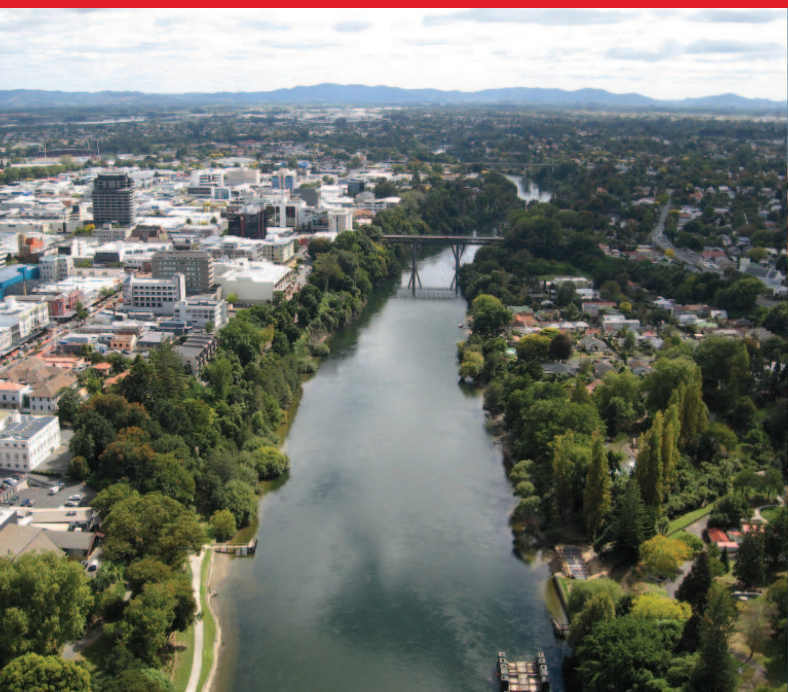
GEOSCIENCES 2012
Hamilton November 25-28

Geoscience Society of New Zealand 2012 Conference

FIELD TRIP GUIDES



HAMILTON 25 - 28 November 2012

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GEOSCIENCES 2012
Hamilton November 25-28

Annual Conference of the Geoscience Society of New Zealand

Field Trip Guides

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Field Trip Leaders
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Photographs on front cover: Maria Lowe (top), Wendy Peel (bottom left)

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Geosciences 2012

Annual Conference of the Geoscience Society of New Zealand, Hamilton

Field Trip 6

Thursday 29 November

Geothermal Exploration and Development

Leaders: Andrew Rae and Greg Bignall

GNS Science

Wairakei

Bibliographic reference:

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HEALTH AND SAFETY

PLEASE READ

Certain hazards will be encountered on this field trip. At all times, participants are to heed and observe the warnings of the field trip leaders, and for the appropriate parts of the trip, staff from MRP Ltd. and Contact Energy.

Participants should carry their own sunscreen and any personal medications for allergic reactions (insect stings, pollen, etc.). Participants need to be prepared for cold, wet, warm and sunny conditions. A sunhat, sunscreen and a waterproof and windproof jacket are recommended, along with sturdy and enclosed footwear. For access to the Ngatamariki drill site clothing that covers the legs and arms is recommended (i.e., trousers and a long-sleeve shirt).

An average level of fitness and mobility is required for this trip. During the Waiotapu walkabout participants are required to stay on the designated pathways. Due to unstable ground, noxious gases and steam drifts, caution should be exercised when examining rocks or taking photographs close to geothermal surface features.

Route and Itinerary

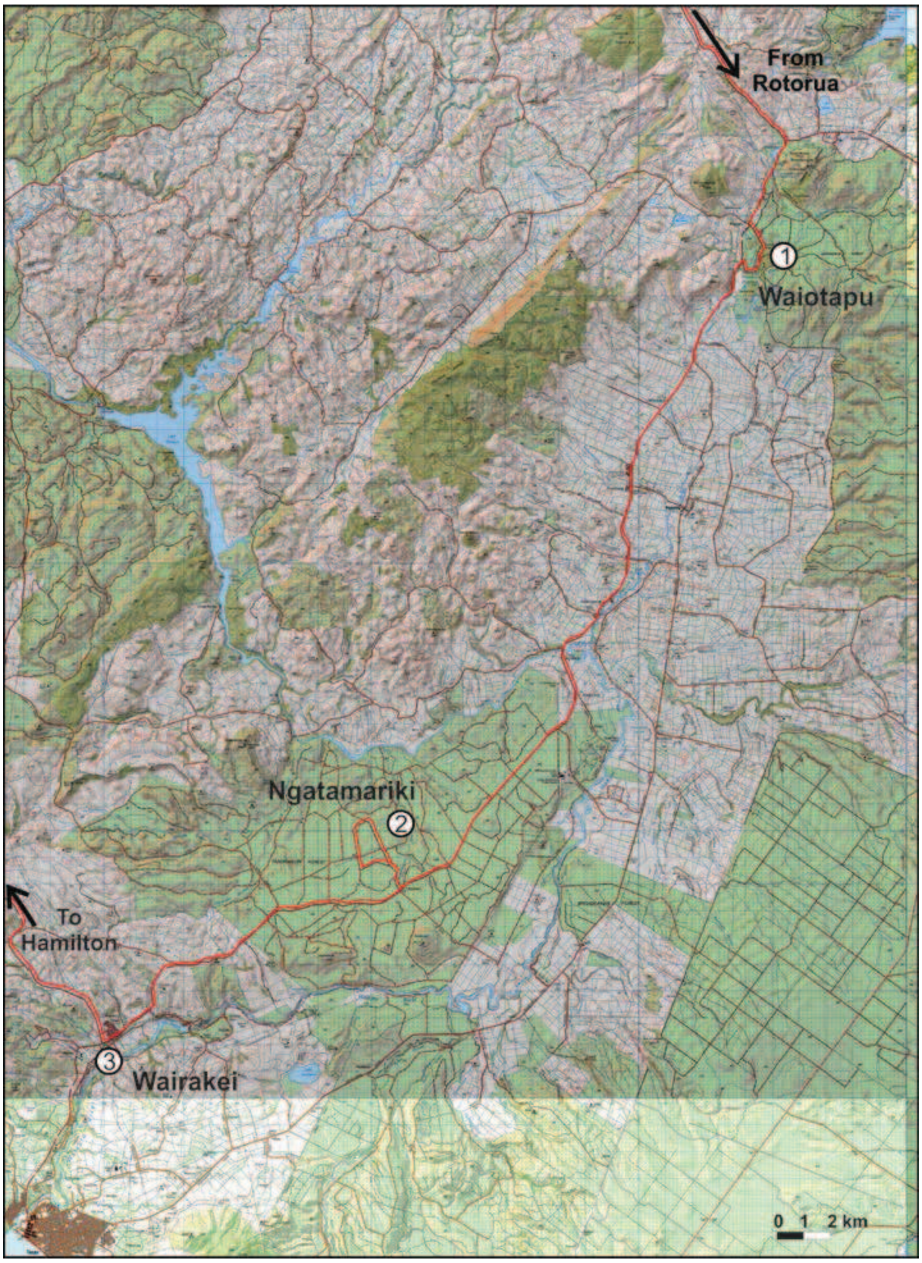

Figure 1. Route map.

Depart Hamilton 0800 hrs, via Rotorua, SH5

Stop	Place	Drive (hr)	Stop (hr)	Toilet	Elapsed (hr)
1	Waiotapu (lunch)	2.0	3.0	T	5.0
2	Ngatamariki	0.3	1.5		6.8
3	Wairakei	0.2	1.0		8.0

Return to Hamilton, via Tokoroa, SH1 by 1800 hrs	2.0		10.0

Introduction

Taupo Volcanic Zone Geothermal Systems

Using electrical resistivity methods (Stagpoole and Bibby, 1998) more than twenty geothermal systems have been recognised within the rhyolite-dominated region of the Taupo Volcanic Zone (TVZ) (Bibby et al., 1995) between the Okataina and Taupo eruption centres (Figure 2). The mean spacing and extent of the geothermal systems is 10-15 km and 20 km^2, respectively. Hydrothermal circulation is driven by density contrasts between heated water in the geothermal reservoir and the colder surrounding water. Meteoric recharge is provided from waters downflowing to more than 5 km depth. Geothermal fluids are predominantly meteoric, with a 6-14% magmatic contribution (Giggenbach, 1995).

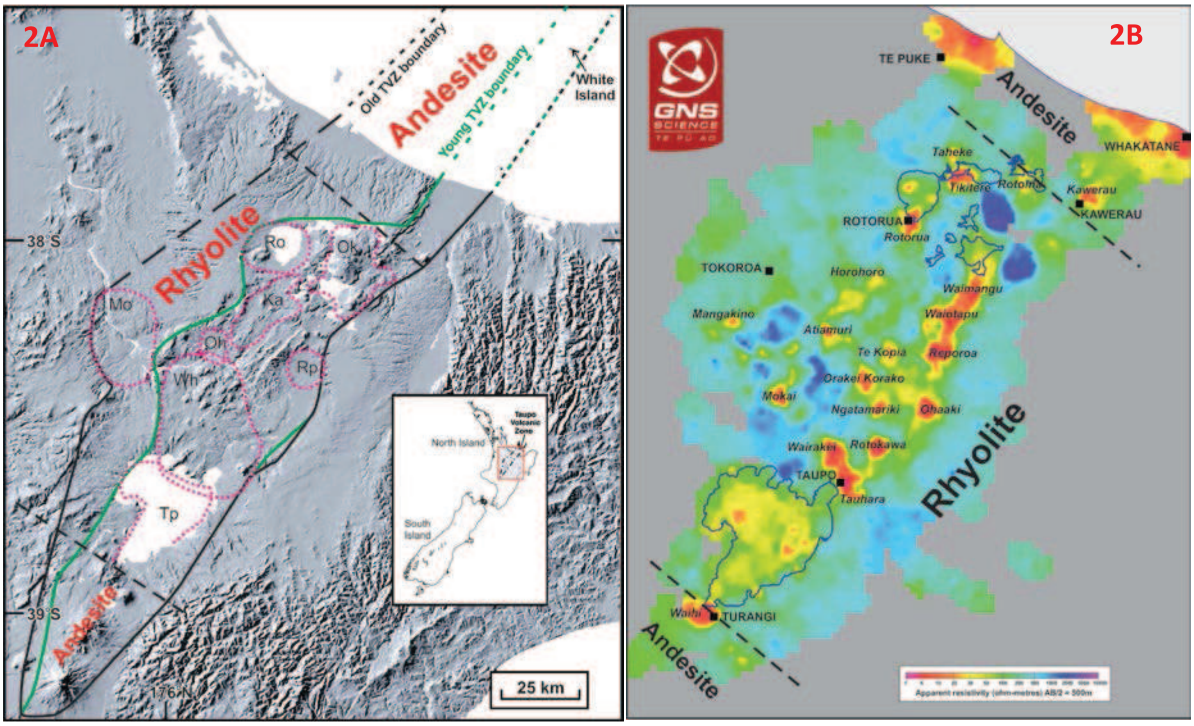

Figure 2A. Taupo Volcanic Zone (boundaries from Wilson et al., 1995) with the central rhyolite-dominated region bounded by northern and southern andesite-dominated regions (Houghton et al., 1995). Rhyolite calderas (after Cole and Spinks, 2009) labelled as follows: Mo = Mangakino; Ka = Kapenga; Wh = Whakamaru; Ro = Rotorua; Oh = Ohakuri; Rp = Reporoa; Ok = Okataina; Tp = Taupo. **Figure 2B.** Electrical resistivity of the Taupo Volcanic Zone (nominal array spacing = 500 m; Stagpoole and Bibby, 1998).

Geothermal Surface Features

Geothermal surface waters can be classified based on their dominant anion species: chloride (Cl^-), sulphate (SO_4^-) or bicarbonate (HCO_3^-) (Figure 3).

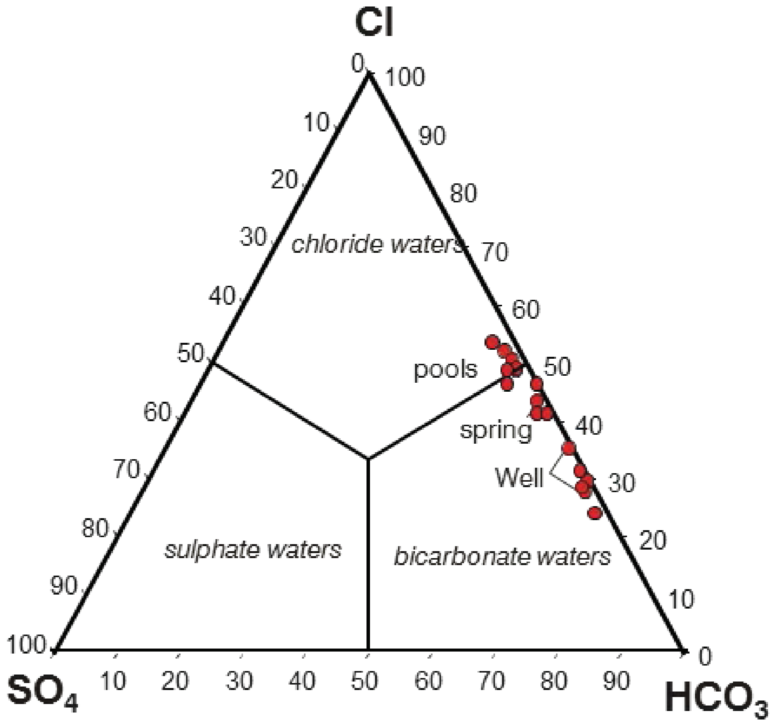

Figure 3. A Cl, SO_4 and HCO_3 ternary plot used to classify geothermal waters into chloride, sulphate and bicarbonate water types.

Chloride waters are the dominant fluid type in most TVZ geothermal systems, with chloride (Cl) the principal anion, usually 1000 – 10000 mg/kg (ppm) or 0.1 – 1.0 wt.% (seawater is typically 1.9 wt% Cl). These waters are typically the least modified of the deep reservoir fluids and as such are the most useful for providing insights into the deep geothermal reservoir conditions. They have near neutral pH, which is largely controlled by the amount of dissolved CO_2. The important cation solutes are Na, K and Ca, and there are generally high concentrations of SiO_2, SO_4 and HCO_3. Chloride waters are usually supersaturated with respect to amorphous silica and as a result silica sinter aprons that form around the spring or pool are a diagnostic feature of these spring types (Figure 4).

Figure 4. Geysers discharging chloride waters at Whakarewarewa geothermal area (left). Champagne Pool (right) discharging 74°C chloride waters at Waiotapu geothermal area. Both have sinter aprons of amorphous silica (Photos source: GNS Science).

Acid sulphate waters occur where steam condenses into surface waters in the vadose zone above the water table. Oxidation of geothermal H_2S gas creates sulphuric acid that chemically degrades the surrounding country rock. These waters form in the shallowest parts of the system and their chemistry reflects the dissolution of the country rock, hence providing little information on the characteristics of the deep reservoir. Typical acid sulphate features are collapse craters and mud pools (Figure 5), and any water contained in them is predominantly rainwater, with minor steam condensate.

Figure 5. Acid sulphate mud pool (top left; photo source: GNS Science); small collapse features at Mokai geothermal area (top right; photo source: D. Graham, GNS Science); Thunder Crater, a collapse feature at Waiotapu geothermal area (bottom; photo source: http://www.photovolcanica.com/VolcanoInfo/Wai-O-Tapu/Wai-O-Tapu.html).

Bicarbonate waters (or CO_2-rich waters) occur on the margins and/or shallow subsurface region of the geothermal reservoir where CO_2 gas is absorbed and steam is condensed into cool ground water. For these waters, like acid sulphate waters, any temperature above ambient is largely provided by steam heating. In contrast to acid sulphate waters, bicarbonate waters form beneath the water table where they are weakly acidic. However with loss of dissolved CO_2 upon reaching the surface, bicarbonate waters become neutral to slightly alkaline. Bicarbonate waters may become supersaturated with respect to $CaCO_3$ and springs may have deposits of travertine ($CaCO_3$) sinter (Figure 6).

Figure 6. Travertine sinter deposit around a bicarbonate thermal spring, Papua New Guinea (photo source: N. Mosusu, Minerals Resource Authority, PNG).

Waiotapu Geothermal Area

Location

Waiotapu Geothermal Field is located between the Reporoa Caldera and Okataina Volcanic Centre (Figure 2), approximately 25 km southeast of Rotorua. Of the TVZ geothermal systems, it has the largest areal extent of surface activity approximately 17 km^2 (Hedenquist and Browne, 1985). This activity extends from steam vents on the flanks of the northern dacite volcanoes (Maungakakaramea and Maungaongaonga), south to the mixed acid sulphate-chloride and bicarbonate-chloride features towards Lake Ngakoro (Figure 7).

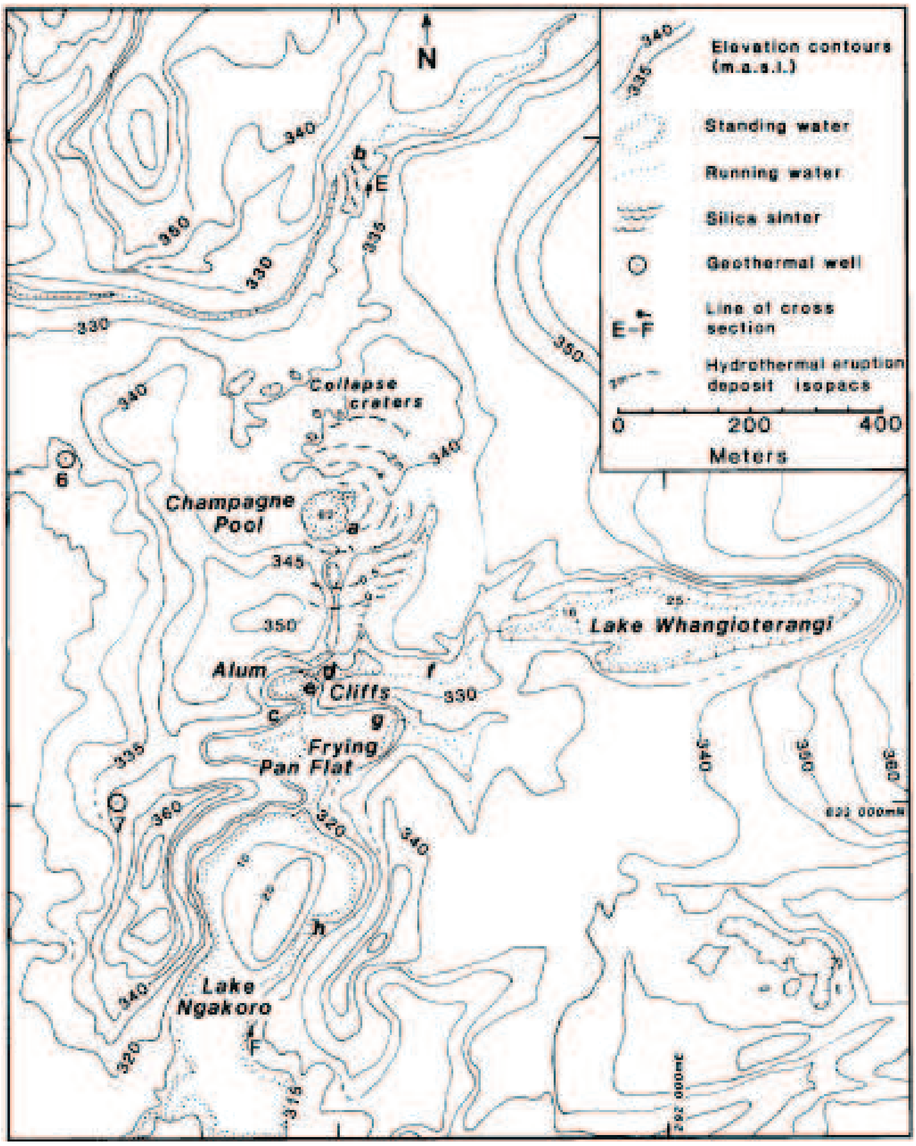

Figure 7. Map showing the location of the main thermal features of the Waiotapu geothermal area, from Hedenquist and Henley (1985).

Surface Geology

Local topography and surface geology are dominated by two dacite domes (Maungakakaramea, Maungaongaonga; >130 ka) on the northern edge of the field, and a rhyolite dome (Trig 8566; approximately 500 ka) to the west (Figure 8). Between these topographic features the valley is floored by Whakamaru-group ignimbrite (340-350 ka), Okataina-derived tephra (240-322 ka), Earthquake Flat Breccia (61 ka) and Taupo Pumice Alluvium (<12 ka) (Leonard et al., 2010). The district is cut by the Ngapouri Fault, striking northeast between the two dacite domes (Figure 8). The Kaingaroa Fault scarp defines the eastern side of Reporoa Caldera and the eastern margin of the TVZ.

Hydrothermal eruptions are part of the geological history at Waiotapu, with several occurring approximately 900 years ago (Lloyd, 1959). Eruption craters at Waiotapu (Hedenquist and Henley, 1985) occur in north, along or close to the Ngapouri Fault (e.g., Lakes Ngapouri, Ngahewa, Okaro; Figure 8). To the south, lineations defined by thermal activity may infer minor NNE-trending faults and possible east-west structures. Hydrothermal eruption craters (Lakes Ngakoro, Whangioterangi, and Champagne Pool) occur at the intersection of these minor structures (Hedenquist and Henley, 1985). The most notable of these craters is the Champagne Pool, with the largest outflow of all the Waiotapu surface features.

Subsurface Geology

Subsurface stratigraphy at Waiotapu (Table 1) is defined by the eight geothermal exploration wells that were drilled to depths between 450 and 1100 m (Figures 8 and 9). Interbedded tephra, breccias and lacustrine sands and muds comprise the upper 50 to 100 m, with the mudstones of the Huka Group acting as an hydrogeological aquitard. The Waiotapu Ignimbrite which occurs at 130-180 m depth, is the deepest unit recognised in the hydrothermal eruption deposits. The Waiora Formation (W2; Table 1) and Waiotapu Ignimbrite (wi) are likely to be the permeable horizons for the deep reservoir. The depth to the greywacke basement rocks (Table 1) remains unknown as it was not encountered by the deepest well (i.e., well 4).

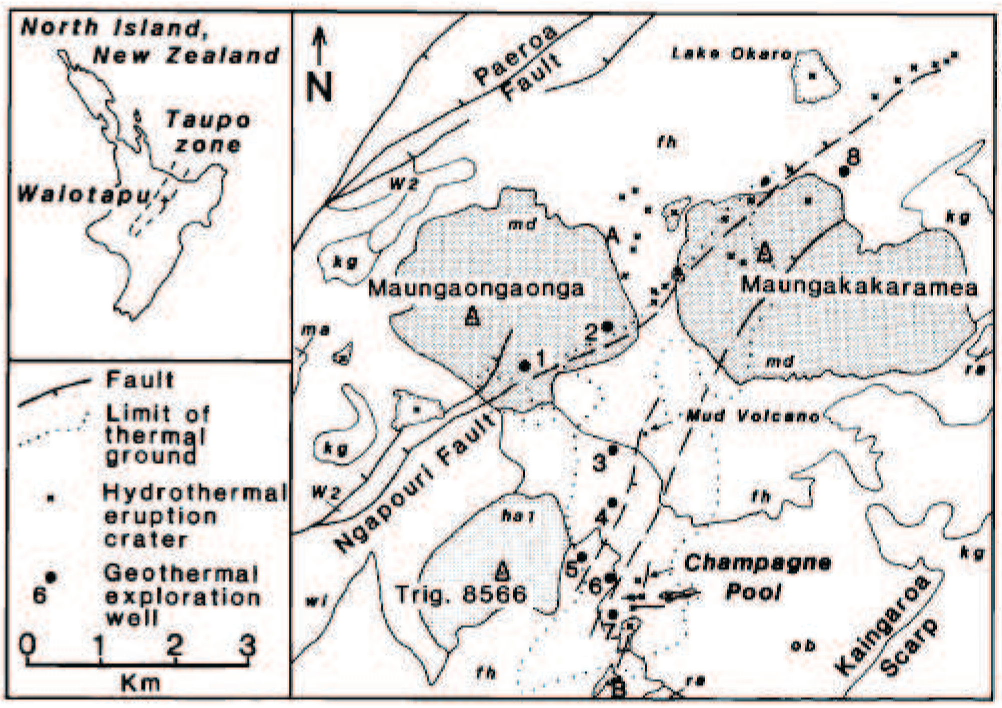

Figure 8. Geology map of the Waiotapu geothermal area, Hedenquist and Henley (1985)

TABLE 1. Stratigraphy and Lithology of the Waiotapu Vicinity (modified from Steiner, 1963, and Nairn, 1973)

Unit and abbreviation	Age	Lithology
Ash (fh)	186 A.D. to ca. 14,700 yrs	At least five rhyolitic ash beds and interbedded alluvium
Kawakawa Tephra Formation (fh)	ca. 20,000 yrs	Fine rhyolitic ash with abundant accretionary lapilli
Earthquake Flat Breccia (fh)	ca. 42,000 yrs	Unwelded rhyolite pumice breccia, biotite-rich
Huka Group (fh)	100,000–400,000 yrs	Lacustrine silts and sands, stratigraphically extensive over Taupo volcanic zone
Maungakakaramea Dacite (md)	ca. 160,000 yrs	Lava domes and flows of dacite
Kaingaroa Ignimbrite (kg)		Upper welded lenticulite and lower unwelded breccia
Matahina Ignimbrite (ma)	ca. 200,000 yrs	Poorly welded pumiceous tuff
Onuku Breccia Formation (ob)		Pumiceous pyroclastics, reworked to silts, sandstones; correlative with Huka Formation
Rangitaiki Ignimbrite (ra)	ca. 230,000 yrs	Moderately welded quartzose ignimbrite
Crystal-rich tuff (qb)		Moderately welded quartzose, biotite ignimbrite
Waiora Formation (W2)		Pumiceous pyroclastics and lacustrine sediments of the lower Huka Group
Haparangi Rhyolite (hal)		Lava domes and flows of rhyolite, with intrusive equivalents
Waiotapu Ignimbrite (wi)		Moderately to highly welded quartz-poor lenticular ignimbrite; occurrence of spherulitic zones common with one 50± m zone of lithophysae about one-half of the way into the sheet
Tuff		Crystal lithic tuff (breccia), reworked
Ngakoro Andesite (nk)		Augite-hypersthene intrusive(?) sill; no surface equivalent
Paeroa Ignimbrite (po-A, -B, -C)	300,000 ± 50,000 yrs (lowest unit)	Three moderately welded ignimbrite sheets separated by tuff breccias; age of oldest unit (C) by fission track analysis (S. Taguchi, pers. commun., 1984)
Graywacke	Mesozoic	Graywacke and argillite basement underlying the volcanics of the Taupo volcanic zone

Table 1. Waiotapu stratigraphy, Hedenquist and Henley (1985).

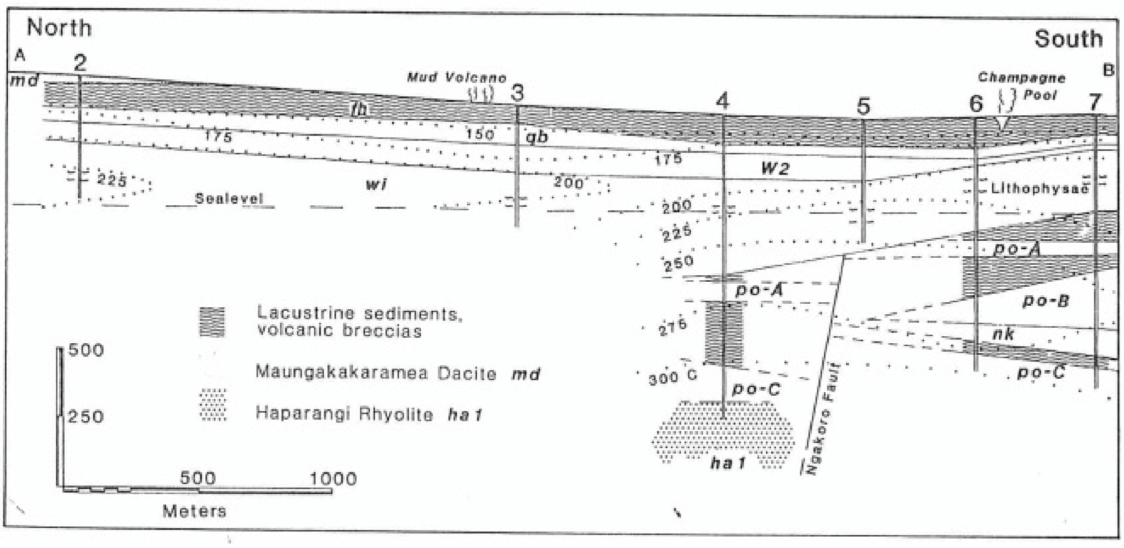

Figure 9. The stratigraphy and downhole temperatures encountered by Waiotapu geothermal wells, Hedenquist and Henley (1985)

Subsurface Hydrogeology

Drillhole data and surface spring chemistry has provided inferences into the Waiotapu hydrogeology (Figure 10; Hedenquist and Browne, 1989). Deep ascending chloride fluids boil from 300° to 230°C at depths <500 m, mixing with steam heated (SO_4- and CO_2-rich) waters overlying and on the margins of the system. Deep fluids ascend close to Champagne Pool and well 4. Temperature inversions in wells 2 and 3 indicate cooler steam-heated incursions into the system. There is a shallow outflow of fluids towards the south and the Reporoa Basin.

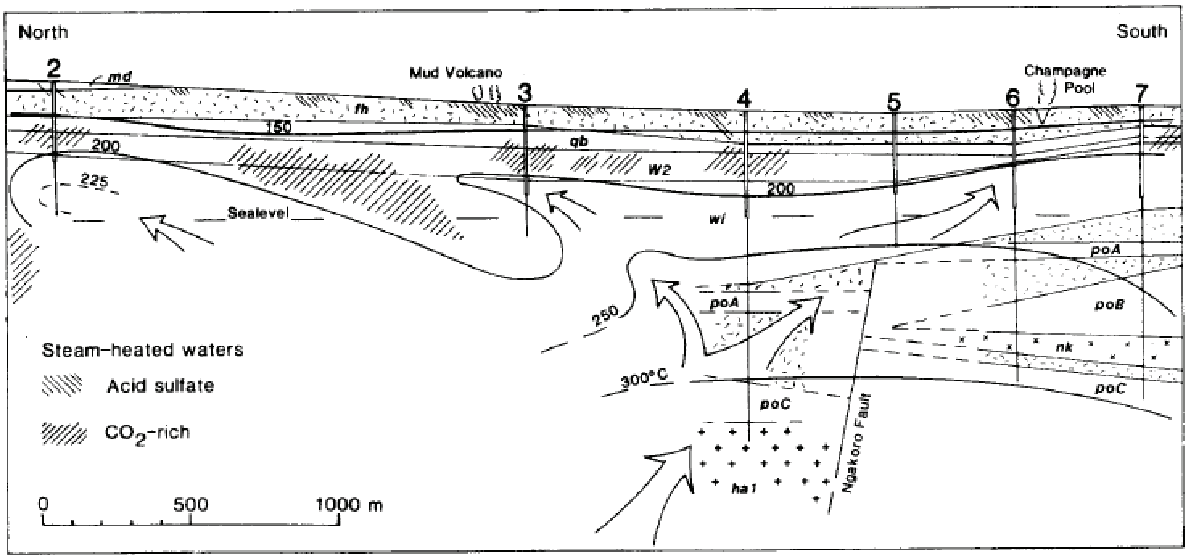

Figure 10. Hydrogeological model of the Waiotapu geothermal system (Hedenquist and Browne, 1989)

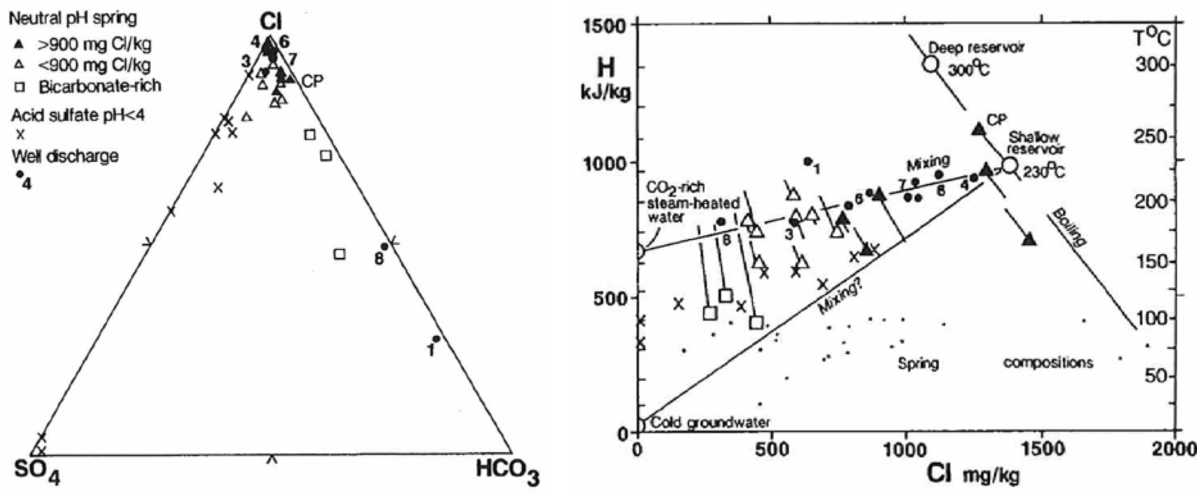

Figure 11. Cl-SO_4-HCO_3 ternary (left) and Cl-enthalpy (right) diagrams displaying chemical data from Waiotapu springs and wells (Hedenquist 1991).

Surface Features
The following brief descriptions of the Waiotapu surface features, shown in Figure 7, are summarised from Simmons et al. (1992):

Collapse Craters: Shallow acid sulphate fluids that react with the surrounding host rock cause chemical degradation resulting in unstable ground and collapse craters. Many craters are floored by fallen debris and are perched above the water table (Devil's Ink Pot), whereas others contain mixed acid sulphate chloride waters (Rainbow Crater), pH = 2.5. Host rocks are hydrothermally altered to sulphur, cristobalite, alunite and kaolinite.

Alum Cliffs: A hydrothermal eruption vent. Pools contain acid sulphate-chloride waters. A dormant Waiotapu Geyser that discharged chloride water in 1980s has a silica sinter apron. Frying Pan Flat and Lake Ngakoro are also hydrothermal eruption craters

Lake Whangioterangi and Sulphur Mound Valley: Sulphur mounds occurring in a drained western portion of Lake Whangioterangi are sublacustrine hydrothermal deposits. These formed where molten sulphur discharged onto the lake floor solidifying as vesicular sulphur clasts, interspersed with fine laminated cristobalite beds.

Champagne Pool: The elevation of the pool is approximately 10 m higher than the surrounding acid sulphate altered ground. It is a hydrothermal eruption crater, 60 m deep, that taps deep reservoir fluids (approximately 230°C). Due to convection, the pool has a vertically homogenous temperature of 74°C. Water effervesces CO_2, with bubbles nucleating at approximately 1 m depth and the high CO_2 gas content stabilising the pH at 5.

Orange precipitates are amorphous arsenic and antimony sulphides, high in gold (80 ppm) and silver (175 ppm), but also thallium (320 ppm) and mercury (170 ppm). The low pH stabilises amorphous arsenic and antimony sulphur compounds which adsorb gold and silver (Hedenquist and Henley, 1985; Renders and Seward, 1989; Webster, 1990).

Ngatamariki (Geothermal Development)

Field Trip Leader: Catherine Boseley, Mighty River Power Ltd.

The 82 MW Ngatamariki plant, currently under development (Figure 12), will involve a four unit ORMAT binary plant using approximately 50,000 t/day of steam. The 2010 resource consent granted a geothermal fluid take of 60,000 t/day with full re-injection (nominally 97%). The first two units are to be commissioned in February 2013, with full-station hand-over in July 2013.

Recent drilling of geothermal wells at Ngatamariki (NM8, NM9, NM10, NM11; Figure 13) has been with a Iceland Drilling Company (IDC) Drill-Mec rig that arrived in New Zealand in September 2011. During September – December 2011 four monitor wells (OKM1, OKM2, NMM17, NMM18) were drilled close to the Orakei Korako geothermal area (Figure 14). Currently, there is on-going infield drilling of injection and production wells (NM8, NM9, NM10, NM11), with NM5 and NM7 (drilled in 2008-2009) used as production, NM6 and NM4 (drilled in 2009 and 1985 respectively) as injection wells, and NM2 (1985) as a monitor well (Figure 13).

Figure 12. The 82 MW Ngatamariki power plant construction site, May 2012.
Source: http://www.mightyriver.co.nz

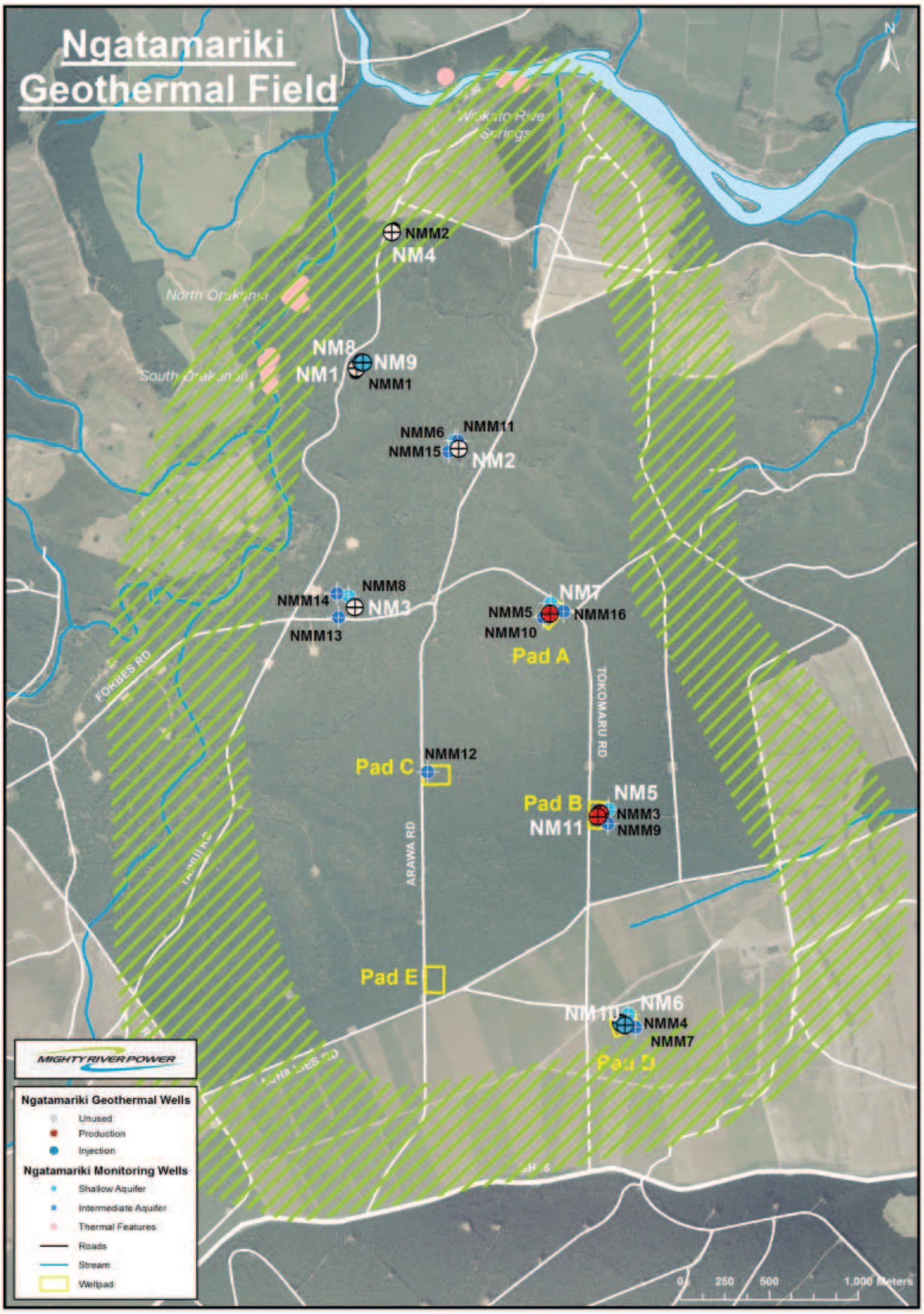

Figure 13. Ngatamariki Geothermal Field, well location map. Source: Mighty River Power.

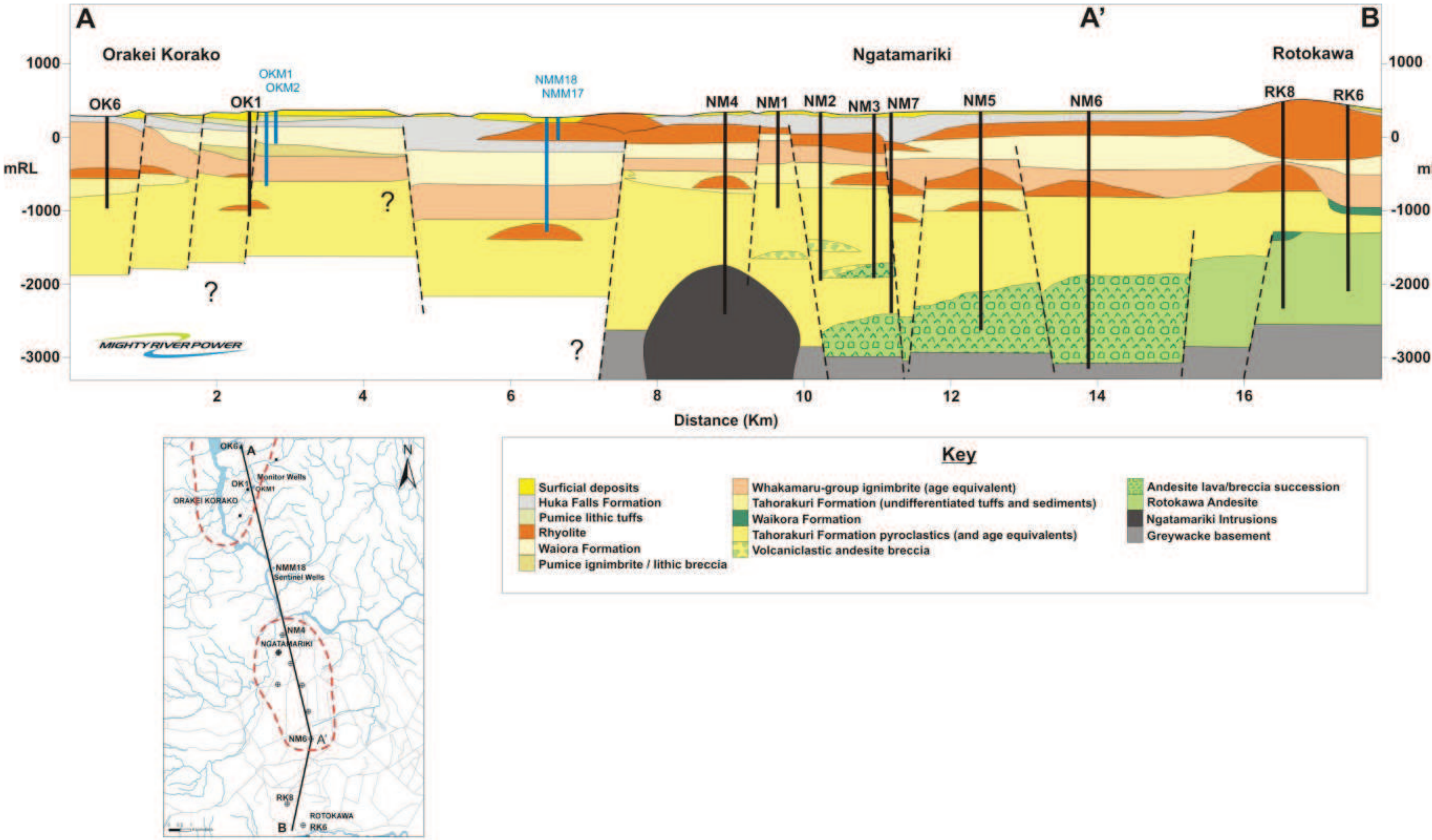

Figure 14. A north – south geological cross-section through the Orakei Korako, Ngatamariki and northern part of the Rotokawa geothermal fields. Source: Mighty River Power

Wairakei (Geothermal Production)

Field Trip Leader: Chris Morris, Contact Energy Ltd.

Commissioned in November 1958, the Wairakei power plant is situated on the edge of a large geothermal system. Previously, the water was at 265°C but with exploitation this has dropped to between 210° and 245°C. Production caused the pressures within the reservoir to drop about 25 bar, but pressures and temperatures appear to have stabilised.

Figure 15 is a flow diagram summarising the steps involved in conventional geothermal power generation. Currently about 5,000 t/hr of fluid is taken from the reservoir for use at Wairakei (another 2000t/h is taken for production at Poihipi). This is separated into roughly 1,500 t/hr of steam and 3,500 t/hr of water at a temperature of about 130°C. Dry steam is also taken from shallow production wells (up to 500 m depth) and piped directly to the turbines. The steam is directed towards the turbines through a network of pipes around the Wairakei steam field. The Wairakei A (Figure 16) and B stations have 10 steam turbines ranging in size from 4–30 MW. The station generates on average 157 MW.

Once steam has passed through the turbines, it is condensed within 'direct contact' condensers. This cooling system uses water pumped from the adjacent Waikato River. After use, the cooling water and steam condensate is discharged back into the river. Non-condensable gases found in the steam supply are pumped from the condenser and released to the air via gas stacks on the power station roof. Hydrogen sulphide, initially within the gas, is removed from the cooling water in a large bioreactor using bacterial oxidation. The hot geothermal water is mainly injected back into the ground while some is supplied to secondary users and discharged into the Waikato River. Two lakes were also built for management of the separated water discharge.

The Poihipi Road power station was commissioned in 1997 and was bought by Contact in 2000. It is now operated as an integral part of Wairakei power generation and is supplied with steam from the Wairakei geothermal system. The consent take for Poihipi is part of the overall Wairakei consent. Poihipi currently generates on average 50 MW.

In 2005, Contact commissioned a new 14 MW binary plant at Wairakei (Figure 17). This plant utilises heat previously untapped by the existing plant. Binary means that it uses the heat in the separated hot water to boil pentane, which passes through a turbine, then is condensed in the large radiators. It was designed with less efficient air cooling so that it does not increase the heat load on the Waikato River.

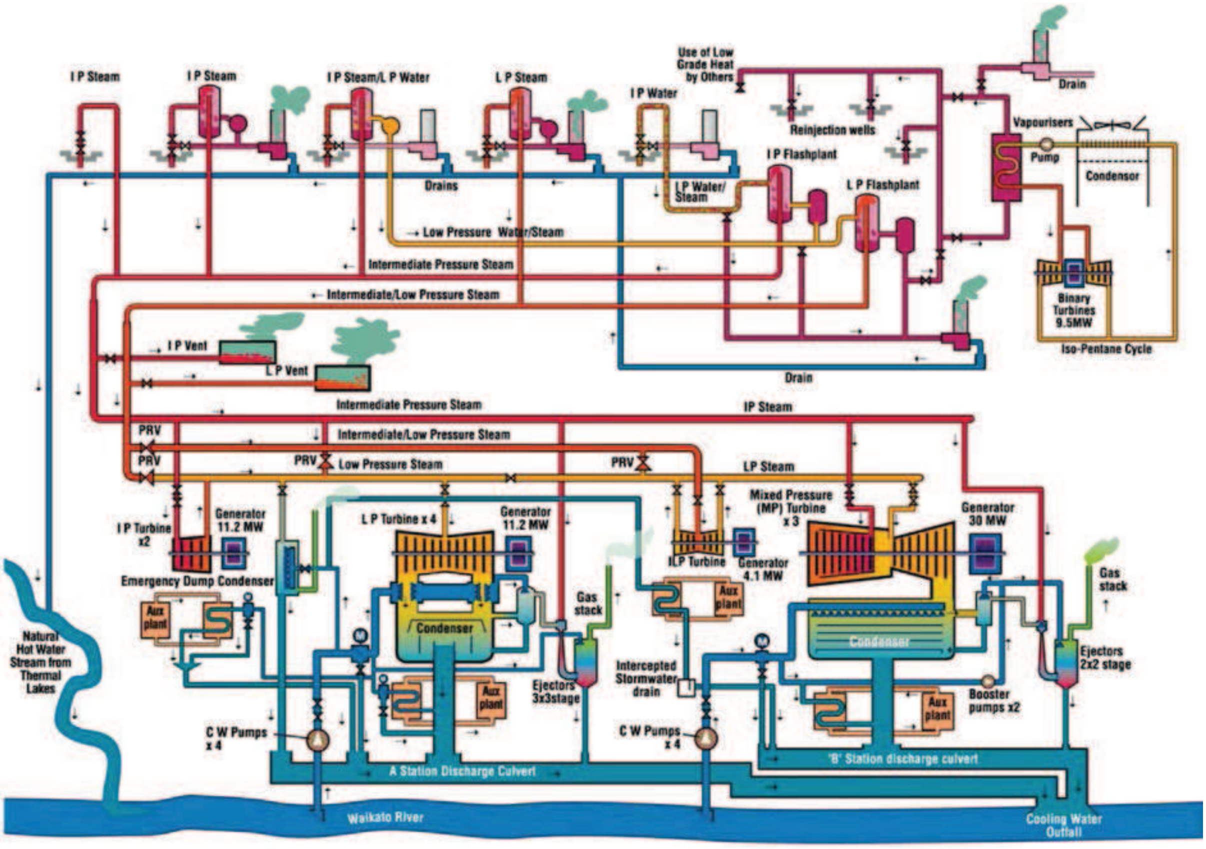

Figure 15. Flow diagram for geothermal power generation using conventional steam turbines. Source: Contact Energy Ltd.

Figure 16. Wairakei A station LP turbine hall, 11 MW condensing turbines. Source: Contact Energy Ltd.

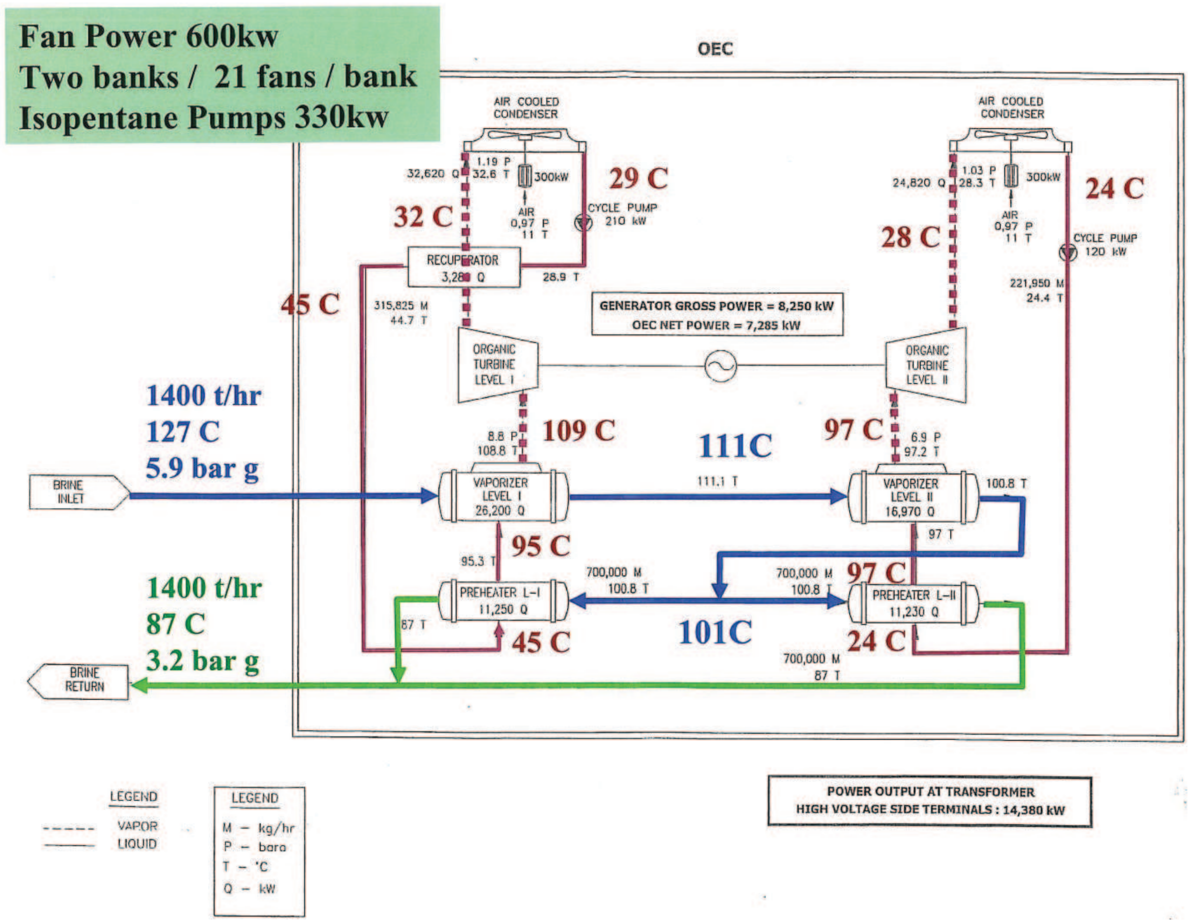

Figure 17. Flow diagram for geothermal power generation using a binary generator. Source: Contact Energy Ltd.

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