Reservoirs of Taranaki Basin, New Zealand: from source to sink

K. Higgs

GWL / PESGB Cluster Meeting, May 2018

Acknowledgements

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- NZP&M sample / data / petroleum report repository
- Student theses (Hopcroft, 2009; Shumaker, 2016)
- GNS PETLAB database

Thanks also to the numerous contributors to this work, including:

Co-author

Peter King

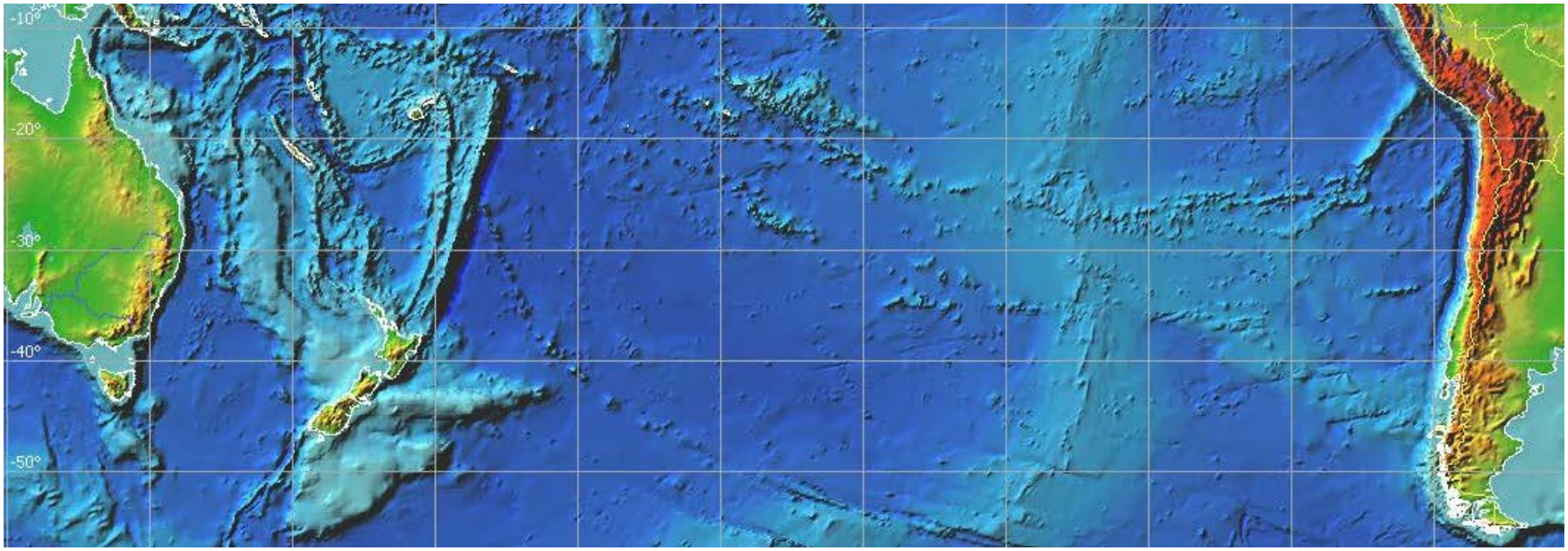
Chris Adams

Nick Mortimer

Andy Tulloch

Greg Browne

Dominic Strogen



Talk Outline

- Who are GNS Science?
- Introducing Zealandia and Taranaki
- Composition: sandstone vs basement
- Provenance and basin evolution
- Diagenetic alteration and implications for reservoir quality

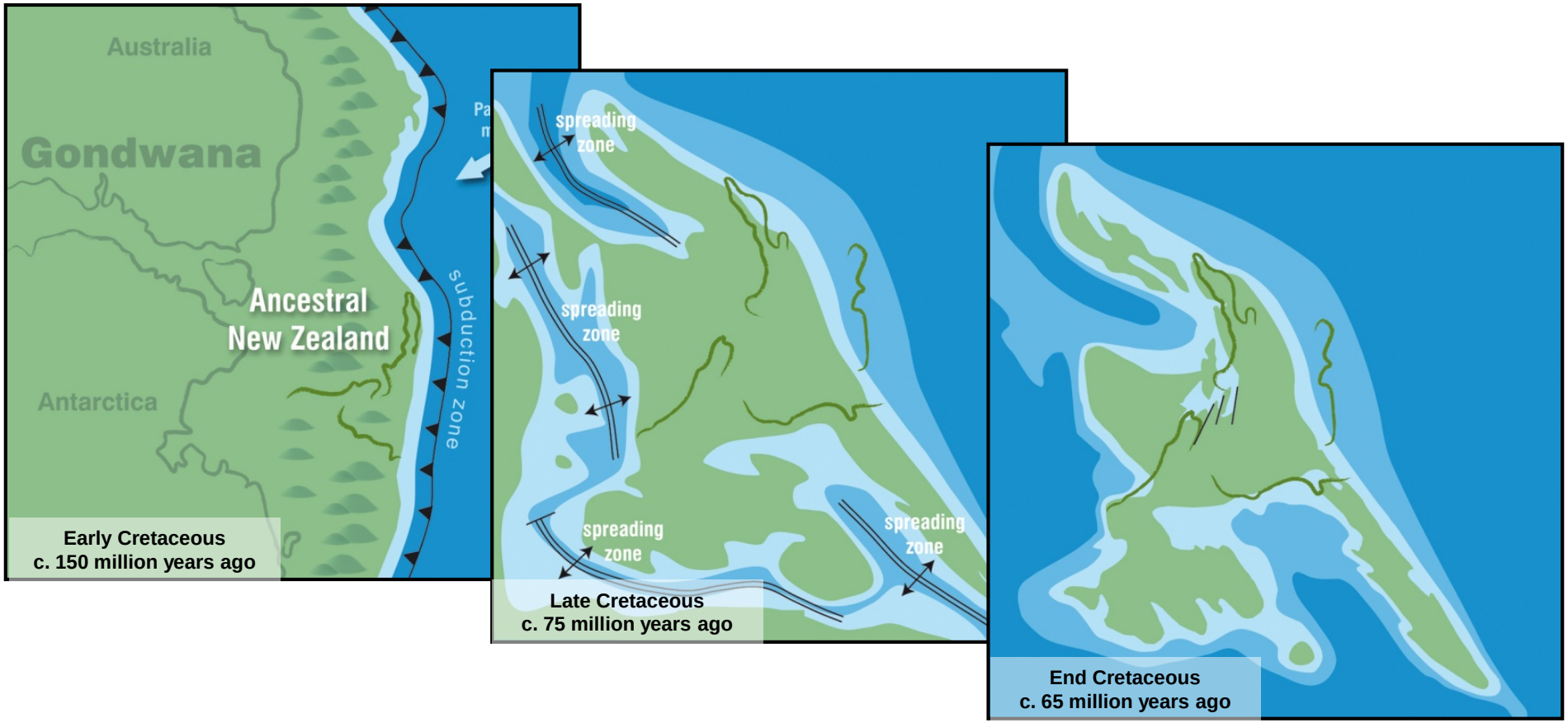
GNS Science

- Government-owned research company (CRI)
- Earth and isotope scientific research and consultancy
- Over 150 years experience New Zealand geology
- Over 350 staff (c. 75% Wellington, 25% Taupo, 5% Dunedin)

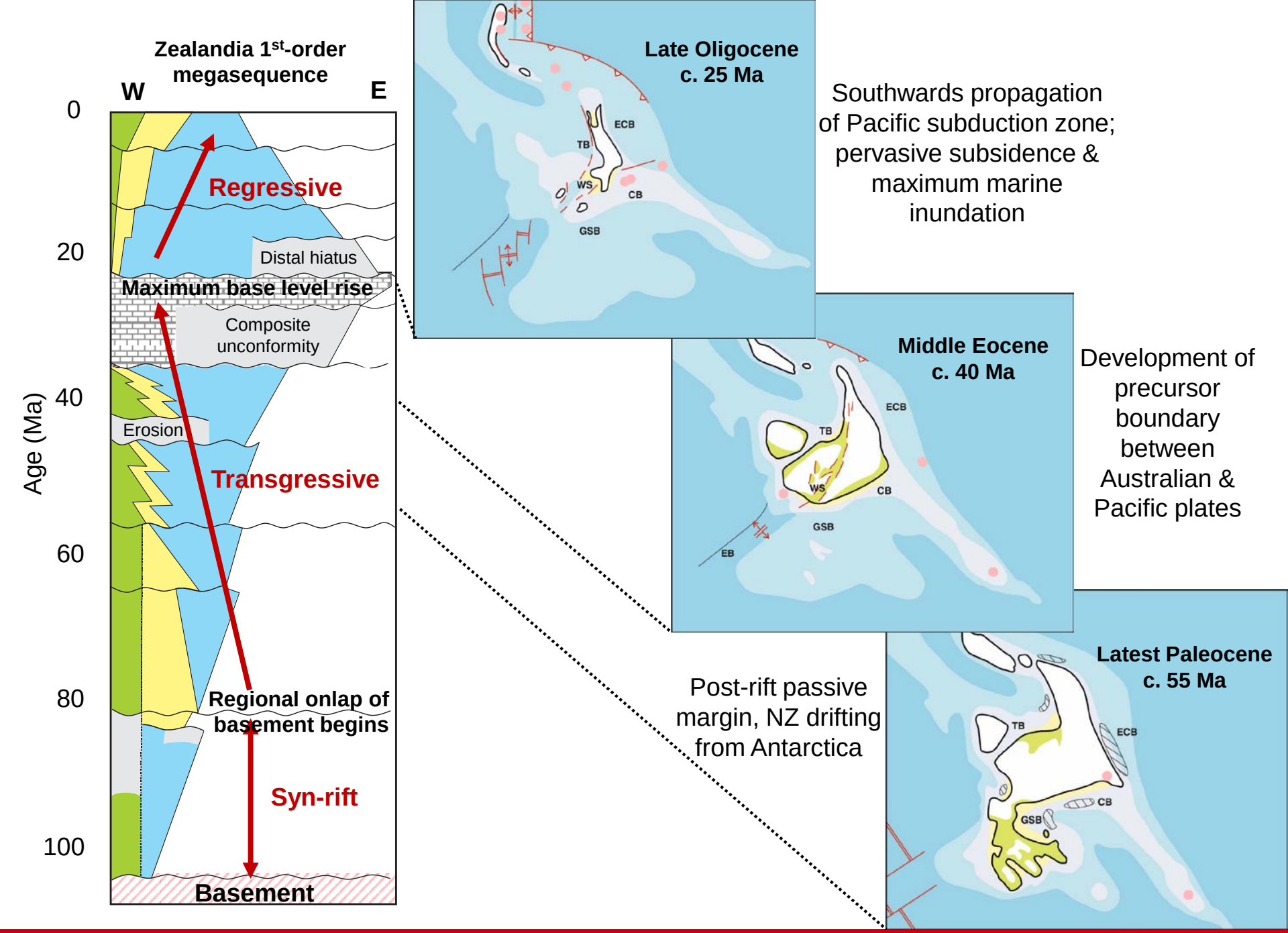
Purpose of Organisation:

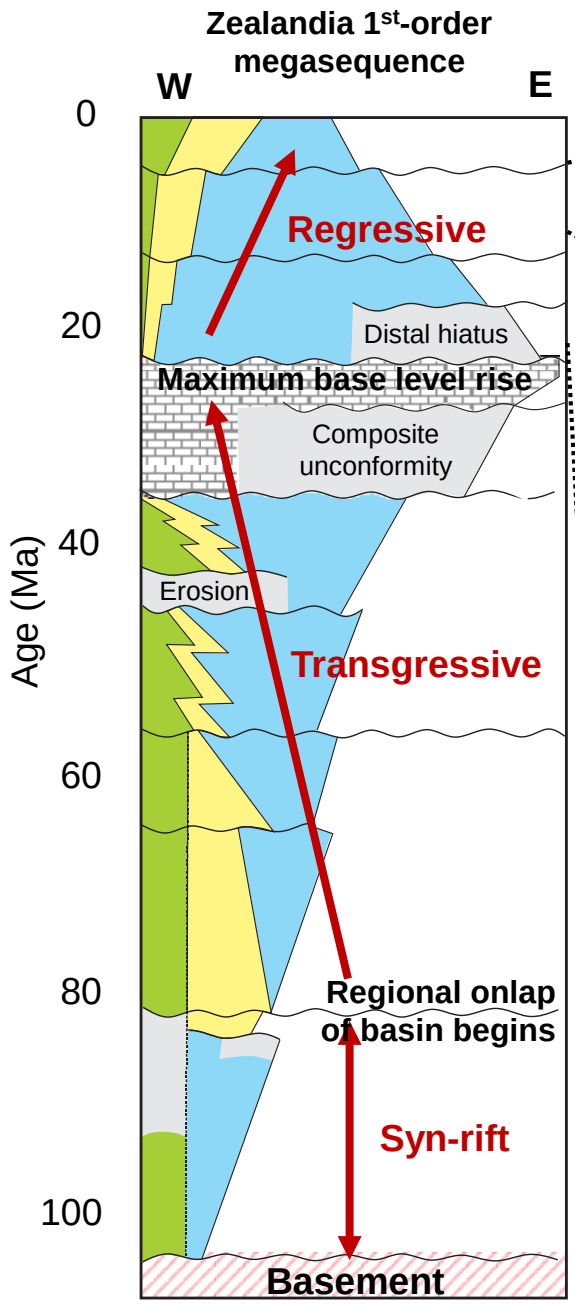
- to understand earth systems
- to transform this knowledge into economic and social benefits for New Zealand

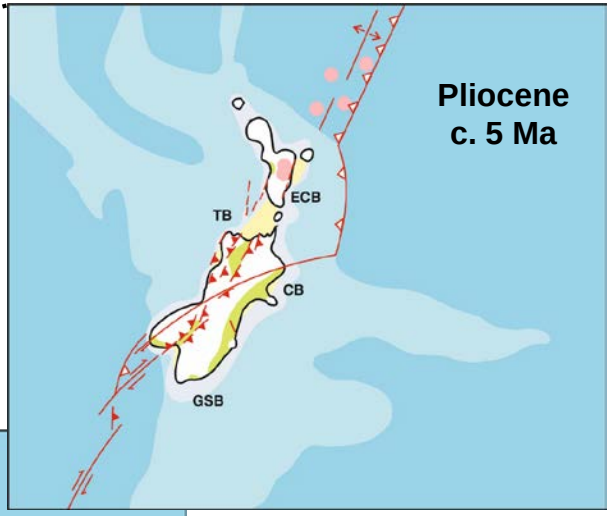
Formation of Zealandia, Early-Late Cretaceous

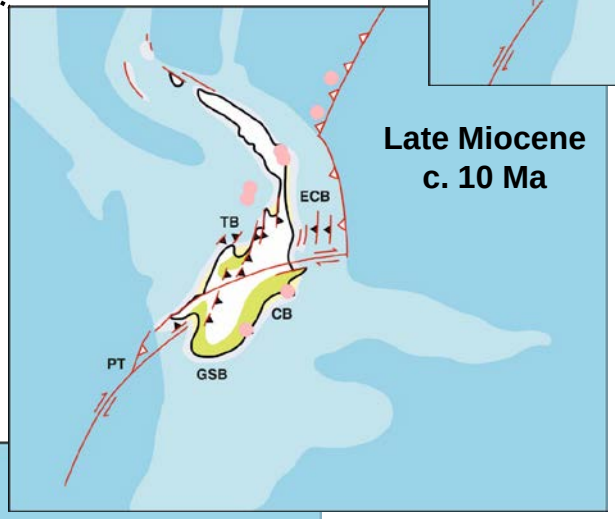


Rift basins in central west, possibly part of a transform system linked to sea-floor spreading

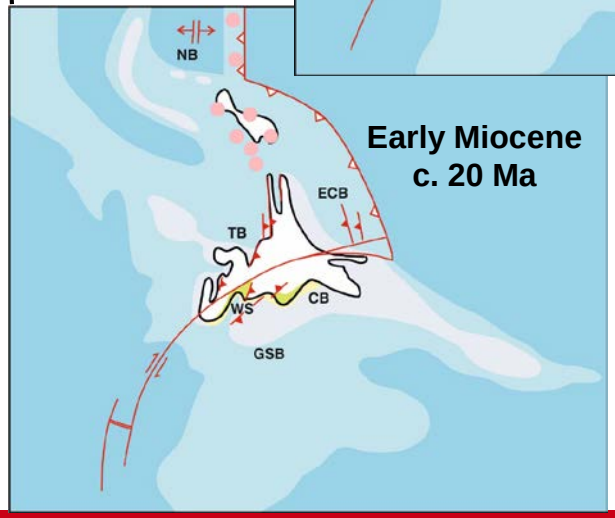

Zealandia 1st-order megasequence
W
E
0
20
40
60
80
100
Age (Ma)
Regressive
Distal hiatus
Maximum base level rise
Composite unconformity
Erosion
Transgressive
Regional onlap of basement begins
Syn-rift
Basement
Late Oligocene c. 25 Ma
ECB
TB
WS
CB
GSB
Southwards propagation of Pacific subduction zone; pervasive subsidence & maximum marine inundation
Middle Eocene c. 40 Ma
ECB
TB
WS
CB
GSB
EB
Development of precursor boundary between Australian & Pacific plates
Post-rift passive margin, NZ drifting from Antarctica
Latest Paleocene c. 55 Ma
TB
ECB
CB
GSB



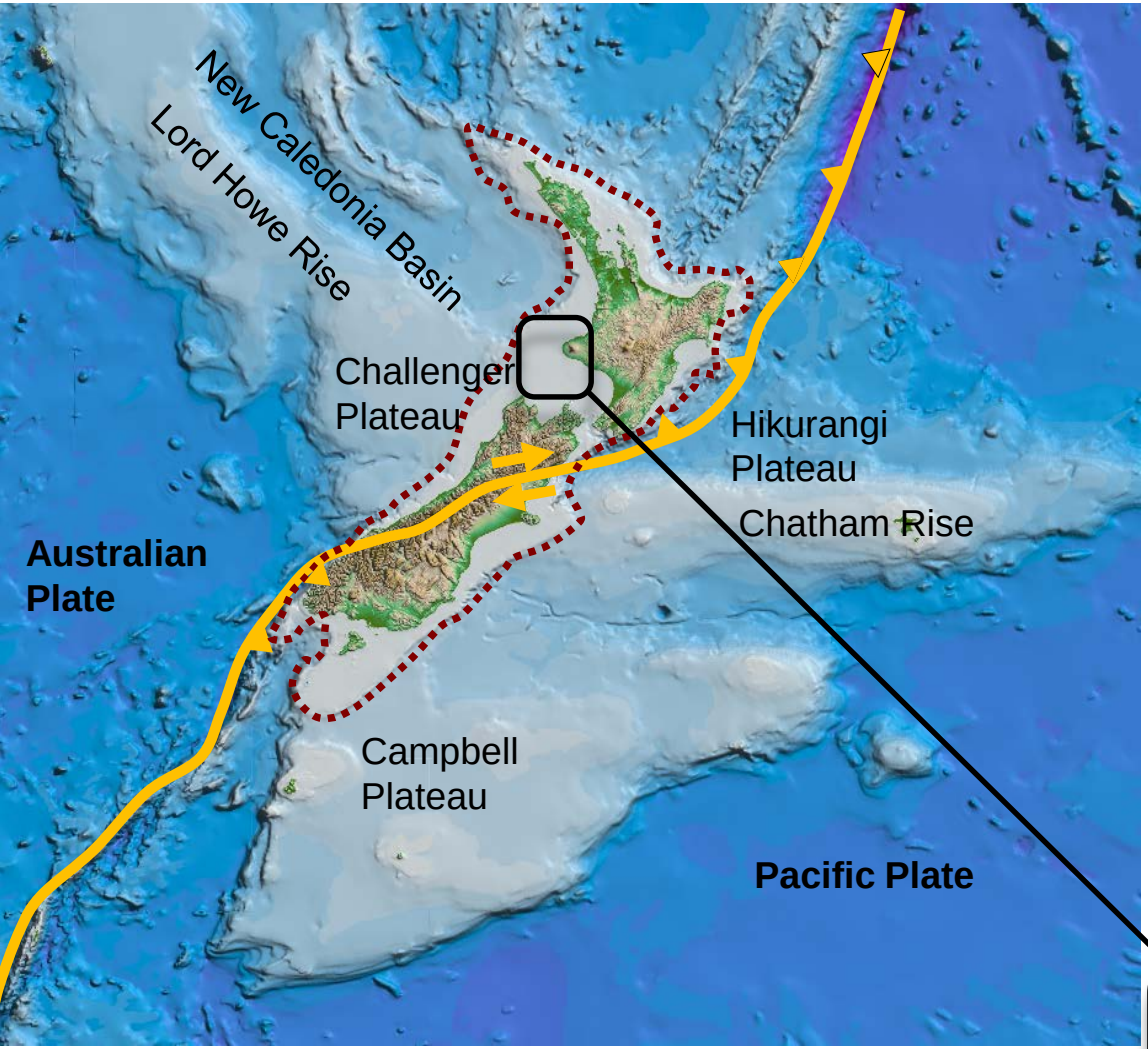




Widespread compression. Clockwise rotation of subduction margin & oblique convergence along Alpine Fault



Start of long-lived regression. Alpine Fault propagated between subduction zone and southern rift; compression and development of fold-thrust belt in Taranaki



Subduction along Hikurangi margin and transpression on Alpine and splay faults

Present-Day Configuration

NZ has a vast offshore territory, ~5,800,000 km^2

Sedimentary basins cover a large part of the EEZ and ECS (~1,700,000 km^2)

All are frontier basins with the exception of Taranaki

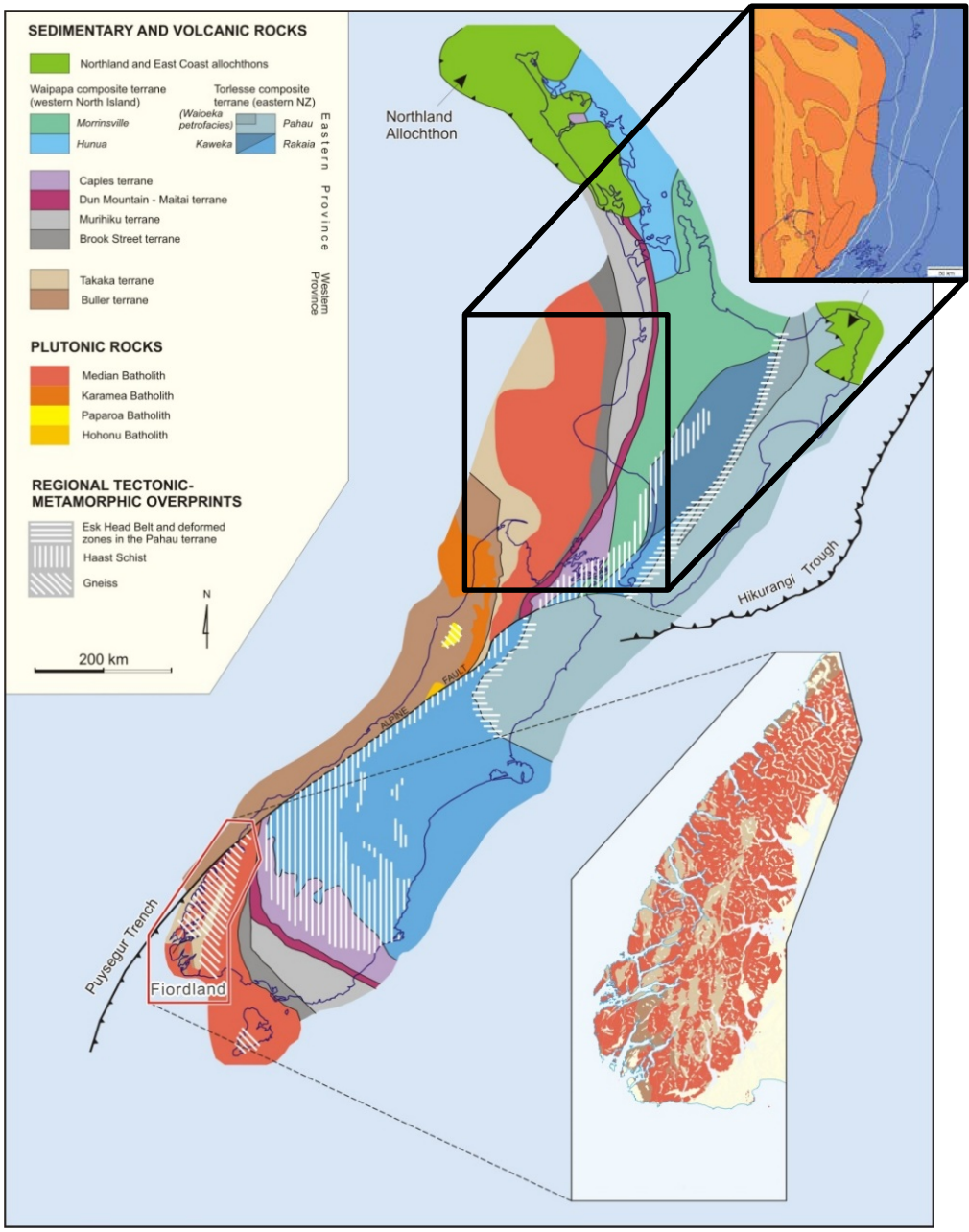
Taranaki is currently the only producing sedimentary basin in New Zealand

New Zealand Basement

Western Province – basement and cover rocks from Gondwana craton (Cambro-Ordovician)

Plutonic rocks - mostly comprising Median and Karamea batholiths (dominant Cretaceous-Jurassic & Devonian)

Eastern Province – elements of the arc-trench-subduction system active along E Gondwana margin (Triassic-Late Cretaceous)



General New Zealand basement map (from Turnbull & Allibone, 2003; Mortimer, 2004) and inset Taranaki summary basement map (modified from Mortimer et al., 1997 and Tulloch et al., in prep.)

W-E Schematic Cross Section

Mt Taranaki

Taupo Volcanic Zone

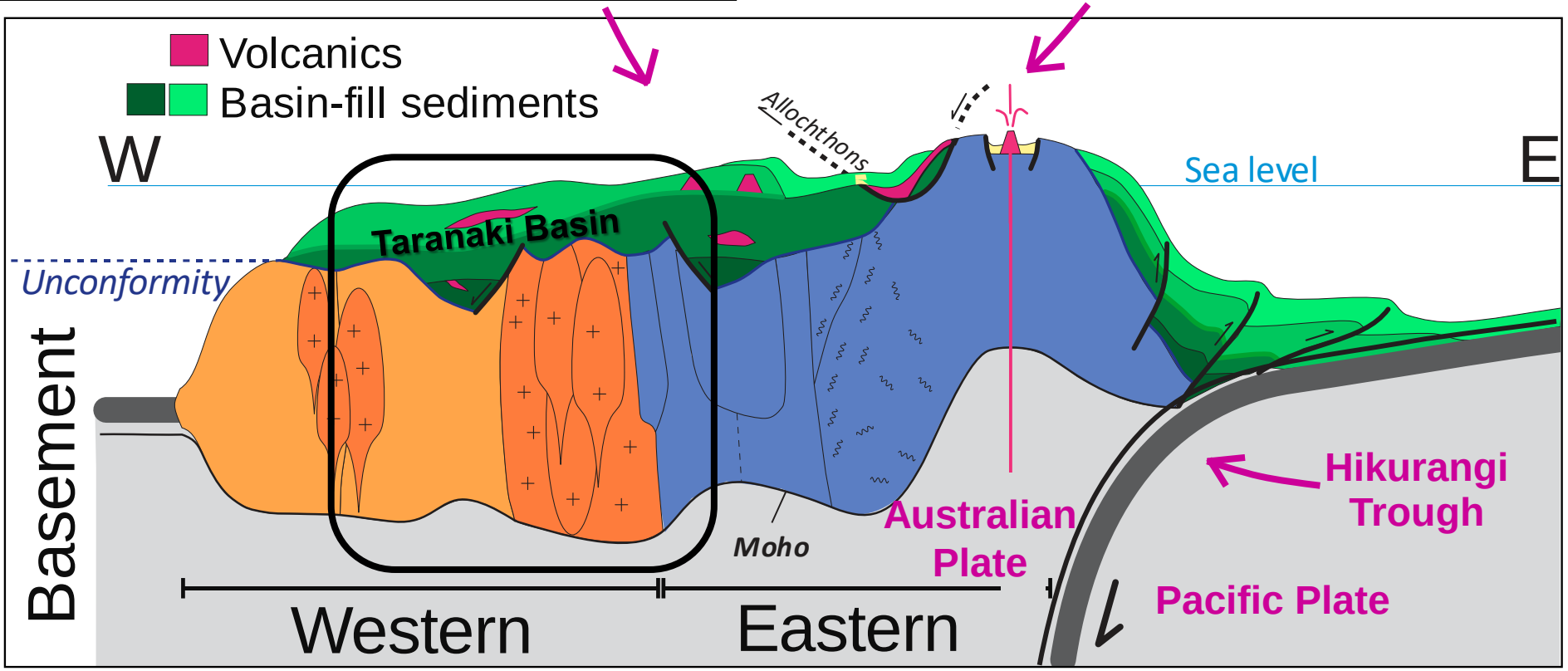


Figure after Mortimer, 2014

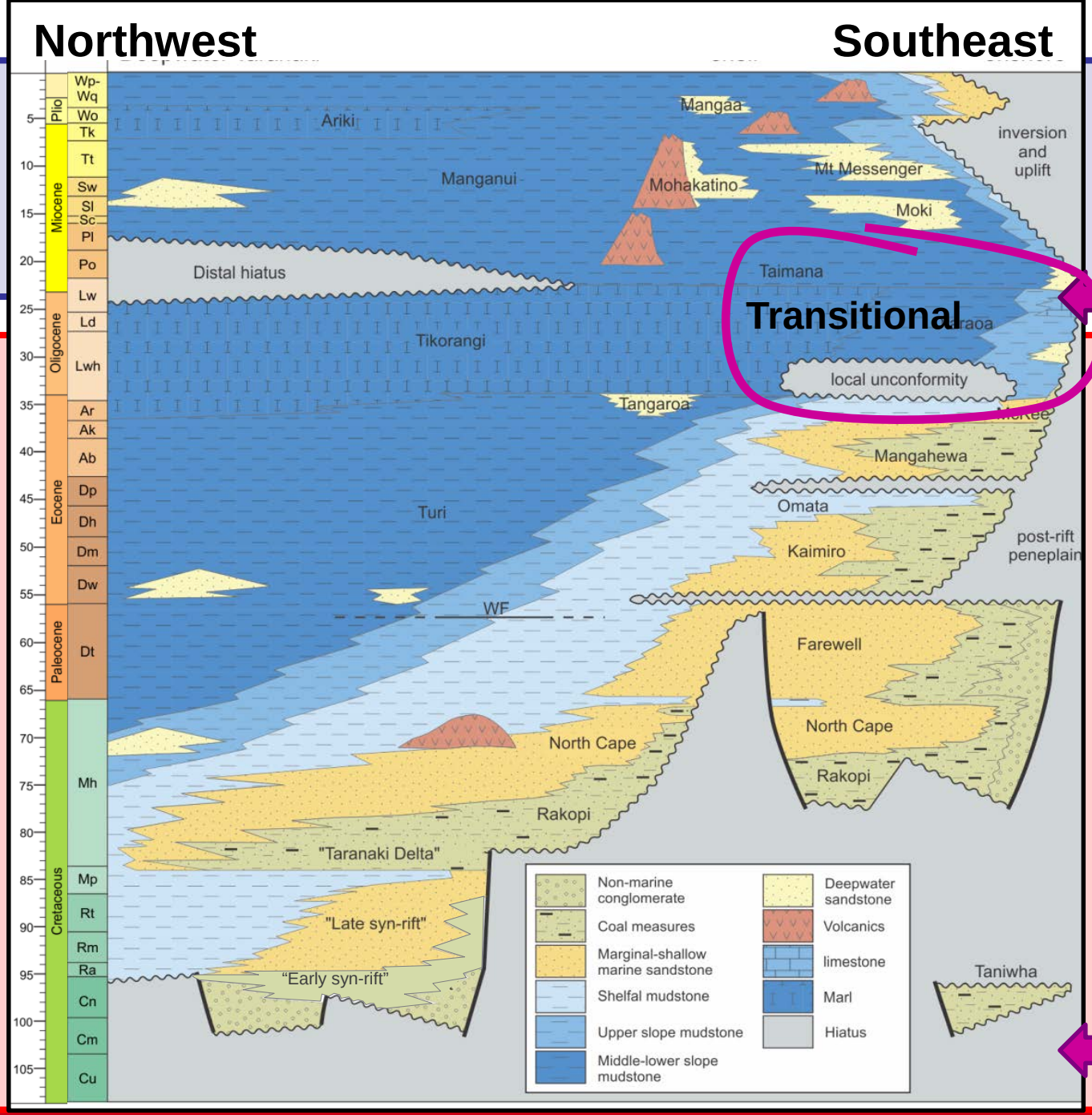


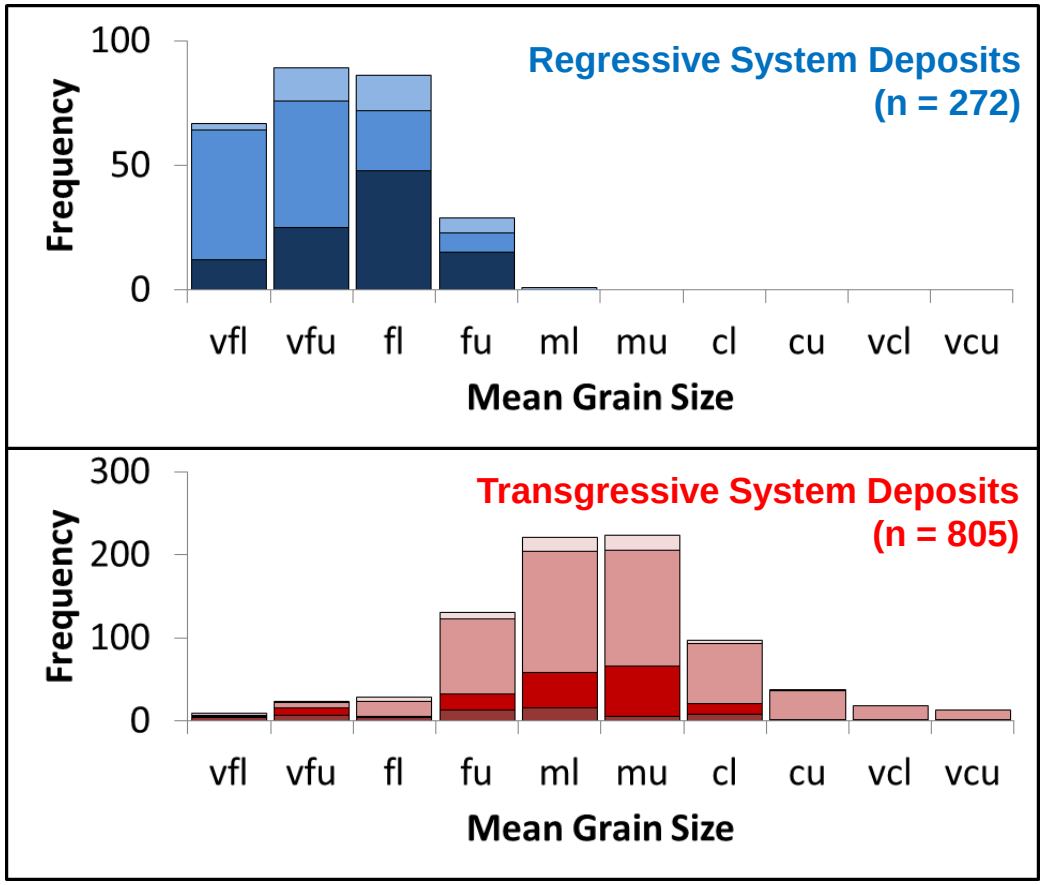
Figure after Bland et al., 2014

Reservoir Facies

Transgressive:

Regressive:

Stratigraphic differences in mean grain size



Miocene (Active Margin)
- Urenui
- Mount Messenger
- Moki

Oligocene (Transitional)
- Tariki/Matapo

Paleogene (Passive Margin)
- Kaimiro/Mangahewa/McKee
- Farewell

Cretaceous (Syn-rift)
- Rakopi/North Cape

Grain Size

vf = very fine f = fine m = medium c = coarse vc = very coarse

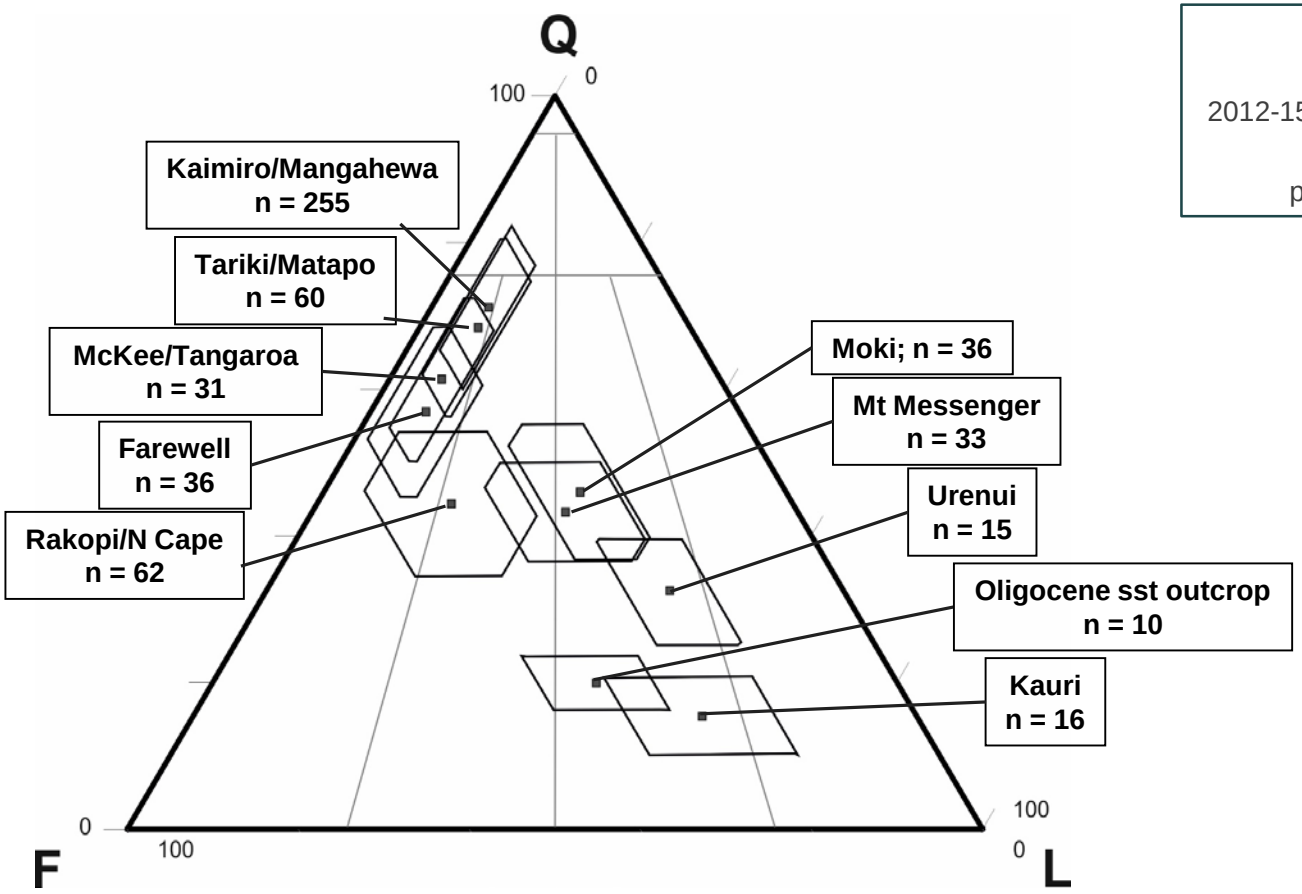
l = lower u = upper

Thin section data from: PEGI (Higgs et al., 2012)

Coarse & granular Rakopi Fm
Alluvial/fluvial facies
Transgressive System Deposits

V fine grained Mt Messenger Fm
Deep Water facies
Regressive System Deposits

Stratigraphic differences in detrital mineralogy



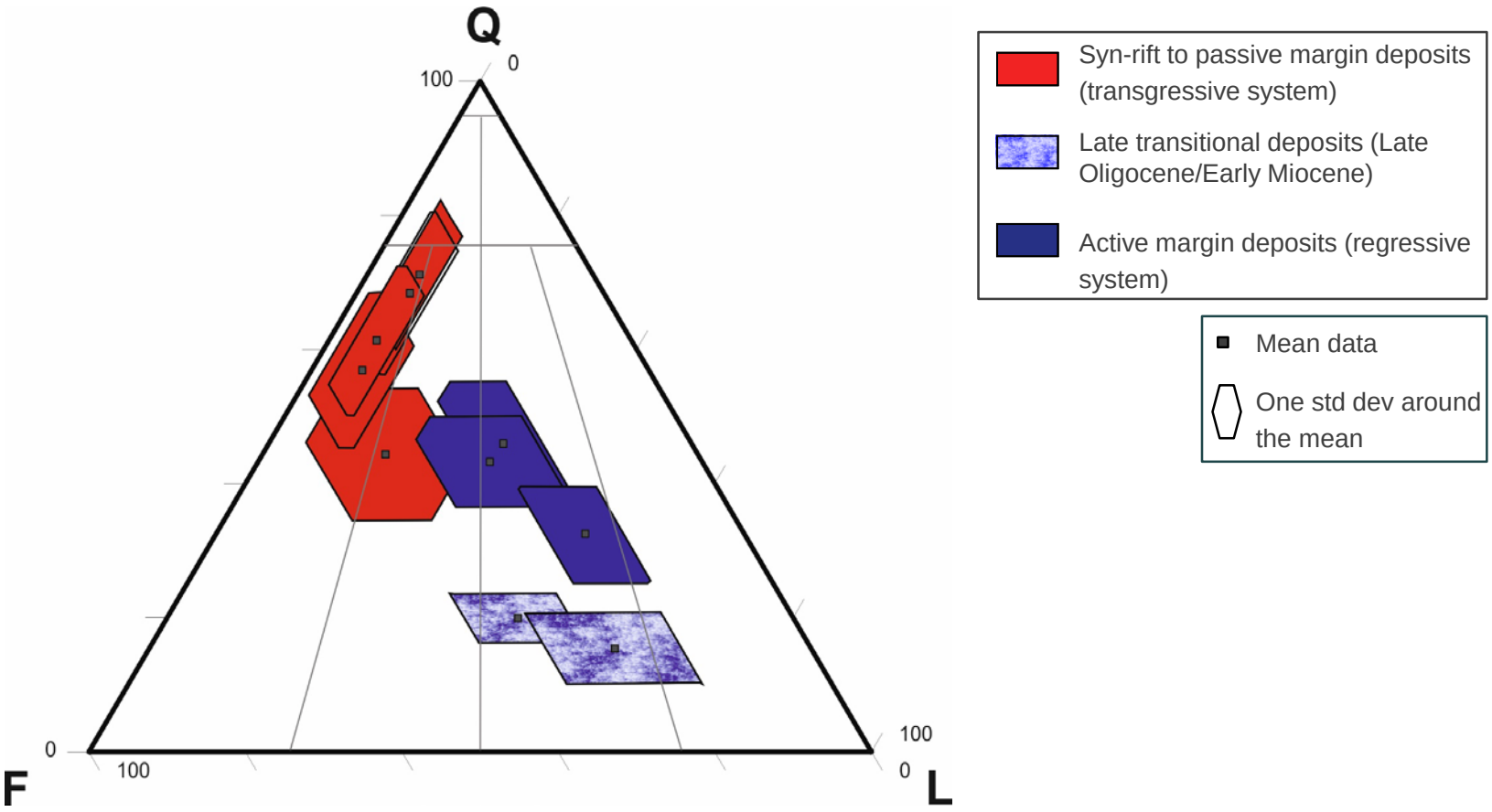
Thin section data from:
PEGI (Higgs et al., 2012),
2012-15 open-file PR reports (GNS),
Kauri Sand Study (GNS with permission from Swift Energy)

Mean data

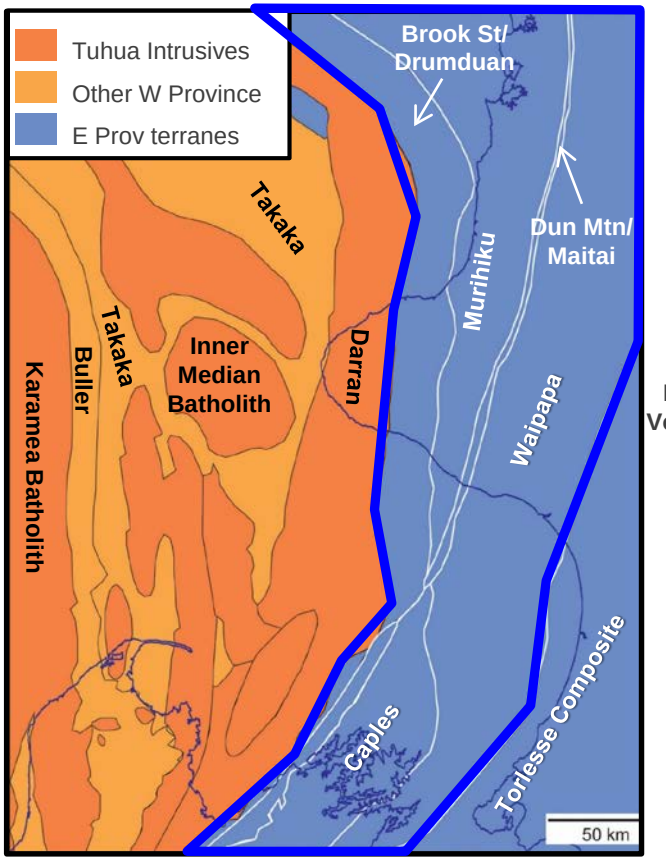
One std dev around the mean

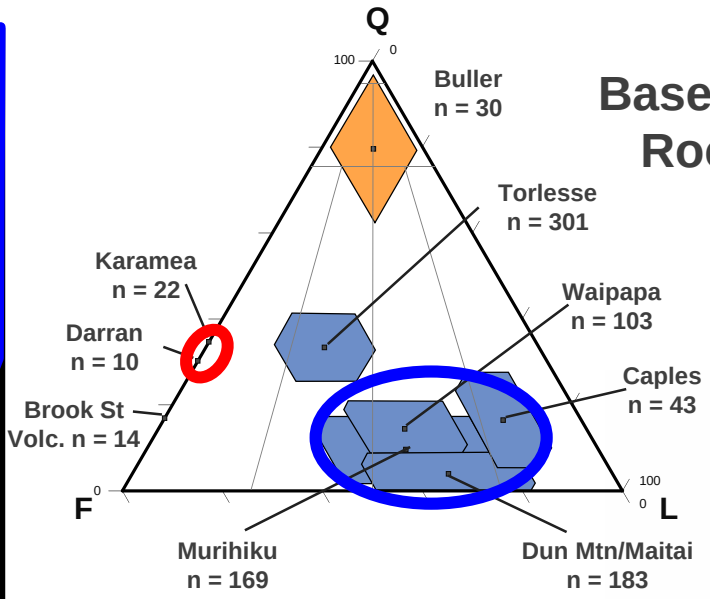
Sandstone classification scheme from Folk et al.,1970

Correlation between mineralogy and basin history



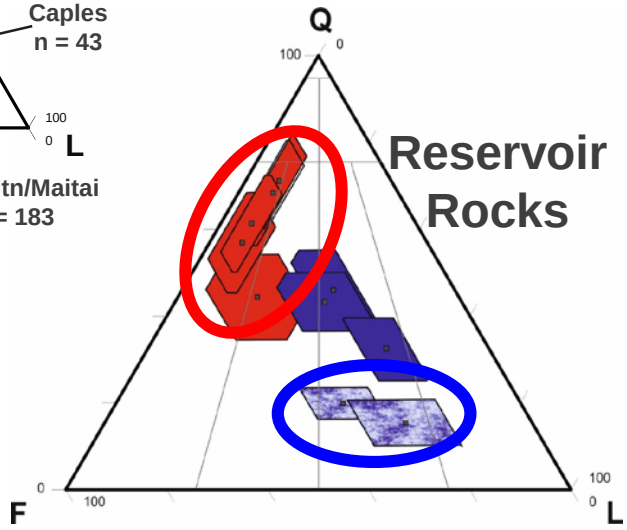
Correlation of mineralogy to basement source





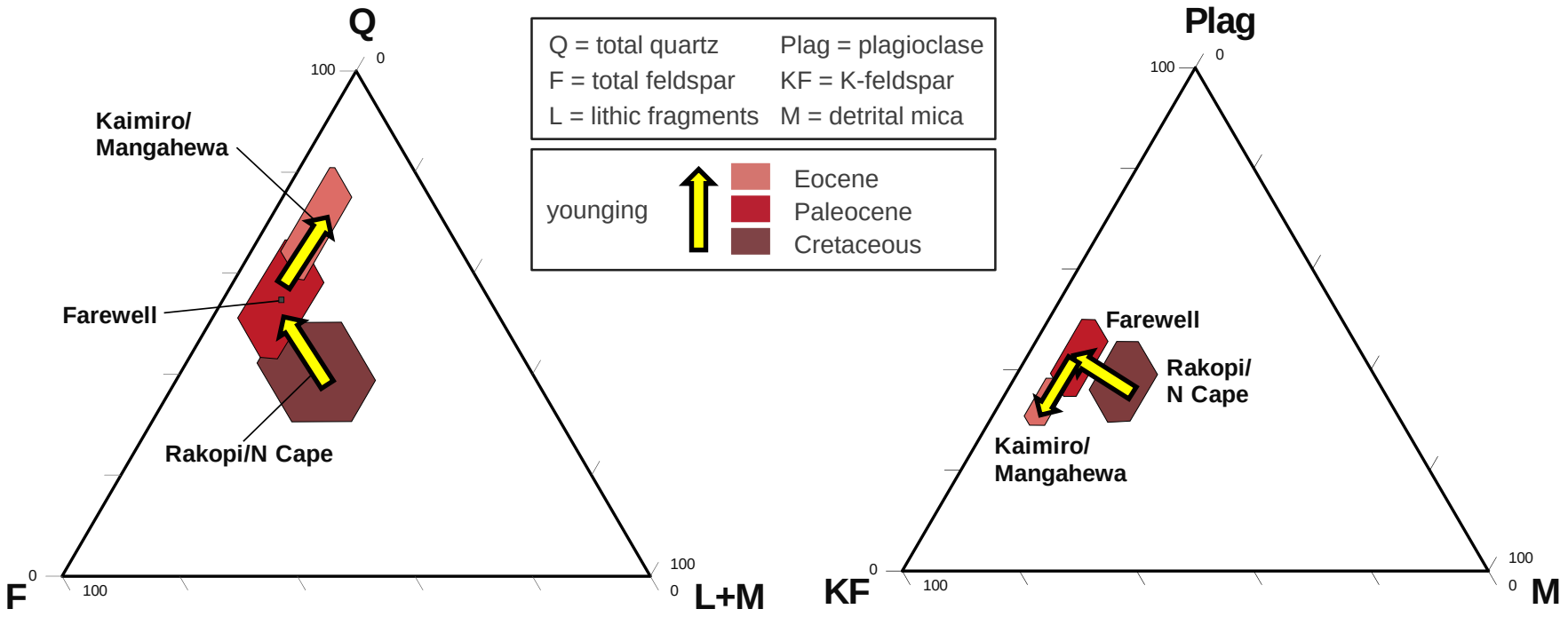
Basement Rocks

TS data from:
GNS PETLAB
(published data & theses
as referenced in PETLAB)



Reservoir Rocks

Mineralogy trends in syn-rift to passive margin deposits (transgressive system)



Cretaceous – most primitive, mica and lithic-rich

Paleocene (Farewell) – intermediate composition, plag-rich

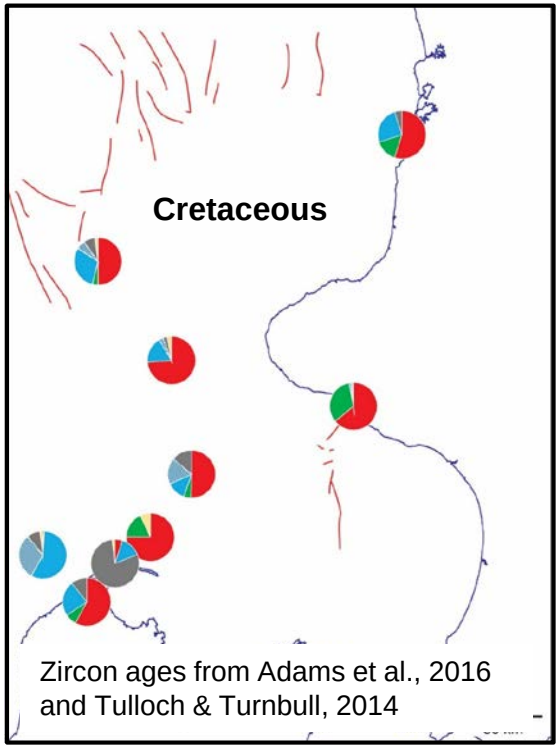
Eocene – most mature, quartz and K-feldspar rich

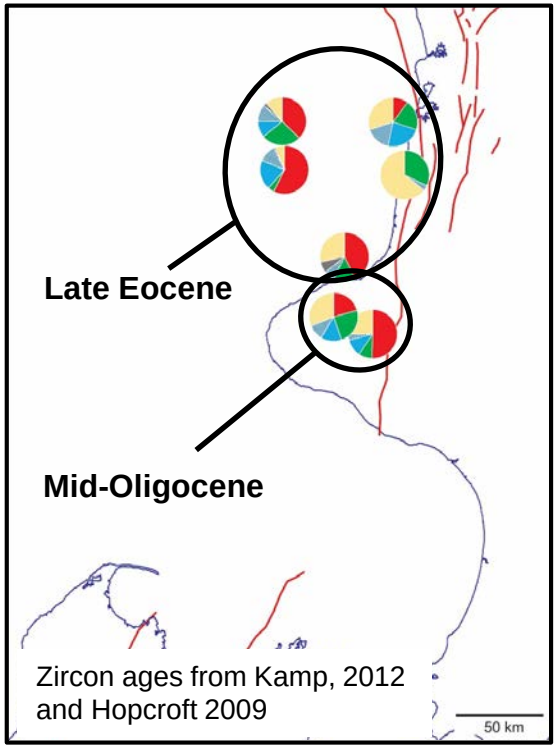
U-Pb zircon geochronology results

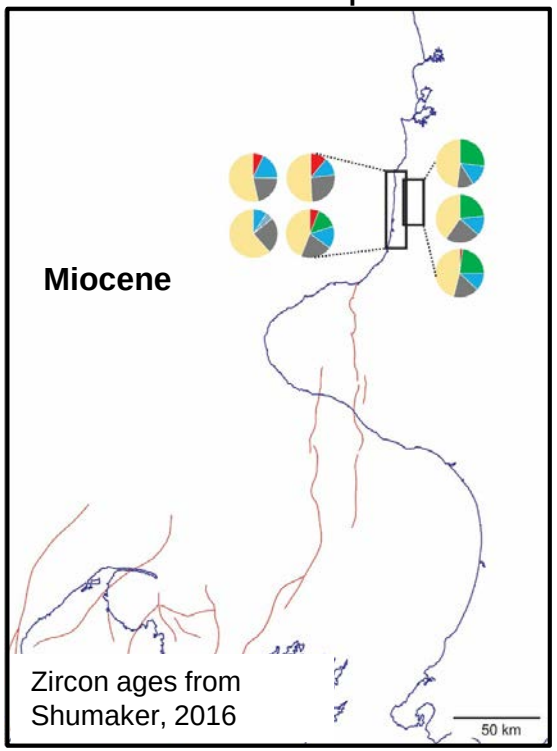
Syn-rift (Cretaceous):
zircon mostly derived from local basement rocks

Early Transition:
zircon mostly derived from granites but some EP source in the NE

Active Margin:
zircons support multiple sources, significant E Province component







Separation Pt Suite
Darran Suite
Karamea Suite
Plutonic Source
Buller/Takaka
Western Province

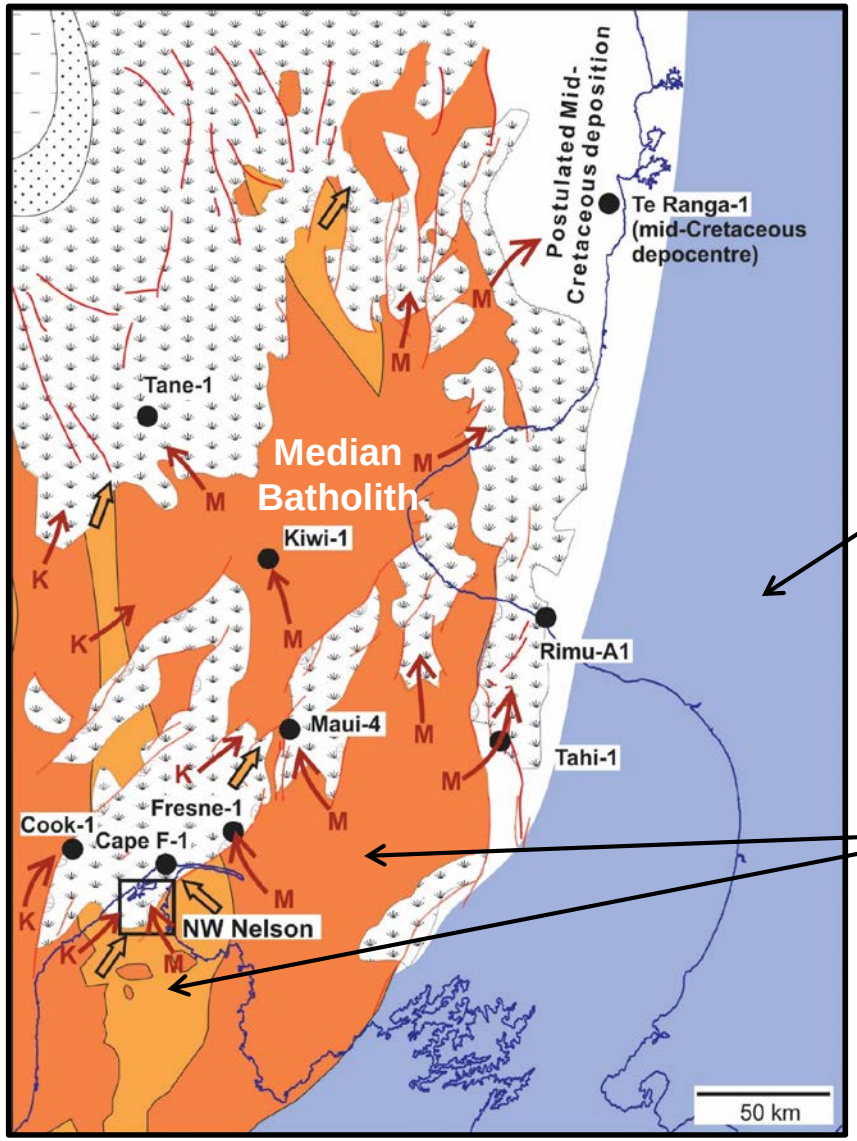
Undiff metasedimentary terranes
Eastern Province

Syn-rift: Local basement provenance dominated by first cycle source from Tuhua Intrusives

T Tuhua Intrusives
WP Other W Province
EP E Prov terranes

Coastal plain facies
Shoreline/shoreface
Offshore marine facies
Submarine fan facies

K Karamea source
M Median batholith source
Eastern Prov source
Western Prov source
Eroded sedi source
Volcaniclastic source



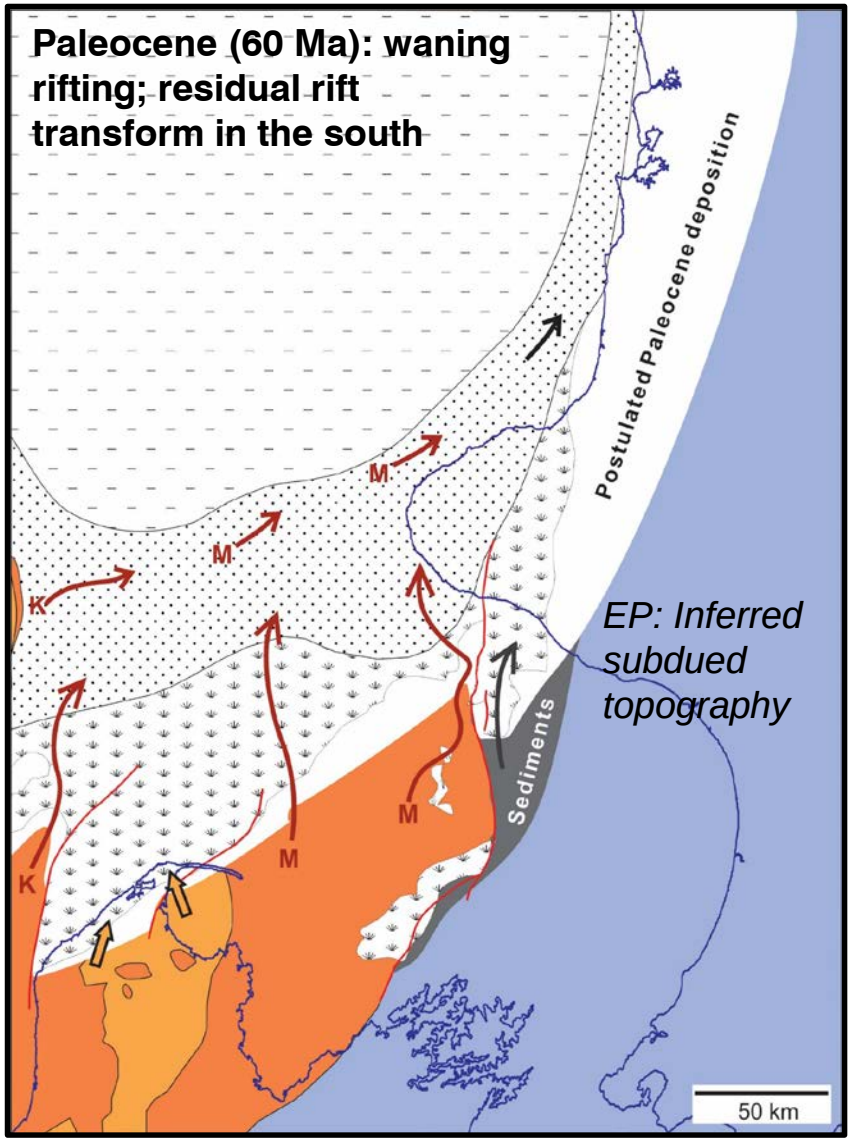
Cretaceous 65-75 Ma: active rift transform zone with development of small rift grabens

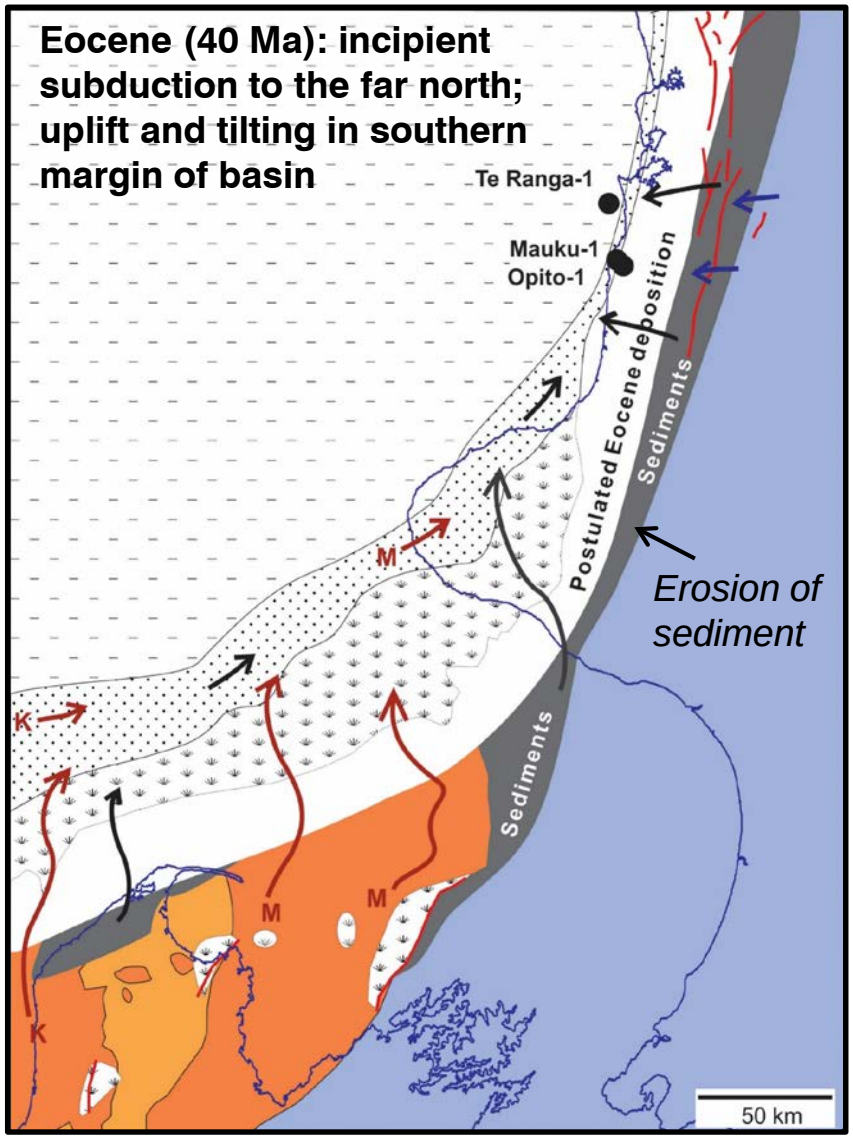
EP: Inferred subdued topography

Exposed & eroding Paleozoic terranes & plutons

Figure from Higgs and King, 2018; paleogeography after Strogen, 2011; basement after Mortimer et al. (1997)

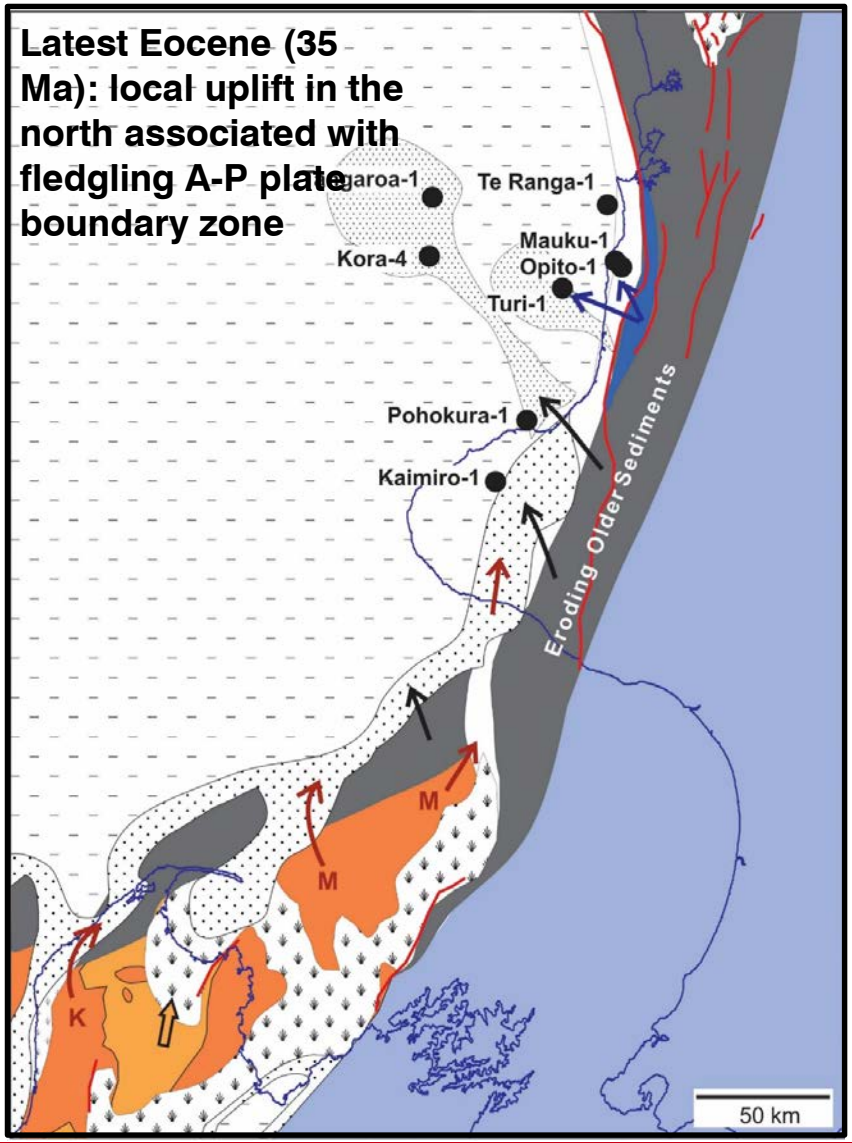
Post-rift, passive margin: 1st & 2nd cycle from intrusives in the south, longer transport distances, some re-working

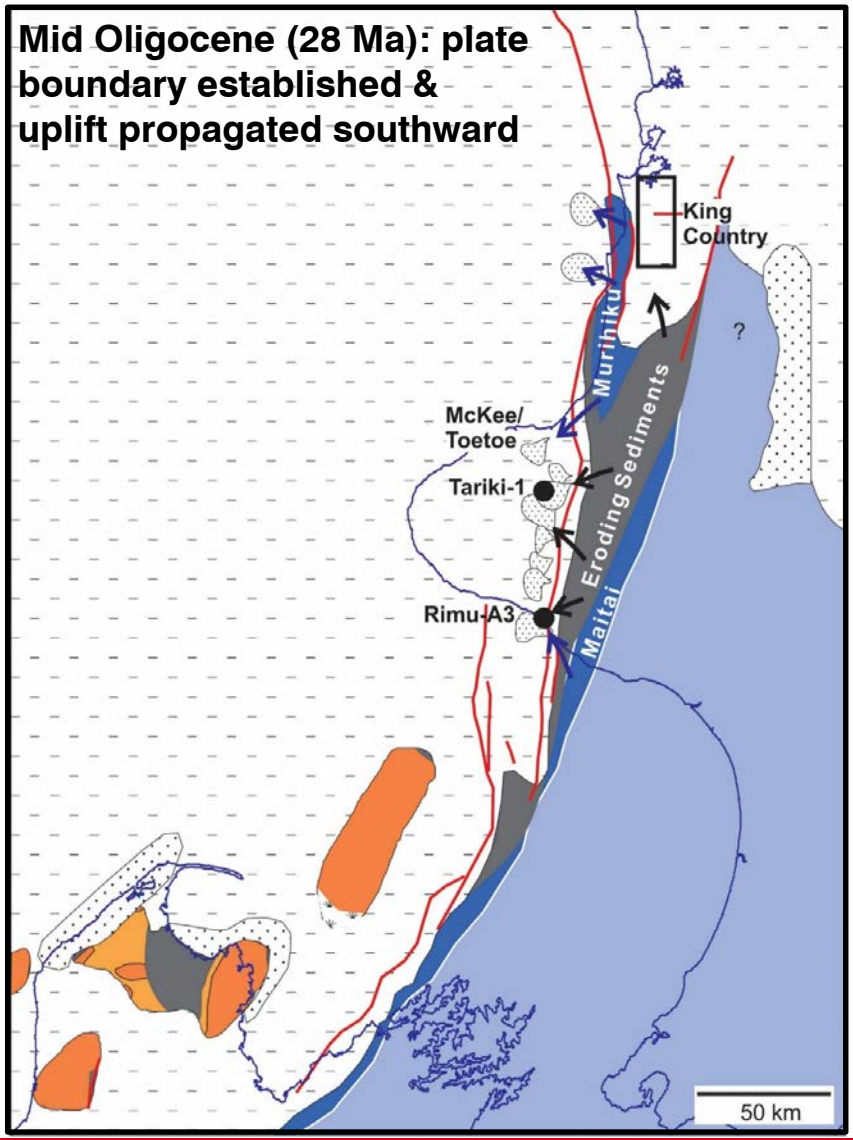




Figures from Higgs and King, 2018; paleogeography after Strogen, 2011; basement after Mortimer et al. (1997)

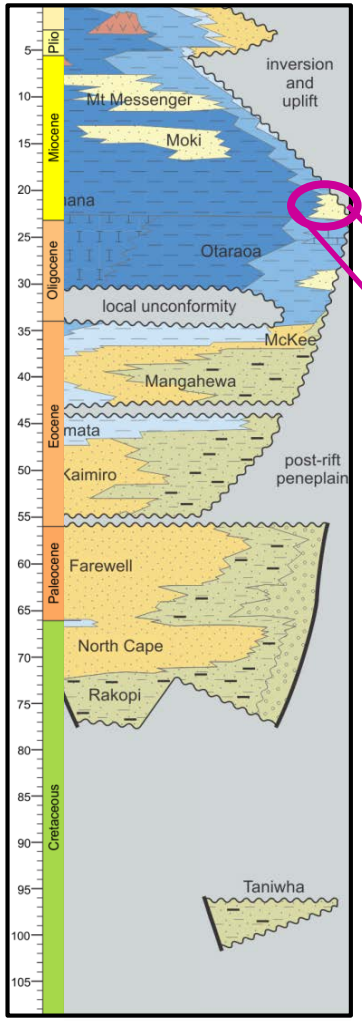
Early transition (35-27 Ma): Erosion of cover rocks with progressive unroofing from N to S



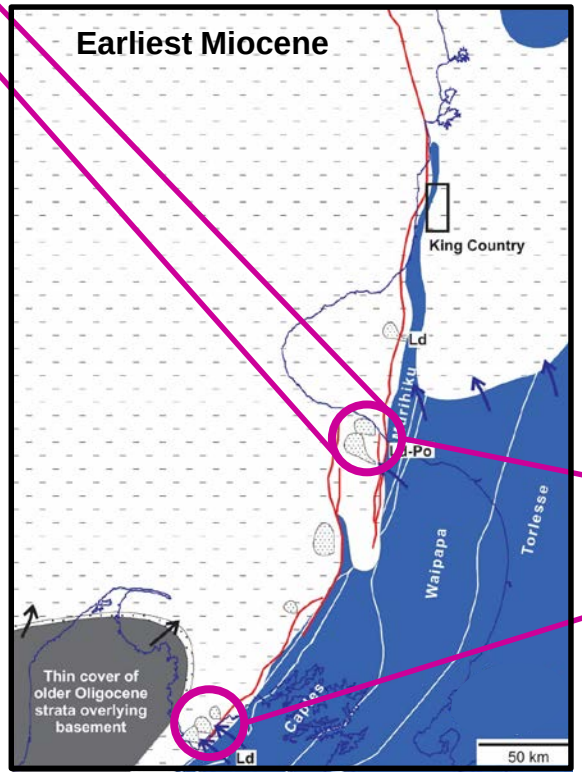


Figures from Higgs and King, 2018; paleogeography after Strogen, 2011; basement after Mortimer et al. (1997)

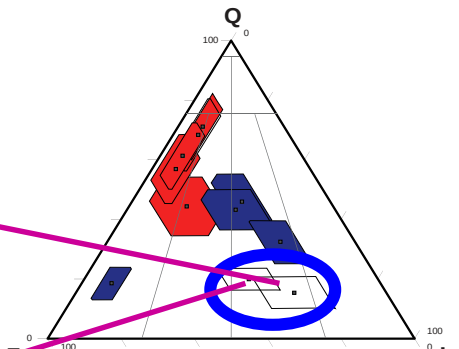
Late transition (21 Ma): Fine-grained, lithic-rich sediments derived from Eastern Province terranes



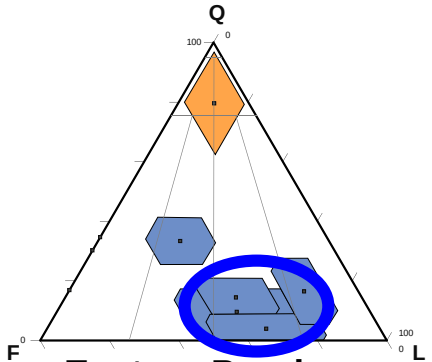
Onset of regression; piggy-back basins and uplift in the east



Earliest Miocene:
Active thrusting on eastern basin margin; provenance from the East

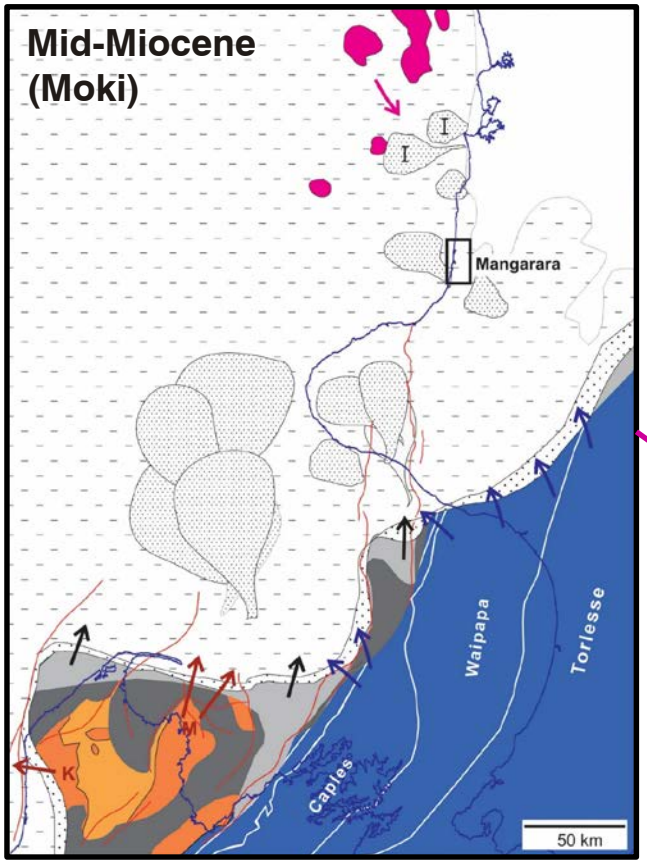


Latest Oligocene-Earliest Miocene



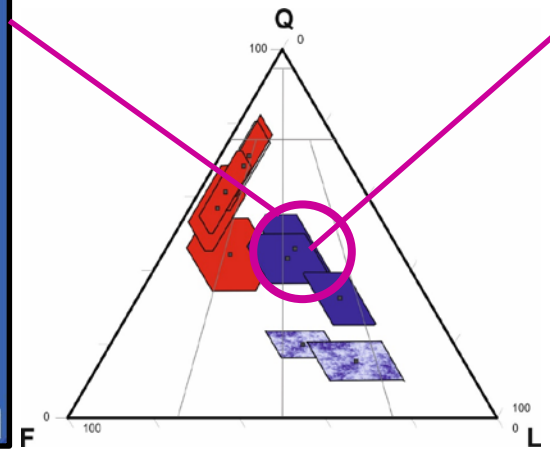
Eastern Province basement

Active margin (Miocene): Mixed sediment sources with significant Eastern Province component



Mid-Miocene:
Some granitic source in southern basin

Late Miocene:
Finer sediments may indicate component of reworked Miocene sediments



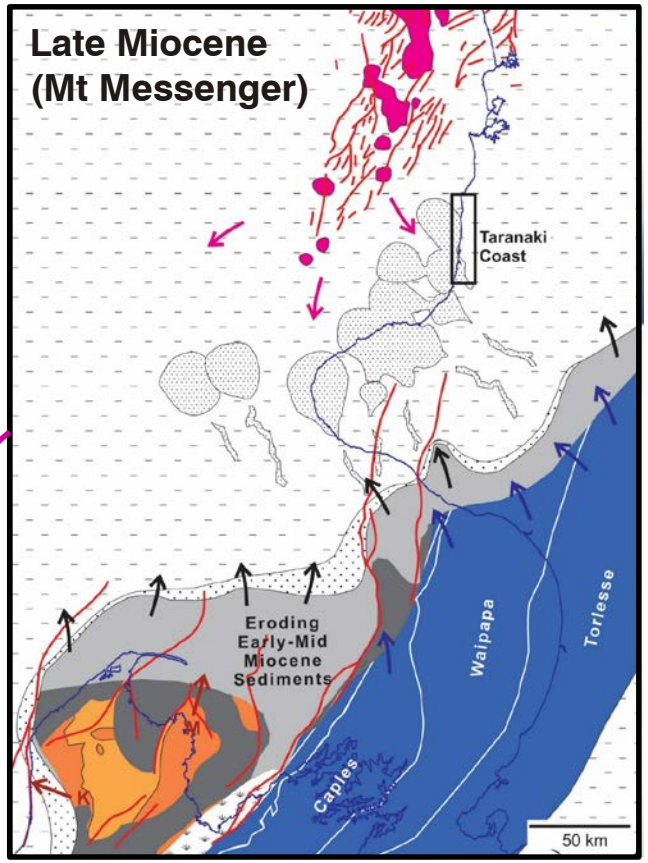


Photo from GNS researchers

GNS Science

Properties at deposition, provenance & facies related

PRIMARY CONTROLS

- **grain size**
- **sorting**
- **mineralogy**

Implications for Reservoir Quality

Diagenesis, dependent on depositional properties AND burial, temperature, fluid history

SECONDARY CONTROLS

- **compaction**
- **mineral cement**
- **authigenic clay**
- **secondary dissolution**

Compaction

Syn-rift to passive margin deposits (Transgressive System)

Coarse grain size
Quartz-feldspar mineralogy

↓

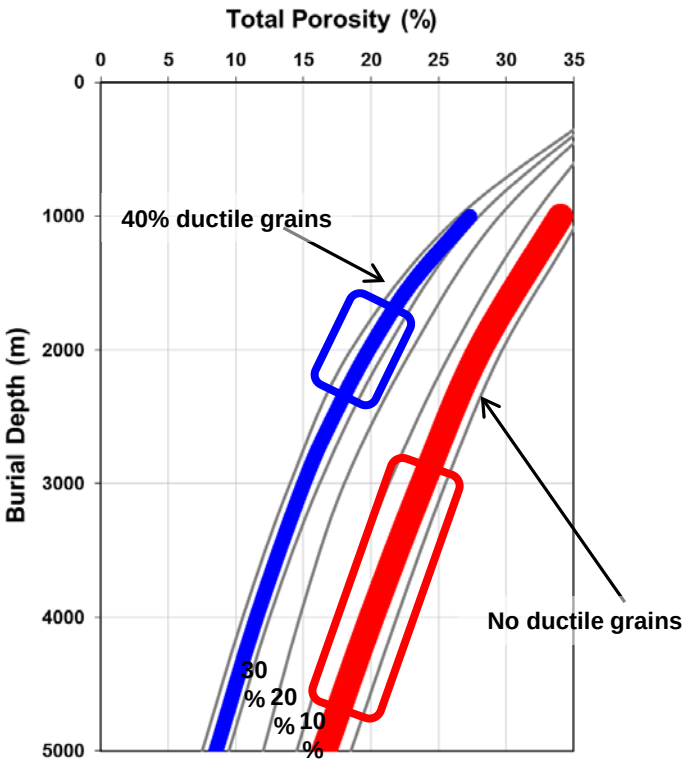
Less prone to compaction-induced porosity loss

Active margin deposits (Regressive System)

Fine grain size
Feldspar-lithic mineralogy

↓

More prone to compaction-induced porosity loss



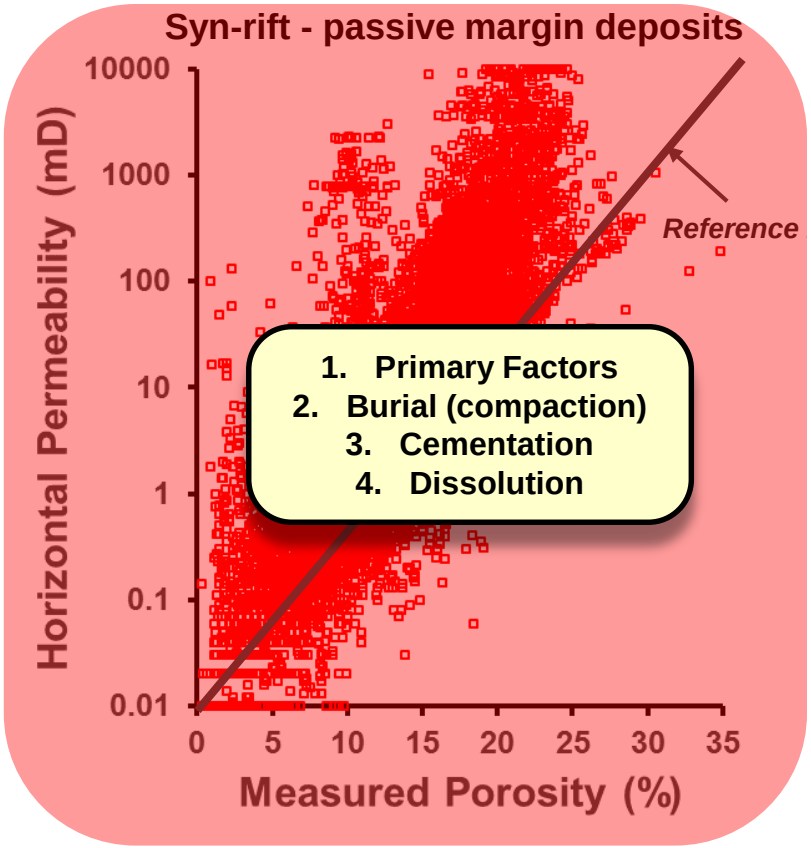
Graph does not include other pore-modifying factors (e.g., cementation / secondary porosity / overpressure)

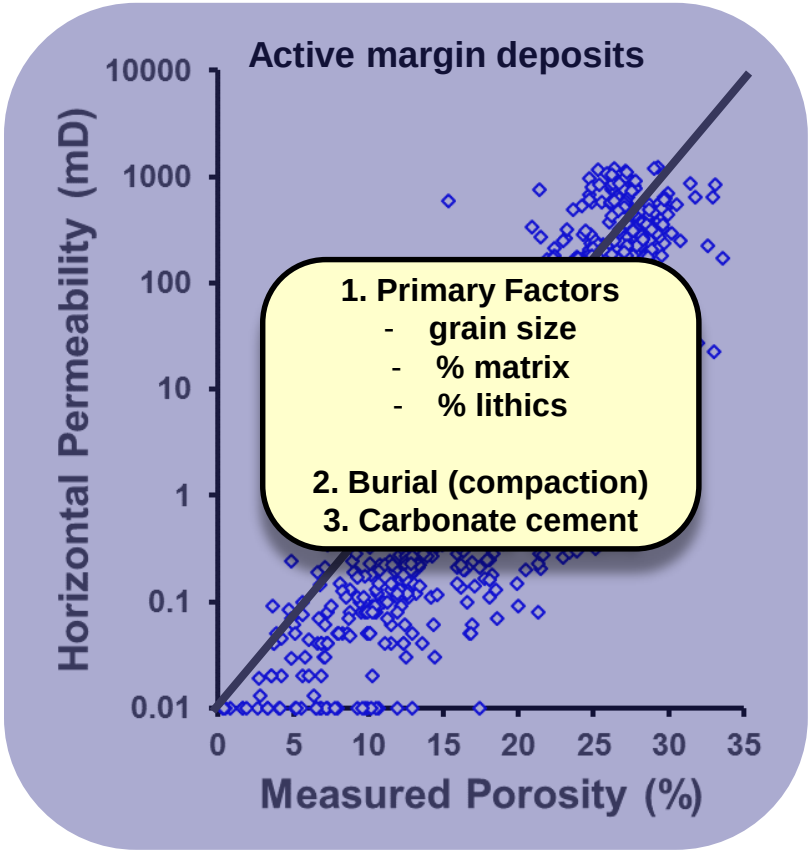
Miocene Sandstones: porosity loss by compaction up to c. 20% - much macroporosity reduced to microporosity

Cret-Eocene Sandstones: porosity loss by compaction c. 15-25% - deeper burial, more complex diagenesis

Compaction curves after Worden et al., 1997 & 2000

Empirical net result: reservoir quality is variably controlled by primary and secondary factors





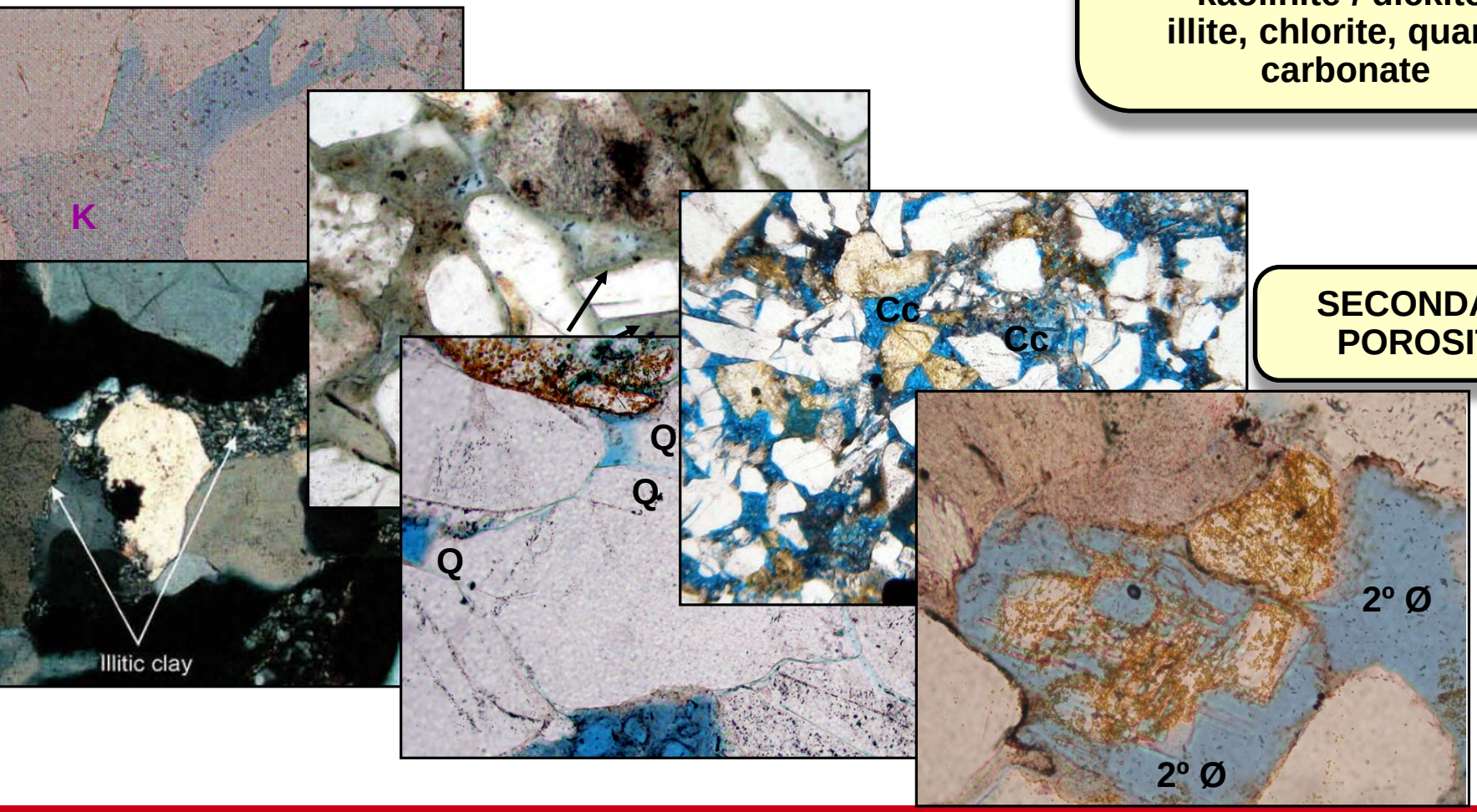
Rift-Passive Margin Deposits: Complex Diagenesis

Variable clay and cement type / abundance due to different facies / burial / fluid histories

TYPICAL AUTHIGENIC MINERALS

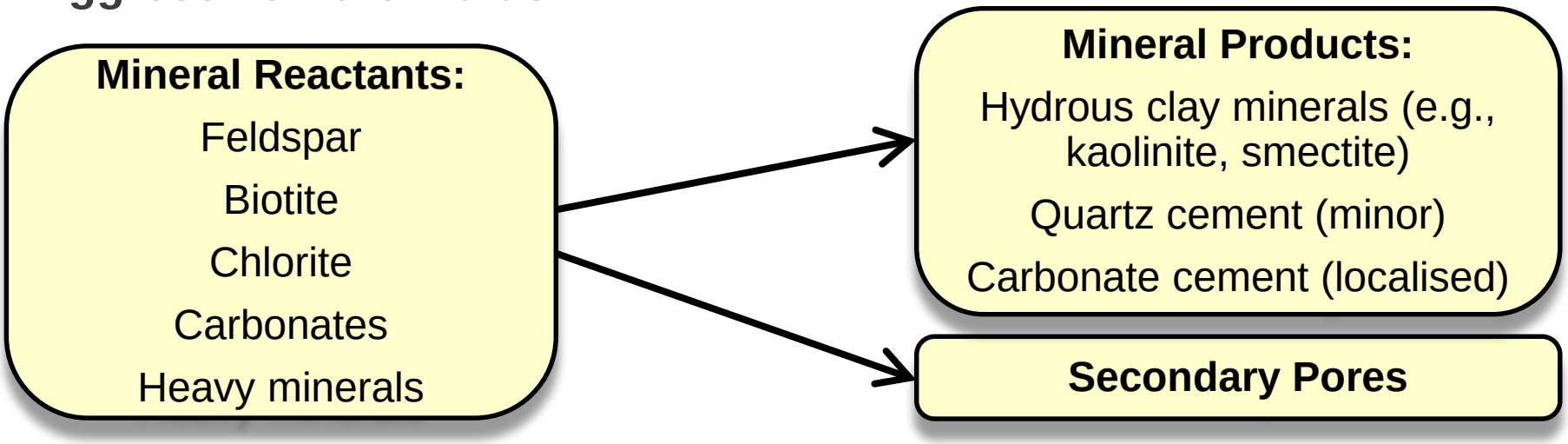
- **kaolinite / dickite, illite, chlorite, quartz, carbonate**

SECONDARY POROSITY

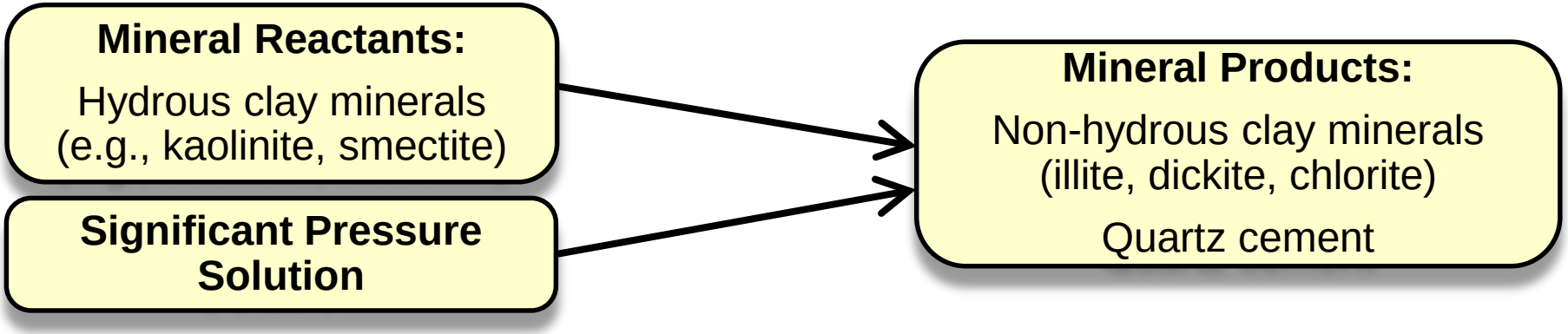


Rift-Passive Margin Deposits: Diagenetic Reactions

1. Aggressive Pore Fluids



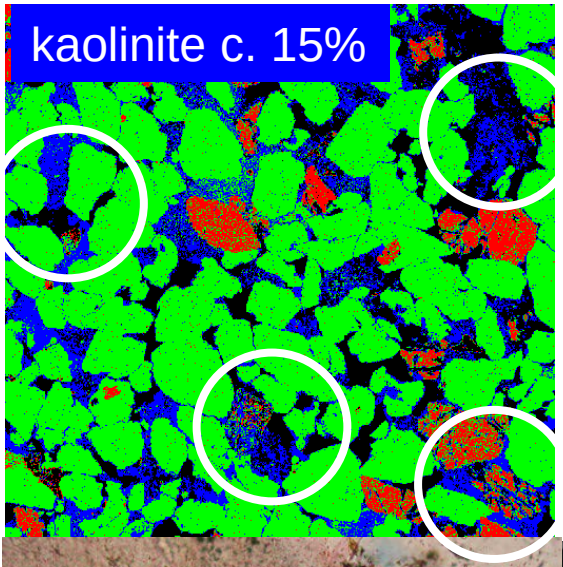
2. High temperature (>120 ºC)



Aggressive pore fluids = meteoric water / CO_2 from maturation of coals / hydrothermal events, etc.

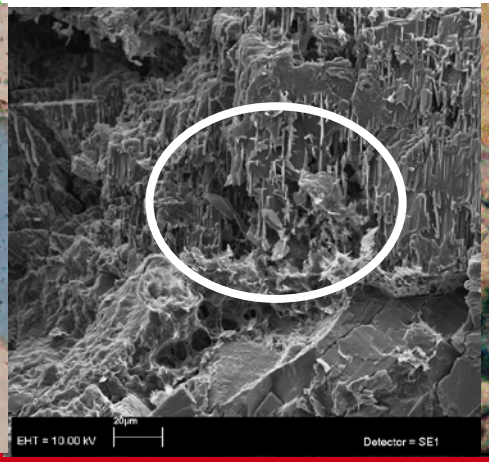
Rift-Passive Margin Deposits: Example of Feldspar Reaction (aggressive fluids)

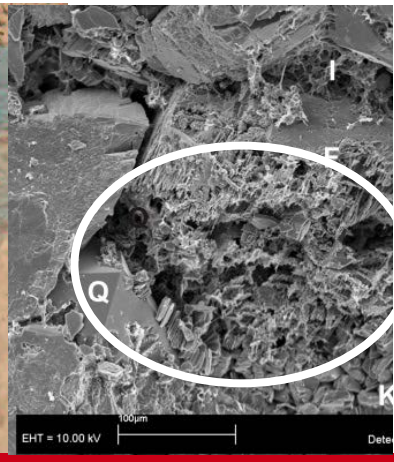
Feldspar + CO_2 + water = <u>kaolinite + silica + K^+/Na^+/Ca^+ + bicarbonate</u>



➡ **Good:** local generation of large secondary pores

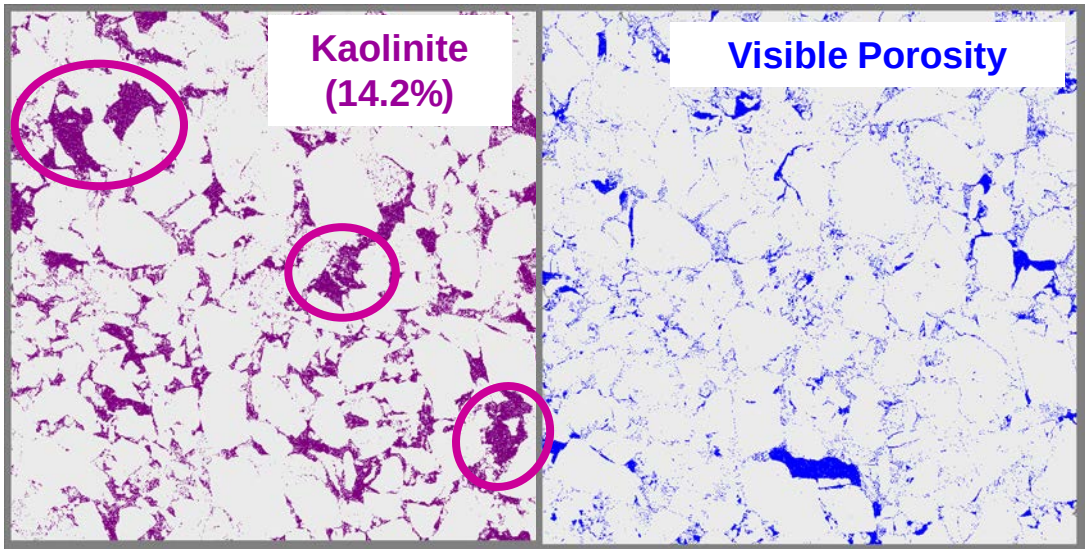
⬅ **Bad:** locally pervasive kaolinite or carbonate

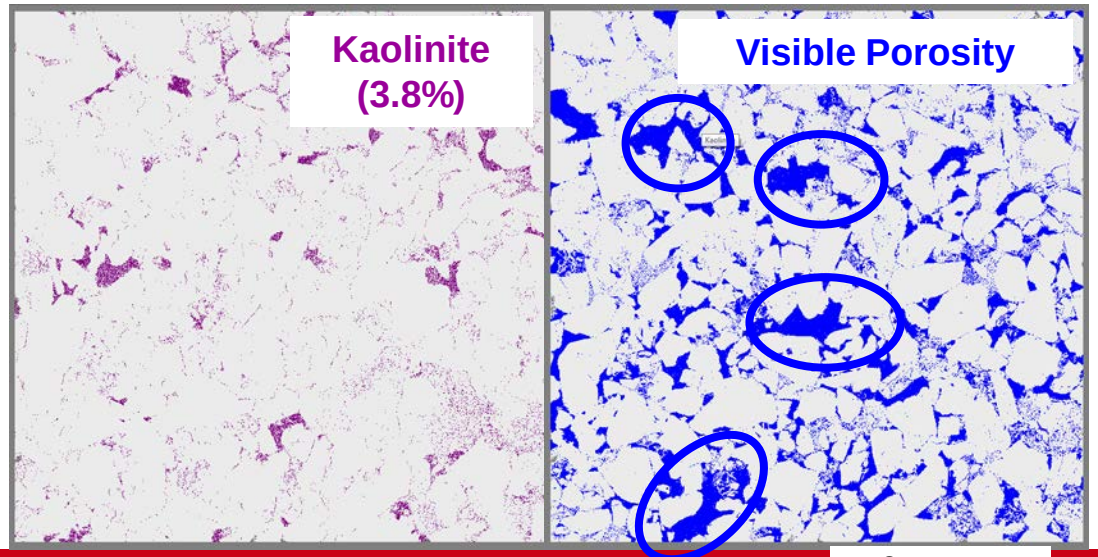




Rift-Passive Margin Deposits: The good & bad effects of feldspar reaction

Feldspar + CO_2 + water = kaolinite + silica + K^+/Na^+/Ca^+ + bicarbonate





Bad

Example 1)
Burial Depth 3,256 m
Much feldspar altered to kaolin

Total Porosity 15.8%
Visible Porosity 6.5%
Permeability 32 mD

Good

Example 2)
Burial Depth 3,503 m
Significant feldspar dissolution pores

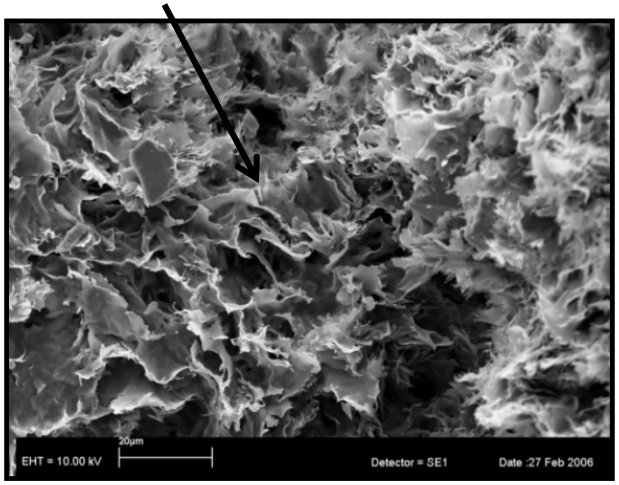
Total Porosity 18.5%
Visible Porosity 16.1%
Permeability 2270 mD

Figure after Higgs et al., 2017

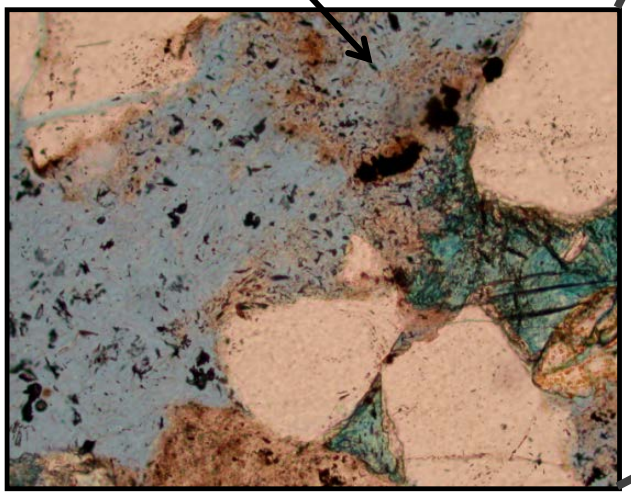
2 mm

Rift-Passive Margin Deposits: Example of Illitisation Reaction (high Ts)

Illitised Kaolinite



Illitised Kaolinite

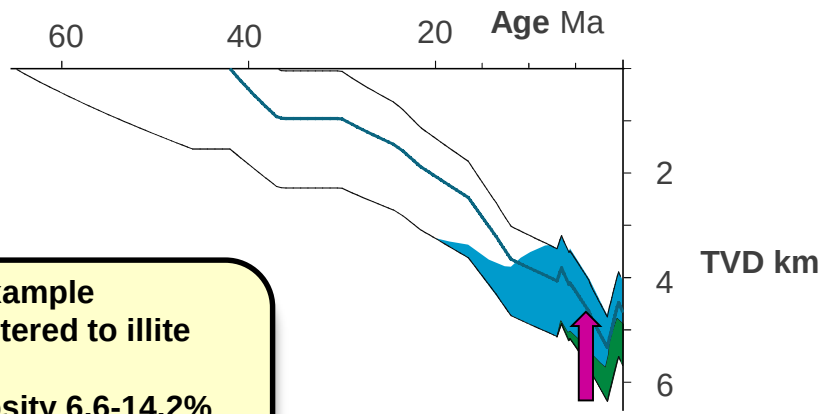


K-feldspar + kaolinite = <u>illite + silica + water</u>

Bad: micro-porous illite and pore-filling quartz

Illitisation reaction based on K-Ar dates: ~130ºC, 4.5 km

Quartz cementation based on FI data: >110ºC, >4 km



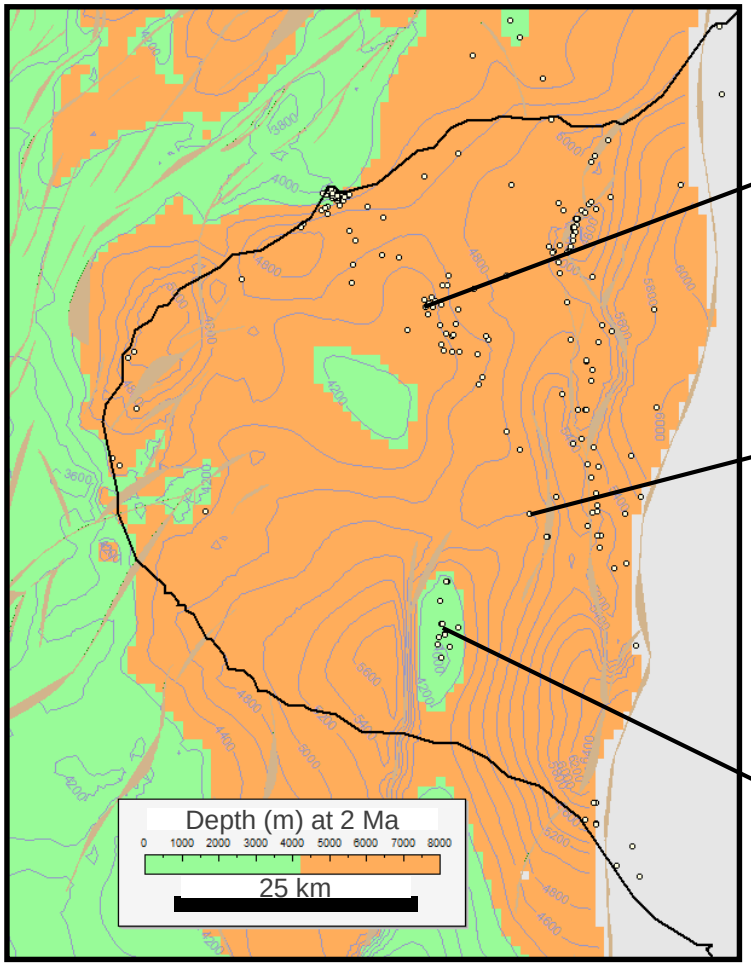
Example
Kaolin altered to illite

Total Porosity 6.6-14.2%
Permeability 0.1-3.3 mD

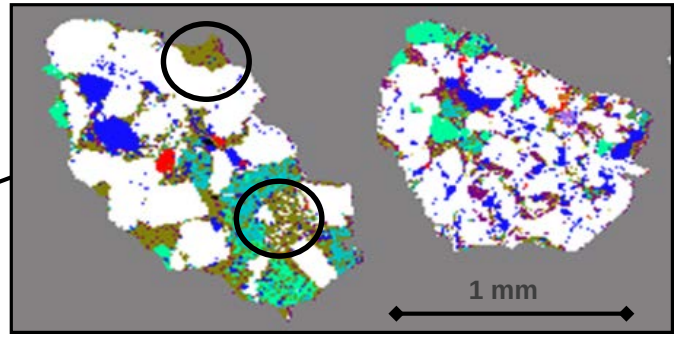
Timing of illitisation ~ intraformational coals mature for oil expulsion (green)

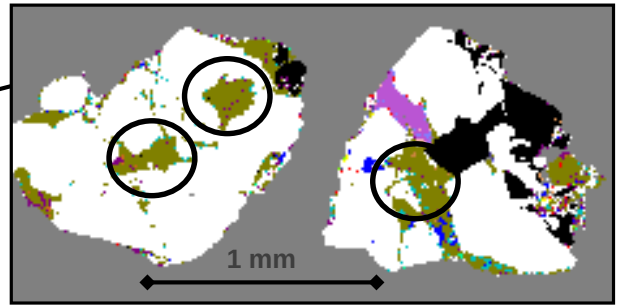
From Higgs et al., 2007

Rift-Passive Margin Deposits: Significant illitisation predicted across most of the Taranaki Peninsula



Depth map, Middle Eocene at 2 Ma (~max. burial); orange > 4.3 km





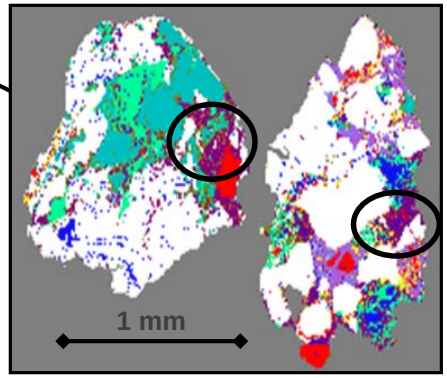


Figure after Higgs et al., 2017

Provenance vs Reservoir Quality

Syn-rift - passive margin deposits

Sediment source:
1st cycle or recycled Tuhua Intrusives

Coarse grain size
Quartz-feldspar mineralogy

↓

Less prone to compaction-induced porosity reduction

However more deeply buried

↓

Greater compaction (porosity reduction), and diagenetic alteration (porosity reduction & enhancement)

Active margin deposits

Sediment source: Multiple with significant E Province & volcanics

Fine grain size
Feldspar-lithic mineralogy

↓

More prone to compaction-induced porosity reduction

Relatively shallow burial

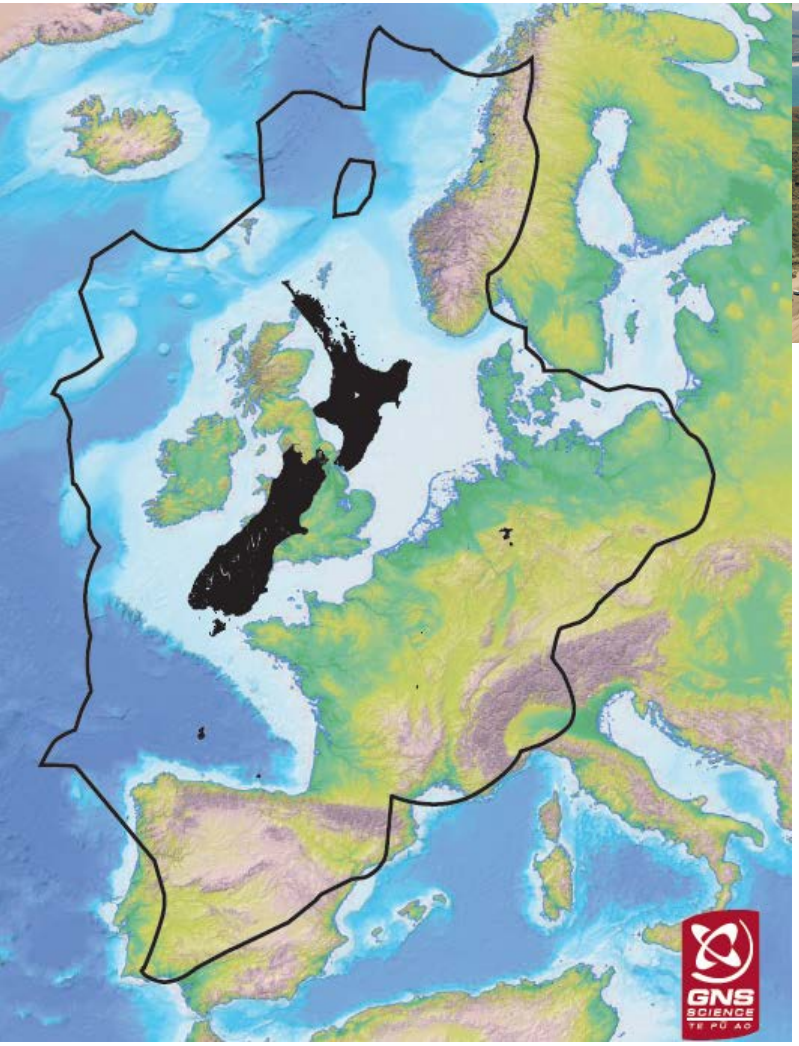
↓

But significant sediment compaction due to texture & composition; less advanced diagenetic alteration

Key message: understanding provenance is a prerequisite to predicting reservoir quality

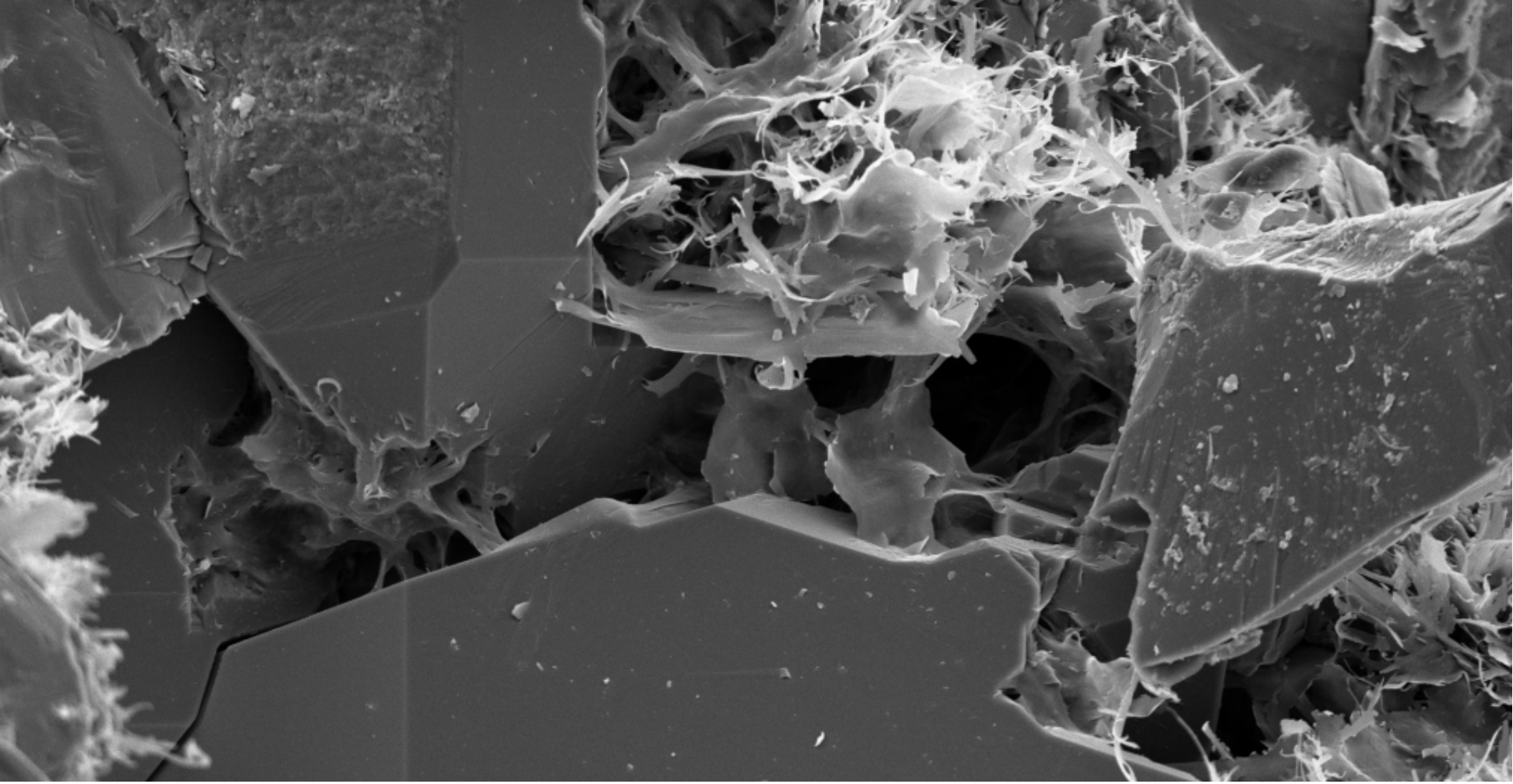
- Based on our integrated studies we can predict sandstone texture & composition across the basin
- We can use this information to predict the type and level of diagenesis
- Make an informed prediction of reservoir quality in an undrilled site

Reservoir heterogeneity
Burial/temperature history
Fluid history



Looking offshore beyond Taranaki

…..a lot of ground to cover



Thank You

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