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FIELD TRIP GUIDES

Edited by
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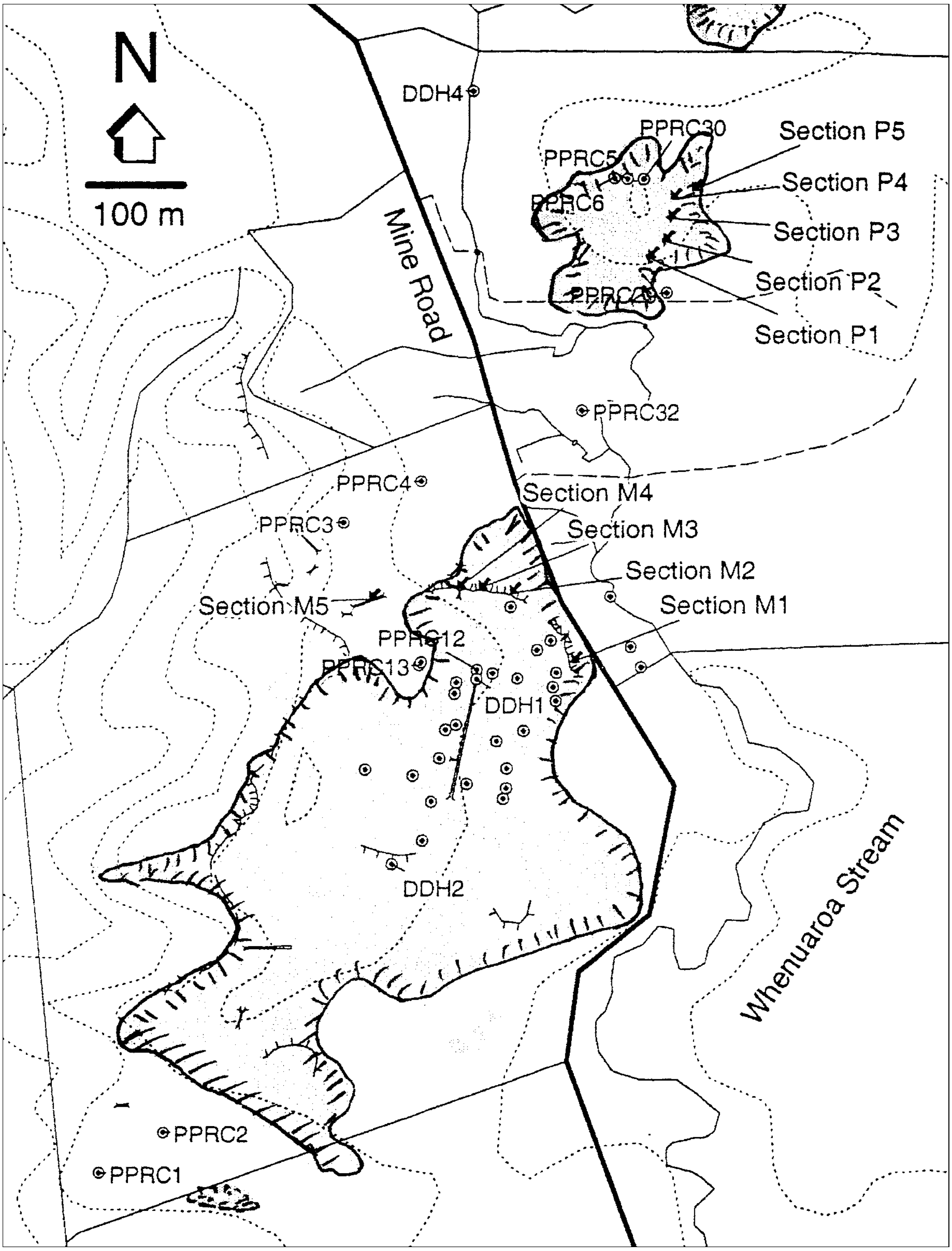

Fig. 6.1: Distribution of silica sinter and sinter breccias at Mt Mitchell (south) Plum Duff (north) and Bush Hill (northern edge of map). Locations of sections, exploration drillholes, trenches and adits shown. We visit only section M1 (Fig. 6.2). From Hampton (2002).

Field Trip 6
Geothermal Northland
Pat Browne, Stuart Simmons, Kathy Campbell, Wendy Hampton, and Dion Pastars

Post conference fieldtrips leave from The Quarterdeck (formerly Valentines) carpark, 56 Otaika Road at 8AM on Friday 6th December.

PUHIPUHI AND LAKE OMAPERE-PART 1
Leave Whangarei at 8 am and drive north on Highway 1 for 20km. Turn east on Puhipuhi Road and then north on Mine Road to Mt Mitchell (Q06/245327). Silver was mined here in the 1890's and the first decade of last century. Mercury was mined from 1915 until the early 1970's and more recently the area has been prospected for gold.

STOP 1-Puhipuhi Silica Sinter

The sinter covers an area of about 600 x 400m (Fig. 6.1) and is up to 23m thick (Grieve et. al., 1997); it thins progressively to the south and west (White, 1983). The sinter exposed in the quarry is layered, dense and contains a variety of fabric types. These include stromatolitic, streamer fabric and bubble mat but geyserite has not been recognized; evidence of plant material occurs. The silica phases present are Opal A, Opal-CT, quartz and moganite (monoclinic) that record some of the depositional and post depositional thermal history of the area. When first deposited the silica did so as Opal-A, which is x-ray indifferent. As the silica lost water it progressively became structurally ordered, changing first to Opal-CT and then moganite plus quartz (some chalcedonic). The presence of texturally late Opal-A, however, indicates circulating groundwaters dissolved some silica and then reprecipitated it.

The sinter in the outcrop is variably coloured and is characterized by coatings, bands and disseminations of yellow and pale orange iron oxide and sulphate minerals, including goethite, jarosite and hematite. More notable here are pyrite fibroids, disseminated cinnabar and rosettes of stibnite. Some livingstonite ($HgSb_4S_7$) has also been reported but is submicroscopic.

The textures, fabrics and composition of the sinter are very similar to those occurring in modern hot spring areas, such as at Waiotapu and Orakei Korako in the Taupo Volcanic Zone (TVZ). No spring vents have been positively identified at Mt Mitchell but they were probably present near the center of the sheet, where columnar structures occur, and/or to the southeast.

Analogy with active systems in the TVZ suggests that the sinter was most probably deposited from cooling alkali chloride waters of near neutral pH. The genesis of the sulphides is not so obvious but most likely records periods of episodic metal deposition. Such events have occurred at Champagne Pool, Waiotapu and the Ohaaki Pool; indeed metals are now precipitating at the former feature.

From the road we will view (Fig. 6.1) Plum Duff, east of Mine Road where silica sinter also occurs, mostly in a variety of breccia types. About 100m or so northeast is Bush Hill also composed of sinter but its relationships to Plum Duff and Mt Mitchell are not known.

We return to SH1 and drive northwest through Kawakawa and Moerewa (there is a concealed fault striking northeast in the valley) to Ohaewai. We bypass Kaikohe and drive along Te Pua Road on southeast shore of Lake Omapere. West of Moerewa we pass a number of well formed late Pliocene to Holocene basalt cones (Fig. 7.3. About 4 to 5 kilometres north of Kaikohe, Putahi Rhyolite and the Te Pua Andesite form two prominent hills either side of the road. The former is a young dome composed of potassic lavas with phenocrysts of sanidine, anorthoclae, quartz and a blue-green amphihole (Brothers, 1965b). There are numerous caves around the flanks of the volcano summit. East of Putahi the Te Pua Andesite is poorly exposed; in places it is altered and vents CO_2. We go to the Omapere Spring, 6 km northeast of Kaikohe (Fig. 6.3).

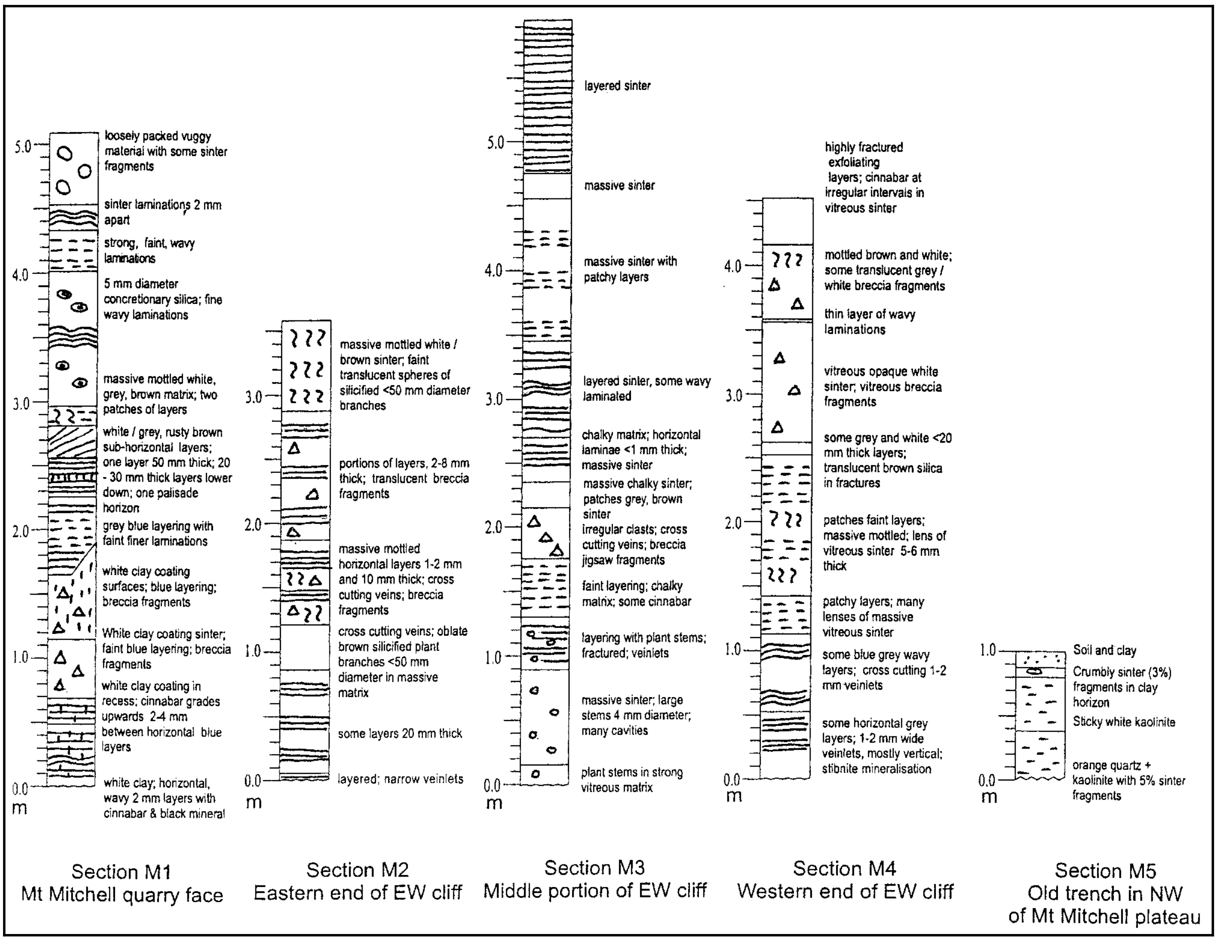

Fig. 6.2: Measured sections at Mt Mitchell showing sinter textures and relations (see figure 1 for locations). We visit only section M1, Mt Mitchell quarry face. (from Hampton 2002).

STOP 2-Lake Omapere

The present day thermal activity consists of a single bubbling spring discharging copious amounts of CO_2 gas. Temperatures recorded vary from 30° to 43° (Petty, et. al., 1987) and the flow rate from 3.5 to 28/per second. Dead birds sometimes lie in the pool, most likely killed by gas. The bottom of the pool is usually covered by an orange brown deposit. The spring was exposed by quarrying many years ago and has no genetic connection with the sinter mound. It is not depositing silica.

This sinter deposit is located on the northern margin of the Ngawha field. Sinter is rare at Ngawha although the field is large in its extent. A smaller sinter deposit occurs about 750m north east and there is also a sinter boulder strewn field 250m to the southwest (Fig. 6.3).

The central sinter covers an area of about 45,000m^2 and is mostly 6 to 7m thick although an unknown amount of sinter has been removed by quarrying. The sinter rests upon silicified, halloysite-rich paleosols, Quaternary alluvium, lacustrine sediments and thin peat beds. The deposit is amoeboid in shape (Fig. 6.4) with 6 splayed arms.

The sinter is well exposed in places and ranges in appearance from bleached white and porous to black and dense vitreous opaline. Plant material abounds, mostly reeds, grasses, stems and leaves. The sinter is cavernous in places and shows discontinuous layering. Some stems remain in their growth positions suggesting that the depositing thermal water had cooled when the surrounding sinter deposited.

Three continuously-cored holes have been drilled through the sinter (Harper, 1980; Mildenhall et. al., in press). All penetrated cavernous silica sinter and two bottomed in peat. The deepest reached 13.47m but little core was recovered from it because of large cavities. However, a 12m deep hole (OM3) yielded 55%

recovery. The shallowest sinter is white, porous and friable with brecciated horizons; deeper sinter is vitreous and black with abundant plant remains. The sinter hosts a rich assemblage of pollen, leaves and

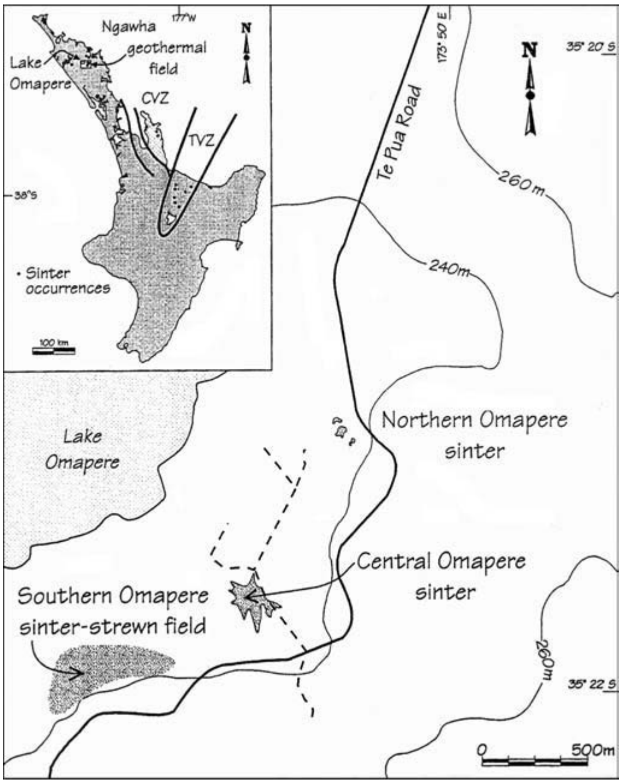

Fig. 6.3: Locality map of sinters on the northern margin of the Ngawha geothermal field (from Mildenhall, et. al., in press).

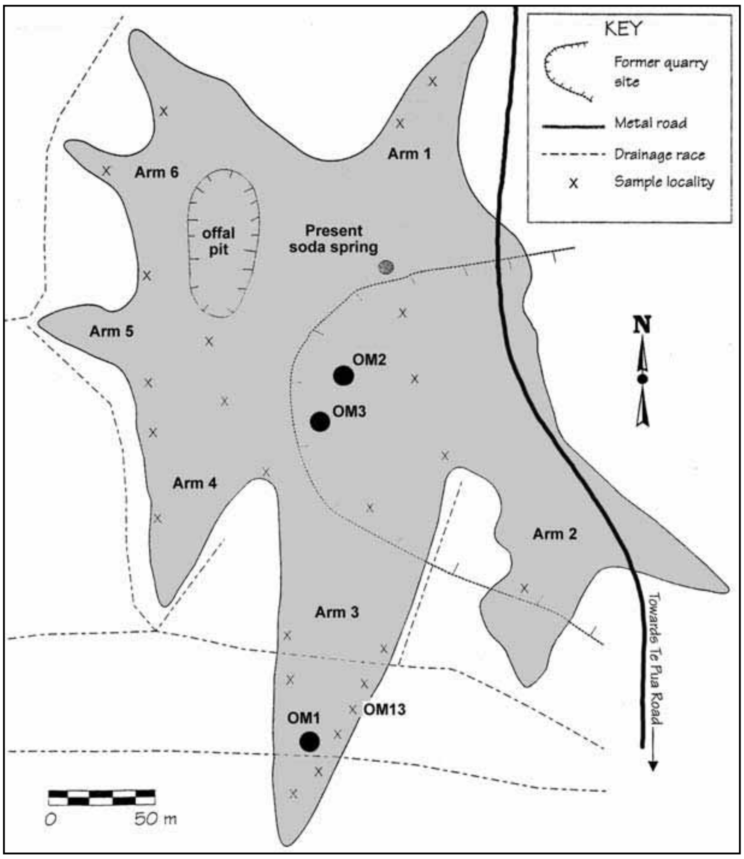

Fig. 6.4: Map of Central Omapere sinter showing locations of drillholes, sample sinters and the presently discharging spring (Mildenhall, et. al., in press).

stems many impregnated or encrusted with silica. Combined pollen and AMS dating show that most sinter was deposited about 40,000 years ago and that deposition continued for longer than 10,000 years (Mildenhall, et. al., in press). Earlier suspicions that some sinter was deposited as recently as European times have not been confirmed.

Despite its age, most sinter is Opal-A; minor Opal-CT has only been recognized in sinter from the bottom of one of the drillholes.

THE NGAWHA GEOTHERMAL AREA-PART II

The Ngawha geothermal area is located approximately 250 km north of Auckland within a broad topographic depression at an average elevation of 200 m asl and surrounded by gently rolling terrain. It lies within the Late Miocene-Holocene Kerikeri basaltic volcanic field (Taheke and Horeke Basalt), and it is 5 km southwest of the Te Pua Andesite (Heming, 1980; Smith et al, 1993; Fig. 6.5).

It has attracted the attention of numerous geoscientists because of the geological setting and unique character of the thermal springs (Bell and Clarke, 1909; Fleming, 1945) and the existence of a modest mercury resource, which was mined in the period 1895-1897 and then again in 1928-1934 (Henderson, 1944; Davey and van Moort, 1986). The prospect of developing the geothermal resource gained momentum in the late 1970s after the first well drilled in 1964 (590 m depth) encountered temperatures reaching 236° C and after the success of the Geysers in California and the Kawerau geothermal field which in both cases have geothermal reservoirs hosted in fractured greywacke. Two DSIR publications (DSIR Geothermal Report 7, 1981; DSIR Geothermal Report 8, 1985) were the outcome of this activity, though these documents seemed to have had limited distribution. Several subsequent theses by students based at the University of Auckland further focussed on various aspects of the geothermal activity (Cox, 1985; Gibson, 1993; Karmon, 1999; Arediningsih, 2001; Harris, 2001).

Currently, the geothermal resource is used for bathing and for production of electricity. A small geothermal power station generates about 10 MWe using fluids from two wells (Ng 9 and Ng 12).

Geothermal Activity
Surface thermal features include neutral to acid hot pools, gas seeps and cold lakes. Several major NE-SW trending faults are important for regional fluid flow as indicated by the alignment of thermal features shown in Fig. 6.5 (Fleming, 1945). The low liquid discharge (1-2 l/s, total) and the vigorous gas flux are distinctive features of the surface activity (Sheppard and Lyon, 1981; Sheppard and Johnston, 1984; Scott and Glover, 2000). Fifteen exploration vertical wells (600 to 2250 m depth) reveal the subsurface conditions (Fig. 6.5).
The geothermal reservoir is hosted by fractured quartzo-feldspathic greywackes and argillites of the Permian-Jurassic Waipapa Group at below about 500 to 600 m depth (Skinner, 1981). The overlying Cretaceous-Tertiary sedimentary rocks are part of the Northland Allochthon, which was deposited by gravity sliding during the Oligocene (Ballance and Spörli, 1979). These rocks comprise siltstones, mudstones, limestones and shales, interleaved with zones of tectonic breccia (Skinner, 1981; Petty, 1985). The deep reservoir water at Ngawha has a temperature of about 230° C and contains about 1200 ppm Cl and 1-2 wt.% CO_2 (Sheppard and Giggenbach, 1985). This fluid is slightly over-pressured with respect to a hot hydrostatic boiling point for depth gradient, due to the confining nature of the shallow sedimentary strata (e.g. Browne and Lawless, 2001).

Ngawha lakes and cold gas seeps
The lakes occur in outlying areas around Ngawha village in an area that is mostly flat, where underlain by Recent alluvium and lake sediments (Fig. 6.5); steep slopes occur around the edges of the area, marking the emergence of the Cretaceous-Tertiary rock from below the Ngawha lake beds (Bell and Clarke, 1909; Fleming, 1945; Skinner, 1966). Around Lakes Waiparaheka and Ngamokaikai there are visible arcuate scarps of the order of 1-5 m height parallel to the lake edge probably derived from inward slumping of material towards the lakes.). Peat deposits surround the lakes, and around Waiapawa Pond; they rise 2-3 m above the general level of the landscape.

Lake Waiparaheka is a cold lake about 300 m by 100 m in area that discharges significant amounts of CO_2. The water is brown and turbid caused by suspended sediment churned by the vigorous bubbling of CO_2, which discharges from what appear to be a number of lake floor vents.

H_2S odour is noticeable, as are thin pale yellow deposits of sulfur around the edge of the lake. There are numerous logs that are part of the surrounding peat deposits and many of these protrude from the lake

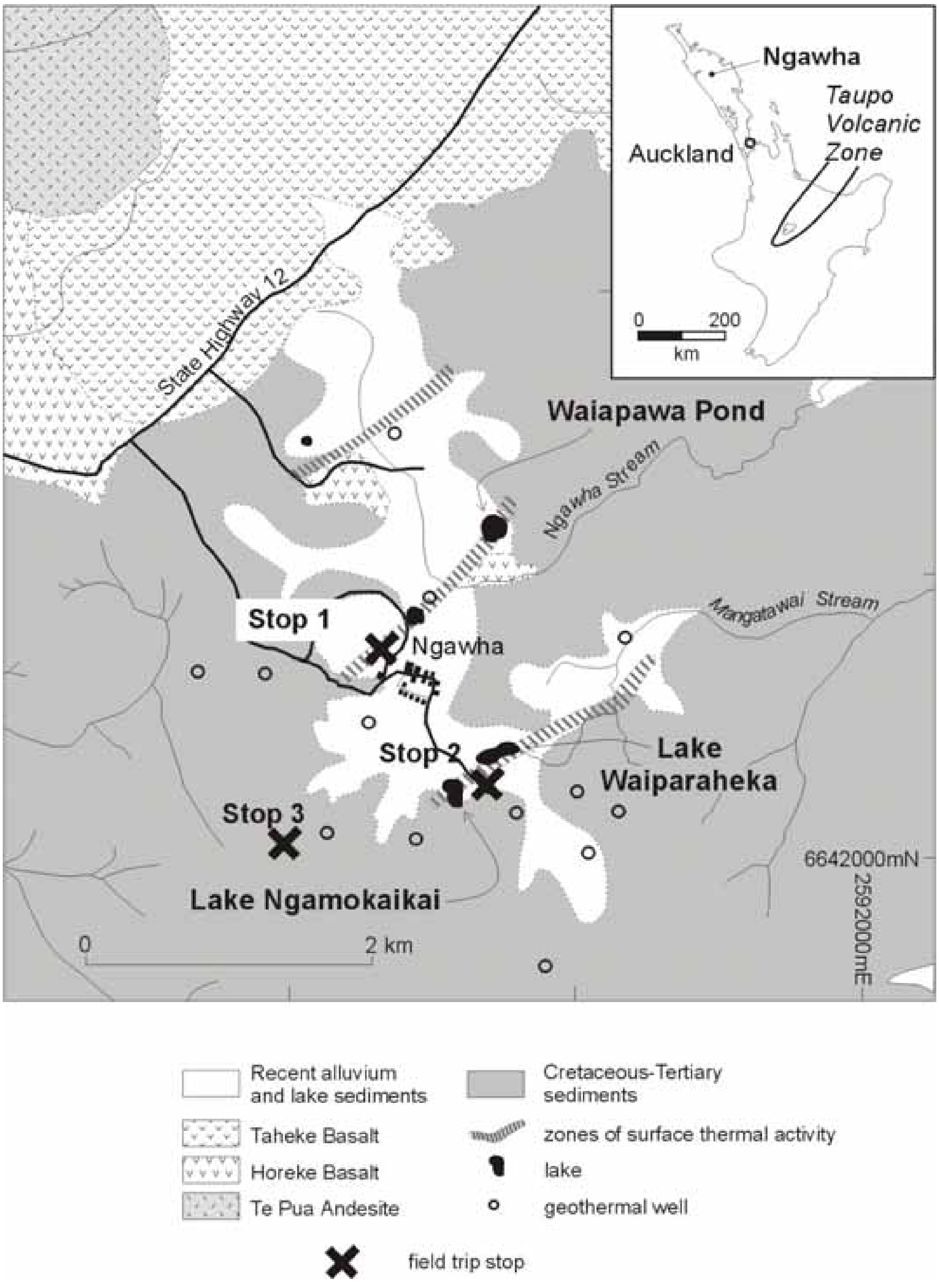

Fig. 6.5: Simplified geological map of the Ngawha area showing the location of lakes, zones of thermal activity and geothermal wells. Inset shows North Island, New Zealand (modified from Harris, 2001).

margin and are partially submerged in shallow water. The bathymetry (Fig. 6.6) is dominated by a cone-shaped depression, which occupies the western lobe that reaches 38 m depth at its centre. This deepest part coincides with the most vigorous gas bubbling. Another smaller cone-shaped depression, surrounded by a shallow shelf, occurs in the eastern lobe and reaches a maximum depth of 8 m, also coinciding with a strong bubble train.

Lake Ngamokaikai and Waiapawa Pond are the two other large lakes in the Ngawha area and they are also relatively deep at 26 and 22 m, respectively. Weak gas bubbling occurs at both lakes but it is not nearly as spectacular as Lake Waiparaheka.

Around all three lakes are barren patches of land that otherwise supports dense native vegetation that grows up to 3-8 m high (Fig. 6.7). Such patches occur along the shores of the lakes where in nearby shallow water, bubbles of CO_2 gas are common and H_2S odour is strong. Away from the lake edge, these areas cover up to 50 m^2 and are completely void of any growth, though traces of pale yellow sulfur deposits are common on the ground surface. The boundary with surrounding bush is knife sharp. These barren patches are similar to areas of cold gas seepage in the Philippines, termed kaipohan (Bogie et al., 1987), where elevated concentrations of CO_2 are toxic to the root system of plants (e.g. Farrar et al., 1995). In addition to these, there are many places, particularly in the vicinity of the Ngawha baths, where gas can be seen bubbling through cracks in the ground and pavement when wet (i.e. during or after a rain shower).

STOP 1. Ngawha Baths

Most of the springs are located on private property and permission to visit these has to be obtained from the owners.

The main locus of surface activity occurs along a northeast trending belt extending about 500 m that skirts the north edge of Ngawha Village. The springs and baths have á wide range of inviting names (e.g. Jubilee, Velvet, Waipiro, Tranquility, Favourite, Bulldog, Universal, Venus, Sulfurs Way, Milky Way) but none of these give a sense of the dark murky nature of the thermal waters ranging in earth tones from dark grey to ochre that attract bathers who swear by their salubrious qualities. Moreover, Davey and van Moort (1986) describe deposition of metallic mercury onto a brass sieve and an iron spade over the course of a few minutes while working near Tiger Bath. This is the same area that was intensively worked and mined for cinnabar and quicksilver, so this is not so surprising.

Springs discharge at relatively cool temperatures (in comparison with TVZ thermal activity), ranging from 35 to 50° C. Old Well, a shallow cased well, has had measured temperatures exceeding 85°C. Water compositions of a few springs are given in Table 1. The main anionic components are chloride, sulfate and bicarbonate, which are the basis by which thermal waters are genearally classified. Hence the analyses show evidence for chloride waters, bicarbonate waters and acid sulfate waters. Jubilee has the highest chloride concentration and most closely reflects the deep reservoir water encountered in geothermal wells, whereas Tiger Bath is one of the most dilute; its acid pH is reflected in the high sulfate content.
Sheppard and Johnston (1985) plot a number of time series graphs showing considerable variation in spring water compositions over time. Much of this seems to be random though a few springs show dilution with heavy rainfall. Overall, however, there seems to be no clear link to easily measured surface activities. The very low discharge of liquid seems to be a contributing factor. It seems that gas lift due to exsolution of CO_2 is a major contributing factor in making the fluids buoyant so that they can discharge at the surface.

Table 1. Major element analyses (mg/kg) from springs at Ngawha (Sheppard and Johnston, 1985)

Location	T ° C	pH	Na	K	Ca	Mg	B	Cl	SO_4	HCO_3	SiO_2
Jubilee (5.9.81)	43	7.0	630	50	12.7	1.7	591	847	185	481	153
Universal (22.7.81)	42	8.2	384	32	26.8	7.2	283	447	185	753	118
Tiger Bath (13.8.81)	45	2.4	125	10	13.5	4.3	107	162	745	-	62
Ng12 (1982) from weir box		7.7	1019	89	3.1	0.1	995	1388	-	488	430

STOP 2. Lake Waiparaheka

As previously mentioned, Lake Waiparaheka is one of the largest and deepest lakes in the area. It is also the site of vigourous gas discharge. On the basis of its situation filling a low lying depression, Browne and Lawless (2001) interpret this to be a hydrothermal eruption crater. However, there is scant evidence for any apron deposits comprising hydrothermal eruption breccia as is seen in most eruption craters in the TVZ (e.g. Champagne Pool, Waiotapu). Harris (2001) examined the stratigraphy surrounding the lake. Although surface exposure is poor, a limited amount of information regarding the stratigraphy has been gained from the few outcrops. Peat deposits dominate around the lake edge, forming two units separated by a layer of claystone breccia. These peat deposits are up to 2 m thick and composed of dark brown plant material, seed pods and wood fragments that mostly derive from *Agathis australis* (Kauri). The upper unit appears restricted to <50 m distance from the lakeshore. It is distinguished by a greater abundance of wood fragments (~50-80% by volume) compared to the lower unit (~50%). Near the lake edge, the upper unit contains numerous logs and trunks (up to 10 m long and 3 m diameter), which protrude from the peat and are partially submerged beneath the lake. Azimuthal measurements on 150 logs show their prevailing NW-SE orientation. A ^{14}C date of 5449±57 years BP was obtained for wood material in the upper unit while a ^{14}C date of 6132±61 years BP was obtained for wood material from the lower unit. These data limit the maximum age of Lake Waiparaheka to less than ~5500 years BP.

The interbedded sediment is a pale buff-colored, unconsolidated, clast-supported breccia that ranges from 0.25 to 0.65 m thickness. It is poorly sorted and clasts range from <2 to 40 mm in diameter. Angular clasts occur which are made up of claystone embedded in a similar clay matrix. Despite poor sorting, weak, normal graded bedding is visible locally and show signs of reworking. The range of elevations suggests that this deposit mantles topography, but the few exposures show no signs of systematic variation in thickness or clast size as commonly seen in hydrothermal eruption deposits (Cross, 1963; Hedenquist and Henley, 1985). A sequence of fine-grained lake sediments underlies the peat deposits, which also occur in nearby geothermal wells. These deposits are up to 25-30 m thick and are thought to have formed in a lake that filled the Ngawha basin after water impounded behind a natural dam created by young lava flows (Skinner, 1966, 1981).

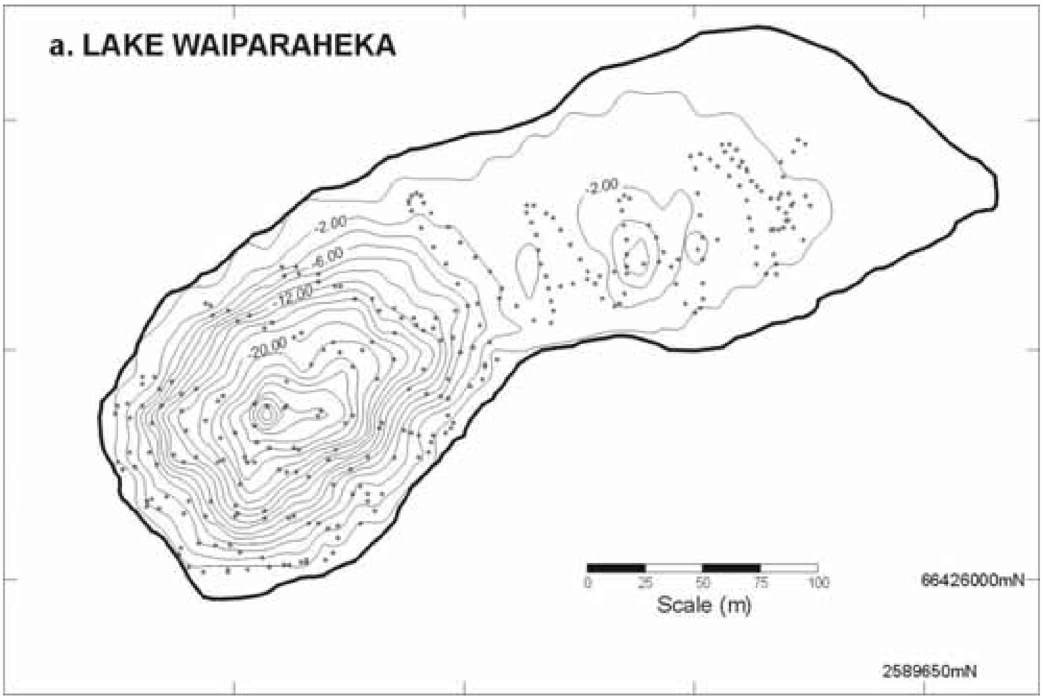

Fig. 6.6: Bathymetric survey of Lake Waiparaheka; contour interval is 2 m (Harris, 2001).

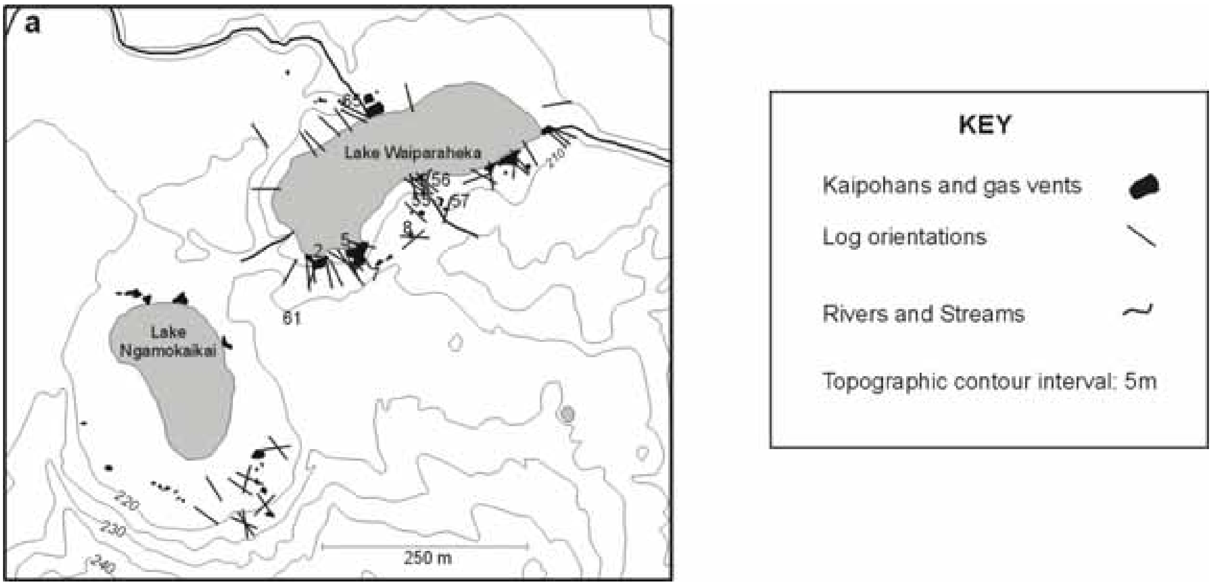

Fig. 6.7: Map showing the locations of kaipohans in the vicinities of the lakes. The locations and orientations of logs are also shown (Harris, 2001).

STOP 3. Ngawha Geothermal Power Station

The power station commissioned in 1998 is run by Top Energy and generates about 10 MWe depending on air temperature. Cool winter temperatures contribute to slightly greater generation compared to the warm summer temperatures.

This is a binary station, constructed by Ormat. It runs off a circuit using isopentane as the working fluid. This fluid is heated via tube and shell heat exchangers using both steam and water that are separated at the well-head of Ng9 and Ng12. The waste fluid comprising condensed steam and water are mixed back together and reinjected in wells to the east.

The power station has encountered relatively few problems though calcite scaling in the wells has to be managed. Unique is the occurrence of stibnite deposits in the heat exchangers, which seems to result from cooling under slightly acid conditions and the anomalous concentrations of antimony in the deep geothermal water (Dorrington and Brown, 2000). Mechanical cleaning with a water blaster and introduction of caustic soda upstream of the heat exchangers are used to manage the problem.