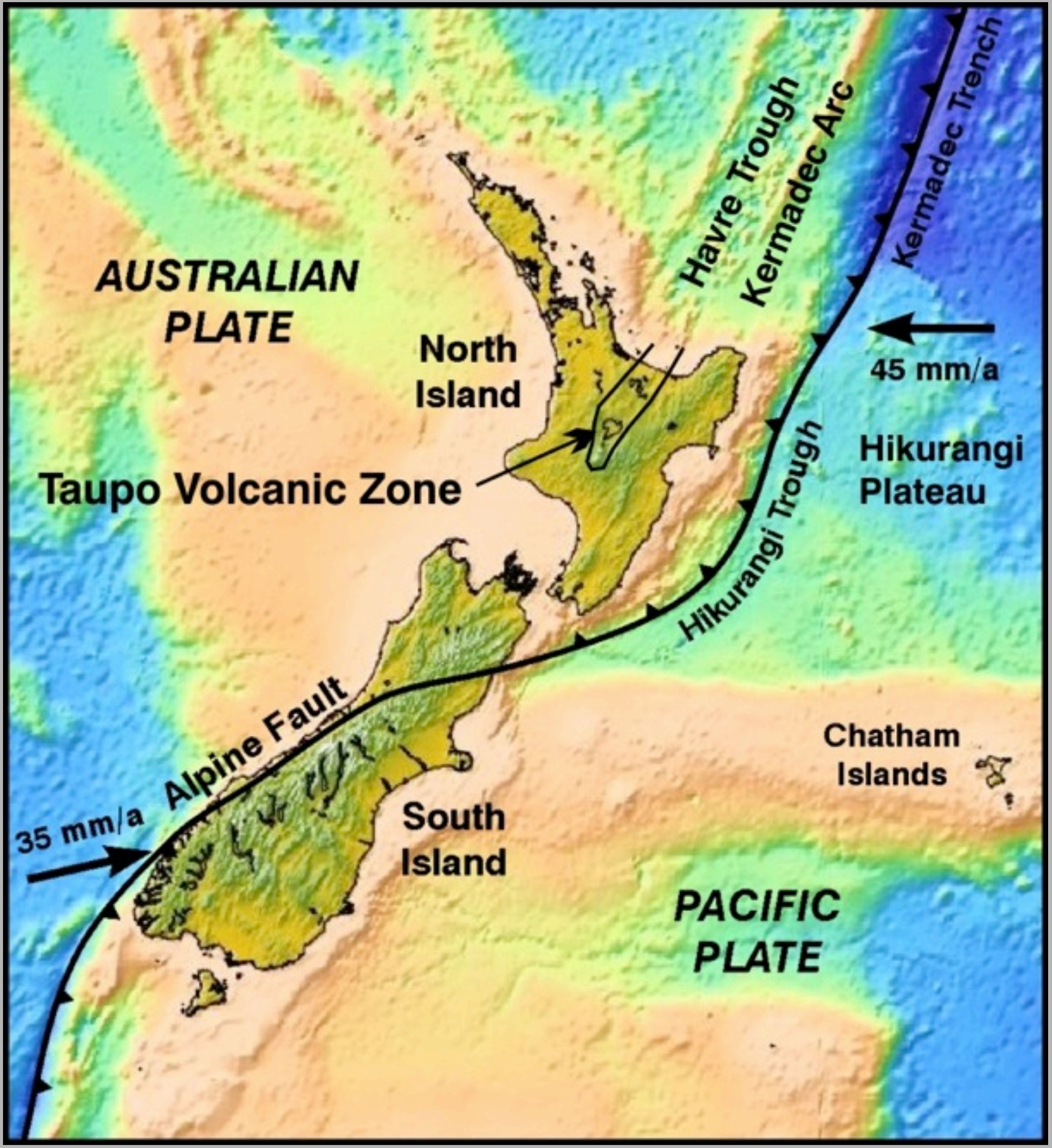
Taupo zone volcanism, extension and large silicic eruptions (Magmatism-Volcanism-Tectonism)

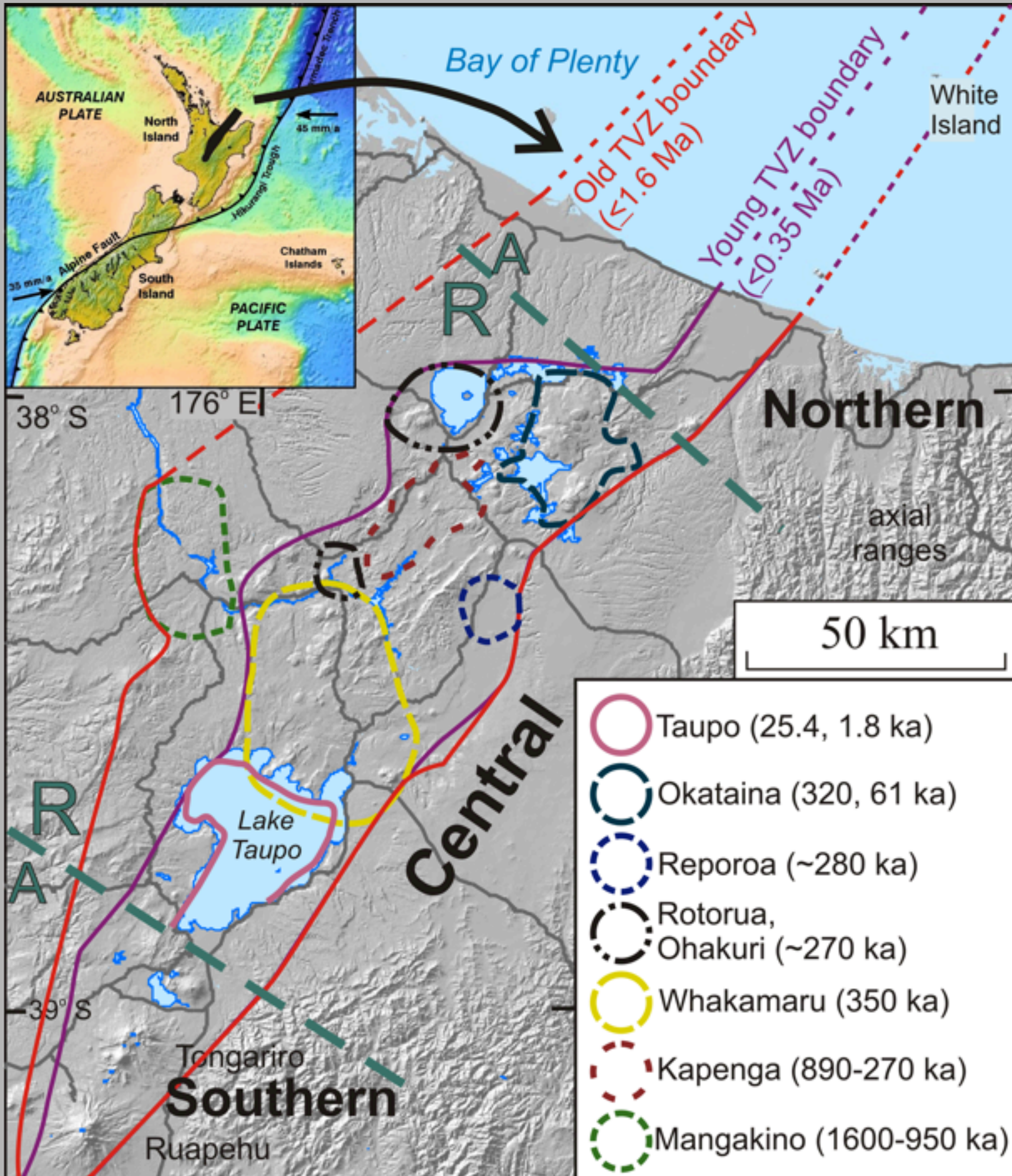
GNS image by Lloyd Homer

Colin J.N. Wilson: Victoria University of Wellington
J.V. Rowland: University of Auckland



Taupo Volcanic Zone (TVZ): the plate boundary setting

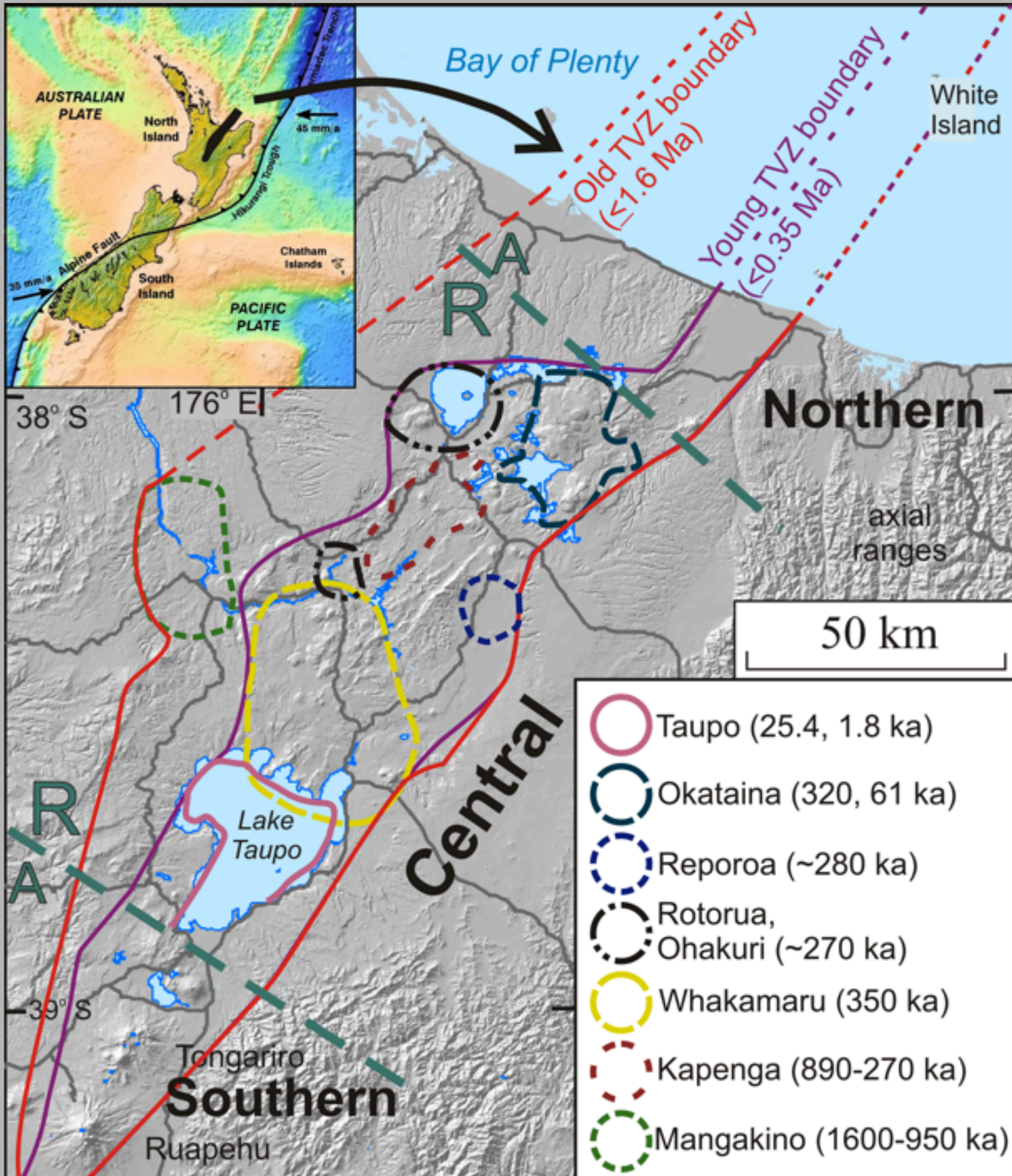
- Slightly oblique convergence
- Oceanic plateau (Hikurangi Plateau), Cretaceous LIP being subducted
- Modest convergence rates (40-45 mm per year)
- No obvious plate-tectonic reason for unusual behaviour



TVZ: a geographical outline

Three segments to TVZ:

1. Northern – normal andesite-dacite arc, continuous with Kermadec arc
2. Southern – normal andesite-dacite arc
3. Central – unusual, dominated by silicic (rhyolitic) eruptions from caldera volcanoes (labelled coloured outlines) Magma volumes and rates are an order of magnitude higher than for cone centres

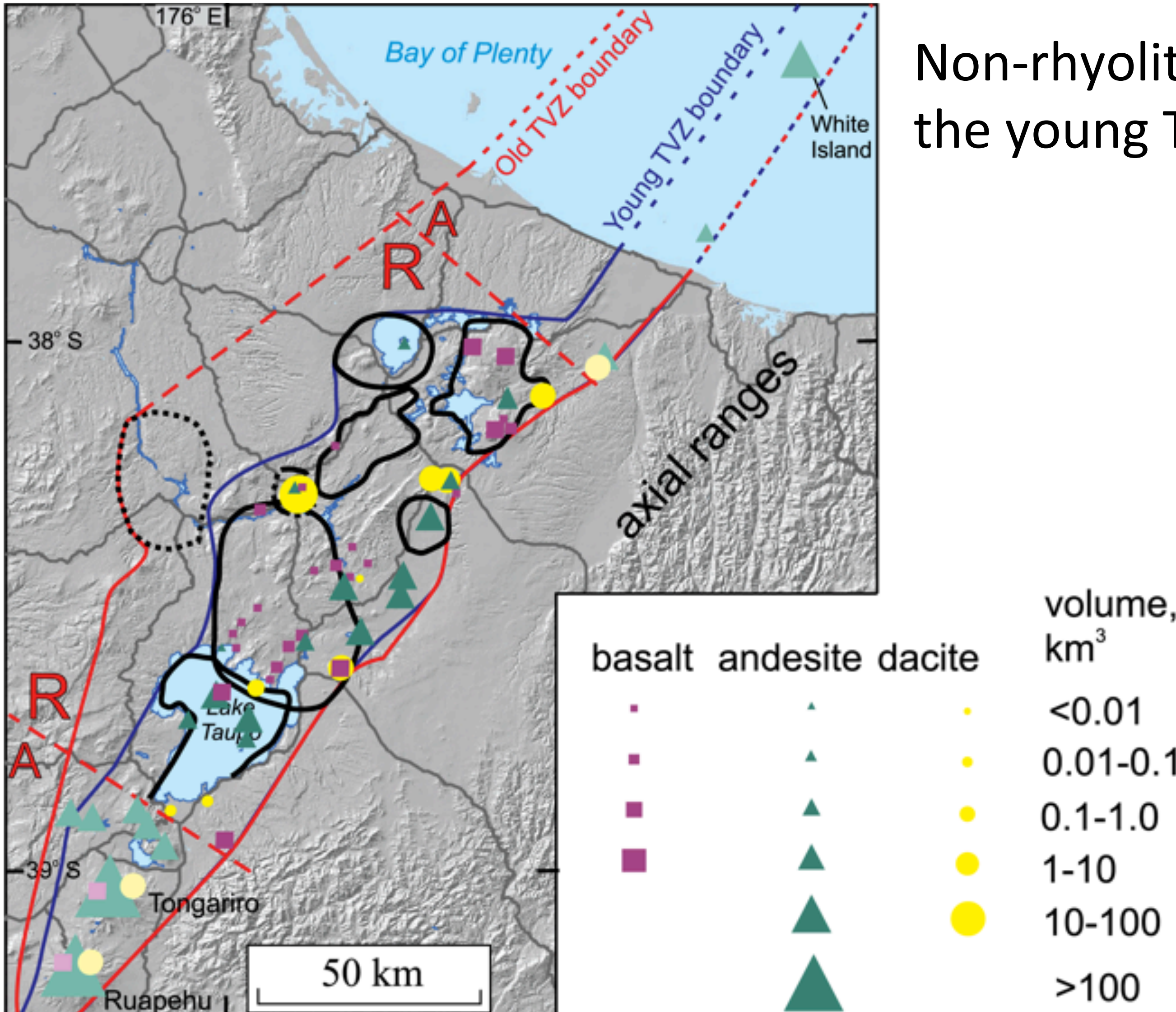


(Central) TVZ: a chronological outline

Three main time periods in (central) TVZ history:

1. Old TVZ: 2.0 Ma to ~350 ka. Many uncorrelated units
2. Young TVZ: 350 ka (Whakamaru Group eruptions) to present day. Most large eruptions documented
3. Modern TVZ: 61 ka to present, representative of the active state of the system. All eruptions known?

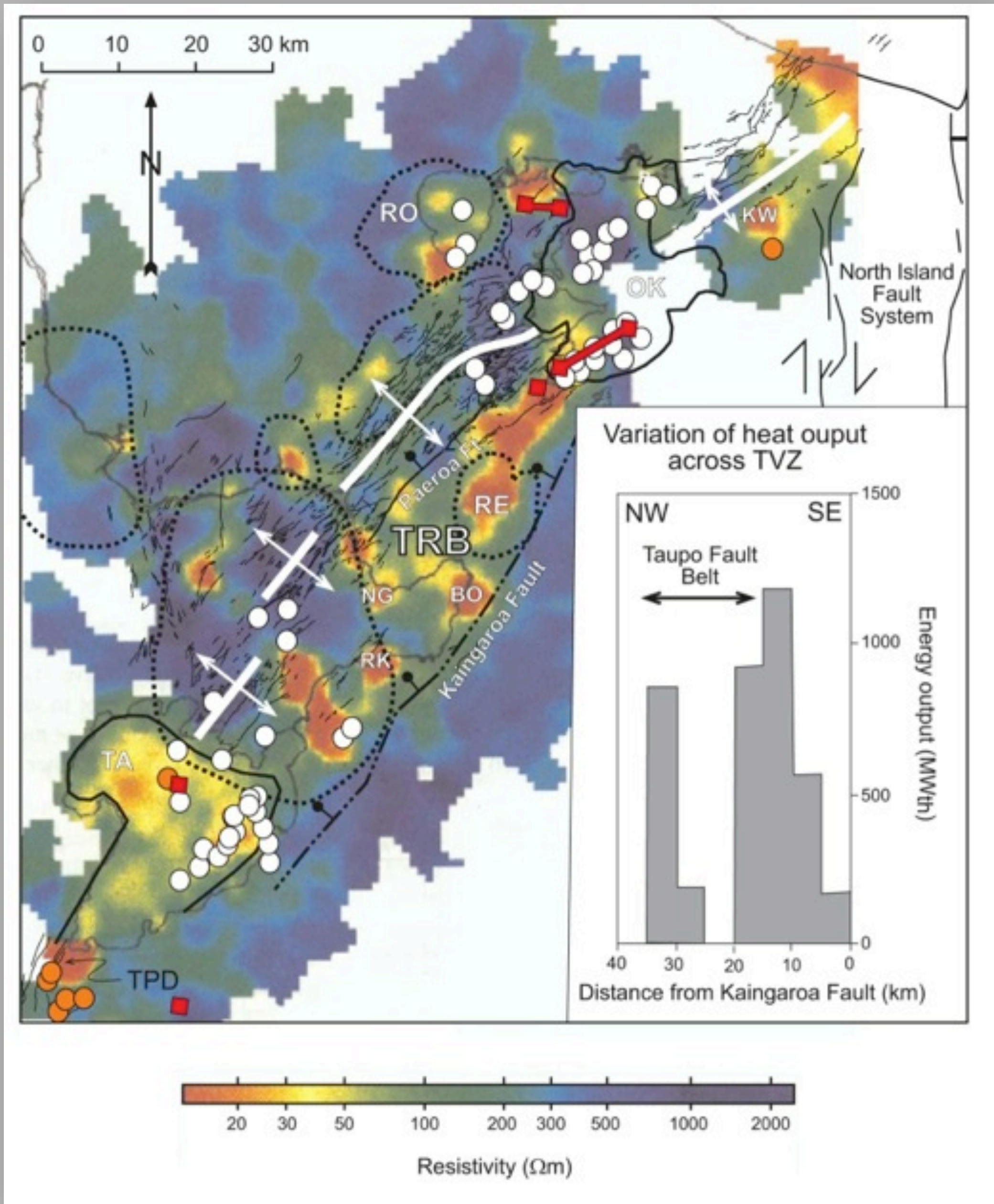
Modest eruption volumes and rates for non-rhyolite lithologies



Non-rhyolitic lithologies in the young TVZ

Key points:

- *Total volumes an order of magnitude lower than that for rhyolite over the past 350 ka*
- *No systematic time-progression from andesite to rhyolite*
- *No arc/back-arc separation*



Warm colours denote geothermal systems (total natural heat flux of ~4.2 GW)

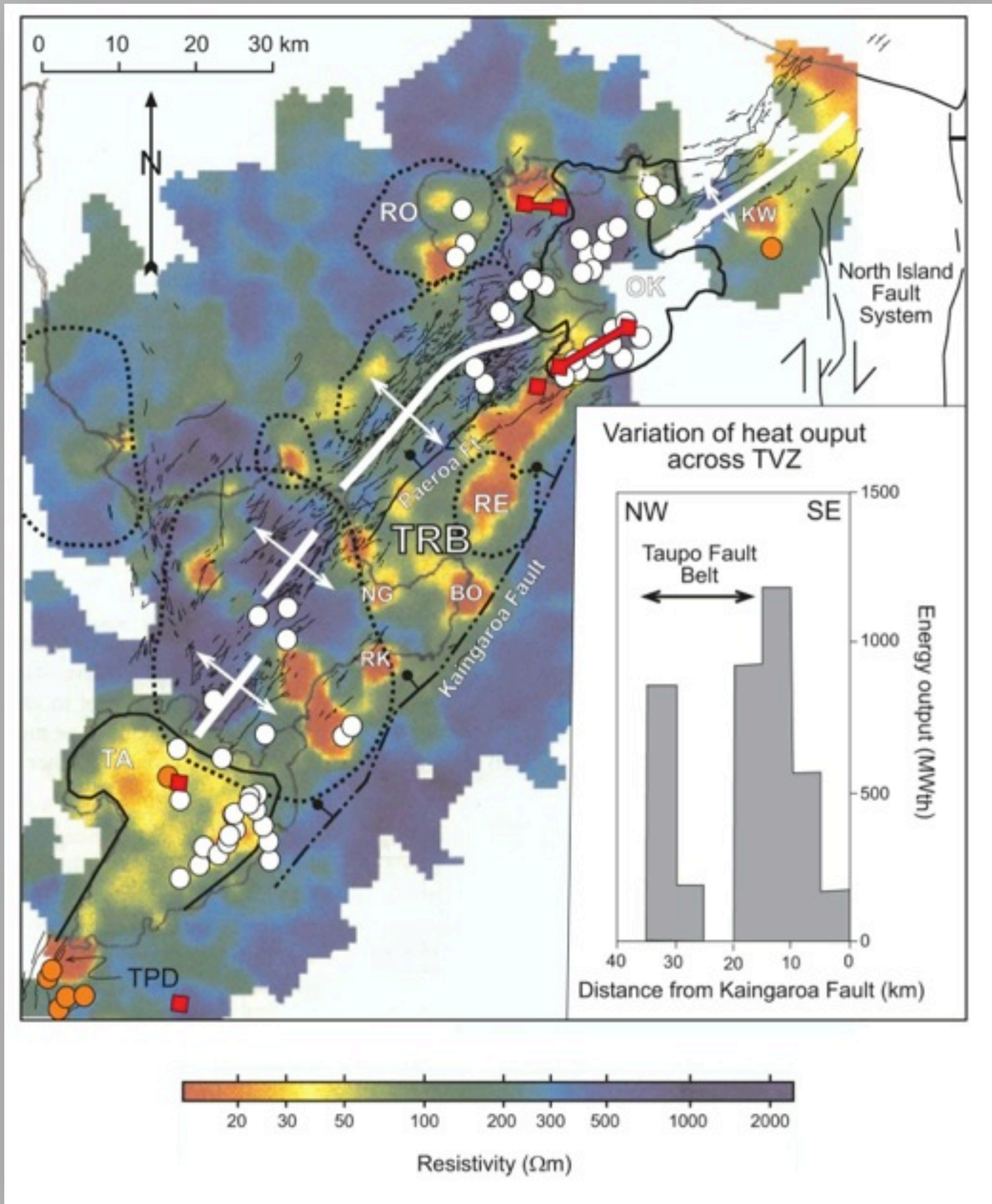
Central TVZ: most productive rhyolitic volcanic zone on Earth (~13 km^3 of rhyolite magma erupted per 1000 yr for the past ~61 kyr)

The volcanic flux only makes up ~25% of the natural heat output: Total of ~50 km^3 magma equivalent intruded or extruded per 1000 yr under central TVZ

Close interplay with tectonic rifting processes

Vents active since 61 ka
- silicic (rhyolite >> dacite)
- andesitic
- basaltic

From: Rowland & Simmons, Econ Geol 107, 427 (2012), after Bibby et al., JVGR 68, 29 (1995) and Stagpoole & Bibby, IGNS Geophys Map 11 (1998)



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Central TVZ: what are the major inferences from volcanic and tectonic studies?

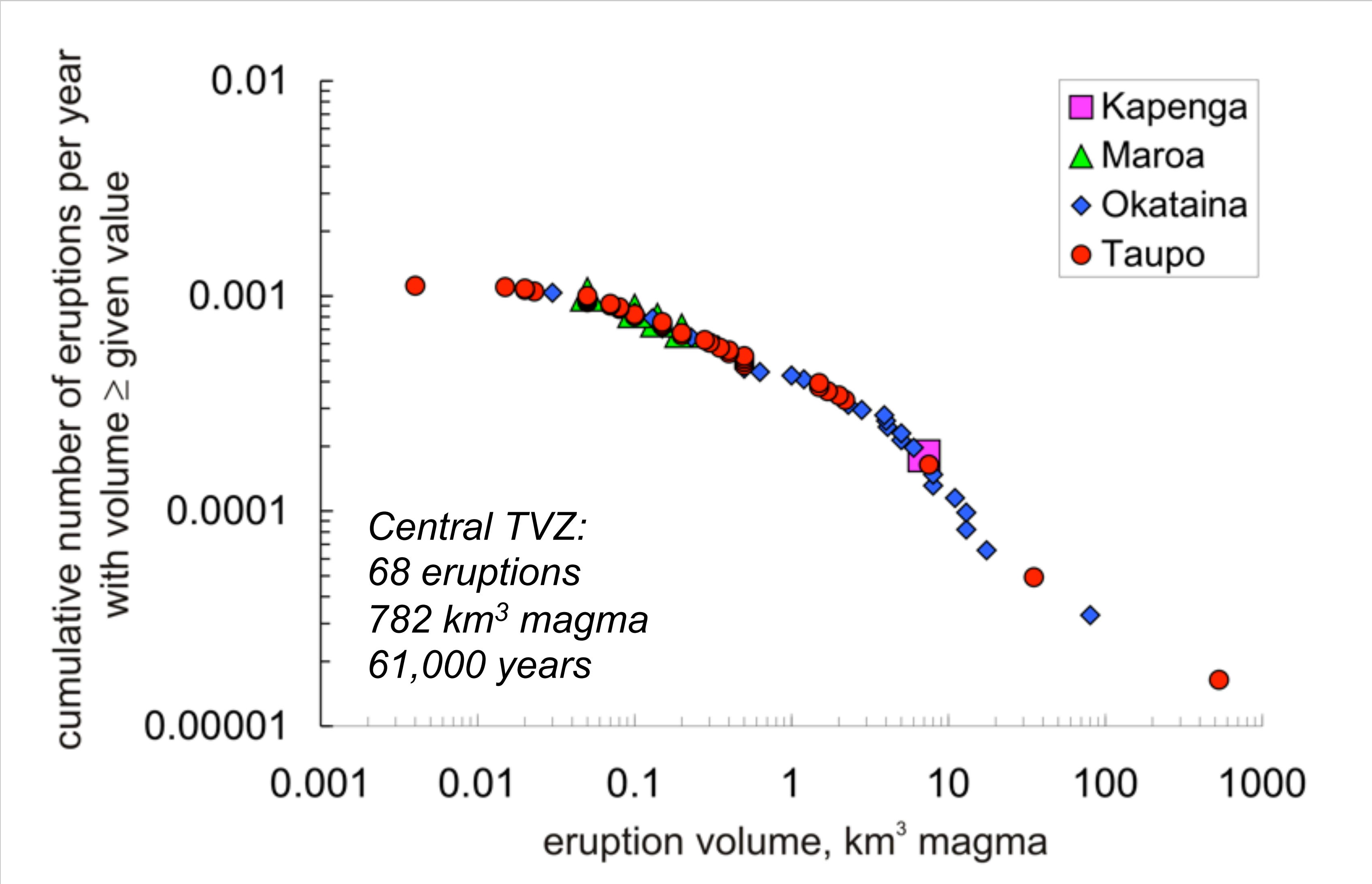
1. What are the major first-order observations from a regional picture? Variations in space and time.

Vents active since 61 ka

- silicic (rhyolite >> dacite)
- andesitic
- basaltic

From: Rowland & Simmons, Econ Geol 107, 427 (2012), after Bibby et al., JVGR 68, 29 (1995) and Stagpoole & Bibby, IGNS Geophys Map 11 (1998)

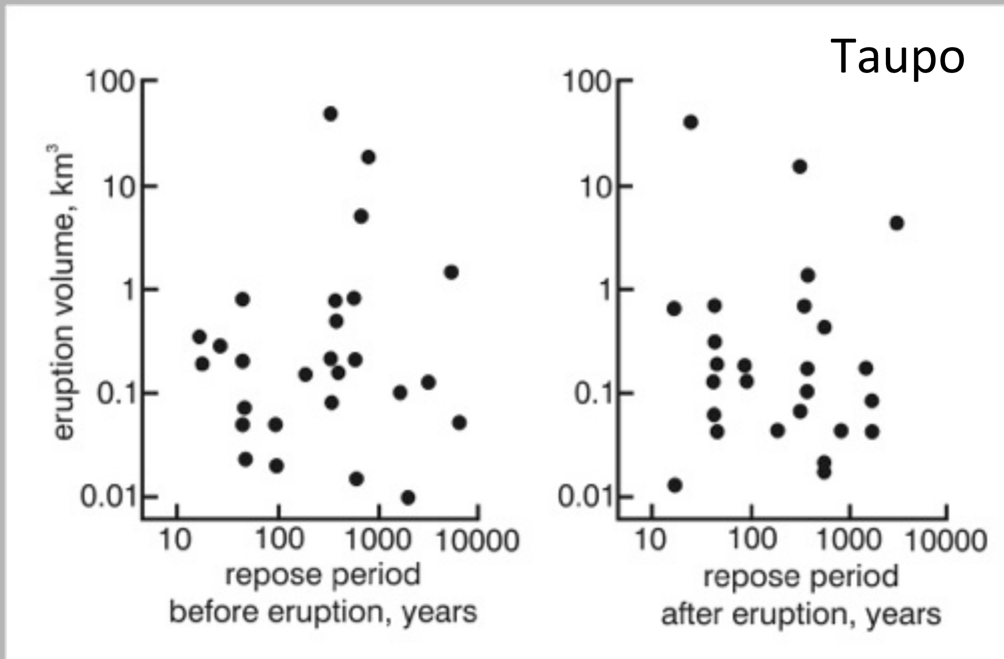
Magnitude-frequency relationships for silicic eruptions?

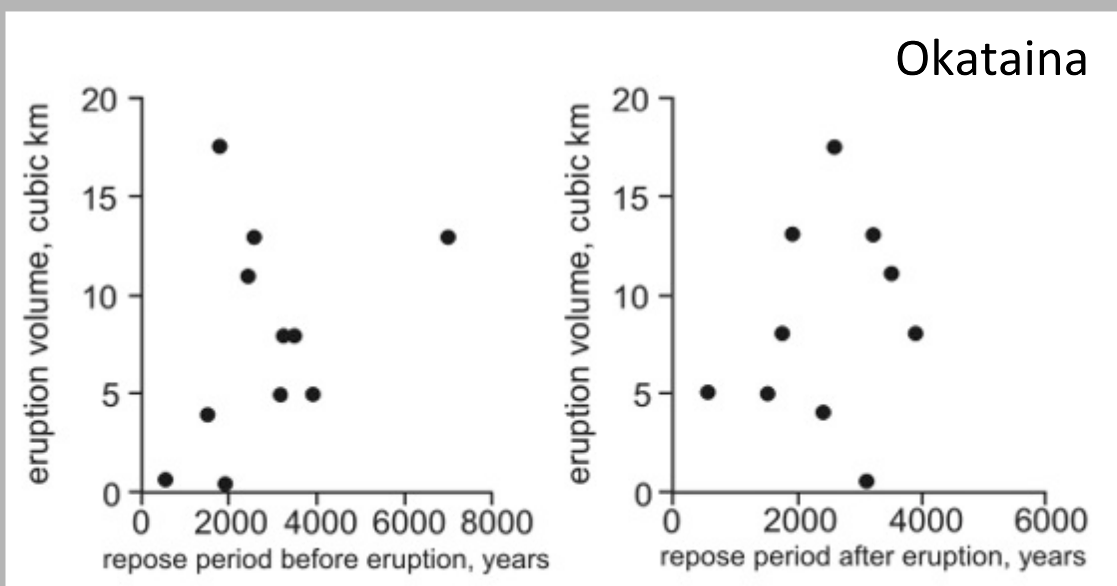


Average of one eruption per 900 years: 5 OM variations in erupted volumes; 3 OM variations in repose periods

Modified from: Wilson et al., Spec Publ IAVCEI 2, 225 (2009)

Forecasting, anyone?

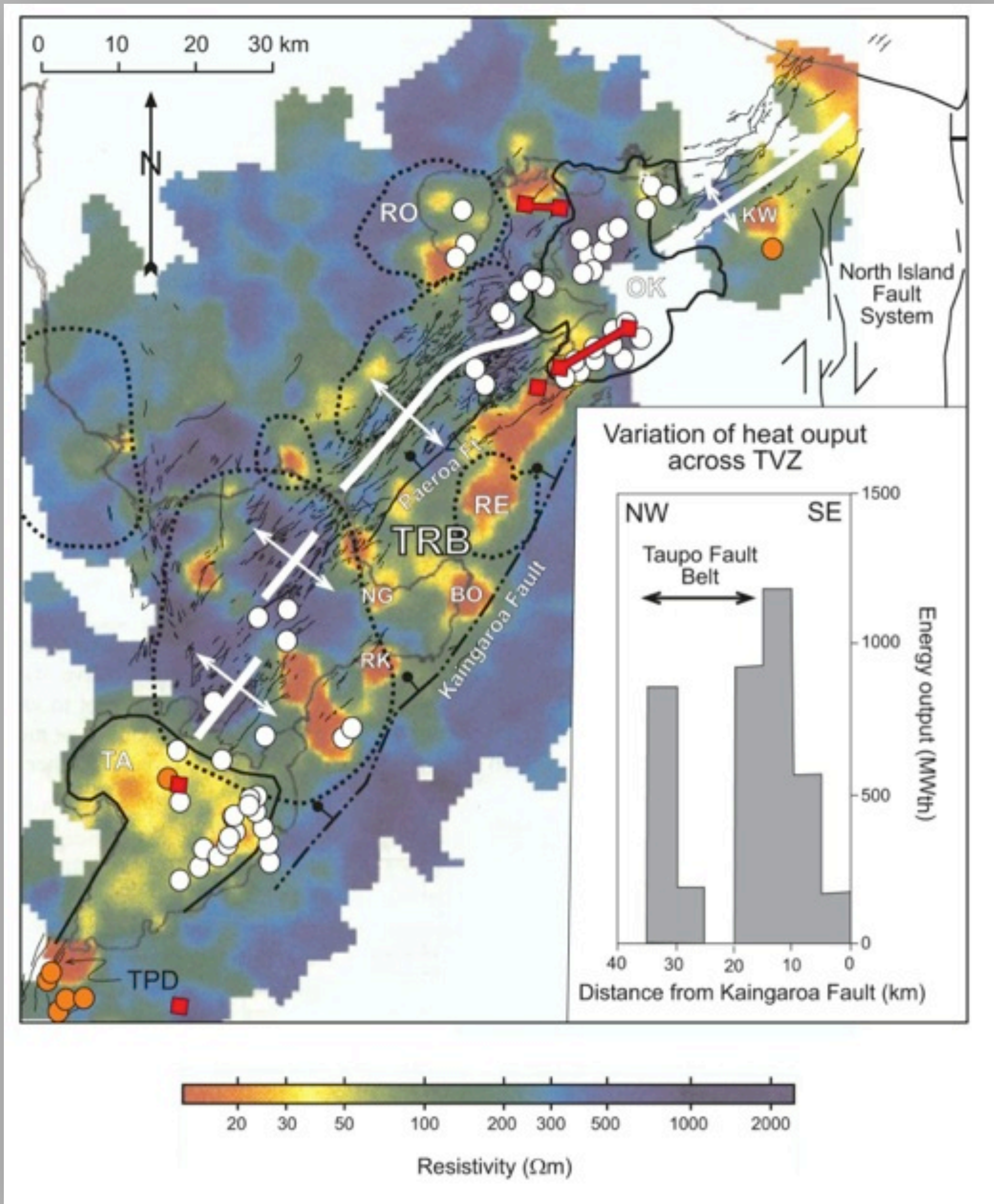




Eruptions after the 25.4 ka Oruanui event (*n = 39*):

Relationships between volumes of magma erupted and repose periods before or after events are not systematic (chaotic?)

What if eruption volumes and repose intervals are driven by a non-linear interaction between two linear phenomena: rates of magma production and rates of tectonism?



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Central TVZ: what are the major inferences from volcanic and tectonic studies?

2. What is the resulting crustal structure, and how does it influence inferences about the deep heat sources?

Vents active since 61 ka

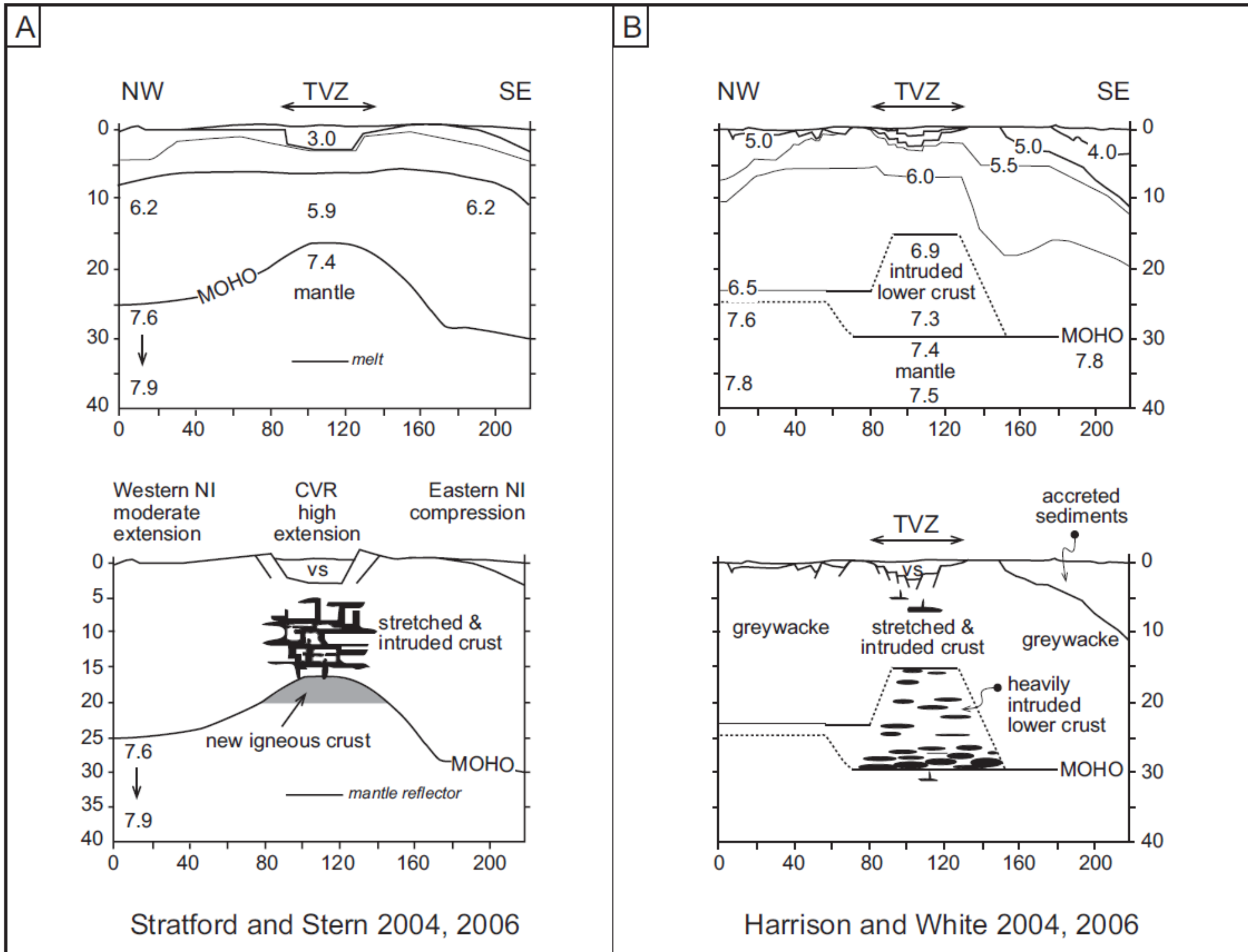
- silicic (rhyolite >> dacite)
- andesitic
- basaltic

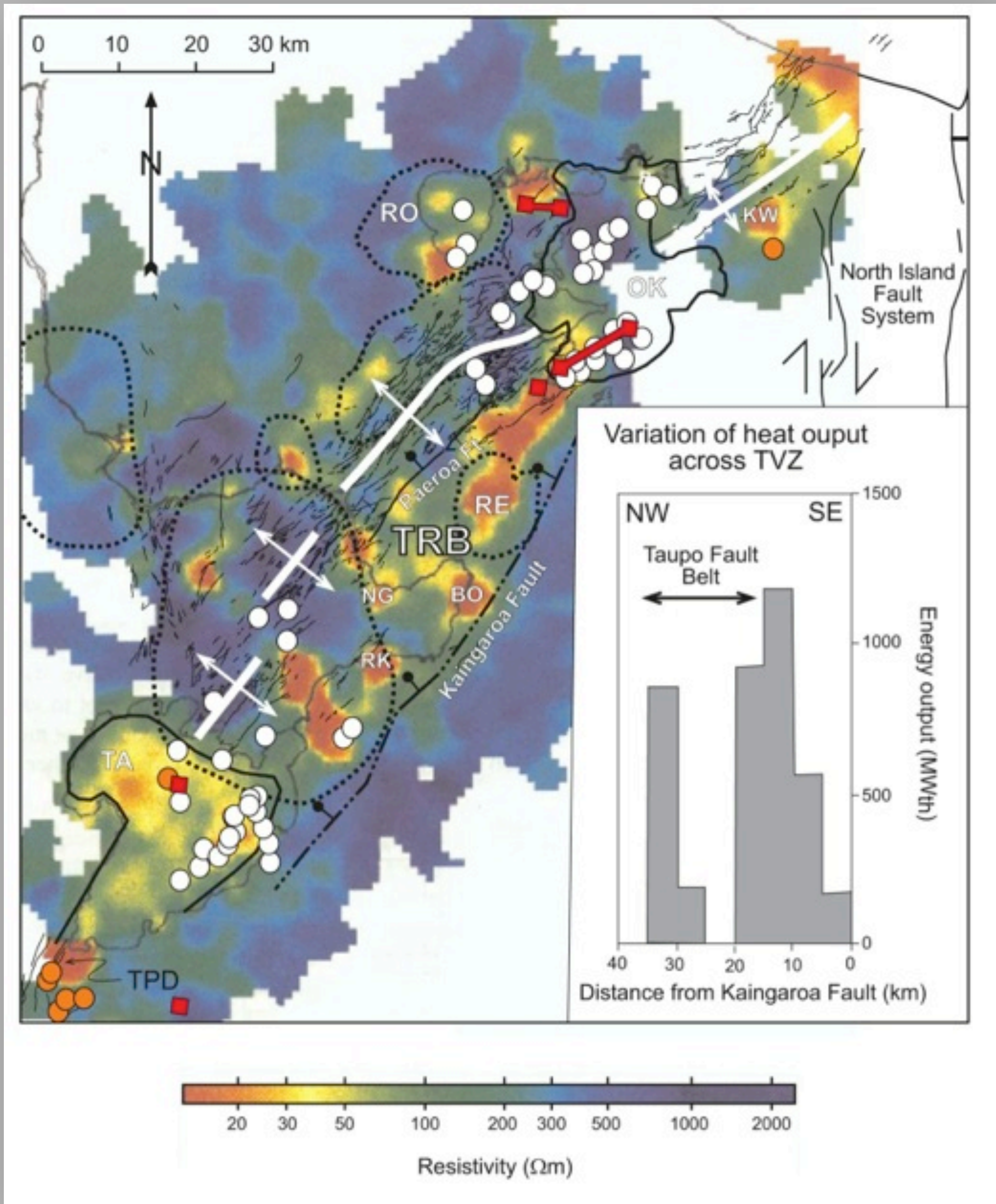
From: Rowland & Simmons, Econ Geol 107, 427 (2012), after Bibby et al., JVGR 68, 29 (1995) and Stagpoole & Bibby, IGNS Geophys Map 11 (1998)

Central TVZ: rifting arc environment (as opposed to arc/back-arc pairing), with thinned, young (Permian or later) crust. Crustal lithologies with V_p values appropriate to dominant quartz-feldspathic densities (and hence lithologies) only 15-16 km thick. Limits depths/pressures for silicic systems.

From: Stratford & Stern, Geophys Res Lett 31, L06622 (2004) and Geophys J Intl 166, 469 (2006); Harrison & White, Geophys Res Lett 31, L13615 (2004) and Geophys J Intl 167, 968 (2006).

Details subject to variations…





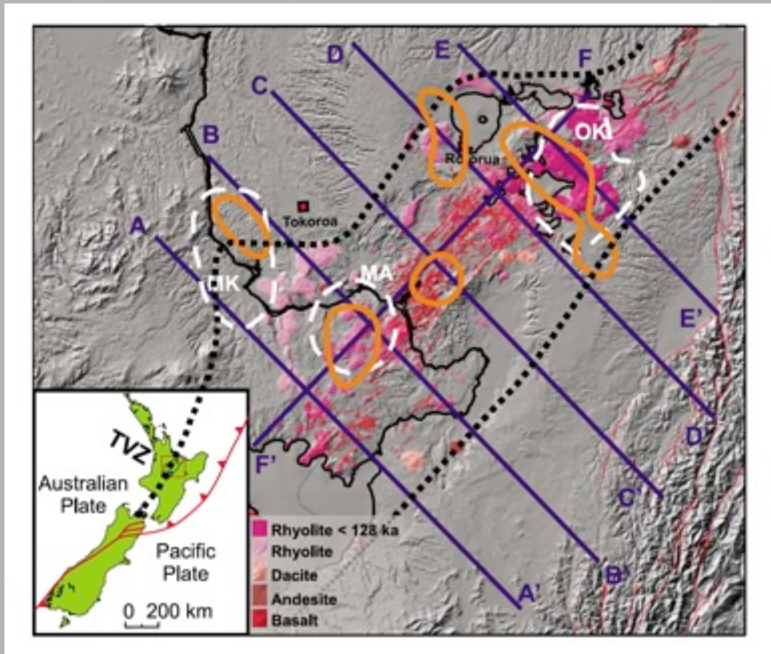
Warm colours denote geothermal systems (total natural heat flux of ~4.2 GW)

Central TVZ: what are the major inferences from volcanic and tectonic studies?

3. Where are the deep magma sources that are driving the volcanism and deep geothermal fluid upflows?

Vents active since 61 ka
silicic (rhyolite >> dacite)
andesitic
basaltic

From: Rowland & Simmons, Econ Geol 107, 427 (2012), after Bibby et al., JVGR 68, 29 (1995) and Stagpoole & Bibby, IGNS Geophys Map 11 (1998)

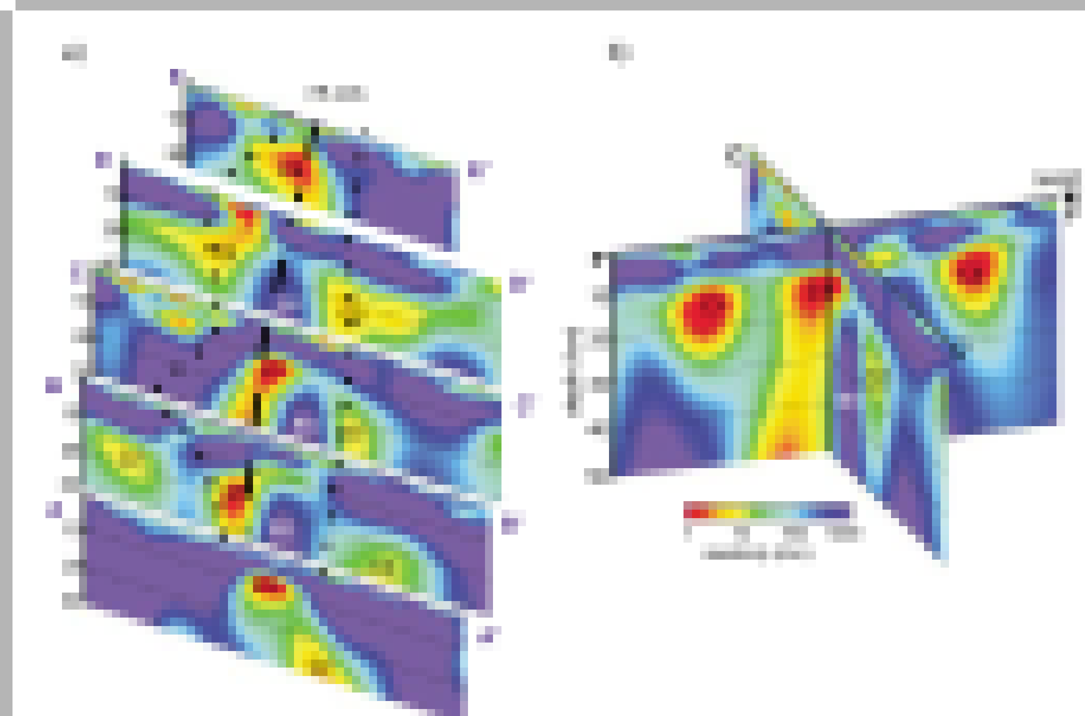


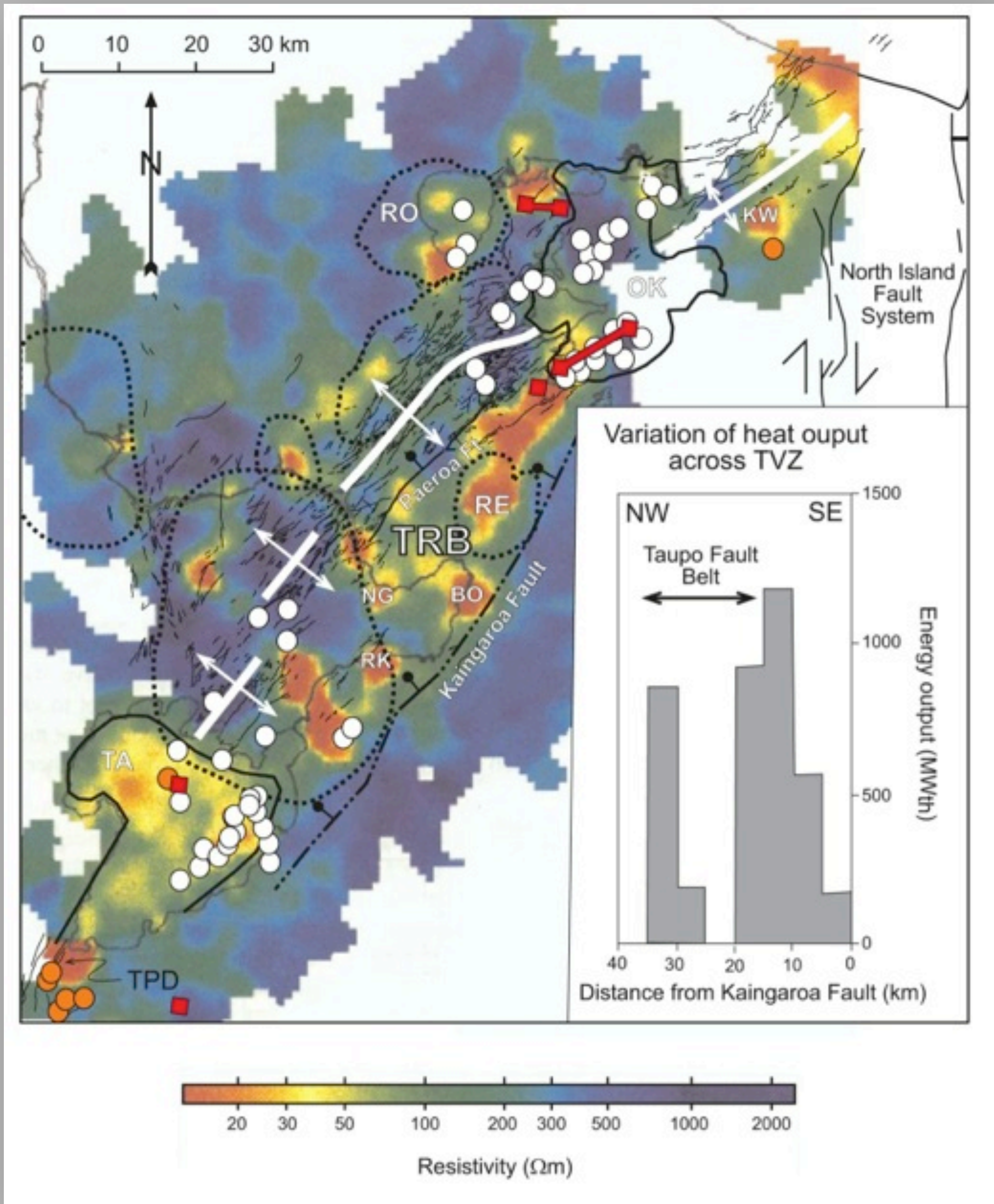
Central TVZ: what are the major inferences from volcanic and tectonic studies?

Not always where they might be expected to be.

From Heise et al., 2010, GRL 37, L10301

Some paradoxes and contradictions inherent in our current data sets and knowledge. Zones of crustal melt implied to be present from MT studies do not relate to volcanism in some key cases, and the ‘rift axis’ defined from surface faulting studies is not where the greatest surface heat flows are occurring.





Warm colours denote geothermal systems (total natural heat flux of ~4.2 GW)

Central TVZ: what are the major inferences from volcanic and tectonic studies?

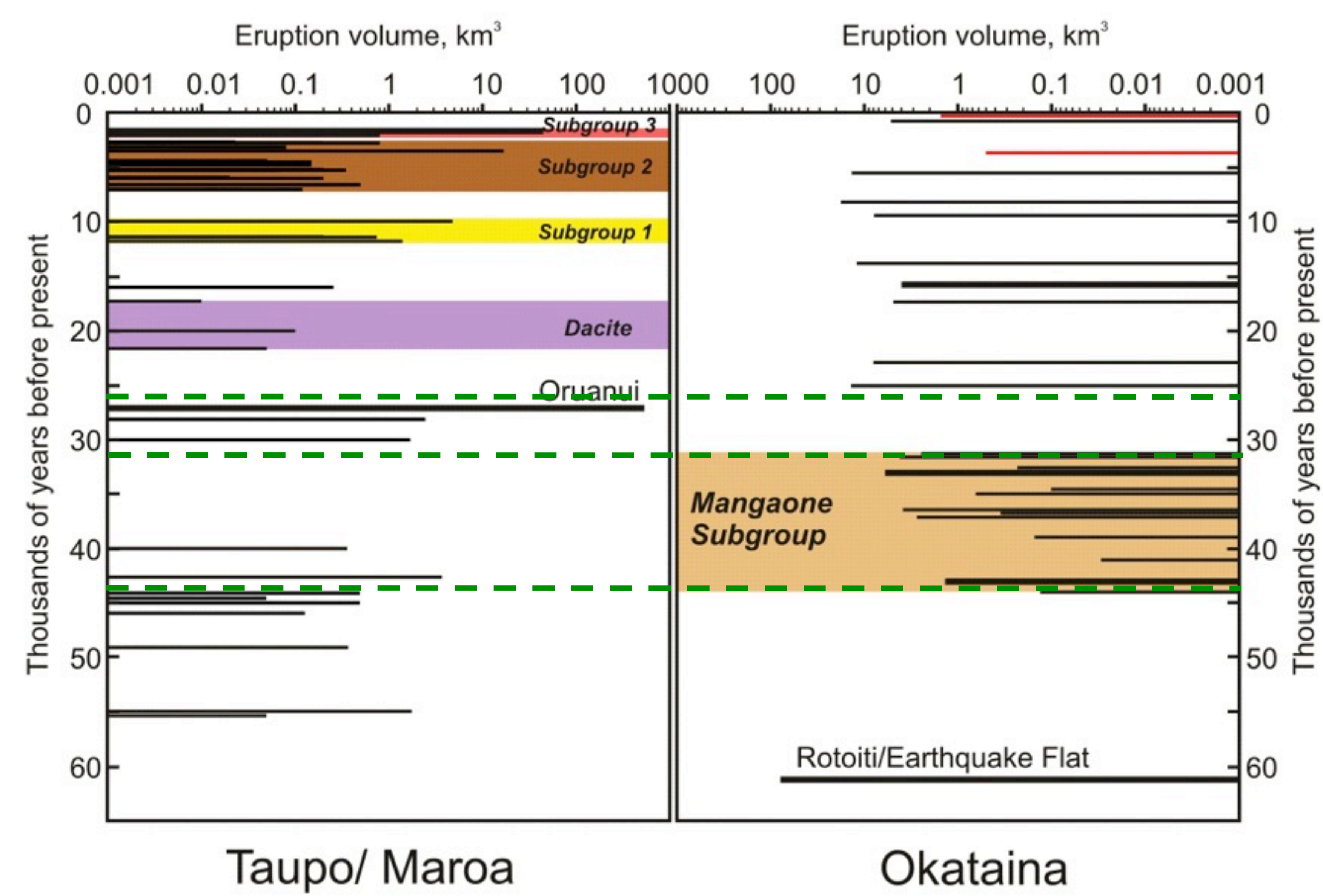
4. Volcano-tectonic interactions during eruptions: the chicken vs the egg.

Vents active since 61 ka

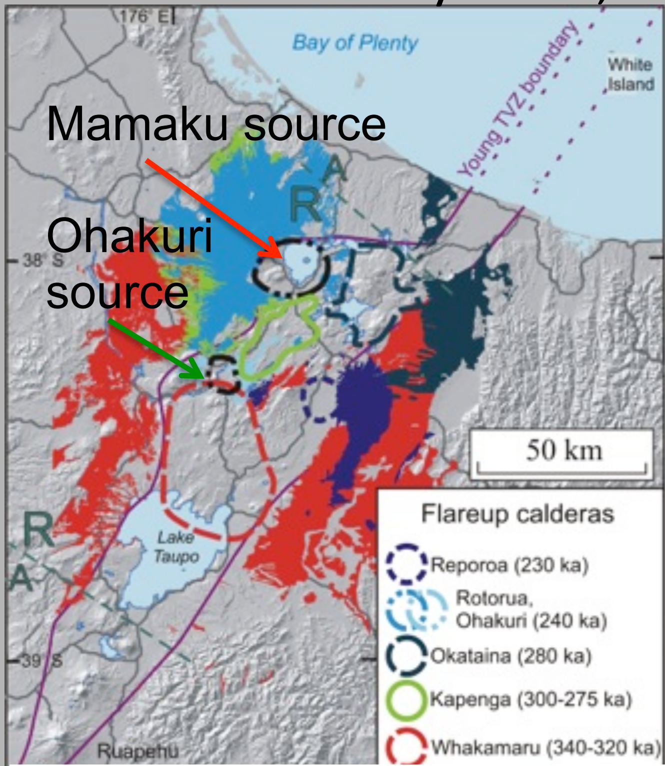
- silicic (rhyolite >> dacite)
- andesitic
- basaltic

From: Rowland & Simmons, Econ Geol 107, 427 (2012), after Bibby et al., JVGR 68, 29 (1995) and Stagpoole & Bibby, IGNS Geophys Map 11 (1998)

Modern central TVZ: dependence versus independence of volcanic systems, and a volcano-tectonic connection?

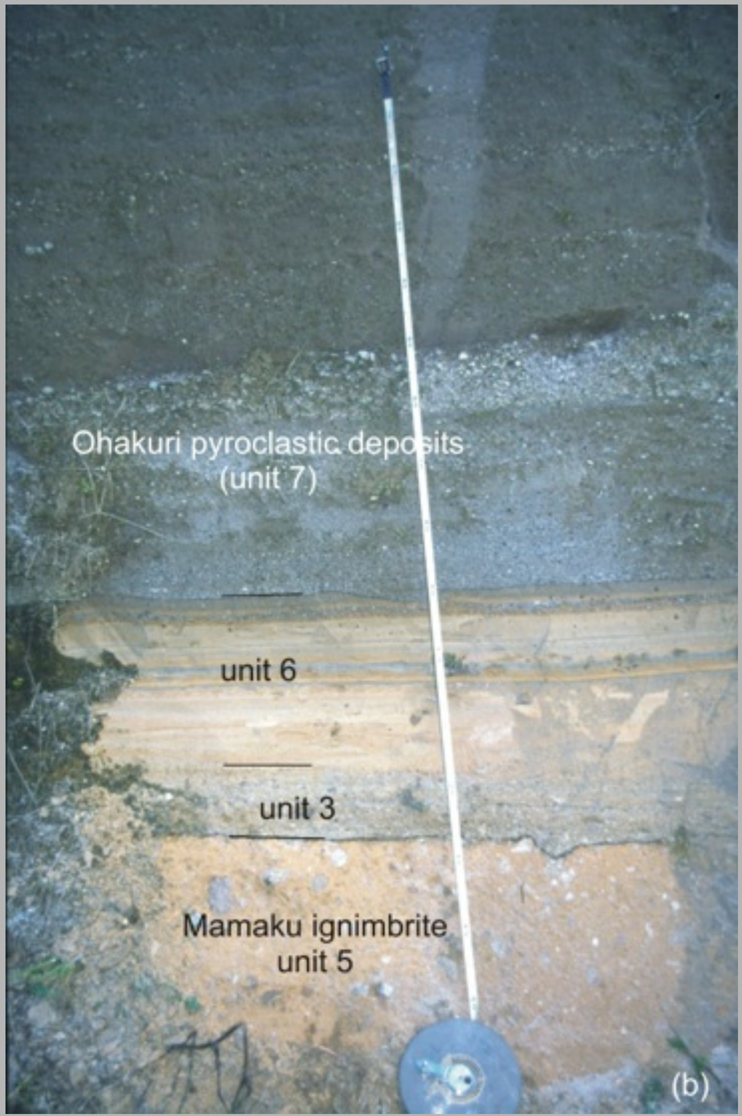


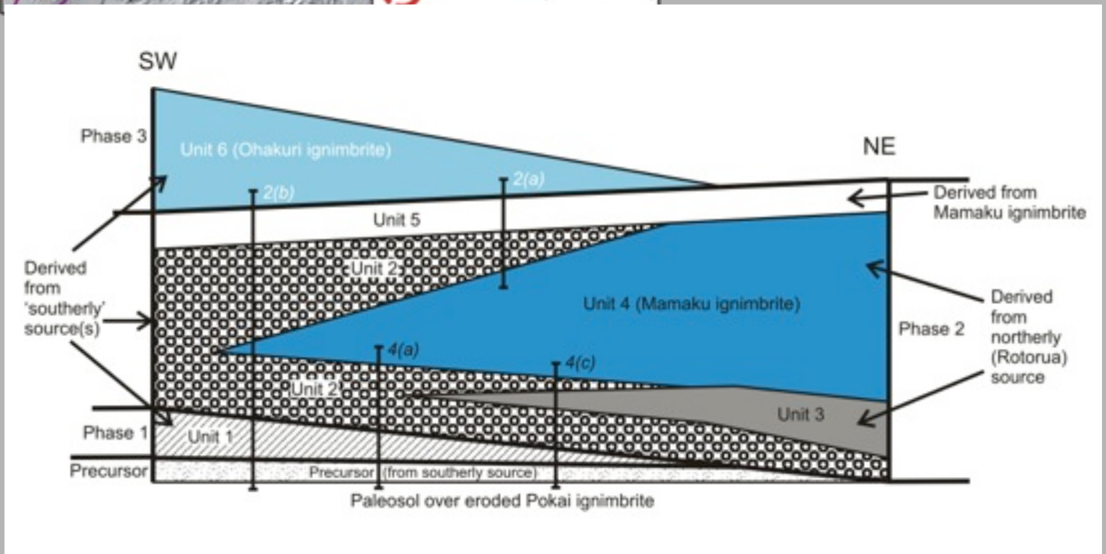
Modern central TVZ: dependence versus independence of volcanic systems, and a volcano-tectonic connection?



Pairing of eruptions through tectonic linkages: example of the Mamaku – Ohakuri pair at ~240 ka

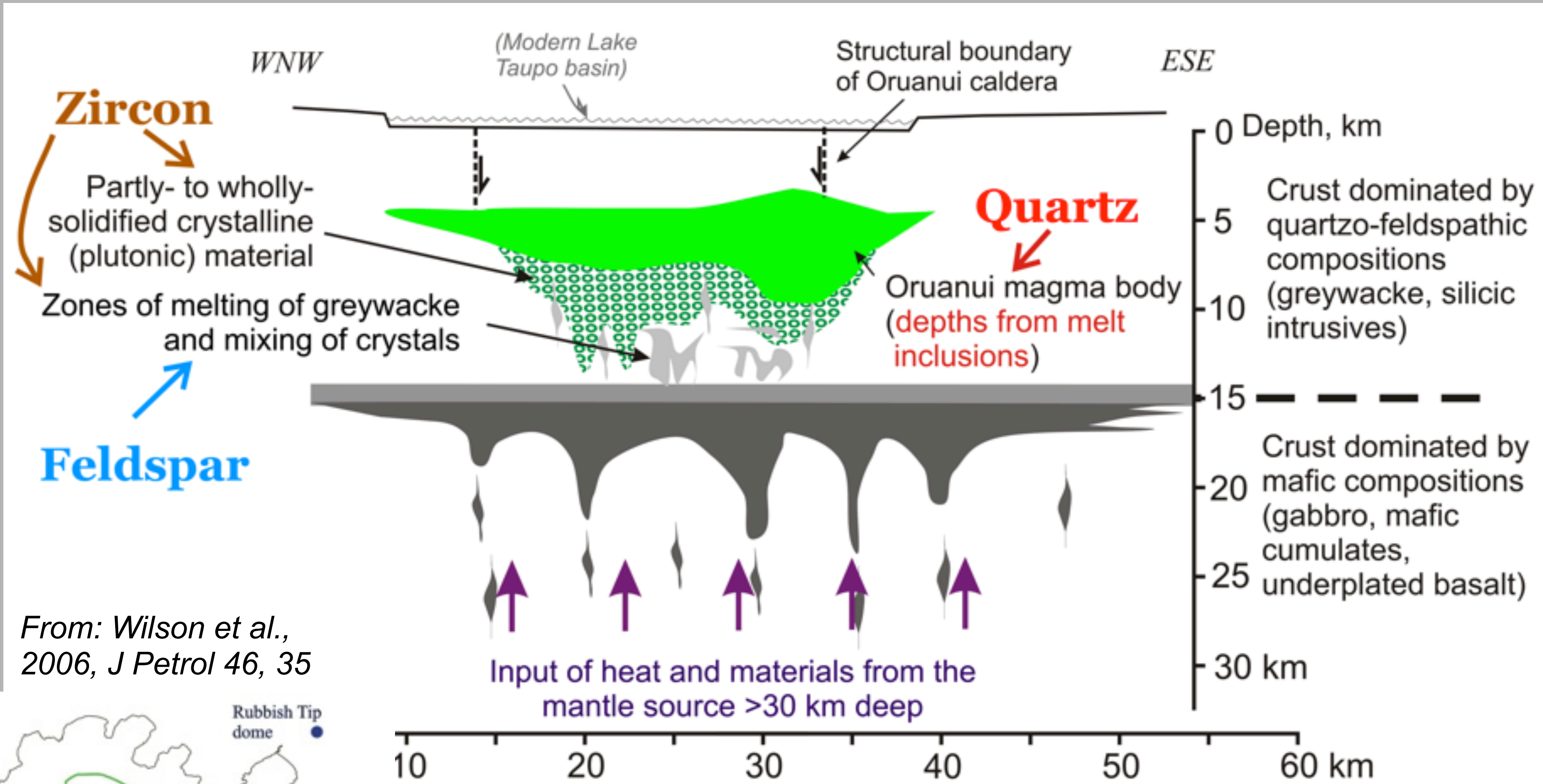
From: Gravley et al. 2007, GSAB 119, 18



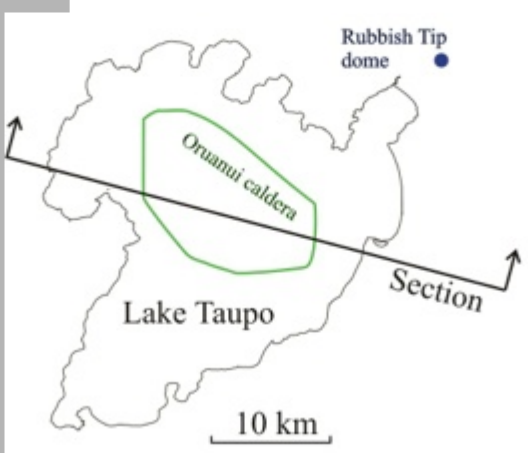


No more than weeks to months between two large eruptions

Reconstructing magma bodies through crystal-specific investigations



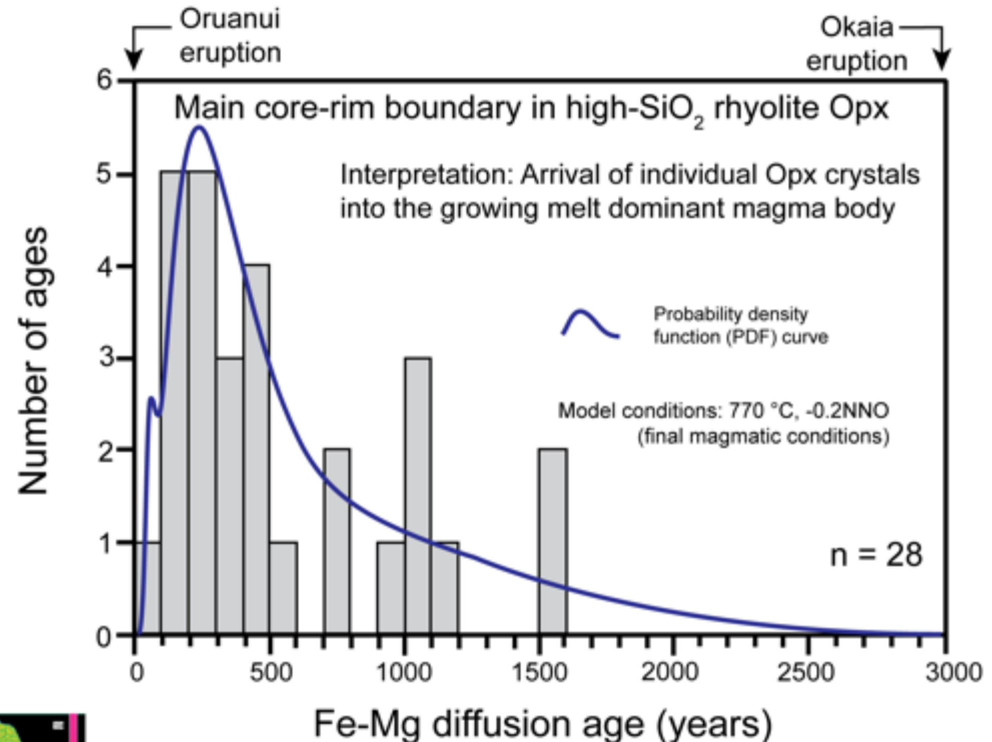
From: Wilson et al., 2006, J Petrol 46, 35

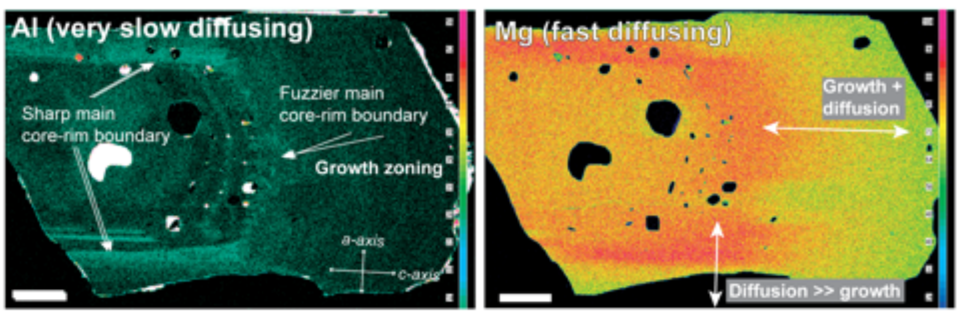


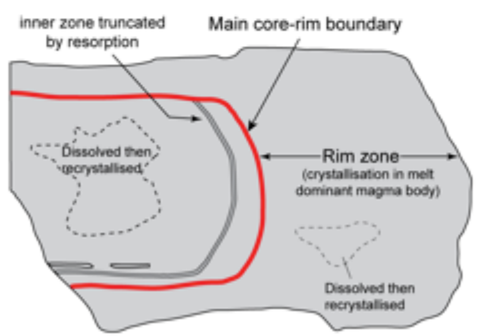
Studies of individual mineral species yields valuable information about the sources of components that go to make up a large magma body (the ~530 km^3 Oruanui in this case). The key questions are, though, relate to the rates of the processes involved.

How rapidly was the Oruanui magma body assembled?

Textural relationships between orthopyroxene (Opx) and amphibole, suggest upward movement of crystals from the mush zone into the melt dominant body. These matched by compositional changes.





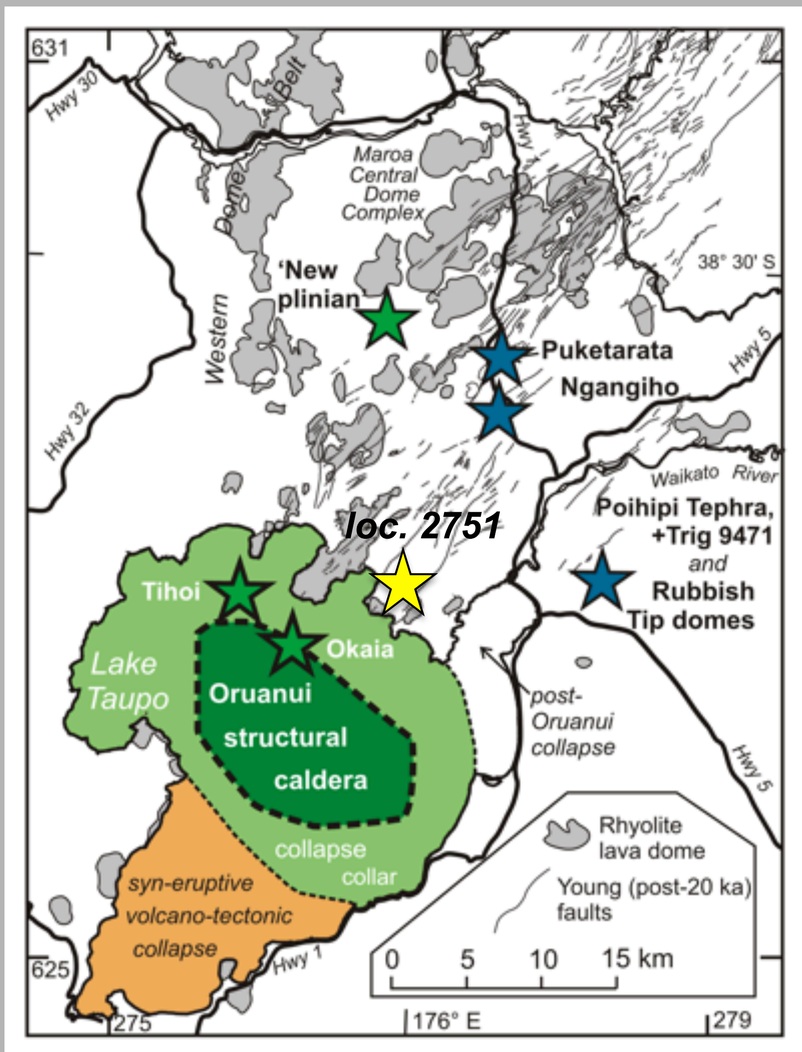


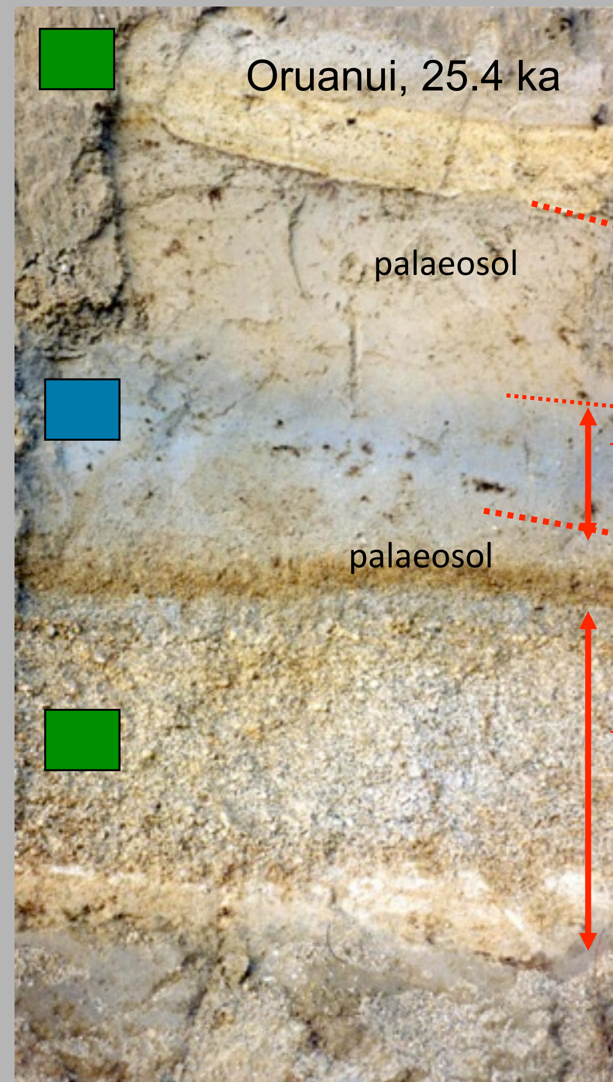
Diffusional boundary in Opx marks entry into the melt-dominant body. Fe-Mg diffusion rates then used to measure residence time in the magma body. Maximum 1600 years, peak 230 years (using final magmatic temperature on eruption). Tectonic control on magmatic processes?

From: Allan et al., 2013, Contrib Mineral Petrol, in press

What controlled the onset and modulation of the Oruanui eruption?

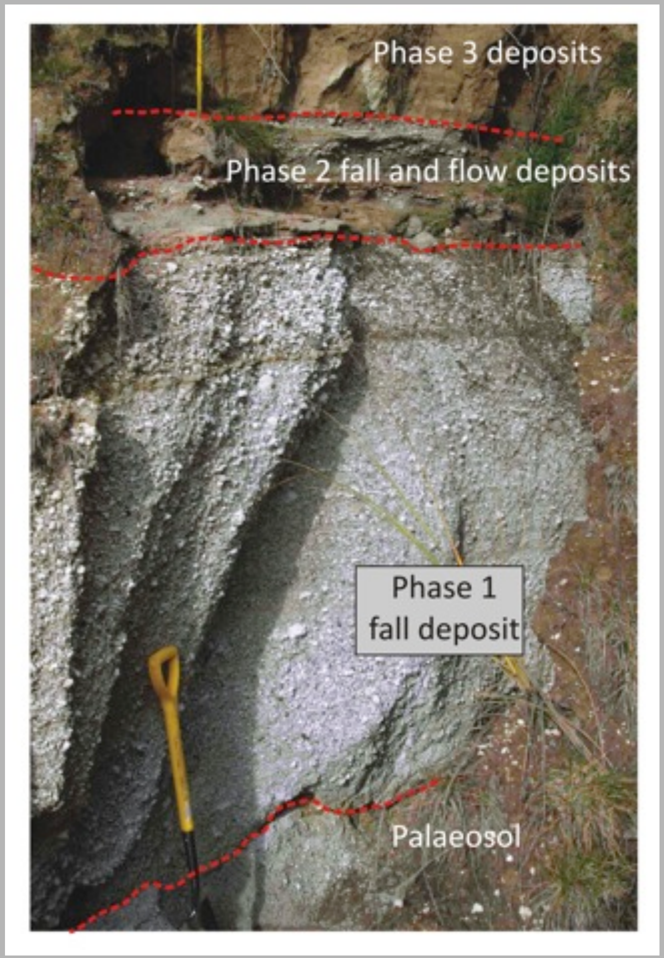
Two geochemically distinct but closely adjacent magma factories in action independently prior to the Oruanui event





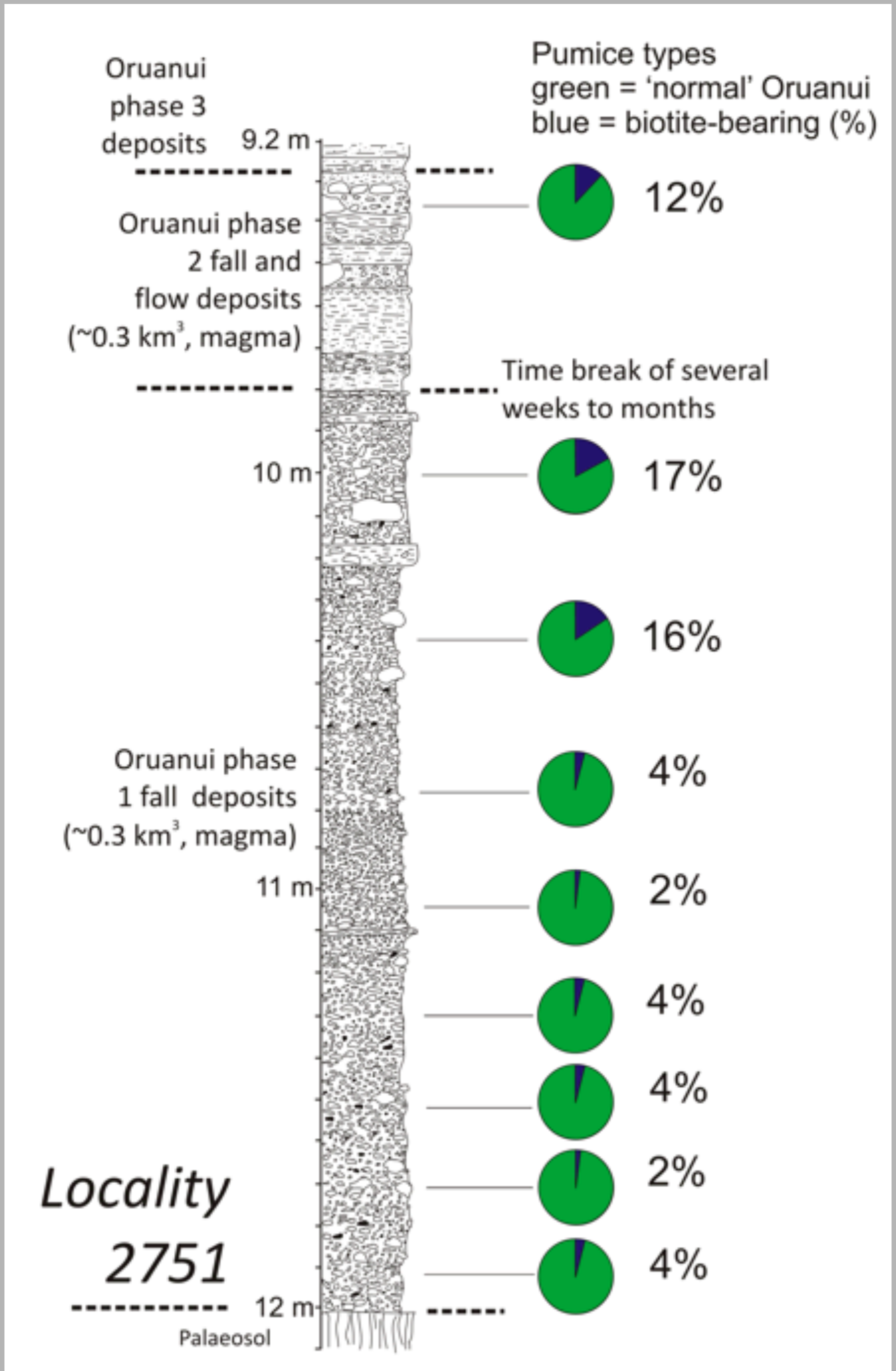
See Sutton et al., 1995, JVGR 68, 253; Wilson & Charlier, 2009, J Petrol 50, 875

Early phases of the Oruanui eruption



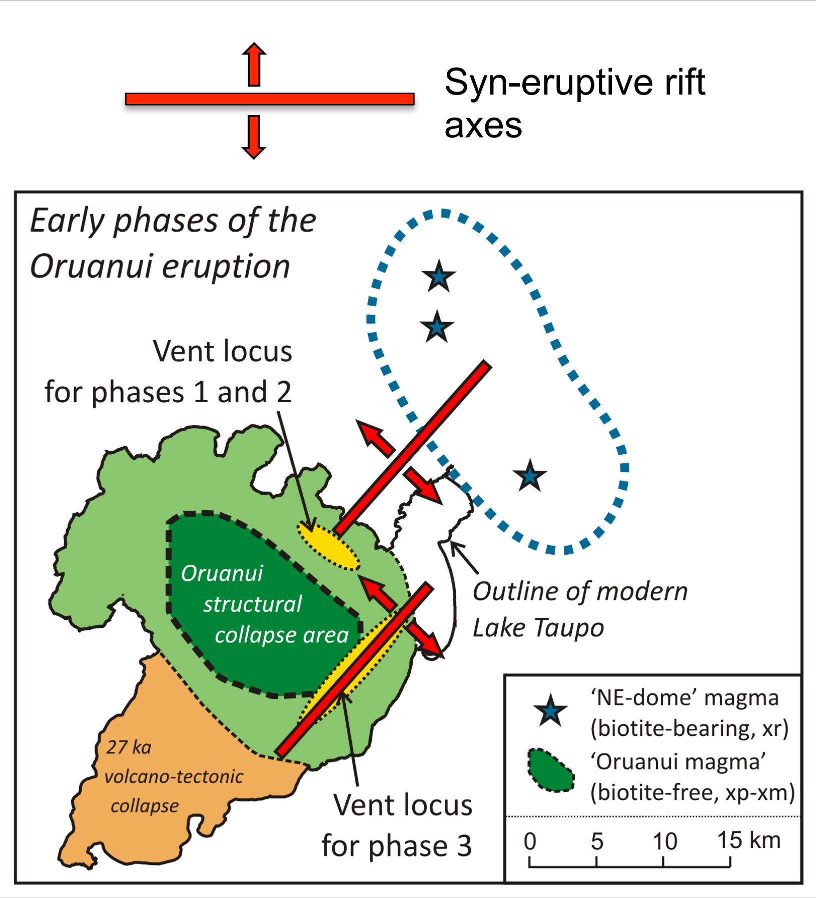
Two types of pumice present in the early Oruanui deposits

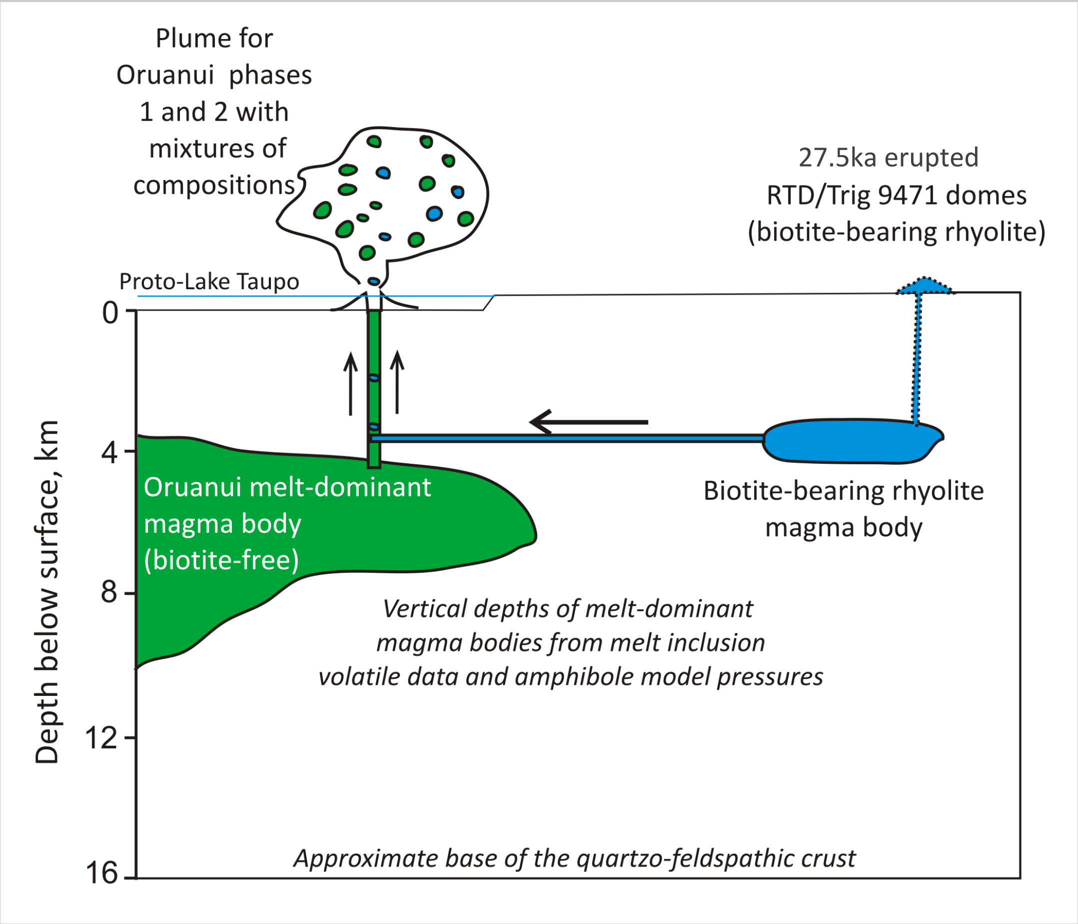
After Allan et al.: Geology 40, 563 (2012)



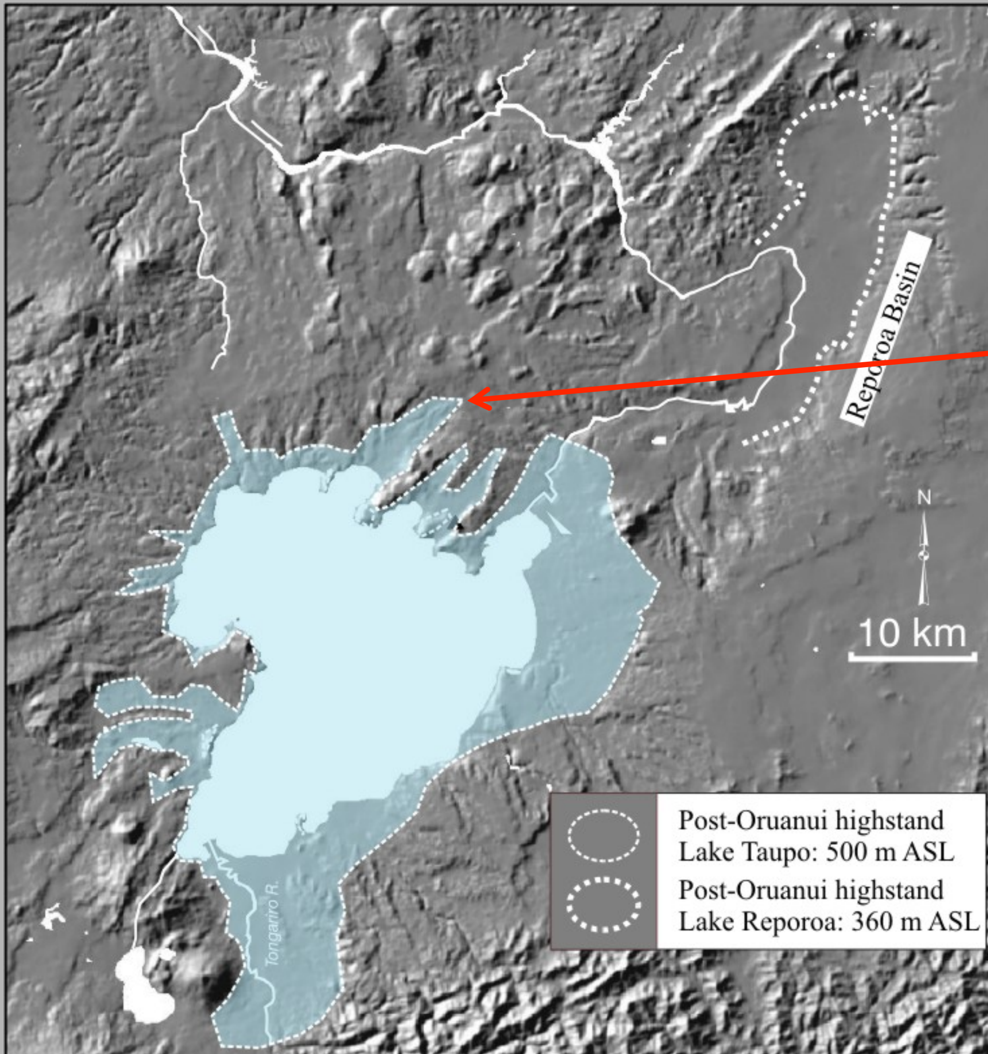
What controlled the onset and modulation of the Oruanui eruption?

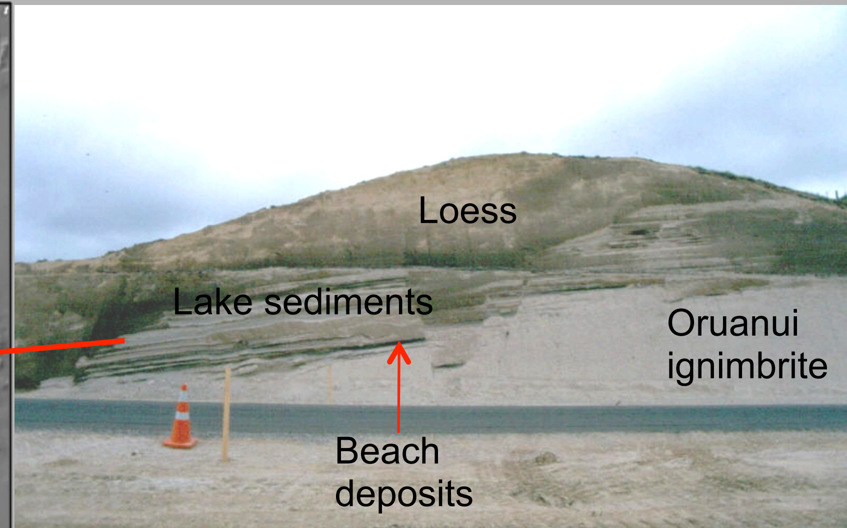
Syn-eruptive rifting the key to (a) lateral transport of independent magmas to a common vent and (b) understanding how the Oruanui eruption started and stopped in its early phases, as well as explaining the escalation into later activity.

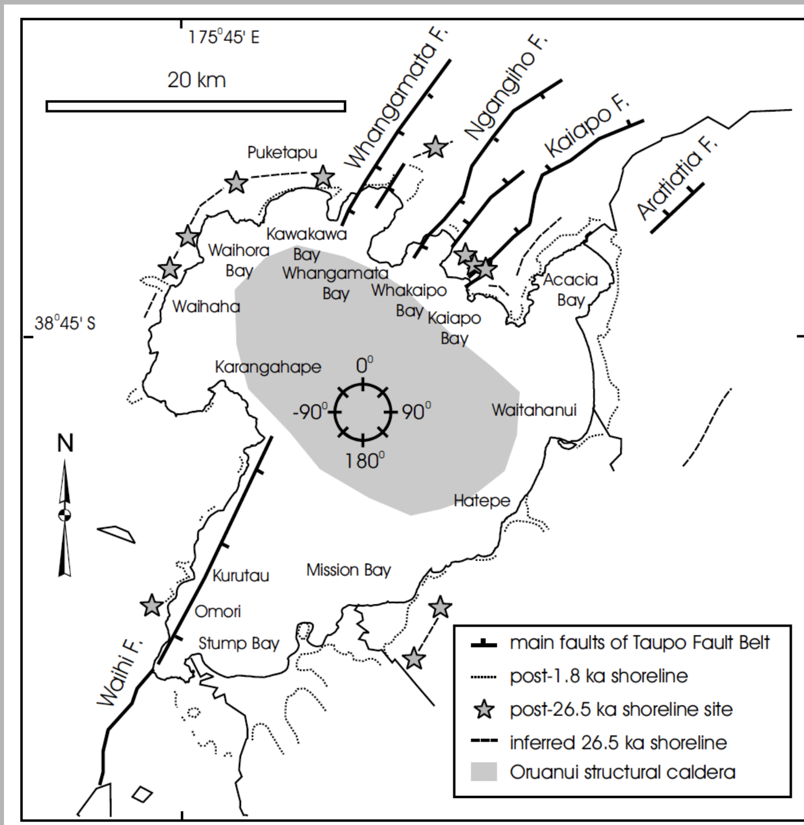




Modified from: Allan et al., Geology 40, 563 (2012)



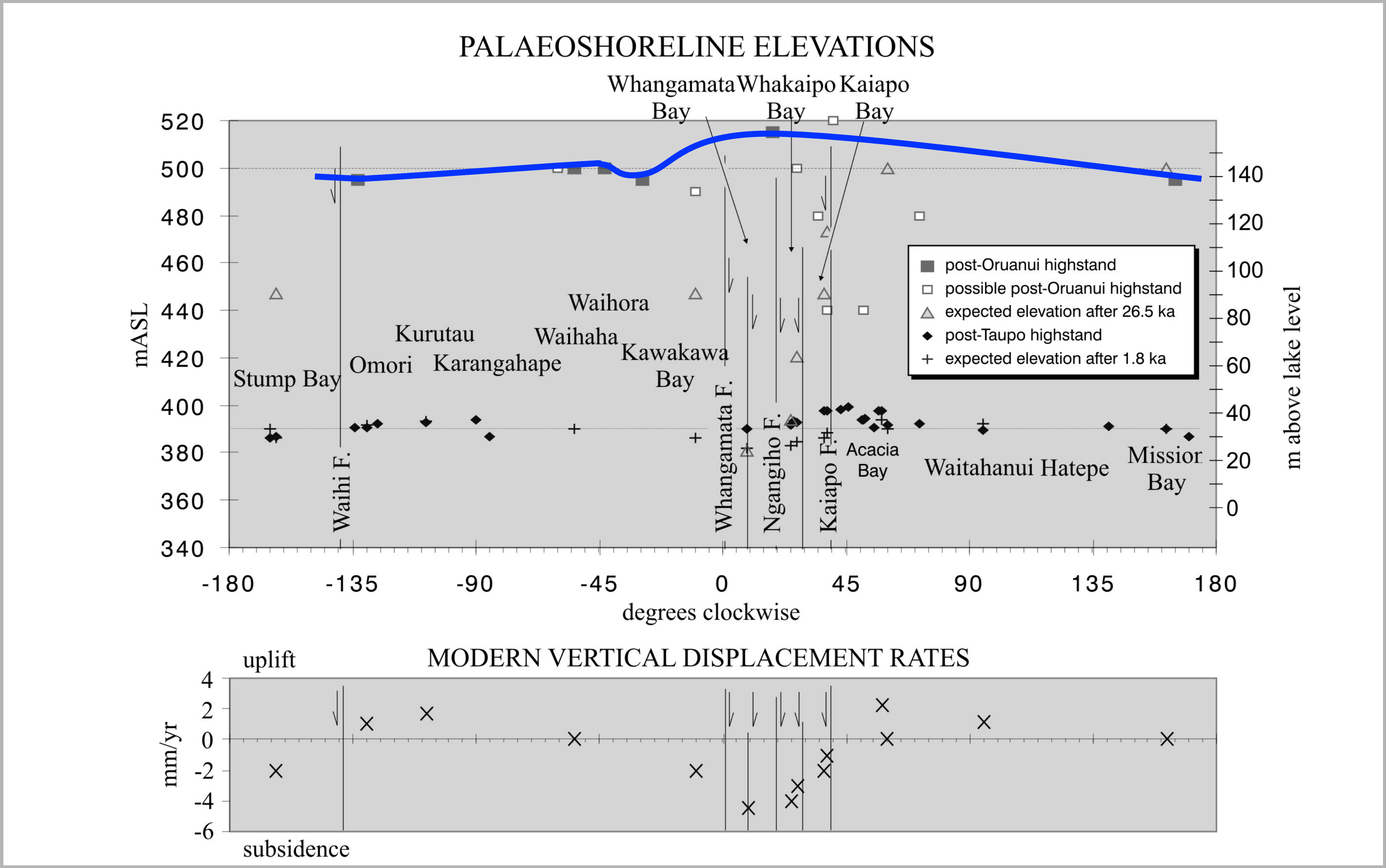




Longer-term interactions of magmatism and tectonics: fossil shorelines of Lake Taupo

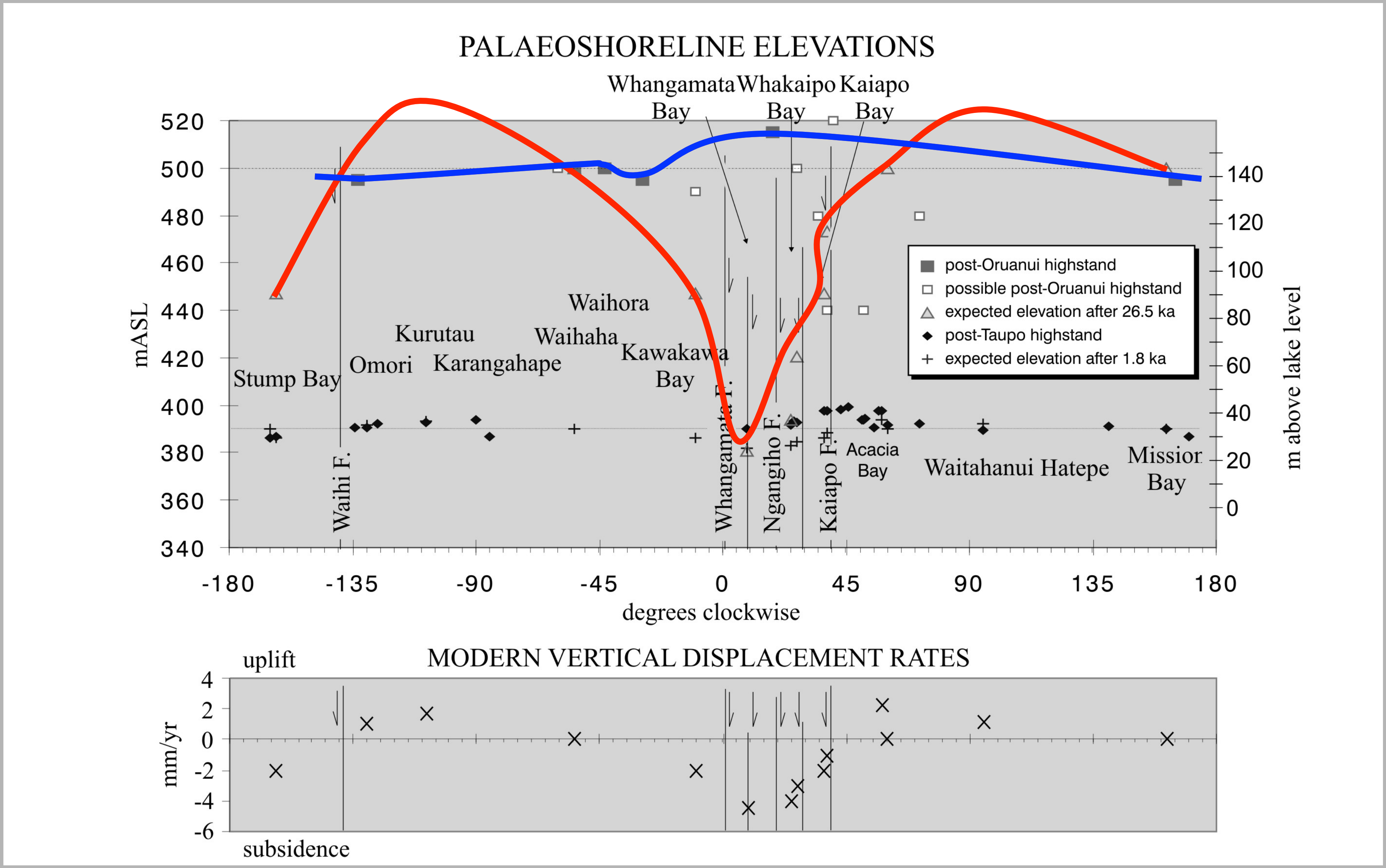
From: Manville & Wilson, 2003: J Geol Soc Lond 160, 3; 2004, NZ J Geol Geophys 47, 525

Information from the post-Oruanui shorelines

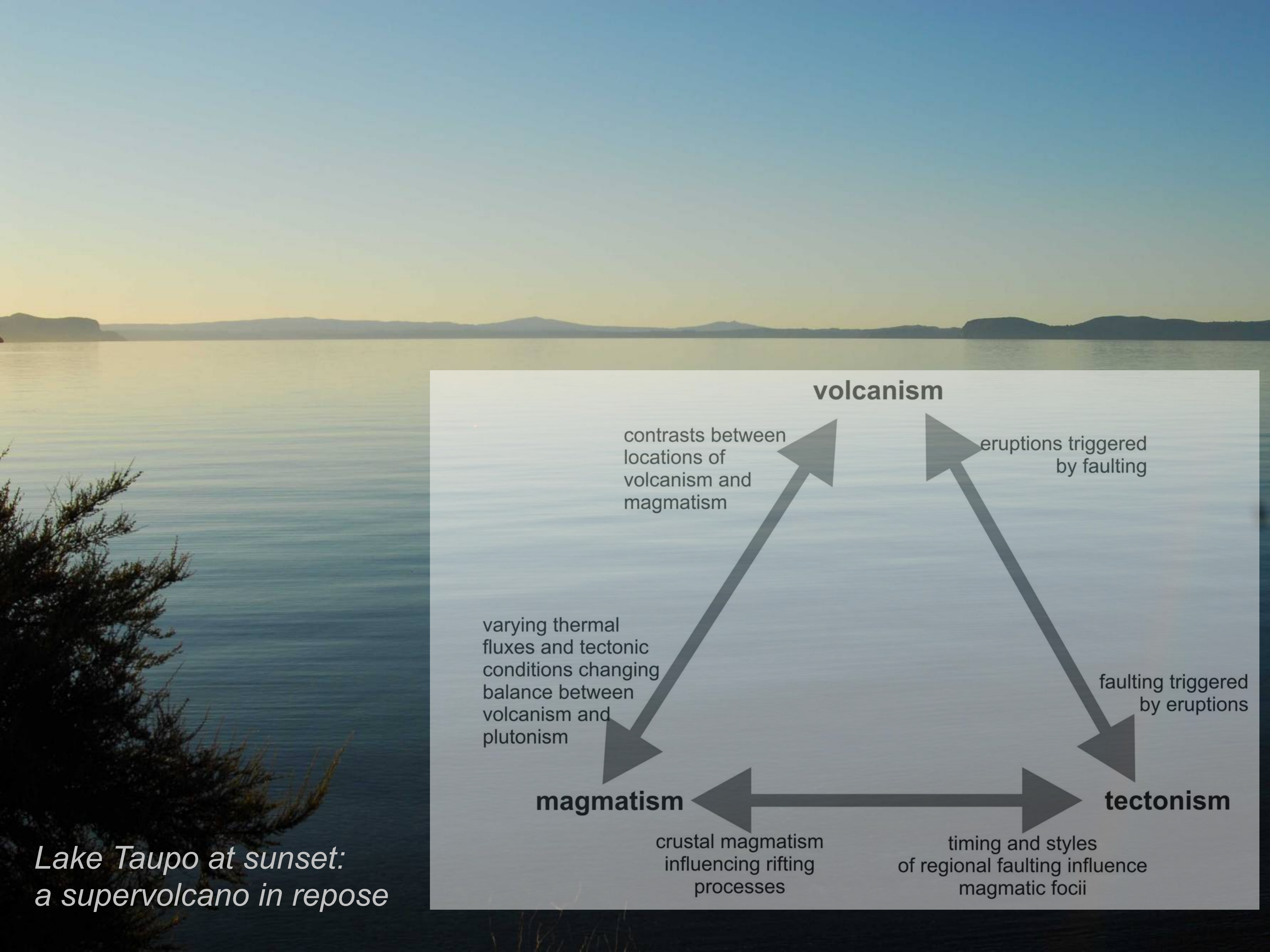


Recorded values for the post-Oruanui highstand terrace (blue trend line)

Information from the post-Oruanui shorelines



Recorded values for the post-Oruanui highstand terrace (blue trend line) contrasted with predicted alignment from modern deformation rates



Lake Taupo at sunset:
a supervolcano in repose