

PS Sub-Millennial Anatomy of Late Miocene Deep-Water Mass-Transport Deposits: Case Studies of the Use of Foraminifera to Decipher the Stratigraphic Architecture of the Mount Messenger Depositional System, Taranaki Basin, New Zealand*

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Abstract

The Mount Messenger Formation represents a highly dynamic deep-water system comprising slope to basin floor fan deposits that form stacked 4th to 5th order cycles deposited over timescales of 20-100 kyr. The late Miocene sedimentary patterns reflect a complex history of shelf progradation, tempered by sediment supply and accommodation, and tectonic controls within and adjacent to the basin. The variable stratigraphic and sedimentological character of the system poses problems for petroleum exploration because rapid lateral and vertical variation in facies make it difficult to correlate, date and predict the spatial distribution of intervals containing potential reservoir facies. In this presentation, we outline the application of new high-resolution biostratigraphic data and tools that have been developed by GNS Science to address correlation problems associated with this interval. Extremely high estimated rates of sedimentation are recognised at times within the Mount Messenger succession, based on sub-millennial-scale dating derived from weight-standardised counts of planktic and benthic forams and a non-linear age interpolation method. Intervals of downslope reworking are also recognised using dynamic facies analysis based on minimum paleodepth data. When applied in combination, the new biostratigraphic tools provide a robust temporal and paleoenvironmental framework that enables the stratigraphic architecture of late Miocene depositional systems to be correlated between wells at a greater level of precision than before. This has shown that reservoir-quality base of slope sands, the primary Mount Messenger exploration play, are confined to overlapping fan-lobes.



Sub-millennial anatomy of Late Miocene deep-water mass-transport deposits

Case studies of the use of foraminifera to decipher the stratigraphic architecture of the Mount Messenger depositional system, Taranaki Basin, New Zealand

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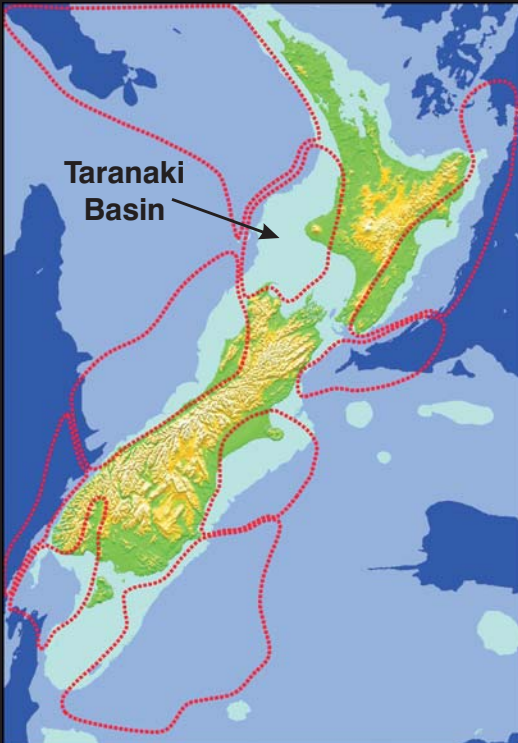
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Introduction



Taranaki Basin, New Zealand

Located along west coast of New Zealand's North Island.

About 100,000 km², principally subsurface and mostly offshore.

New Zealand's only economic petroleum producing basin.

Discovered reserves
 – 465 mmbbls oil/condensate
 – 6470 BCF gas
 – 38 MT LPG
 from total of 20 pools, including 14 producing or producible fields.

Sedimentary basin fill

Transgressive Late Cretaceous to Early Miocene succession, followed by a regressive succession.

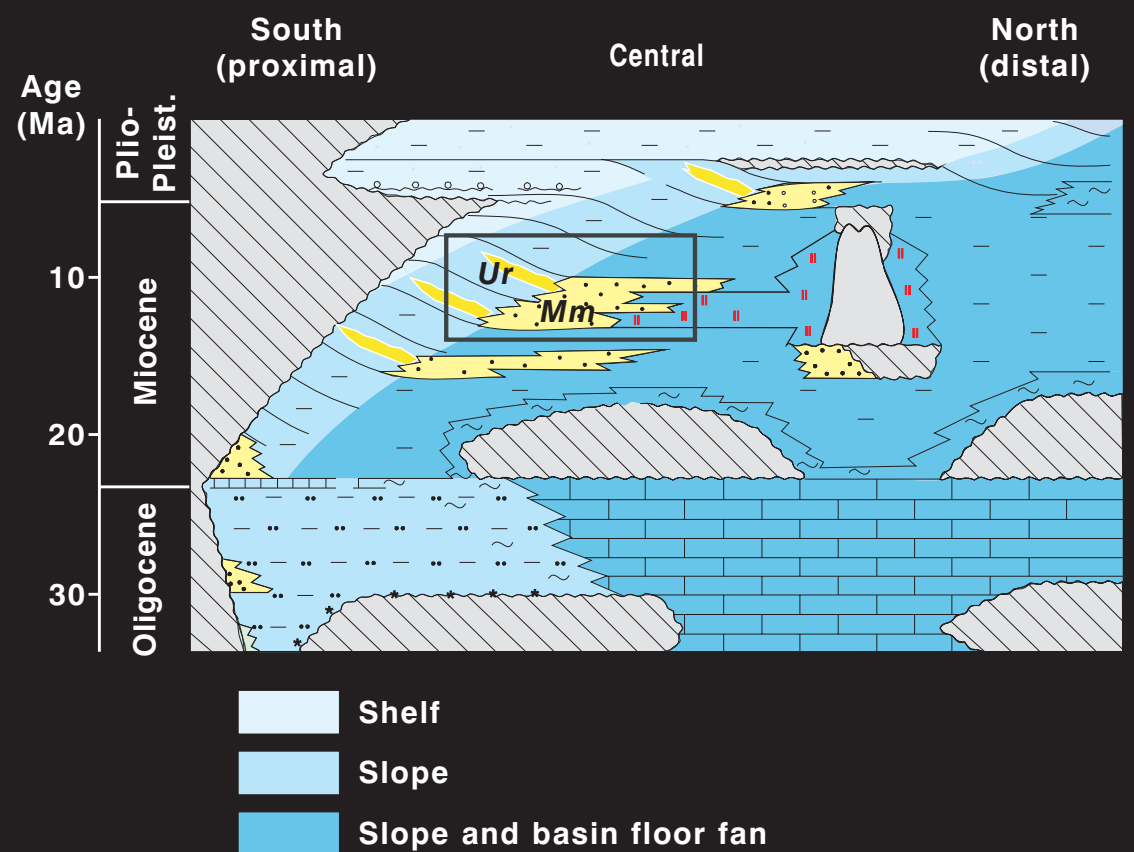
Primary source rocks

Hydrogen-rich coals and terrestrial carbonaceous mudstones of Late Cretaceous to Eocene age.

Primary oil and gas plays

- Mount Messenger sands: Late Miocene
- Moki sands: Middle Miocene
- Tikorangi Limestone: Oligocene
- Mangahewa and Farewell sands: Late Cretaceous to Eocene

Late Cenozoic chronostratigraphy of Taranaki Basin



Urenui Fm (Ur)

- Late Miocene (6.5-8.88 Ma)
- >500 m thick
- progradational shelf and upper slope system

Mount Messenger Fm (Mm)

- Late Miocene (8.88-10.92 Ma)
- 1500 m thick
- progradational deep-water slope and aggradational basin floor fan system
- rapid vertical and lateral facies variation
- oil and gas play

Mount Messenger production

Kaimiro Field

- estimated oil reserves 4.5 mmbbls
- produced 3.2 mmbbls since 1985
- gas reserves 29.6 Bcf

Ngatoro Field

- estimated oil reserves 9.4 mmbbls
- produced 4.7 mmbbls since 1992
- gas reserves 23.0 Bcf

Cheal Field

- no reliable production figures

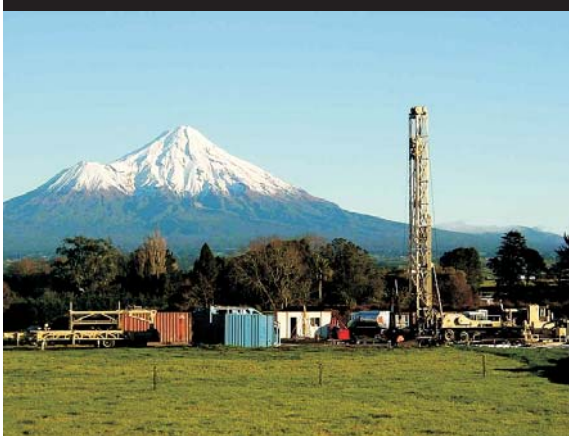
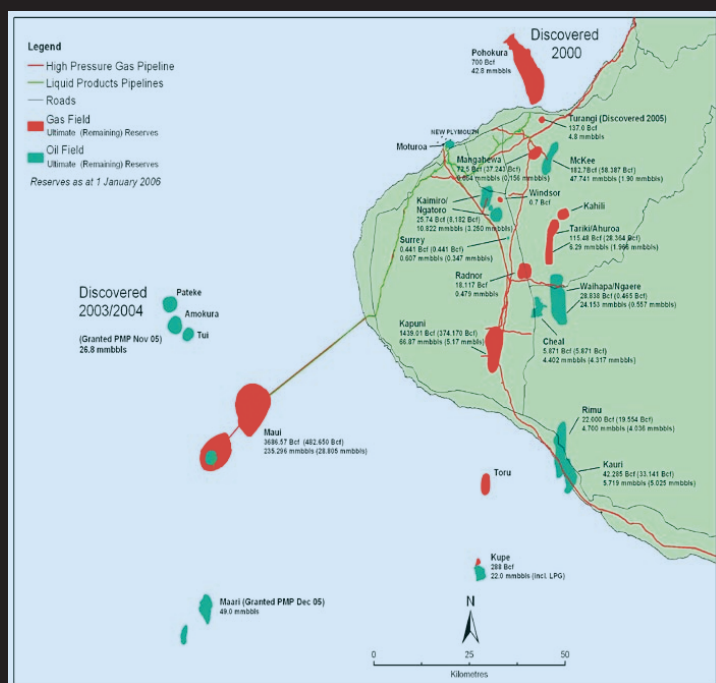
Mount Messenger reservoirs

Upside

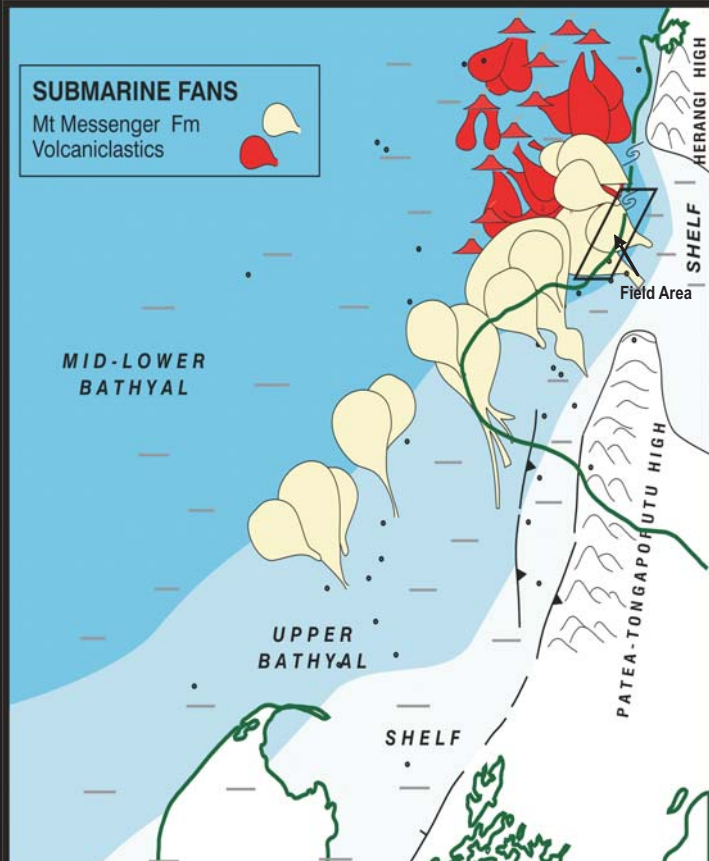
- shallow targets: 1000-2500 m
- cheap to drill
- existing infrastructure
- outcrop analogue

Downside

- small reservoirs
- poor lateral continuity
- structural complexity
- difficult to correlate regionally and locally



Depositional setting



Mount Messenger deep-water clastic system

- Late Miocene (Tortonian) 3rd-order progradational system (2-3 Ma)
- Superimposed with 4-5th order cycles (<100 k yr)
- Complex structural setting: part fold thrust belt, foreland basin and intra-arc basin
- Slope fan to basin floor fan deposits
- Relatively small-scale fans (<10 km)

Overview

In sequence stratigraphic terms, the Mount Messenger and Urenui succession represents a complete lowstand systems tract, from basin-floor fan to prograding complex.

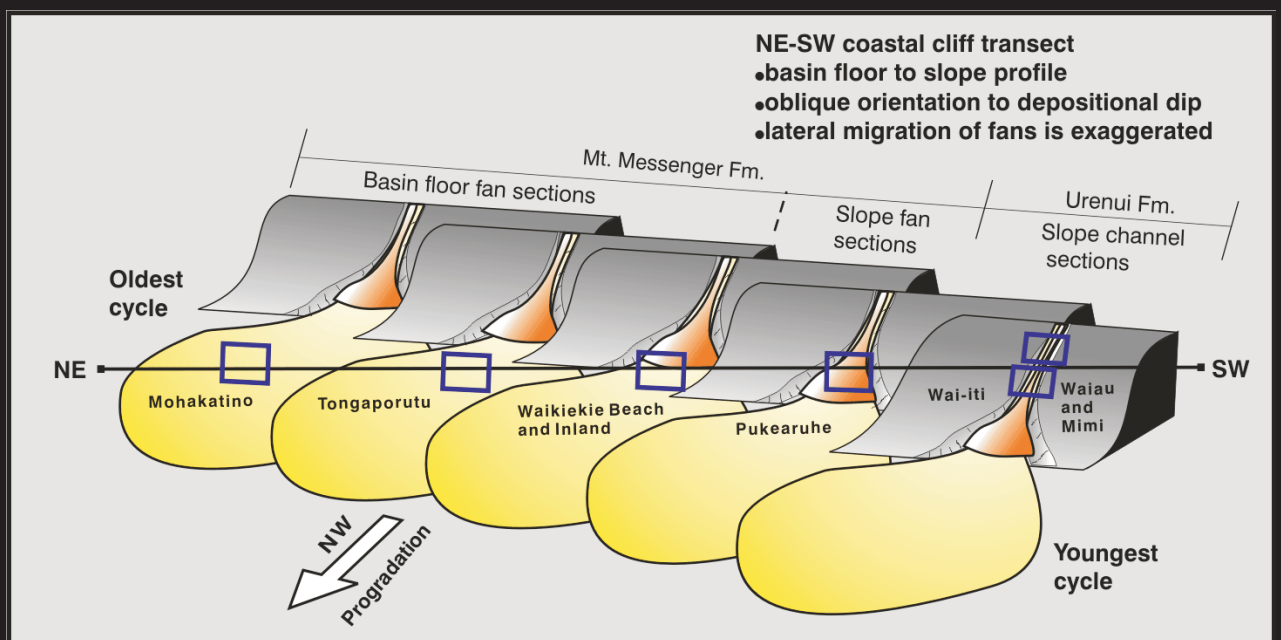
This outwardly reflects rapid basin floor aggradation and slope outbuilding.

A consequence of high volumes of sediment supply caused by plate-convergent-related uplift and erosion.

Sediment supply

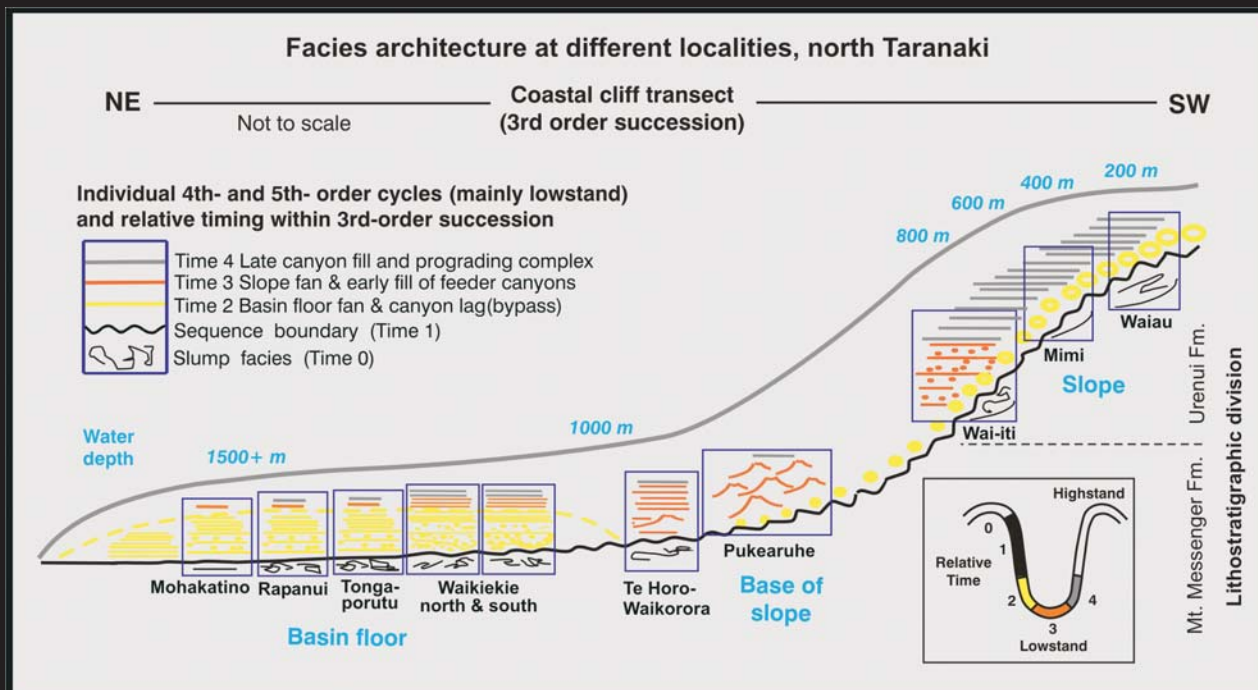
Mount Messenger sediments are largely derived from uplift and erosion of Cenozoic rocks of the eastern hinterland and Mesozoic greywackes of the main South Island ranges.

Submarine andesite stratovolcanoes in the NW also contributed volcanogenic sediments.



NE-SW Coastal cliff transect

- Basin floor to slope profile
- Oblique orientation to depositional dip
- Lateral migration of fans is exaggerated



Generic facies architecture

- Urenui sequence: progradational shelf and upper slope facies
- Mount Messenger sequence: progradational slope fan to aggradational basin-floor fan facies

Coastal cliff section

Unique field laboratory for studying deep-water clastic sedimentation.

Excellent exposure along 50 km of coastline.

Oblique 2-D window through Urenui and Mount Messenger deep-water clastic system.

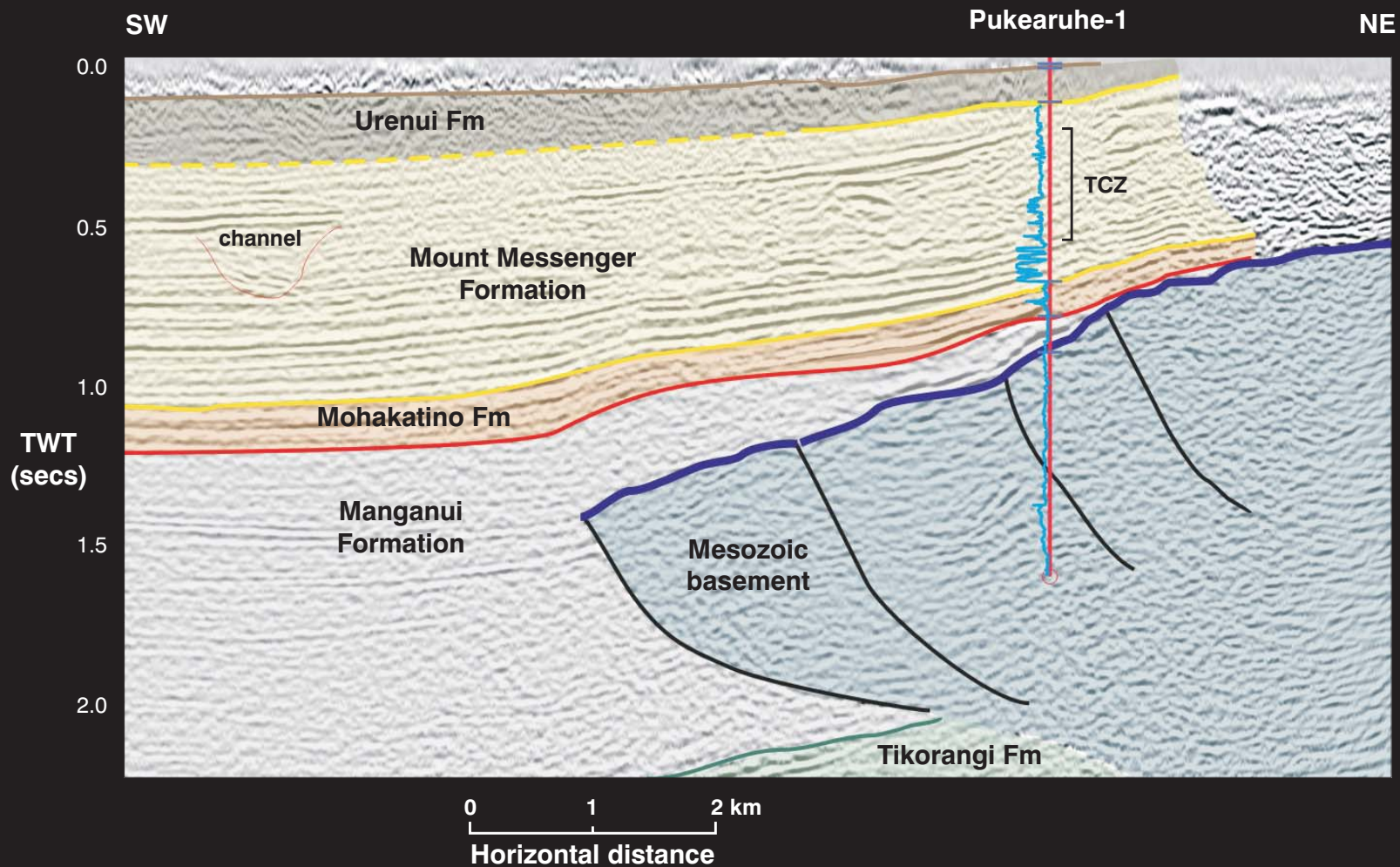
Rocks dip gently southwest at 2-3° and are buried beneath the Taranaki Peninsula at depths of 1000-2500 m.

Regional paleoslope and direction of progradation runs northwest.



Subsurface correlation

Seismic correlation

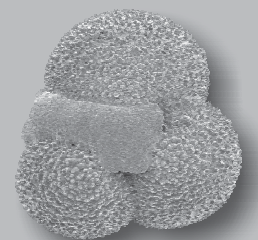


Biostratigraphy

High-resolution biostratigraphy using robustly dated bioevents provides a fully independent and valid test of seismic and well-log correlations, but is often underutilised.

In addition to being a valuable correlation tool, high-resolution biostratigraphy provides reliable dating for determining rates of sedimentation and deformation, and other geological processes.

The acquisition of high-resolution biostratigraphic data is relatively cheap compared to geophysical data.



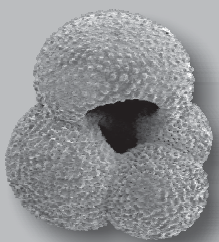
Globigerininta glutinata

Dating

In the case of the Late Miocene Mount Messenger sequence, high-resolution biostratigraphy can resolve dating to less than 50-thousand years, which is on a scale comparable to seismic resolution.

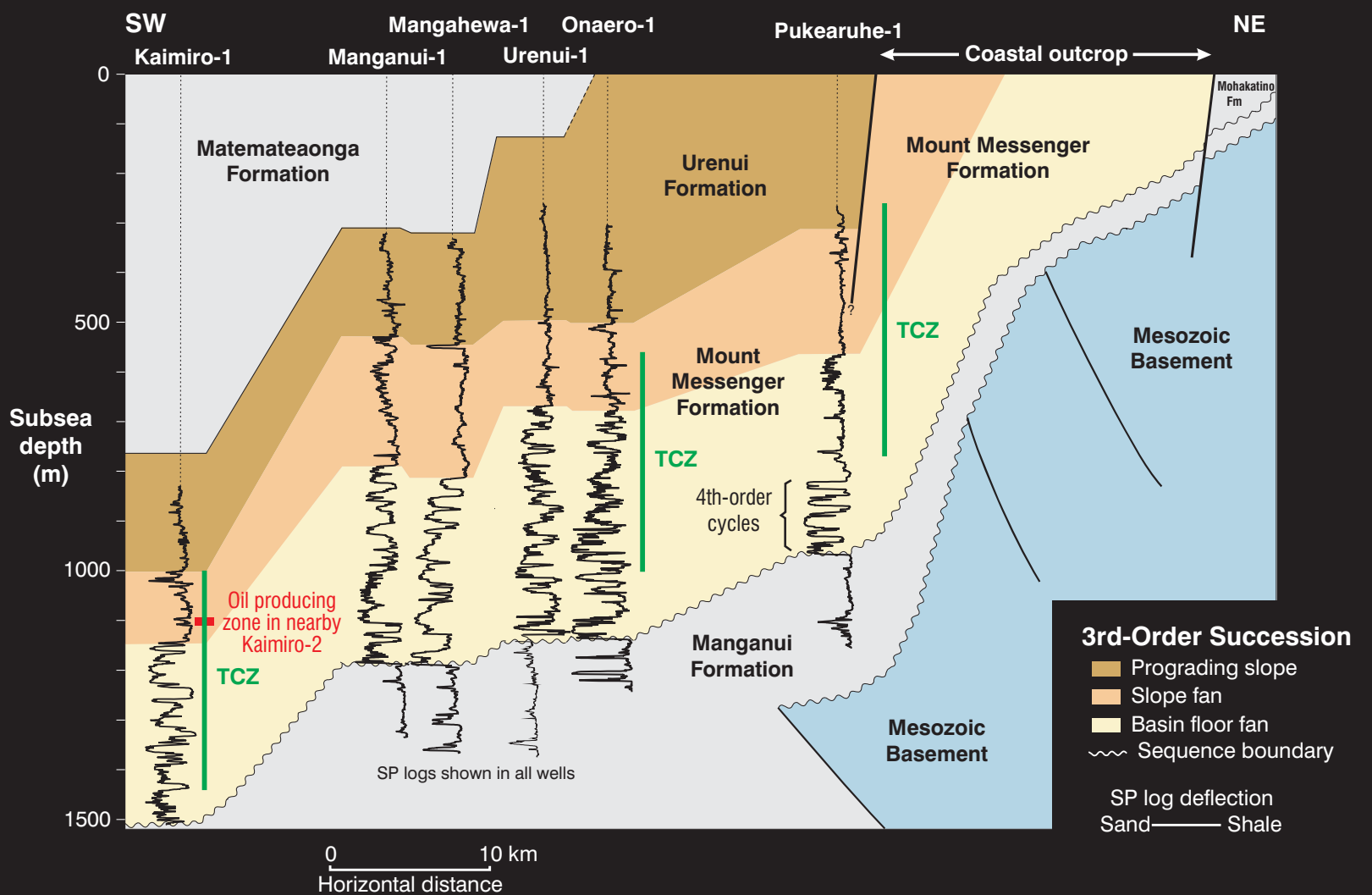
Such dating is important for elucidating Milankovich-scale sedimentary detail and identifying eustatically-forced shifts in facies that are often unresolved with geophysical data.

Reliable dating is also important for geohistory analysis.



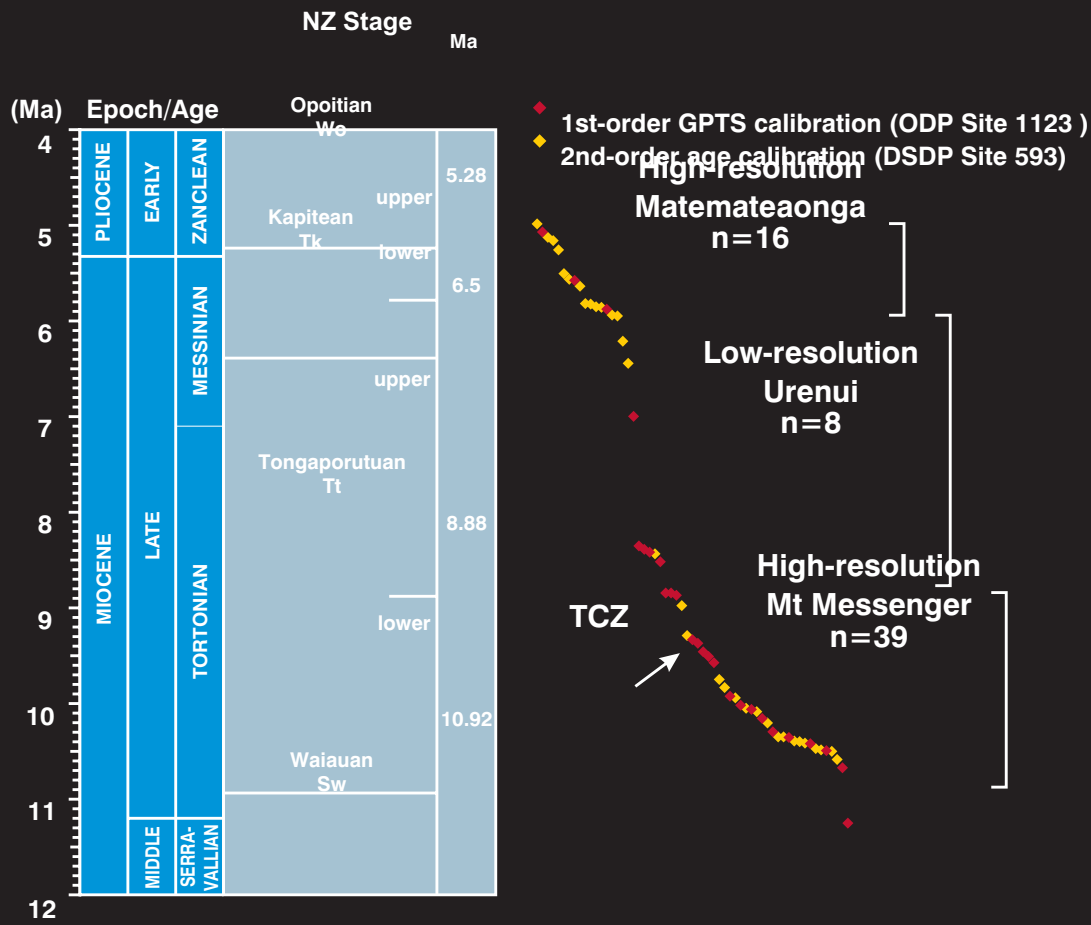
Globigerina bulloides

Well-log correlation



Biostratigraphic correlation

Locally age-calibrated bioevents



Mount Messenger biostratigraphy

The Late Miocene Mount Messenger sequence is up to 1500 m thick and is dated 8.88-10.92 Ma.

39 robustly dated planktonic bioevents have been identified in the Mount Messenger interval; this equates to an average biostratigraphic resolution of about 50 ka.

The bioevents include planktic foraminiferal and bolboformid appearances, disappearances, acme events, and coiling changes.

Tukemokihi Coiling Zone (TCZ)



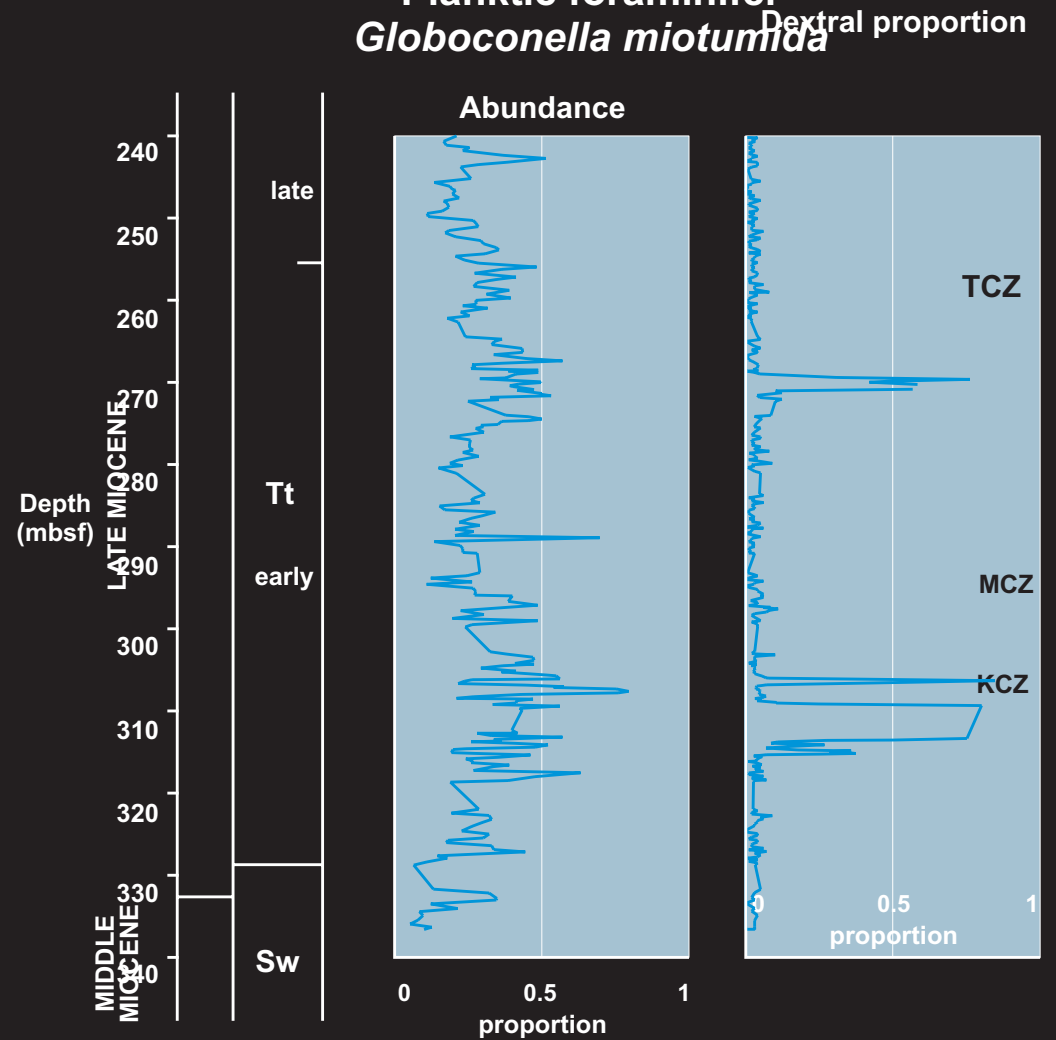
The TCZ is the youngest of three intervals of dextrally-coiled *Globocconella miotumida* within the Mount Messenger sequence.

The TCZ is robustly dated (9.27-9.31 Ma) and it spans 40,000 years.

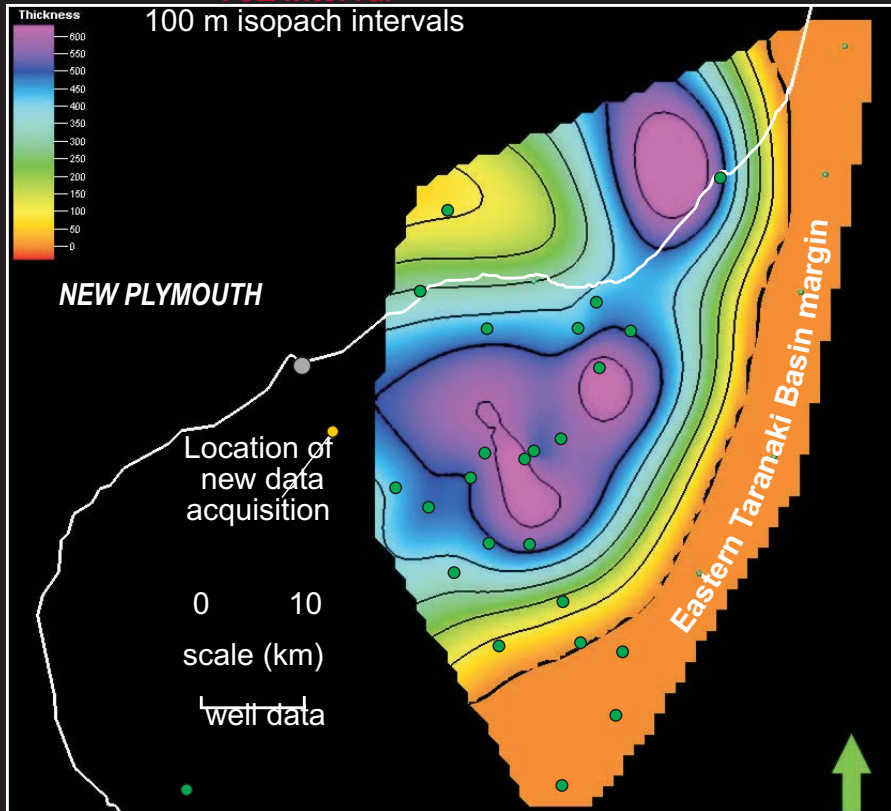
The coiling zone has been identified in more than 20 wells in North Taranaki and it is regionally isochronous.

DSDP Site 593

Planktic foraminifer *Globocconella miotumida*



TCZ interval

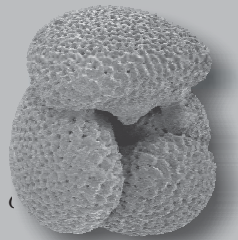


TCZ interval

The TCZ interval is reliably identified in most marine environments, except inner neritic facies where there is a paucity of planktic foraminifera.

Isopachs on the TCZ interval show two primary depocentres along the eastern Taranaki Basin margin.

The TCZ is up to 630 m thick, which indicates a very high average sedimentation rate (15.8 m/ka).



Non-linear age interpolation

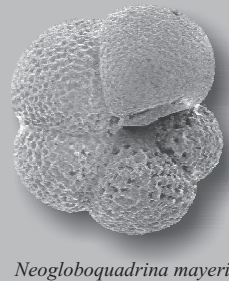
Theory

Weight standardised counts of foraminifera provide useful information about changes in sedimentation.

Where productivity is constant, high foram numbers (i.e. weight standardised counts) indicate low rates of sedimentation, and low foram numbers indicate high rates of sedimentation.

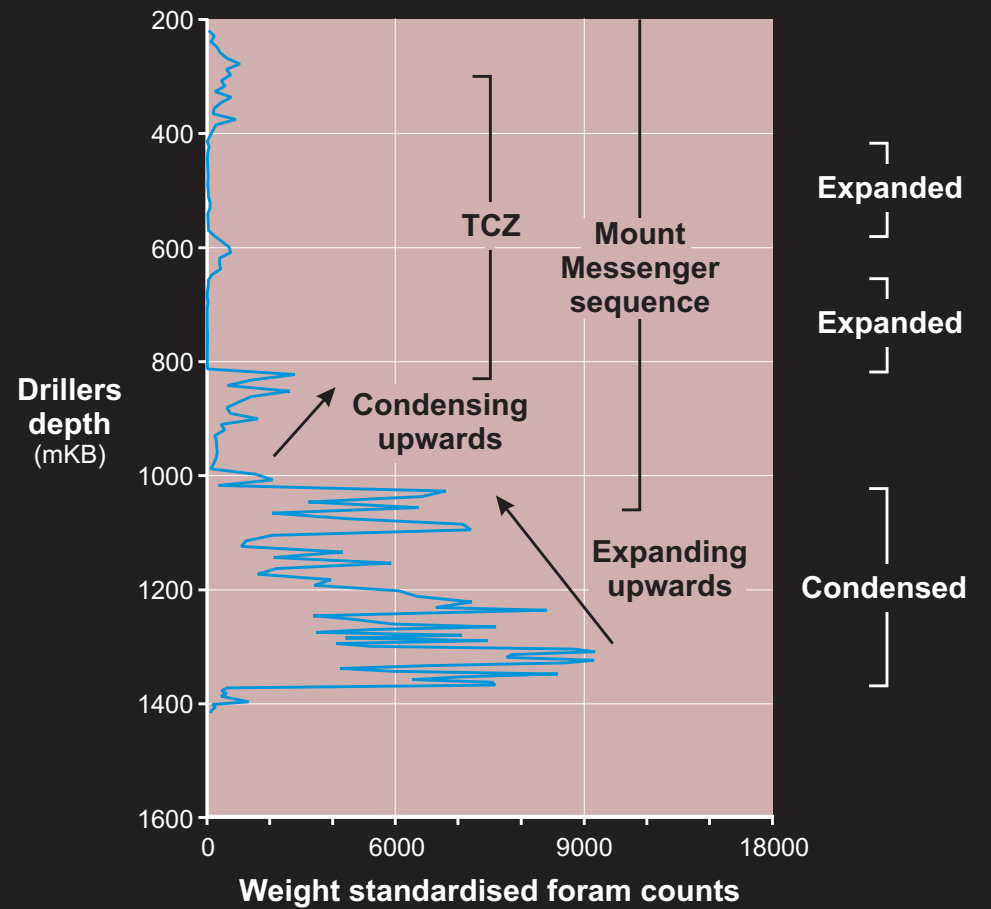
Verification

When the signatures of planktic and benthic foram numbers are in phase, productivity can be assumed to be constant, and when they are out of phase, productivity must be taken into consideration.

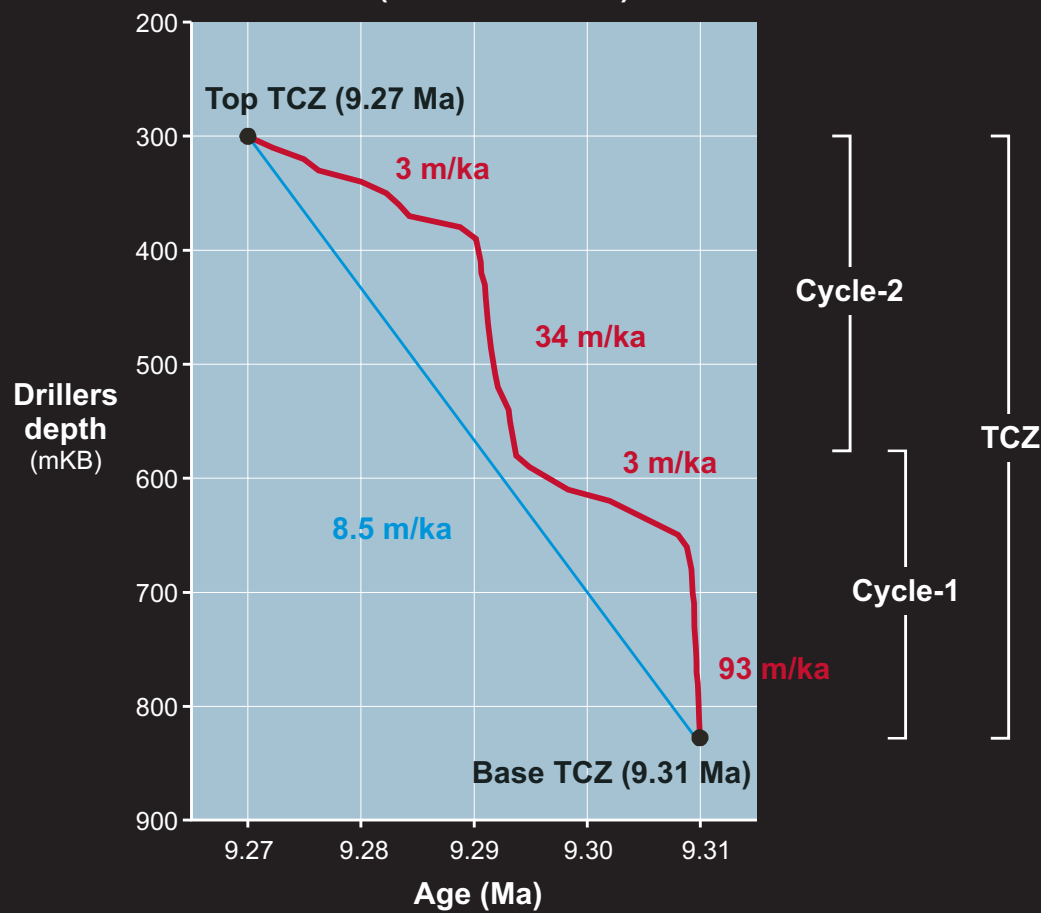


Neoglobobidrina mayeri

Foram counts: Pukearuhe-1



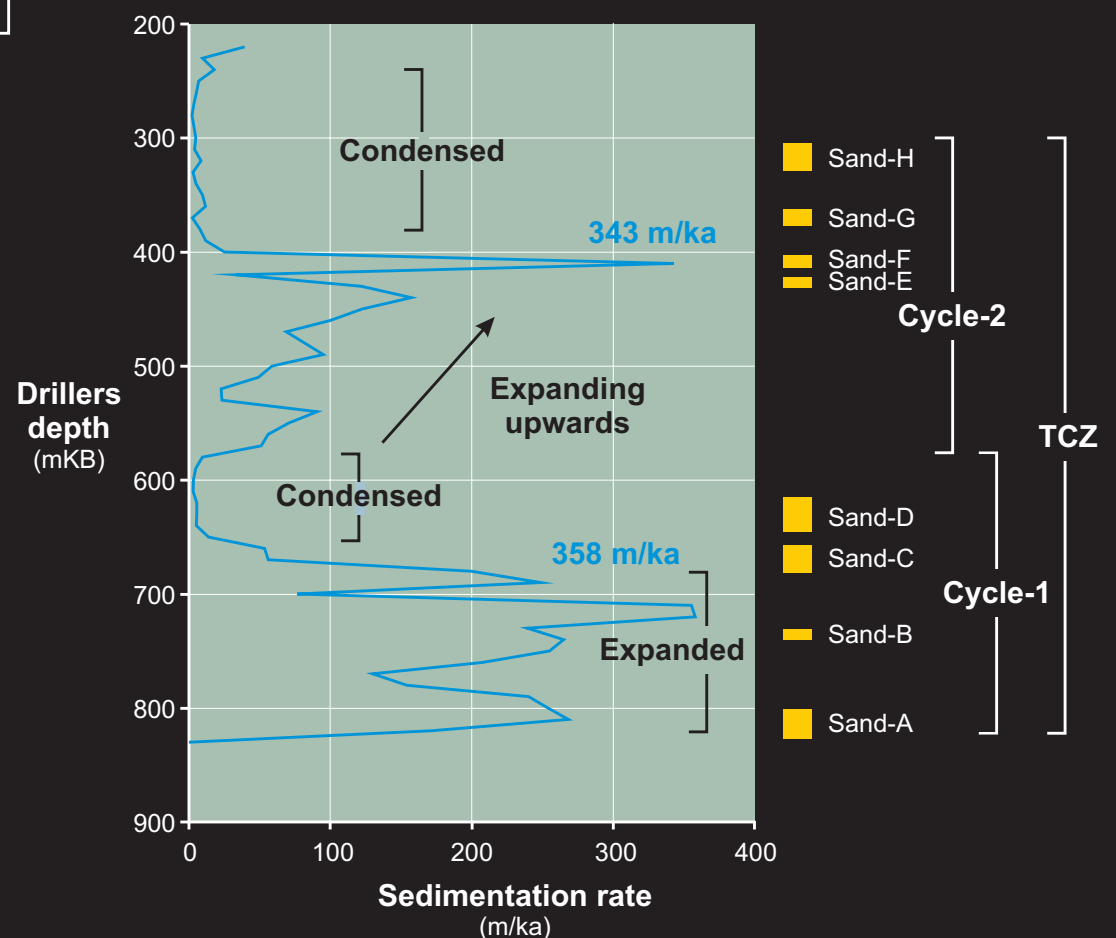
Age models: Pukearuhe-1 (TCZ 530 m thick)



Foram counts

- In the lower part of the drilled section where foram numbers are high, decreasing foram numbers suggest the section becomes slightly less condensed uphole.
- Immediately below the TCZ this trend is reversed and the section becomes more condensed.
- It then becomes highly expanded, especially in the middle and upper parts of the TCZ.

Sedimentation rate: Pukearuhe-1



Non-linear age model

The non-linear age model shows two sedimentary cycles within the TCZ, and a very high rate of sedimentation through the lower part of the TCZ (93 m/ka), maximum rate 358 m/ka.

Cycle-1

Includes four sands: sands A, B, and C within the lower rapidly deposited part of the cycle, and sand D within the upper slightly more condensed part of the cycle.

Cycle-2

Includes four sands: sands E and F within the lower rapidly deposited part of the cycle, and sands G and H within the slightly more condensed part of the cycle.



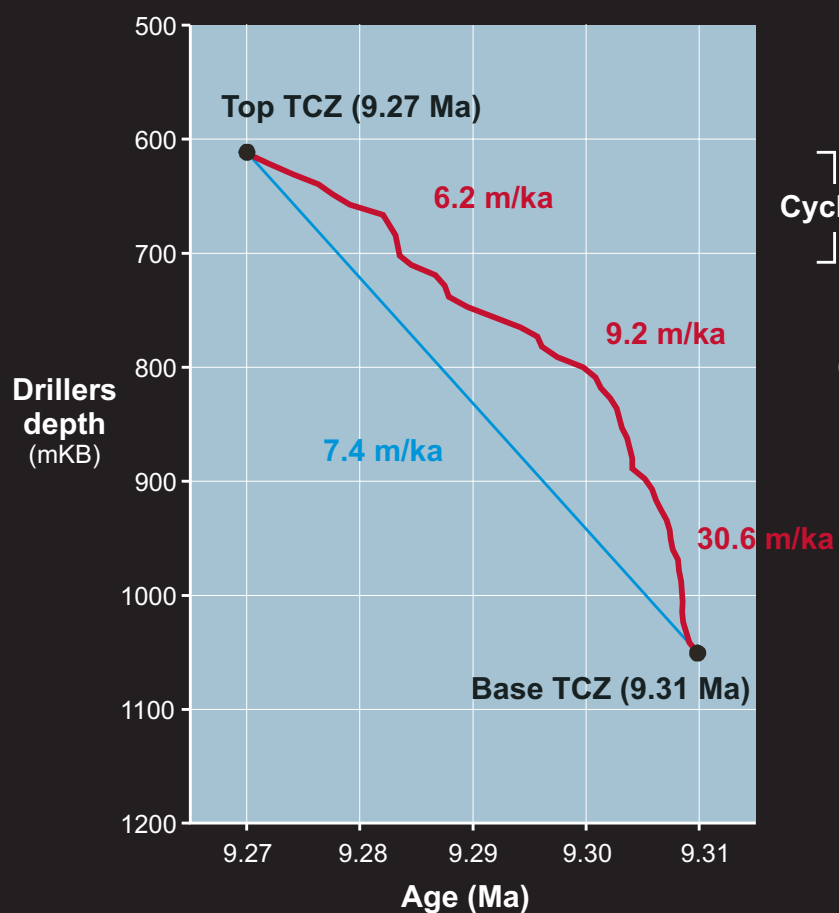
Zeaglobigerina nepenthes



Non-linear age interpolation

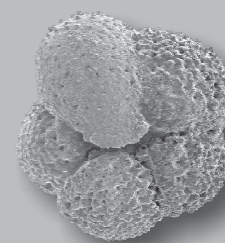
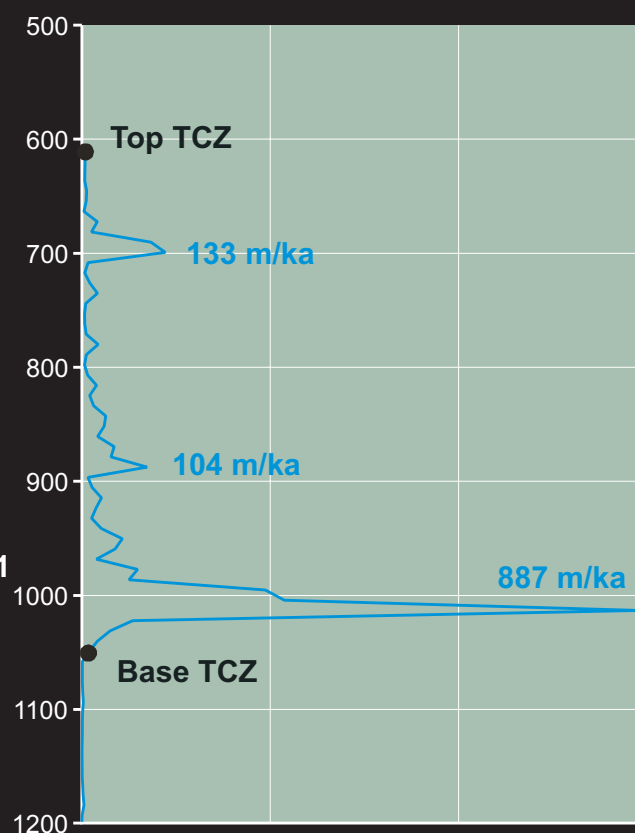
Onaero-1

TCZ linear and non-linear age models
(441 m thick)



Onaero-1

TCZ sedimentation rate



Turborotalita quinqueloba

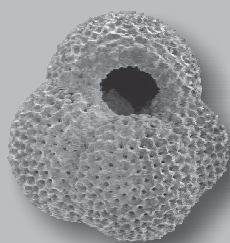
Onaero-1

The non-linear age model shows three sedimentary cycles within the TCZ.

The highest sed rate (887 m/ka) occurs in the lower part of cycle-1 within the lowermost part of the TCZ.

The 9.31 Ma age of cycle-1 and the very high sedimentation rate, suggest it is a potential correlative of the Tongaporutu Sandstone in the coastal cliff section, 30 km NE of Onaero-1.

Outcrop photo shown bottom right introduction panel.



Zeaglobigerina woodi

Ngatoro-3

The non-linear age model shows five sedimentary cycles within the TCZ.

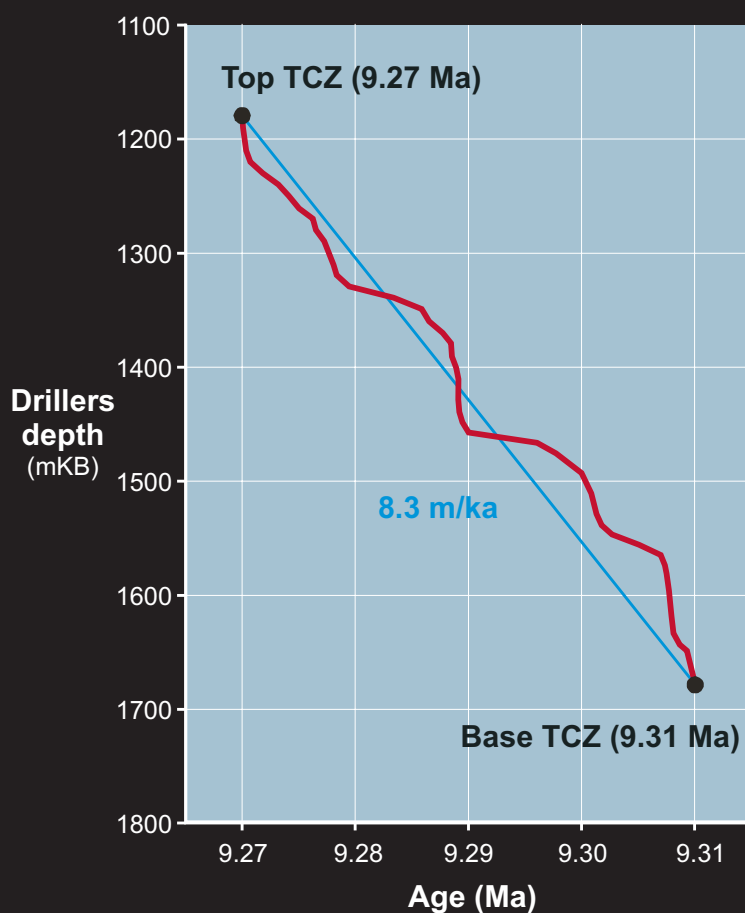
The highest sed rate (817 m/ka) occurs in cycle-3 near the middle of the TCZ.

The 9.29 Ma age of cycle-3 and the very high sedimentation rate, suggest it is a potential correlative of the "Waikiekie Sandstone" in the coastal cliff section, 53 km NE of Ngatoro-3.

The 5-cycles are inferred to represent a succession of overlapping slope fan lobes.

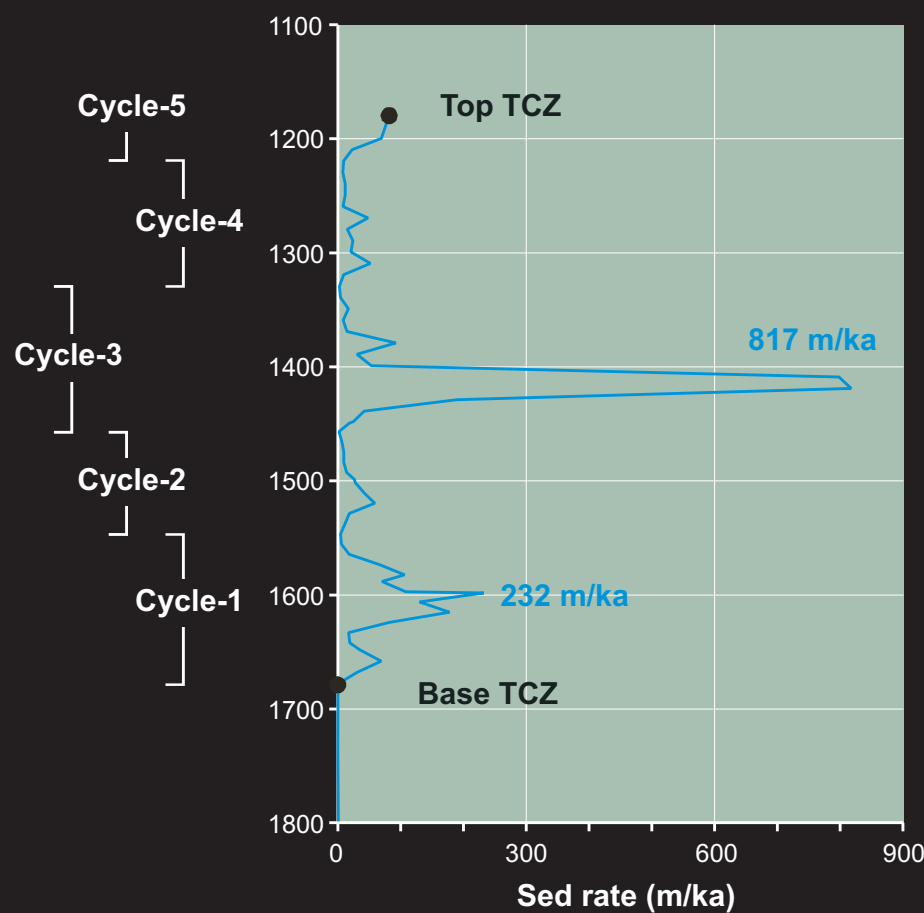
Ngatoro-3

TCZ linear and non-linear age models
(500 m thick)



Ngatoro-3

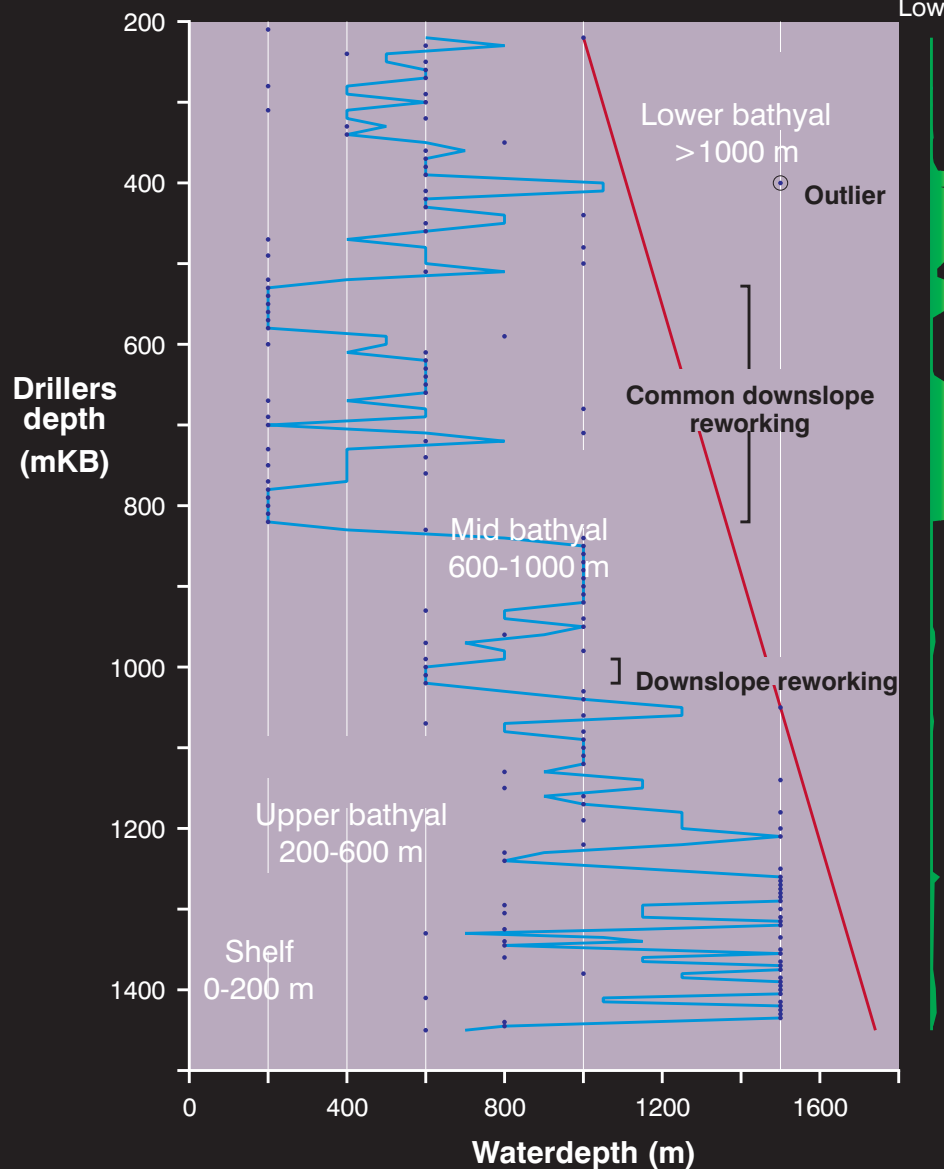
TCZ Sedimentation rate



Facies analysis

Paleobathymetry

Pukearuhe-1



Sedimentation rate
Low → High



Paleobathymetry

Estimates of paleobathymetry are an essential input in geohistory analysis and modelling of depositional systems.

Methodologies

Depth paleoecology in New Zealand has been based on two different methodologies:

- 1) The biofacies approach to recognising depth constrained faunal associations
- 2) The key taxa approach of determining the upper paleobathymetric limits of selected isobathyal taxa.

In the key taxa approach, shown here, the upper paleobathymetric depth limits of calibrated taxa constrain the minimum depth of deposition.

Marked excursions in the paleobathymetry signature that are shallower than background depths identify intervals of downslope reworking.

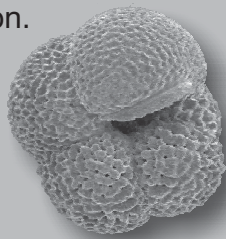
Paleobathymetry of Pukearuhe-1

- water depths increase downhole
- common downslope reworking occurs through the TCZ interval where sedimentation rates are very high
- minor downslope reworking in the lowermost part of the drilled section
- no shelfal reworking, mostly upper and mid bathyal
- estimated water depth at base of drilled Miocene section 1740 m

Oceanicity

Low planktic foraminiferal abundances through the TCZ indicate unfavourable “turbid” conditions and support high rates of sedimentation and slope fan deposition.

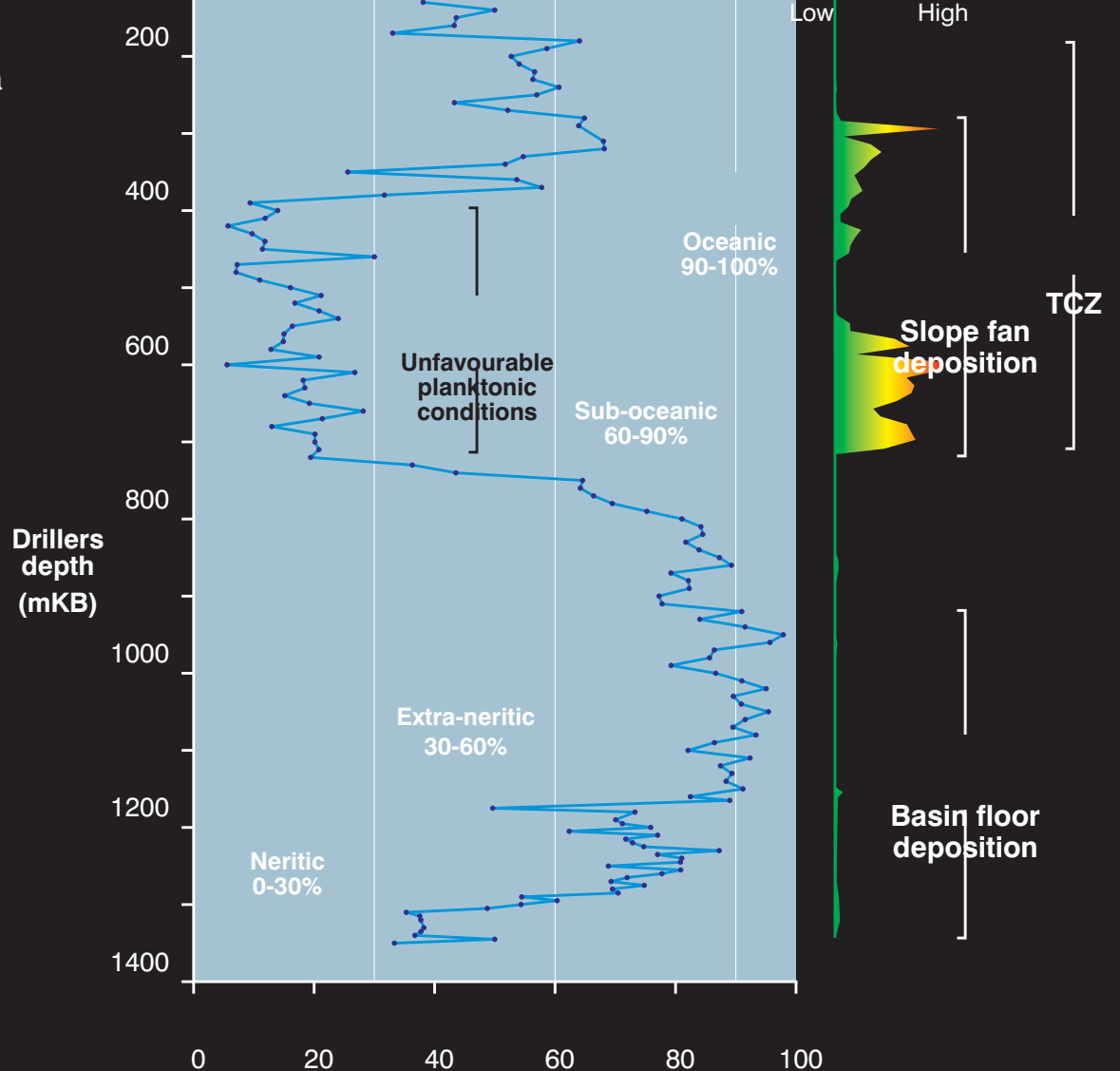
Very high planktic foraminiferal abundances through the lower part of the drilled section are consistent with very low rates of sedimentation and basin floor fan deposition.



Neogloboquadrina pachyderma

Oceanicity

Pukearuhe-1



Sedimentation rate
Low → High

TCZ





Summary

Tukemokihi Coiling Zone (TCZ)

- 1) The TCZ is a robustly dated interval of dextrally-coiled *Globoconella miotumida*, within the Mount Messenger sequence.
- 2) The TCZ spans 40,000 years, and a sedimentary sequence up to 630 m thick accumulated in that time, along the eastern margin of the Taranaki Basin.

Non-linear age models

- 1) Very high rates of sedimentation within the TCZ (30-100 m/ka, reaching 870m/ka) point to high local volumes of sediment supply.
- 2) Millennial-scale sedimentary cycles with sub-millennial-scale heterogeneity have been identified within the TCZ interval of the Late Miocene Mount Messenger sequence.
- 3) Highly refined dating within the TCZ interval enables lateral continuity of sands to be tested independently of seismic and well-log data.
- 4) Reservoir quality sands within the TCZ interval do not always coincide with the most rapid rates of deposition; some occur within the slightly more condensed intervals.



- 5) Variations in the number of sedimentary cycles between different localities; suggest deposition was associated with small-scale (<10 km) overlapping fan-lobes.
- 6) The provisional correlation between cycle-1 in the Onaero-1 well and the Tongaporutu Sandstone, 30 km NE of Onaero-1, and the correlation between cycle-3 in Ngatoro-3 and the "Waikiekie Sandstone", 53 km NE of Ngatoro-3, suggest some sedimentary cycles may be correlated over ten's of kilometers, especially those that are associated with major glacio-eustatic cycles.

Downslope reworking

- 1) The upper paleobathymetric depth limits of calibrated isobathyal taxa constrain the minimum depth of deposition and help identify intervals of downslope reworking, and also the source of reworked sediments.
- 2) There is a strong correlation between low planktic foraminiferal abundances, high rates of sedimentation, and downslope reworking.

Acknowledgements

We would like to thank colleagues at GNS Science, especially Peter King and Greg Browne, whose work we called upon in the compilation of this poster. We would also like to thank Austral Pacific and Greymouth Petroleum for their collaboration on the Mount Messenger project.

