GROUNDWATER CONTRIBUTIONS TO WAIKITE GEOTHERMAL FLUIDS

M.K. STEWART

Institute of Geological and Nuclear Sciences, Lower Hutt, NZ

SUMMARY - Isotopic data are reported for hot springs in the Waikite area. The data, along with chemical data, are used to produce a consistent interpretation of mixing between deep chloride water and groundwater, with some samples being affected by evaporation after rising to the surface. The constant ratio between chloride and bicarbonate concentrations shows that mixing takes place at depth before any boiling occurs. Reservoir temperatures are assessed using the KMg geothermometer. Tritium concentrations in springs with the highest temperature reservoirs are non-zero indicating a small input of 1960's water. Groundwater downflow from the nearby Paeroa Range is inferred. The weight of evidence supports the springs being a peripheral outflow on the margin of the Waiotapu system rather than being genetically related to Te Kopia.

1.0 INTRODUCTION

Hot springs from the Waikite thermal area (Fig. 1) have been exploited for tourism and for thermal pools. The springs discharge copious amounts of chloride-bicarbonate waters with relatively low chemical concentrations (chloride < 250 mg/kg), at up to boiling temperatures.

This survey was initiated to investigate the hydrology of the Waikite system and its relationship to surrounding areas using isotopic data, as part of a multidisciplinary study of protected geothermal areas (Waimangu and Waiotapu) south of Rotorua. This paper gives a preliminary account of the data.

The spring waters have not been definitely related to any of the nearby geothermal areas (eg Waiotapu or Te Kopia /Orakeikorako), although their chemical characteristics.were thought to be more similar to those of the latter areas (Ellis and Mahon, 1977). In recent years, several papers have discussed the origin of the springs. Broadly, Glover *et al.* (1992a) and Bromley (1992) favoured a link with Te Kopia, while Giggenbach et al. (1994) and Bibby *et al.* (1994) see the system as an offshoot of the Waiotapu system.

2.0 SETTING

The volcanic region of the central North Island occupies a basement depression bounded by north-north-east trending faults (the Taupo Volcanic Zone). The basement structure is that of tilted blocks with northeast trending faults on the eastern margins and basement depth decreasing to the west. The Paeroa Fault *scarp* in the Waikite area terminates the Paeroa block where basement rises close to the surface. Hydrothermal activity occurs at several places along the fault; i.e. Puakohurea, Waikite, Te Kopia, Orakeikorako. South of Te Kopia, the Paeroa Fault splits into numerous southwest trending faults of small displacement.

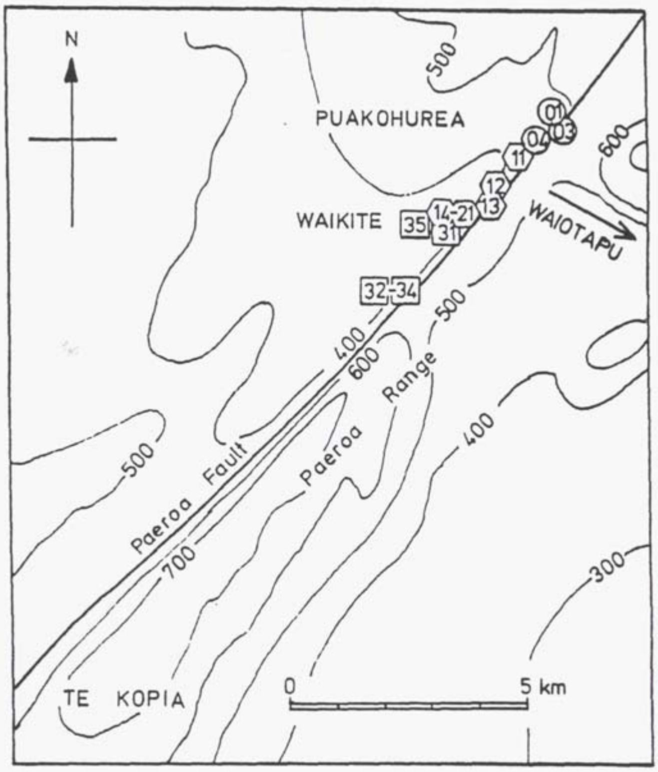

Figure 1 - Map of Waikite area showing sampling locations, the Paeroa Fault trace and topographic contours in m above mean sea level.

The topography reflects the underlying structure, with the Paeroa Range and Maungaongaonga east of the Paeroa Fault being dominant features. Downthrow on the fault in this area is 125 m. Waikite springs emerge at the foot of Paeroa Fault. The Waiotapu system lies 5 km to the east, with many of its chloride springs occupying a topographic low west of the Kaimanawa Fault. To the southwest are the low-chloride steam-heated springs of Te Kopia (at a distance of 12-15 km from Waikite). Orakeikorako geothermal area lies further southwest along the fault.

3.0 SAMPLING

Water samples were collected from all of the known springs in the district by Glover *et al.* (1992b), who also clarified the naming and location of individual springs. Isotopic results for a representative collection of their samples are given in this paper. Sample locations are marked in Fig. 1. The springs are distributed along the Paeroa Fault with numbers 01 - 04 in the north (Puakohurea), 11 - 21 in the centre and 31 - 34 in the south. Sample 35 is from the stream draining the central area. The names of the springs are given in Table 1.

4.0 RESULTS

The isotopic and chemical results are given in Table 1 and selected plots in Figs 2, 3, 4, 5 and 6. Chloride and bicarbonate concentrations show a linear relationship (Fig. 2), which can be explained by dilution and cooling of a deep chloride water. Bicarbonate is formed by reaction of dissolved CO_2 with rock as a result of cooling by dilution with groundwater (Giggenbach, 1985; Stewart et *al.*, 1992). The important point is that dilution must occur before steam (and CO_2) is lost from the deep fluid in order that the HCO_3/Cl ratio be constant. Alternative explanations, such as dissolution of CO_2 from steam in groundwater would not yield the linear relationship observed in Fig. 2, although dissolution of steam may be the explanation for the more variable ratios of samples 01-04, which have lower chloride concentrations. The slope of the line gives a molar ratio of CO_2/Cl of 1.4 for the deep water. Springs from the central region (Scalding, Waikite Scarp and Waikite Springs) have the highest chloride and bicarbonate concentrations, and therefore contain the greatest proportions of deep water.

The trilinear plot of Na, K, Mg concentrations (Giggenbach, 1988) gives an indication of subsurface reservoir temperatures. Fig. 3 is a modified plot which is more suitable for lower temperatures (W.F. Giggenbach, pers. comm.). NaK temperature estimates are based on the slower reacting NaK geothermometer and represent deeper reservoirs, possibly of the deep chloride water identified above. All samples within the full to partial equilibrium region of Fig. 3 have NaK temperatures in the range 160-

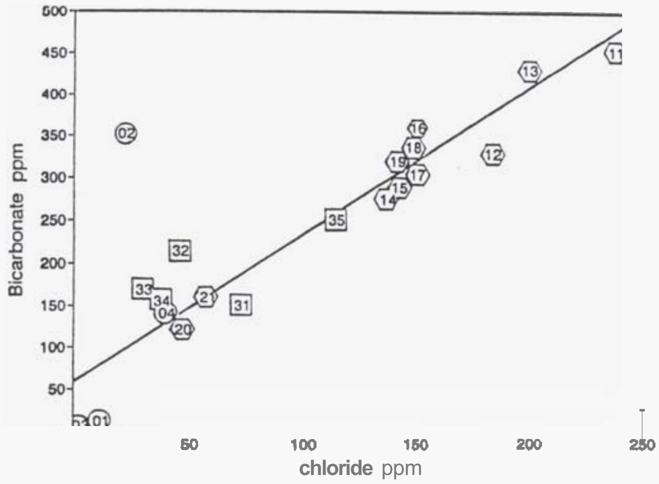

Figure 2 - Chloride versus bicarbonate concentrations for Waikite spring waters.

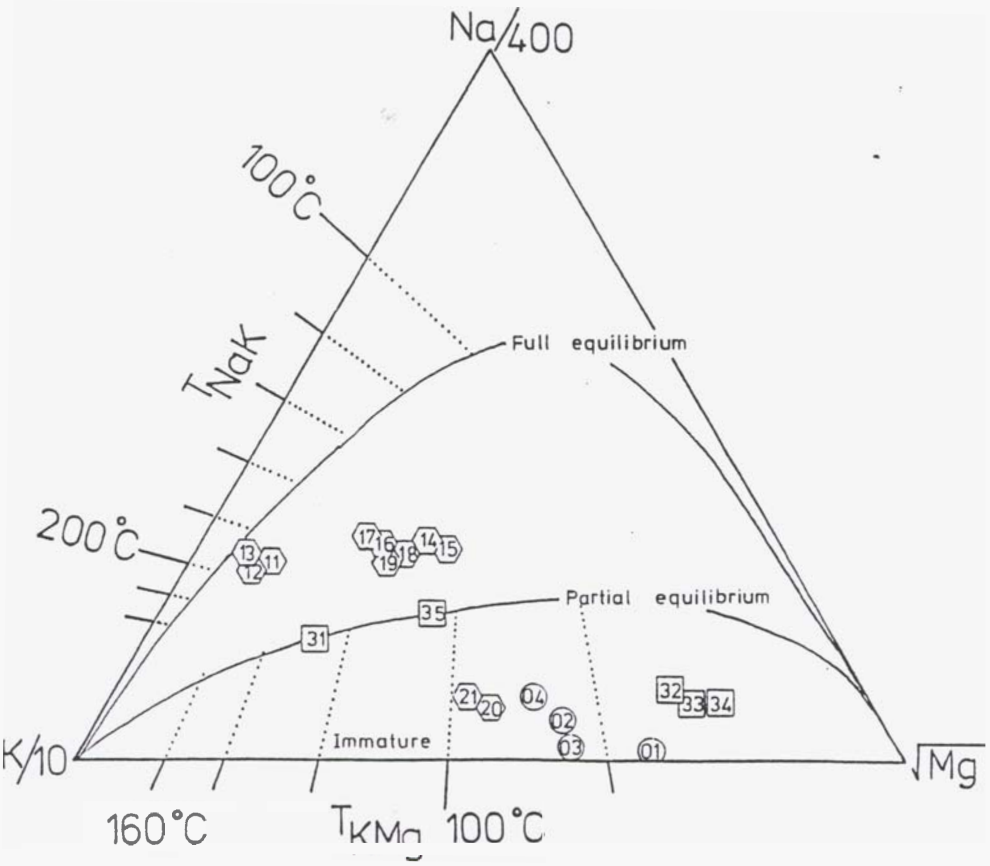

Figure 3 - Trilinear diagram of Na, K, Mg concentrations. The curved lines show full and partial equilibrium of water with average rock compositions.

Table I - Isotope and chemical data from the Waikite Geothermal System.

No.	Source No.	Date mm/dd/yy	Temp ("C)	Cl mg/kg	HCO_3 mg/kg	SO_4 mg/kg	$\delta^{18}O$ (‰)	δD (‰)	Tritium (TR)
	Puakohurea Lake								
01	S5640	08/30/91	12.6	7	11	8	-6.60	-40.3	
02	S5638	08/30/91	47.6	22	352	14	-7.03	-44.0	
	Cold, Gassy Spring								
03	S5646	12/17/91	15.9	6	10	174	-6.88	-41.8	
	Submerged Spring								
04	S5632	08/30/91	40.6	40	142	16	-6.66	-43.8	
	Scalding Spring								
11	S5644	08/30/91	89.3	237	454	45	-5.29	-43.2	0.184±0.018
	Waikite scarp Springs								
12	S5665	08/30/91	98.1	183	330	42	-5.78	-39.9	
13	S5651	08/30/91	85.5	199	432	46	-5.88	-48.2	0.243 ±0.023
	Waikite springs								
14	S5598	12/18/91	98.6	140	278	38	-6.52	-42.1	
15	S5597	12/18/91	97.7	141	287	39	-6.50	-42.9	
16	S5580	01/17/92	97.5	150	361	39	-6.20	-42.7	0.226±0.021
17	S5585	01/17/92	98.9	146	300	38	-6.53	-41.4	
18	S5586	01/21/92	99.5	145	338	39	-6.37	-42.1	
19	S5595	02/03/92	99.4	144	321	34	-6.37	-42.0	
20	S5576	04/01/92	19.4	47	122	16	-6.12	-38.3	
21	S5577	04/01/92	33.4	58	161	16	-6.15	-40.8	
	Tree Spring								
31	S5567	01/21/92	50.2	73	152	24	-6.77	-41.9	
	Te Waro Scarp Springs								
32	S5558	12/18/91	38.7	44	215	3	-7.02	-44.5	
33	S5555	12/18/91	37.1	36	170	6	-7.02	-44.8	
34	S5554	12/18/91	37.0	36	156	7	-7.01	-43.3	
	Otamakokore Stream at Corbett Road Bridge								
35	S5566	02/25/92	53.8	114	252	31	-6.00	-40.3	

200 °C. Samples lying in the immature region would be xpected to have less reliable NaK temperatures. The more apidly reacting KMg geothermometer indicates temperatures n reservoirs nearer the surface, but before any boiling has ccurred. The Puakohurea springs (01-04) lie in the mmature region of the plot and have KMg temperatures less han 100 °C. Scalding and Waikite *Scarp* Springs (11-13) lie lose to the full equilibrium line with KMg temperatures of 60 °C. Waikite Springs (14-19) have KMg temperatures of 00-120 "C, except samples 20 and 21 which are more ilute and have lower temperatures. Tree Spring (31) dicates a higher KMg temperature, probably before dilution on the way to the surface. Te Waro *Scarp* Spring waters have low KMg temperatures (60-80°C). The stream water sample (35) reflects outflow from the central region. Silica temperatures were discussed by Giggenbach *et al.* (1994). Silica concentrations are not in equilibrium with quartz and show evidence of being influenced by amorphous silica.

Figs. 4 and 5 show plots of deuterium and chloride versus oxygen-18 concentrations. Rain and groundwaters plot on the meteoric water line (MWL) in Fig. 4 if they are not affected by evaporation. Samples 01-03 and 31 -34 plot close to the MWL in agreement with their low chloride concentrations. The other samples plot to the right of the MWL, showing that they either contain significant amounts of oxygen-18 enriched deep water (as deduced from Fig. 2), or have been affected by evaporation which preferentially enriches oxygen-18 compared to deuterium, or both. A mixing line between groundwater and deep water (solid) is shown on the plot. The deep water is assumed to be enriched in both oxygen-18 and deuterium compared to the groundwater, but its actual composition is unknown at present. Since some of the springs are derived from subsurface water reservoirs with temperatures above 100°C, steam will be lost as the waters rise to the surface. The effect of this evaporation is shown by the dotted line for sample 11. Equivalent mixing and evaporation lines are shown in Fig. 5.

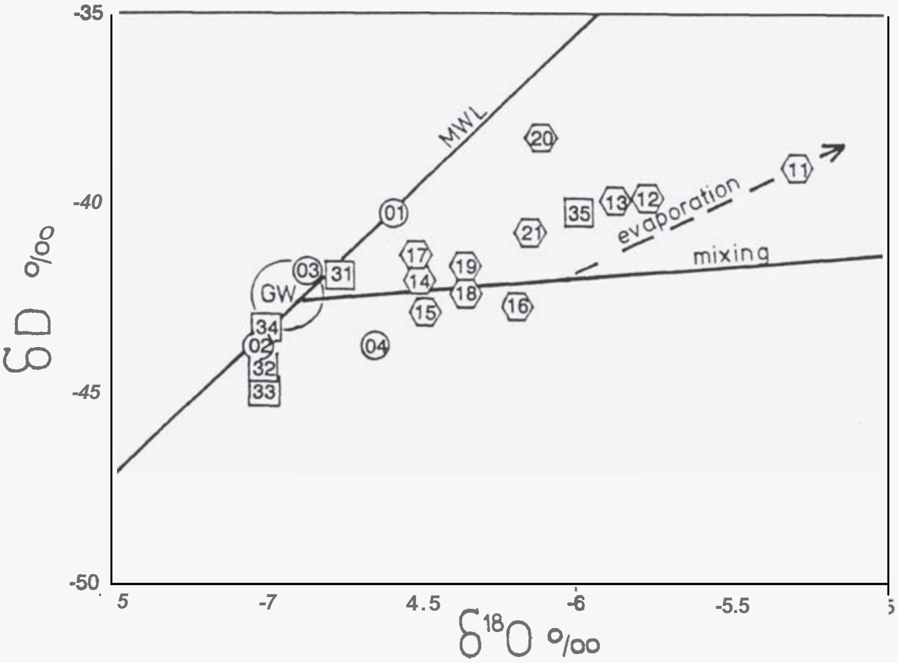

Figure 4 - Stable isotope plot for hot springs from the Waikite geothermal area. The plot shows the meteoric water line (MWL) and mixing and evaporation lines.

A few measurements of tritium concentration are available (Fig. 6). The results for what are the hottest sourced springs are low but clearly non-zero (our zero water standard has a mean of TR = 0.004 ± 0.024 for repeated measurements). A tentative mixing line is drawn through these data to represent mixing between tritium-bearing groundwater (TR = 0.4) and deep chloride water (TR = *0*). A tritium ratio of 0.4 indicates that a small proportion of rainwater from the high-tritium years (1960's) following atmospheric testing of nuclear weapons is likely to be present; pre-bomb water would now have TR < 0.2.

It is instructive to compare these results with those for Rotorua (Stewart *et al.*, 1992). At Rotorua, tritium concentrations in the thermal waters were very low (TR < 0.1) in areas identified as upflow areas (i.e. the chloride-rich east side of the system, and the Kuirau area), but had measurable concentrations (TR up to *0.96)* in chloride-bicarbonate waters in a central north-south zone. The latter showed input of tritium-bearing groundwater from above. At Waikite therefore, it is likely that groundwater penetrates from above, probably from the high side of the Paeroa Scarp or Maungaongaonga to dilute water, that is probably already diluted *compared* to Waiotapu fluid.

5.0 DISCUSSION

Giggenbach *et al.* (1994) gave a thorough evaluation of the geochemistry of the Waikite waters in relation to deep Waiotapu water (as derived from the highest chloride spring, Champagne Pool). Deep Waiotapu water was found to have Cl = 1250 mg/kg, $\delta^{18}O$ = -2.5‰ and δD = -40‰, giving a relatively large ^{18}O shift of 4.5%. At Cl = 250 mg/kg, the Waikite ^{18}O shift is 1% (Figure 4), so if the deep ^{18}O shift were 4.5‰ the corresponding chloride content would be 1125 mg/kg, in good agreement with the deep Waiotapu

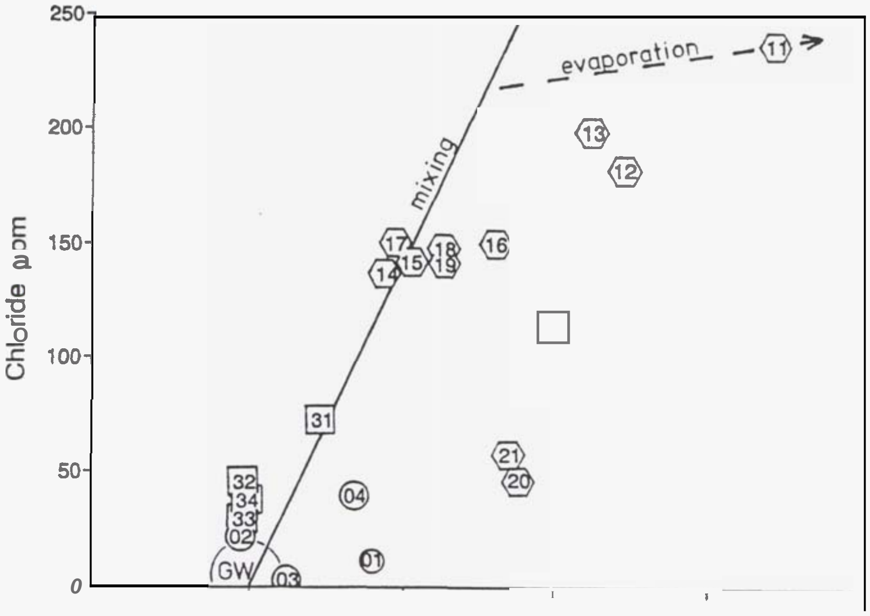

Figure 5 - Plot of chloride versus oxygen-18 for Waikite hot springs. Mixing and evaporation lines are shown. GW is the mean groundwater composition.

water composition. Thus the geothermal water feeding Waikite could very well be like that at Waiotapu. The observed composition of Waikite water then indicates at least *80%* dilution of the deep wafer with groundwater.

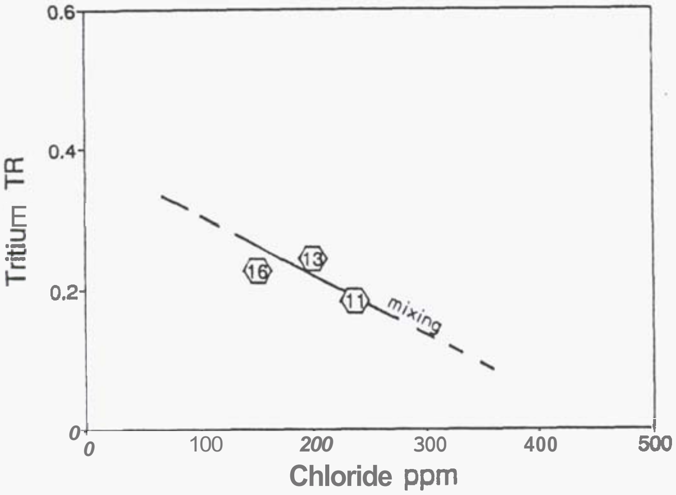

Figure 6 - Tritium **versus chloride** composition for **Waikite** hot springs. A mixing line is shown.

Compared to Waiotapu water, Waikite waters are depleted in Rb (and in some cases **Cs)** suggesting increased uptake of these in clays at the latter area (Glover *et al.* (1992); Giggenbach *e?al.* (1994)). The Cl/B and Cl/As ratios of the two areas are similar.

Waikite waters are similar to those at Te Kopia and Orakeikorako in terms of their low mineralisation and similar Cl/HCO_3 ratios. It is suggested that this may arise from their similar geologic and topographic settings, rather than being due to any actual connections between the areas.

On geophysical grounds, Bromley (1992) suggested there was a link between the Waikite and Te Kopia areas. However, Bibby *et* al. (1994) identified a low resistivity lobe fiom the Waiotapu low extending towards Waikite and suggested that the same deep source feeds both Waiotapu and Waikite.

Evidence supporting a common source for Waikite and Waiotapu geothermal fluids includes the following:

1) Distance. Waiotapu (at **5 km)** is much closer to Waikite than Te Kopia **(12** km).

2) Topography. Thermal water will tend to flow from topographic highs to lows (i.e. to outflow points at Waikite and Southern Waiotapu) rather than from low to low (e.g. from Te Kopia to Waikite).

3) Stable isotopes and chloride. The oxygen-18, deuterium and chloride concentrations at Waikite are consistent with groundwater dilution of deep chloride water feeding Waiotapu. About *80%* dilution is indicated.

4) Geochemical ratios. Ratios of chemical constituents are consistent with the same source for Waiotapu and Waikite fluids.

5) Chloride and bicarbonate concentrations Deep groundwater dilution is indicated by the linearly related Cl and HCO_3 concentrations.

6) Tritium concentrations. Input of tritium indicates groundwater dilution. If water had flowed **from** Te Kopia to Waikite, little dilution is required and no tritium would be expected.

7) Resistivity contours. Resistivity contours over the area show a pronounced lobe extending **fiom** Waiotapu towards Waikite.

6.0 ACKNOWLEDGEMENTS

I thank Mr Lew Klyen for collection of much of the samples and for assistance with the remainder. The Foundation for Research Science and Technology is acknowledged for funding this research.

7.0 REFERENCES

Bibby, **H.M.** ,Bennie, **S.L.**, Stagpoole, V.M. and Caldwell, **T.G.** (1994). Resistivity structures of the Waimangu, Waiotapu, **Waikite** and Reporoa geothermal areas, **New** Zealand. *Geothermics* (accepted for publication).

Bromley, **C.J.** (1992). Waikite-Te Kopia: **The missing** link? ***Proc. 14th New Zealand Geothennal Workshop*,** Auckland, **NZ.** Pp. 217-222.

Ellis, A.J., and Mahon, **W.A.J.** **(1977).** Chemistry *and geothennal systems.* Academic Pres, New York.

Giggenbach, W.F. (1988). Geothermal solute equilibria: Derivation of Na-K-Ca-Mg geoindicators. *Geochimica et Cosmochimica Acta 52*, 2749-2765.

Giggenbach, W.F., and Glover, R.B. (1992). Tectonic regime and major processes governing the chemistry of water and gas discharges fiom the Rotorua Geothermal Field, New Zealand. *Geothennics 21,* 121-140.

Giggenbach, W.F., Sheppard, **D.S.**, Robinson, **B.W.**, Stewart, M.K. and **Lyon, G.L.** (1994). Geochemical structure and position of the Waiotapu Geothermal Field. New Zealand. *Geothermics* (submitted).

Giggenbach, W.F., and Stewart, **M.K.** (1982). Processes controlling the isotopic composition of **steam and** water discharges from steam vents and steam-heated pools in geothermal areas. *Geothennics 11,* 71-80.

Glover, R.B., Klyen, **L.E.** and Crump, **M.E.** (1992). The location and chemistry of natural features in the Waikite

Geothermal system. *DSLR Chemistry Technical Report No. 92/14.* 68 p.

Glover, R.B., Klyen, L.E. and Crump, M.E. (1992). Spring chemistry of the Waikite-Puakohurea Thermal Area. *Roc. 14th New Zealand Geothermal Workshop,* Auckland, NZ. Pp. 63-72.

Stewart, M.K., Lyon, G.L., Robinson, B.W. and Glover, R.B. (1992). Fluid flow in the Rotorua Geothermal Field derived from isotopic and chemical data. *Geothennics 21,* 141-163.