

# Analogues for North Taranaki Mio-Pliocene depositional systems

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## Abstract

Surveys of the modern sea floor, in particular modern swath bathymetry which provides rapid, accurate coverage of large areas, provide key detailed insights into the depositional and other processes that operate on the margin between continental shelf and deeper water, a paleogeographic setting for much of the Miocene and younger fill of Taranaki Basin, and the associated petroleum reservoir targets. With these insights, seismic data can be interpreted with improved prediction of stratigraphic and structural relationships.

**Keywords:** *Modern deep-water depositional systems, reservoir analogues, seismic interpretation.*

## Introduction

It is an axiom of historical geology that the present is the key to the past. A corollary for understanding sedimentary basins and the potential petroleum reservoir systems within them is that the surface is the key to the sub-surface. In this paper we present examples of the modern sea-bed and shallow sub-surface to illustrate the geometry and origins of depositional (and erosional) elements analogous to actual and potential oil and gas reservoirs that originated at and beyond the shelf margin.

During and since the Miocene, the Taranaki Basin has progressively filled by an overall progradation of clastic sediments across its southern and eastern margins. Sands deposited in deep-water settings form important reservoir plays beneath the modern shelf and the Taranaki Peninsula. Miocene and Pliocene formations which contain proven deep-water reservoir sands include the Moki, Mount Messenger, Urenui and Mangaa.

The depositional processes operating in deep water settings are dominated by gravity-driven remobilisation of material from the shelf margin (including indented canyon systems) into slope and basin floor settings. These processes result in complex stratal geometry that can be challenging for seismic interpreters to map effectively. A sound conceptual appreciation of deep-water clastic depositional systems and processes is necessary for effective exploration in reservoir target systems such as the Taranaki Basin Miocene and Pliocene.

NIWA has been conducting marine surveys around the New Zealand margin for many decades, and in recent years deploying swath bathymetry as well as high-resolution seismic equipment with sediment coring. Data from three regions provide useful insights for the interpretation, mapping, and reservoir characterisation of Taranaki Miocene-Pliocene formations.

## Mapping the modern continental margin

Mapping depositional systems on the modern New Zealand continental margin (Fig. 1) is routinely undertaken by seafloor multibeam surveying and high-resolution multichannel seismic reflection acquisition. Some 20% of the margin shallower than 2500 m has been mapped by either 12 kHz EM12 or 30 kHz EM300 Simrad multibeam systems. The latter, onboard *RV Tangaroa*, comprises 135 beams, with real-time sound velocity corrections and beam steering compensating for ship motion, at survey speeds of typically 8-10 knts. Swath coverage, dependent on water-depth, is typically 2-5 km across track. The multibeam data (both backscatter and bathymetry) are processed and gridded at 25 m cell-size though higher resolution can be obtained in shallower water. The data have a vertical resolution of ~ 1–2 m within 2000 m water-depths (an error of 0.1%).

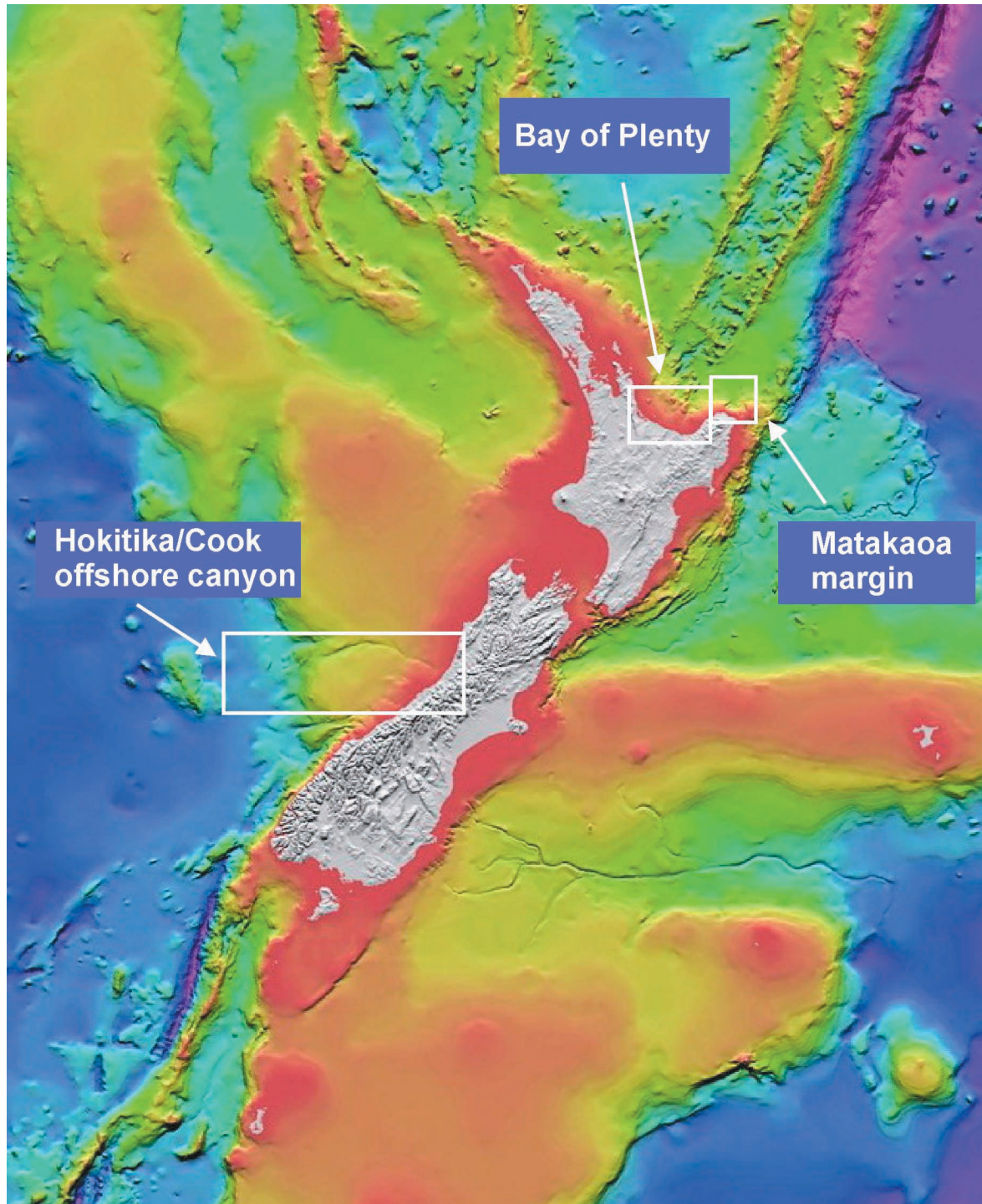
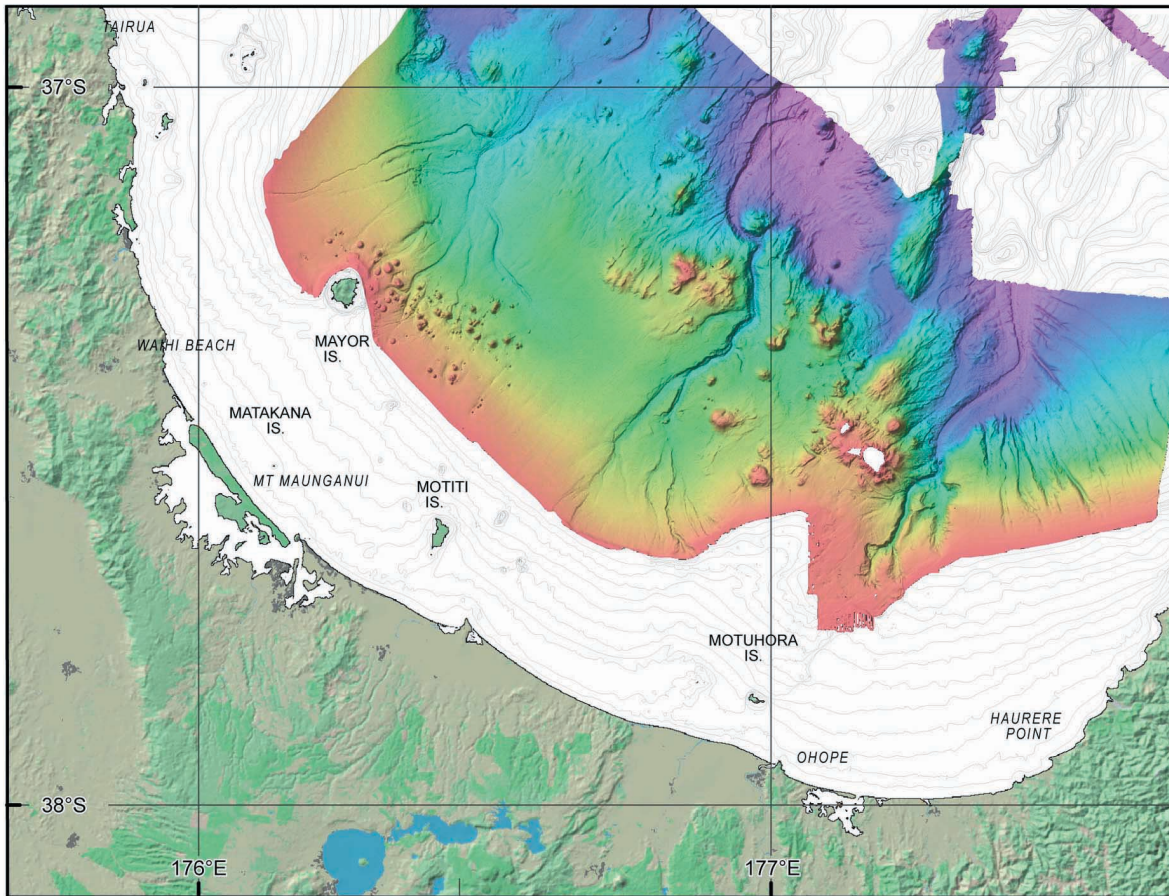


Figure 1. Regional bathymetry showing New Zealand tectonic setting and location of modern analogue depositional systems.

Multi-channel seismic reflection data have been typically acquired with a 75/75 cu<sup>3</sup> GI gun and 300-600 m long, 48-channel streamer with a maximum apparent frequency of 150 Hz, with excellent resolution down to 1.5-2 s two-way travel-time. Line spacing is variable and site specific, but more recent surveys have included line spacings of 1-3 km (Lamarche et al. 2005), and even a pseudo 3-D survey with 150 m line spacing (Lamarche et al. 2000, Taylor et al. 2004). Seismic processing generally includes true amplitude recovery, custom-designed band-pass filter and predictive deconvolution functions, long-offset muting, normal move-out correction, and stack and Kirchoff-Stolt migration. The stacked seismic data are 12-fold with a CDP spacing 6.25 m.



**Figure 2. EM300 multibeam bathymetry for the Bay of Plenty, showing the volcanic and tectonic setting of a submarine and emergent island arc close to a continental landmass.**

### **Proximal volcanic arc – modern example**

Offshore Bay of Plenty, forming the transition between the subaerial Taupo Volcanic Zone (central North Island) and the largely submarine Kermadec arc, is characterised by a series of arc volcano massifs which are extensively faulted, and bounded by slope channel systems (Fig. 2). The latter are interpreted to be dominantly active during glacial low-stands, but also following onshore eruptions (particularly silicic caldera eruptions), and during White Island eruptions and collapse of its submerged flanks. Progradation of terrestrially-sourced sediments seaward has nearly engulfed the Motuhora volcano, and reached the inner flank of the White Island massif.

Sector collapse of varying scale and temporal frequency is observed on most offshore Taupo - Kermadec arc edifices, with associated dispersal of avalanching and debris deposits on to the surrounding seafloor. The largest collapses can have volumes of 4-5 km<sup>3</sup>, (e.g., Rumble III), though it is uncertain whether such volumes represent single or repetitive event failures. For the most historically active volcanoes

(e.g., Monowai) single collapses can have volumes as small as 0.09 km<sup>3</sup>, but occur on a temporal frequency of < 10 years (Wright et al. 2005). For some volcanic centres (e.g. Macauley), volcanism has included silicic eruptions, with caldera-collapse events forming mega-bed density flows and penecontemporaneous edifice foundering (Wright et al. 2006).

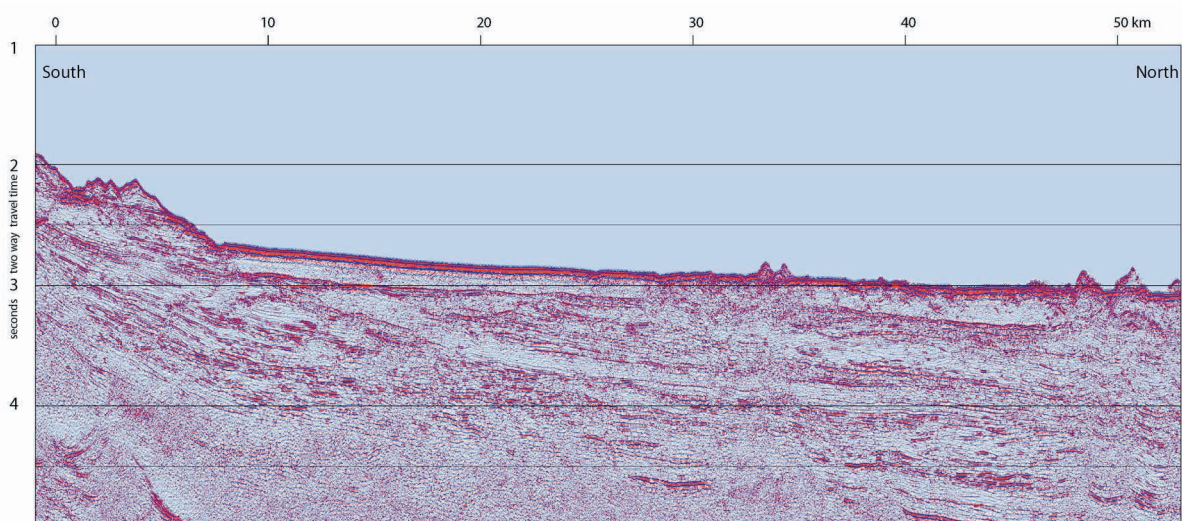
## Proximal volcanic arc – Taranaki subsurface

The Mohakatino arc of submarine volcanoes occupied the North Taranaki Graben during the middle and late Miocene (eg Thrasher et al. 2002). Concurrently, the continental shelf margin was prograding northwards and westwards over basin-floor and base of slope fan systems comprising the Moki, Mount Messenger, and Mangaa formations. In the Northern Graben, the basin-floor depositional systems were considerably constrained by both active extensional faulting (as in the modern Bay of Plenty), and by onlap onto the volcanic edifices such as Kora (Bergman et al. 1991), that may in some cases have been emergent during their eruptive periods as islands similar to the modern White Island. As the shelf margin advanced across the graben system during the Pliocene and Pleistocene (Hansen and Kamp 2004), the considerable relief was compensated resulting in a near-flat modern shelf underlain by several hundred metres of cyclothemetic topset strata.

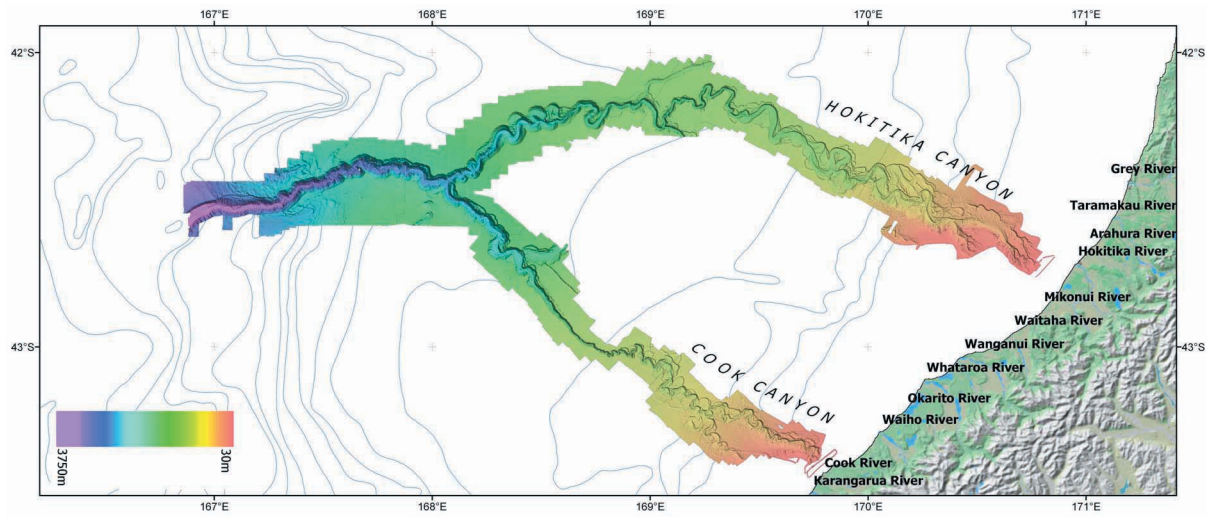
The modern shelf margin of Taranaki has yet to be surveyed with swath multibeam, but a highly indented character indicative of repeated gravitational collapse and slope canyon headward erosion is evident from bathymetric charts. Insight into the processes and depositional (and erosional) elements of such a setting, which is highly analogous to the Taranaki subsurface formations, can be gleaned from similar margins elsewhere around New Zealand.

## Margin avalanching – modern example

Massive erosion by recurrent submarine landslides and slope instability off the North Island coast has resulted in the formation of several conspicuous re-entrants. The Matakaoa re-entrant along the north continental slope of East Cape is ~45 km-long, ~30 km-wide, semi-circular and incises the entire > 1 km-thick sedimentary pile from the top of the continental shelf, at ~150 m of water depth to the deep Raukumara Plain in >2300 m of water (Lamarche et al. 2004).. Multibeam bathymetry and multichannel seismic reflection data (Fig. 3) reveal multiple large debris flows, and one large debris avalanche that originates directly from the re-entrant. The ~35 kyr Matakaoa debris flow is the latest mega-debris flow identified in the region. It has remobilised approximately 600 km<sup>3</sup> of slope material and extends more than 160 km north of the top of the continental slope into the Raukumara



**Figure 3. NIWA multichannel seismic reflection profile along the flow direction of the Matakaoa avalanche system, which images several debris flows with low amplitude to transparent seismic reflectors, and large blocks with coherent internal reflectors that are interpreted as being “rafted” from the flow margins.**



**Figure 4. EM300 multibeam bathymetry of the Cook – Hokitika channels systems (West Coast, South Island) showing the progradational character of these interglacial high-stands systems as shelf and slope sediment distributary systems.**

Plain (Carter, 2001). The Matakaoa debris avalanche, of which age is yet to be constrained, consists of large blocks of consolidated margin material scattered over the seafloor within 50 km of the shelf. The larger block, 10x2 km and <1 km high, has slid >15 km from its inferred origin on the east side of the re-entrant. A large basement anticline protruding from the surrounding seafloor immediately north of the re-entrant has either stopped, or deflected, the course of the debris avalanche and debris flows. Older slumps and debris flows are also imaged at depth beneath the youngest debris flows and avalanche exposed at the seafloor. Debris flows have a transparent, incoherent seismic character and clear lateral boundaries, within the uppermost kilometre of section. Large slumps are characterised by a high amplitude basal decollement with a characteristic phase reversal, highly diffractive internal structures, and numerous small scale stacked blocks (Ribodetti et al. 2005).

## Margin avalanching – sub-surface Taranaki

Examples of gravitationally-transported blocks that have deformed but not completely disaggregated into turbidity currents, have been described from the Mount Messenger Formation outcrops along the northern Taranaki coast (King et al. 1993 e.g. figures 25 and 26) but not widely reported from seismic data. We have observed features analogous to those described off the modern Matakaoa margin (above) in the Mount Messenger/Urenui succession onshore northern Taranaki, and also within the Mangaa Formation offshore.

It is important to recognise the nature of margin avalanching when interpreting seismic lines over deep water and slope successions. Abrupt lateral boundaries can be mis-interpreted as through-going faults when in fact they are related to intra-formational detachment surfaces. Commonly related features that have recently been recognised elsewhere, particularly in the North Sea (e.g. Hurst et al. 2002) are sand injectites, resulting from extrusion of overpressured sand due in some cases to the differential loading of mass flows.

## Shelf and slope distributary system – modern example

Transport of sediment, although undoubtedly higher in glacial low-stands, is an important process during inter-glacial high-stands for a number of New Zealand shelf and slope distributary systems. The West Coast, South Island is the second largest such system with three of five New Zealand's highest sediment load rivers producing ~29% of New Zealand's riverine contribution (Hicks and Shankar 2003). Most sediment is transferred to a narrow inner shelf, apart from a minor component trapped in small coastal lagoons. During the last glacial low-stand, large alluvial plains and major valley glaciers reaching the coast provided voluminous sediment loads directly to the continental slope.

Multibeam mapping shows four principal conduits in the Hokitika / Cook offshore canyon – channel system, with two dominant channels (Hokitika and Cook) active in the modern day (Fig. 4), extending at least ~ 700 km with a vertical fall of 3000 m and locally entrenched 1000 m into the continental slope. Both have actively prograded with sealevel rise, fed by river discharge and littoral drift along their respective upper reaches where they cross the shelf and upper slope. The upper reaches are up to 28 km wide and comprise sinuous ox-bowed meandering thalwegs. In contrast, the lower reaches of the channels are incised and erosional. The confluence of the two channels is marked by a waterfall indicating the Cook is either the system with latest and / or largest “flow” at least during interglacial high-stands. The two abandoned glacial low-stand channels (largely unmapped) also have “waterfalls” where they intersect with the main Hokitika – Cook channels. Dependent on location, sediments within these channel systems vary between well-sorted mica-rich silts and sands, coarser turbidite deposits, and last-glacial gravels.

## **Shelf and slope distributary system – subsurface Taranaki**

The West Coast slope canyon distributary system is an important newly-described analogue for the important exploration target reservoir systems of the Taranaki Basin, including the Moki, Mount Messenger, and Mangaa formations and their up-dip equivalents (such as the Urenui). Again, it is difficult to fully appreciate from seismic data (particularly 2D) the detail of lateral relationships within submarine fan and associated slope systems. However, leveed channels can be recognised in the Mount Messenger/Urenui at least. It is possible that the modern analogue over-samples these inter-glacial (highstand) depositional elements relative to the large mass-flow elements that are mostly believed to be associated with relative lowstands, and comprise the larger proportion of the deep-water submarine fan systems.

## **Conclusions**

To conclude, with the effectiveness of modern marine geoscience technologies, the deep water margins and the processes that operate on them are no longer out of sight. Observations and interpretation of the modern systems should be kept in mind when exploring for oil and gas in Miocene-Pliocene strata in Taranaki Basin and in deep-water paleo-settings elsewhere.

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