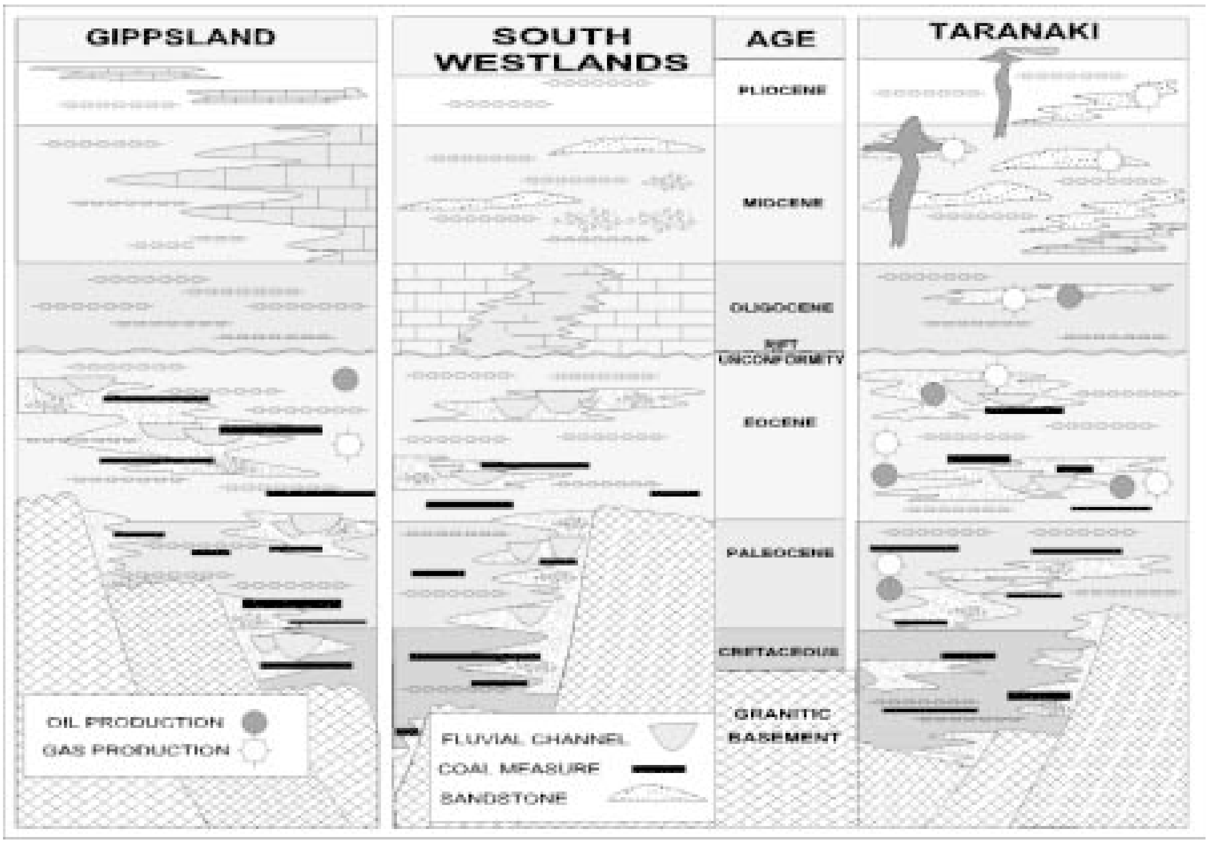

Figure 2: Tasman Rift stratigraphy

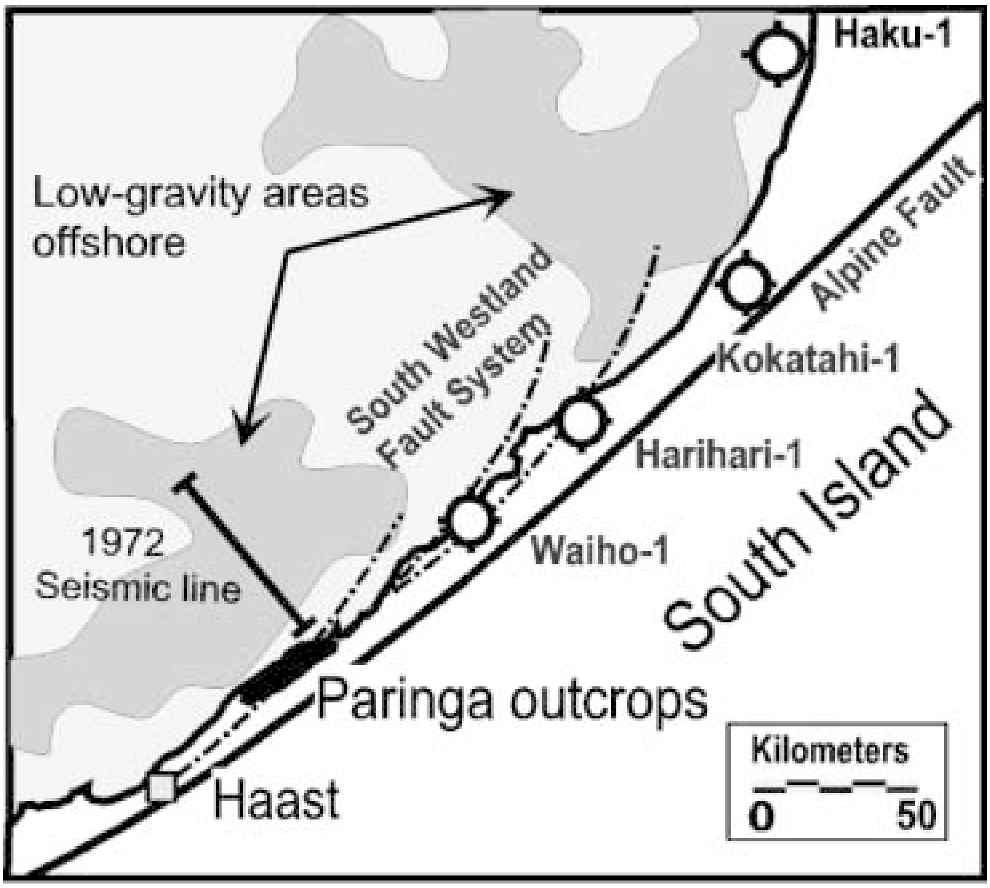

Figure 3: South Westland well control

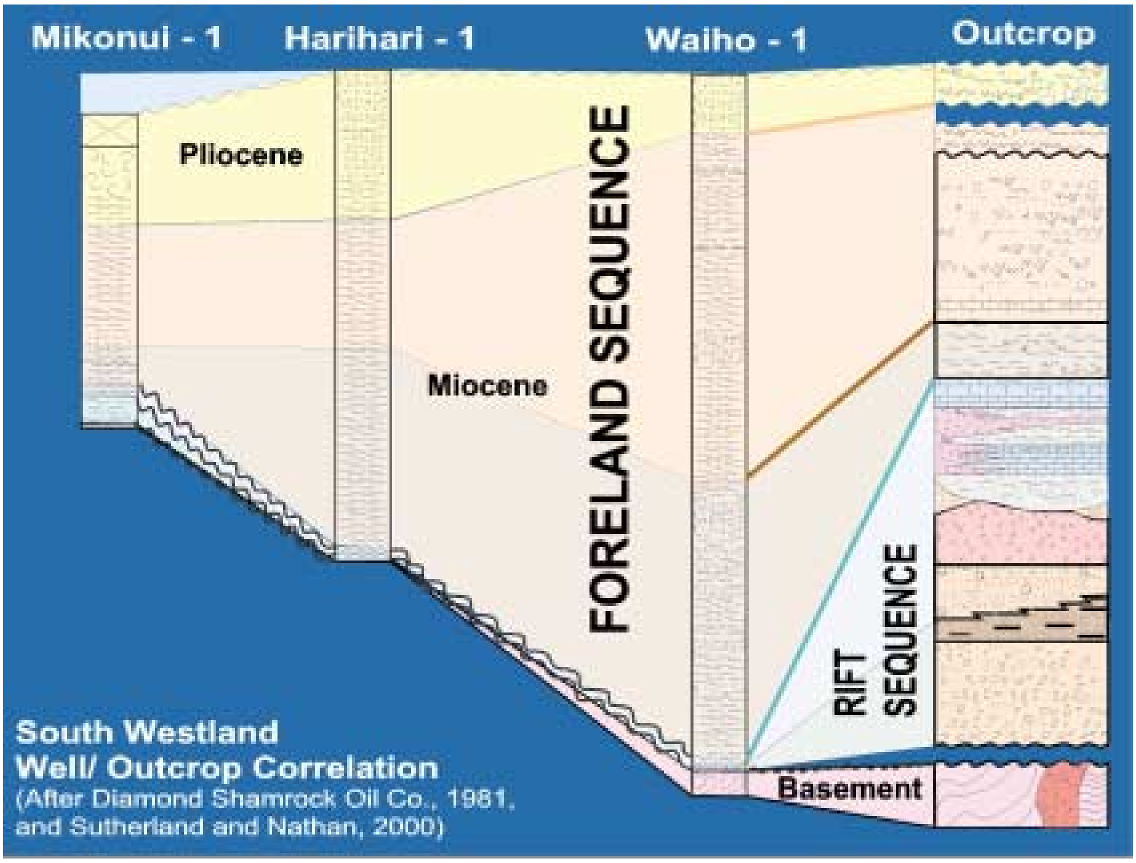

Figure 4: Well columns and outcrop section (see Figure 3 for well and outcrop locations)

Figure 5: Gravity map with onshore rift sequence

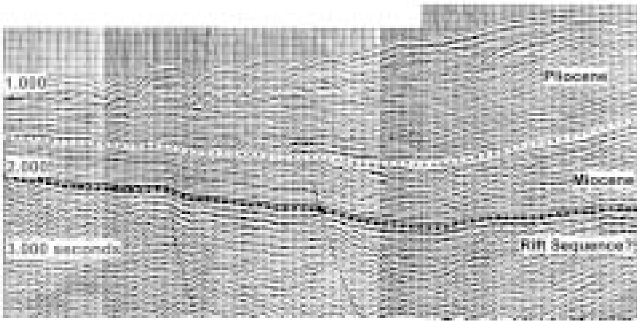

Figure 6: Seismic line, 1972 processing

unconformity is above 1.5 seconds, the gravity maps indicate a thin sediment thickness and the rift sequence is likely missing. In other areas however, especially where the rift unconformity is below 1.5 seconds, primary reflections are not visible. The primaries are almost entirely masked by water-bottom and interbed multiples.

As seen in Figure 7, reprocessing and redisplaying the data can extract a great deal of valuable information in spite of the limitations imposed by the acquisition parameters. The reflections below the rift unconformity are probably multiples, but very faint primaries are occasionally visible. This is corroborated by associated high velocity anomalies in velocity semblance plots. However, the Pliocene and Miocene section contains numerous high- amplitude mounded reflections, which in this clastic-dominated foreland compressional basin are interpreted to be basin-axis turbidite accumulations, similar to those in the Ventura Basin of California. The Mio-Pliocene section encountered in outcrops and wells in the area supports this interpretation.

In addition to potential for traps in the Mio-Pliocene, topography on the rift unconformity shows considerable relief, indicating the possibility for Maui-size traps.

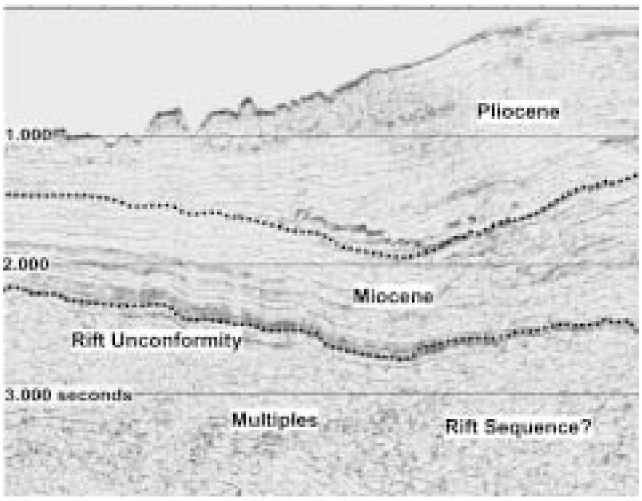

Figure 7: Seismic line, 2000 reprocessing

The reprocessed seismic lines were converted to depth using stacking velocities edited with sonic log data from the Taranaki Basin (Figure 8). The low-velocity water wedge modifies the topography on the rift unconformity, and the Plio-Miocene turbidite fans show increased relief due to the relatively high velocities in the Plio-Miocene sediment wedge.

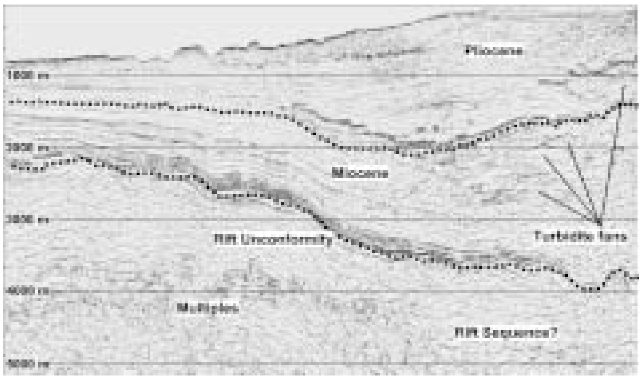

Figure 8: Reprocessed 1972 Seismic Line, Depth Converted

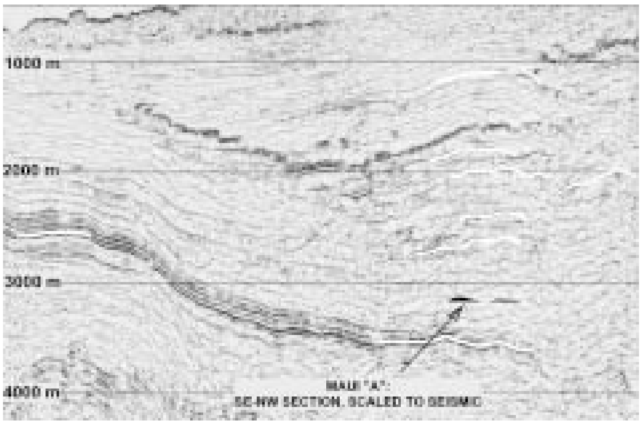

Figure 9: Seismic line with Maui “A”.

Looking more closely at the basinal portion of the line (Figure 9), the relief and extent of structures on the Unconformity is similar to the Maui Field. The cross section was constructed in a NW-SE direction across Maui A, to be in the same structural direction, normal to the maximum compressive stress, as the seismic line.

It thus appears that there may be traps with dimensions larger than Maui in the offshore South Westland basins.

Geochemistry and thermal history

Thermal history models for the South Westland basins can be fairly well constrained by depth-converted seismic data, regional outcrop geology and by analogous thermal resistivity and heat flow information from the Taranaki Basin. Maturation models for the area offshore of the Paringa outcrops indicate that the oil expulsion window is between

3000 and 5000 meters depth, within the area of thick Mio-Pliocene sediments shown on the seismic line (right side of Figure 9).

The geochemistry of the rift sequence source rocks is well established in both the Gippsland and Taranaki basins. Cretaceous-Eocene coal beds are the source for the great majority of oil and gas in both areas. The resultant expulsion models indicate that substantial volumes of hydrocarbons can be expelled from the rift sequence if present. Numerous oil seeps onshore and soil gas samples taken in the Paringa outcrop area (Figure 10) provides evidence that the source rocks are present and are actively expelling hydrocarbons. The Pixler plot (Figure 10) displays soil gas sample compositions as ratios of C2/C1, C3/C1, and C4/C1. In general, ratios below 100 are considered oil-prone, and ratios above 100 gas-prone. However, calibration samples taken at producing oil and gas wells in the Taranaki Basin showed reversals of this relationship, probably due to the small number of samples taken. In addition, a sample taken at the Kotuku gas seep showed ratios indicative of thermally degraded oil. In spite of this, the samples were considered by the laboratory to be unusually clean and clearly definitive of hydrocarbons being expelled at depth. My conclusion is that the rift sediments exposed at the surface are present at depth, and if present immediately below the outcrop, then probably present offshore, as shown on in Figure 14.

Gravity models

The Institute of Geological and Nuclear Sciences constructed a gravity model using the satellite altimetry-derived data, with the depth-converted seismic line (Figure12) as a guide for lithosome geometry. The base of Pliocene and the base of Miocene (approximately the rift unconformity) are well-defined seismic sequence boundaries. The base of the rift sediments and the rift faults are conjectural, since primary events below the unconformity are completely masked by multiples.

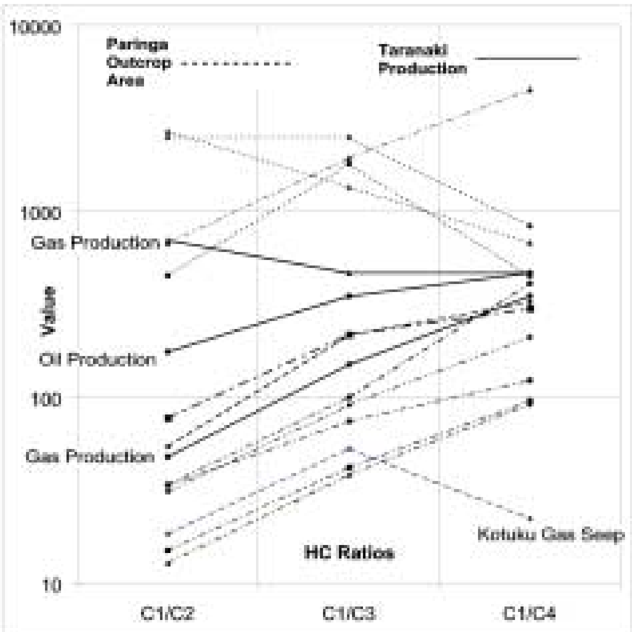

Figure 10: Paringa Soil Gas Samples Pixler Plot

The lithosomes chosen for the model coincide with the Plio-Pleistocene, the Miocene, the Eocene-Cretaceous rift sequence, Paleozoic basement ("lower crustal rock") and the upper mantle. Figure 12 shows the distribution of these lithosomes, and a plus-or-minus one kilometer uncertainty in the boundary between the mantle and the lower crust, or basement.

The higher position of the mantle boundary, plus a basement overlain only by Pliocene and Miocene sediments, produces a modeled gravity response that fits the observed data. However, when the lower mantle boundary position is used, a wedge of Eocene-Cretaceous rift sequence can be inserted as shown in Figures 12 and 13 (Figure 13 shows only the upper portion of the gravity model).

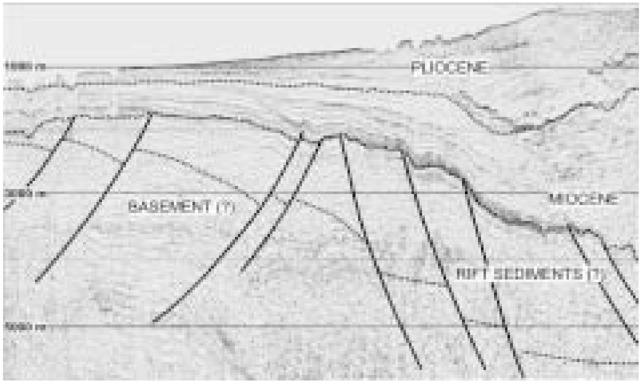

Figure 11: Seismic line for gravity model.

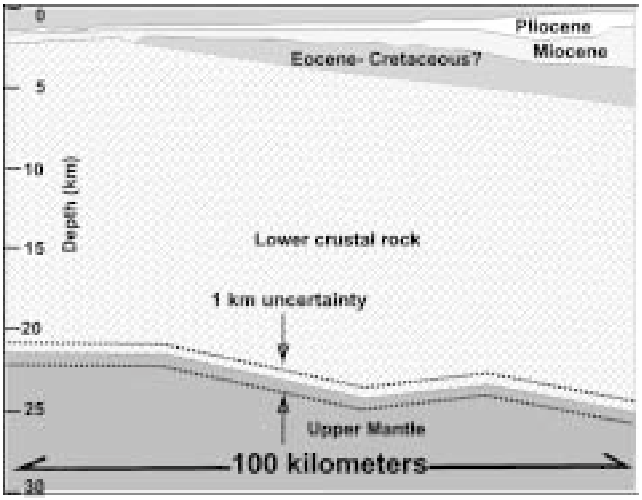

Figure 12: Gravity model with rift sequence

A one-kilometer variance at 22 kilometers depth is less than 5% error, and may be optimistically small, when the uncertainties in identifying refraction/reflection arrival times are compounded with inaccuracies inherent in velocity determination. It is considered to be representative of a "most-likely" interpretation. The "upside case" would be based upon the lowest reasonable position of the mantle boundary, and would allow inclusion of a thicker wedge of source rock. Such a wedge would provide for the expulsion of several hundred billion barrels of oil.

The most-likely case, shown here, was the basis for expulsion models that indicate some 30+ billion barrels of oil are available for migration and entrapment within the thickest portion of the Mio-Pliocene basin. Because both rift unconformity traps and Miocene turbidite traps directly overlie the kitchen area, relatively high migration and entrapment efficiencies are reasonable. If only 10% of the expelled hydrocarbons are entrapped, then 3 billion barrels of oil would be trapped in the single sub-basin visible on the seismic line shown here.

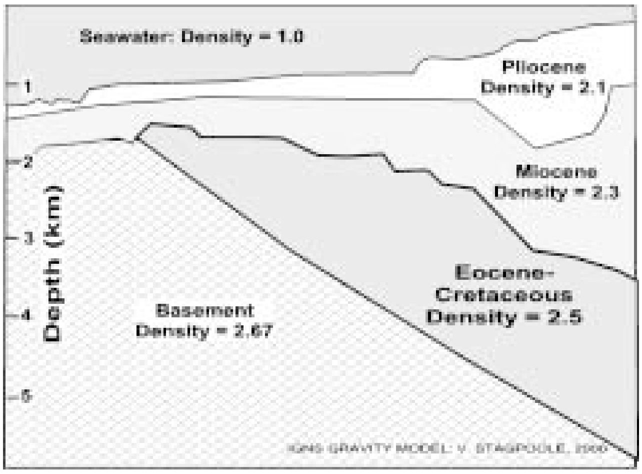

Figure 13: Gravity model, Shallow

The last illustration (Figure 14) shows all the elements described in this paper. The interpretation of the basement fault geometry is conjectural. Its geometry is modeled on known rift basin geometry, using the topography of the unconformity and the rift sequence thickness indicated by gravity modeling. The rift sequence outcrops at Paringa (Figure 3) lie directly onshore of the SE end of the seismic line. The NW-SE Alpine Fault lies east of the outcrops; therefore the basement rocks in outcrop are thus displaced some 500 km along the fault from the northeast. The South Westland fault system (Figure 3) may have some 100 to 150 kms of right slip movement, so the rocks exposed at Paringa are representative of those at depth offshore. The total thickness of the rift sequence is approximately 3000 meters (Figure 5).

Conclusions

Four wells drilled in South Westland were unsuccessful because the Tasman Rift source rock section was thin or absent in each well. The wells were positioned on gravity highs that are likely isolated rift horst blocks. No wells have been drilled in the South Westland basins where the rift sequence is present.

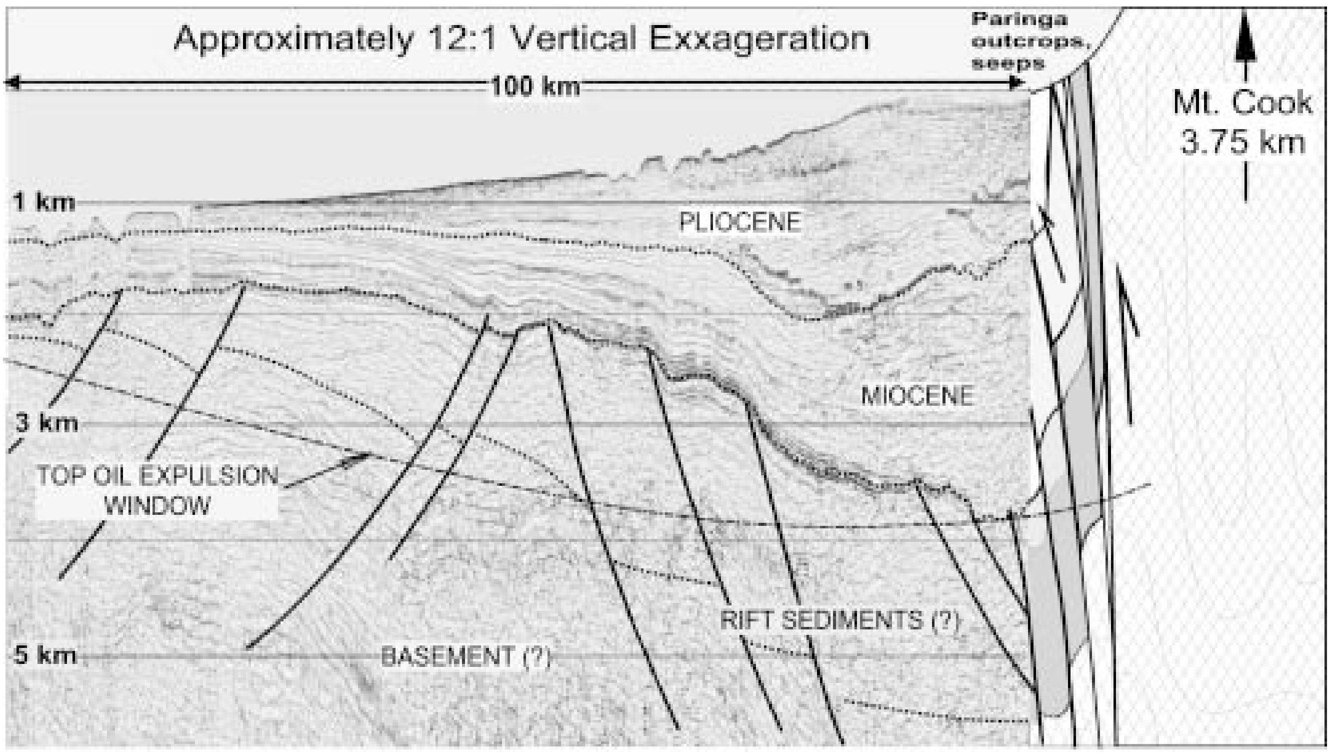

Figure 14: Seismic line with onshore extension

Reprocessed seismic data indicates that the rift sequence should be buried deep enough to reach thermal maturation in several areas. Thick sections of the rift sequence exist in outcrops and have been penetrated in onshore wells further north, west of the Alpine Fault, and thus in the same tectonic province as the offshore South Westland basins. Oil seeps and soil gas samples prove that where the rift sequence is mature, it is capable of generating hydrocarbons.

The richness of the source rocks, the excellent reservoir and seal lithologies in the overlying rocks, and the documented presence of structural and probable stratigraphic traps show that the South Westland basins will likely contain hundreds of hundreds of millions to billions of barrels of oil.

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