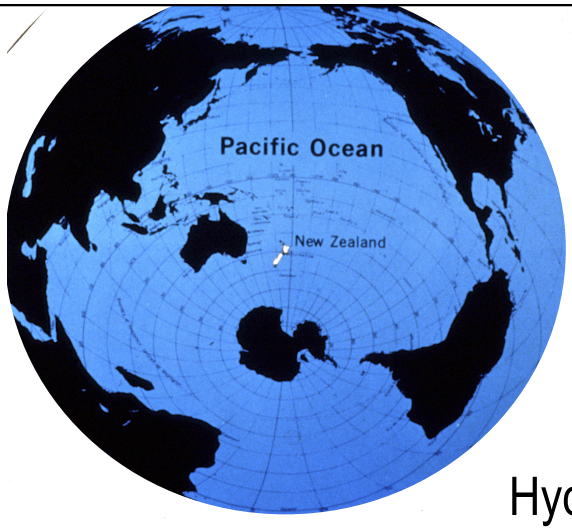
Active Geothermal Systems: Chemical & Thermal Structure



Main points

Geological setting

Hydrological features

Geochemical & thermal structure and fluid types

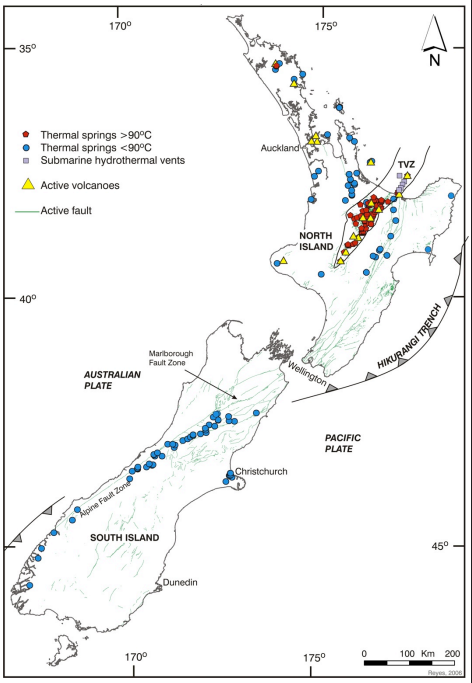
Introduction to metal occurrences

New Zealand Hydrothermal Systems

Unique tectonic setting straddling a plate boundary.

Extensional volcanic arc (10 mm/y) due to oblique subduction (North Island)

Transpressional transform fault-Alpine Fault (South Island)



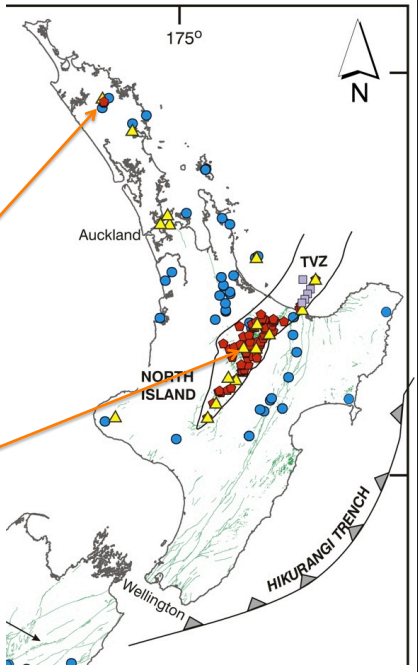
map: Reyes and Jongens, 2003

New Zealand Hydrothermal Systems

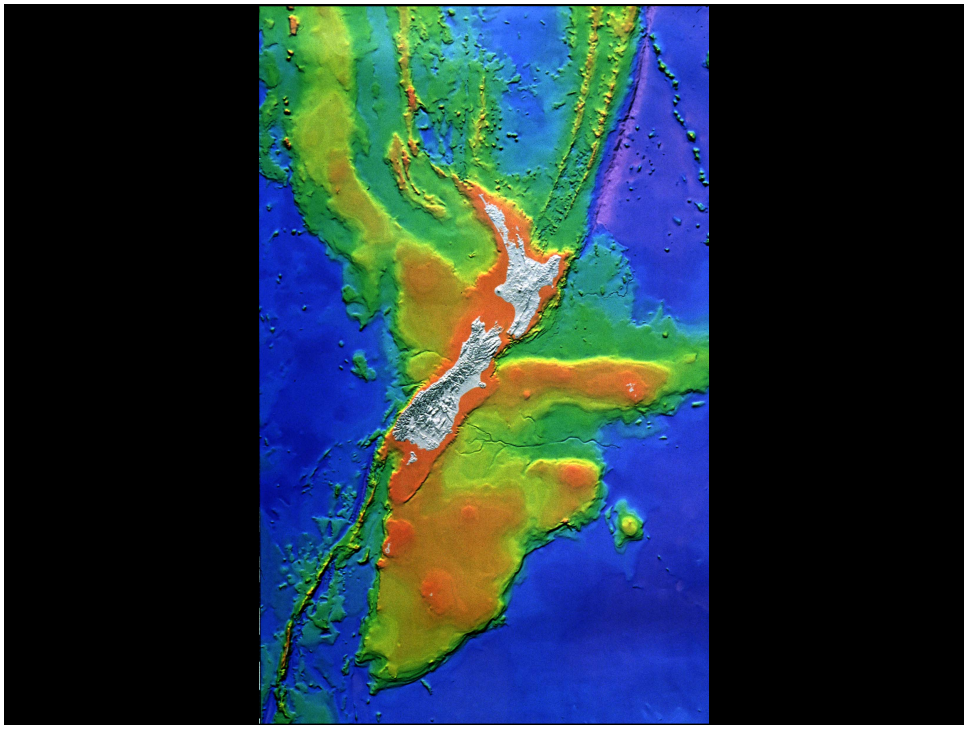
North Island high temperature systems

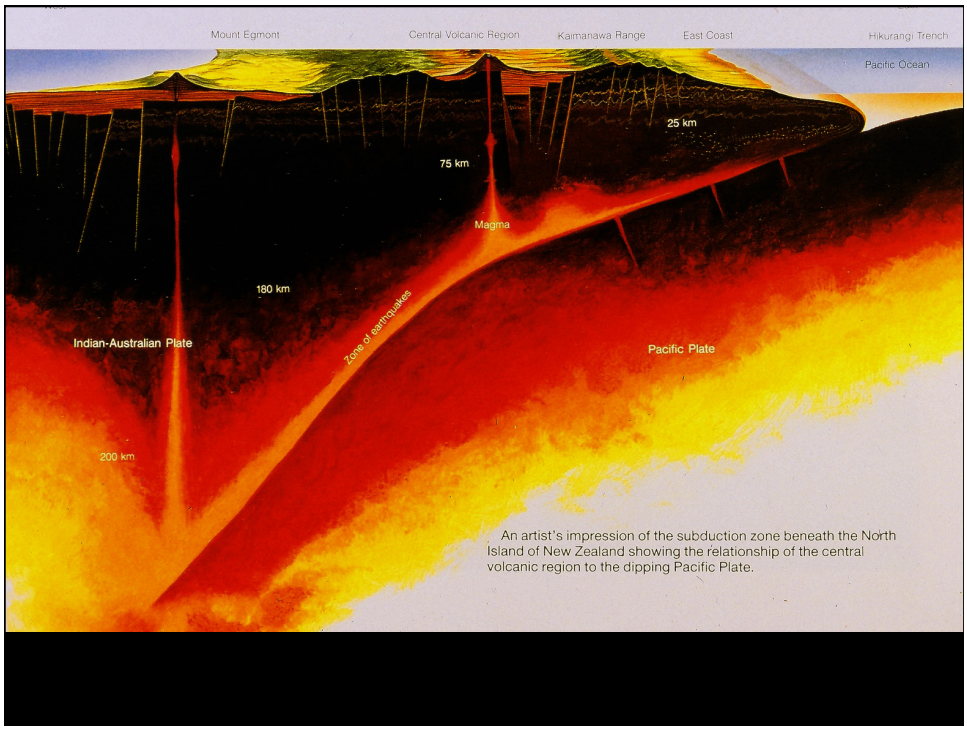
Intraplate basalt (rhyolite) magmatism)

Extensional volcanic arc andesite-rhyolite (basalt) magmatism

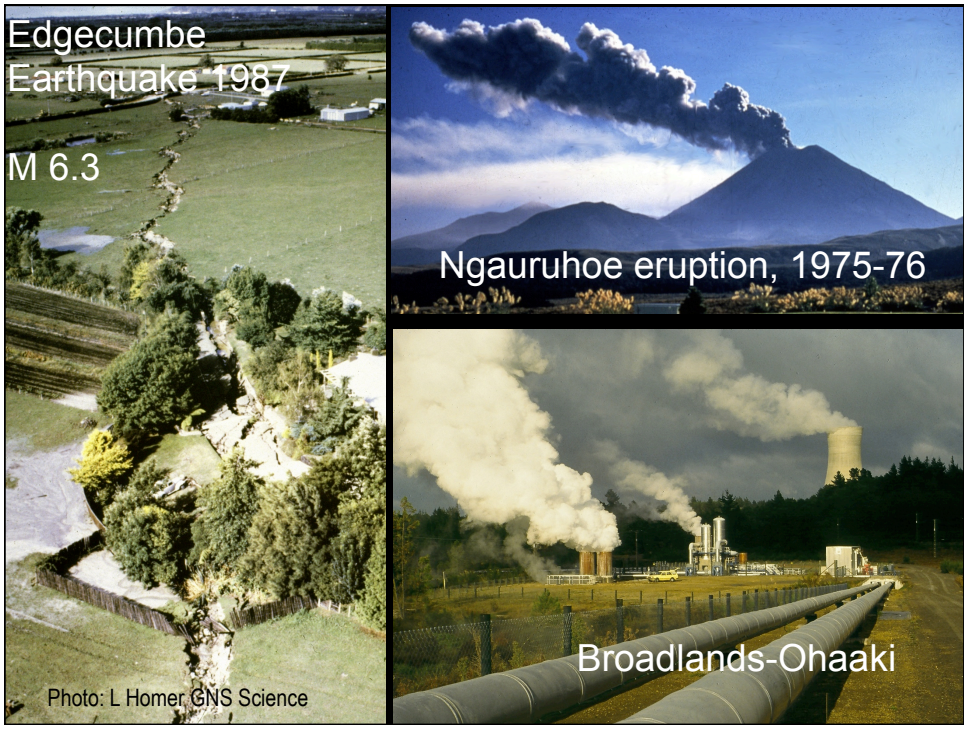


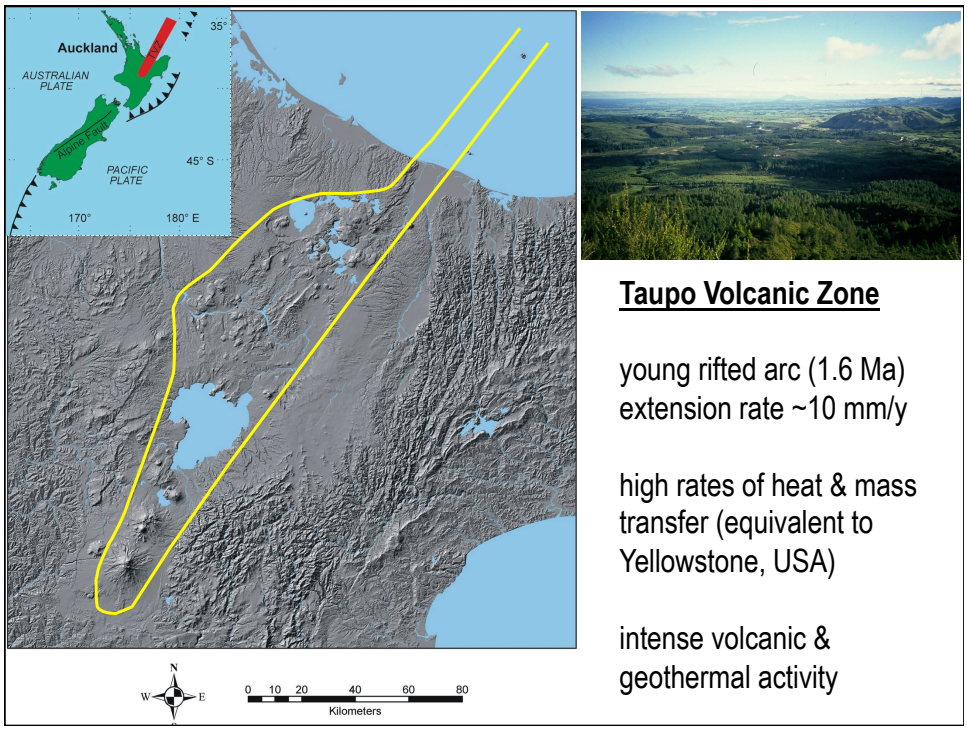
map: Reyes and Jongens, 2003





An artist's impression of the subduction zone beneath the North Island of New Zealand showing the relationship of the central volcanic region to the dipping Pacific Plate.



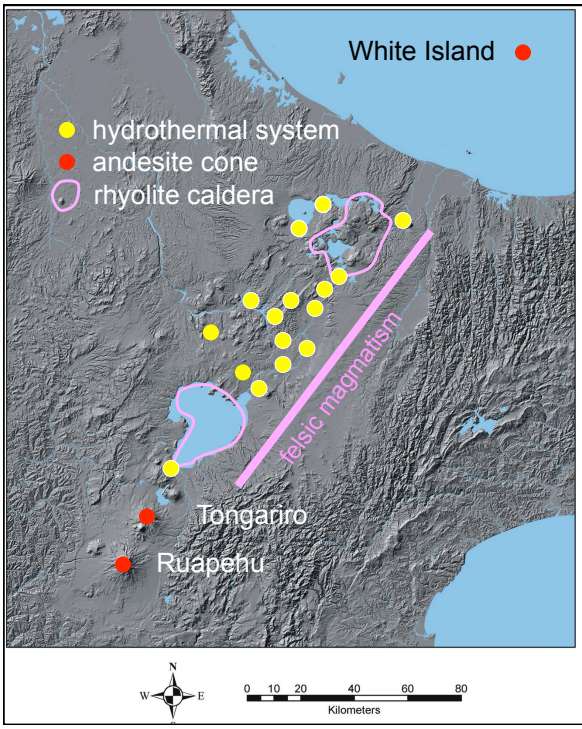


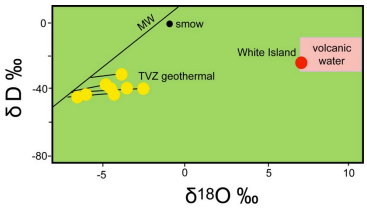
Taupo Volcanic Zone

young rifted arc (1.6 Ma)
extension rate ~10 mm/y

high rates of heat & mass transfer (equivalent to Yellowstone, USA)

intense volcanic & geothermal activity



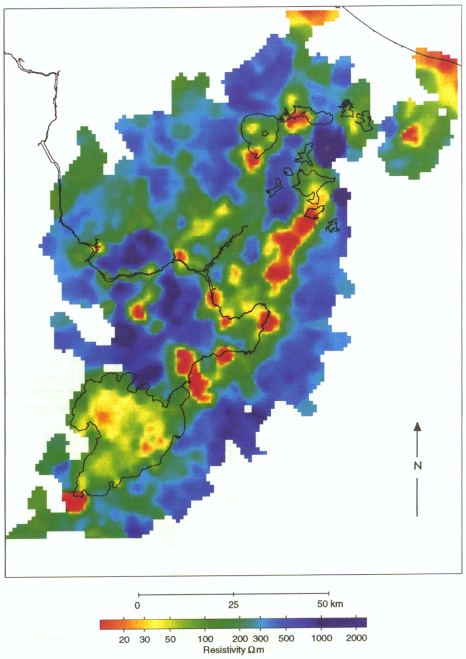


Taupo Volcanic Zone

Twenty meteoric-water dominated hydrothermal systems

70% of heat transfer by hydrothermal convection

2000 kg/s total fluid flow



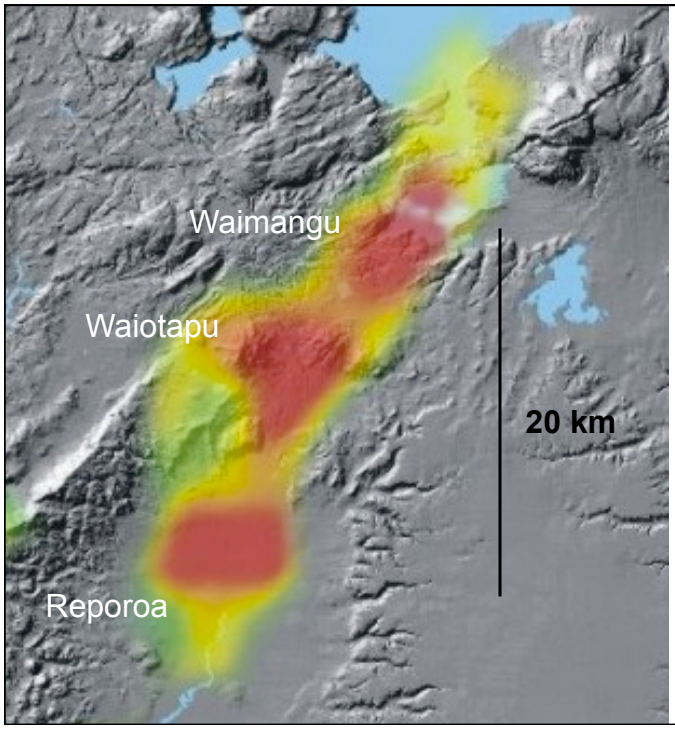
Taupo Volcanic Zone

Shallow geophysical surveys – hot water & altered rocks.

Total heat flow in central TVZ is ~4200 MW, roughly 48 km^3/kyr of magma.

~70% heat transfer to surface by geothermal convection

Central TVZ: DC apparent resistivity (Stagpoole and Bibby, 1998)



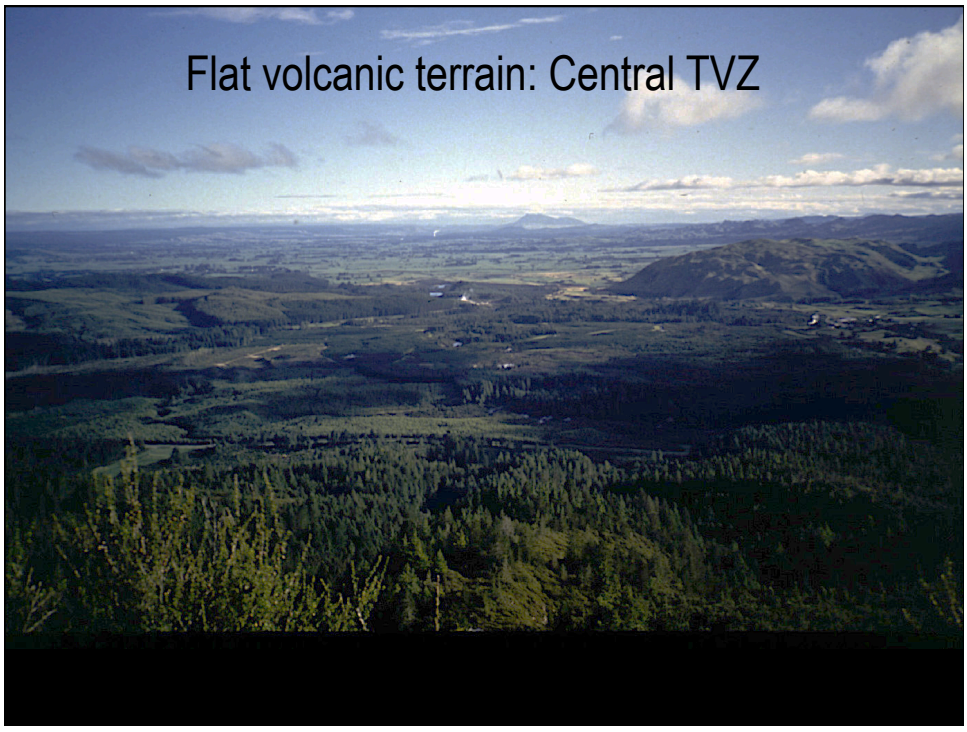
Resistivity pattern:
3 separate centers

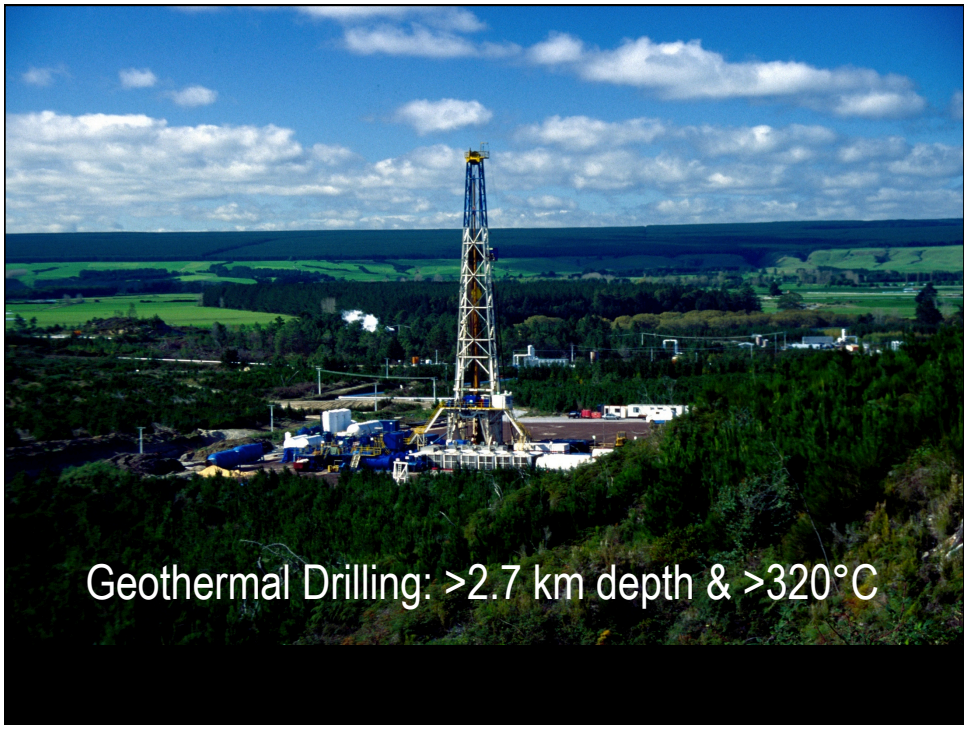
Waimangu
Waiotapu
Reporoa

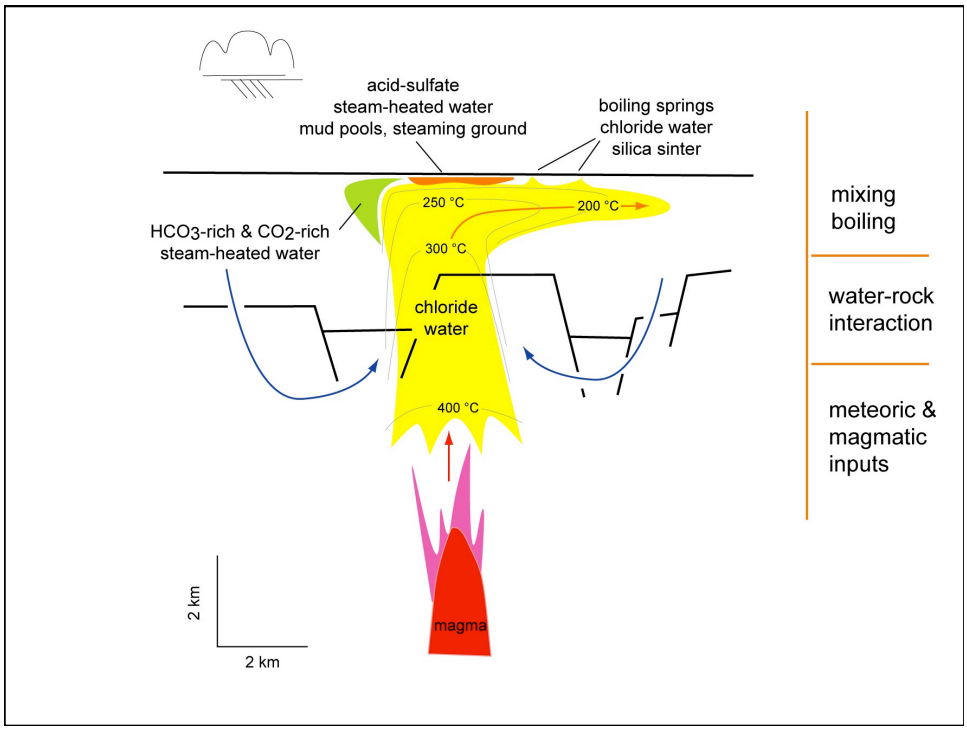
At ~500 m depth there is ~100 km^2 of contiguous hydrothermal alteration

Contrasting volcanic environments & processes

Volcanic strata >3 km depth thick

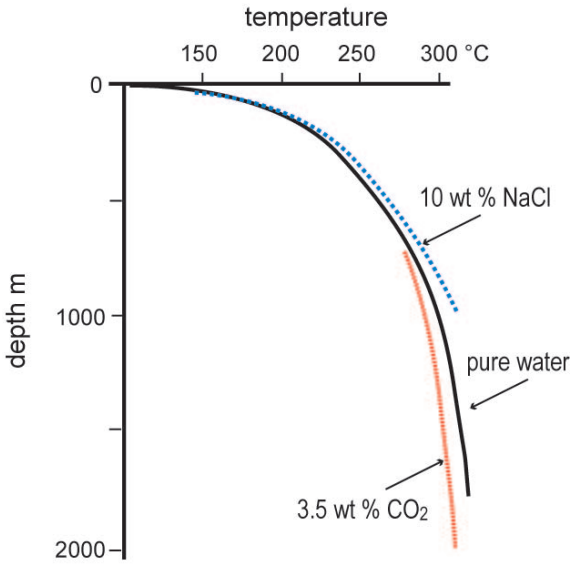



Geothermal Drilling: >2.7 km depth & >320°C


acid-sulfate
steam-heated water
mud pools, steaming ground
boiling springs
chloride water
silica sinter
250 °C
200 °C
300 °C
HCO3-rich & CO2-rich
steam-heated water
chloride
water
400 °C
magma
2 km
2 km
mixing
boiling
water-rock
interaction
meteoric &
magmatic
inputs

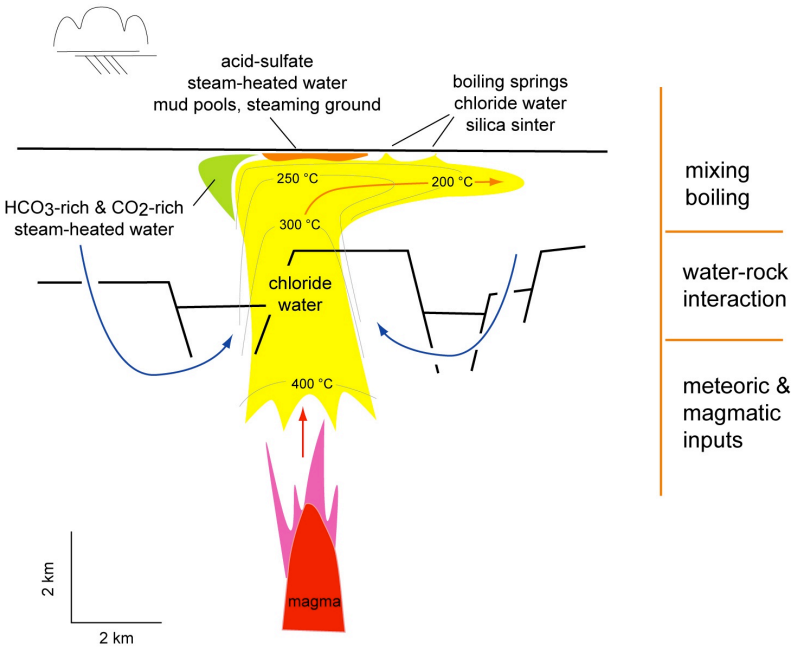
Heat transfer by convection

Life expectancy of a geothermal system is 50,000 to 500,000 years



Hydrostatic boiling point for depth curve

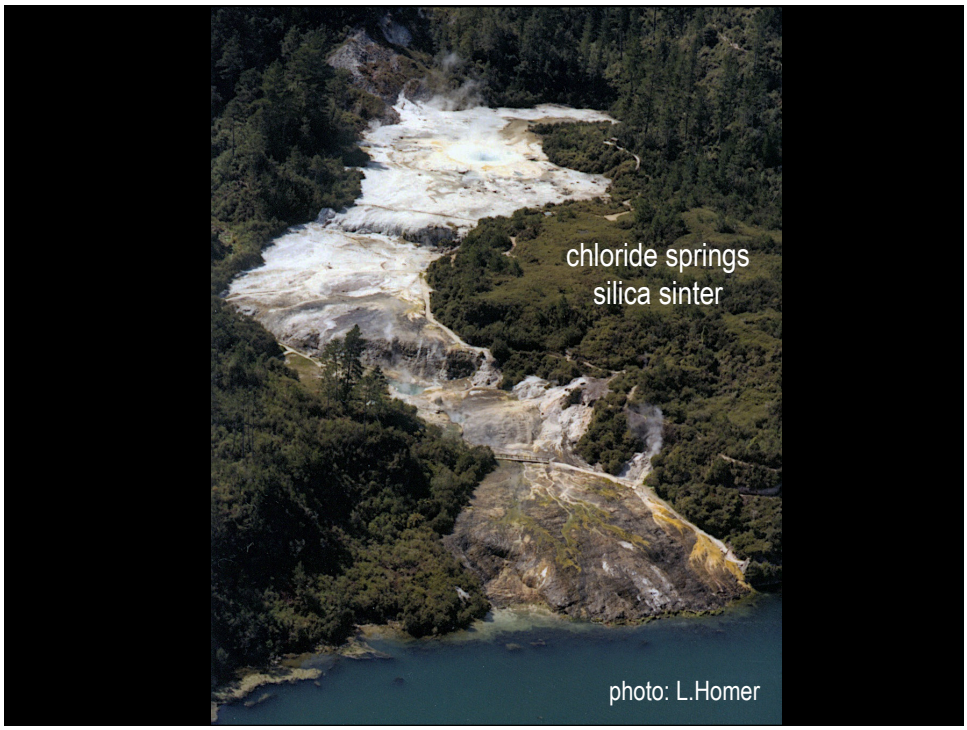
T-P gradient in upflow zone



Geothermal Waters (mg/kg)

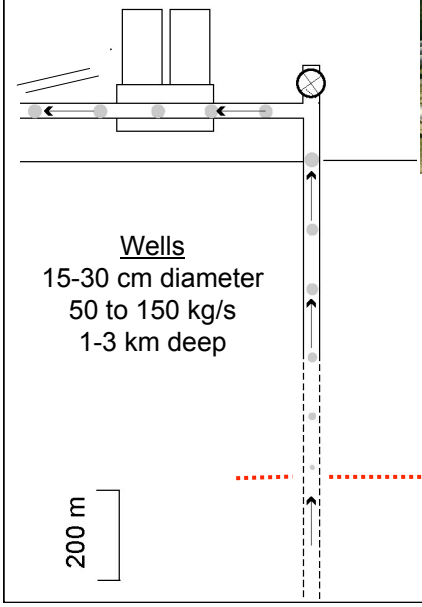
	Chloride	Acid Sulfate	Bicarbonate
$pH_{20°C}$	8.0	1.8	7.0
Na	1070	4	398
K	102	6.2	31
Cl	1770	<2	30
SO_4	26	1047	96
HCO_3	76	-	8492
SiO_2	338	151	190


chloride springs
silica sinter
Artist's Palette-Orakeikorako


chloride springs
silica sinter
photo: L.Homer

production well discharge: chloride water

2 phase (boiling) well



Wells
15-30 cm diameter
50 to 150 kg/s
1-3 km deep

two-phase boiling conditions confined to well

~25% of deep liquid evaporates to steam on ascent to the surface

level of boiling

Geothermal Waters (mg/kg)

	Chloride	Acid Sulfate	Bicarbonate
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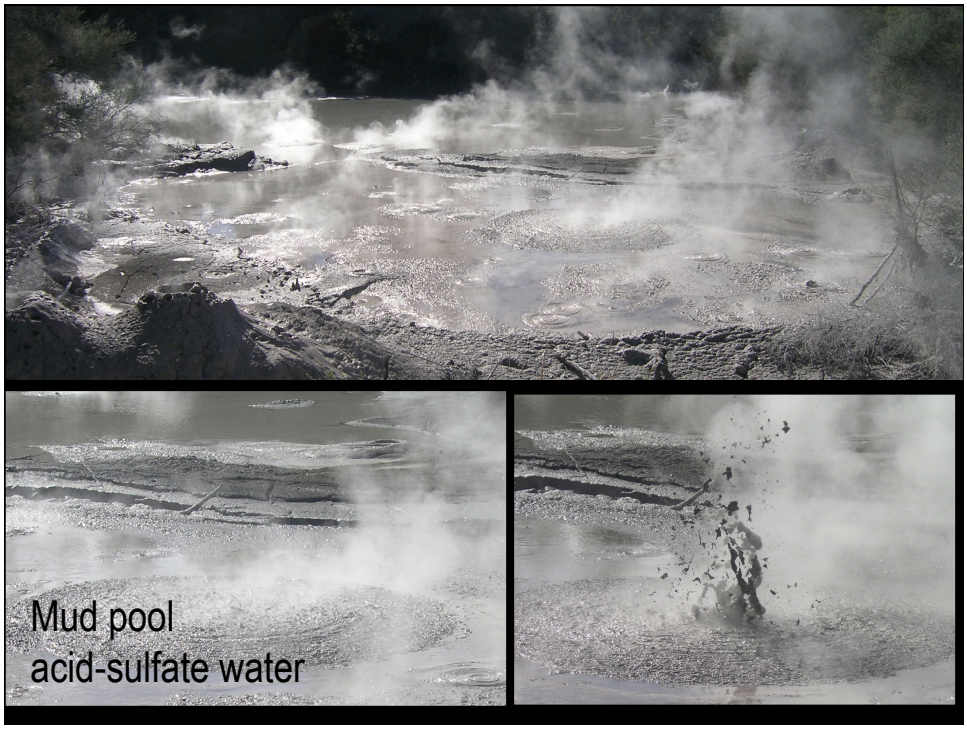
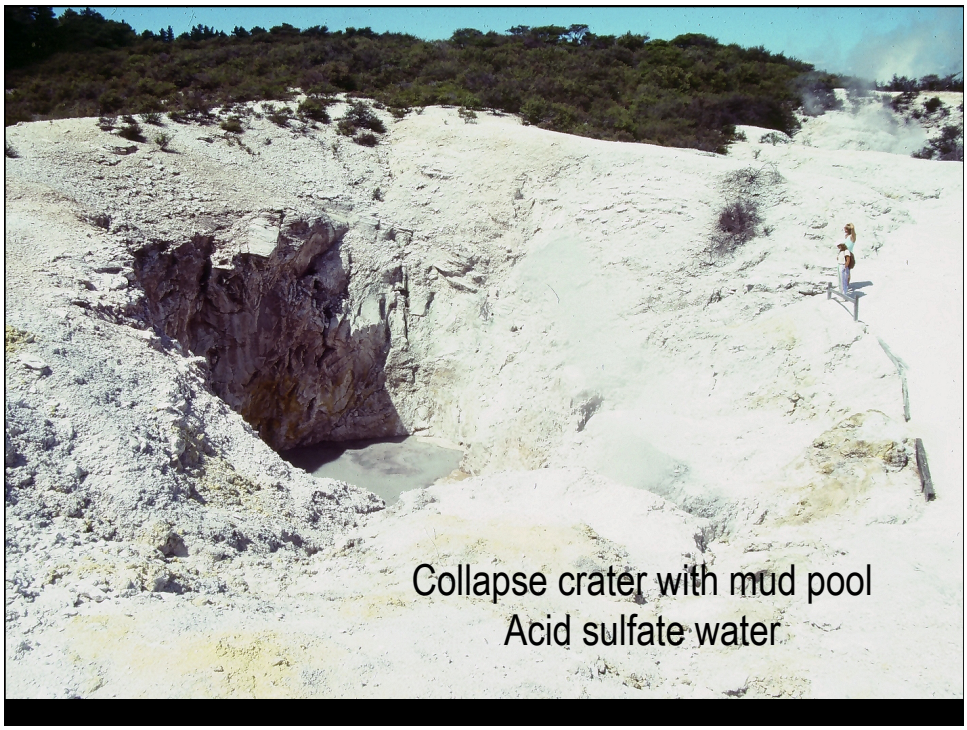
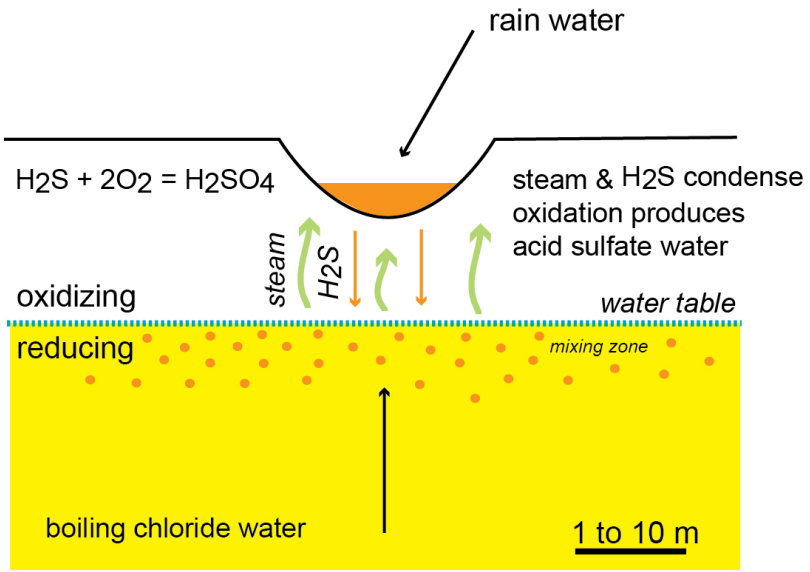
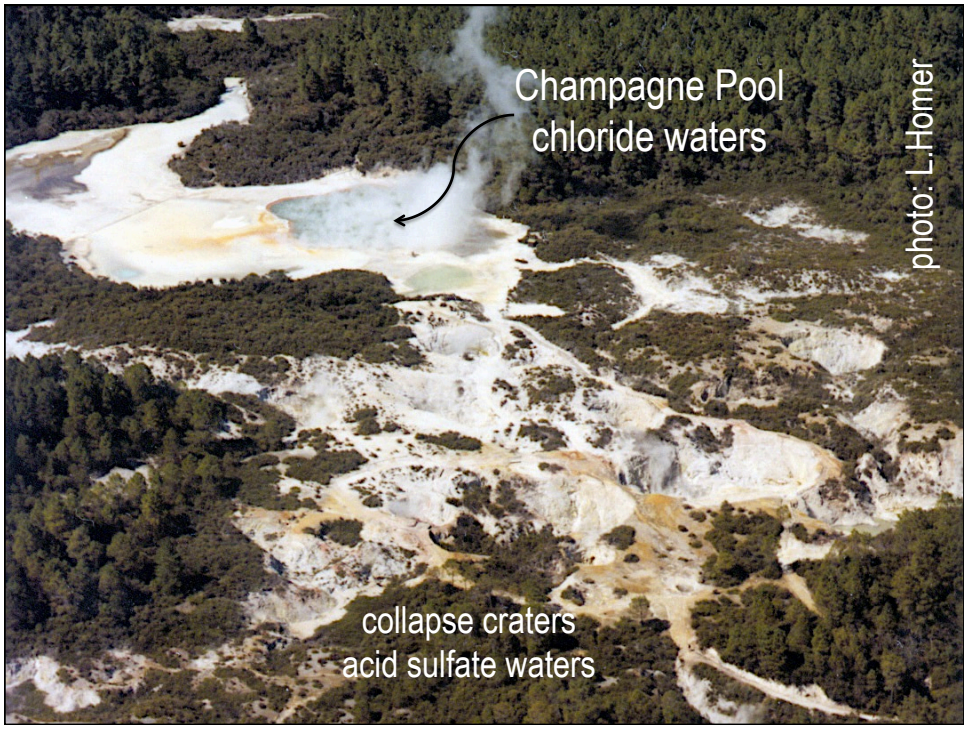

Mud pool
acid-sulfate water


Collapse crater with mud pool
Acid sulfate water

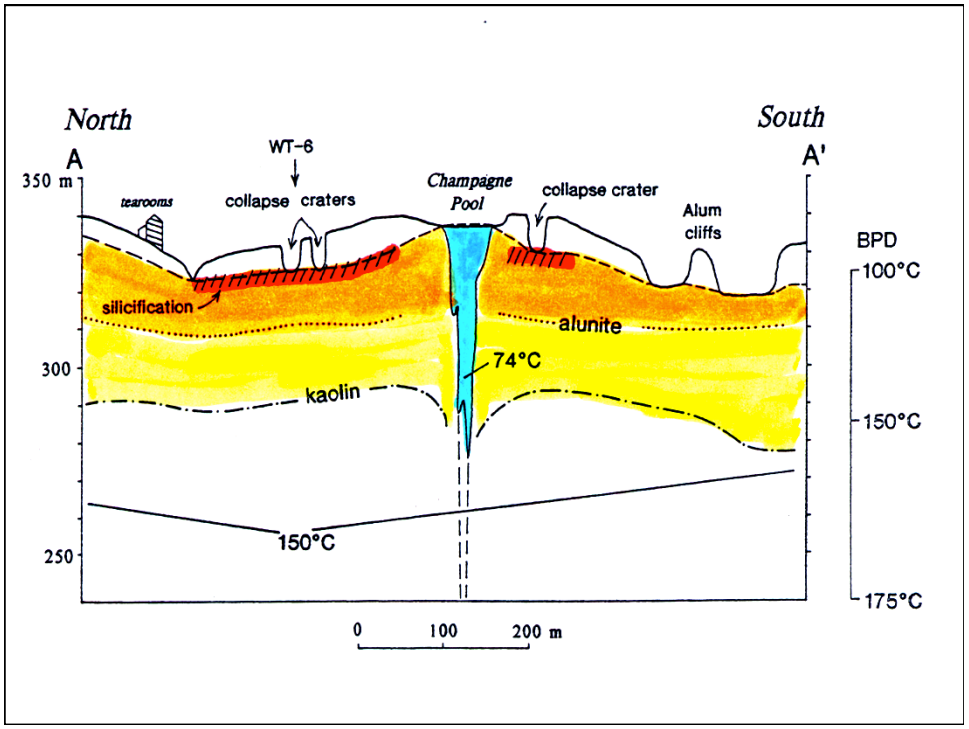
Steam-heated acid sulfate water





Champagne Pool
chloride waters

As-Sb-Tl-Hg sulfides
540 ppm Au, 750 ppm Ag



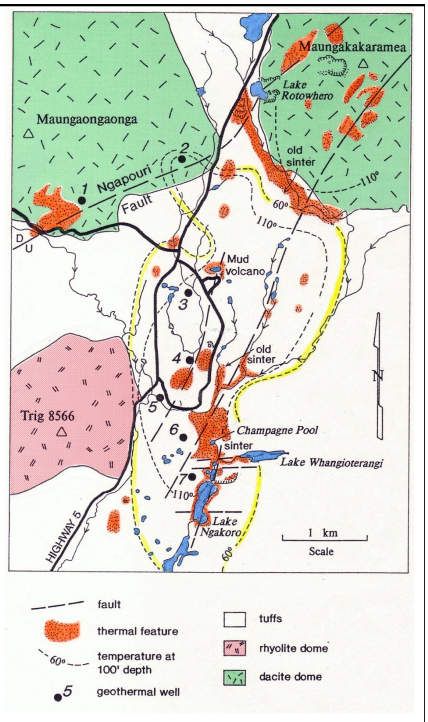
Waiotapu

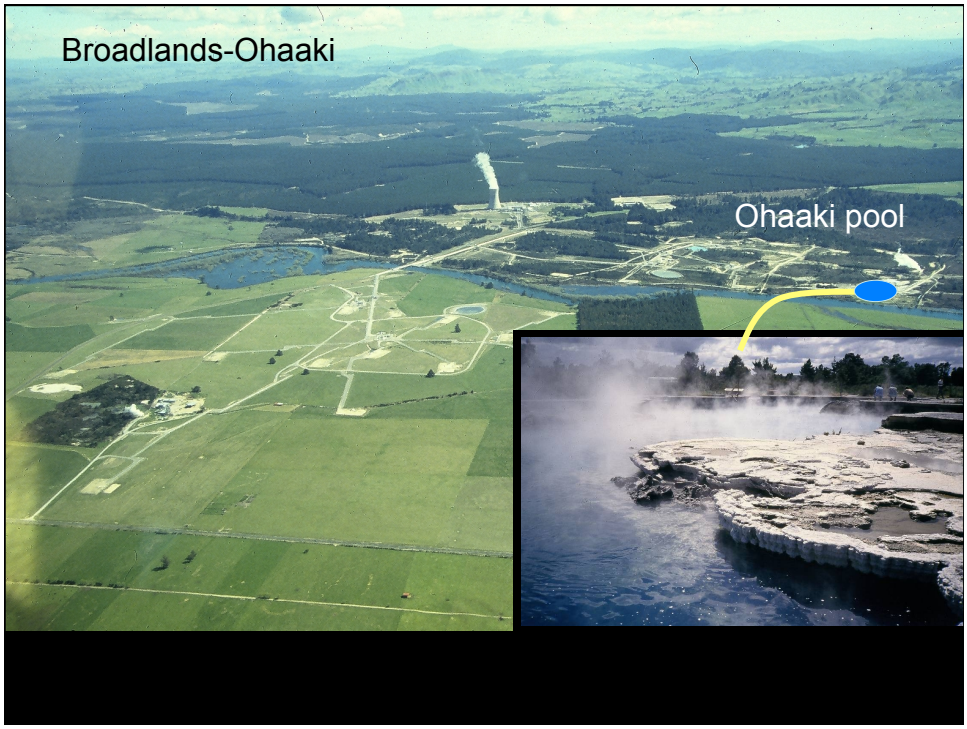
extent of surface activity

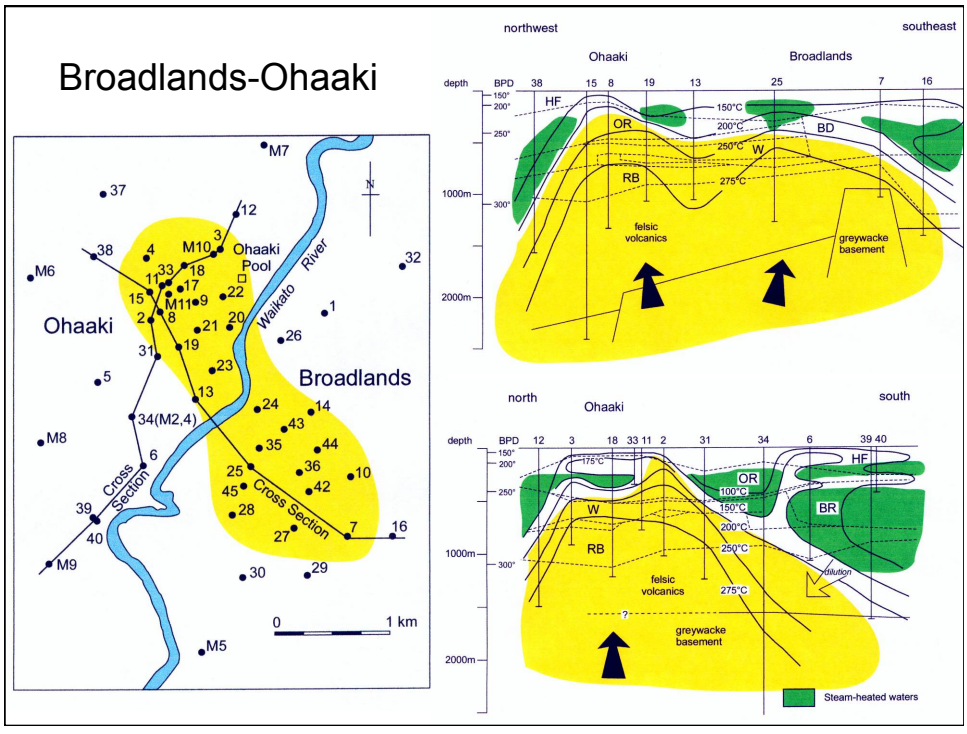
volcanic domes

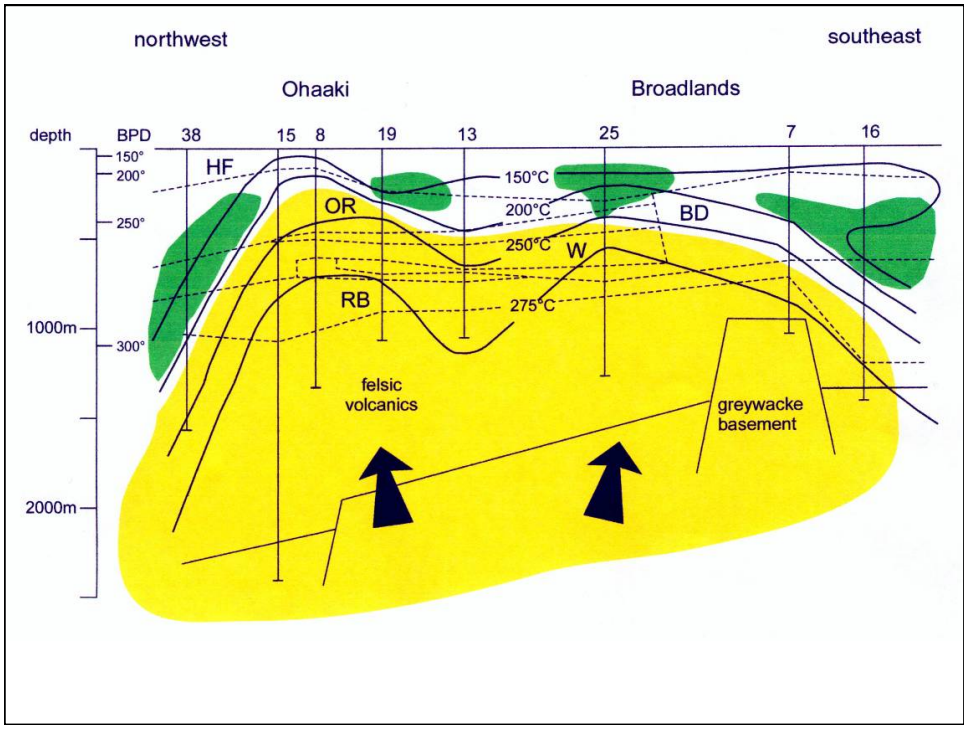
fault traces

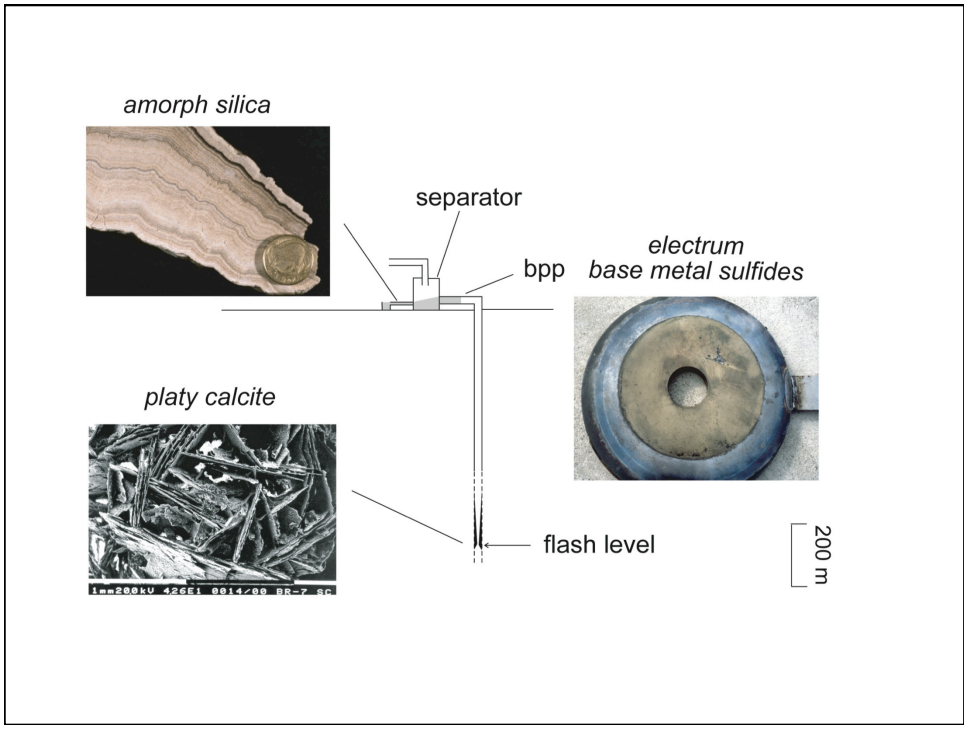
Champagne Pool




Broadlands-Ohaaki
Ohaaki pool


Broadlands-Ohaaki
Ohaaki
Broadlands
Waikato River
Ohaaki Pool
Cross Section
Cross Section
0
1 km
northwest
southeast
Ohaaki
Broadlands
depth
BPD
HF
OR
BD
W
RB
felsic volcanics
greywacke basement
1000m
2000m
north
Ohaaki
south
BR
dilution
Steam-heated waters


northwest
southeast
Ohaaki
Broadlands
depth
BPD
38
15
8
19
13
25
7
16
150°
200°
250°
300°
1000m
2000m
HF
OR
RB
W
BD
150°C
200°C
250°C
275°C
felsic
volcanics
greywacke
basement

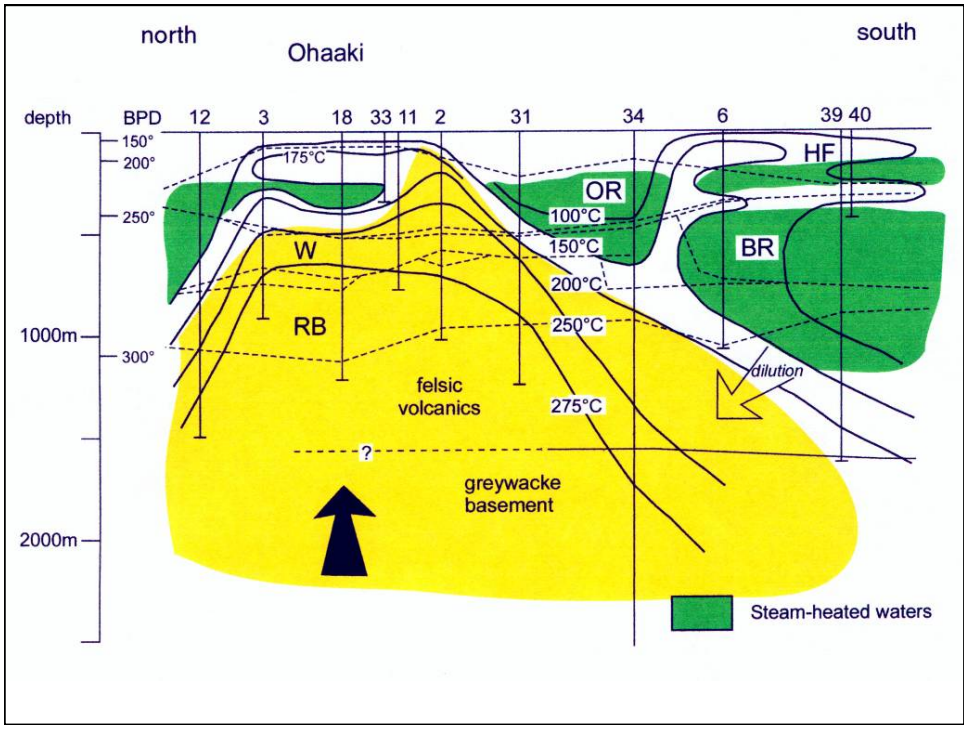

amorph silica
separator
bpp
electrum
base metal sulfides
platy calcite
flash level
200 m

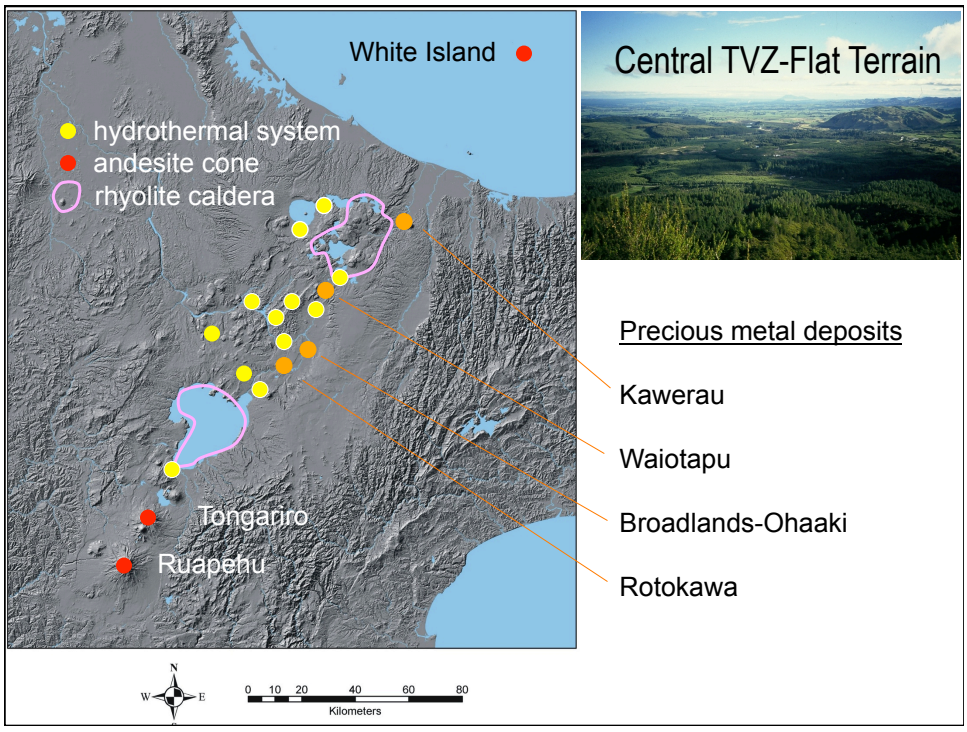
Geothermal Waters (mg/kg)

	Chloride	Acid Sulfate	Bicarbonate
$pH_{20°C}$	8.0	1.8	7.0
Na	1070	4	398
K	102	6.2	31
Cl	1770	<2	30
SO_4	26	1047	96
HCO_3	76	-	8492
SiO_2	338	151	190

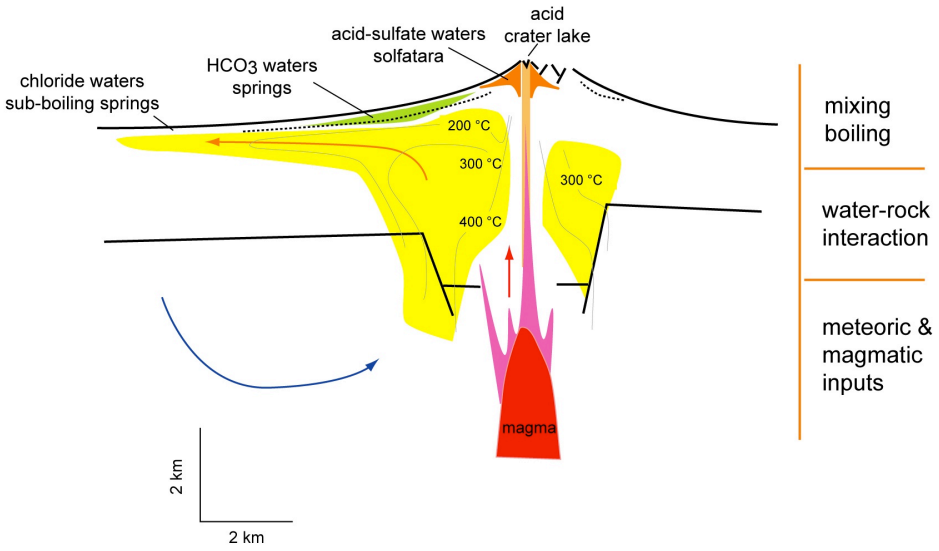
CO_2-rich waters

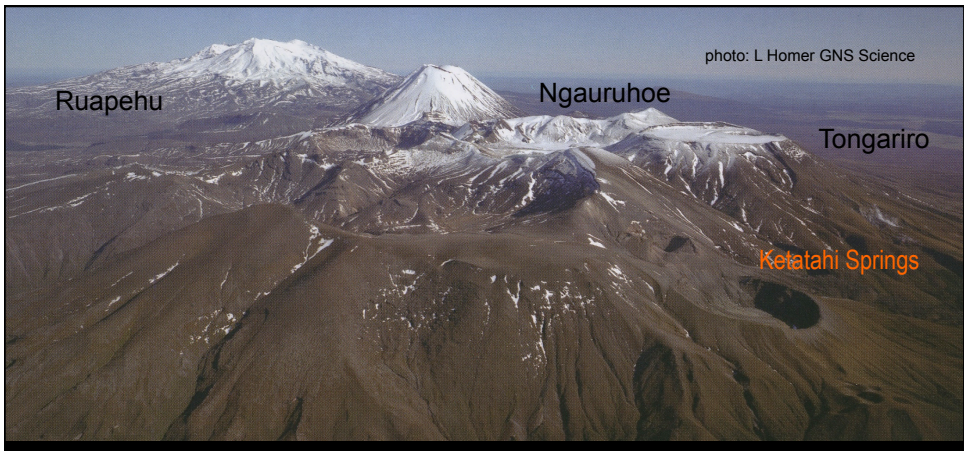
Br-6


north
Ohaaki
south
depth
BPD
12
3
18
33
11
2
31
34
6
39
40
150°
200°
250°
300°
1000m
2000m
175°C
HF
OR
100°C
150°C
200°C
250°C
275°C
W
RB
BR
dilution
felsic
volcanics
?
greywacke
basement
Steam-heated waters

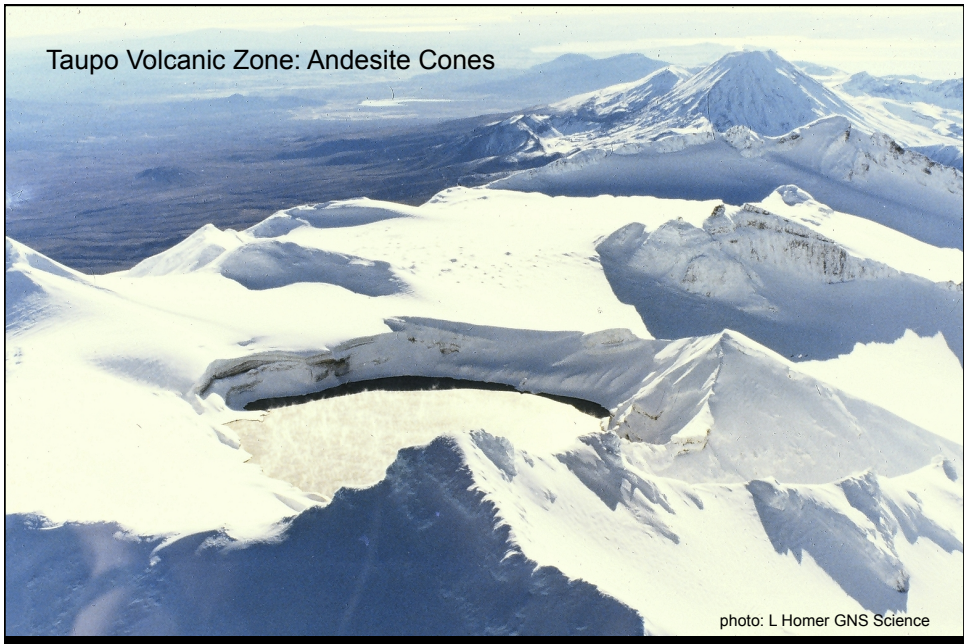

White Island
hydrothermal system
andesite cone
rhyolite caldera
Tongariro
Ruapehu
N
W
E
0 10 20 40 60 80
Kilometers
Central TVZ-Flat Terrain
Precious metal deposits
Kawerau
Waiotapu
Broadlands-Ohaaki
Rotokawa

High temperature system in steep terrain

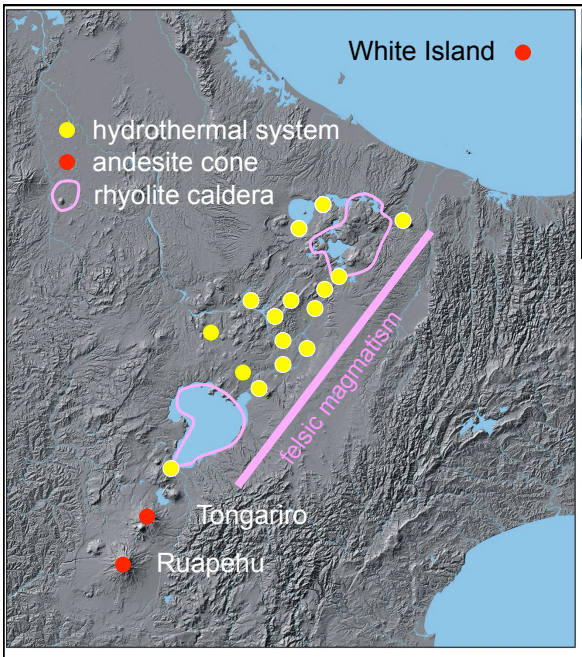




Andesite cones at Tongariro National Park, with fumaroles-hot springs on upper flank.



Ruapehu volcano and summit crater lake filled wth acid water, 2700 m elevation.

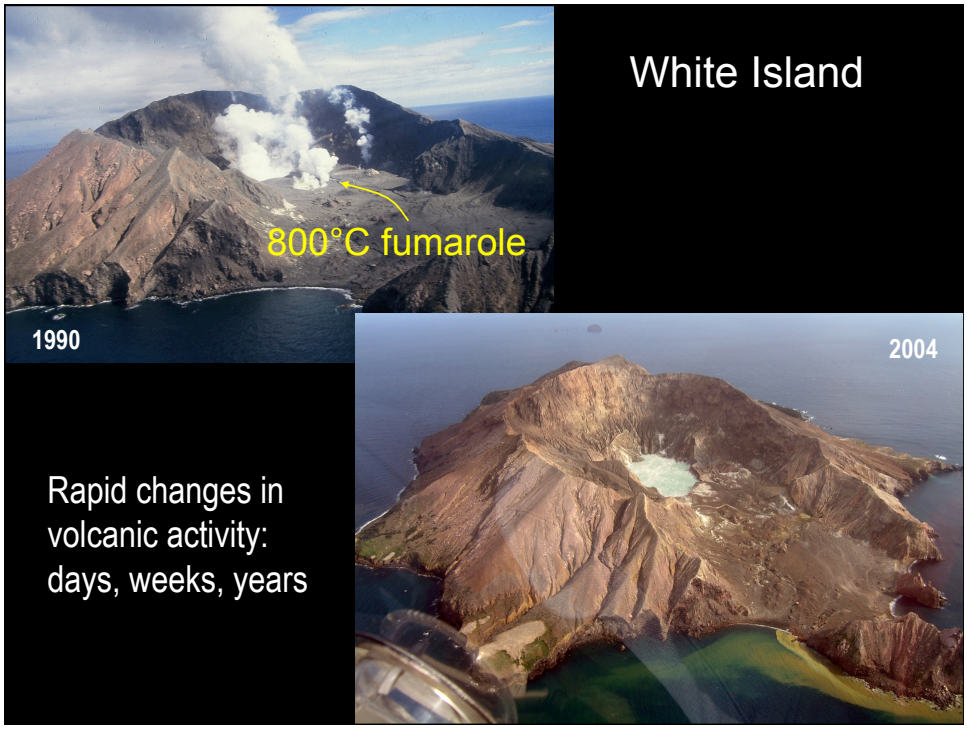


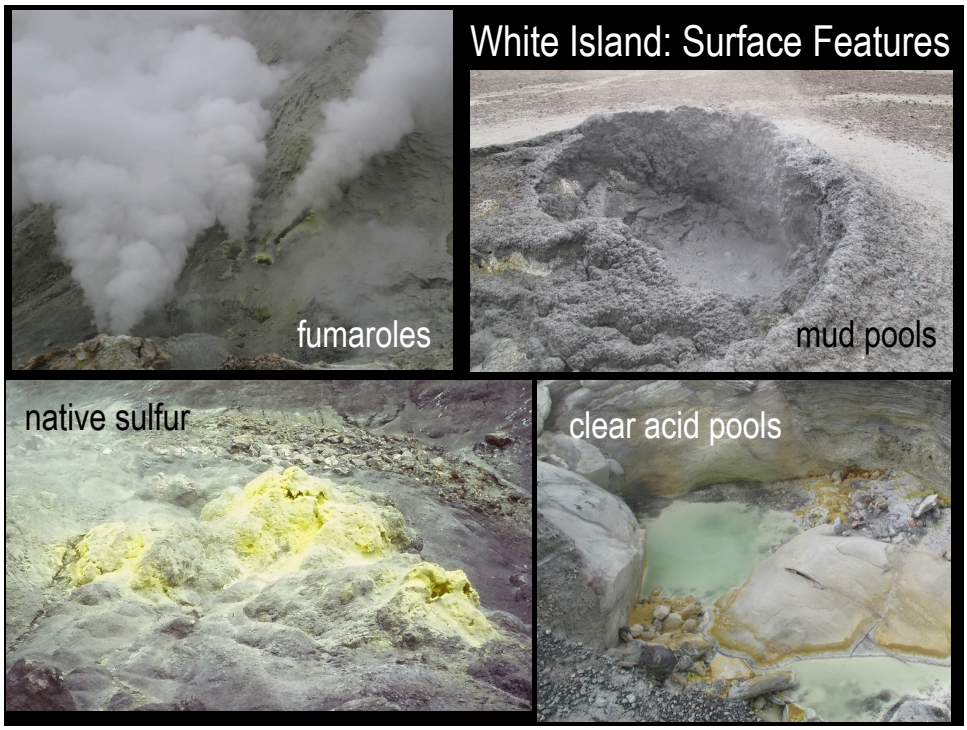
Southern & Northern TVZ

Steep terrain-volcanic cones

predominantly andesitic magmatism

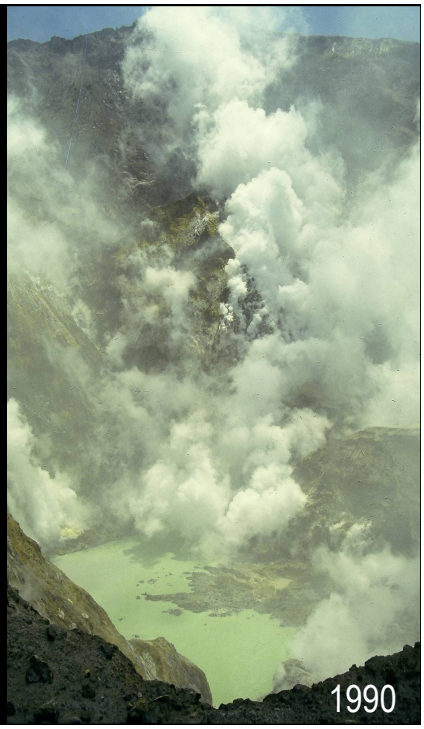
White Island-unique ocean island setting

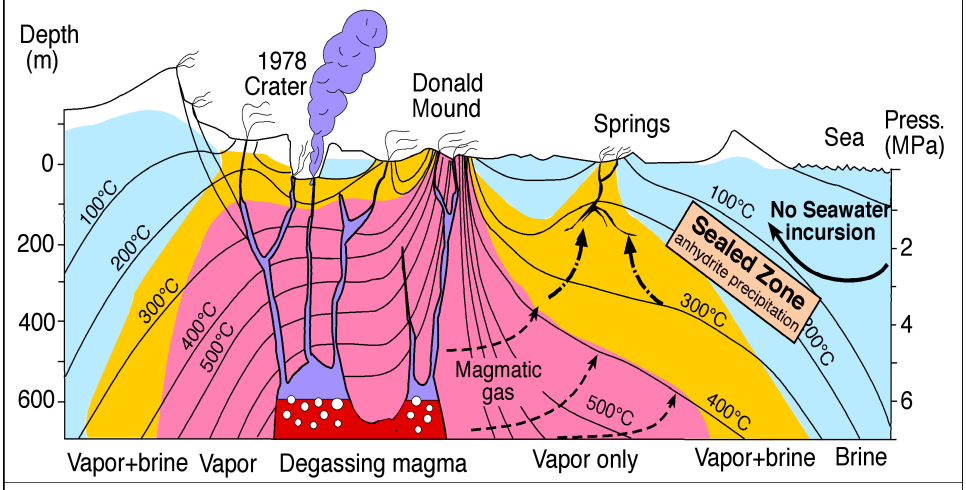

White Island
800°C fumarole
1990
2004
Rapid changes in volcanic activity: days, weeks, years


White Island: Surface Features
fumaroles
mud pools
native sulfur
clear acid pools

Acid sulphate chloride water

T°C	79
pH	1.4
Na	5910 ppm
K	635 ppm
Cl	38700 ppm
SO4	4870 ppm
HCO3	0 ppm





Giggenbach et al. 1989