

Petroleum Potential of the Late Cretaceous-Palaeogene Sediments of the Reinga, Northland and Deepwater Taranaki Basins*

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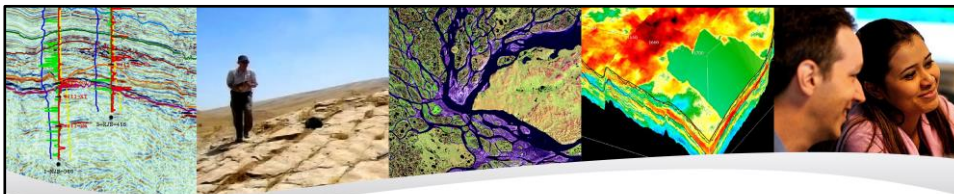
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Abstract

Extensive sampling from 15 wells and a set of 2D seismic dip lines located close to the shelf margin of Reinga, Northland and Deepwater Taranaki Basins formed the key datasets for a regional study. Existing biostratigraphic reports and petrophysical analysis of wireline data were reviewed and integrated with new petrographic and geochemical TOC analyses, reservoir quality QEMSCAN analyses and a detailed sequence stratigraphic interpretation, and post-stack seismic inversion. This integrated approach allowed the extrapolation of well analysis across the whole area based on a framework of key sequence boundaries interpreted from Cretaceous through Miocene. Basin modelling was conducted to assess source rock maturity, and reservoir interval porosity was inferred from acoustic impedance via seismic reservoir characterization, enabling quantification of reservoir quality in deeper water away from well coverage. These basins formed near the margin of Gondwana in a mainly Late Cretaceous rift phase that led to the separation of the New Zealand micro-continent from Australia and Antarctica. Two post-rift inversion events have been recorded. Also, the study has identified mass transport systems, including Cretaceous delta complexes, Miocene channels and Miocene deepwater turbidites. All petroleum systems elements are present in the study area: source rock intervals in the syn-rift and early post-rift; clastic reservoirs have been identified and attempts made to quantify quality; regional seal intervals have been identified; traps types include listric faults, four-way dip closures and inversion structures.



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Passion for Geoscience



Presenter's notes: This project was put together by several teams across the CGG network, incorporating a suite of different disciplines now available to us as a result of recent integration. More specifically, the 'traditional' disciplines of sedimentology, biostratigraphy, geochemistry and basin modelling from teams in North Wales worked closely with the seismic reservoir characterisation teams in Houston TX in a two way QC process to create a unique dataset.

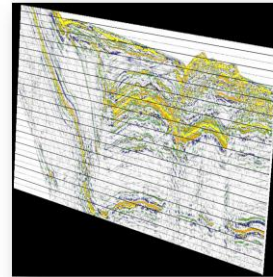
Also, local expertise from our Australian colleagues based in Perth WA proved an invaluable addition to the team.

Summary

- Four main reservoir intervals have been previously recognised within the Taranaki, Deepwater Taranaki and Reinga Basins
 - Miocene, Eocene, Paleocene and Cretaceous
- The reservoir quality of these four intervals from 15 wells have been studied using a variety of techniques and integrated in order to gain insight into their character into the wider basin
- All wells located upon the shelf – use them to add geological value to seismic in the less constrained part of the basin
- **Step 1:** Petrography and Automated mineralogy (QEMSCAN) and the Identification of depositional features using seismic
- **Step 2:** Extrapolation and QC of well data can be applied to identifiable features from seismic using Seismic Reservoir Characterisation

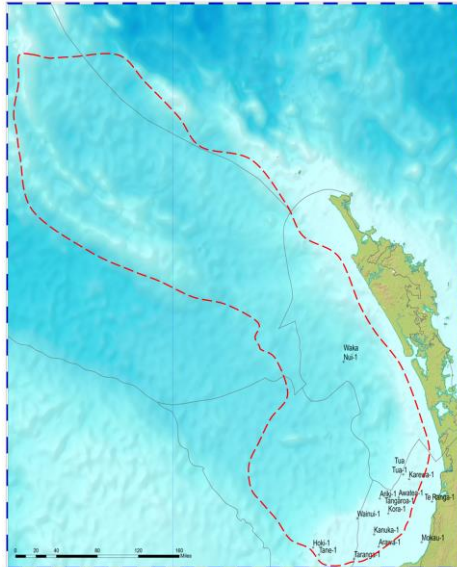
The integration of these traditional methods allows us to bring geology to the seismic

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Presenter's notes: 4 main reservoir intervals are widely recognised, namely Miocene and Eocene turbidites, shallow marine Paleocene sands and marginal marine to deltaics of the Cretaceous. Step 1 was to identify 15 wells and carry out a thorough biostratigraphical, sedimentological and geochemical analysis on each in order to identify reservoirs and reservoir quality as well as possible source rock intervals in well using core description, petrography and automated mineralogy (QEMSCAN). Step 2 was then to use this in-well data and carry out petrophysical analysis carried out by our SRC colleagues in Houston, QC'd using the geological findings from step 1 in order to improve accuracy. The petrophysical analysis then formed the bases of the inversion models used to extrapolate reservoir quality into the wider basin. The main reasons for doing this project are were to use the geological in-well knowledge gained to provide geological value to the seismic across the wider basin which may be less constrained.

Study Area



- Under-explored area
- 250,000 km²
- No wells in Reinga Basin
- Reinga is significantly more structurally complex
- Using wells located on the shelf to extrapolate into the deepwater

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Presenter's notes: As of early 2015 the Deepwater Taranaki Basins and Reinga Basins remain highly underexplored with only Romney-1 being drilled in 2014 in the Deepwater Taranaki and none at all in the Reinga Basin.

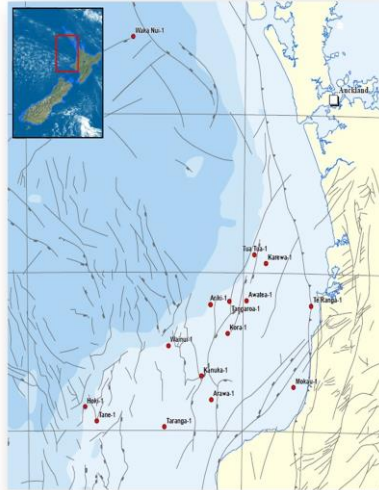
The study used an array of seismic datasets covering the Taranaki, Deepwater Taranaki and the 2009 Reinga survey in order to identify potential structural and stratigraphic features which may offer promising prospects, with the aid of seismic reservoir characterisation.

Reinga offered several challenges in carrying this out however, due to the lack of well constraints and structural complexities.

The map to the left shows the list of wells selected upon the Taranaki shelf. The wells were selected based on depth of penetration (thus range of reservoir intervals present) and completeness of sample availability for analysis.

Well Data

- 15 study wells from the Taranaki Basin margin and Reinga Basin
- Five wells also had cores
 - Kora-1, Mokau-1, Tane-1, Tangaroa-1 and Te Ranga-1
- Cores and side wall cores were preferentially selected for petrography.
 - Cores were analysed using Automated Mineralogy (QEMSCAN)
 - Side-wall cores analysed using petrography
- Where neither was available, ditch cuttings were used



Presenter's notes: The figure on the right shows the 15 wells selection in more detail. 5 of the wells had core available which were described in order to ascertain a possible depositional environment through facies analysis. The cores were also sampled for automated mineralogy and a series of side wall core plugs were taken from each well where available from various intervals through the well and analysed using petrography. Where neither core or side wall cores where available, ditch cuttings were used. The aim of the sampling was to cover as many of the possible reservoir intervals as possible and characterise them lithologically as best as possible.

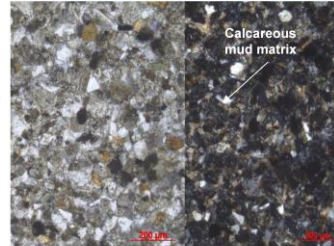
Step 1 ...

The identification and analysis of reservoir quality at well scale using petrography, automated mineralogy and biostratigraphy and also the identification of large scale depositional systems within the basin ...

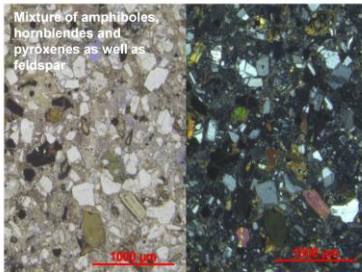


Petrography: example from the Miocene

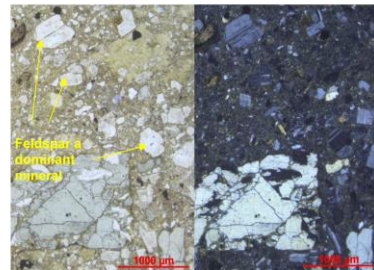
- Petrographic data highlights significant volumes of basic minerals such as hornblende and amphibole as well as feldspar in the Miocene
- Supported by a clay-rich matrix, likely to contain smectite and kaolinite
 - authigenic illite is unlikely due to shallow burial depths
- Virtually zero macroporosity is visually apparent, with any log porosity most likely associated with microporosity from the clay and calcareous matrix



Example from Kora-1 2631m



Example from Tangaroa-1 2347m



Example from Wainui-1 2490m

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Presenter's notes: This slide contains an example of the petrographic results from sidewall cores collected from Miocene intervals. The samples collected were made into thin sections and each was described in terms of their detrital and authigenic mineralogy.

These observations formed an integral part of the reservoir quality analysis through the observations of habits of authigenic minerals and how they affect reservoir quality through either the filling or preservation of macroporosity.

In this example it was found that significant amounts of basic minerals were found as well as feldspars which are locally degraded, increasing clay content.

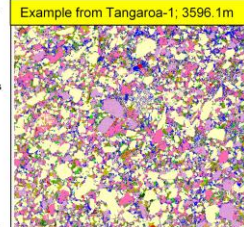
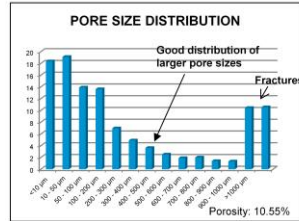
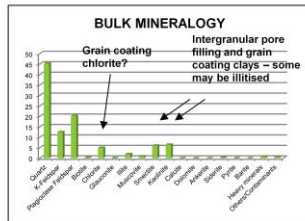
A clay-rich matrix supported most of the samples, possibly made up of smectite and kaolinite, although illite is unlikely due to shallow burial depths.

Virtually no macroporosity is observed in this example, most likely associated with clay abundance and local calcareous intervals.

Any porosity seen on wireline logs is most likely associated with less effective microporosity.

Automated Mineralogy: example from the Eocene

- Automated Mineralogy provides wider insight into sample composition and porosity characteristics where petrography might not
- Highlights notable amounts of intergranular kaolinite and minor illite in the matrix
 - At depths >3500m, the illitisation of clays may have taken place which can reduce permeability by narrowing pore throats
- However, it suggests good macroporosity (10.55%, below) where petrography may not do so
 - Pore size can also be quantified with many macropores being <200 microns
- Larger macropores are still present however, which may be connected through the smaller pores



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Presenter's notes: This slide is an example of the analysis performed through automated mineralogy.

The images and plots below show summary of the data collected as part of this analysis. This includes (from left to right) a summary of the bulk mineralogy, pore size distribution and a 'mineralogical map', showing the forms and habits of minerals.

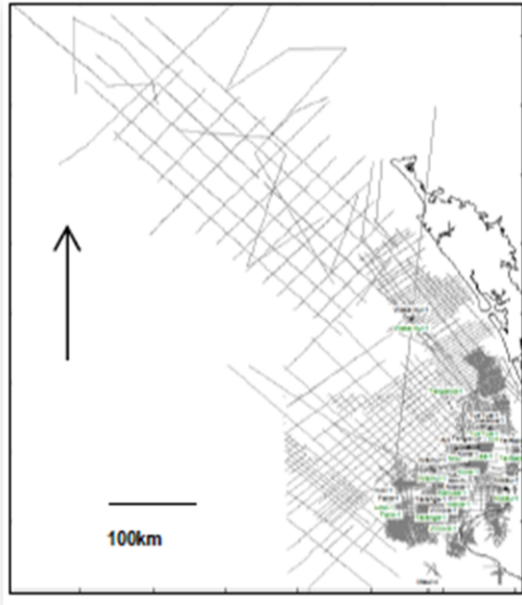
The image above shows the a thin section from a sandstone of similar texture and composition. The benefits of automated mineralogy is the accurate quantification of both detrital and authigenic minerals and their habits, which can form an important part of reservoir quality analysis. Another benefit of the analysis of core pieces, is being able to carry out pore distribution analysis, which allows for the determination not only of porosity but also the frequency of pore sizes and locations.

For example, if a sample is found to have a porosity of 15% but the majority of pores are <50microns, we can say it may be a less effective reservoir than first thought.

The example above shows an example data set from the Miocene. In the samples from the Tangaroa Formation of Tangaroa-1, AM found notable amounts intergranular kaolinite and minor illite which may filled some pore spaces and occluded pore throats. However, AM also suggests porosity to remain relatively good at just over 10%, which when looking at the thin section slide may not be quite so obvious. The pore size distribution also indicates a significant percentage of macropores of between 50-200microns. However the mineralogy map suggests connectivity may be the main issue.

Seismic Dataset

- This exercise allowed us to identify geological features and upscale potential reservoir systems on a regional scale
- Over 260,000 km² of seismic was available for the study from the Taranaki, Deepwater Taranaki and Reinga basins

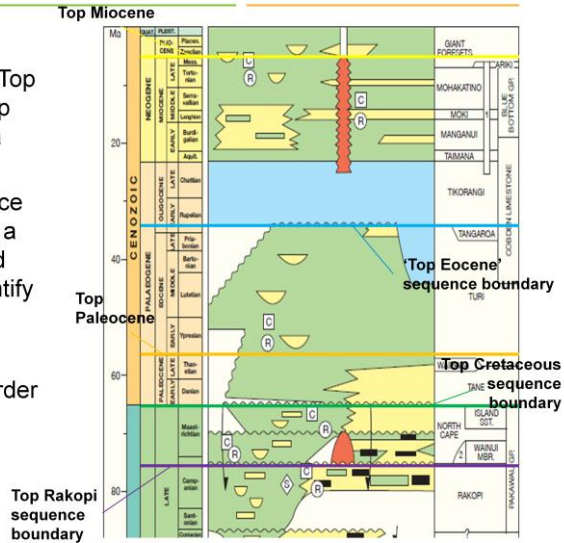


Presenter's notes: The seismic dataset was used principally to identify any key geological features which may hold promise as reservoirs, such as stratigraphic or structural traps. The map on the right shows a summary of the seismic suite used.

Over 260,000km² was made available for the study covering the offshore Taranaki, Deepwater Taranaki and recently released 2009 Reinga survey.

Seismic Dataset

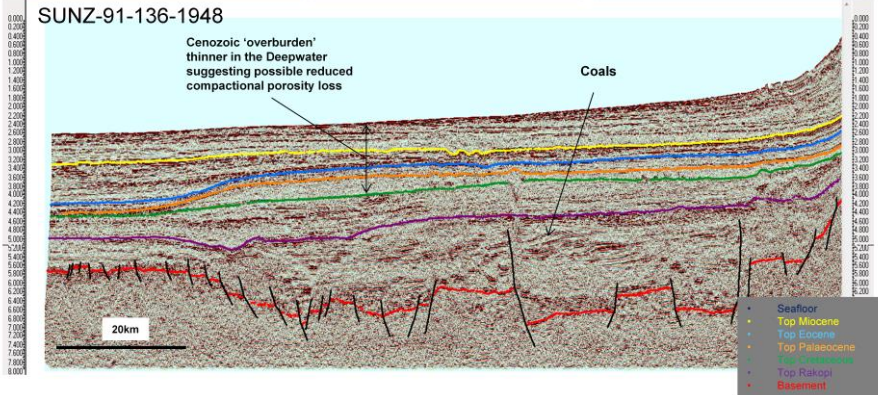
- Seven surfaces were mapped:
 - Basement, Top Cretaceous, Top Paleocene, Top 'Eocene', Top Miocene, Intra Pliocene, Sea floor
 - The constitute major sequence boundaries identified through a hard copy review of lines and tied to biostratigraphy to identify ages
- SRC then also performed a seismic inversion exercise in order to produce reservoir quality insights into the deeper basin



Presenter's notes: 7 surfaces were mapped across the entire seismic study area. They represent a series of major and important sequence boundaries with their ages constrained by biostratigraphy. These included; basement, top Cretaceous, top Paleocene, top Eocene (biostratigraphy found this surface to be slightly younger but tied with a major sequence boundary and so the surface was kept), top Miocene, intra-Pliocene and the sea floor.

SRC then performed the inversion exercise was then constrained by these sequence boundaries in order to produce insights into reservoir quality into the deeper parts of the basin.

Deepwater Reservoir Potential – Taranaki Delta



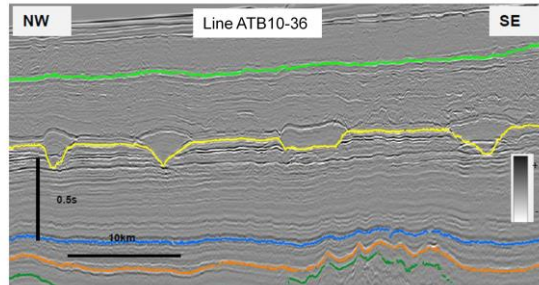
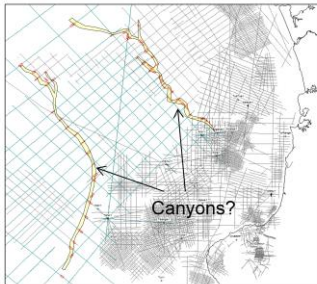
- High amplitude reflections suggest the continuation of deltaic facies well into the Deepwater Taranaki Basin
- There is also potential for the presence of thick packages of distributary channels, splays and overbanks within the synrift sections
- The character of these reservoirs may not necessarily reflect that of the Taranaki Basin due to thinner Cenozoic 'overburden' possibly allowing for lower compactional loss??
- These high amplitudes may represent coals, potentially in great thicknesses and frequency, which could be a possible source rock

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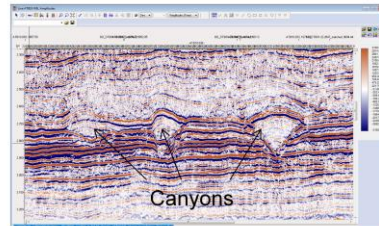


Presenter's notes: One of the well known features in the Deepwater Taranaki region the Taranaki Delta of Cretaceous age. The delta contains an array of coaly source facies and reservoir deltaic sandstone within it, also with the possibility of distributary channels, splays and capping overbanks further down in the synrift sections. The more coaly facies can be identified by the high amplitude reflectors that can be identified in the Rakopi Formation (purple top). However, these facies are not so much in uppermost Cretaceous North Cape Formation (green top), suggesting a possible more marginal marine influence as a result of transgression. In the offshore Taranaki region, many of the associated sandstones have undergone significant compaction due to being buried under over 4km of substrate. However in the Deepwater Taranaki region the 'Cenozoic overburden' is considerably thinner (approximately 2km) which may have led to reduced compactional porosity loss and thus possibly improving reservoir quality. It is also unknown as to how far to the north and west this feature extends and may have developed a more marine signature much earlier as a result of the onset of transgression from the north east.

Major Miocene submarine canyons



- Submarine canyons feed sediments into deep-water basins
- Over 250km in length and 5–6km in width
- Differential compaction suggests they may be sand-filled



Presenter's notes: Another important feature that was found as part of the seismic analysis was the presence of submarine canyons developed in the Miocene spreading out to the north west. These canyons suggest the redistribution of sediment from the uplifting areas to the south and east to the New Caledonia Basins over 250km away to the north and west. The channels have been observed to be 5-6km in width. The differential compaction surrounding the channels themselves suggests they may be sand filled, as alluded to by the curvature of the substrate above the channel and apparent difference in amplitude in the channel.

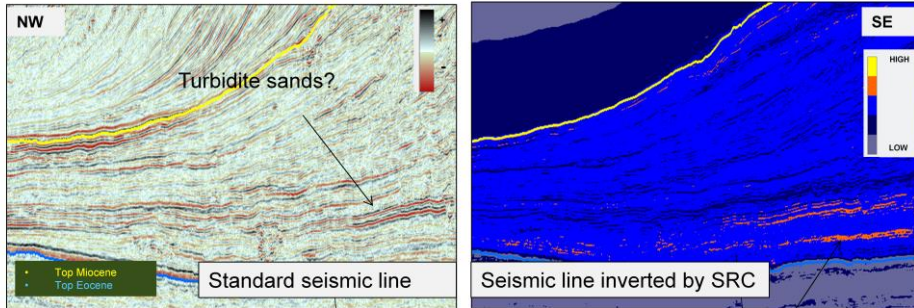
Step 2...

Having QC'd lithology and reservoir properties through sedimentology at well scale and identified potential depositional systems in seismic, we can extrapolate this into the wider basin by integrating with Seismic Reservoir Characterisation in order to identify reservoir properties and migration pathways in unconstrained seismic



Seismic inversion - Miocene toe of slope sands

Example from Deepwater Taranaki Survey



High porosity
sands at toe of
slope? – low
impedance



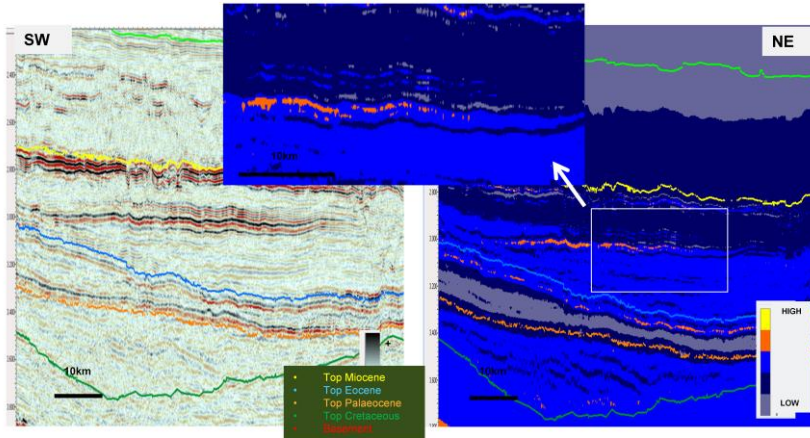
Presenter's notes: One of the major benefits of performing the seismic inversion is that it can turn an otherwise uninteresting section of seismic (left) into something that may be of more interest (right). The example on the right has had all of the middle impedance values rendered out with only high impedance values in blue and high values in a red to orange colour (the key on the right indicates porosity not impedance).

Therefore the image can be thought of as a probability of porosity image with the orange features having a high probability of good porosities due to them containing only low impedance values and the surrounding blue features having a high probability of being low porosity as they contain mostly high impedance.

It is thought the example on the right is a possible turbidite sandstone unit with basinal muds overlying them. The orange colours suggest the sands have a good probability of good porosities within it.

Seismic inversion - Eocene and Miocene sands?

Example from Reinga Survey



Bodies with low impedance – high porosity?

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Presenter's notes: This is another example from the Reinga survey.

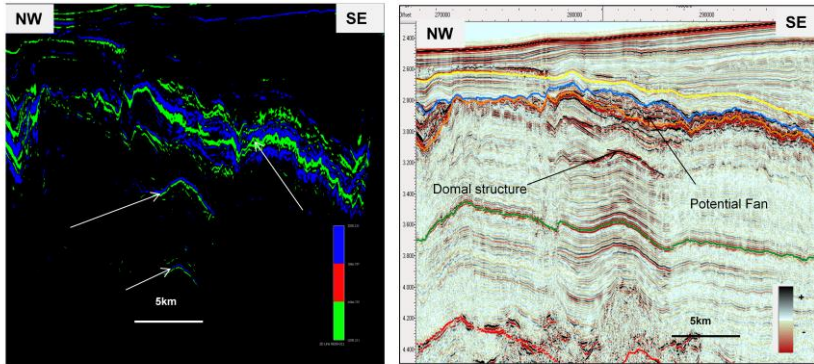
Again with the middle impedance values rendered out we can see numerous extensive features with bright orange colours in the Miocene (top is yellow horizon) and small patches in the Eocene (top is light blue horizon), suggesting a high probability of good porosities within these bodies, surrounded by lithologies of poor porosities.

These bodies may offer the possibilities of stratigraphic traps with good porosity sands surrounded by shales. However, facies of these bodies remain unknown due to poor well coverage.

Although, given our knowledge of the overall tectonic and depositional setting of the region it is suggested that these units may be mass flow deposits of some sort, but this open to be proven otherwise.

Seismic inversion - Eocene fan systems

Example from Reinga Survey – RE09-09



- Possible fan systems back-stepping above an unconformity?
- Due to the lack of well control, the sedimentary character of these systems is unknown
- SRC results suggests a low impedance which may indicate the potential for moderate to good porosities

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Presenter's notes: This slide shows a much nicer example, again from the Reinga 2009 survey, of a series of units with the probability of good porosity (blue) overlain by units with a high probability of low porosities (green).

Geologically, this suggests the possibility of a series of reservoir sandstone stratigraphic traps (blue) with intra-formational seals (green) overlying them.

Again, the facies and sedimentary character of these units remain unknown, however there is clearly a backstepping pattern apparent.

These deposits may represent either a mass flow deposit or even possibly a back-stepping shoreface of some sort, although this interpretation is speculative at best due to the lack of well control.

Seismic inversion – Insights into petroleum potential

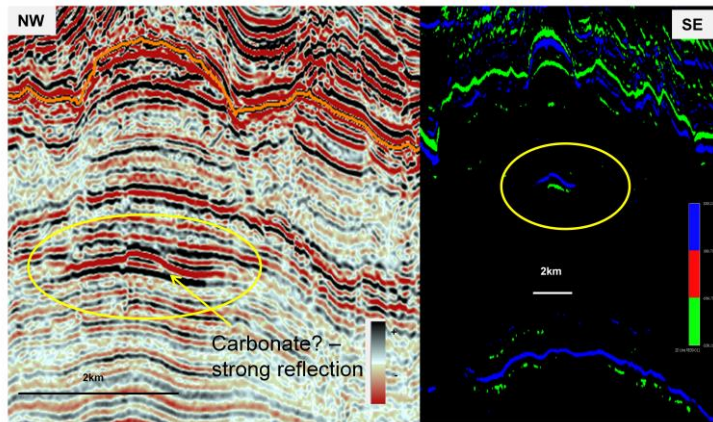
- Direct hydrocarbon indicators seen on seismic and seismic attributes/inversion
- Structural traps observed – flat spots
- Stratigraphic traps - fans
- Possible vertical migration pathways



Presenter's notes: Once we looked at the seismic inversion results in more detail, we found it had other uses than just identifying units with good porosity. For example;

- We were able to spot direct hydrocarbon indicators also seen on seismic and seismic attributes
- We were able to identify structural traps through the observations of flat spots which were emphasised by the inversion
- As previously alluded to, stratigraphic traps became more obvious as a result of the relationship between high porosity and low porosity units directly overlying each other
- And also we were able to spot possible migration pathways as a result of carrying out inversion through faulted sections.

Charging? – Paleocene mound



Lower impedance values more opaque

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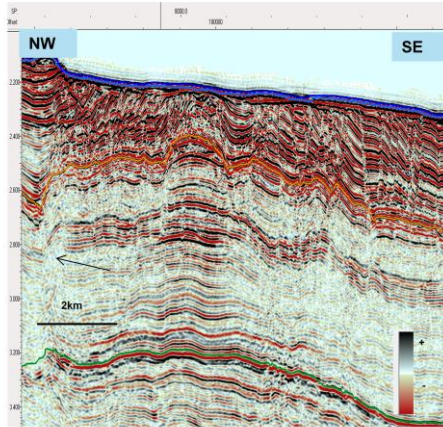


Presenter's notes: This slide has created much debate in our teams with one of two explanations possible. The strong reflection of the feature circled from the Reinga survey could possibly represent a carbonate mound of some sort, although as this has been identified in the Palaeocene, this seems unlikely under our current knowledge.

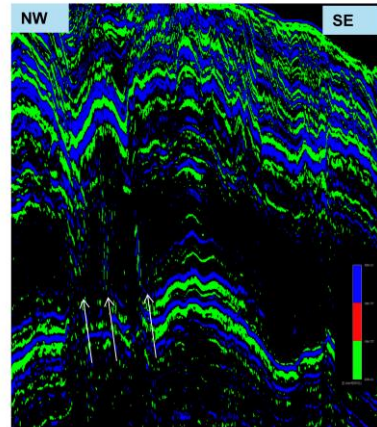
Alternatively, it could possibly represent a flat spot of some sort, indicating charging of a unit.

Further understanding of this is quite important as the latter interpretation hints at the possibility of active petroleum systems in the Reinga Basin.

Hydrocarbon migration?



Evidence of hydrocarbon migration?

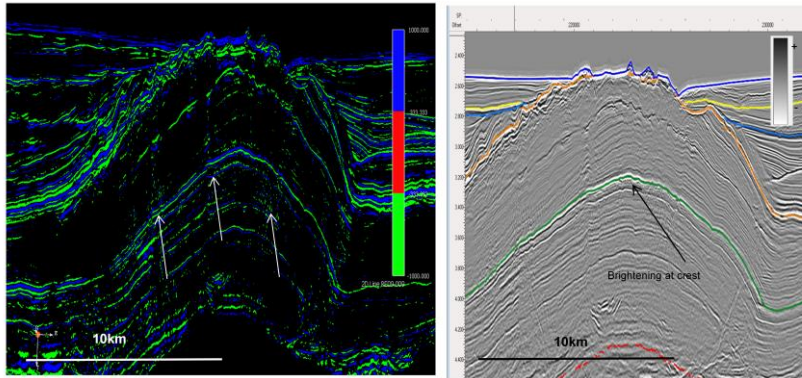


Opacity rendering of relative impedance



Presenter's notes: Another addition to the inversion study was the identification of possible migration pathways along faults. Looking at the seismic section on the left, the faults are easily identifiable but little else is known about them. However, once the inversion is run it became apparent that the faults were highlighted by low impedance colours (image on the right) indicating porosity of some sort. This has been interpreted as the faults may in fact be open which would allow for migration through them.

Migration? - Vertical migration pathways and brightening



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Presenter's notes: This is a much larger example from the Wanganella Ridge in the Reinga Basin.

Again the faults are easily visible on the seismic section (right) but the inversion also highlights the faults with low impedance colours, suggesting that they also might be open.

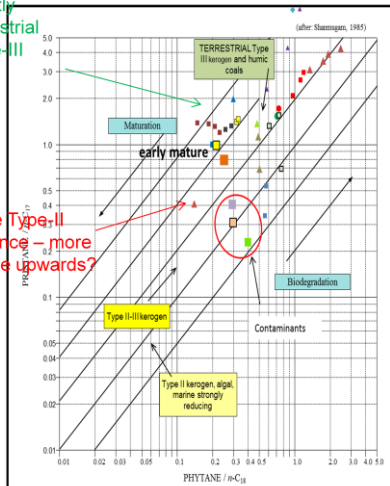
In this example it is worth noting that the faults penetrate the Cretaceous sections which, at least given our current knowledge, hold the most promise for source rocks and therefore may allow for any hydrocarbons to migrate to the good quality reservoirs of the Miocene and Eocene.

Another promising feature from this example is the brightening at the crest of the Cretaceous Top (green horizon) suggesting hydrocarbons may be produced in some form or other.

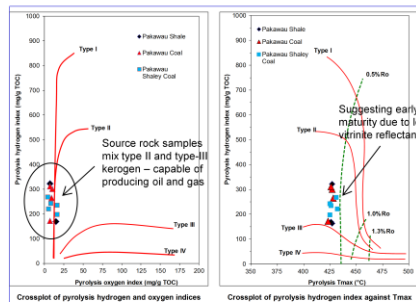
What are the sources? - Cretaceous coals

Mostly terrestrial
Type-III

Some Type-II
influence – more
marine upwards?



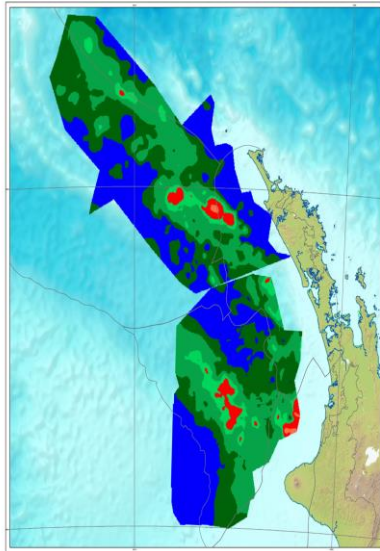
- Geochemistry data suggests Cretaceous coals are capable of producing both Type-II and –III kerogen
 - can produce both oil and gas
- The samples analysed in Tane-1 are just early mature
- However in deeper parts of the basin, or areas with a higher geothermal gradient due to volcanism, these coals may become more mature



20

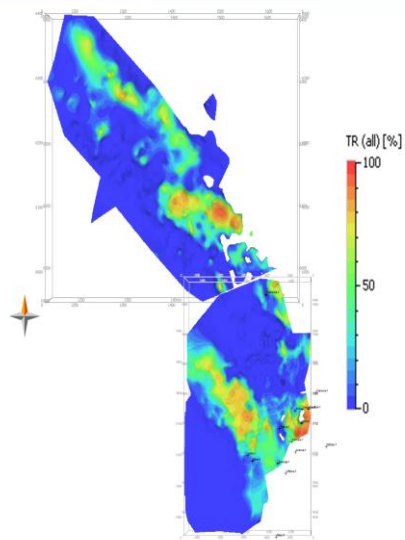
Presenter's notes: Geochemical analysis was also carried out, and this example shows the findings from the Cretaceous Wainui Member of the North Cape Formation from Tane-1. It was found that this formation contain a mix of type II and type III kerogens, capable of producing both oil and gas. Which interestingly suggests a terrestrial setting with a strong marine influence. This may indicate a series of frequent transgressions periodically inundating the area. Disappointingly these analysis found the kerogens to be early mature. However, in the Deepwater Taranaki basin where they are buried much deeper or in areas with a higher geothermal gradient possibly such as the Reinga due to all of the volcanics and tectonic activity, the coals may be more mature due to higher heats and pressure.

What are the sources? - Cretaceous coals



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Source rock maturity map



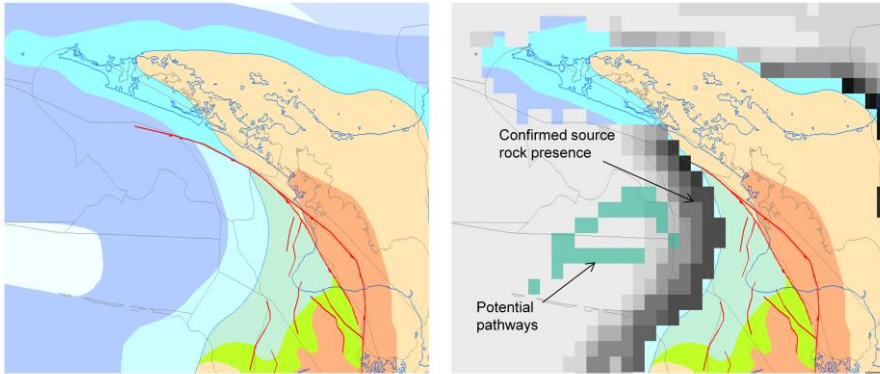
Transformation Ratio overlay



Presenter's notes: The basin modelling undertaken shows the Cretaceous Coals within the oil window with deep areas in the gas window. Transformation ratios over 50% are described in a few depocenters.

Further source potential?

- Turi Formation (Waipawa?)
 - Paleocene coastal to marine on shelf – marine oil-prone kerogens in deepwater
 - Also Cretaceous becomes more marine upwards – Type II?



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Presenter's notes: Also, other source rock possibilities exist.

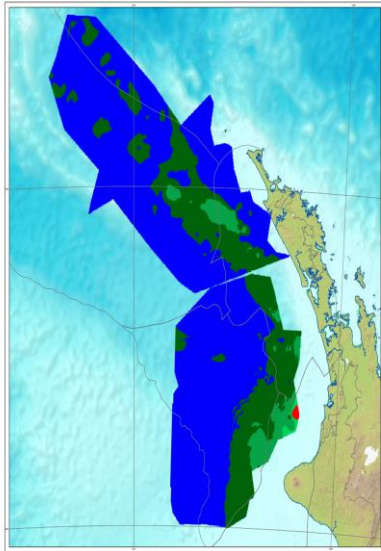
This is an example of source rock prediction work carried out on the Turi Formation Waipawa equivalent interval by the Robertson Merlin product.

The black colouration on the right image shows confirmed areas of source potential with the grey colour highlighting areas of greater uncertainty.

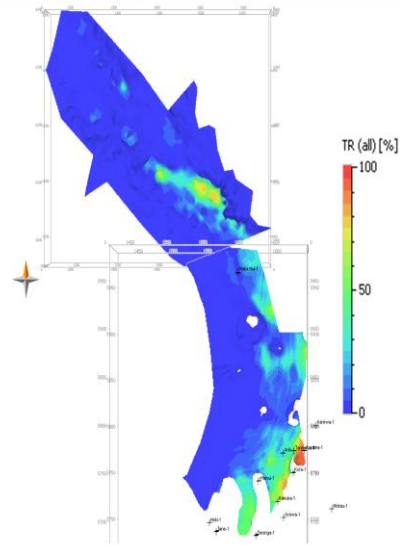
It would appear the Waipawa source rock is mostly confined to the shelf edge where very little clastic input penetrated in the Paleocene due to coastline retreat but water depths still remained shallow enough for organic material to accumulate.

It is unknown at this point if this source rock was established in the Reinga.

Further source potential? Turi Formation (Waipawa?)



23 **Source rock maturity map**



Transformation Ratio overlay



Presenter's notes: The basin modelling undertaken shows Turi Formation partially within the oil window, especially in Northland and Deepwater Taranaki. Transformation ratios over 50% are described in a few depocenters.

Summary and Study Implications



Summary and Study Implications

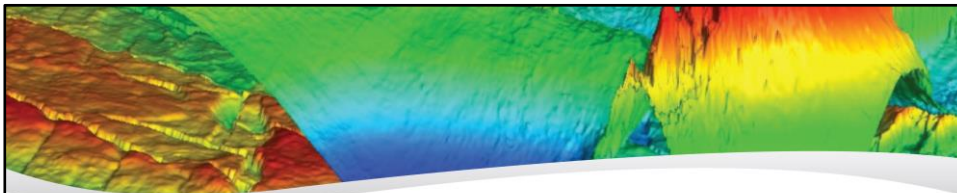
- Cretaceous reservoirs are likely to be abundant across much of the Deepwater Taranaki Basin due to the extensive Taranaki Delta complex
 - Compactional porosity loss may not be so significant due to reduced Cenozoic overburden
- Seismic inversion highlights the possibility of a range of reservoirs in the Reinga Basin through various intervals of the Cenozoic
- The early mature coals found in Tane-1 could possibly become mature in the Deepwater Taranaki Basin, under greater burial depths (thus heat and pressure)
 - Seismic inversion suggests the vertical migration of hydrocarbons, highlighting pathways and flat-spots



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Thank you

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