NEW ZEALAND PETROLEUM SYSTEMS

The presence of commercial accumulations of oil and gas is critically dependent on key geological factors such as deposition and preservation of adequate source rocks, maturation, generation and expulsion of petroleum, followed by migration to porous and permeable reservoir rocks in structural or stratigraphic traps bounded by adequate seals.

SOURCE ROCKS

Most of New Zealand's known oil and gas accumulations are geochemically typed to coaly facies of Late Cretaceous and Paleogene ages. Lacustrine rocks are known from several periods and one Eocene formation has been mined as an oil shale. Oil from the Kora-1 discovery in the Taranaki Basin is typed to a Late Paleocene marine mudstone, which commonly occurs in many basins around New Zealand. Similarly, oil seeps in the East Coast Basin have been typed to the same unit as well as to an older Cretaceous to Paleocene marine mudstone.

As exploration moves out into deeper water, marine systems are being increasingly encountered leading to the suggestion that the deep-water basins around New Zealand may be more oil-prone than those onshore and in shallow water. In addition to in situ coaly rocks, turbidite successions may, in some instances, have entrained large volumes of coaly kerogen and may be effective "self-sourcing" reservoir facies. Another trend is that possible source rocks older than those now known to contribute to New Zealand petroleum systems are recognised. Finally, some basins, such as Raukumara and Pegasus, appear to have experienced very rapid rates of deposition in the Neogene, suggesting that older Neogene rocks with high total organic carbon (TOC) may be effective source rocks in some regions. New Zealand's potential source rocks therefore range in age from Jurassic to Miocene.

The range of petroleum source rocks known to be present and effective in New Zealand basins, as well as those believed to be present, includes:

+ in situ coaly rocks, coals and coaly mudstones;
+ lacustrine mudstones;
+ marine mudstones and black shales;
+ turbidites containing entrained coaly kerogen.

Coaly source rocks

In New Zealand basins, coal-bearing successions occur in most periods from Jurassic to Miocene. Most petroleum accumulations discovered to date were sourced from Late Cretaceous and Paleogene coals and coaly mudstones. The spread of age of these source rocks indicates that the important factors are facies and maturation history, not geological age.

Triassic to Early Cretaceous sedimentary rocks of western and southern New Zealand were deposited in a large fore-arc basin along the Gondwana margin. In outcrop, these rocks are commonly, but not always, metamorphosed to a low grade. As such, although they are known to include organic-rich marine and non-marine facies, including coal measures, they have been considered until recently to be economic basement. At Waka Nui-1 in the Reinga Basin, Jurassic coal measures with vitrinite reflectance values of around 0.7% were sampled, suggesting that these and similar beds elsewhere have source potential.

Mid-Cretaceous syn-rift terrestrial and marginal marine coals and coaly mudstones are present in the Taranaki, Reinga, West Coast and Great South basins and may be present at depth within the Northeast Slope, Raukumara, East Coast, Pegasus and Chatham Slope basins, as well as Campbell Plateau basins.

Late Cretaceous rift basin alluvial and coastal plain facies cover large areas. Late Cretaceous source rocks comprise variably carbonaceous mudstone and coal deposited in alluvial and coastal plain settings with marginal marine influence. These facies are widespread and economically important. In the Taranaki Basin they include the Rakopi Formation, the source rock for much of the oil discovered in New Zealand so far; equivalent units are present in other basins with an early rift history such as Canterbury, the West Coast and Great South Basin. The coal-forming vegetation was mainly woody gymnosperms such as podocarps and araucarians, and the resulting coals are dominated by hydrogen-rich vitrinite, with variable amounts of liptinite. Late Cretaceous coals and coaly mudstones have total organic carbon (TOC) and hydrogen index (HI) values typically in the ranges of 2 to 75% and 200 to 400 mg HC/g TOC, respectively, indicating mixed gas- and oil-prone to oil-prone kerogen.

As the New Zealand continent drifted away from Australia and Antarctica, basins became progressively inundated and coaly facies were restricted to shrinking coastal plain regions. Nevertheless, thick coal measures were deposited during the Paleogene and these contributed to hydrocarbon charge, particularly for the oil and gas-condensate fields of onshore Taranaki. Coal-bearing units as young as Late Miocene in age are known from onshore in Northland and some examples may have been buried deeply enough to expel hydrocarbons.

Lacustrine source rocks

Lacustrine rocks are recorded from Triassic and Jurassic outcrops onshore, where they are considered to be part of the economic basement. However in deep-water areas, such as around the Waka Nui-1 well, any examples of lacustrine organic-rich shales may be effective source rocks.

Mid- to Late Cretaceous lacustrine rocks are known from the Western Southland region and interpreted to be present in the Great South Basin, although no organic-rich examples have been described. Late Cretaceous to Paleocene lacustrine mudstones crop out and have been extensively drilled in the West Coast basins.

In Western Southland, Eocene lacustrine mudstones are known in the Waiau Basin and at Ohai and a correlative oil shale at Orepuki was mined for a short while around the start of the twentieth century. Although no discovered oils in New Zealand basins have been geochemically typed to lacustrine sources, organic-rich lacustrine rocks may make a significant contribution to undiscovered petroleum accumulations in some regions.

Marine source rocks

The Cretaceous period contains some of the world's richest marine source rocks, deposited during global anoxic events. As exploration progresses in the deep-water basins, more examples of Early Cretaceous marine deposition have been encountered. Marine shales deposited during known global anoxic events may include rich organic shales. These events occurred in the Early Aptian (about 120 Ma), the Early Albian (about 110 Ma), across the Albian/Cenomanian boundary (about 100 Ma) and the Cenomanian/Turonian boundary (about 93 Ma).

The best known New Zealand example of a marine black shale is the Late Paleocene Waipawa Formation, an organic-rich unit deposited in marginally marine (hyposaline), anoxic to oxic environments. It has a distinctive biomarker signature and its age is well known from northern Taranaki and East Coast basins, where it is seen in outcrop, and the Great South Basin, where it has been drilled by several wells. It is also present in the Reinga Basin, where it is found in outcrop and was drilled by Waka Nui-1. It is also likely to be present in the Raukumara, Pegasus and other basins. The shale has an average thickness of about 30 m. TOC values are generally between 2 to 6% (up to 12.5%), with variable amounts of terrestrial-derived material as part of the organic matter assemblage. HI values vary widely from less than 200 to more than 300 mg HC/g TOC, indicating variably gas- to oil-prone kerogen.

MATURITY AND MIGRATION

The required depth of burial for source rocks to generate and expel oil and gas is variable, mainly due to differences in heat flow histories and source rock properties. Thermal modelling studies predict that, over most of New Zealand, the required present-day depth of burial for source rocks to start expelling oil is 4,000 to 4,500 m. However, where source rocks have been buried to moderate depths for long periods of time and recent sedimentation rates are low (as in Great South Basin), the required depth of burial may be as little as 3,000 m.

Many Taranaki oils, such as those from the Tui and Maari-Manaia fields, have been geochemically typed to coal measures of the Late Cretaceous Rakopi Formation. Recent work has shown that leaf cuticle forms much of the kerogen available for conversion to oil and that large volumes of oil may be expelled from cuticle-rich coals and coaly mudstones. Many of the coaly source rocks in New Zealand basins have a marine influence, which is beneficial for oil generation and expulsion.

In general, the deepest source rocks comprise Type III terrestrial coals, shaly coals and coaly mudstones, with variable syn-sedimentary marine influence. In the deep parts of some basins, petroleum may have been expelled as early as the Late Cretaceous, but in many basins the present-day mature kitchen areas are essentially confined to areas where there has been significant Neogene deposition. Paleocene Type II marine source rocks are generally close to maturity or have just entered the window for oil expulsion across the northern Taranaki, Reinga, East Coast and Great South basins.

Migration from source rock to trap is not well understood. Where there has been significant deformation, faults are considered as pathways for petroleum migration, as seals for trapping and development of structural compartmentalisation, or as leakage pathways that compromised integrity of top seals. Lateral migration distances are generally considered to have been short, although in one area there is some evidence for migration distances from source to accumulation of as much as 30 km.

In most basins, generation, migration and entrapment of petroleum are likely to have taken place in the last 10 million years. Due to the composite tectonic evolution of most of the basins there may have been more than one critical moment - the time when all prerequisite geological factors for the charging of traps were in place. In general the key critical moment is likely to have been in Neogene time for all basins except in Deepwater Taranaki and Great South basins, and the more remote southern basins, where it is likely to have occurred in the Paleogene.

RESERVOIRS

Potential reservoir rocks are present throughout the stratigraphic record. The reservoirs for the gas-condensate discoveries in Galleon-1 in Canterbury Basin and Kawau-1A in the Great South Basin are Late Cretaceous non-marine and shallow marine sandstones. The most productive Taranaki Basin reservoir rocks are in Paleogene transgressive shoreline systems, as in the Kupe, Maui and Pohokura fields, and a variety of facies belts within Tertiary Neogene clastic depocentres. Oligocene to Early Miocene limestone with high fracture permeability is the reservoir in the Waihapa Field. Petroleum is also produced from Miocene and younger, deep-water turbidite sandstones in the Maari, Kaimiro and Ngatoro fields. Oil is known from Miocene volcaniclastics in the Kora-1 well and gas is present in Pliocene sands at Karewa; similar Neogene slope and basin floor fans are present in many New Zealand basins and gas shows have been encountered in East Coast Basin Miocene turbidites at Titihaoa-1. In the East Coast region, Pliocene and Pleistocene coquina limestone has favourable reservoir characteristics.

SEALS

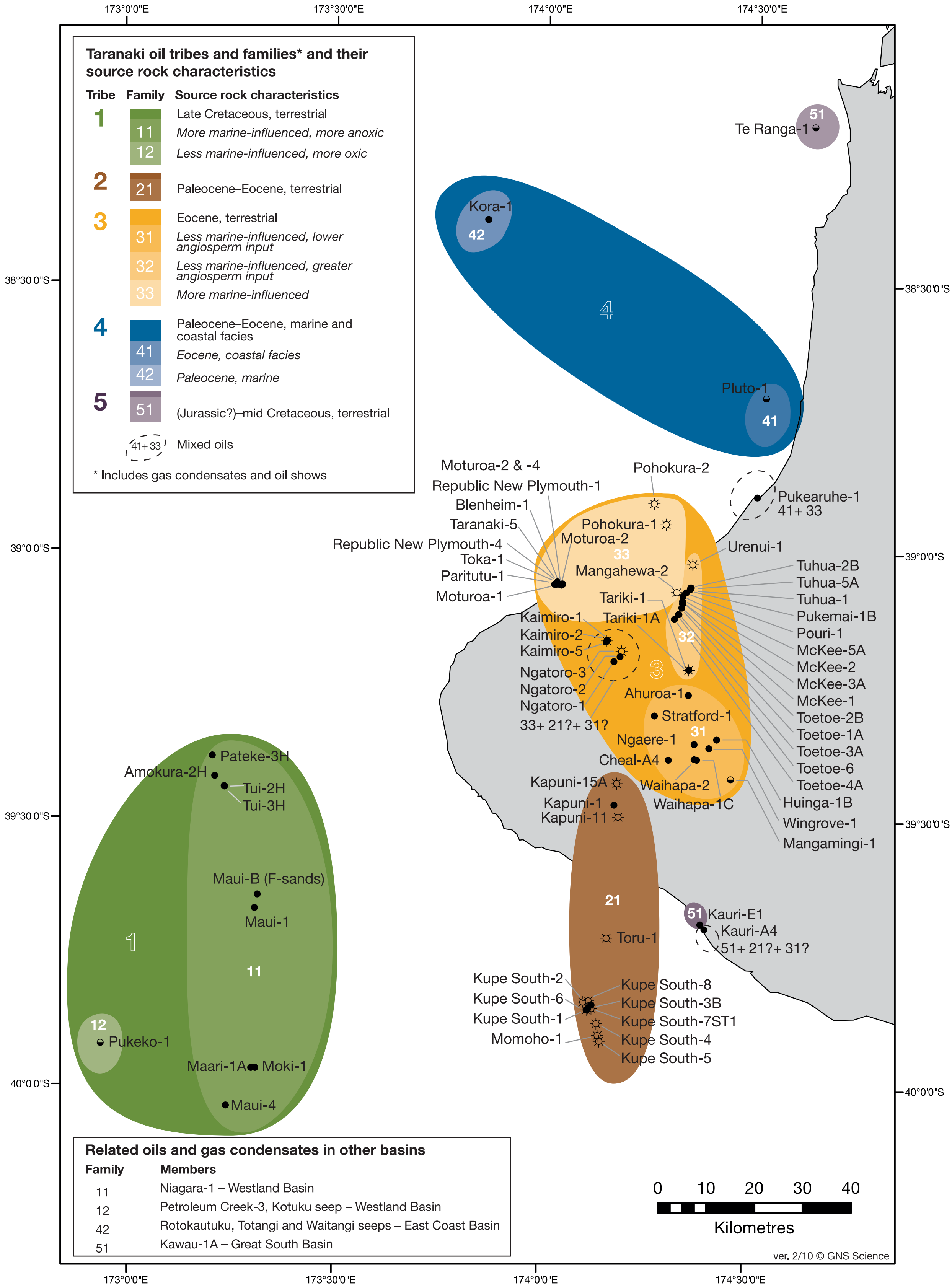
Seals are abundant in all potential petroleum basins and overpressures, indicative of fluid confinement within the stratigraphic sequence, are often encountered during drilling. Seal rocks in most basins are marine mudstones deposited during both the passive margin transgressive phase and the regressive convergent margin phase. Those Oligocene and Early Miocene limestones which were not fractured during Neogene tectonism may also provide seals in many basins.

OVERBURDEN

In general, two major periods of sediment deposition resulted in substantial burial. Late Cretaceous rifting produced grabens several kilometres deep that rapidly filled with sediments. Petroleum generation may have begun in the deepest of these basins during the Late Cretaceous and early Cenozoic. A second phase of rapid sedimentation occurred in many basins during the Neogene, when the development of the plate boundary through New Zealand caused rapid uplift and erosion. Very high Neogene sedimentation rates, in excess of 1,000 m per million years, have occurred in some basins. For example, deposition of the Giant Foresets Formation increased the overburden thickness by as much as 2,000 m over a large part of Taranaki Basin in just 3 million years. The volume of the Giant Foresets Formation is greater than the present day volume (above sea level) of the New Zealand landmass.

TRAPS

The commercial petroleum accumulations encountered in the Taranaki Basin to date are in structural traps formed in the Neogene, though the Kupe Field also has an element of stratigraphic trapping. Traps include four-way dip closures, three-way and fault closures, drape folds over basement horsts, thrust-controlled anticlines, and overthrusts. The same range of trap types is predicted to be present in other basins around New Zealand, which share this structural history. Dip-closed and thrust-bounded anticlines are common in the East Coast Basin as a result of the post-Early Miocene convergent margin overprint.



Taranaki oil tribes and families* and their source rock characteristics
Tribe Family Source rock characteristics
1 Late Cretaceous, terrestrial
11 More marine-influenced, more anoxic
12 Less marine-influenced, more oxic
2 21 Paleocene–Eocene, terrestrial
3 Eocene, terrestrial
31 Less marine-influenced, lower angiosperm input
32 Less marine-influenced, greater angiosperm input
33 More marine-influenced
4 Paleocene–Eocene, marine and coastal facies
41 Eocene, coastal facies
42 Paleocene, marine
5 51 (Jurassic?)–mid Cretaceous, terrestrial
41+33 Mixed oils
* Includes gas condensates and oil shows
173°0'0"E
173°30'0"E
174°0'0"E
174°30'0"E
38°30'0"S
39°0'0"S
39°30'0"S
40°0'0"S
Te Ranga-1
Kora-1
Pluto-1
Pukearuhe-1
41+33
Moturoa-2 & -4
Republic New Plymouth-1
Blenheim-1
Taranaki-5
Republic New Plymouth-4
Toka-1
Paritutu-1
Moturoa-1
Pohokura-2
Pohokura-1
Moturoa-2
Mangahewa-2
Tariki-1
Tariki-1A
Urenui-1
Kaimiro-1
Kaimiro-2
Kaimiro-5
Ngatoro-3
Ngatoro-2
Ngatoro-1
33+21?+31?
Ahuroa-1
Stratford-1
Ngaere-1
Cheal-A4
Kapuni-15A
Waihapa-2
Waihapa-1C
Kapuni-1
Kapuni-11
Tuhua-2B
Tuhua-5A
Tuhua-1
Pukemai-1B
Pouri-1
McKee-5A
McKee-2
McKee-3A
McKee-1
Toetoe-2B
Toetoe-1A
Toetoe-3A
Toetoe-6
Toetoe-4A
Huinga-1B
Wingrove-1
Mangamingi-1
Pateke-3H
Amokura-2H
Tui-2H
Tui-3H
Maui-B (F-sands)
Maui-1
Pukeko-1
Maari-1A
Moki-1
Maui-4
Kauri-E1
Kauri-A4
51+21?+31?
Toru-1
Kupe South-2
Kupe South-6
Kupe South-1
Momoho-1
Kupe South-8
Kupe South-3B
Kupe South-7ST1
Kupe South-4
Kupe South-5
Related oils and gas condensates in other basins
Family Members
11 Niagara-1 – Westland Basin
12 Petroleum Creek-3, Kotuku seep – Westland Basin
42 Rotokautuku, Totangi and Waitangi seeps – East Coast Basin
51 Kawau-1A – Great South Basin
0 10 20 30 40
Kilometres
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