NEW ZEALAND
PETROLEUM & MINERALS

New Zealand
Petroleum Basins

MINISTRY OF BUSINESS,
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New Zealand Government

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Why New Zealand?

New Zealand has a proven record of successful discoveries, vast potential for resources to be discovered, and an open, low risk and straightforward permitting system. New Zealand is also ranked as one of the best countries in the world to do business.

New Zealand rates internationally as a country in which to invest and is prominent in a number of reports:

+ New Zealand tops Forbes' 2012 Best Countries for Business list, which labels New Zealand as a free market economy that can compete globally
+ New Zealand is rated the least corrupt country in the world on Transparency International's 2011 Global Corruption Index; New Zealand is consistently at or very near the top of this Index
+ New Zealand is ranked 1st in the world for protecting investors by the World Bank in its 2013 Doing Business report and ranked third for ease of doing business
+ In 2012, credit-reporting company Dun & Bradstreet named New Zealand Asia Pacific's fourth safest country. New Zealand was described as "a low-risk environment for business investment"
+ The 2011 Index of Economic Freedom, compiled by The Heritage Foundation and The Wall Street Journal, ranked New Zealand's economy as fourth most-free in the world
+ According to AUPEC (July 2009), New Zealand has the fourth lowest effective royalty and taxation rate of approximately 42 percent

New Zealand offers a stable economy and political system, and a government that actively encourages foreign investment and the safe and responsible development of oil, gas and minerals resources.

Global benchmarking from the Fraser Institute has highlighted the attractiveness of New Zealand, as one of the top 10 countries in the world for investment in petroleum exploration.

New Zealand's oil and gas industry is built on the back of early exploration and development dating back to the 1950s. The modern industry in New Zealand has a well-developed oil and gas infrastructure, experienced support industry, and a proactive globally-competitive oil and gas regime. It is attracting industry participation from national and international investors.

New Zealand is highly prospective for further discoveries of oil and gas, with many offshore basins remaining largely, or entirely, unexplored. New Zealand provides explorers with multiple basins, excellent opportunities for portfolio development, as well as cost-competitive operating conditions.

An established oil and gas sector is supported by a wide range of expertise, including consultancy to underpin entry strategies, assistance with land access, provision of

New Zealand has a deregulated economy, an excellent business environment and high prospectivity. It has:

+ Abundant natural resources
+ Safe and secure investment environment
+ Economic and political stability
+ World-class transportation and communications infrastructure
+ Highly skilled workforce
+ High quality technical services
+ Extensive free trade agreements
+ Active Government support for international investment
+ Extensive databases of geological and exploration information
+ Comfortable standard of living

A full range of New Zealand economic statistics, such as GDP, migration and employment, can be sourced from Statistics New Zealand (www.stats.govt.nz).

professional services, collection and analysis of seismic acquisition, district planning, geology and geophysics, environmental advice, assistance with health & safety, engineering, design, electrical and mechanical work, and transportation.

The development of New Zealand's oil, gas and mineral resources is regulated by agencies responsible for allocation of rights to explore for and produce Crown resources, as well as for the protection of the environment and for the safety of workers. Recent changes to the legislative framework are designed to ensure New Zealand's overall regulatory regime is transparent, robust, future-proof, and reflects best international practice.

AN ISLAND NATION

New Zealand lies 1,150 nautical miles east of Australia, across the Tasman Sea. It comprises of two main islands, the North Island and the South Island.

It has a total land area of 250,000 km², but that's just the emergent parts of a mainly submerged continental landmass. Approximately 96% of the continent is under sea water. To the northwest, south and east of New Zealand are large areas of relatively shallow sea, underlain by plateaux and ridges that border the deep ocean basins of the Pacific Ocean and Tasman Sea.

SOVEREIGN RIGHTS

In August 2008, a United Nations Commission confirmed New Zealand's custodial rights to more than 5.7 million km² of seabed. The New Zealand Government exercises authority to allocate rights to petroleum over this extensive subsea area – called the Exclusive Economic Zone [EEZ]. This extends out to 200 nautical miles from the coastline and the Extended Continental Shelf beyond that [United Nations Convention on the Law of the Sea [UNCLOS]].

New Zealand has the fourth largest EEZ in the world, with a maritime jurisdiction up to 22 times the size of its land area; equivalent in size to the European Union, the North Sea, and a quarter of the Mediterranean combined.

Government Commitment to Oil and Gas Development

The New Zealand Government has placed oil and gas development as a key priority in its economic policy. Launched in 2012, the government's Business Growth Agenda is based on six key "ingredients" businesses need to grow: export markets, innovation, infrastructure, skilled and safe workplaces, natural resources and capital. The Building Natural Resources workstream of the Business Growth Agenda aims to make better use of New Zealand's abundant natural resources, to continue to grow the economy and look after the environment.

The business unit responsible for managing the Crown's oil, gas and mineral resources, including permitting, Block Offer promotion and provision of free data on New Zealand's resources is New Zealand Petroleum & Minerals.

To realise the potential of New Zealand's resources, New Zealand Petroleum & Minerals introduced annual Block Offer permitting rounds from 2012. The annual permitting rounds are the basis for exploration permit allocation that is promoted internationally.

To attract international interest in exploration, there has been significant government investment in providing an understanding of New Zealand's frontier basins through seismic survey acquisition and releases.

The government is committed to ensuring that New Zealand has a world-class and robust regulatory environment for the safe and environmentally responsible exploration, production and transportation of our petroleum resources. A number of initiatives aim to strengthen the regulatory regime, including:

+ strengthening upfront provisions in the Crown Minerals Act 1991 regarding the health and safety and environmental credentials of operators
+ putting in place a comprehensive regime to manage the environmental effects of all petroleum exploration activities in the EEZ and on the extended continental shelf
+ strengthening the health and safety regulation of wells and well drilling activities following international best practice
+ the establishment of a new High Hazards Unit with an increase in the number of inspectors and the appointment of a Chief Inspector
+ strengthening guidelines for minimising acoustic disturbance to marine mammals from seismic operations.

Legislative Environment

LEGISLATION

Development of New Zealand's oil, gas and mineral resources is governed by various pieces of legislation which are managed by different regulatory agencies. The government's goal is for New Zealand's regime to be transparent, robust, future-proofed, and reflecting best international practice.

PERMITS

Awarding a permit is the first legislative step in developing a Crown-owned resource. Permitting is managed by New Zealand Petroleum & Minerals.

The requirements for awarding and managing permits and collecting royalties are set out in the Crown Minerals Act 1991 and supporting regulations and minerals programmes (known as the Crown Minerals Act regime). The Crown Minerals Act regime is currently under review, with a new regime expected to be in place in early 2013.

+ More information can be found at www.nzpam.govt.nz/cms/petroleum/legislation

LAND ACCESS

A permit does not give its holder a right to go on to land covered by the permit. If a permit holder needs access to explore or mine they must have a land access arrangement with the landowner and land occupiers. The exception is where access is required for minimum impact activities (e.g. geological, geochemical, and geophysical surveying, taking samples by hand or hand held methods, aerial surveying, and land surveying).

The Crown Minerals Act 1991 sets out the process for reaching a land access arrangement.

+ More information can be found at www.legislation.co.nz

ENVIRONMENTAL MANAGEMENT

Before a company can undertake certain activities such as exploration drilling, they must apply for environmental consents from the appropriate authority.

Onshore and offshore - up to 12 nautical miles from the coastline

Local authorities manage environmental consenting processes in their region under the Resource Management Act.

+ More information on the Resource Management Act 1991 can be found at www.mfe.govt.nz/rma

Offshore - more than 12 nautical miles from the coastline

Exploration activities more than 12 nautical miles from the coastline will need to comply with new legislation that is expected to come into force by 2014, and will be managed by the Environmental Protection Authority. For more information, visit www.epa.govt.nz

+ More information on the Exclusive Economic Zone and Continental Shelf (Environmental Effects) Act 2012 can be found at www.mfe.govt.nz

Other marine protection

Our marine environment is also protected under the Maritime Transport Act 1994, and the marine protection rules that come under the Act. This legislation applies to vessels, installations and ports, and is managed by Maritime New Zealand and by local councils.

+ More information can be found at www.maritimenz.govt.nz

HEALTH AND SAFETY

Under the Health and Safety in Employment Act, all New Zealand employers have a general duty to provide and maintain a safe working environment for the workforce.

Petroleum and mineral mining operators must also comply with specific health and safety regulations for the oil and gas industry and for underground mining.

The Ministry of Business, Innovation & Employment's High Hazards Unit administers the Health and Safety in Employment Act 1992 and other regulations for extractive industries.

Updated regulations for the oil and gas industry are expected to come into force mid-2013.

+ More information can be found at www.dol.govt.nz

Annual Block Offer
Permitting Rounds

The New Zealand Government allocates the right to exploration through the annual release of petroleum exploration acreage; called Block Offers.

Release Areas are selected to offer the global petroleum exploration industry a variety of investment opportunities; areas vary in size, level of existing geological knowledge and are located in a range of water depths. All release areas are supported by a pre-competitive geological and geophysical data and analysis either undertaken by the Crown or previous industry exploration.

Areas can be offered in a graticular system, or by a predefined block selection method.

+ View the current Block Offer at www.nzpam.govt.nz/cms/petroleum/block-offers

History
and Track Record

EARLY DISCOVERIES IN TARANAKI

New Zealand has a proven record of oil and gas successes that make an important contribution to the national economy. Discoveries can be traced to pre-1865 when early settlers in Taranaki noticed an oily residue on a New Plymouth beach. This led to the Alpha well, the first oil well in the Commonwealth and one of the first in the world. Further wells located both east and west of Alpha-1 were subsequently drilled to take advantage of oil seepage from the shallow Moturoa oil field.

The Taranaki Basin was the first sedimentary basin in New Zealand to be explored for hydrocarbons and is currently New Zealand's only producing province. Located predominately offshore, the Taranaki Basin is found on the west coast of the North Island and covers approximately 330,000 km^2.

KAPUNI (1959) AND MAUI (1969)

In the 1950s, the modern age of exploration emerged in New Zealand. With the advantage of seismic reflection data, Shell discovered the onshore Kapuni field in 1959. The ability to explore and drill offshore led to the discovery of New Zealand's largest hydrocarbon field, Maui, in 1969. At the time, Maui-1 was New Zealand's second offshore well drilled and provided evidence for a prolific offshore Taranaki petroleum system through the discovery of the approximately 3.4 tcf Maui oil/gas field. To date, this is New Zealand's largest hydrocarbon field.

RECENT YEARS

Today New Zealand has a series of established commercial fields.

The large gas discoveries of Maui and Kapuni fields have suggested that New Zealand is gas-condensate prone. However, geochemical research suggests similar oil potential to that of prolific oil provinces in South East Asia. This is substantiated with the discovery of the Taranaki McKee Oil Field (Australasia's largest onshore oilfield), and offshore oil fields such as the Maari and Tui fields.

Maui still contains the majority of New Zealand's proven reserves, but this field is mature. Two other fields, Maari and Pohokura, contain about 49% of oil and condensate reserves, with Pohokura also accounting for 45% of gas reserves. In total there are 16 producing fields in the Taranaki Basin.

The complex tectonic and sedimentary history of New Zealand has led to a variety of successful plays within the Taranaki Basin. Discoveries have been made at all potential reservoir levels except the Cretaceous. The economics of New Zealand's gas market has controlled the Taranaki basin's exploration, with the early discovery of the large Kapuni and Maui fields limiting offshore exploration. However, new discoveries have been made at a steady rate in recent years, and new plays are still being tested, both onshore and offshore. Of the offshore fields to have recently come onstream, Maari and Kupe have been known for over two decades; whereas Tui oilfield was brought onstream well within five years of its 2003 discovery.

There are underexplored basins, with the possibility of significant unrealised reserves. Readily available, free seismic information covers some of these basins. Exploration includes both conventional and unconventional oil and gas.

Highlights

- Fields brought into production: Pohokura (2006), Turangi (2007), Tui (2008), Maari (2009), Kowhai (2009) and Kupe (2010)
- Ahuroa started commercial gas storage (2010)
- McKee LPG plant (2011)
- 4000 km^2 multi-client seismic data acquisition in the Northern Graben, offshore Taranaki (2013)
- New Zealand exploration and production (E&P) sector has had at least five significant independently net present value (NPV) positive projects in the last five years
- New Zealand E&P market has an increasing number of high quality players, most actively reinvesting.

BASINS

New Zealand has had limited exploration outside of the Taranaki Basin with discoveries in the East Coast Basin, Canterbury Basin and Great South Basin; Kauhauroa-1, Galleon-1 and Kawau-1A respectively.

Although the Taranaki Basin is New Zealand's premier oil and gas exploration region, the Great South Basin, Canterbury, Reinga-Northland, East Coast and the deep water possibilities of New Zealand's petroleum acreage, have attracted significant interest as emerging basins of petroleum potential.

Several other nearshore and onshore basins have had a small number of wells drilled, but these, and the far offshore frontier basins, remain largely unexplored.

Limited exploration began in the East Coast and Westland basins before 1900, with shallow wells drilled near oil seeps. Until 1970, most exploration was conducted onshore, but increasing acquisition of marine seismic reflection data led to offshore drilling in several basins.

In offshore Canterbury, the Galleon-1 well (1985) produced 10 mmscf/d of gas and 2,300 bbl/d of condensate on testing. In the Great South Basin, Kawau-1A (1977) flowed 6.8 mmscf/d gas and has estimated reserves of 461 bcf.

In 1998, an onshore gas discovery was made at Kauhauroa-1, on the North Island's East Coast. At the time with cheap, readily accessible gas from Maui dominating the local marketplace, these discoveries were all deemed un-commercial. While their size still precludes economic viability, they prove the existence of effective petroleum systems outside of the Taranaki Basin.

Since the mid-2000s, New Zealand Petroleum & Minerals has undertaken concerted data acquisition. Together with advances in deepwater drilling and production technology, the focus is shifting further offshore – where the biggest new discoveries are anticipated.

Large international companies currently hold licences to parts of four frontier offshore basins: Great South, Canterbury, Pegasus, and Deepwater Taranaki.

Accessing Data

ONLINE EXPLORATION DATABASE

New Zealand Petroleum & Minerals maintains a world class collection of petroleum exploration data, collected as part of permit holders' work programme obligations, and from the academic community's voluntary donations.

Data includes geological/ geophysical/ geochemical reports, geophysical studies (2D and 3D seismic, gravity and magnetic), and well results (geophysical data and physical samples).

Access to this data is free, allowing you to easily discover, preview and access exploration information by browsing database fields and digital reports online.

+ Access the Exploration Database at data.nzpam.govt.nz

PETROLEUM BASINS EXPLORER (PBE)

PBE is an interactive web-based tool that allows you to discover and access a wide range of petroleum exploration and geoscience data from across the New Zealand sub-continent using both geographically-based and text searches.

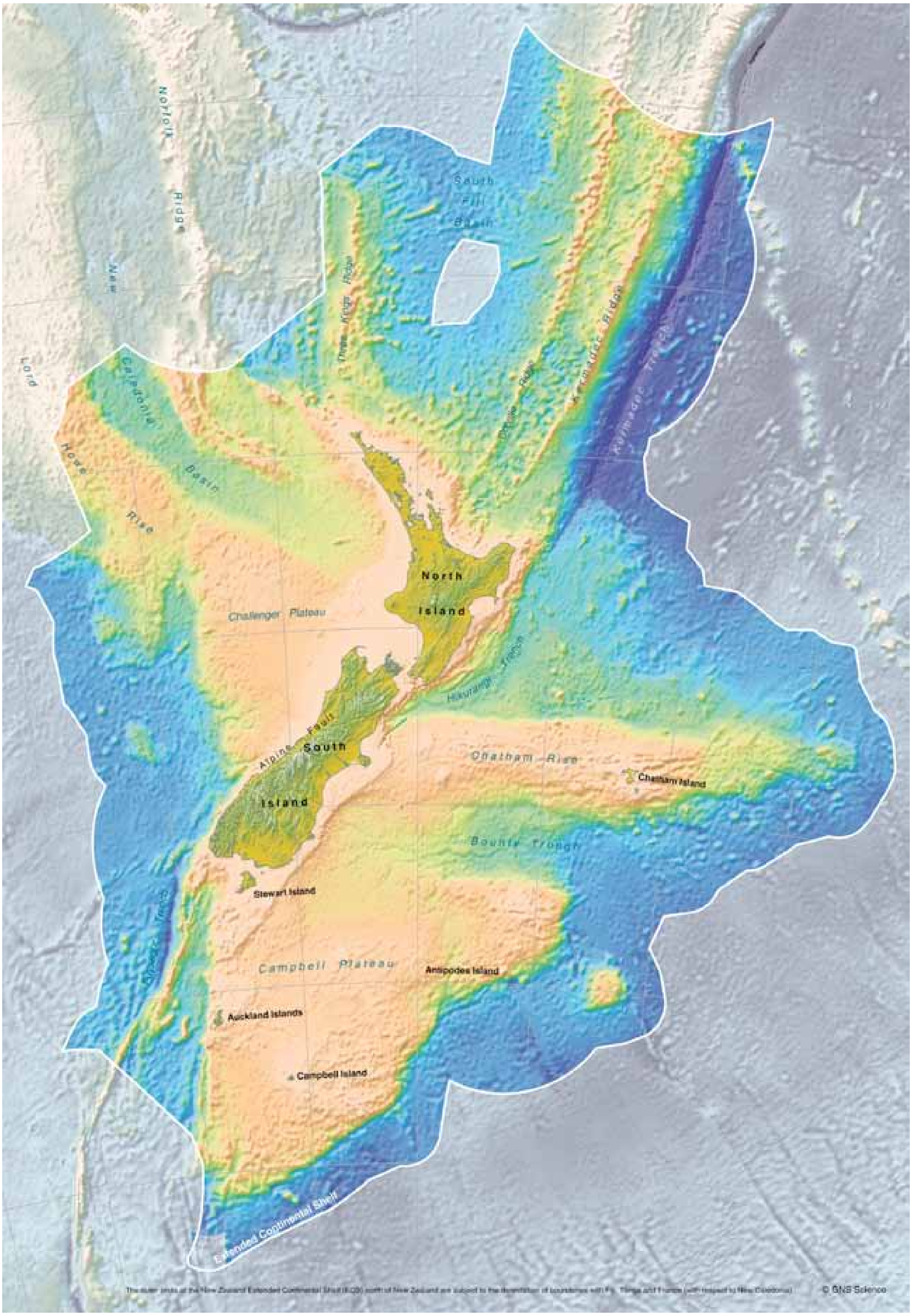
PBE contains a wide variety of data and products, ranging from simple GIS layers of the New Zealand coast to detailed oil and gas geochemical data, and includes outputs from the PEGI project and GNS Science's petroleum and basin studies research.

+ Access PBE at data.gns.cri.nz/pbe

DATA ACQUIRED

A large area of New Zealand's offshore territory is covered only by reconnaissance surveys; however the available data suggest large sedimentary basins that may host oil and gas cover about 20% of New Zealand's territory - over a million km².

For some of the basins, present understanding is based on modern, industry-standard seismic surveys (e.g., Deepwater Taranaki 2001–2009, Raukumara 2005–2007, Reinga 2009 and Pegasus 2010). For other basins there is a range of seismic data acquired from the 1970s onward, of variable quality. For remote areas there are limited seismic surveys completed for the 2008 New Zealand continental shelf submission to the United Nations.


Norfolk Ridge
New
Lord
Howe
Rise
Caledonia
Basin
South
Fiji
Basin
Three Kings Ridge
Kermadec Ridge
Kermadec Trench
North
Island
Challenger Plateau
Hikurangi Trench
Alpine Fault
South
Island
Chatham Rise
Chatham Island
Bounty Trough
Stewart Island
Campbell Plateau
Antipodes Island
Auckland Islands
Campbell Island
Extended Continental Shelf
© GNS Science

The Continent of New Zealand

A SUBMERGED CONTINENT

The islands of New Zealand have a total area of about 268,000 km^2 and are the emergent parts of an extensive, mainly submerged continental landmass with a total area of more than 6 million km^2. Northwest, south and east of New Zealand are large areas of relatively shallow sea underlain by plateaux and ridges that border deep ocean basins in the Pacific Ocean and Tasman Sea.

New Zealand established an Exclusive Economic Zone (EEZ) in 1977, defined by a line 200 nautical miles from the New Zealand coastline and, in 2004 established maritime boundaries with Australia. New Zealand's entitlement to an Extended Continental Shelf (ECS) beyond the EEZ, as defined in the United Nations Convention on the Law of the Sea (UNCLOS), was confirmed by the United Nations in August 2008. The outer limits of the ECS north of New Zealand are currently subject to delimitation with Fiji, Tonga and France in respect of New Caledonia. New Zealand now has sovereign rights over more than 5.7 million km^2 of seabed. This is an area more than 21 times greater than its land area and is equivalent in size to the European Union, the North Sea, and a quarter of the Mediterranean combined.

NEW ZEALAND'S SEDIMENTARY BASINS

A large area of New Zealand's offshore territory is covered only by reconnaissance surveys, however the available data suggest large sedimentary basins that may host oil and gas cover about 20% of New Zealand's territory – more than 1 million km^2. For some of the basins, present understanding is based on modern, industry-standard seismic surveys (e.g. Deepwater Taranaki 2001–2009, Raukumara 2005–2007, Reinga 2009 and Pegasus 2010). For other basins there is a range of seismic data acquired from the 1970s onward, of variable quality. For remote areas there are limited seismic surveys completed for the 2008 New Zealand continental shelf submission to the United Nations. Additional information from gravity and magnetic surveys and satellite data help define little known basins.

The basin boundaries shown on the map (on page 14) are mainly determined by major geological structures or seafloor physiography. In general, regions with stratigraphic continuity and a common geological history are included within a single basin. In places, the basin limits are set at a minimum sediment thickness. For some, sub-basins and provinces can be differentiated on geological or geographical criteria respectively.

MODERN SETTING

New Zealand's land area straddles the active boundary between the Australian and Pacific tectonic plates, and is above sea level mainly because of deformation and uplift in the last 20 million years. The North Island is a part of the Australian Plate and the South Island is mainly on the Pacific Plate. In the east, the Pacific Plate is moving southwest and downward beneath the North Island but southwest of the South Island the polarity is the reverse; the Australian Plate is being forced eastward and down beneath the South Island. These opposing subduction systems (represented by the Hikurangi Trough and Puysegur Trench) are connected by the Alpine Fault, a major strike-slip zone that borders the Southern Alps. Close to the active plate boundary, deformation is moderate to intense but, away from it, seismic surveys show that in many of the basins the thick successions of sedimentary rocks are little disrupted.

MESOZOIC BASIN INITIATION

In Paleozoic and early Mesozoic time, the basement rocks of New Zealand's islands and offshore plateaux were part of the Pacific margin of the Gondwana supercontinent, adjacent to the continental hinterlands of Australia and Antarctica. Triassic and Jurassic sedimentation in back-arc settings close to the Gondwana margin formed the thick marine and non-marine, structurally simple, low metamorphic grade Murihiku rocks of western and southern New Zealand, traditionally considered as economic basement.

Evidence from radiometric dating indicates that subduction persisted at the active continental margin until Early Cretaceous time (about 100 to 120 million years ago). After subduction ceased, the subsequent Gondwana continental break-up was preceded by a period of extensional tectonics, including rifting, with one margin-parallel rift basin becoming the Tasman Sea.

Basins initiated during this period contain both marine and terrestrial sediments, including coals. Although many onshore outcrops exhibit low-grade metamorphism, samples from offshore wells remain un-metamorphosed and immature for petroleum generation. Although no petroleum accumulations have yet been geochemically typed to source rocks older than Late Cretaceous age, where carbon-rich facies are present under the right conditions, they may be effective source rocks, particularly in the deep-water frontier basins.

RIFTS AND A PASSIVE MARGIN

In onshore and near-shore New Zealand, an unconformity representing Early Cretaceous uplift and erosion separates the Cretaceous and Cenozoic sedimentary rocks from underlying basement. A large part of the New Zealand region was land in Early Cretaceous time. Early basin-fill sedimentary rocks remain poorly dated. By the late Early Cretaceous, non-marine clastic sediments were accumulating in fault-controlled basins. The oldest basin-fill rocks are typically coarse-grained alluvial fan, fluviatile and lesser lacustrine facies, restricted to grabens and half-grabens. Deposition of thick passive margin marine sequences also began in the New Zealand region of the Gondwana margin in the late Early Cretaceous.

Magnetic anomalies show seafloor spreading in the Tasman Sea was well established in the Late Cretaceous (83-79 million years ago), by which time most of the major seafloor physiographic features of the New Zealand region had been formed. Large river systems developed and thick accumulations of non-marine and paralic sediments, including coal measures, accumulated in the valleys and extensive coastal plains. A thick progradational sequence that is present offshore from Taranaki represents the delta of a major river, built out into the accommodation space of a failed rift basin. It is capped by Late Cretaceous coal measures. In Taranaki, these coal measures became the source rocks for a large proportion of the oil discovered to date. Late Cretaceous marine shelf and slope sediments accumulated adjacent to the paleo-Pacific continental margin and in the more restricted seaways elsewhere.

QUIESCENCE AND TRANSGRESSION

Active seafloor spreading in the Tasman Sea and southern Pacific Ocean prevailed in Late Cretaceous, Paleocene and earliest Eocene time, when the New Zealand region was tectonically stable. With post-rift thermal subsidence and associated marine transgression, early-formed rift basins were progressively inundated. By Paleocene time, rift sedimentation was confined to small sub-basins while, at the margins of the land, coastal plain, marginal marine and shelf deposits accumulated. They include thick units of coal measures that are source rocks for oil and gas accumulations. Eocene deposits represent late-rift and post-rift transgressive sequences and, by Middle Eocene time, the reduced landmass was surrounded, in the west and south, by extensive coastal plains. Fine-grained clastic sediments and carbonates accumulated in marine settings distal from land areas.

PLATE BOUNDARY PROPAGATION AND INUNDATION

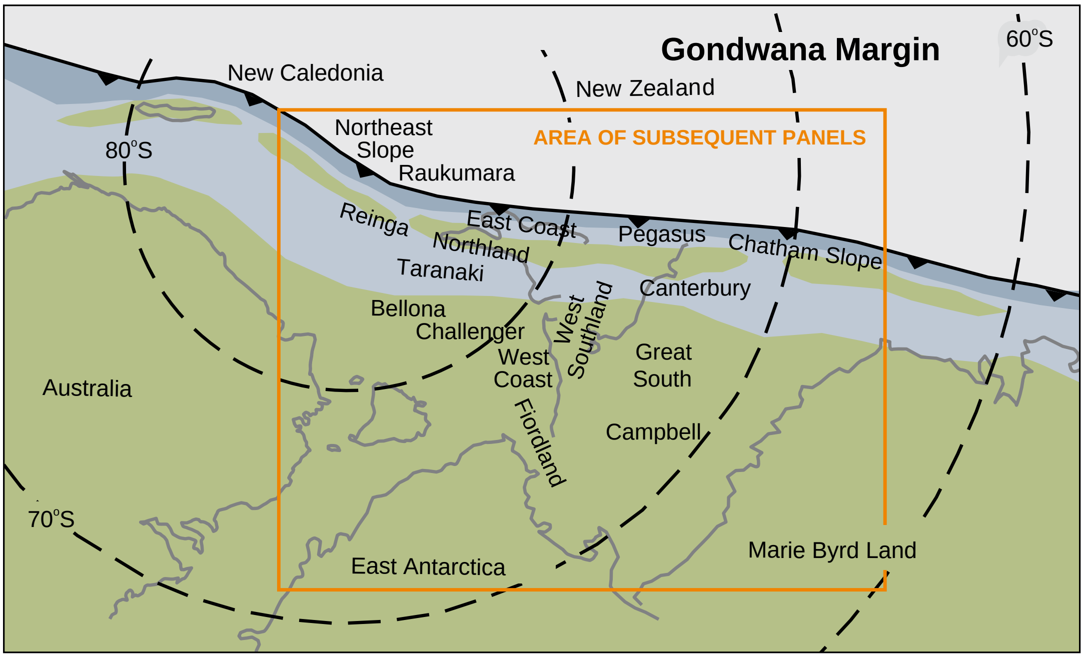
Seafloor spreading ceased in the Tasman Sea in Early Eocene time but continued in the southern Pacific Ocean. A new Australia-Pacific plate boundary formed south of New Zealand, where opening of the Emerald Basin resulted in anticlockwise rotation of eastern New Zealand relative to the west. For much of the region there was only minor deformation. In Southland there was rifting and the rotation resulted in compression in the Reinga Basin. By Late Oligocene time, the land area was greatly reduced and New Zealand may have been completely submerged. The Oligocene rocks are mainly calcareous. Differential compaction across basement highs and deformation associated with the new plate boundary formed a range of structures during this time.

NEOGENE PLATE BOUNDARY – UPLIFT AND DEPOSITION

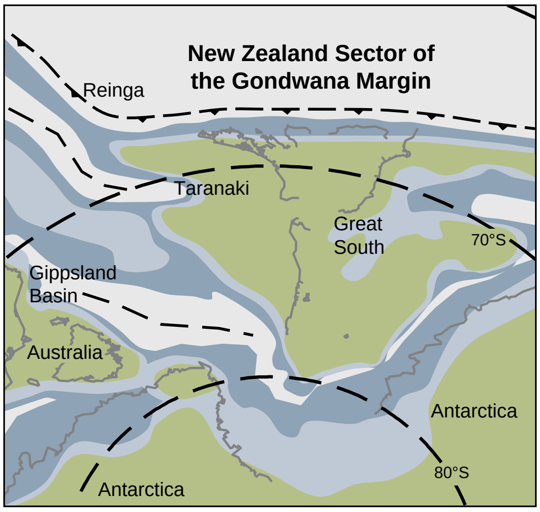
By earliest Miocene time, a southwest-dipping subduction zone was present in northern New Zealand. Large calc-alkaline stratovolcanoes erupted on and immediately west of what is now Northland, a part of the overriding Australian Plate. The Reinga Basin, originally a rift, became an intraplate back-arc basin. The thick Cretaceous to Oligocene passive margin sedimentary sequence which had accumulated northeast of the New Zealand landmass was obducted and emplaced part-way into the Reinga, East Coast and Raukumara basins as a series of thrust sheets (Northland and East Coast allochthons). Southwest-directed subduction in northernmost New Zealand was short-lived and calc-alkaline volcanism had all but ceased there by the end of the Early Miocene. Allochthon emplacement took place over about three million years.

Southwest-directed oblique convergence at the plate boundary east of North Island and Kermadec Ridge continues at the present day. The Kermadec Trench and its prolongation as Hikurangi Trough extend south to meet Chatham Rise just south of Cook Strait. In South Island, deformation on the Alpine Fault is mainly strike-slip, with about 480 km of dextral offset in the last 20 million years. The rate of plate boundary convergence accelerated from Middle Miocene time, resulting in increasingly rapid uplift, with erosion of Northland volcanoes, the axial ranges of the North Island, and the elevated mountain chain of the Southern Alps. The supply of vast amounts of sediment resulted in progressive infilling of marine depocentres and progradation of the continental shelves. Most New Zealand basins have thick Neogene successions of slope and basin floor mudstones, with intercalations of turbidite sandstones. Burial by thick Neogene sequences has raised the maturity of underlying Cretaceous and Paleogene rocks to levels sufficient to generate and expel hydrocarbons.

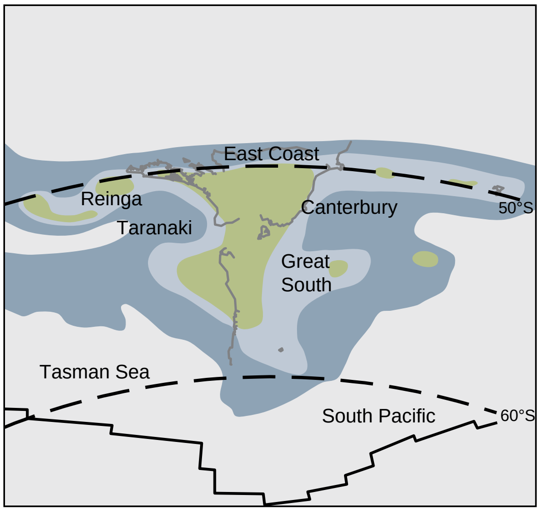
EARLY CRETACEOUS -APTIAN- 120 Ma



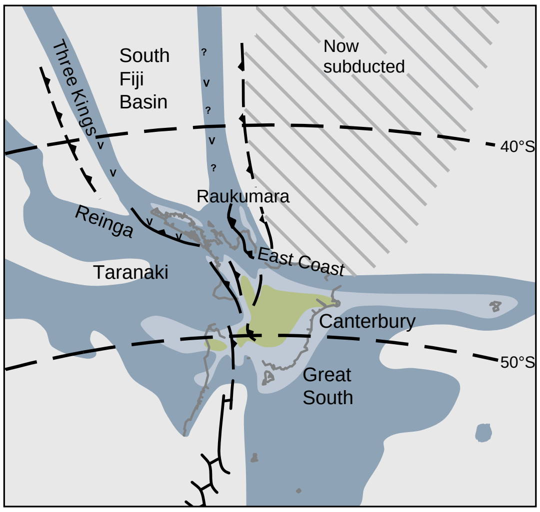
LATE CRETACEOUS - SANTONIAN- 85 Ma



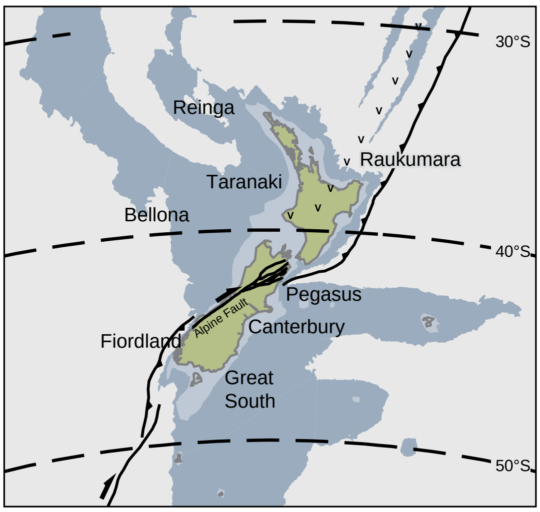
LATE PALEOCENE - 57 Ma

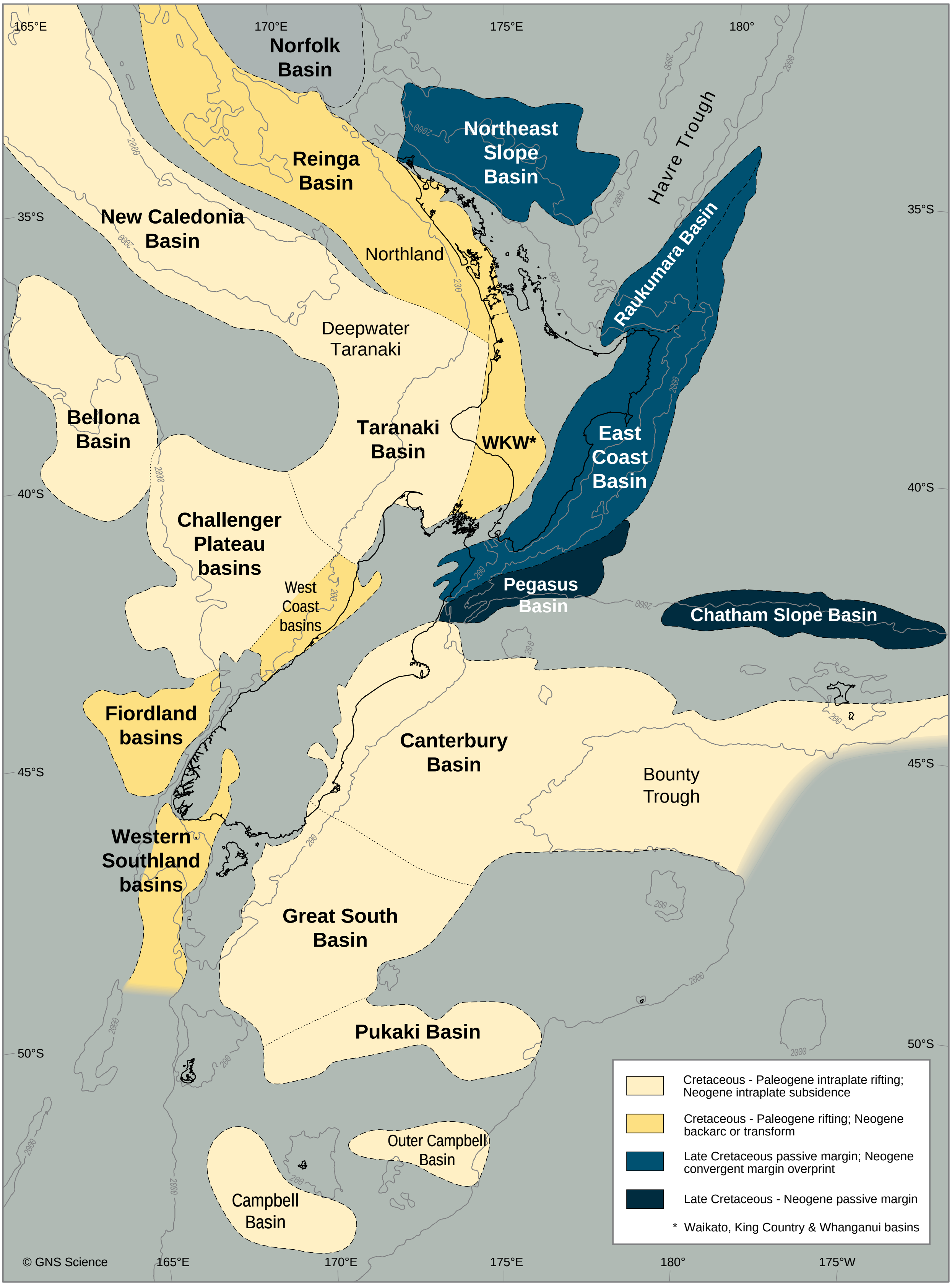


EARLY MIOCENE - 22 Ma



PRESENT DAY - 0 Ma





165°E
170°E
175°E
180°
175°W
35°S
40°S
45°S
50°S
Norfolk Basin
Northeast Slope Basin
Havre Trough
Reinga Basin
New Caledonia Basin
Northland
Raukumara Basin
Deepwater Taranaki
Bellona Basin
Taranaki Basin
WKW*
East Coast Basin
Challenger Plateau basins
West Coast basins
Pegasus Basin
Chatham Slope Basin
Fiordland basins
Canterbury Basin
Bounty Trough
Western Southland basins
Great South Basin
Pukaki Basin
Outer Campbell Basin
Campbell Basin
Cretaceous - Paleogene intraplate rifting; Neogene intraplate subsidence
Cretaceous - Paleogene rifting; Neogene backarc or transform
Late Cretaceous passive margin; Neogene convergent margin overprint
Late Cretaceous - Neogene passive margin
* Waikato, King Country & Whanganui basins
© GNS Science

SEDIMENTARY BASINS OF NEW ZEALAND

BASIN	AREA (km²)	LATE CRETACEOUS CHARACTER	NEOGENE CHARACTER
TARANAKI BASIN	330,000	Failed rift, subsidence and marine transgression	Intraplate to back-arc subsiding, minor compression
CANTERBURY BASIN	360,000	Failed rift, subsidence and marine transgression	Intraplate subsiding basin
GREAT SOUTH BASIN	130,000	Failed rift, subsidence and marine transgression	Intraplate subsiding basin
BELLONA BASIN	80,000	Failed rift, subsidence and marine transgression	Intraplate subsiding basin
CAMPBELL BASIN	40,000	Failed rift, subsidence and marine transgression	Intraplate subsiding basin
CHALLENGER BASINS	120,000	Failed rift, subsidence and marine transgression	Intraplate subsiding basin
OUTER CAMPBELL BASIN	20,000	Failed rift, subsidence and marine transgression	Intraplate subsiding basin
PUKAKI BASIN	60,000	Failed rift, subsidence and marine transgression	Intraplate subsiding basin
REINGA BASIN	170,000	Failed rift, subsidence and marine transgression	Back-arc subsiding basin, some compression
WAIKATO, KING COUNTRY, AND WHANGANUI BASINS	40,000		Back-arc subsiding basin, some compression
WEST COAST BASINS	25,000	Failed rift, subsidence and marine transgression	Transform
WESTERN SOUTHLAND BASINS	40,000	Failed rift, subsidence and marine transgression	Transform to back-arc
FIORDLAND BASIN	35,000		Transform
EAST COAST BASIN	120,000	Passive margin, subsidence and marine transgression	Convergent margin fore-arc
RAUKUMARA BASIN	36,000	Passive margin, subsidence and marine transgression	Convergent margin fore-arc
NORTHEAST SLOPE BASIN	80,000	Passive margin, subsidence and marine transgression	Convergent margin fore-arc
PEGASUS BASIN	25,000	Passive margin, subsidence and marine transgression	Passive margin, subsidence and marine transgression
CHATHAM SLOPE BASIN	40,000	Passive margin, subsidence and marine transgression	Passive margin, subsidence and marine transgression
NEW CALEDONIA BASIN	300,000	Failed rift, subsidence and marine transgression	Intraplate subsiding basin

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 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 seafloor dredging 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 sometimes 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.

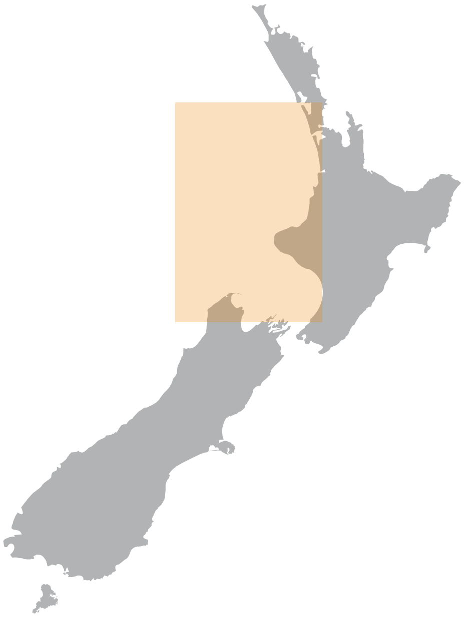
OVERBURDEN

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 Basin



BASIN SUMMARY

The Taranaki Basin covers an area of about 330,000 km^2 and is currently the only producing basin in New Zealand. This basin is contiguous with the Reinga Basin to the north and the West Coast basins to the south. Over 400 onshore and offshore exploration and production wells have been drilled in Taranaki to date. None have been drilled beyond the shelf edge. The basin remains under-explored compared to many comparable failed rift complex basins of its size and there remains considerable potential for further discoveries.

PLAYS

+ **Inversion structures**
+ **Thrust features**
+ **Extensional fault blocks**
+ **Volcanic edifices**
+ **Half-graben fills**
+ **Submarine fans**

EXPLORATION AND PRODUCTION

Wells

Over 400 onshore and offshore exploration and production wells drilled since 1950. No wells beyond the continental shelf.

Producing Fields

Offshore: Maui (gas-condensate and oil), Tui Area (oil), Pohokura (gas-condensate), Maari-Manaia (oil), Kupe (gas-condensate).

Onshore: Kapuni (gas-condensate), McKee (oil and gas), Tariki-Ahuroa (gas-condensate), Waihapa-Ngaere (oil and gas), Ngatoro (oil and gas), Kaimiro (oil and gas), Mangahewa (gas-condensate), Rimu-Kauri (oil and gas), Cheal (oil), Turangi (gas).

Recent Discoveries

Tui (2003, oil), Karewa (2003, gas), Turangi (2005, gas), Awakino South (2008, gas), Kowhai (2008, gas), Beluga (2010, gas), Copper Moki (2011, oil/gas), Sidewinder (2011, oil/gas)

GEOLOGY

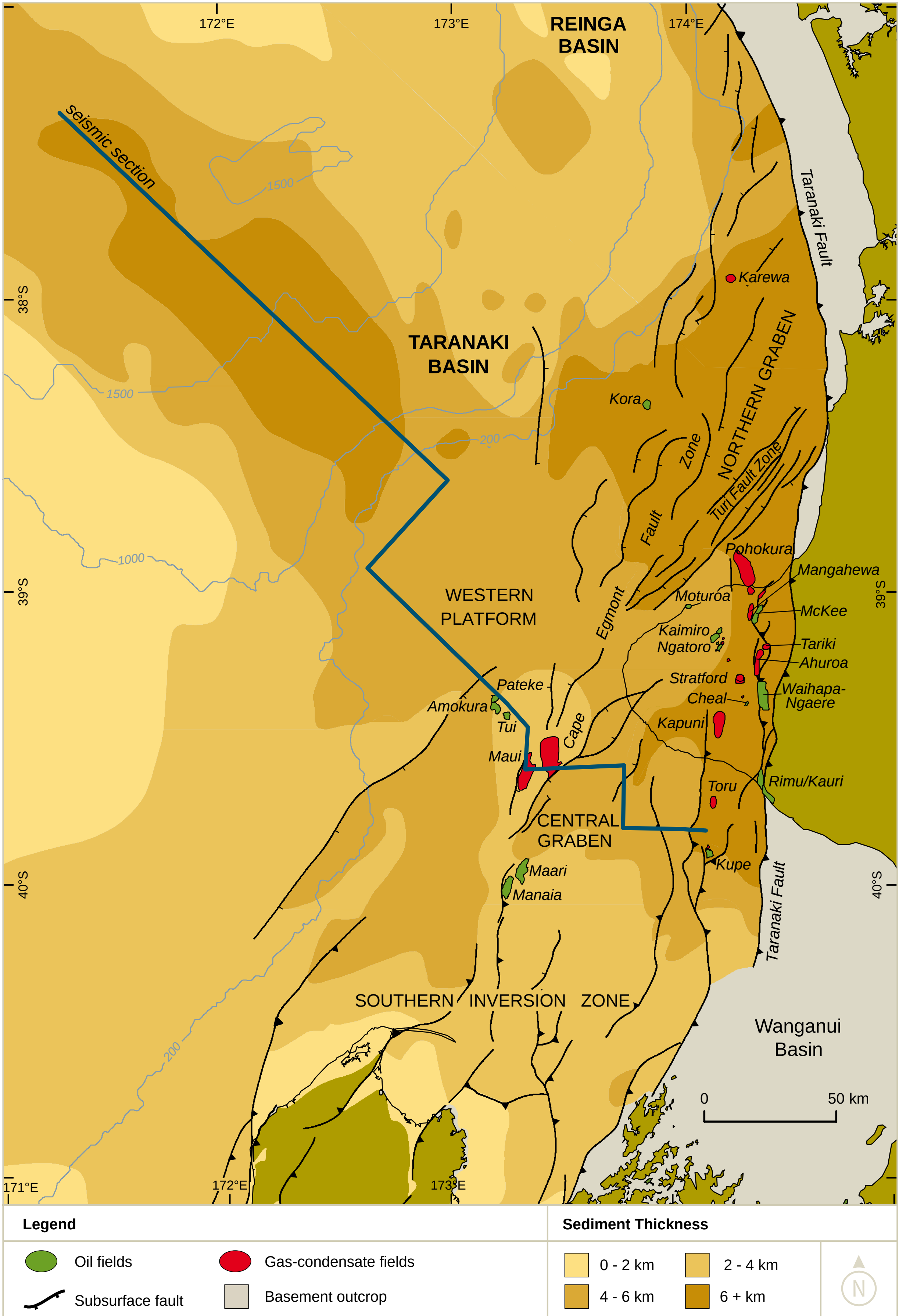
Jurassic Murihiku marine rocks and coal measures may be basement or earliest basin-fill. Early Cretaceous to Paleogene intraplate rift basin, with marine transgression and onlap. Large Cretaceous delta beyond the shelf edge. Back-arc subsidence and some compression in Neogene. Basin-fill up to 9,000 m.

Source Rocks

Jurassic, mid- to Late Cretaceous and Paleogene coaly rocks, Cretaceous and Paleocene marine shales.

Reservoir Rocks

Late Cretaceous to Eocene terrestrial, paralic and near-shore sandstones, Late Cretaceous to Pliocene turbidites, fractured Oligocene limestone, Miocene volcaniclastics, Pliocene shelf sands.


172°E
173°E
174°E
REINGA BASIN
seismic section
1500
1500
1000
200
200
38°S
39°S
40°S
171°E
TARANAKI BASIN
Taranaki Fault
Karewa
NORTHERN GRABEN
Kora
Zone
Fault
Egmont
Turi Fault Zone
Pohokura
Mangahewa
Moturoa
McKee
Kaimiro
Ngatoro
Tariki
Ahuroa
WESTERN PLATFORM
Stratford
Waihapa-Ngaere
Cheal
Pateke
Amokura
Tui
Kapuni
Cape
Maui
Toru
Rimu/Kauri
CENTRAL GRABEN
Kupe
Maari
Manaia
Taranaki Fault
SOUTHERN INVERSION ZONE
Wanganui Basin
0
50 km
Legend
Oil fields
Gas-condensate fields
Subsurface fault
Basement outcrop
Sediment Thickness
0 - 2 km
2 - 4 km
4 - 6 km
6 + km
N

BASIN HISTORY

EXPLORATION AND PRODUCTION

The Taranaki Basin produces from about 20 fields, from the giant Maui gas-condensate field (original gas reserves 3.4 tcf), to a number of small oil and gas fields of about 10 mmboe. Some 418 mmbbl of oil and 6190 bcf of gas had been produced by the end of 2011. All wells drilled so far have been onshore or on the shelf. Exploration has focused on four-way dip closures, horsts, rotated fault blocks, foreland folds and detached thrust sheets along the overthrust eastern margin of the basin. Petroleum has been encountered on a commercial scale at every stratigraphic level from Pliocene to Paleocene. Structural, stratigraphic and diagenetic trapping mechanisms have yet to be fully evaluated. Cretaceous reservoirs, especially those in the deepwater province, have not been drilled, with the first well in the deepwater province scheduled to be drilled in 2013/14.

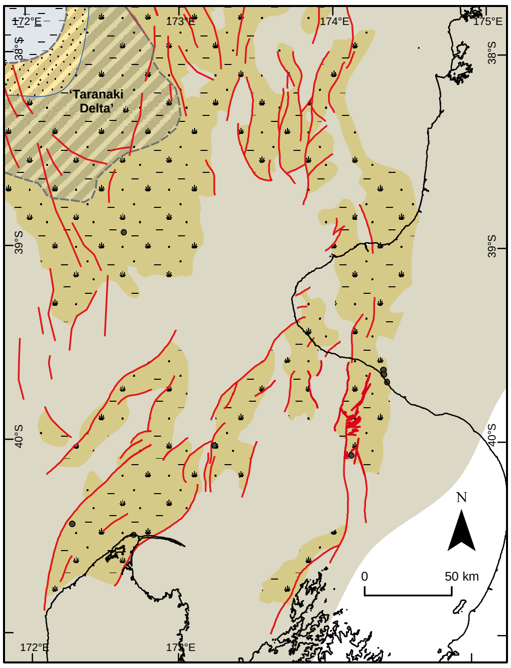
EXTENT

The Taranaki Basin was considered to extend only as far offshore as the continental shelf edge but seismic surveys over the last decade proved that thick sedimentary sequences extend into deep water beneath the modern bathymetric feature of New Caledonia Basin. Limits of the Taranaki Basin are now defined by the Taranaki Fault and associated Waimea-Flaxmore faults in the east, by a minimum sediment thickness along the flanks of Challenger Plateau and Lord Howe Rise to the southwest, and the West Norfolk Ridge to the northeast. It merges with the Reinga Basin to the north and the West Coast basins to the south. Northwest beyond New Zealand territory satellite gravity indicates that it may merge with the New Caledonia Basin. It is about 1,000 km long and up to 300 km wide and extends beyond the limit of New Zealand jurisdiction.

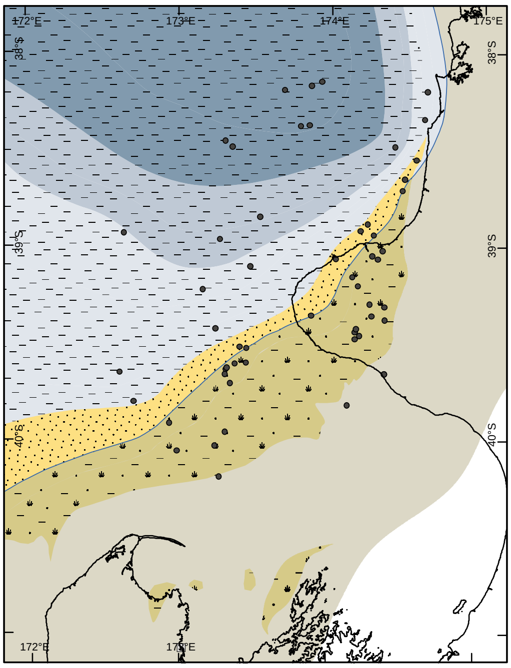
GEOLOGICAL HISTORY

The Taranaki Basin was the site of late Mesozoic extension on the landward side of the Gondwana margin. Jurassic to earliest Cretaceous Murihiku marine and non-marine rocks form either basement or the earliest basin-fill. Rift faulting diminished through the Late Cretaceous with sea floor spreading in the Tasman Sea. Terrestrial sediments deposited in early grabens and half-grabens were succeeded by thick marine rocks. A large delta built out to the northwest of the present-day shelf, fed by Late Cretaceous fluvial systems, which were transgressed in the latest Cretaceous. Eastern parts of the basin experienced north-south rifting in the Late Cretaceous and Paleocene as part of the breakup of Gondwana. Terrestrial and shallow marine deposits, including coal measures, were deposited throughout the Paleogene but, by the Oligocene,

Late Cretaceous (75 Ma) paleogeography



Middle Eocene (40 Ma) paleogeography



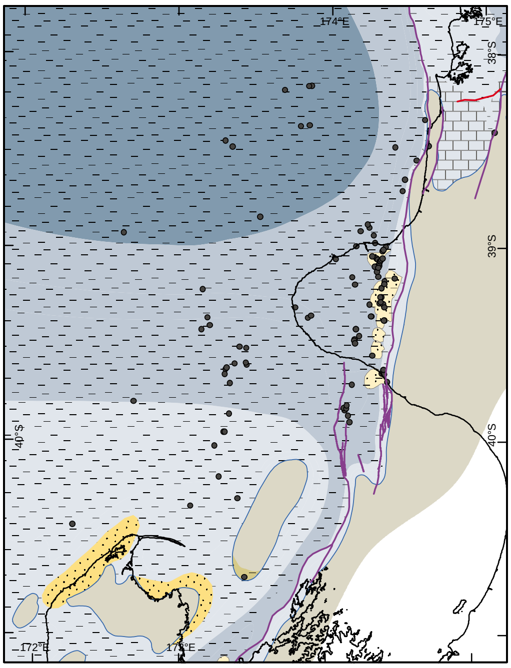
carbonates were dominant. In the Early Miocene, the first effects of the modern plate boundary were seen with the influx of an increasingly large volume of clastic sediments. Andesitic volcanism began in the Middle Miocene and continues to the present day. Turbidite systems developed from Late Eocene time (Tangaroa Fm.). Shelf progradation during the Neogene was mud-dominated, but punctuated by discrete turbidite depositional phases in the Late Oligocene (Tariki Sandstone), Middle Miocene (Moki Formation), Late Miocene (Mt Messenger Formation), and Pliocene (Mangaa Formation). The deep-water province contains a major channel and turbidite system. From the Pliocene, high rates of uplift and erosion in the hinterland led to the progradation of the shelfal clinoforms of the Giant Foresets Formation. Migration of the developing Neogene subduction complex resulted in rifting of the North Taranaki Graben during the Pliocene.

SUB-BASINS

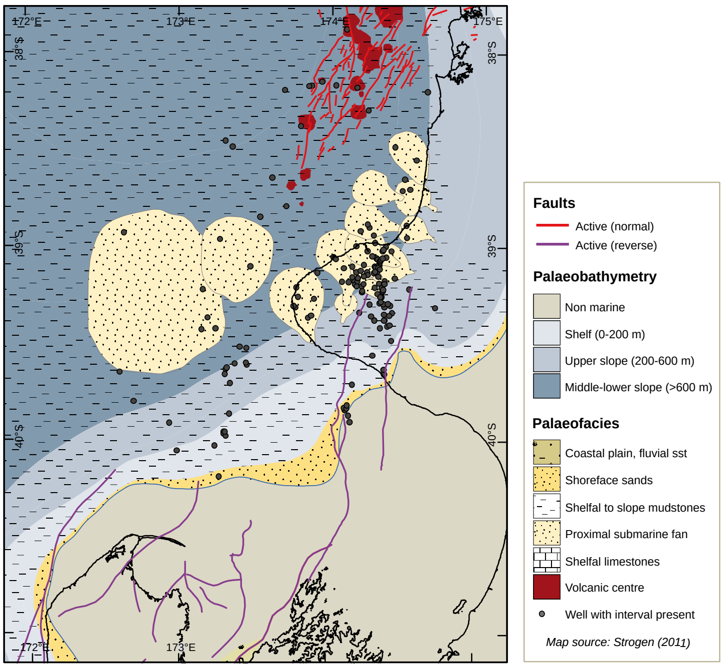
The Northern Graben is a 50 km wide Neogene depocentre, bounded by the Cape Egmont and Turi fault zones. Source rocks are mixed gas- and oil-prone and generally mature. Buried volcanoes and volcaniclastics are prospective as shown by the Kora oil discovery. Cenozoic submarine mass flow sand systems are present in stacked systems and prospective. Other significant leads include fault block plays along both margins. The Central Graben lies mostly over and south of the Taranaki Peninsula between the faulted Cape Egmont high in the west and the Manaia anticline in the east. This deep graben contains thick, mature source rocks. Possible plays include structural closures in the Cretaceous-Paleogene and stratigraphic traps in Neogene formations. The Taranaki Fault is the major reverse fault forming the eastern margin of the basin.

Neogene movement has deformed sedimentary rocks beyond the hanging wall in the complex Tarata Thrust Zone. Deformation has formed a wide range of traps at multiple levels. To the south, the zone of deformation continues in the comparable Waimea and Flaxmore faults. The Western Stable Platform has undergone limited or no Neogene deformation. It includes the Maui Field, and the recent Tui discoveries, which have confirmed generation and prospectivity. Paleogene shoreface sandstone are likely to be prospective elsewhere in the area. Beyond the present shelf edge, the Cretaceous Taranaki Delta is a thick unit of marginal to marine facies, likely to contain both source and reservoir facies. Northwest of the delta front, laterally equivalent facies of presumed mid-Cretaceous age are inferred to include marine shale source rocks and possible Cretaceous turbidites.

Oligocene (27 Ma) paleogeography



Late Miocene (10 Ma) paleogeography



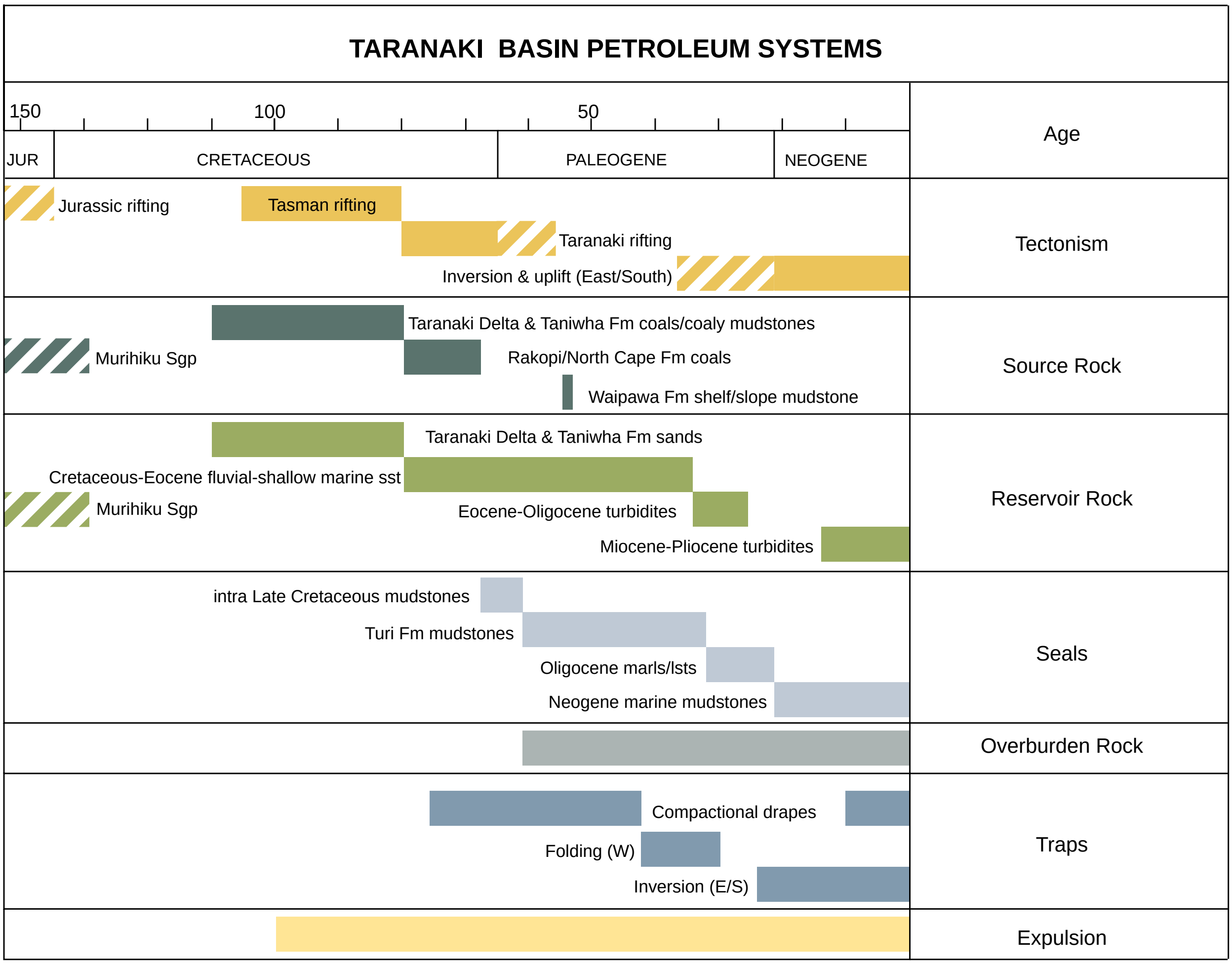
Map source: Strogen (2011)

SOURCE ROCKS AND GENERATION

Modelling of source rocks in the shelf and onshore parts of the basin suggests that about 1,600 billion bbl of oil and 2,400 tcf of gas have been expelled by Cretaceous to Eocene source rocks. No modelling has yet been attempted for the sequence beyond the shelf edge. The full potential has yet to be assessed.

The majority of Taranaki oil, primarily waxy crude of about 45° API, has been geochemically typed to Late Cretaceous to Paleogene coaly source rocks. Paralic facies accumulated on a broad, landward-migrating shelf and coastal plain, where extensive coal swamps developed. Rapid Neogene burial has brought these rocks to depths where they are mature and expelling both oil and gas today. In the deep water province, much of the Rakopi Formation remains at, or just above, the present oil expulsion window. Paleocene and Eocene coaly source rocks are generally more gas-prone than those of the Late Cretaceous, but have sourced commercial accumulations of oil in McKee and other onshore fields.
They are modelled to be mature and expelling mostly gas in deep onshore and nearshore kitchens and may be the source of gas in Kapuni and Pohokura fields.

The Waipawa Formation, a thin Late Paleocene organic-rich marine shale, is present around much of New Zealand. Oil from the Kora discovery in the Northern Graben has been geochemically typed to the Waipawa Formation, suggesting the formation is both present and mature in this area. Older pre-Late Cretaceous source rocks may be present in parts of the basin, especially in the deep water province, but are poorly understood. These include Mid Jurassic to Early Cretaceous coal measures of the Murihiku Supergroup, and the mid Cretaceous Taniwha Formation. Early parts of the basin fill in the deep water province could also include Cretaceous marine source rocks.



TARANAKI BASIN PLAYS

Taranaki Basin is characterised by its variety of play types, mostly structural in nature. The majority of wildcats to date have targeted anticlinal or four-way dip closures. The mechanisms that produced these features can be radically different due to the basin's complex tectonic history. A Miocene compressional phase following Late Cretaceous rifting produced most of the structures currently trapping hydrocarbons at several stratigraphic levels with the multiple tectonic events leading to accumulations of oil above gas. Other play concepts are associated with half-graben fill, submarine fan systems, buried volcanic edifices and diagenetic traps.

THRUST FEATURES

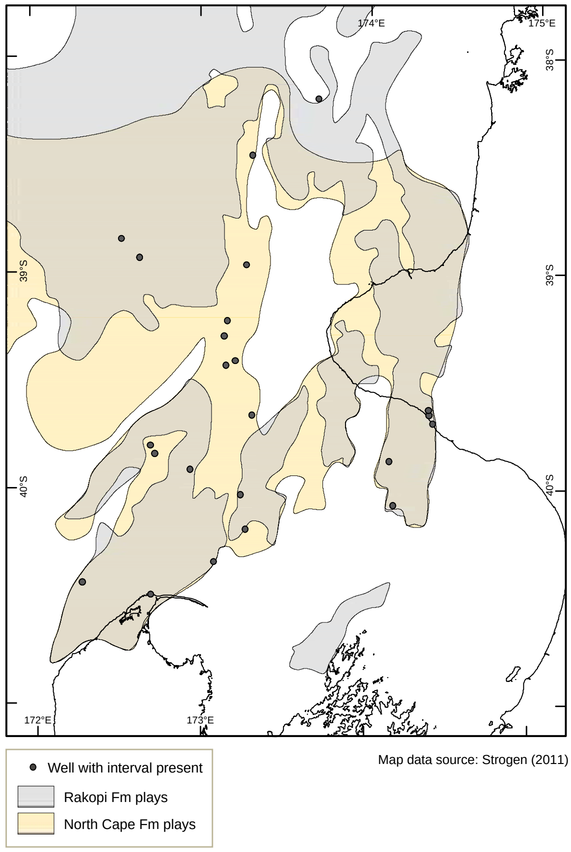
There are a number of plays along the eastern side of the Taranaki Basin associated with thrusting along the Taranaki Fault which has formed structures making up the Tarata Thrust Zone. Traps along the Tarata Thrust Zone are composed of relatively thin sheets of detached allochthonous material thrust in a westward direction. Mesozoic rocks have been thrust into Tertiary sequences forming anticlinal structures ahead of the older rocks, dislocation and repetition of Oligocene and Miocene rocks, or anticlines below the Taranaki Fault.

The producing McKee, Tariki, Ahuroa, Waihapa and Ngaere fields are assigned to this play category. Thrust traps have been the primary target of several recent successful exploration programs in the eastern Taranaki Basin, including wells drilled at Rimu-1, Huinga-1, Tuihu-1, Kauri-1 and Kahili-1. In these thrusts there are often repeated sequences below the thrust basement providing a separate play and accumulations.

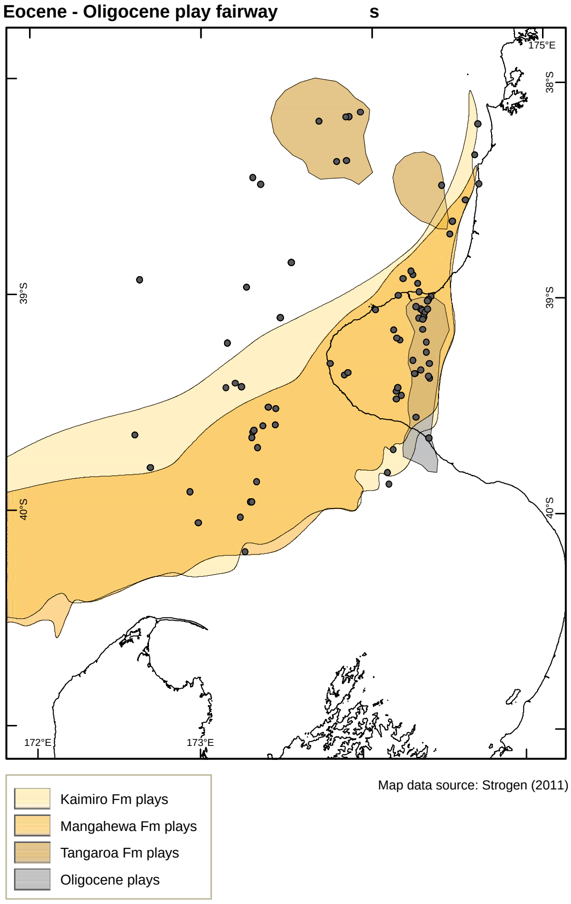
INVERSION STRUCTURES

The largest fields discovered so far in the Taranaki Basin are trapped in inversion structures. Crustal shortening during the Miocene uplifted and inverted sub-basins in the eastern and southern parts of the Taranaki Basin, causing reactivation and reversal of movement along many of the basin's extensional faults. The resulting features are generally asymmetric with more steeply dipping beds to the west. The developed and undeveloped fields at Kapuni, Mangahewa, Kupe, Maari and Pohokura fall into this category.

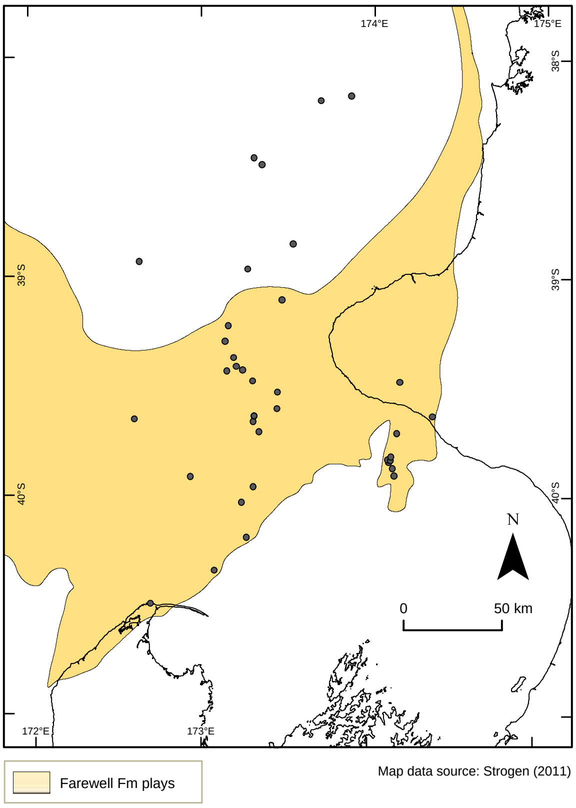
Cretaceous play fairways



Eocene - Oligocene play fairway s

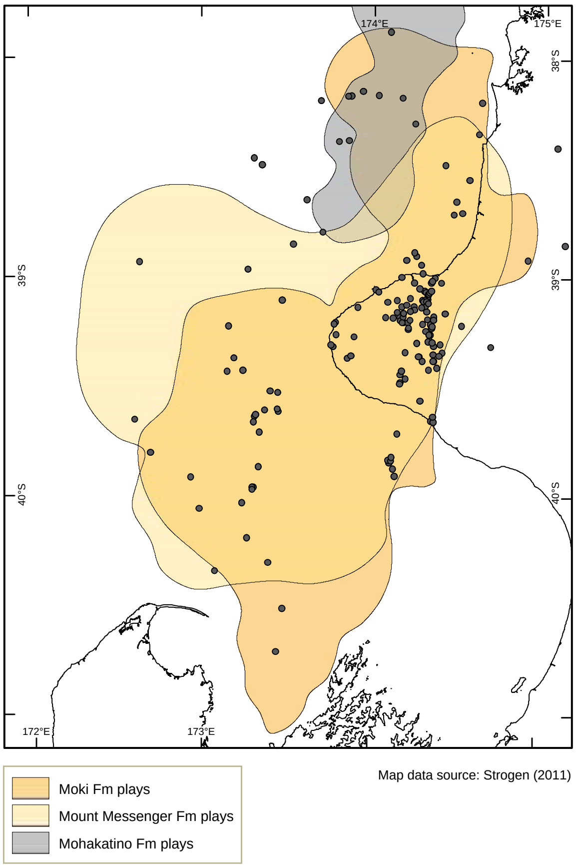


Paleocene play fairways



Map data source: Strogen (2011)

Miocene play fairways



Map data source: Strogen (2011)

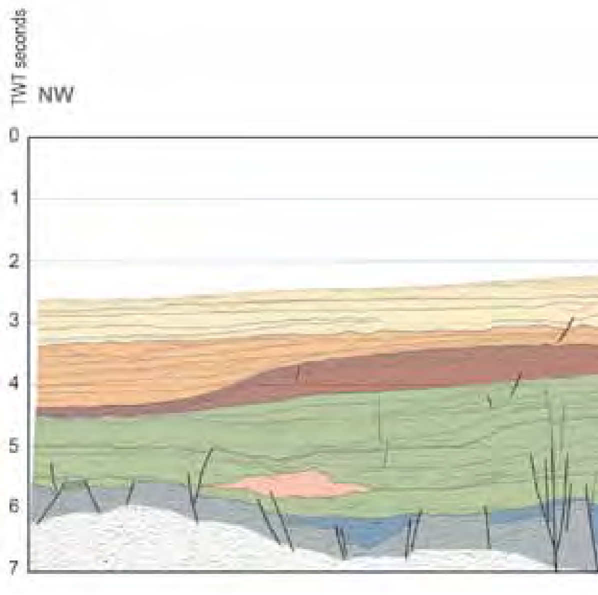
While the Maui structure is similar, it is mainly a drape structure over a fault block but with a steeper eastern limb.

Due to the early exploration successes in drilling this type of trap, most of the obvious inversion structures in the basin have been penetrated during the past five decades. Future exploration of this play concept will involve step-out wells on these features to delimit any traps with stratigraphic or diagenetic components along their margins.

EXTENSIONAL STRUCTURES

Post-compressional relaxation established a second extensional phase in the Taranaki Basin. Some normal faults that formed during Cretaceous and Paleocene rifting and experienced reverse movement in the Miocene were again subjected to a normal sense of movement in the Pliocene. Miocene uplift and subsequent Pliocene extensional tilting and block faulting created the traps at Kaimiro, Ngatoro and the recent Goldie and Windsor discoveries.

In the Northern Graben, where the inversion phase of regional tectonism had little effect, structures have been subjected primarily to extensional stresses since Late Cretaceous. Many basement-cored horst and tilted fault blocks adjacent or in the source rock kitchen depocentres have not been explored in this part of the basin. Compaction and drape of younger sediments over these highs may play an important role in trapping hydrocarbons in this part of the basin.



VOLCANIC EDIFICES

During the Miocene, a belt of submarine stratovolcanoes developed along the axis of the Northern Graben. The structures are primarily andesitic in composition and consist of volcanic and lapilli tuffs and volcanic slump breccias. Pore geometry is complex and highly variable and reservoir distribution is vertically and laterally discontinuous. Many stratovolcanoes are overlain by 1,500 to 2,000 m of Pliocene sediments and have been displaced by later normal faulting.

Kora-1, a well drilled in 1988 on the margin of the Northern Graben, penetrated the flank of the Kora stratovolcano en route to a deeper Eocene target. The volcaniclastics tested 668 bopd of 35° API gravity oil. Although not deemed economically viable at the time because of lack of adequate top seal, Kora-1 demonstrated volcaniclastic reservoir porosities up to 30% and permeabilities as high as 300 mD.

The stratovolcanoes along the axis of the Northern Graben are more deeply buried by Pliocene sediments than at Kora, and seal may be improved. In addition, the intrusive nature of the volcanic pipes that supplied magma to the stratovolcanoes has uplifted the underlying Eocene and Early Miocene reservoirs into large domes. Both of these parameters enhance the trapping capabilities in and beneath the volcanic edifices.

HALF-GRABEN FILL

Many half-grabens developed in the Taranaki Basin during the Cretaceous-Paleocene rifting episode. Although formed during extensional tectonism, half-graben traps generally differ from rotated fault blocks in the basin as they contain more unconformities and stratigraphic elements. Uplift and rotation of basement-cored blocks with syn-rift sedimentation and episodic erosional and non-depositional events produced wedges of Cretaceous fluvial and marginal marine lithologies on the dip slopes. Although potential reservoirs in Cretaceous rocks have yet to be explored, the proximity of source to reservoir in these sequences is promising. Rakopi Formation coals are believed to be the source rocks for Maui oil.

SUBMARINE FANS

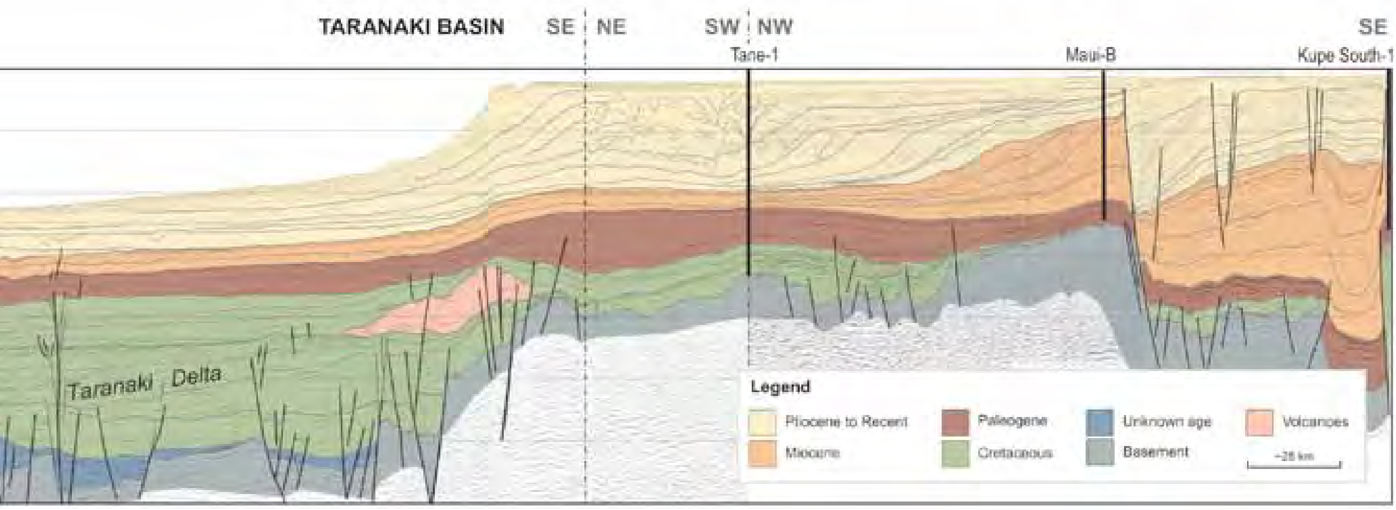
Historical exploration in Taranaki Basin concentrated on drilling anticlinal or fault block traps and the stratigraphic trapping capabilities of the Miocene turbidite sandstones were ancillary considerations. Neogene shelf and basin mass-emplaced sandstones outcrop along the Taranaki coastline and have now been penetrated by numerous wells. Miocene turbidites are the primary reservoirs in the Kaimiro and Ngatoro fields, and in Windsor-1 and Goldie-1.

Late Eocene turbidite systems have also been penetrated by several wells in the Northern Graben. Kora-1 recovered oil on test from the Tangaroa Formation, a relatively large fan complex north of the Kora structure. Thin turbidite sandstones of the Eocene Mangahewa Formation in Turi-1 exhibited good gas shows.

These wells indicate that slope and basinal fan sandstones are valid targets in the Northern Graben north of the fairway of productive Eocene paleocoast sediments that trend northeastwards through the Maui field to Pohokura. Post-rift deposition of Eocene sands is likely along the axis of the graben, but this depocentre has never been drilled. This play concept provides the most promise of large undiscovered commercial resources in the Taranaki Basin. The 2003 Karewa discovery is probably in Mangaa Formation turbidite sands of earliest Pliocene age.

DIAGENETIC TRAPS

Some of the most difficult plays to define in the Northern Graben are associated with diagenetically altered sandstones, where Miocene volcanism has altered the reservoir characteristics of Cenozoic rocks proximal to the intrusive centres. In Kora-1, located within 2 km of the igneous pipe complex that supplied magma to the Kora stratovolcano, the Eocene Tangaroa Formation exhibits much lower porosity and permeability values than penetrated by Kora-4 (20% porosity and 150 mD permeability) situated approximately 5 km from the pipe. This relationship demonstrates that a circlet of tight reservoir rock may exist near the igneous pipes that fed the stratovolcanoes, creating possible diagenetic traps for hydrocarbons in the more porous reservoir downdip. Determining the location of the transition between seal and reservoir in the same rock unit is difficult in the Northern Graben due the resolution of available seismic data, overlying volcanic edifices and lack of well control.



TARANAKI BASIN RESERVOIRS

The Taranaki Basin has producing reservoirs of Paleocene to Pliocene ages. Although there are no producing reservoirs of Cretaceous age, they remain prospective in parts of the basin. Gas-condensate and oil are found in Paleogene reservoirs, whereas Neogene reservoirs mainly trap oil. Stacked reservoirs are common in the Maui, Kapuni and Rimu/Kauri fields.

Rakopi Formation

Age: Late Cretaceous (85 to 75 Ma)

Facies: fluvial sandstones. Marginally marine-influenced in part

Distribution: Cretaceous valleys below the present shelf and onshore; coastal plain of 20,000 km^2 now below the present slope and basin floor

Porosity: up to 20%

Permeability: up to 18 mD

North Cape Formation

Age: Late Cretaceous (75 to 65 Ma)

Facies: dominantly marine, transgressive sandstones

Distribution: widespread across the basin except over the larger basement highs

Porosity: up to 26%

Permeability: over 500 mD

Farewell Formation

Age: Paleocene (65 to 55 Ma)

Facies: dominantly fluvial sandstones

Distribution: widespread across the basin except over the larger basement highs

Porosity: up to 20%

Permeability: several hundred mD

Fields: Kupe (gas), Maui (oil), Tui (oil)

Production rates:
Maui (7,500 bopd), Tui (early production 45,000 bopd from horizontal wells)

Kaimiro Formation

Age: Early to Middle Eocene (55 to 45 Ma)

Facies: cyclic lower alluvial plain, coastal plain and marginal marine sandstones

Distribution: widespread across Taranaki shelf and onshore

Porosity: over 20%

Permeability: sub-mD to several Darcies

Fields: Maui (oil and gas-condensate)

Production rates: Maui (11,000 bopd)

Mangahewa Formation

Age: Middle and Late Eocene (45 to 34 Ma)

Facies: terrestrial and marginal marine sandstones

Distribution: widespread across Taranaki shelf and onshore

Porosity: 8 to 27%

Permeability: sub-mD to several Darcies

Fields: Kapuni (gas-condensate), Maui (gas-condensate), Mangahewa (gas-condensate), Pohokura (gas-condensate)

McKee Formation

Age: Late Eocene (38 to 33 Ma)

Facies: shallow marine transgressive sandstones

Distribution: Taranaki Peninsula

Porosity: average 17%

Permeability: 20 to several hundred mD

Fields: McKee (oil and gas)

Production Rates: McKee-1 (350 bopd)

Tangaroa Formation

Age: Late Eocene (38 to 33 Ma)

Facies: turbidite sandstones

Distribution: northwestern and central Taranaki shelf

Porosity: over 20%

Permeability: up to 100 mD

Fields: shows in Tangaroa-1 and Kora-1-4

Tariki and Matapo Sandstone members

Age: Oligocene (33 to 25 Ma)

Facies: submarine fan sandstones adjacent to upthrown blocks and marine glauconitic sandstones

Distribution: northern and eastern Taranaki Peninsula (Tariki); widespread across the basin (Matapo)

Porosity: up to 23%

Permeability: very variable, up to a few hundred mD

Fields: McKee (oil), Tariki-Ahuroa (gas), Rimu (oil and gas)

Tikorangi Formation

Age: Oligocene to earliest Miocene (33 to 23 Ma)

Facies: limestones and marls

Distribution: widespread across the entire basin

Porosity: fractures - variable

Permeability: highly variable

Fields: Waihapa-Ngaere (oil), Toko, Piakau, Kupara, Rimu

Production Rates: Waihapa (early production 10,000 bopd)

Moki Formation

Age: Middle Miocene (17 to 13 Ma)

Facies: basin floor fan turbidite sandstones

Distribution: southern and central Taranaki Shelf

Porosity: up to 26%

Permeability: variable, 100 mD in Maari

Fields: Maari (oil), Kaimiro, Ngatoro

Production Rates: Maari (40,000 bopd from 5 wells)

Mount Messenger Formation

Age: Late Miocene (11 to 9 Ma)

Facies: basin floor fan and slope fan turbidite sandstones

Distribution: northern coastal outcrops, central Taranaki Peninsula, and along the axis of the deep water part of the basin

Porosity: 14 to 25%

Permeability: 20 to 800 mD

Fields: Kaimiro (oil), Ngatoro (oil)

Urenui Formation

Age: Late Miocene (9 to 5 Ma)

Facies: slope sandstones

Distribution: inshore and onshore North Taranaki, offshore, south of Taranaki Peninsula

Porosity: more than 15%

Permeability: several hundred mD

Fields: Cheal (oil)

Mangaa Formation

Age: Latest Miocene to Early Pliocene (5 to 3 Ma)

Facies: seafloor turbidite fan sandstones

Distribution:within the North Taranaki Graben and extending along the axis of the deepwater part of the basin

Porosity: 15 to 25%

Permeability: up to 200 mD

Fields: Karewa (biogenic gas)

Matemateaonga Formation

Age: Latest Miocene to Early Pliocene (7 to 5 Ma)

Facies: shelf and marginal marine sandstones and conglomerates

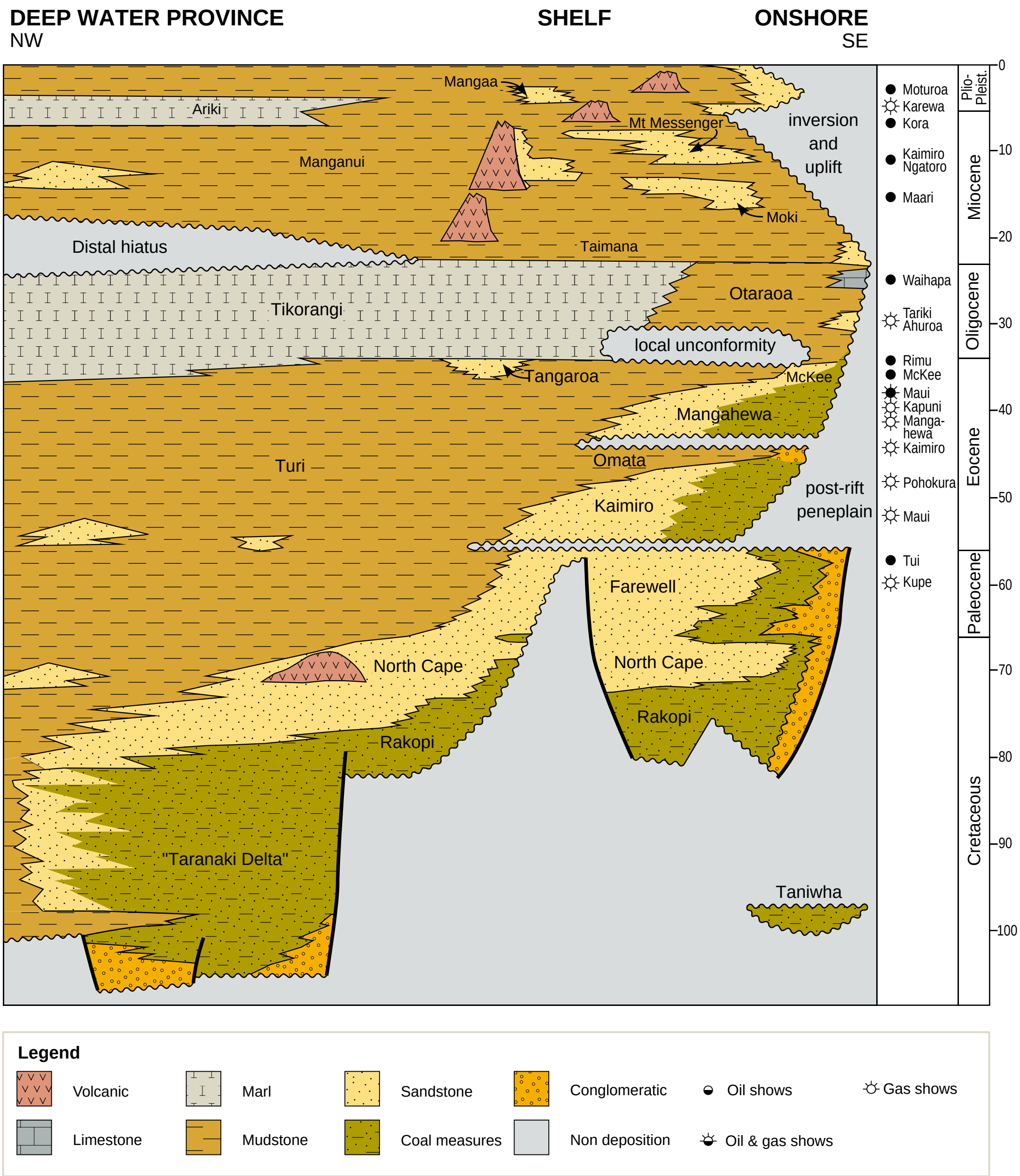
Distribution: Taranaki Peninsula and offshore to the south

Porosity: up to 25%

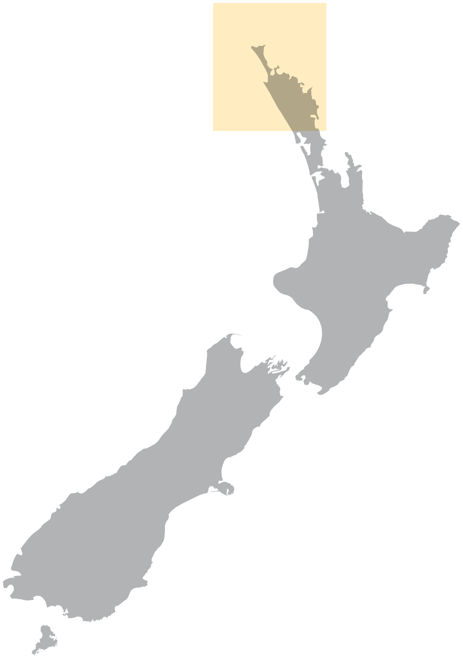
Permeability: up to 1,000 mD

Fields: Moturoa (oil)

Production Rates: Moturoa (at times up to 55 bopd)



Reinga-Northland Basin



BASIN SUMMARY

The Reinga Basin (including its Northland sector) is a large, little-explored basin that is geologically similar to the better known Taranaki Basin. In the Reinga Basin there is evidence of greater compression in the Eocene and Early Miocene, the presence of an allochthon close to the eastern margin, and some evidence of higher heat flow. The top of the oil expulsion window is modelled at 4.0 +/- 0.5 km below the seabed, implying a potential kitchen area of approximately 15,000 km^2 for Cretaceous source rocks, or a broader area if Jurassic source rocks are present. Oil and gas expulsion is modelled to occur from Late Cretaceous time, with significant expulsion predicted during and after the Eocene to Miocene folding and reverse faulting events that created structural traps.

PLAYS

- **Drape by younger sediments across upstanding basement blocks**
- **Eocene compressional structures**
- **Early Miocene compressional structures**
- **Transgressive on-lap against paleo-slopes**

EXPLORATION AND PRODUCTION

Wells

Six relevant wells: Waimamaku-1 and -2 onshore 1969 to 72; Waka Nui-1 offshore 1999; Karewa-1 (2003), Koromako-1 and Tarapunga-1 (2010) offshore at boundary with Taranaki Basin.

Hydrocarbons

Gas shows in Waimamaku-2 and reported in Koromako-1 and Tarapunga-1; small gas discovery at Karewa-1. Two gas seeps onshore. Satellite imagery shows three clusters of unassigned slicks offshore.

GEOLOGY

Jurassic marine beds and coal measures may be earliest basin-fill. Failed rift basin, transgression and on-lap from Early Cretaceous to Paleogene; Late Eocene contraction and erosion; Early Miocene back-arc subsidence, overthrusting and volcanism. Contiguous with Taranaki Basin. Up to 8,000 m of basin-fill.

Source Rocks

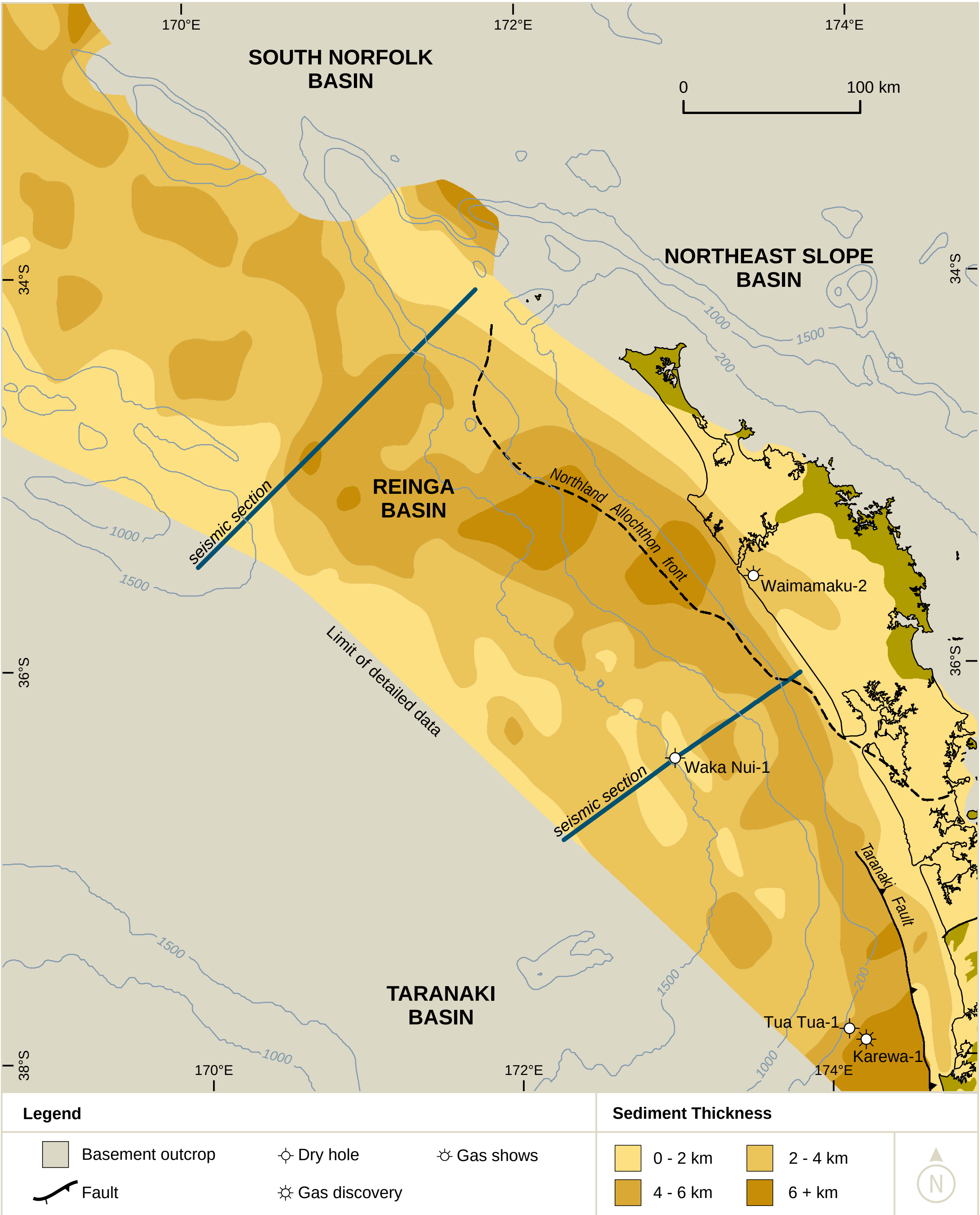
Jurassic to Eocene coal measures; Cretaceous to early Cenozoic marine mudstones including Waipawa Formation.

Reservoir Rocks

Late Cretaceous terrestrial, paralic and nearshore sandstones; Late Eocene turbidites related with erosion of the Reinga and West Norfolk ridges; Miocene volcaniclastics and turbidites.

Prospects

Strong geological similarities with the Taranaki Basin but virtually unexplored. Numerous anticlines in the north formed by Late Eocene contraction. Also includes a range of fault block highs and potential stratigraphic traps.



170°E
172°E
174°E
SOUTH NORFOLK BASIN
0
100 km
NORTHEAST SLOPE BASIN
34°S
1000
200
1500
seismic section
REINGA BASIN
Northland Allochthon front
Waimamaku-2
Limit of detailed data
36°S
Waka Nui-1
seismic section
Taranaki Fault
TARANAKI BASIN
Tua Tua-1
Karewa-1
38°S
Legend
Basement outcrop
Dry hole
Gas shows
Fault
Gas discovery
Sediment Thickness
0 - 2 km
2 - 4 km
4 - 6 km
6 + km
N

BASIN HISTORY

EXTENT

The Reinga Basin extends northwest for about 750 km, from basement outcrop in onshore Northland to the Norfolk Ridge, at the limit of New Zealand territory. It has an area of about 170,000 km^2, and is contiguous with Taranaki Basin in the south and South Norfolk Basin in the northeast. The Reinga Basin is bounded by the West Norfolk Ridge and its now-buried extension to the southwest.

EXPLORATION

The first offshore seismic data from the basin were acquired in the 1960s. In the 1970s, Mobil, Gulf and Shell each completed a regional reconnaissance survey around New Zealand, including lines across the Reinga Basin. In 1982 Geco acquired a good quality speculative survey southwest of the Northland Peninsula. Research surveys by GNS Science and Geoscience Australia included seismic acquisition and dredging, which in the early 1990s, showed that the basin extended at least as far northwest as the limit of New Zealand territory and indicated the presence of source and reservoir rocks. The basin is now covered at reconnaissance level by industry-standard seismic data, some only recently acquired. Conoco held a large permit off Northland in the 1990s and acquired about 8,000 km of 2D seismic. A 5,400 km 2D survey was acquired by Crown Minerals and CGGVeritas in 2009.

Four relevant wells have been drilled, two of which (Waimamaku-1 and -2) predated recognition that the onshore Cretaceous and Paleogene sequence is mainly allochthonous. Waimamaku-2 drilled through thrust sheets of the Northland Allochthon before reaching thin autochthon overlying earliest Cretaceous Murihiku Supergroup rocks. Minor gas shows were encountered but the drillhole was not a valid test of a structural or stratigraphic trap.

Conoco drilled Waka Nui-1 in 1,490 m of water on the dip slope of a Northland Ridge tilted fault block. Coal measures that overlie non-reflective basement were anticipated to be Cretaceous and analogous to Taniwha Formation of Taranaki. However, they were found to be Middle Jurassic, and correlated with the onshore Murihiku Supergroup. At the well site they are overlain by Paleocene conglomerate and sandstone. The well, drilled some distance down dip from the crest on the western side away from the main depocentre, found no significant hydrocarbons.

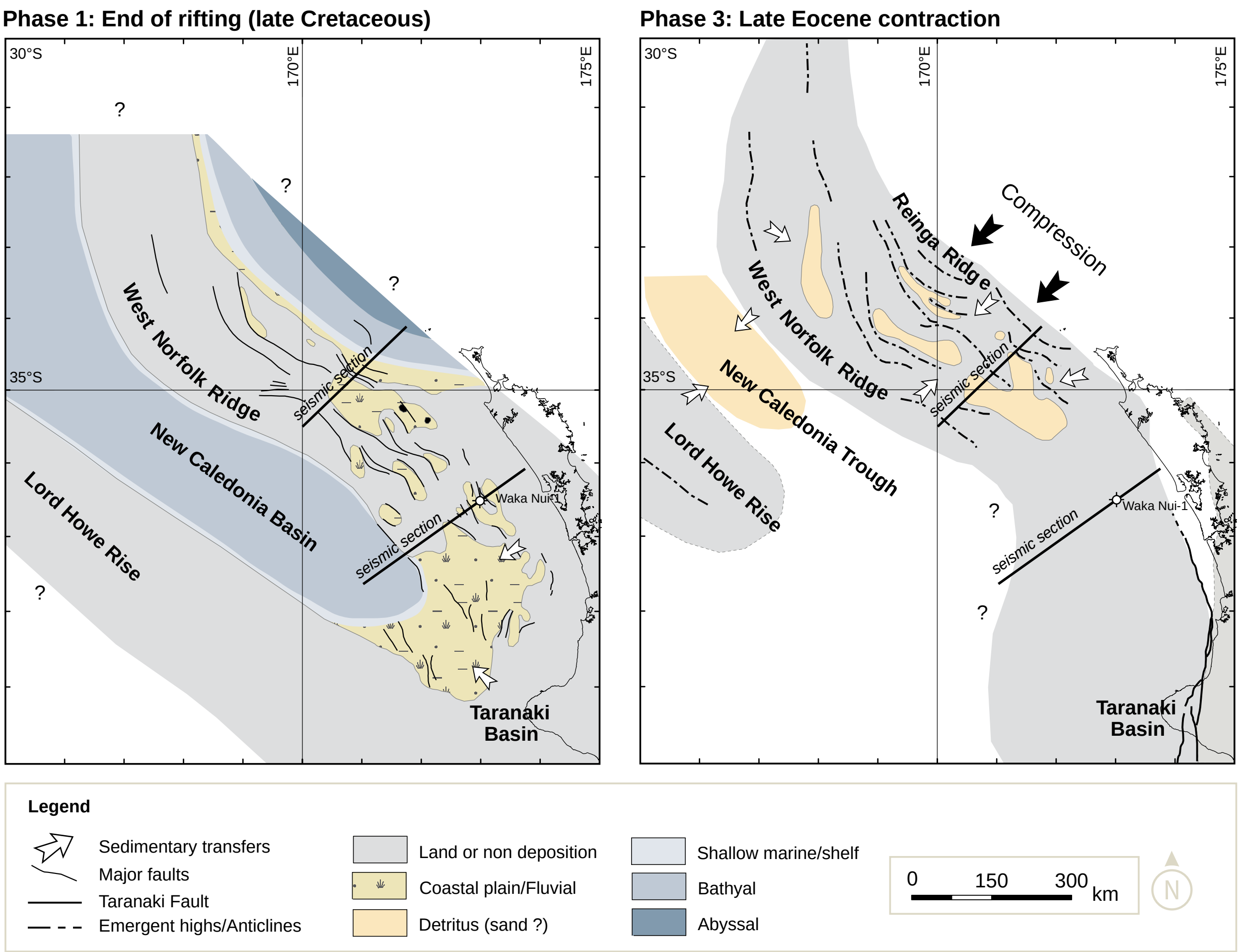
Conoco, Inpex and Todd Energy drilled Karewa-1 in 2003 to a TD of 2,023 m, discovering dry gas in Mangaa Formation turbidite sands draped across a Miocene volcano. The gas appears to be biogenic, although some higher hydrocarbons were reported.

In 2010 Origin Energy drilled Koromako-1 and Tarapunga-1 wildcat wells to a TD of about 1,000 m targeting Late Miocene and Pliocene fan complexes. Both wells had minor gas shows, but no intervals of immediate economic significance were identified.

GEOLOGICAL HISTORY

The Reinga Basin occupies a site of late Mesozoic back-arc extension close to the Gondwana margin. Jurassic and earliest Cretaceous Murihiku marine and non-marine rocks, as drilled in Waimamaku-2 and Waka Nui-1, may represent the earliest basin-fill. The Northland margin was a northwest-verging Mesozoic back-thrust to the Gondwana subduction zone, analogous to the Taranaki Fault, the margin of the modern Taranaki Basin.

Basin evolution of the Reinga Basin from the Cretaceous can be subdivided into six phases. (See the papers by Bache et al in the Suggestions for Further Reading for a more detailed explanation of the basin's evolution.)



Phase 1

Cretaceous rifting and the formation of northeast-southwest oriented elongate sub-basins.

Phase 2

Late Cretaceous and Paleogene subsidence and marine transgression. Early rift sediments were buried beneath a marine sequence.

Phase 3

Late Eocene compression and folding related to initiation of subduction by reactivation of the ancient Gondwana margin to the northeast. The Reinga and West Norfolk ridges were uplifted and eroded while detrital products were deposited in the centre of the Reinga Basin. This phase characterizes the northwestern sector of the Reinga Basin and is not clearly observed farther south in the Northland or Taranaki basins.

Phase 4

Oligocene to Early Miocene tectonism associated with subduction included regional subsidence that led to the creation of accommodation space in the centre of the basins, southwest-directed emplacement of Northland Allochthon thrust sheets into the basin, and eruption of back-arc andesitic stratovolcanoes along and close to what is now the Northland Peninsula.

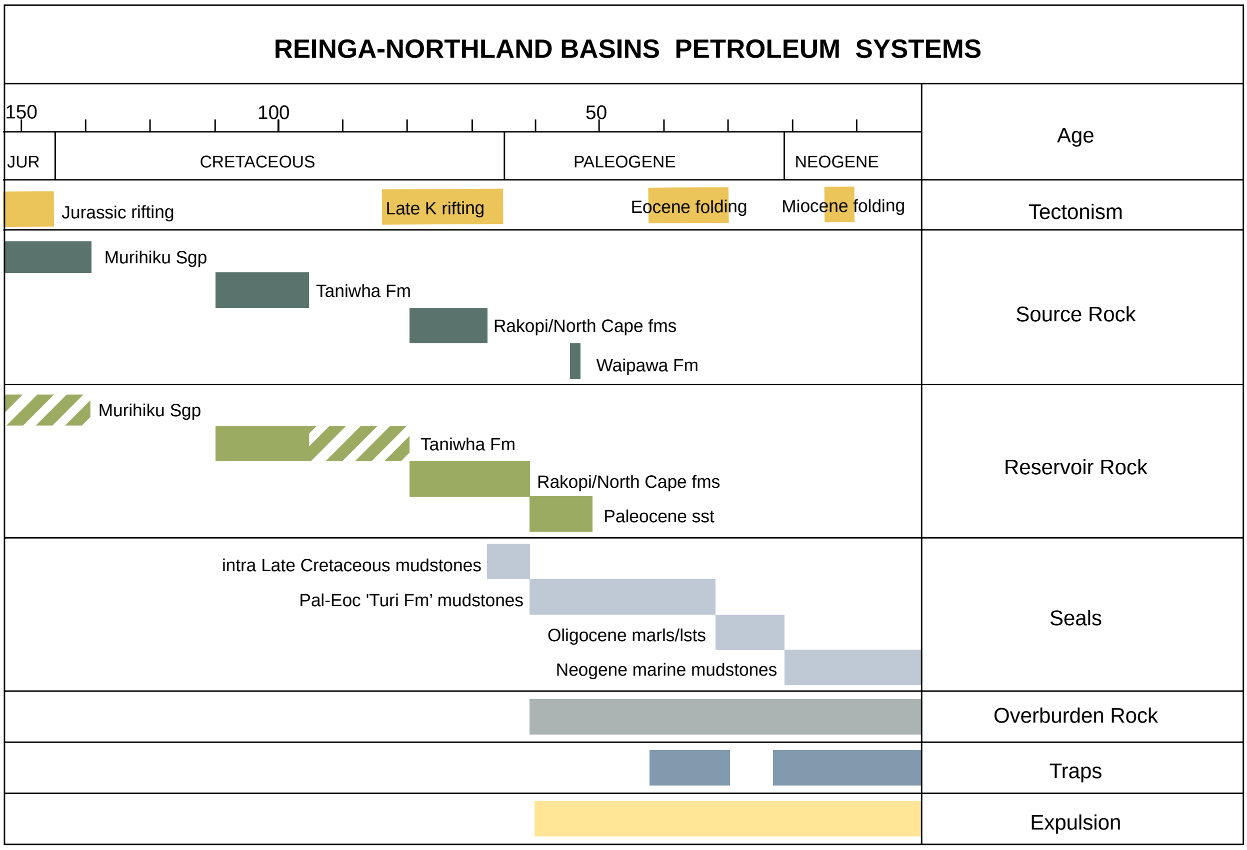
Phase 5

Uplift of the Wanganella Ridge occurred at the end of the early Miocene. In the southeastern part of the Northland Basin, the Mohakatino volcanic center was most active from middle to late Miocene. Phases 4 and 5 are interpreted to have occurred during the roll-back of the Kermadec Trench and the opening of the Norfolk and South Fiji basins. At this time dextral slip on the Veining-Meinesz Fracture Zone has been inferred to displace the Three Kings Ridge along the Reinga Ridge.

Phase 6

Late Miocene to present day quiescent period. During this time shelf and foreset beds developed in the Northland and Taranaki basins and hemipelagic ooze has been deposited in distal parts of the Reinga Basin.

There have been no petroleum exploration boreholes drilled in the Reinga Basin, and only one in the offshore Northland Basin (Waka Nui-1). As a consequence, our understanding of potential petroleum systems elements in the Reinga and Northland basins draws heavily on correlations with the Taranaki Basin.



SOURCE ROCKS AND GENERATION

Four sedimentary formations that may be present in the Reinga Basin contain potential source rocks. These are, from oldest to youngest: Murihiku Supergroup, Taniwha, Rakopi, and Waipawa formations.

High-amplitude seismic facies observed in the Reinga Basin near the base of grabens and the top of horst structures are interpreted as coaly facies. This high amplitude seismic unit is observed at the top of the horst penetrated in the Waka Nui-1 well, where Jurassic Murihiku Group mudstone, interbedded sandstone, siltstone, and coal were intersected between 3,544.5 and 3,682 m.

Seismic units in the Reinga and Northland basins are interpreted as lateral equivalents of the Taniwha, Rakopi and North Cape formations in the Taranaki Basin, and where deposited in similar settings may, contain coaly source rocks. Late Cretaceous carbonaceous sandstones and mudstones, typically associated with coal measures, have been dredged from two sites on the West Norfolk and Reinga ridges.

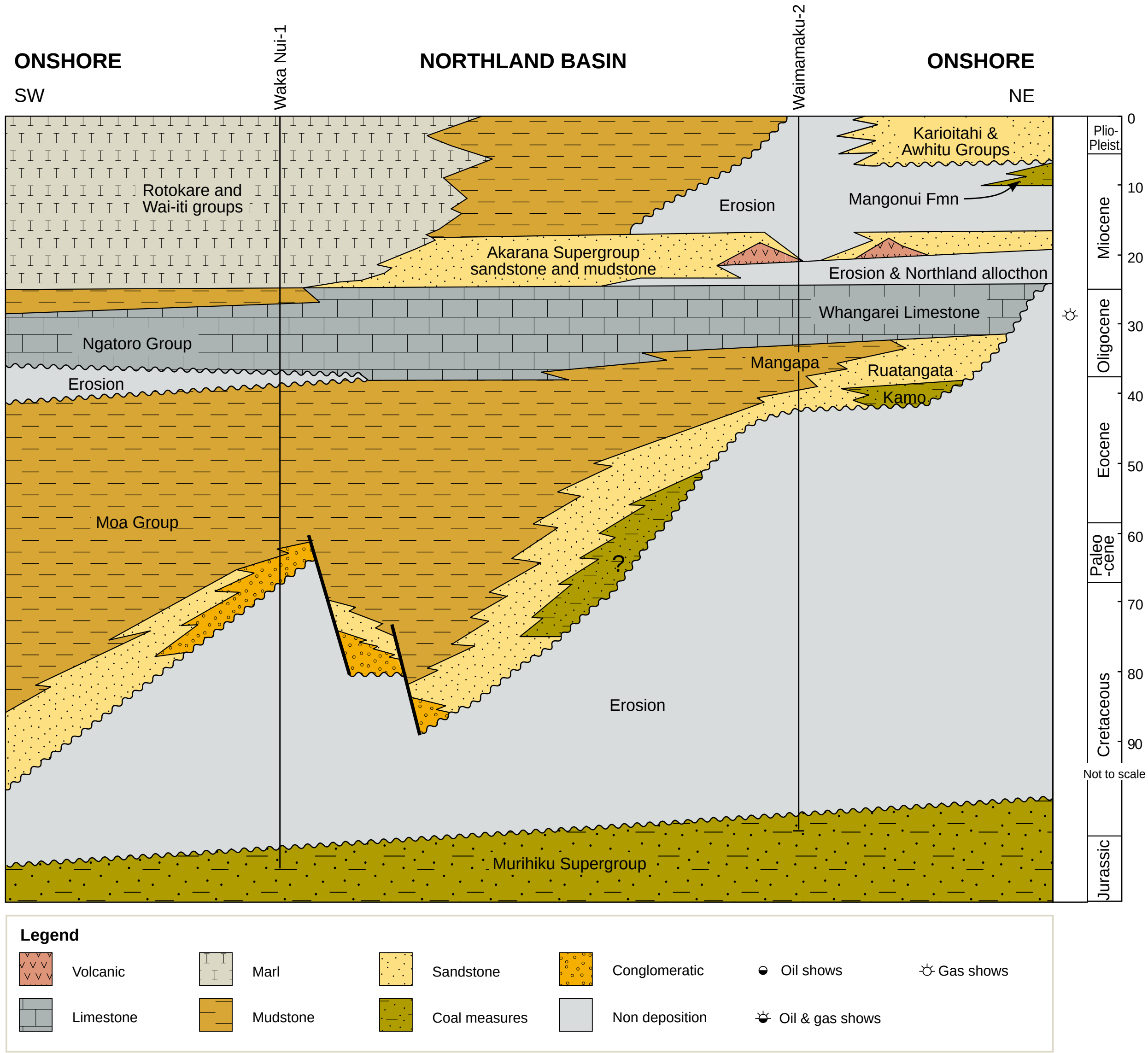
Waipawa Formation black shale of Paleocene age was drilled in Waka Nui-1. The characteristic high-amplitude signature corresponding to the formation diminishes to the north, so it is difficult to assess the presence of the Waipawa Formation in the Reinga Basin.

Maturation models predict that Cretaceous coaly source rocks within basal strata would begin to generate and expel petroleum in early Cenozoic time and expulsion would continue to the present day. The top of the oil expulsion window is modelled at 4.0 +/- 0.5 km below the seabed, implying a potential kitchen area of approximately 15,000 km^2 for Cretaceous source rocks, or a potentially broader area if Jurassic source rocks are present. Significant oil and gas expulsion is predicted to occur during and after the Eocene to Early Miocene folding and reverse faulting events that created structural traps.

REINGA-NORTHLAND BASIN PLAYS

A range of play types is recognised. In the Northland sector, where seismic coverage is relatively dense, about 50 four-way dip closures have been mapped at levels from basement to top-Miocene. Over the remainder of the basin the available seismic coverage is a reconnaissance grid with a line spacing of about 50 km, and is too coarse to map potential trap structures. However, a number of single line leads have been interpreted.

A common play type is drape by younger sediments across upstanding basement blocks. Differential compaction forms four-way dip closures. Some Eocene compressional structures are present in the central part of the basin but they are more significant in the northwest where major folds have been identified. Southwest directed convergence associated with Early Miocene subduction at the plate boundary may also have formed compressional structures. Emplacement of the Northland Allochthon resulted in deformation of the autochthonous rocks ahead of, and below, the thrust sheets.

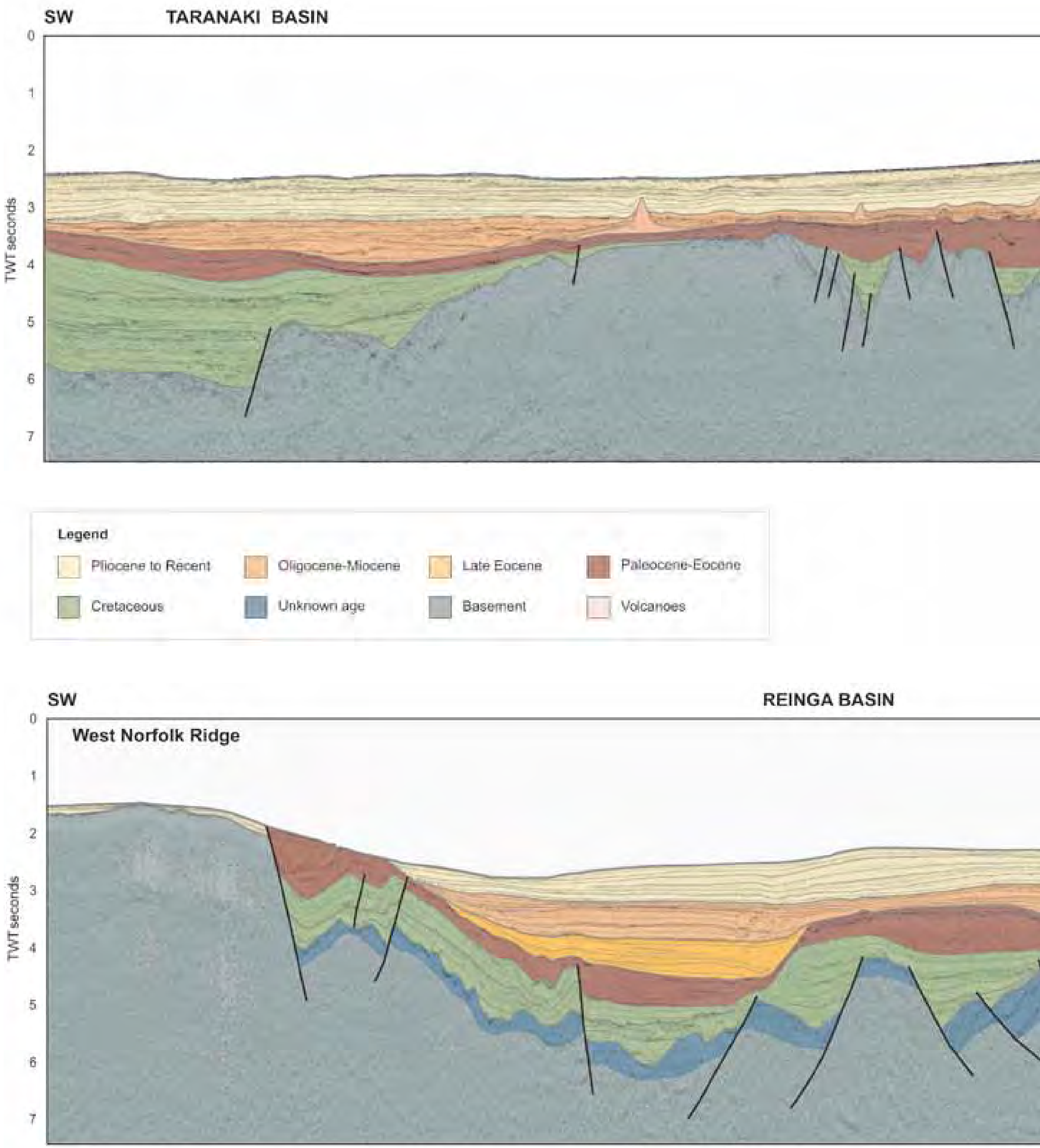


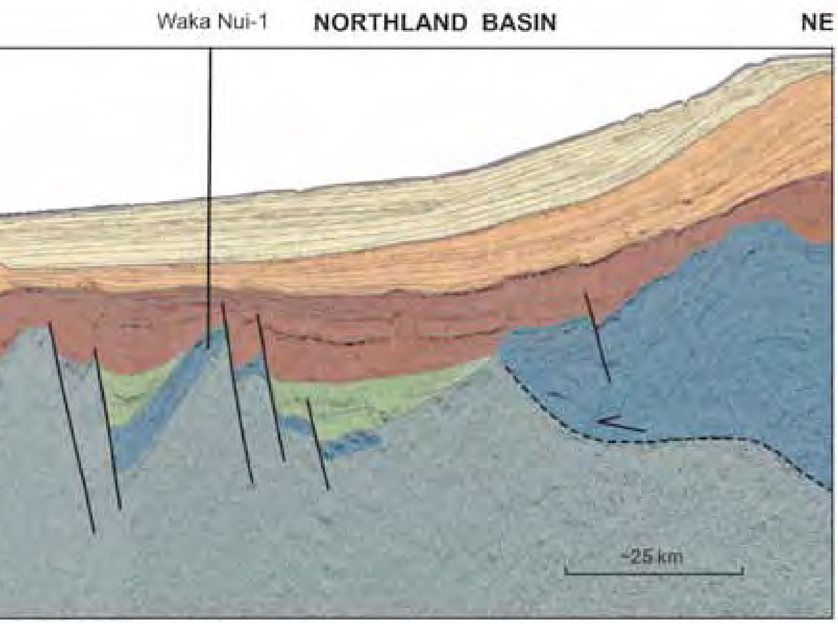
Loading by the thick thrust sheets is likely to have caused crustal flexure and roll-over, with the potential to form large traps. The area at the allochthon front is also the area of deepest burial of potential source rocks. The potential for stratigraphic trapping includes transgressive on-lap against paleoslopes, channels, and turbidite fan mounds.

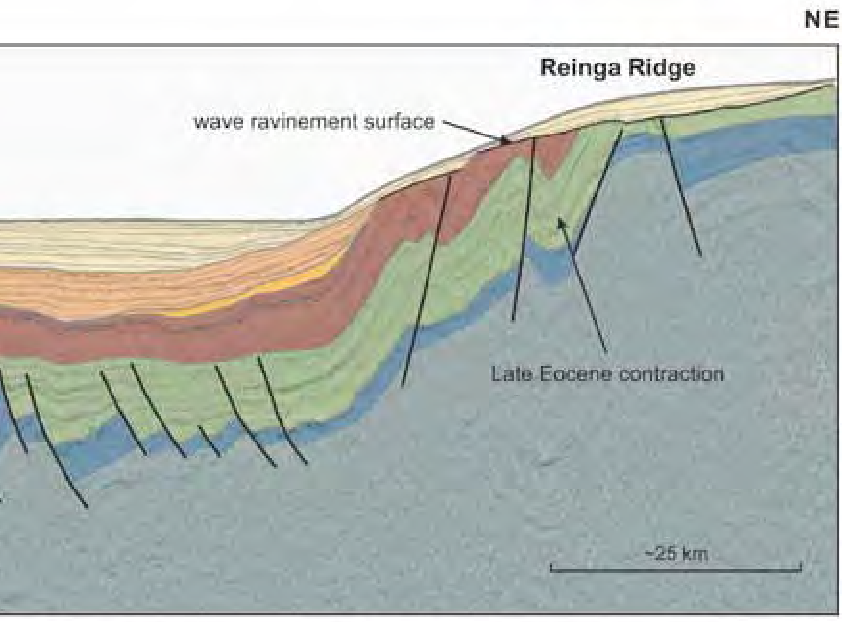
REINGA-NORTHLAND BASIN RESERVOIRS

Paleocene transgressive sands were found in Waka Nui-1. The Karewa-1 reservoir is Pliocene turbidites. Both facies are likely to be present at other levels in the basin-fill. Late Cretaceous to Eocene rocks are inferred to include shallow marine and non-marine facies as parts of the overall transgressive succession. Other possible reservoir facies are Neogene turbidite sandstones, Early Miocene volcaniclastics (as in Kora-1), and Eocene to Miocene fractured carbonates.

Late Eocene contraction (Phase 3) is recorded in the Reinga Basin by folding of older seismic units, subaerial erosion of the West Norfolk and Reinga ridges and deposition of sediment in sub-basins between uplifted structures. In sub-basins high-amplitude seismic facies within the seismic unit could represent reservoir sandstones; however this seismic unit has never been sampled. Oligocene to Early Miocene deformation (Phase 4) also led to a supply of sediment from wave abrasion, which may have been deposited as reservoirs in deep-water fans. In summary, both contractional phases recorded in the Reinga Basin (Phases 3 and 5) may have resulted in contemporaneous deposition of reservoir facies, and a wide range of structural traps were created at various deeper stratigraphic levels.


SW
TARANAKI BASIN
TWT seconds
0
1
2
3
4
5
6
7
Legend
Pliocene to Recent
Oligocene-Miocene
Late Eocene
Paleocene-Eocene
Cretaceous
Unknown age
Basement
Volcanoes
SW
REINGA BASIN
West Norfolk Ridge


Waka Nui-1
NORTHLAND BASIN
NE
~25 km


NE
Reinga Ridge
wave ravinement surface
Late Eocene contraction
~25 km