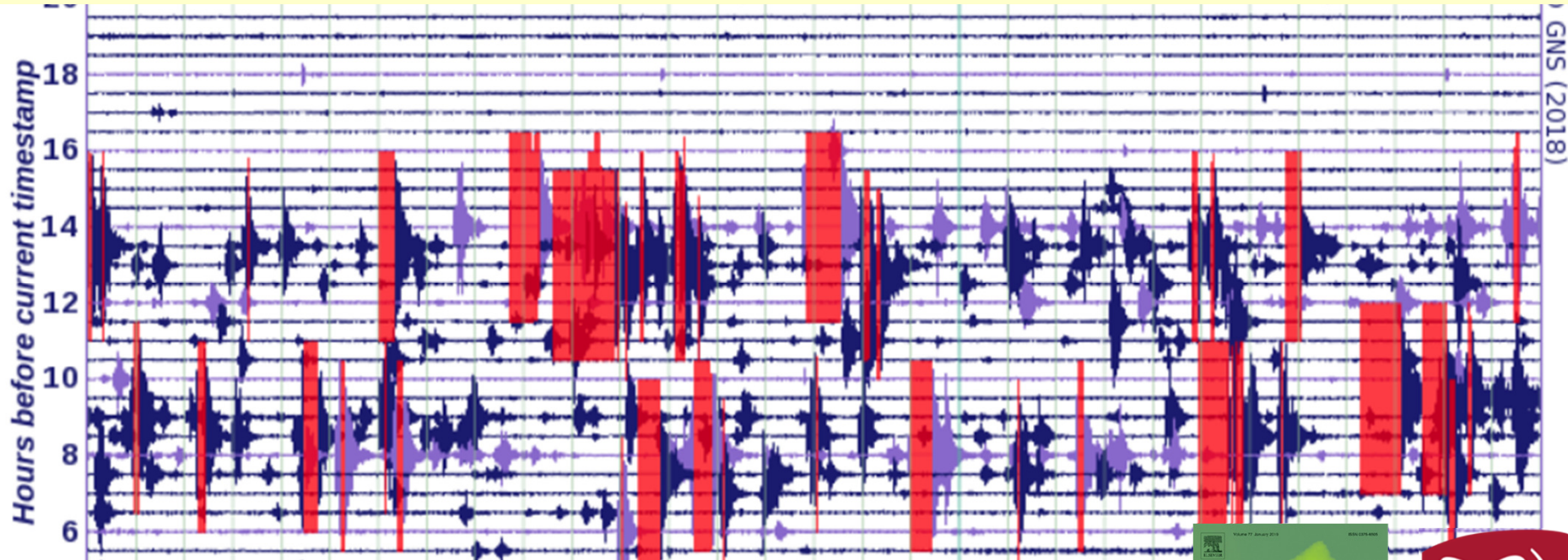


Geothermal Induced Micro-Seismicity in New Zealand : a Publicly-Acceptable, Reservoir Permeability Enhancement Process

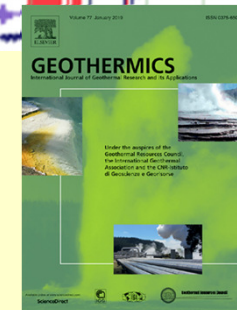


Chris Bromley GNS Science New Zealand

Co-Editor-in-chief : **GEOTHERMICS**

Vice-Chairman : **IEA-GEOTHERMAL**

3rd Induced Seismicity Workshop, Schatzalp, Davos, 5-8 March 2018



IEA Geothermal

Highlights

Review of learnings from 60 years of micro-seismic monitoring at New Zealand Geothermal Fields

- Information is open and immediately available; Public perception : MEQ are normal, not to be feared
- Mechanisms : Coupled geophysical property changes - rock stress, compressibility, density, porosity, permeability, saturation, temperature & pressure
- MEQ data helps improve conceptual models of reservoir processes, helps select make-up well targets, optimize production-injection strategy & improve estimates of sustainable energy capacity
- Monitoring informs adaptive resource management; interpretation assists reservoir model calibration



Working Group 13 Task D
IEA-GIA.org

Induced Seismicity: Objectives and Outputs

Encourage collaboration of researchers and share results of funded research undertaken by participants.

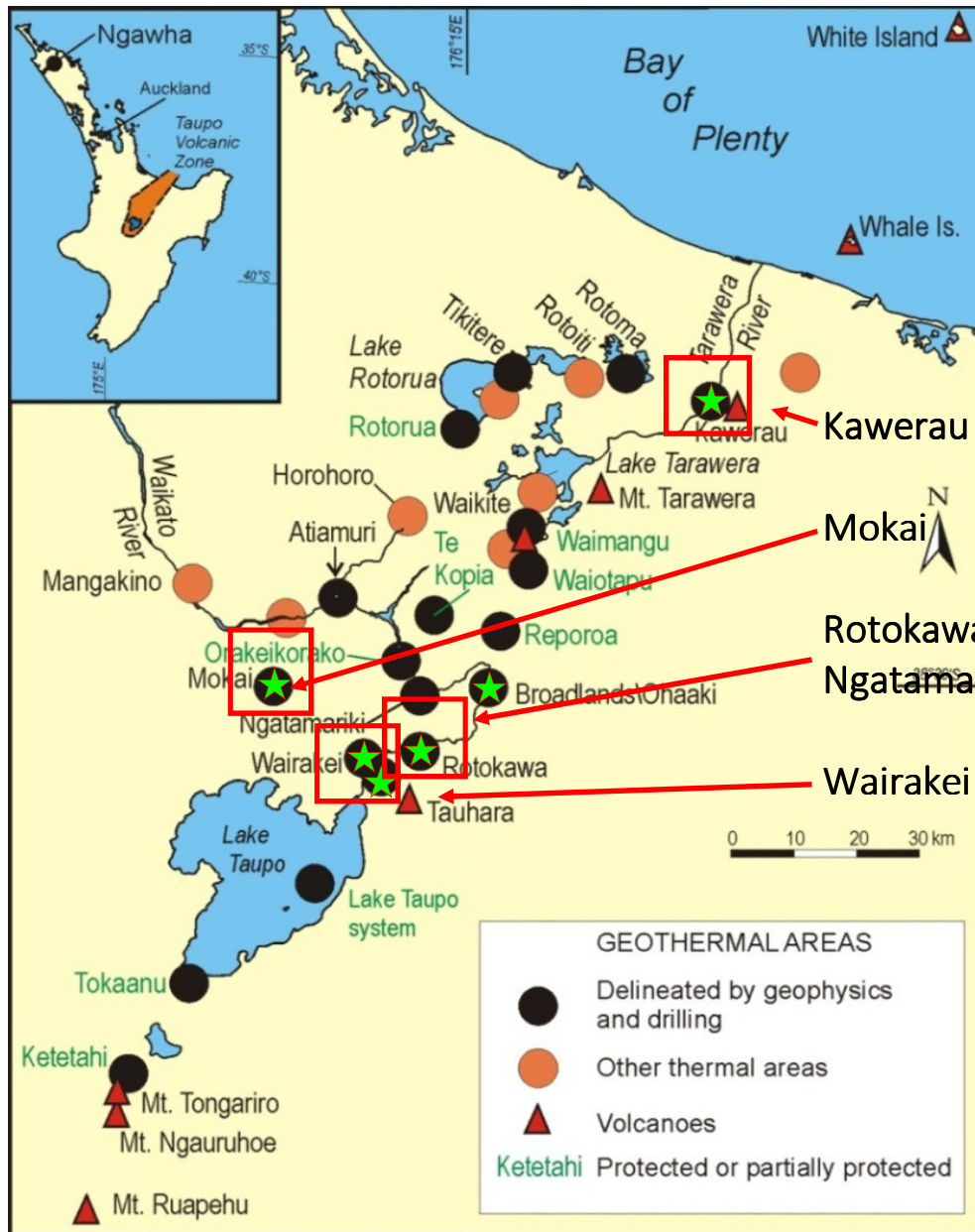
Countries with a strong interest in this topic include : Germany, France, Switzerland, Iceland, Japan, USA and New Zealand.

Some outputs are specific to one project or one country, while others represent joint work of individuals from several collaborating organisations, with funding from a variety of sources.

Topics that have attracted most interest and collaboration are: induced seismicity observations, mechanisms and models

“Our strength is not as an individual but as a collective”

New Zealand – geothermal micro-seismicity arrays

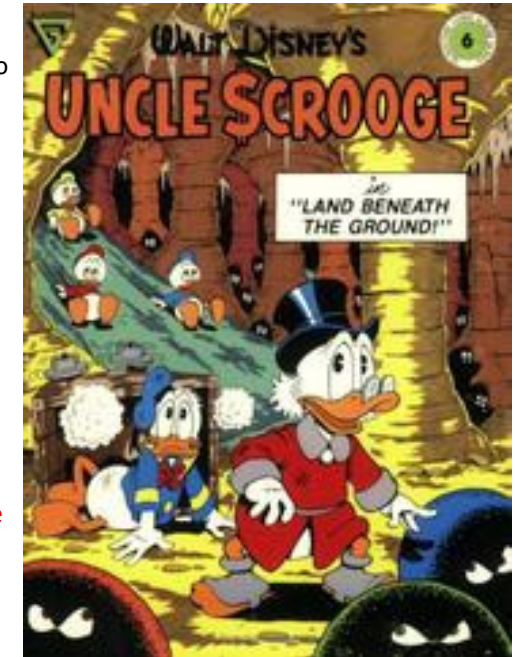


No seismicity at Ohaaki and Ngawha

5 operating geothermal fields
 ...up to 60 years history (with nationwide GEONET)
 ..plus local network arrays >10 yrs

'Down-Under' Mechanisms: Terries and Fermies

WIKIPEDIA:
 Scrooge is worried about earthquakes damaging his money bin and is determined to find out what causes them. So Scrooge McDuck and his nephews meet two types of underground beings known as Terries and Fermies that live in enormous caverns underneath the surface of the earth. The Terries and Fermies look like bowling balls with arms and a head, but no legs..... Terries cause earthquakes by rolling in massive groups of thousands against the giant pillars that support the land on the surface of the earth. Fermies cause earthquakes by gathering together in massive numbers and lifting up pieces of the Earth's crust.Whichever group causes the biggest earthquake wins the contest and gets the prizeThe Terries and Fermies can hear radio broadcasts through certain magnetic rocks which allows them to determine by the damage reports whether the Terries or the Fermies caused the biggest earthquake...
etc



Reference: Land beneath the Ground, 1956 Scrooge McDuck comic by Carl Barks



Immediate GEONET bulletins and Media Reports

Rotokawa 15th June 2017

“Main-shock, after-shock sequence”

- Max. Mag. = 3.8, at ~5 km depth
- Located about 10 km NE of Taupo
- “Earthquake activity is very common about the Rotokawa Geothermal Field. We have located over 70 earthquakes there in the last year.”

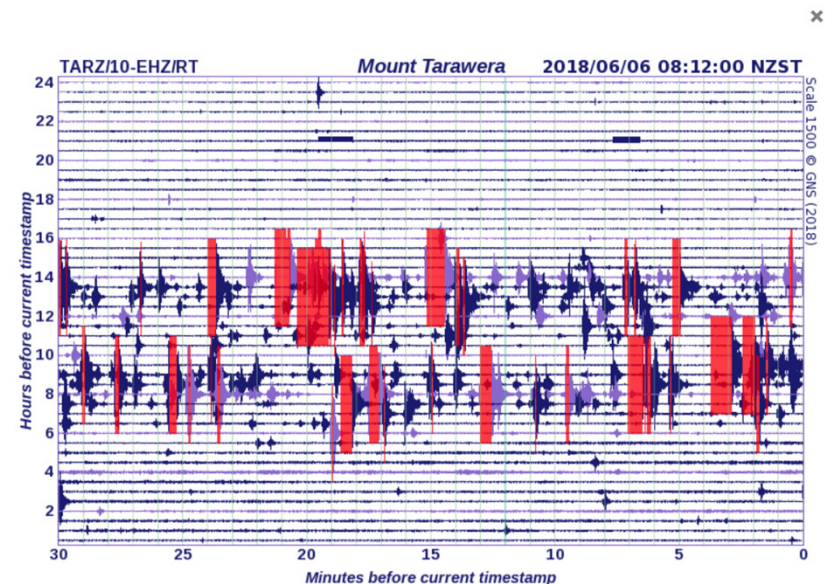


Showing 11 of 11 returned quakes.

Copyright.

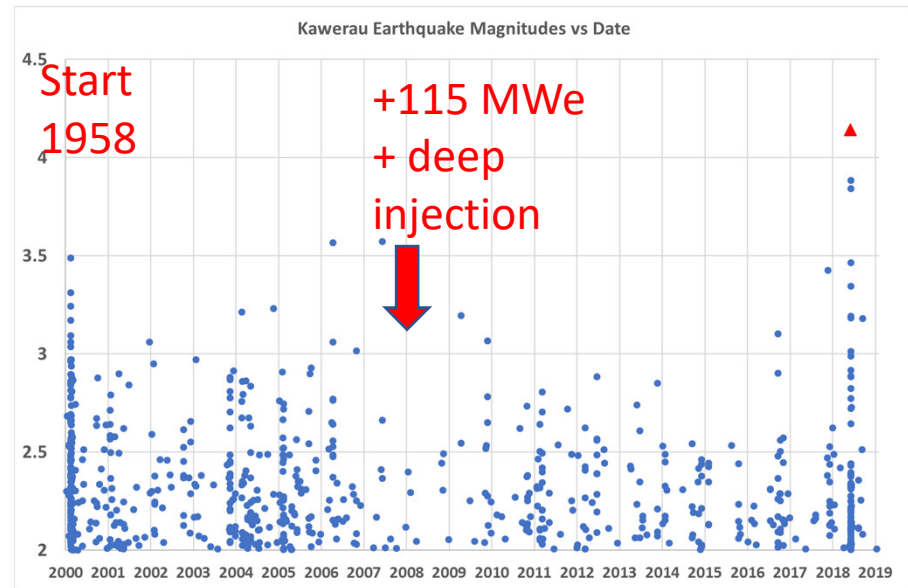
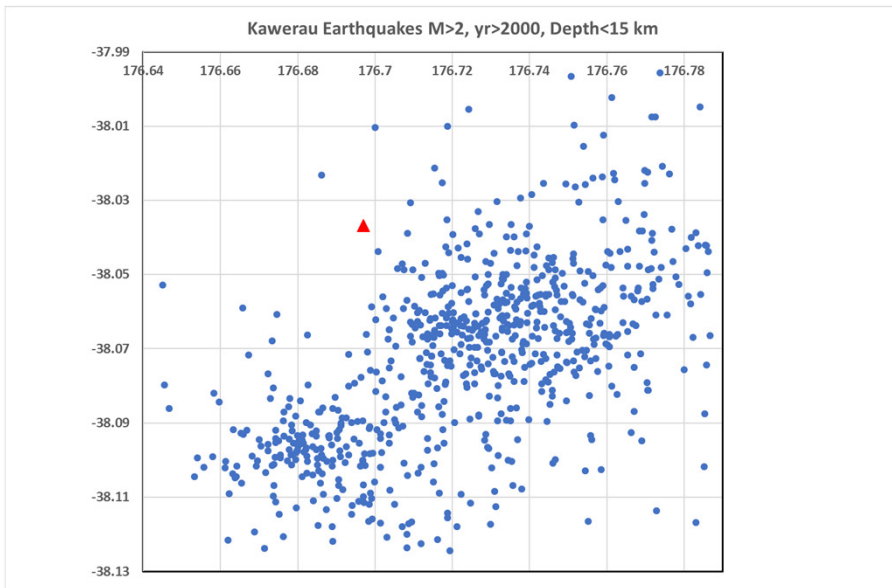
Kawerau 6th June 2018

- Swarm of MEQ “near Geothermal Systems”
- Not volcanic related
- Max. Mag. = 4.1
- Tripped all local geothermal turbines
- Rumbling noise from steam venting
- Safety systems worked as expected
- Although “unsettling” were “perfectly normal”

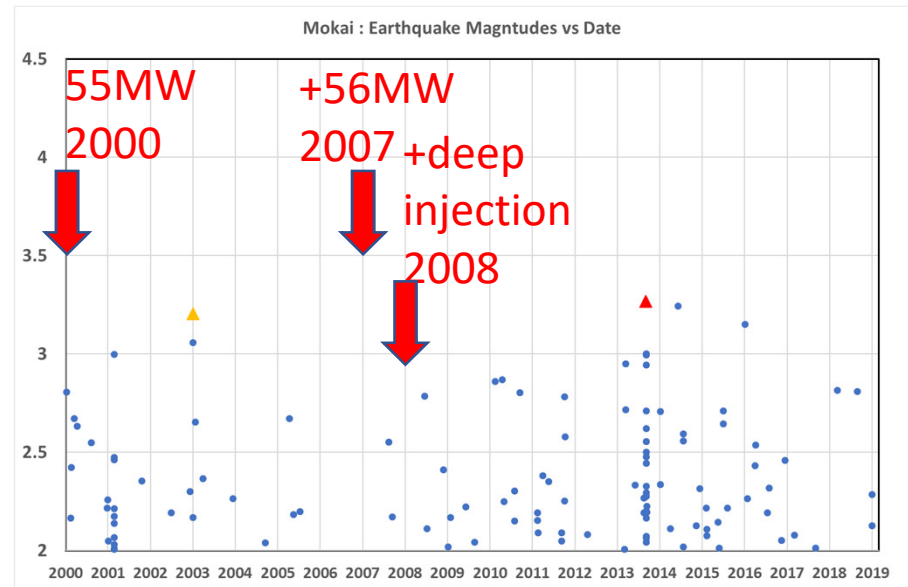
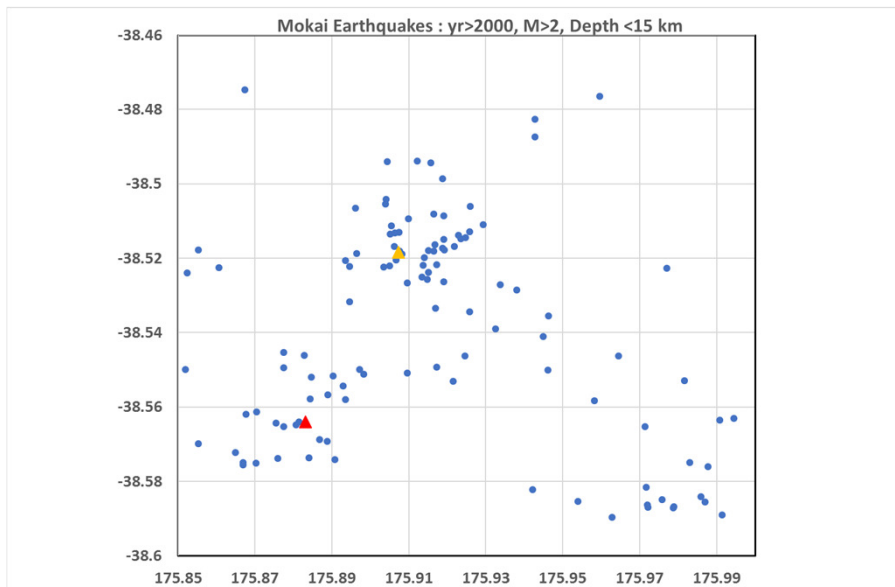


GEONET.org data (available to anyone)

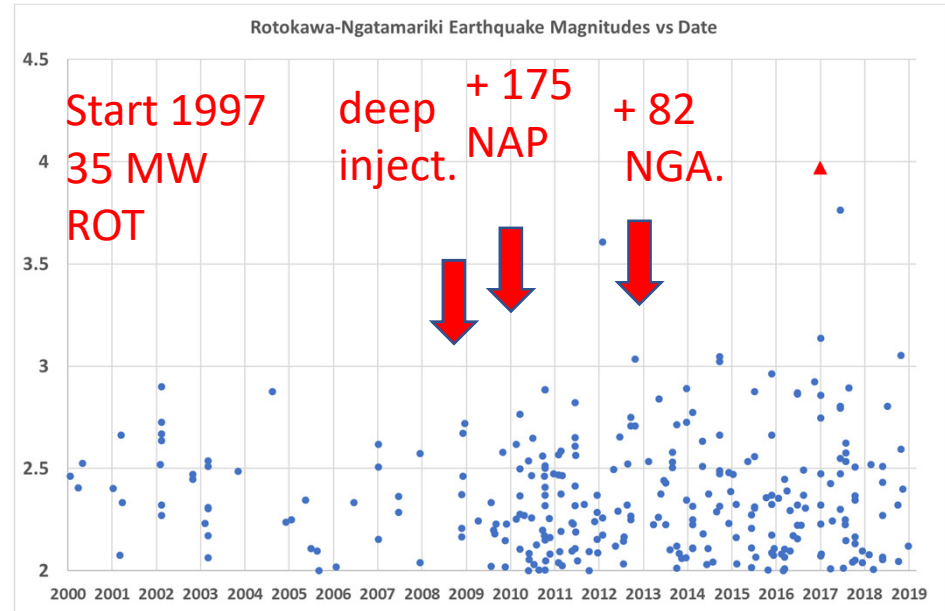
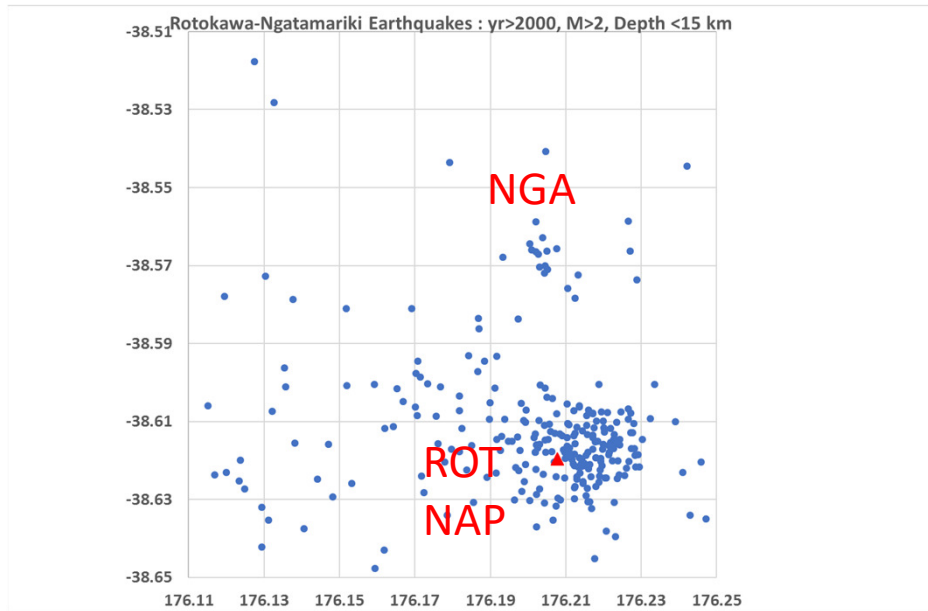
Kawerau : 19 years, $M > 2$, Depth < 15 km, 240 km^2



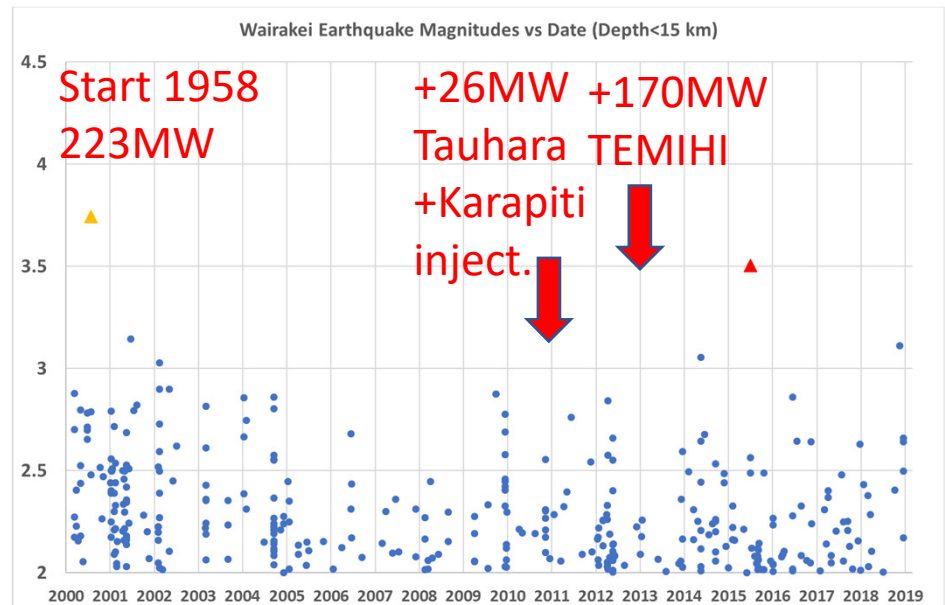
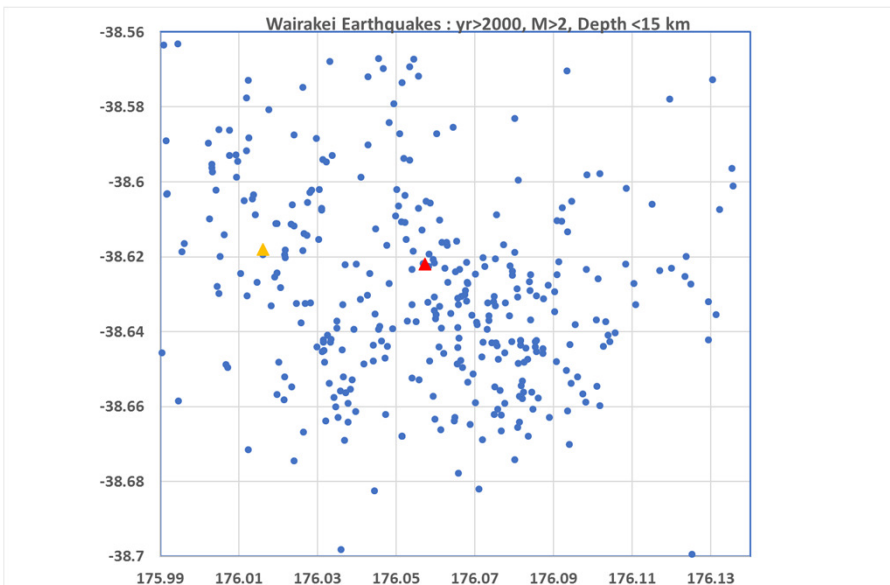
Mokai : 19 years, $M > 2$, Depth < 15 km, 240 km^2



Rotokawa – Ngatamariki : 19 years, M>2, Depth<15 km, 240 km²

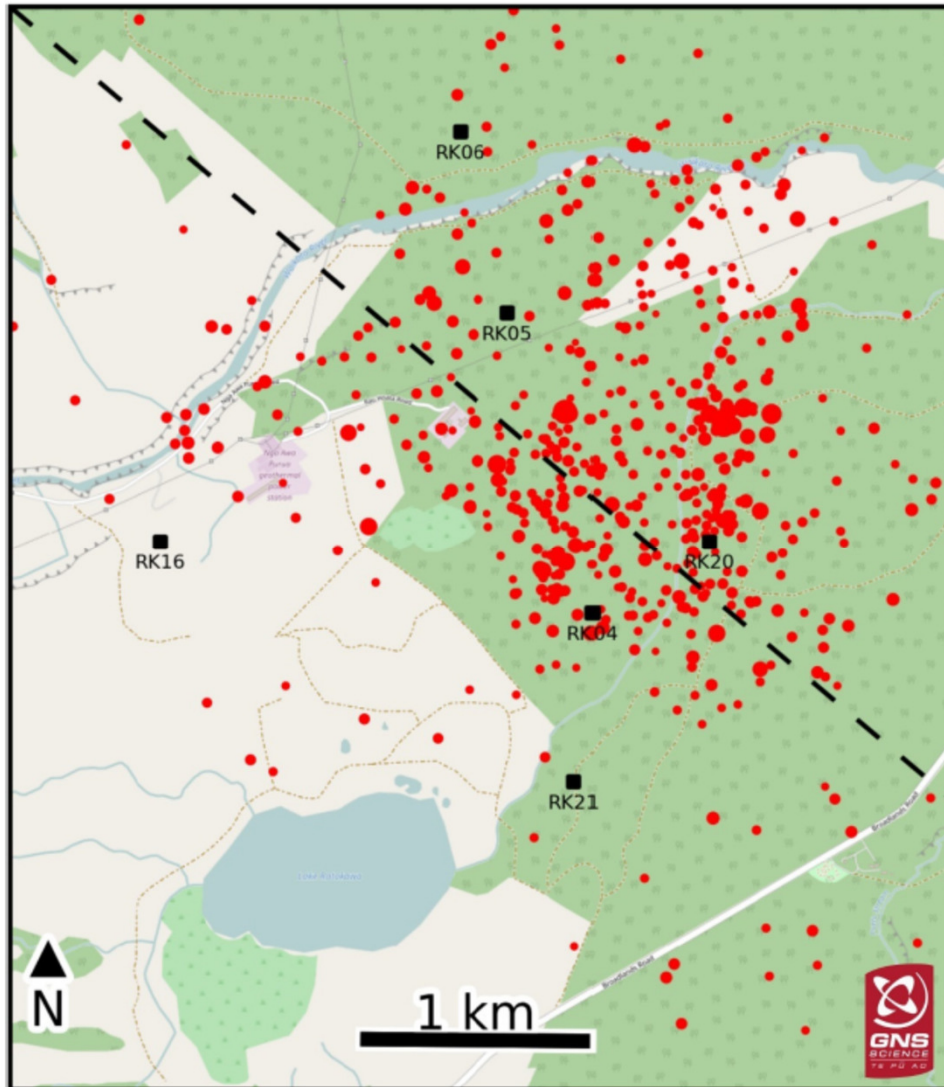


Wairakei : 19 years, M>2, Depth<15 km, 240 km²

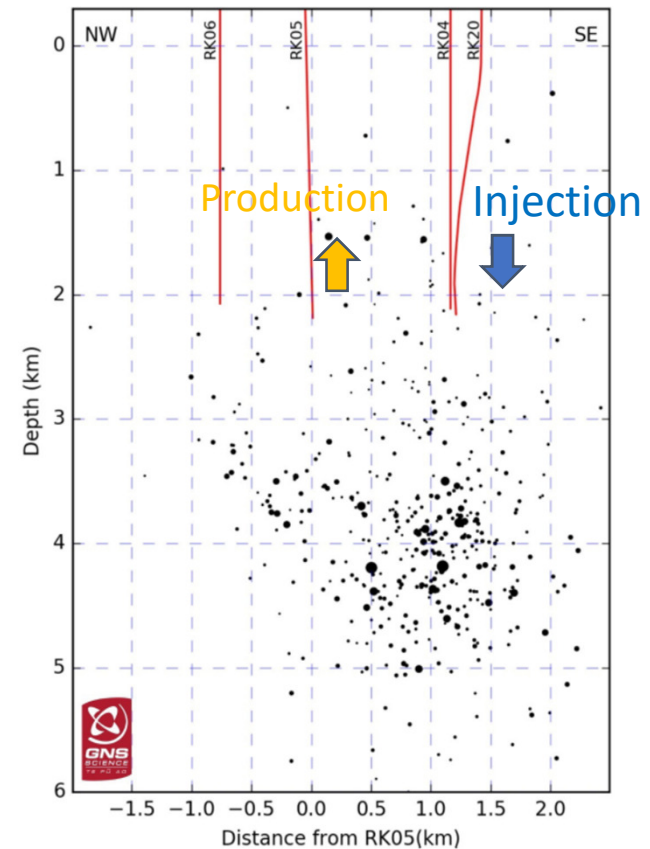


Rotokawa MEQ monitoring

permeability structure, triggering mechanisms, seismic tomography, stress & fault anisotropy, shear-wave split, moment tensors, brittle-ductile transition, changes over time



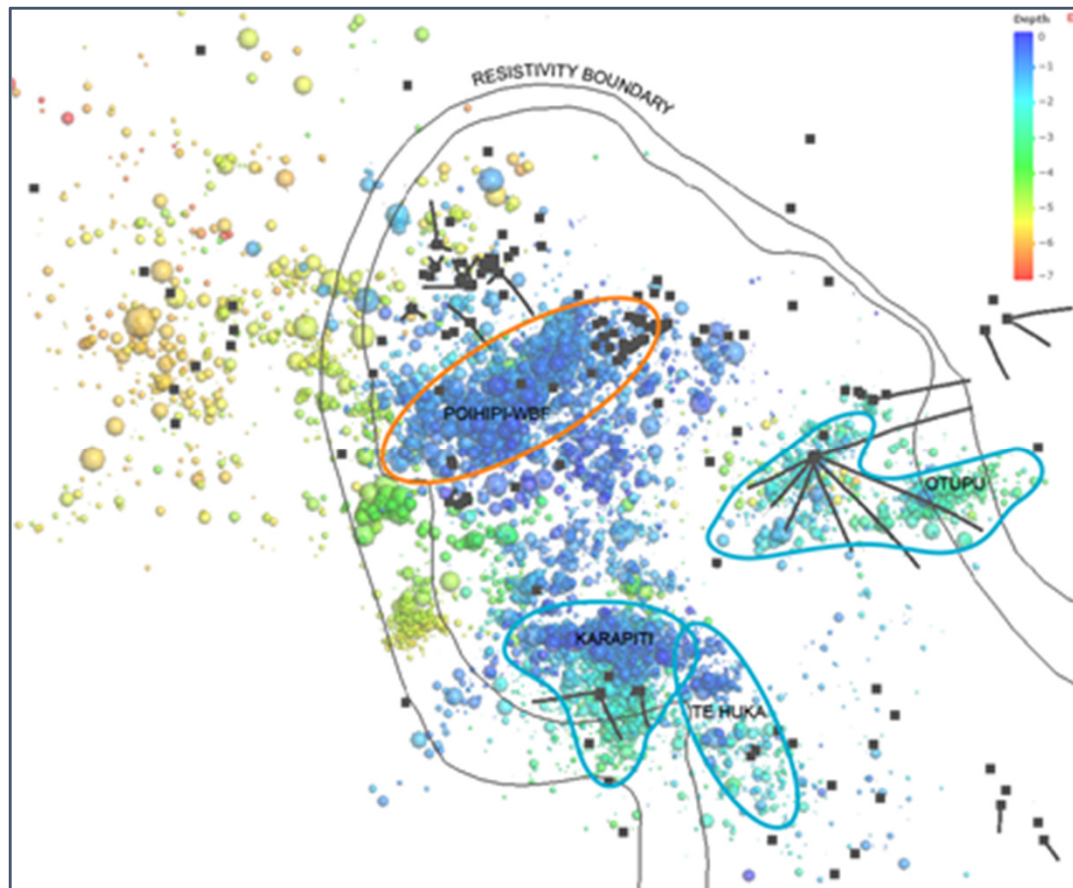
1 year of data from local network M>0.5



Depths modified with revised velocity model

- Sherburn et al WGC 2015
- Sewell et al WGC 2015, NZGW 2017
- Stefan Mroczek et al NZGW 2016
- Bromley et al Stanford 2018

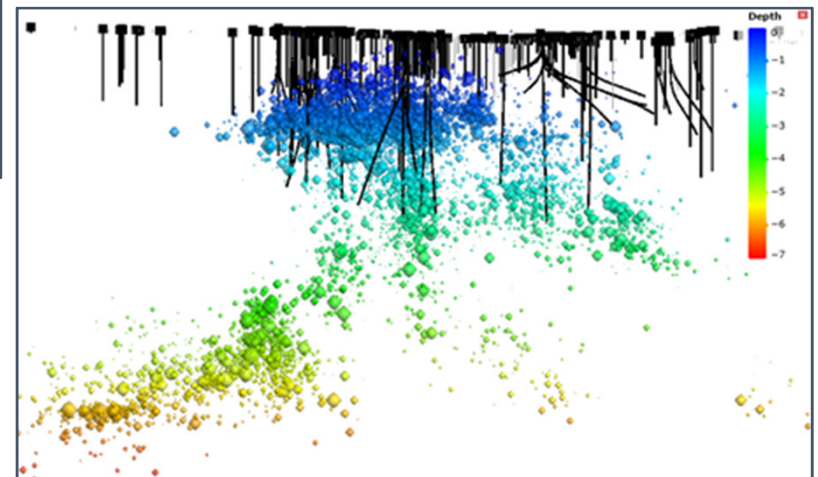
Wairakei MEQ monitoring



Wairakei seismicity map (2009-2017) showing clustered seismicity

Size of dot proportional to magnitude (relative scale) and color proportional to depth

Cross-section view from the south



...shows permeability structure & changes, clustering & triggering mechanisms, fluid flow, seismic tomography, stress & fault anisotropy, moment tensors, brittle-ductile transition...