HEAT AND MASS TRANSFER OF THE HIPAUA THERMAL AREA (TOKAANU-WAIHI GEOTHERMAL FIELD) LAKE TAUPO, NEW ZEALAND

C.M. SEVERNE AND M.P. HOCHSTEIN

Geothermal Institute and Geology Department, The University of Auckland, Private Bag 92019, Auckland, NZ

SUMMARY: The Hipaua thermal area covers 70,000 m^2 of hot and Steaming ground. It forms a 750 m long segment of the eroded Waihi fault scarp which constitutes the northwestern boundary of the Tokaanu-Waihi geothermal field. The largest manifestation is the Hipaua fumarole which discharges 1.4 MW. The surface heat output of the Hipaua area is at least 21 MW, the heat deriving from steam flashed in the reservoir. Only minor, practically unmineralized condensates are discharged from the area. The hot ground is more extensive than indicated by infra-red surveys. The whole area is intensely altered as a result of steam condensation.

Introduction

The active steaming ground of the Hipaua thermal area lies at the northwestern boundary of the Tokaanu-Waihi geothermal field located at the southern end of Lake Taupo (Fig. 1). The manifestations include bare steaming ground, hot ground, fumaroles and steam vents, and minor mud and acid pools. The features occur within a 750 m long segment, up to 150 m wide, of the northeast trending Waihi fault scarp (Fig. 2).

The Hipaua thermal area was visited by v. Hochstetter in April 1859 (v. Hochstetter, 1959). Grange (1937) mapped the surrounding terrain and provided some information about the fault scarp. The area was studied in more detail as part of the greater Tokaanu-Waihi geothermal system by Healy (1942). No further studies of the Hipaua area have been undertaken apart from geochemical reconnaissance studies by Mahon and Klyen (1968) and Robinson and Sheppard (1986). The first detailed map of hot ground along the Waihi fault scarp was published only recently (Fig. 2 in Bromley and Mongillo, 1991); it is based on an aerial infra-red (IR) survey. One aim of our study was to correlate details of the IR survey with ground temperatures and to obtain further information about the heat transfer of the area. A reconnaissance survey of the Hipaua area was made in September 1993 (Severne, 1993).

Another aim of the on-going study is to obtain more information about parameters affecting alteration and, hence, stability of the fault scarp. At least three major landslides have originated from the Waihi fault scarp; all of these caused devastation and loss of life (Healy, 1970, cited in Crampton, 1993). The earliest event recorded in oral Maori tradition probably occurred in the 18th century; it destroyed the ancient Omoho village with the loss of 140 lives. The 1846 landslide destroyed Te Rapa village, killing 60 people. In 1910, a landslide occurred during daytime destroying the cultivated fields along the foreshore; all those working in the fields were able to escape except for one person. Today, much of the land on the foreshore consists of accumulated landslide material. The last two earth movements originated from unstable, presumably thermal ground, along the Waihi fault scarp.

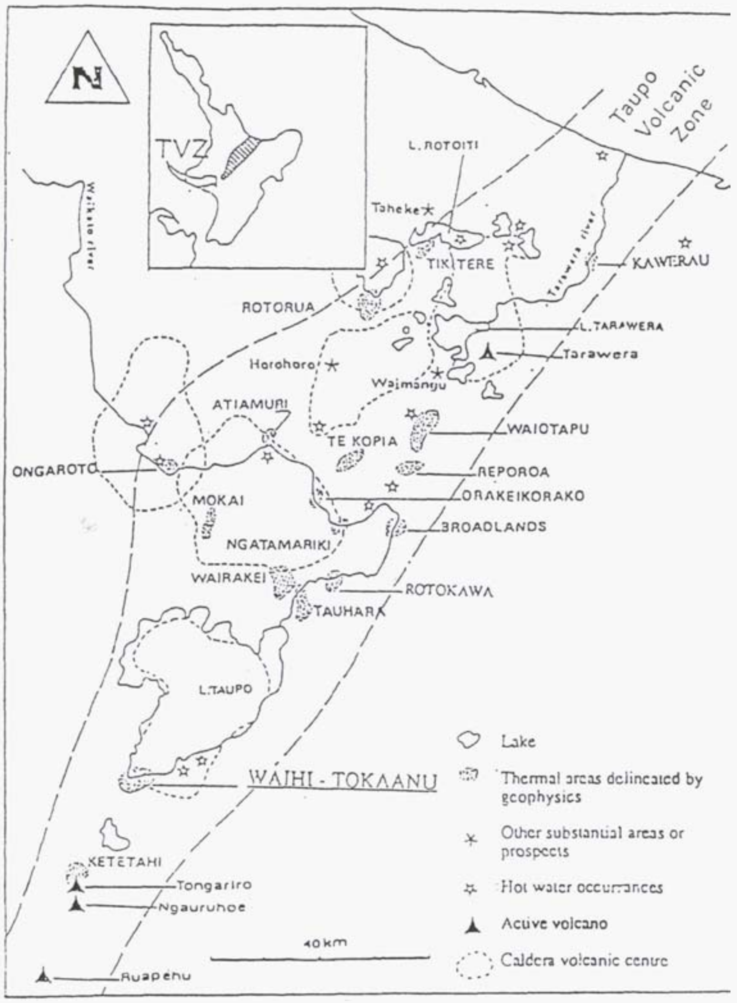

Figure 1: Map showing location of the Tokaanu-Waihi geothermal field.

Setting of the Hipaua thermal area

The area is a thermally active segment of the Waihi fault scarp. This fault is probably associated with a broad fracture zone striking 040° which displaces Kakaramea andesites belonging to the Tongariro

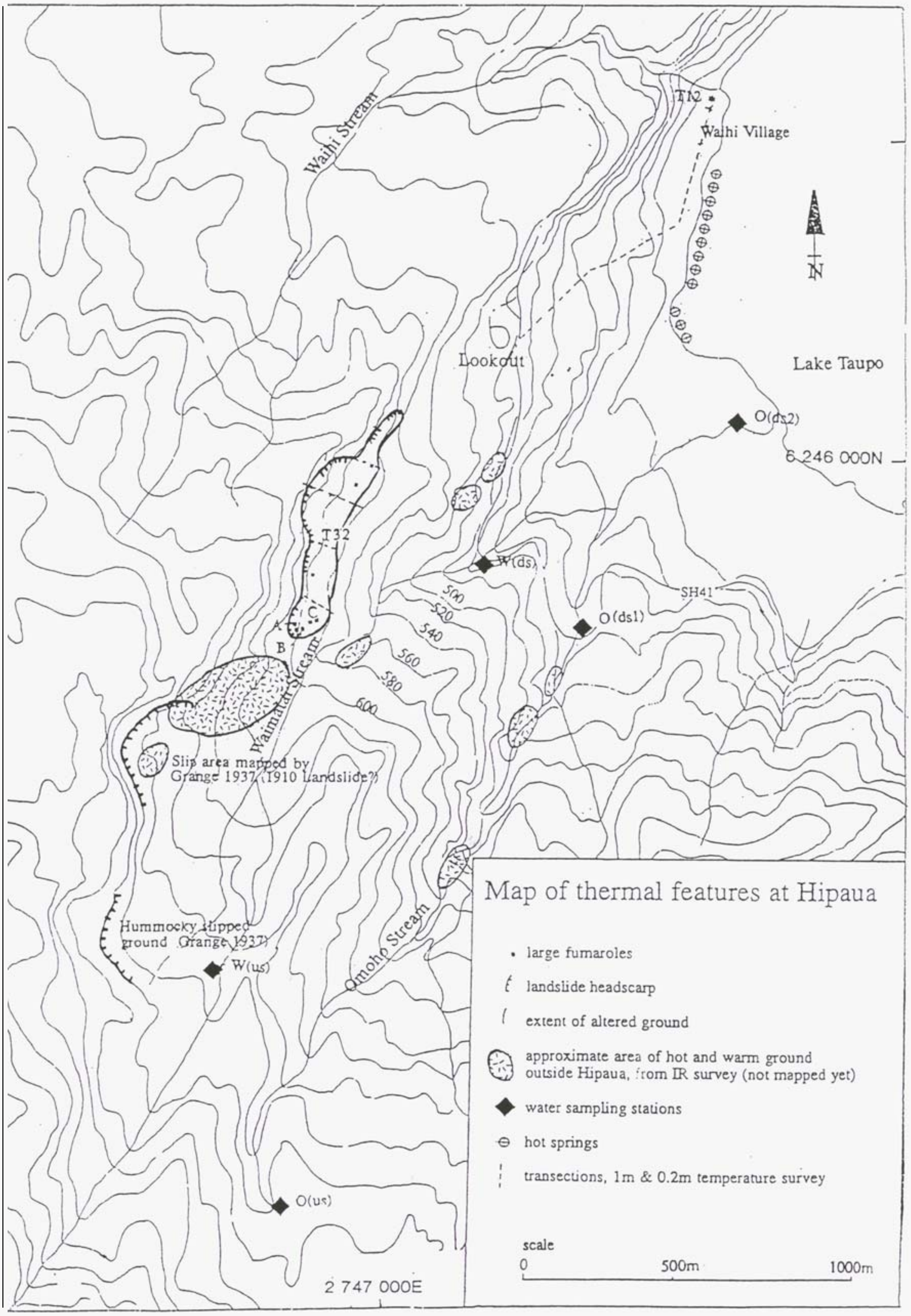

Figure 2: Map showing the extent of the Hipaua thermal area and areas of hot ground associated with the northwestern boundary of the Tokaanu-Waihi geothermal field.

andesitic complex (Grange, 1937). The top of the fault scarp can be recognised from the topographic contours shown in Fig. 2. The *scarp* also defines approximately the northwestern boundary of the Tokaanu-Waihi geothermal system which, according to older resistivity surveys, extends from the *scarp* about 5 km to the southeast (Banwell, 1965). The southwestern extent is unknown, but active surface manifestations in the map of Grange (1937) extend up to 3.5 km from the lake shore to the southwest.

The whole area is underlain by a coherent body of hot neutral chloride water which is discharged in the Tokaanu Domain; mixed hot water also discharges along the foreshore in Waihi Village (Fig. 2). The high chloride content of the unmixed waters (3g/kg) is anomalously high in comparison with that of other geothermal fluids discharged in the Taupo Volcanic Zone. The hot springs at the Waihi foreshore are associated with an outflow along the Waihi fault zone, although the water is significantly diluted (Mahon and Klyen, 1968). The Waihi fault probably consists of a broad fracture zone or a set of parallel fractures (Waihi fracture zone), as indicated by the width of the Hipaua thermal area and nearby patches of thermal ground, all of which show a NE alignment (see also Fig. 5).

Along several segments of the Waihi fracture zone, vapour ascends to the surface which originates from deeper boiling. Robinson and Sheppard (1986), using geochemical data, have argued that boiling might take place at depth, where a temperature of 190°C prevails. The steam condensates cause intensive alteration of the ground. The most active and altered segment is at present the 750 m long strip of the Hipaua thermal area. Some steam probably still ascends along another segment of the fault *scarp* about 0.5 km to the south west of the Hipaua area where a larger IR anomaly has been observed (see Fig. 2) although no steam can be seen today at the surface. The lateral extent of the hot and altered segments of the fracture zone may be controlled by cross faulting, as mapped by Prebble (1986). Erosion and ancient landslides have led to a quasi-stable surface slope of about 30' across the Hipaua thermal area resulting in an eroded fault *scarp*. Altered and unstable ground also occurs at the bottom of this *scarp* near State Highway 41 where thermally altered ground is exposed (see Fig. 2). The stability of the whole fault scarp is affected by local earthquake swarms, some occuring beneath the Tokaanu-Waihi geothermal reservoir (Sherburn, 1993).

Mapping thermal ground in the Hipaua area, and assessment of heat transfer

Until 1940, the Hipaua area was part of a Maori land block farmed by several families, and easily accessible. Since then, access has deteriorated due to rapid growth of trees and dense bush. The scarp to the southwest of the Hipaua area is now practically inaccessible. The area was mapped by establishing various fix points using satellite navigation and various transects linked by polygon traverses. Temperature measurements were taken at the surface, at 0.2 m and 1 m depth.

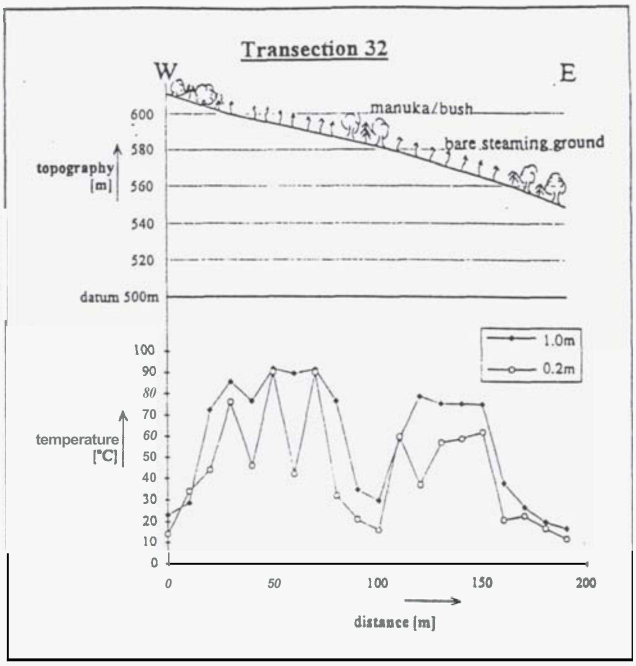

Figure 3: Ground temperatures at 1 and 0.2 m depth across the Hipaua thermal area along transect 32 (for location see Fig. 2).

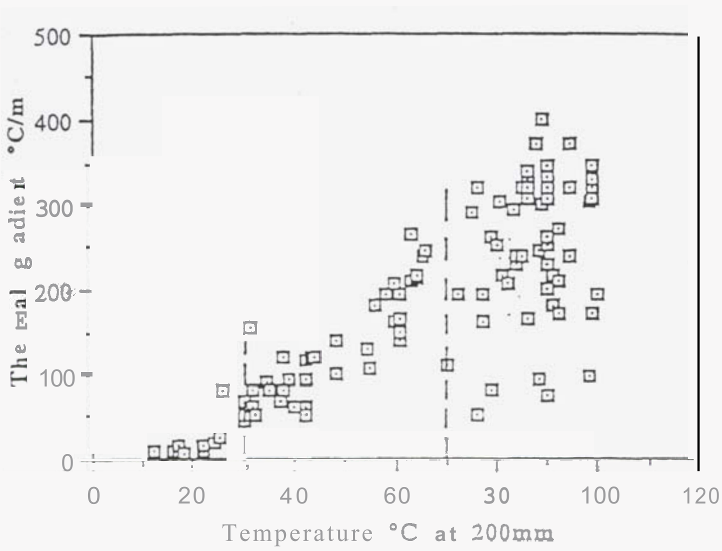

Figure 4: Temperature at 0.2 m versus temperature gradient between 0 and 0.2 m depth. The data for T <30°C occur on the fringe; those for 30°C < T ≤ 70°C were observed mainly in areas with stunted manuka; points for T > 70°C refer to mainly bare hot ground.

The extent of the hot ground is well defined by 1 m temperature profiles (see Fig. 3 for results from transect 32). Together with temperatures taken at 0.2 m depth, these data indicate areas with conductive and convective heat transfer at the surface. Stunted manuka shrubs (about knee height) predominate where the temperature at 1 m depth is between 30' and 60'; higher temperatures at this depth are associated with open, often bare ground, partly covered in grass and moss. Plotting the near-surface temperature gradient (0 to 0.2 m) versus temperature at 0.2 m depth showed that heat is transferred by conduction if T is <70°C;

only if T at 0.2 m depth **exceeds** 70°C does convective transfer occur, although conductive transfer is still significant. The data in Fig. 4 were used, together with appropriate thermal conductivity values, to assess the ***surface*** heat transfer.

Comparison with IR photos of the survey described by Bromley and Mongillo (1991) showed that significant IR anomalies are confined to ground where the temperature at 1 m depth is **>60°C**. Occasionally, isolated anomalies occur over hot ground covered by stunted manuka. However, the extent of hot ground is greater **than** that indicated by IR anomalies. No inference concerning ground affected by landslides *can* **be** made using **patterns** of IR anomalies.

An important finding resulted from a 1 m temperature survey obliquely **across** the Waihi fault *scarp* **from** the 'lookout' to Waihi village (T14 *to* T12, *see* Fig. **2).** Ground temperatures reduced for seasonal variations (McKenzie et al., this issue) are not more than 2°C above **mean** annual temperatures. The ground along the profile is unaltered at the surface. Anomalous temperatures, however, occur again in Waihi Village, reflecting the effect of the subsurface flow of hot water discharged along the foreshore. Apart from the small patch of altered ground near State Highway 41 mentioned earlier, the *scarp* between the northern end of the Hipaua area and Waihi is apparently not greatly affected by concealed *steam* discharge.

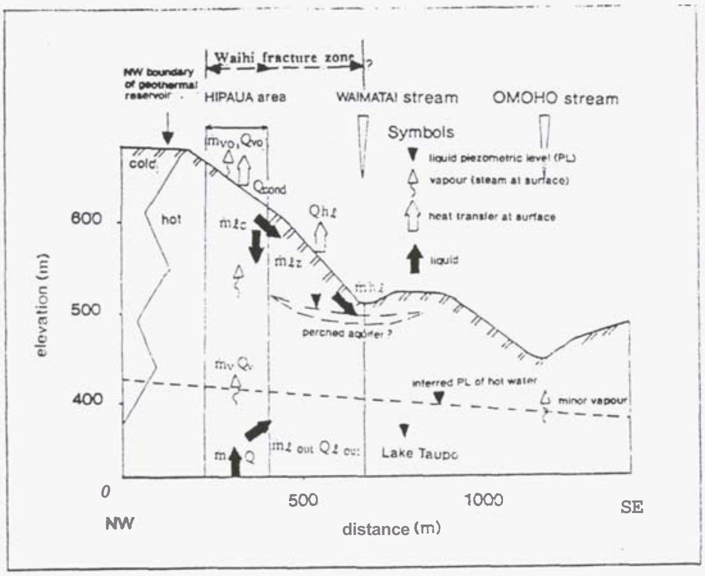

Figure 5: Simplified model describing heat and mass transfer of the Hipaua thermal area along **a NW-SE section.** Details of the parameters listed are given in Table 2.

The outstanding thermal manifestations of the Hipaua **area** are two larger fumaroles at the southwestern end, noted by Hochstetter when he visited the area in 1859. The largest fumarole (A in Healy's 1942 map) is called 'Hipaua' (i.e., 'the chimney'), and lent its name to the whole area of steaming ground. Condensates from this fumarole exhibit the largest δO^{18} shift (up to *5%)* **of** all fluids sampled in the Tokaanu-Waihi area by Robinson **and** Sheppard (1986). Recently we measured the output of the Hipaua fumarole with **a** pitot **tube** and a thermistor, using **a** method described by Dawson (1964). The inclination of the **steam** jet is 30' to the horizontal; the maximum **speed** was **42** m/s (T_{max} = 98.5°C). The ***total*** heat discharged **was** about 1.4 MW on 14.9.94. The output of another nearby fumarole (B in Healy's 1942 map) was about 1.0 MW (v_{max} ≈ *26* m/s; T_{max} = 97°C). A fumarole of intermediate size (C in Healy's map) discharges 0.2 MW and occurs close to several smaller, hot acid (pH = **2.5)** pools which **drain** into a larger, ephemeral pool. One of the hot pools **has** been sampled with the surprising result that it contains a significant amount of chloride (~40 mg/kg). Numerous smaller steam vents occur over bare hot ground along the whole Hipaua thermal area; all ***those*** with audible **steam** discharge (v ≥10 m/s) were mapped in 1993 (n = **46).**

The total area of the Hipaua thermal ground is therefore **about** 70,000 m^2; total heat transfer is about 21 MW of which 5 MW (hot pools and fumaroles) result **from** a direct discharge of ***steam*** at the surface causing the visible ***steam*** clouds along the scarp. Various modes of heat transfer are listed in Table 1. The output values cited are conservative estimates; the uncertainty is large - probably about ±5 MW for the total. The largest portion of discharged heat results **from** shallow condensation of steam; a minor portion of the condensates is discharged by small springs **at** the foot of the ***scarp;*** most of the condensates are drained by subsurface channels and are discharged into the Waimatai **stream. Stream** gauging and chemical analysis showed **that,** at the end of an extensive drought in April 1994, about **3.5** kg/s of slightly acidic, almost non-mineralised, condensates entered the Waimatai **stream.** The condensation of 15 MW **steam** would produce about **6.6 kg/s** of condensates, with about half being discharged into the creek. The remainder probably drains back into the reservoir. Assuming that flashing of ***steam*** occurs at about 190°C beneath the Hipaua **area,** a heat and mass transfer mechanism **as** shown in Fig. ***5*** is indicated, and described in more detail in Table **2.** Conservation of energy and mass indicates that a vertical **vapour** flow of **8.5** kg/s requires a horizontal outflow of about **40** kg/s of hot water **(towards** Waihi village?).

Landslides from the Waihi fault scarp

Minor slope movement occurs along **the** whole Hipaua segment of the fault scarp, and during 1993 and 1994 this caused smaller fresh head scarps and minor displacements at the bottom. The movement is presently being monitored at 17 **fixed** stations (steel rods ***to*** **2** m depth). The intensely altered ground and the high moisture content of the clay-rich soils saturated with condensates facilitates downslope movement. The concave embayment **associated** with a steep head scarp in the centre of the Hipaua area is the result of at least one older landslide, also indicated by hummocky ground further downslope. The historic landslides mentioned *in* the introduction, however, did not originate from the **Hipaua area.**

Table 1: Heat output of Hipaua thermal area

Type	*Mode*	*Area* *(E3 m^2)*	*Output* *(MW)*
warm ground (manuka on fringe)	conductive	20	~1
hot ground (stunted manuka)	conductive	40	8.5
hot bare ground	conductive & convective	10	~5.5
hot pools	evaporation	–	1
fumaroles and steam vents	direct discharge	–	4
outflow of condensates	direct discharge and conductive	–	1.2
Total	–	70	21.2

Table 2: Parameters of heat and mass transfer of Hipaua thermal area (see Fig. 5)

Parameters:	Q	=	heat transfer rate (MW)
	m	=	mass transfer rate (kg/s)
	h	=	enthalpy (kJ/kg)
Subscripts:	v	=	vapour (steam at surface)
	ℓ	=	liquid
	cond	=	heat transferred by condensation (i.e. Q_{cond})
Modifying subscripts:	o	=	pertaining to surface
	c	=	condensate
	z	=	downward flowing condensates
	h	=	horizontal flowing condensates
	out	=	deep outward flowing liquid after flashing

The following numerical values are indicated:

$Q_{cond} = \dot{m}_{\ell c}(h_v - h_\ell) = \underline{15\ MW}.$

$\dot{m}_{\ell c} = 6.6$ kg/s;

$\dot{m}_{\ell h} = \underline{3.5\ kg/s}$; $\dot{m}_{\ell z} \approx 3.1$ kg/s.

$Q_{\ell c} = \dot{m}_{\ell c}(h_\ell - h_{\ell o}) = 2.3$ MW.

$Q_{vo} = \underline{5\ MW}.$

$Q_v = Q_{cond} + Q_{vo} + Q_{\ell c} = 22.3$ MW.

$\dot{m}_v = \dot{m}_{vo} + \dot{m}_{\ell c} = 8.5$ kg/s.

$\dot{m} \approx 48.5$ kg/s; $\dot{m}_{\ell\ out} \approx 40$ kg/s

(steam fraction y for flashing of hot water at 190°C = 0.176;
observed parameters are underlined.)

Old photographs cited in Crampton (1993) show, for example, that the 1910 landslide most likely started from the quasi-circular embayment of the fault scarp about 0.5 km SW from the Hipaua fumarole (Fig. 2). The area was mapped as a 'slip area' by Grange (1937) when it was still accessible. A cluster of IR anomalies occurs close to the area (see Fig. 2). Because of access problems we have not been able to reach this slip area, but intensely altered cold ground was found about 0.3 km SW from the Hipaua fumarole. It is possible that the 1846 landslide also originated from another area further to the SW from the 1910 slide which now appears to be cold.

Discussion

The Hipaua thermal area is presently the most active area of the Tokaanu-Waihi geothermal field. It is associated with the tectonically-active Waihi fault zone and occurs along a 750 m segment of the eroded fault scarp. The area consists of 70,000 m^2 of hot ground, and includes 10,000 m^2 of steaming ground. The total surface heat output is of the order of 21 MW, of which 5 MW are discharged directly by steam. The area is unstable, and was probably the source area of a smaller, ancient landslide. The heat output is maintained by a constant deeper vapour flux of 8.5 kg/s. Steam condensates maintain a high saturation of the intensely altered ground even during a period of drought. The hot ground at Hipaua is significantly greater than that indicated by infra-red anomalies. The study has shown that detailed ground temperature surveys are required for the evaluation of infra-red anomalies observed in a similar setting.

Acknowledgment

The authors express their appreciation to all people and organisations who helped and supported this study: Sir Hepi Te Heu Heu, Whanaunga of Ngati Turumakina, Ngati Tuwharetoa Maori Trust Board, Department of Conservation, ECNZ Wairakei, Environment Waikato, WORKS Geothermal.

References

Banwell, C.J. (1965). Tokaanu/Geophysics. In: Thompson, B.N., Kermode, L.D., Ewart, A. (Eds.): New Zealand Volcanology - Central Region. DSIR Information Series 50: 152-155.

Bromley, C., Mongillo, M. (1991). Infra-red video survey of Tokaanu-Waihi Geothermal Field. Proc. 13th NZ Geothermal Workshop, The University of Auckland, 27-32.

Crampton, C.J. (1993). Transit New Zealand SH41: RP37/13.3 - Waihi Hill Landslide. Unpublished Geotechnical Investigations Report No. 1787, Works Consultancy Services, Hamilton, 11 pp.

Dawson, G.B. (1964). The nature and assessment of heat flows from hydrothermal areas. NZ J. Geol. and Geophysics 7: 155-171.

Grange, L.I. (1937). Geological map of Puketi and Omoho survey districts. In: The Geology of the Rotorua-Taupo Subdivision. Geol. Survey Bull. 37, NZ DSIR, Wellington.

Healy, J. (1942). Boron in hot springs at Tokaanu, Lake Taupo. NZ J. Science and Technology 24: 1-13.

v. Hochstetter, F. (1959). Geology of New Zealand. Contributions to the geology of the provinces of Auckland and Nelson (transl. by C. Fleming). Govt. Printer, Wellington, 320 pp.

Mahon, W.A.J., Klyen, L.E. (1968). Chemistry of the Tokaanu-Waihi hydrothermal area. NZ J. Science 11: 140-158.

Mackenzie, K.M., Browne, P.R.L., Hochstein, M.P. (1994). Changes in thermal activity of the northern Te Kopia geothermal field (NZ) during 1993-94. Proc. 16th NZ Geothermal Workshop, The University of Auckland.

Prebble, W.M. (1986). Geotechnical problems in the Taupo Volcanic Zone. In: Gregory, J.G., Watters, W.A. (Eds): Volcanic hazard assessment in New Zealand. NZ Geological Survey Record 10: 65-80.

Robinson, B.W., Sheppard, D.S. (1986). A chemical and isotopic study of the Tokaanu-Waihi geothermal area, New Zealand. J. Volc. Geotherm. Research 27: 135-151.

Severne, C.M. (1993). Thermal mapping of Hipaua steaming ground (Tokaanu-Waihi system). Unpubl. Project Report 93.23, Geothermal Institute, lodged with the Library, The University of Auckland.

Sherburn, S. (1993). The 1987 January Tokaanu earthquake sequence, New Wand. NZ J. Geol. and Geophysics 36: 61-68.