

14TH AUSTRALIA & NEW ZEALAND YGP CONFERENCE

Field Trip Guide

5 November, 2022

Bradley Scott

GNS Science, Wairakei Research Centre, Taupo

INTRODUCTION

The purposes of this excursion are to illustrate:

- The complexity of the interactions between tectonic and volcanic processes in the northern Taupo Volcanic Zone (TVZ),
- The association of geothermal surface features to Rotorua Caldera,
- The large volumes of extruded lava in the Okataina Volcanic Centre, diversity of eruption sizes and styles,
- The extent of extensional faulting south of the Okataina Volcanic Centre,
- The development of the geothermal resources,
- The dependence of our awareness of volcanic hazards on the information available in the geological record

These notes are intended to be a brief guide to the localities of geological interest that are visited during this field trip to the Rotorua area. The notes are not all-encompassing, but I have referenced some topics as a starting point for further reading that you might like to pursue. The field trip will visit localities associated with the Rotorua and Okataina Volcanic Centres. It will not pass through the Taupo Fault Belt south of Rotorua, but notes are included. The bias of the trip is to the broad geomorphic structures in this area – at best a small snapshot of this interesting area.

FIELD TRIP ITINERARY

This field trip is focused on caldera volcanism (explosive and effusive) in the northern TVZ that has occurred in the last 450 kyr. During this time period there have been several large caldera forming events especially in the 350 to 280 ka period and intra caldera eruptions the last ~60 kyr (the Modern TVZ of Wilson et al., 1995).

Leave 8.30 am.

- 1) Rotorua Caldera over view (Tihiotonga reserve).
- 2) Kuirau Park geothermal features.
- 3) Blue Lake caldera boundary, moat lake.
- 4) Lunch stop, Stony Bay Lake Tarawera
- 5) Mt Tarawera 1886 overview.
- 6) *Return to Rotorua.*

BACKGROUND

The Bay of Plenty – Waikato regions are highly vulnerable to volcanic activity, due to their locations within the Taupo Volcanic Zone (TVZ), the focus of intense volcanic activity that extends from White Island in the north to Tongariro National Park in the south. Volcanic activity within the TVZ is characterised by an enormous range of eruption magnitudes, as indicated by the volumes of erupted material. The larger events have ejected 200-700 km³ of pyroclastic material, whilst the smallest produced less than 0.001 km³ (Houghton et.al 1995, Wilson et. al 1984) The duration of eruptive episodes is also highly variable, ranging from a few hours to months, through to sustained intermittent activity for several centuries.

Two dominant types of volcano are present in the TVZ; cones like Ruapehu, White Island and Ngauruhoe, which erupt small volumes on a geologically regular basis (5-20years); and the major caldera volcanoes which erupt significantly less frequently (1000-5000 years) but their eruptions, would be regionally catastrophic.

A lesser known source of volcano hazard is ‘Caldera Unrest’. This is where a volcano shows signs of unrest, but these may not lead to an eruption. The unrest creates uncertainty and brings about costs. Episodes of heightened caldera unrest have occurred frequently across the globe, including in New Zealand. Unrest in the form of seismicity, deformation and hydrothermal activity can be indicative volcanic phenomena. This style of unrest is commonly recorded at calderas; however, there is uncertainty over when the activity increases from “background” levels to “volcanic unrest” and an eruption threat.

GEOHERMAL ACTIVITY

There are approximately 20 known geothermal systems, over half have been explored by drilling down to a maximum depth of ~ 3500 m (Figure1). In the central TVZ, hydrothermal systems are regularly spaced (10 to 20 km apart) and separated by zones of recharge. The main control on their distribution is uncertain though a few systems are clearly related to either major fault structures e.g. Orakeikorako, Te Kopia, Waikite or caldera boundaries e.g. Waimangu, Waiotapu (Wood, 1995). Most modern hydrothermal systems have been active for at least 10,000 years and possibly more than 300,000 years. The total estimated heat flow, due to hydrothermal convection, ranges between 2000 and 4000 MW, within an order of magnitude of that contributed by volcanism (last 200,000 years), 500 to 1000 MW.



Figure 1. Distribution of active geothermal systems in the TVZ.

Rotorua Caldera

The Rotorua Caldera in its present form dates back about 240 000 years to the major ignimbrite eruptions that formed the Mamaku plateau. A large volume of magma rose under Rotorua to occupy shallow magma chambers. Following the large scale 'Mamaku eruptions' the roof of the magma chamber was weakened and collapsed to form the Rotorua basin (caldera) as we know it today (Figures. 2, 3, 4 and 5). There were also similar large eruptions to the south centred on the Artiamuri area, generating a complex eruption sequence between the two areas.



Figure 2. A view from the Tihī o Tonga stop, showing the caldera basin.



Figure 3. Aerial view of Rotorua Caldera from the north (DB Townsend).

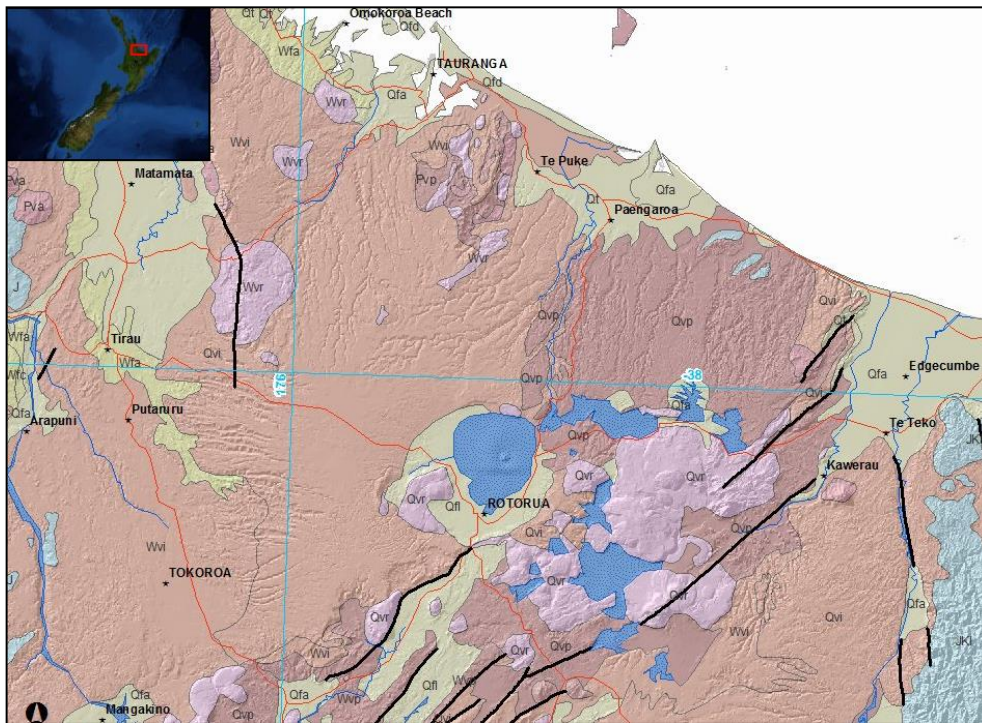


Figure 4 Simplified regional geology, Rotorua District (QMap).

Post formation of the caldera basin lava domes have grown within the caldera, like Mt Ngongotaha, Mokoia Island (Figures 4 and 5). Lava dome growth had stopped by about 80 – 50 000 years ago.

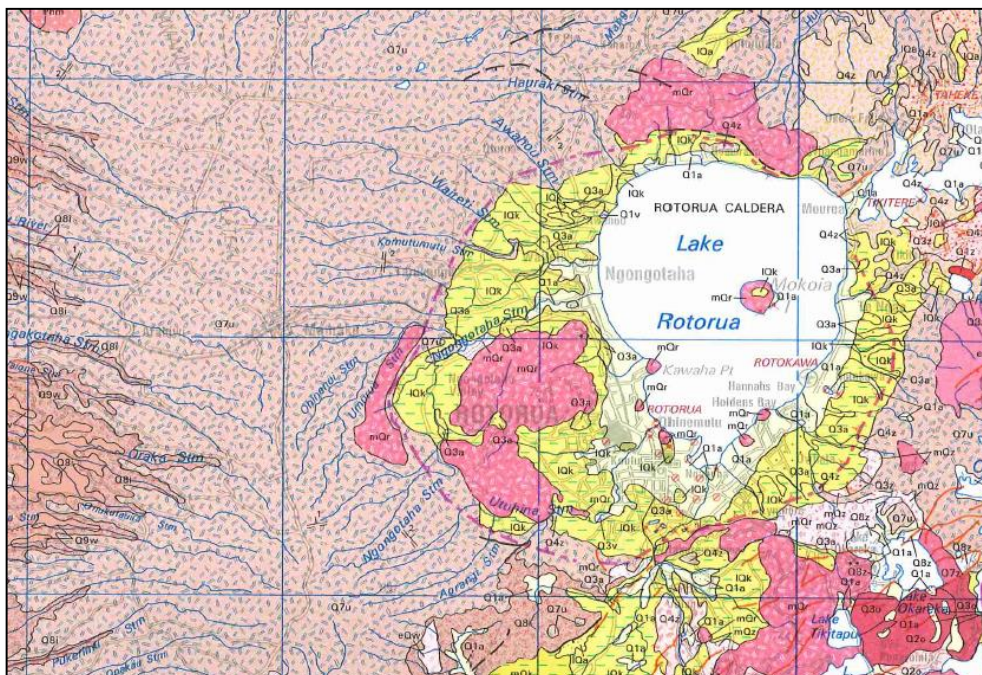


Figure 5. Simplified geology of the Rotorua Caldera (QMap).

Discharge energy High ↑ ↓ Low	1. Geysers	4. Intermittent or active hydrothermal eruption craters	7. Mud geysers	10. Fumaroles
	2. Flowing springs	5. Mixed springs	8. Ejecting mud pots	11. Steaming ground
	3. Non flowing pools	6. Mixed pools	9. Mud pools	12. Heated ground
<i>Primary geothermal fluid</i>		<i>Mixed/diluted geothermal fluid</i>		<i>Steam Fed</i>
Geothermally-influenced aquatic habitat				
Geothermal habitat on heated/acid dry ground				
Habitat dependent on geothermally-altered atmosphere overlays all types (warm air, frost-free)				

Figure 7. A schematic representation of surface geothermal features (BOPRC 2014, after Scott 2012). Note the inclusion also of three broad categories of habitat (atmosphere, aquatic and heated ground).

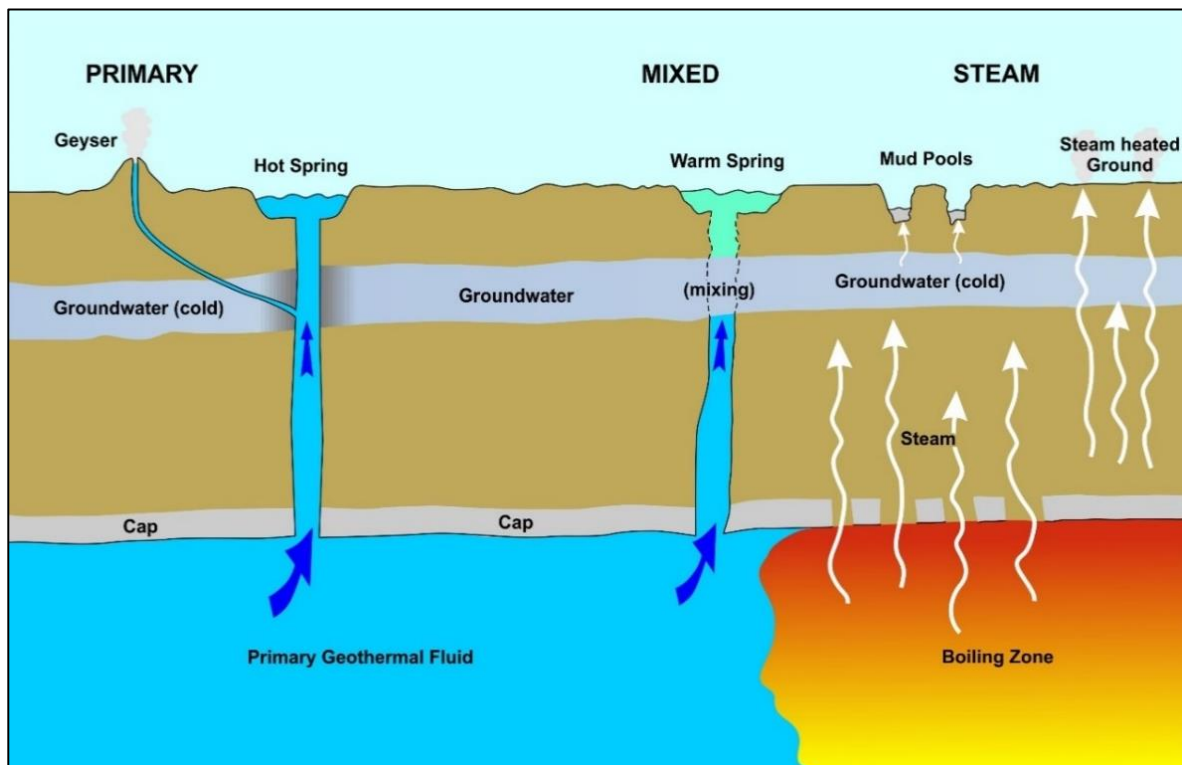


Figure 8. Schematic relationship between the various types of geothermal surface features and process's that support them.



Figure 9. Impacts of a small scale hydrothermal eruption in Rotorua City.

Okataina Volcanic Centre

Okataina Volcanic Centre (OVC) is located east of Rotorua city and south-west of Kawerau (Figures 10, 11). OVC consists of a series of vents along two lineations, magma has erupted from multiple vents along both lineation's (Nairn, 1989, 2002). OVC has undergone some very large and explosive eruptions, which have caused pyroclastic flows and deposited large amounts of ash and pumice over the Bay of Plenty. Historically, in 1886 Mount Tarawera underwent a short but explosive basalt eruption (Figures 16, 17), depositing scoria and mud across the Bay of Plenty and blocking the outlet to Lake Tarawera, which subsequently caused a dam-break flood that flowed through the Kawerau area in November 1904 (Nairn 1979, 1986 2002; Nairn et. al 2001, 2003; Leonard et. al 2002).

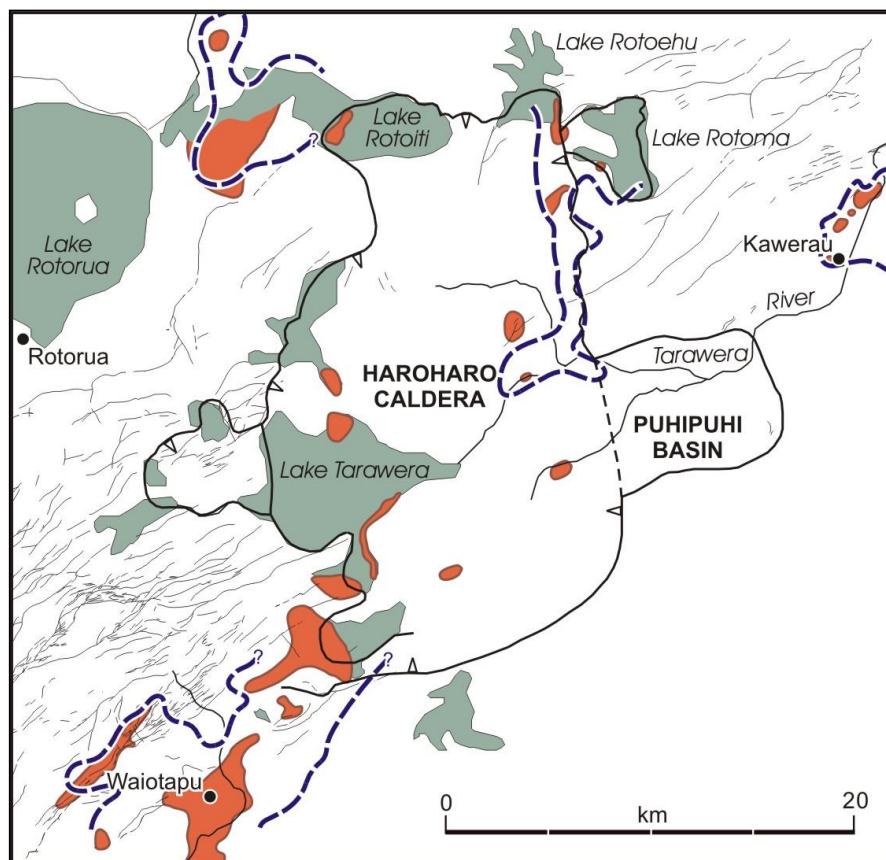


Figure 10. Simplified structure map of the Okataina Volcanic Centre, showing the caldera boundary (black), major faults (grey) and geothermal systems (orange). After Nairn 2002.

The topography and lakes of the Rotorua District are controlled by the activity from the Okataina Volcanic Centre (Figure 10, 11). Many of the lakes are trapped as moats around the caldera edges (Rotoiti, Tarawera, Okataina, Blue and Green Lakes) while others are part of eruption sources/craters (Rotoma, Okareka) and others form behind lava flows which have dammed valleys (Rotoehu, Green Lake).

The Okataina Volcanic Centre has erupted about 80 km³ of lava and pumice in the last 22,000 years (Table 1; Figure 11). A very active volcano system.

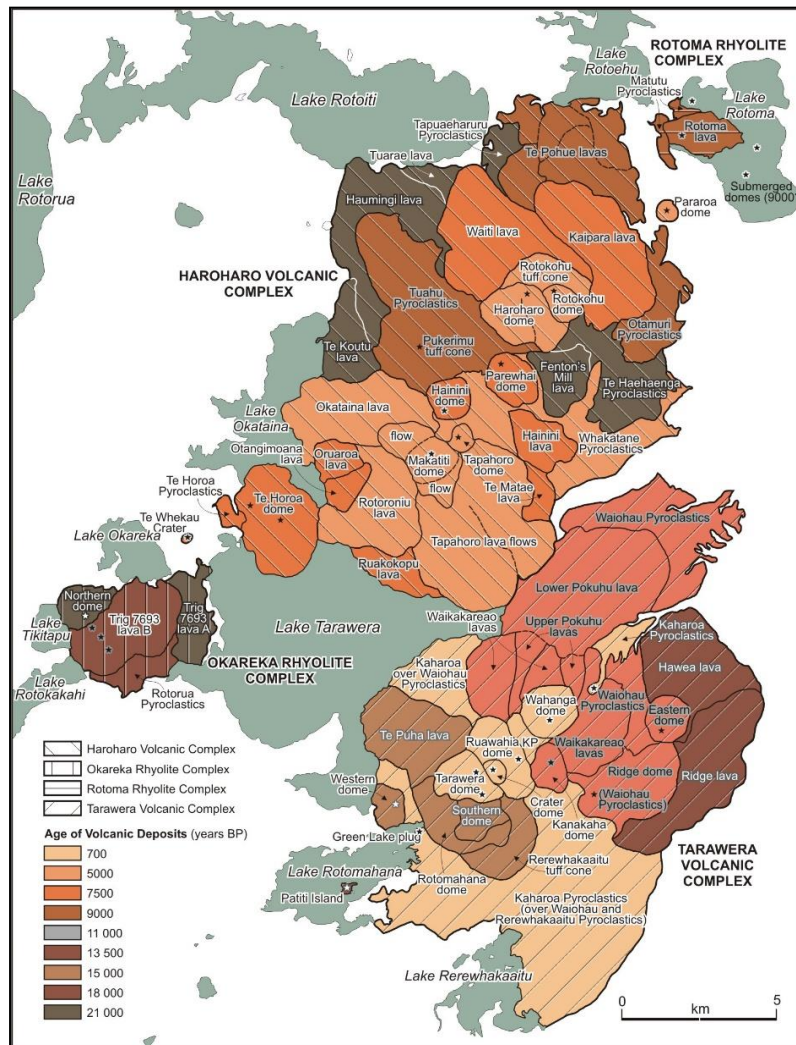


Figure 11. Simplified geological map of the Okataina Volcanic Centre, showing the ages of the major lava domes (after Nairn 2002).

Table 1. Sequence of OVC eruptions and volumes (after Nairn 2002).

Eruptive Episode	Age (ka)	Lava Volume km ³	Pumice Volume km ³
Tarawera	1886 AD	-	2
Kaharoa	0.7	2.5	5
Rotokawawau	3.4	-	0.7
Whakatane	5	9	10
Mamaku	7.5	15	6
Rotoma	9	2	13
Waiohau	11	4	15
Rotorua	13.5	1	7
Rerewhakaaitu	15	2	6
Okareka	18	5	6
Te Rere	21	10	5

Earthquake Flat volcano

On the south western boundary of the Okataina Volcanic Centre lies Earthquake Flat volcano (Figure 12). About 50 km³ of unwelded ignimbrite was erupted from here about 60,000 years ago. This is a typical example of an explosive rhyolite volcano, low angle cone, shallow summit crater.



Figure 12. Aerial view of Earthquake Flat Volcano, looking north northwest towards Rotorua.

FAULTING

The Taupo Volcanic Zone is an area of crustal extension. It is characterised by numerous normal faults (Villamor et. al 2001, 2011). These are best seen in the Ngakuru and Waikite Valleys and north east of Earthquake Flat (Figures 13, 14 and 15). Spreading of the TVZ is happening at about 7-9 mm/yr and subsidence is at about the same rate. The largest Fault structures are the Paeroa, Ngapouri, Tumunui, Whirinaki and Horohoro.

None of these fault structures can be traced into the Okataina Volcanic Centre or directly align with the vents within the caldera. However we do see faulting associated with the eruptive episodes (Figure 14, 15).

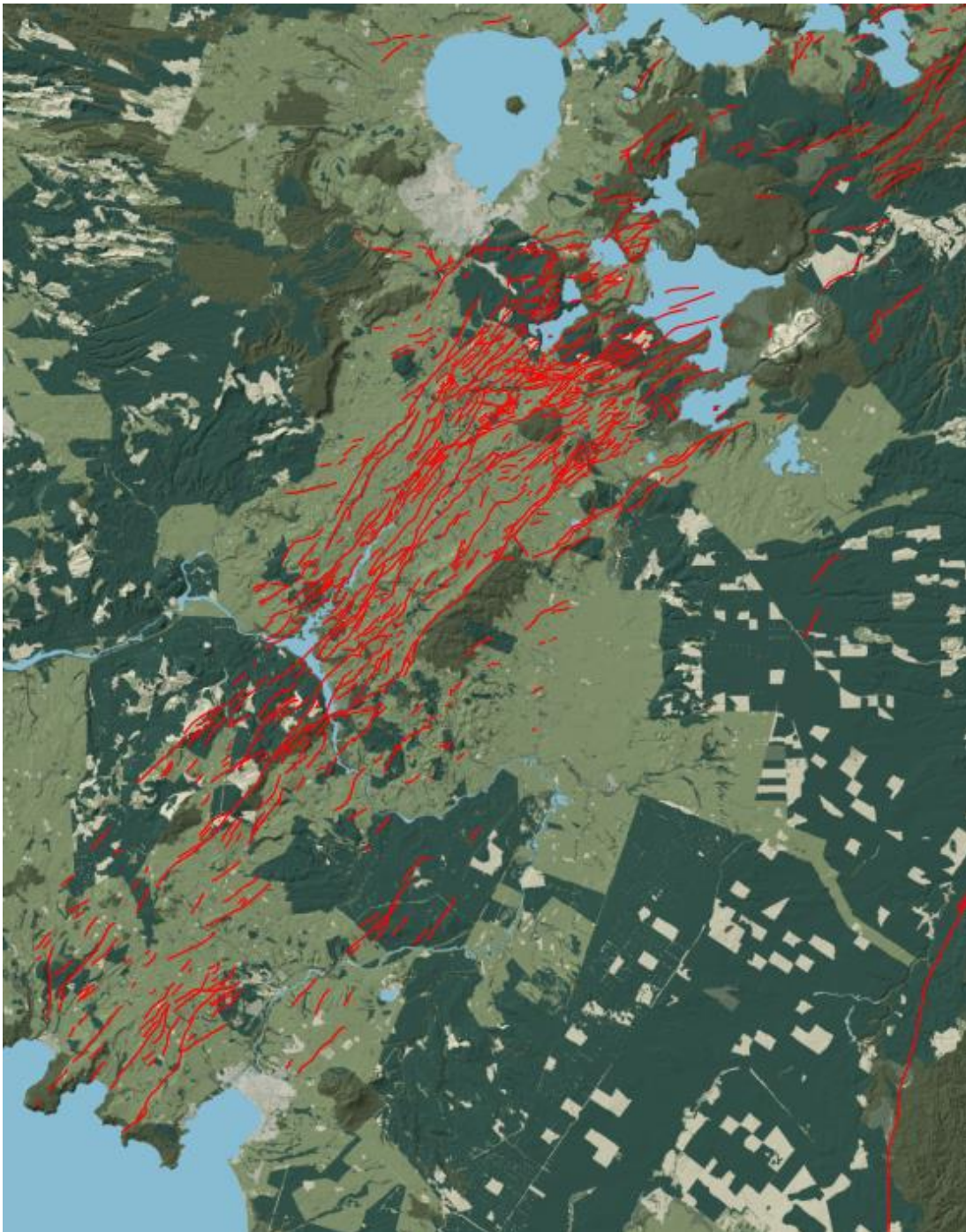


Figure 13. Map showing the faulting in the Rotorua-Taupo area. After NZ Active Faults database.

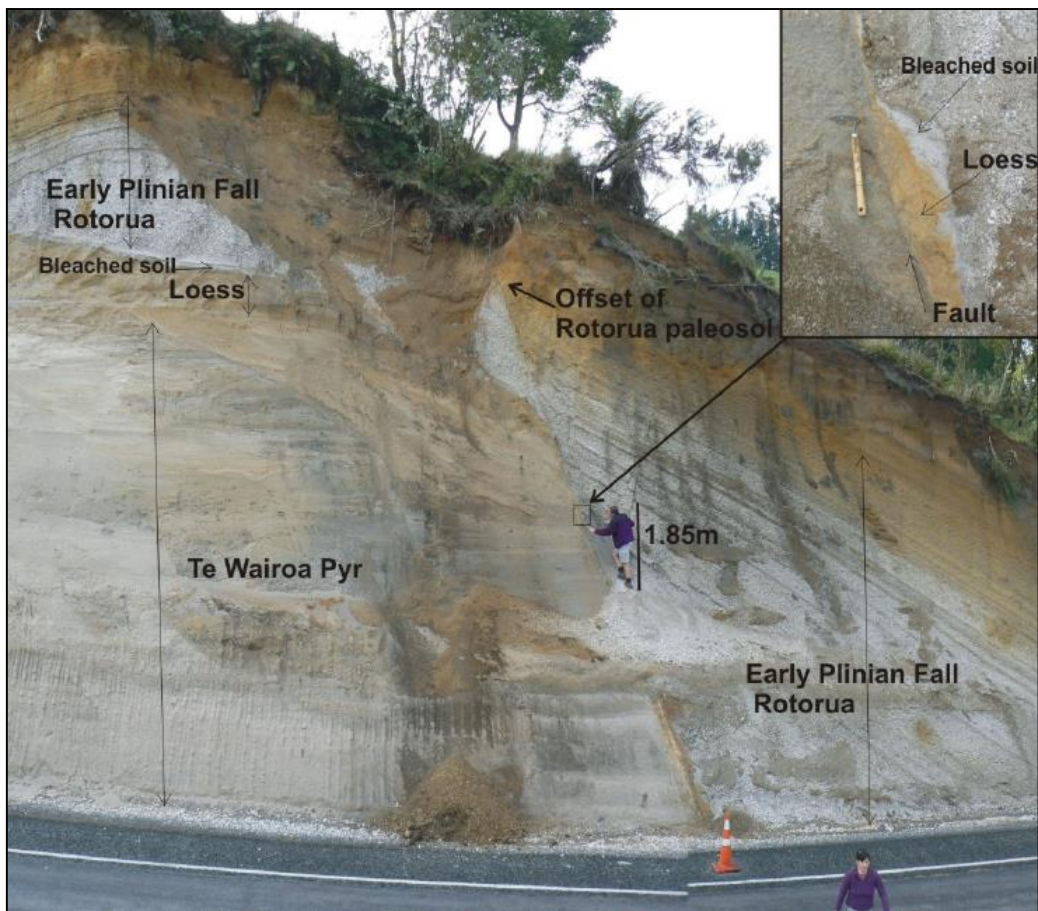


Figure 14. Exposure of the Opawhero Fault on Tarawera Road, showing the large displacement (~6m) of the Rotorua ash (13.5 ka).



Figure 15. Active fault scarp on Waimangu Loop Road (Earthquake Flat).

Tarawera-Waimangu-Rotomahana

The Okataina Volcanic Centre is the most recently active one in the TVZ with pyroclastic and dome building events occurring about 650 years ago within the Tarawera complex (Nairn et al., 2003, Leonard et. al 2002). However, the youngest event was the 1886 basaltic eruption from a south-west trending line of vents, extending from the summit of Mt. Tarawera to the Waimangu Valley (Nairn 1979, 2002).

The Waimangu-Rotomahana hydrothermal system is located along the southern margin of the Okataina Volcanic Centre (Figures 16, 17).

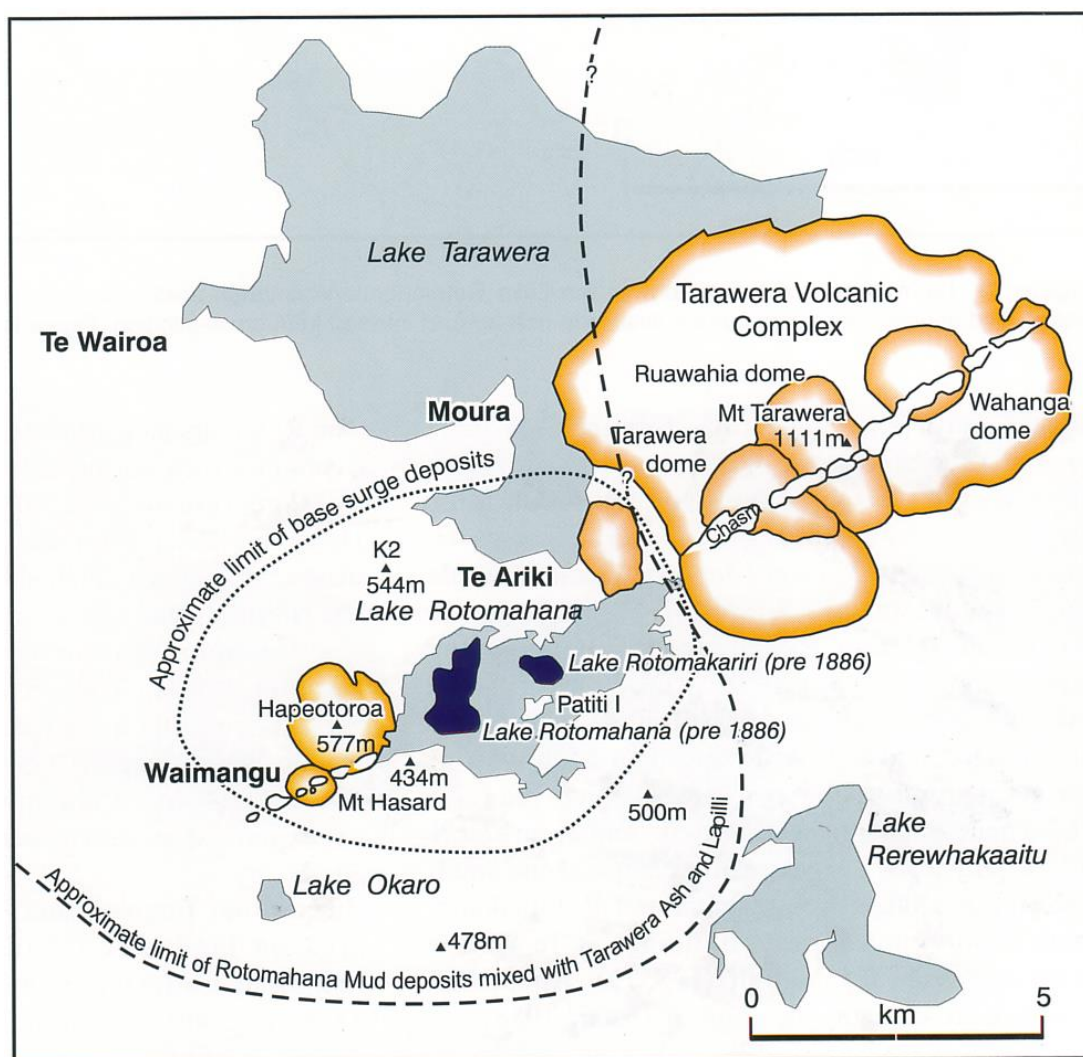


Figure 16. Map of the Tarawera-Rotomahana-Waimangu area showing the 1886 rift, Tarawera domes, limits of surge and airfall deposits and sites of pre and post eruption lakes (after Nairn, 2002).



Figure 17. View along the Tarawera vent lineation from Waimangu, across Lake Rotomahana, to Tarawera and Mt Edgecumbe. Photo D.L. Homer.

Volcanic Hazards

Hazard maps (Figure 18) and scenarios have been developed for Okataina Volcanic Centre (Johnston and Nairn, 1993; Scott and Nairn, 1998) and it is noted that a number of smaller settlements are located within destructive volcanic hazard areas (e.g. Lake Okareka, Lake Tarawera). Hazards expected from OVC include ash fall, pyroclastic flows, lava flows,

hydrothermal eruptions, volcanic gases, lahars and floods and volcanic earthquakes. The types of hazards expected at OVC are often compared with those experienced during and after the 1991 Pinatubo eruption in the Philippines.

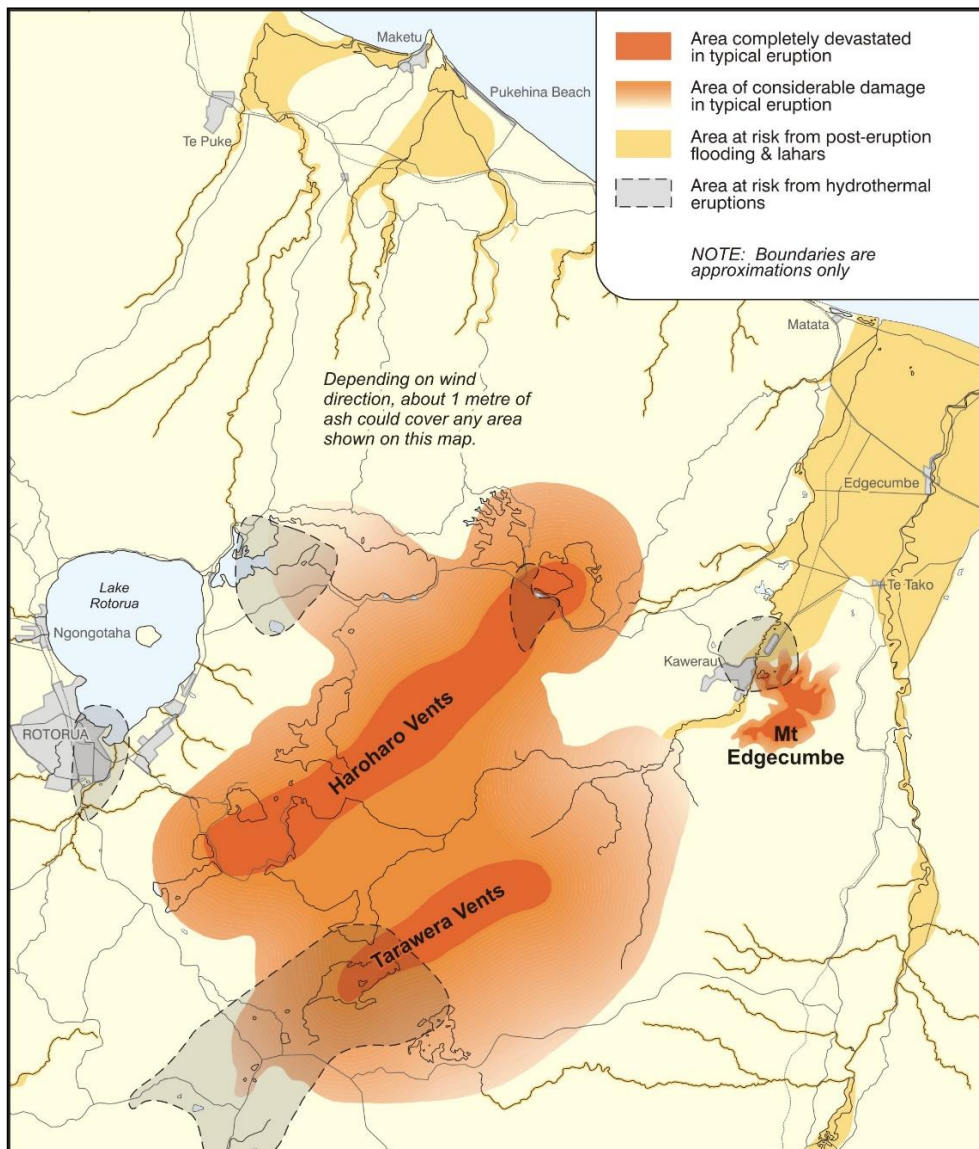


Figure 18. Volcanic hazard map of the Okataina Volcanic Centre (in Nairn, 2002 and adapted from Scott and Nairn, 1998).

References

Brooker, M.R.; Houghton, B.F.; Wilson, C.J.N.; Gamble, J.A. 1993. Pyroclastic phases of a rhyolitic dome-building eruption: Puketarata tuff ring, Taupo Volcanic Zone, New Zealand. *Bulletin of Volcanology*, 55(6): 395-406

Chambefort I, Lewis B, Wilson C.J.N, Rae A, Coutts C, Bignall G, Ireland T, 2014. Stratigraphic and structure of the Ngatamariki geothermal system from New zircon U-Pb geochronology: Implications for Taupo Volcanic Zone evolution. *Journal of Volcanic and Geothermal Research*. 274:51-70.

- Houghton, B.F., Wilson, C.J.N., McWilliams, M., Lanphere, M.A., Weaver, S.D., Briggs, R.M. and Pringle, M.S., 1995. Chronology and dynamics of a large silicic magmatic system: Central Taupo Volcanic Zone, New Zealand: *Geology*, v. 23: 13-16.
- Johnston, D.M.; Nairn, I.A. 1993. Volcanic impacts report: the impact of two eruption scenarios from the Okataina Volcanic Centre on the population and infrastructure of the Bay of Plenty, New Zealand. Whakatane: Environment BOP. Resource planning publication / Bay of Plenty Regional Council 93/6. vi, 153 p.
- Leonard, G.S., Cole, J.W., Nairn, I.A. and Self, S., 2002. Basalt triggering of the c. AD 1305 Kaharoa rhyolite eruption, Tarawera Volcanic Complex, New Zealand. *Jour. Volc. & Geothermal Research* 115: 461-486.
- Nairn, I.A., 1979. Rotomahana-Waimangu eruption, 1886: base surge and basalt magma: *NZ Jour. Geology and Geophysics*, v. 22: 363-378.
- Nairn, I.A., 1986. Volcanism in the Taupo Volcanic Zone: Part 2. Okataina Volcanic Centre: in *Guide to the Active Epithermal Systems and Precious Metal Deposits of New Zealand* (eds R.W. Henley, J.W. Hedenquist, P.J. Roberts) Monograph Series Mineral Deposits, Gebruder Borntraeger, Berlin, n. 26: 29-36.
- Nairn, I.A., 1989. Mt Tarawera: Geological Map of New Zealand, 1:50 000, Sheet V16 AC.
- Nairn, I.A., 2002. Geology of the Okataina Volcanic Centre, 1:50 000. Institute of Geological and Nuclear Sciences Geological Map 25.
- Nairn, I.A., Self, S., Cole, J.W., Leonard, G.S. and Scutter, C., 2001. Distribution, stratigraphy and history of proximal deposits from the c. AD 1305 Kaharoa eruptive episode at Tarawera Volcano, New Zealand. *NZ Jour. Geol. & Geophys.* V44: 467-484.
- Nairn, I.A., Shane, P.R., Cole, J.W., Leonard, C.J., Self, S., Pearson, N., 2003. Rhyolite magma processes of the ~AD 1315 Kaharoa eruption episode, Tarawera volcano. *JVGR* 2732: 1-30.
- Scott, B.J.; Cody, A.D. 2000. Response of the Rotorua geothermal system to exploitation and varying management regimes. *Geothermics*, 29(4/5): 573-592
- Scott, B.J.; Nairn, I.A. 1998. Volcanic hazards: Okataina volcanic centre. Scale 1:100,000. [Whakatane]: Bay of Plenty Regional Council. Resource planning publication / Bay of Plenty Regional Council 97/4. 1 map
- Villamor, P.; Berryman, K.R. 2001 A Late Quaternary extension rate in the Taupo Volcanic Zone, New Zealand, derived from fault slip data. *New Zealand Journal of Geology and Geophysics*, 44(2): 243-269.
- Villamor, P.; Berryman, K.R.; Nairn, I.A.; Wilson, K.J.; Litchfield, N.J.; Ries, W. 2011 Associations between volcanic eruptions from Okataina Volcanic Center and surface rupture of nearby active faults, Taupo rift, New Zealand: insights into the nature of volcano-tectonic interactions. *Geological Society of America Bulletin*, 123(7/8): 1383-1405.
- Wilson, C.J.N., Rogan, A.M., Smith, I.E.M., Northey, D.J., Nairn, I.A., Houghton, B.F., 1984. Caldera volcanoes of the Taupo Volcanic Zone, New Zealand: *Jour. Geophys. Res.*, v. 89 B10: 8463-8484.
- Wilson, C.J.N., Houghton, B.F., McWilliams, M.O., Lanphere, M.A., Weaver, S.D. and Briggs, R.M., 1995. Volcanic and structural evolution of Taupo Volcanic Zone, New Zealand: A review. *Jour. Volc. Geothermal Res.*, v. 68: 1-28.
- Wood, C.P., 1995. Calderas and geothermal systems in the Taupo Volcanic Zone, New Zealand. In *proceedings of the World Geothermal Co*