CHANGES IN MAJOR GAS CONCENTRATIONS IN THE KARAPITI THERMAL AREA IN RESPONSE TO DEVELOPMENT AT WAIRAKEI

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SUMMARY - The Karapiti Thermal Area is part of the Wairakei Geothermal Field and contains numerous steam-dominated features in an area of approximately 3 km^2. Since 1952 there have been many changes to the surface features and thermal activity at Karapiti related to the development-induced pressure drawdown over most of the field. The hot chloride water originally underlying Karapiti has been replaced by a greatly expanded steam cap fed by a large low pressure steam zone in the Wairakei reservoir. There have been intermittent chemical surveys of the steam vents at Karapiti since 1951, with major chemical surveys undertaken in 1961 and 1990. In 1990, the concentrations of CO_2 were found to be about double the 1961 values. Of particular interest is the change between 1936 and 1987 in gas chemistry of the main Karapiti feature, the Karapiti Blowhole which follows the change in heat flow from the Karapiti Thermal Area. ***Since 1990, the gas concentrations appear to be dropping to low, pre-development levels, most likely due to the decreasing pressures in the lower pressure steam zone.***

1. INTRODUCTION

The Karapiti Thermal Area, also known locally as "Craters of the Moon" is part of the Wairakei Geothermal Field. It is located about 3 km south of the main production borefield (Fig. 1) and has an area of roughly 3 sq km. The Area contains hot ground, numerous fumaroles and steaming craters which, at times, contain boiling mud pools. The original heat source for Karapiti is believed to be hot fluid moving laterally from the vicinity of the borefield into a dome structure known as the Karapiti Rhyolite. Beneath the Area the Huka Mudstones which forms the cap-rock over most of the field is absent and the rhyolite dome is in direct contact with two relatively permeable layers: the Oruanui Ignimbrite, and the surface layer of Taupo Pumice. It is this structure of rhyolite dome aquifer in direct contact with permeable surface layers that accounts for the hot ground and surface activity at the Karapiti Thermal Area (Grindley, 1965; Allis, 1979, 1981).

Karapiti owes its present state to the development and use of the Wairakei Geothermal Field, since 1952. Before development, most of the heat and mass loss from Karapiti was through a powerful steamjet known as the Karapiti Blowhole. This fumarole, located at the northern perimeter of the area, gradually diminished in strength, finally ceasing to flow in February 1987 when its vent was blocked by the collapse of the roof of the steam conduit. This event simultaneously opened up a new steam vent above the collapsed roof (Mongillo and Allis, 1988).

Previous studies of the area have concentrated on heat flow and temperature measurements (Fisher, 1964; Thompson, 1959, 1960; Dickinson, 1964, 1968; Dawson and Dickinson, 1970; Allis, 1979 and 1981; Mongillo and Allis, 1988), and the investigation of hydrothermal eruptions or the activity of a particular feature (Ledger, 1950; Banwell, 1954; Dickinson, 1961; Allis, 1984). The earliest comprehensive chemical survey of 26 fumaroles in the area was undertaken by Glover (1961). Since then the chemistry of several features was monitored occasionally (including nine samples from the Blowhole between 1962 and 1987) but was not intensively surveyed again until 1990/91. Since that time two fumaroles were sampled in 1993 and 1994 as part of monitoring of thermal features in the Wairakei-Taupo area by the Waikato Regional Council. In 1998, further samples were collected from these same features as part of monitoring related to the operation of the McLachlan Power Station. This power station, which is located on the western periphery of the Wairakei geothermal field, began full scale operation in 1997 and taps the same low pressure steam zone that currently feeds the features at Karapiti and some low pressure, dry steam wells in the main Wairakei Borefield.

This paper presents these later data and in particular the results of a chemical survey of steam vents in the Karapiti Thermal Area during 1990. The purpose is to relate changes in gas chemistry to physical changes in the Wairakei geothermal field with time. As the carbon dioxide is usually over 95% of the gases in the fumarole steam, this paper focuses mainly on that gas. Other gases will be discussed in a further paper.

Figure 1. Map of Karapiti Thermal Area and Wairakei Borefield

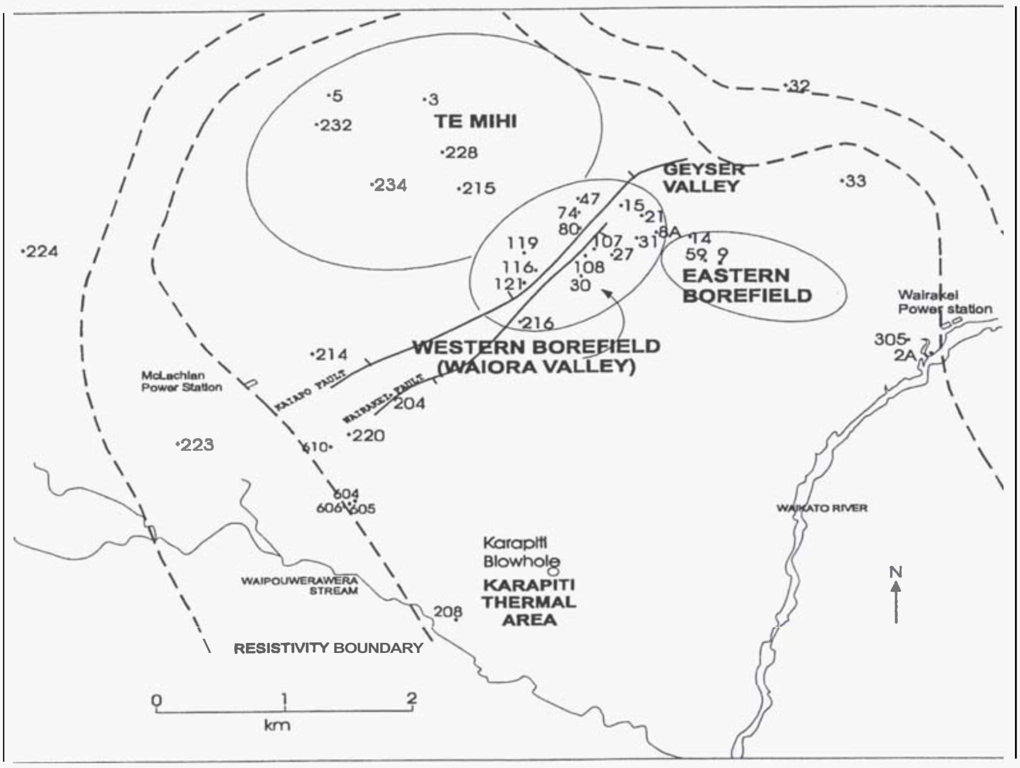
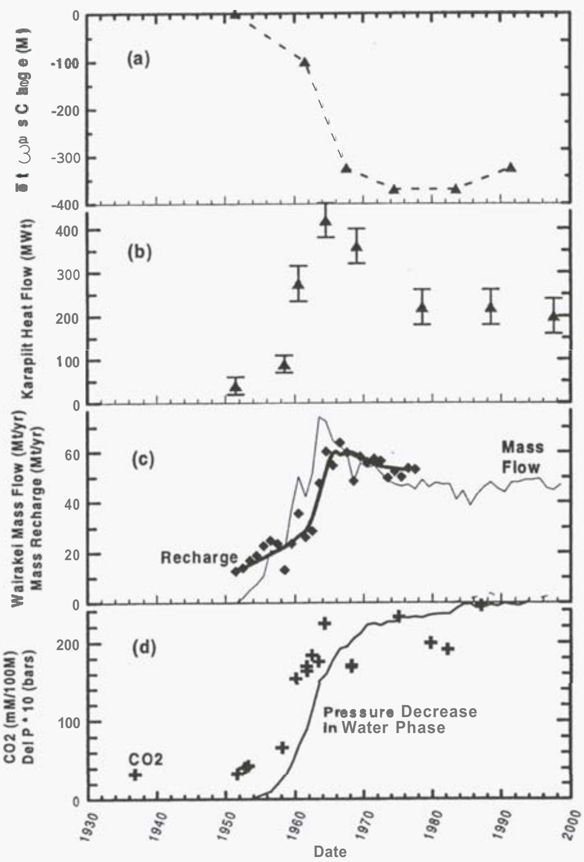


Figure 2. Karapiti Blowhole CO_2 concentrations and Heat Row and Wairakei Borefield Mass and Pressure Data



Year	Site Name	CO_2 (mmoles/100 Moles) of H_2O
1961	Fa	46
1975	Fa	252
1990	K-21	192
1961	Fd	48
1990	K-7	210
1961	Fe	51
1990	K-9	160
1961	Fj	9.1
1990	K-22	223
Aug 1993	K-22	187
Jun 1994	K-22	207
Apr 1998	K-22	34
Jul 1998	K-22	60
1961	Fk	13
1990	K-2	215
1961	Fp	9.7
1990	K-3	172
1961	Fq	52
1975	Fq	152
1990	K-19	152
1961	Fs	45
1990	K-10	203

Table 1. Major gas chemistry for 8 fumarole pairs from the 1961 and 1990 surveys as well as Fa and Fq from 1975 and K-22 from 1993 to 1998 at the Karapiti Thermal Area.

2. THERMAL ACTIVITY AND HEAT FLOW

In the natural state the main surface discharge of hot water at Wairakei was in Geyser Valley, near the northern edge of the Wairakei field (Glover,1977). Water also discharged through springs near the Waikato River. At higher elevations steam was discharged from Karapiti and the Upper Waiora Valley. In 1950, Karapiti was predominantly a warm, clay-soil area, with thermal activity restricted to relatively small zones of mudpools, hot ground, and one large fumarole (Karapiti Blowhole) with an output of 12 MW situated at the NE corner of the area. Some fluid drained into the Waipouwerawera Stream, approximately 1 km south of the Blowhole. The temperature of the Waipouwerawera was 45°C in 1961 and decreased to 24°C in the early 1970s. The deep hot water reached close to the surface at Karapiti as evidenced by up to 25 mg/l chloride measured in three of the pools in 1951. Water squeezed out of mud from a hydrothermal eruption at F715 in 1960 contained 840 mg/l chloride (Glover, unpub data). Layered silica ejected by the same eruption, also suggesting that water had flowed there in the past. Further evidence is obtained by comparing elevations of chloride springs in 1951. Karapiti Blowhole is at RL=450m. In the Waiora Valley springs discharging Chloride were found up to RL=446m (Cl=107mg/kg). The elevation of the Waipouwerawera stream south of Karapiti is approx. RL=415m.

The Wairakei bores began significant discharge in 1953 (Fig 2c). The annual mass discharge rose to a peak of 74 Mt (2900 MWt) in 1963, decreased to about 46 Mt in the mid 1970s. The natural discharge prior to exploitation was about 12.6 Mt/yr (Allis, 1981). The increased discharge, up to 6 times the natural discharge (and natural recharge) gave rise to a large imbalance between the discharge and recharge. One consequence of this was a drawdown of pressure (Fig 2d) and a decrease in the mass of fluid in the field. The nett mass change in the Wairakei reservoir as calculated from gravity changes (Hunt, 1995) is shown in Fig 2a. This indicates the formation of a larger steam zone than was earlier present. Enlargement of the steam zone and hence greater permeability enabled a greater flow of steam to the Karapiti area (Fig 2b).

Since 1953, dramatic changes in thermal activity have occurred at Karapiti. The formation of a new fumarole, and the spread of thermal ground was first noticed in 1954 (Banwell, 1954). Since then there has been a new hydrothermal eruption every 1 to 2 years. Heat flow in the Karapiti area increased from the pre-development value of 40 MW (thermal) in 1950 to 90 MWt in 1958 when the Wairakei Power Station began producing electricity. The heat flow was 275 MWt in 1961 and reached a maximum of 420 MWt in about 1964 (Allis, 1979). This dramatic rise was due to the pressure drawdown in the Wairakei reservoir (Allis, 1979 and 1981). After 1965, the heat flow gradually declined until it reached an estimated value of 220 MWt in 1978 and has not changed significantly since then. In contrast the total heatflow from surface features at Wairakei reached a maximum of 800 MWt in 1965 and has been decreasing steadily to reach 400 MWt in 1998 (Hunt et al., 1998).

The increased mass discharge and the pressure drawdown also stimulated an increase in mass recharge to the reservoir (Fig 2c). The increased recharge and discharge resulted in a reduction of the residence time of the fluid in the reservoir (about 1/6th of that in the natural state). The pressure in the low pressure steam zone as determined by WK205, WK214 and WK210 has decreased from c.20 b.a. in 1965 to c.12 b.a. in 1990 and 10 b.a. in 1997 (Contact Energy, 1999). The effects of these physical changes on the chemistry of the steam are discussed later.

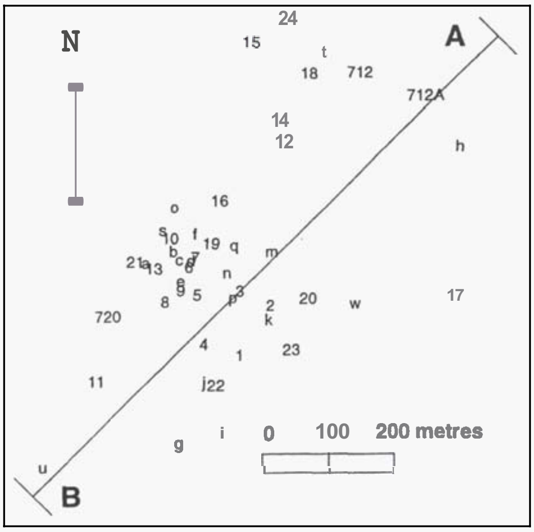
3. LINK BETWEEN ROGUE BORE AND KARAPITI

The base of the Huka Formation (the top of the steam cap) is above RL = 350m between WK 204 (the Rogue Bore) and Karapiti. The structural contours reveal a prominent plateau in the Huka Beds southwest of the borefield, and a slight anticline on this strikes southeast towards Karapiti. In May 1960, during drilling of WK204 control was lost and the well abandoned. WK204, known as the Rogue Bore, had an estimated heat output of 270 Mwt during its first few months (Banwell, 1960). In January that year the temperature of the Blowhole was 119°C. This declined to 117.4°C on 25 May and to 114°C in August 1960 (Dickinson, 1961). A blowout had also occurred where Poihipi Road crossed the Waipouwerawera stream, about 1 km SW of the Blowhole. However, the explosion had no noticeable effect on the temperature of two fumaroles within 500m or on the temperature of the Waipouwerawera Stream. Thus this blowout was unlikely to have effected the discharge temperature of the Blowhole. It appears that the 5°C drop in temperature of the Blowhole was entirely due to the eruption of the Rogue Bore which must have caused a drop in pressure of the steam supply to the Blowhole. The CO_2 content of the Blowhole did not change significantly between January 1960 and August 1961 (154 and 167 mM/100M respectively). However, this link shows that the Rogue Bore and the Blowhole probably tapped the same steam zone.

4. 1990 SURVEY

The second comprehensive chemical survey was conducted during February and March of 1990, at

Figure 3. Relative positions of the 1961 and 1990 fumarole sites. Karapiti Blowhole is feature 7 12.



approximately the same number of vents as in 1961 (Fig 3). No attempt was made to locate and resample the 1961 vents, because after nearly 30 years, the many physical changes at Karapiti had either resulted in the loss of the 1961 vents or they were no longer identifiable.

Samples were collected and analysed using conventional techniques developed for geothermal steam and gas samples (Klyen, 1982; Giggenbach and Goguel, 1989). Samples containing O_2, were assumed to be contaminated with air, and in these cases, the results corrected to "air-free" analyses.

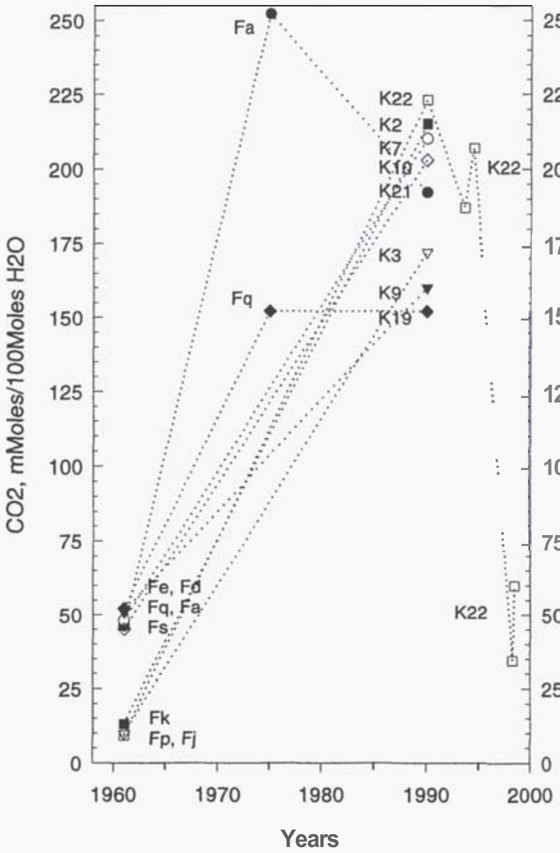
5. KARAPITI DATA SET 1936-1998

The complete chemistry data set for Karapiti and other Wairakei fumaroles is too big to be presented here and will be available in an IGNS Science Report. Extended discussion of the data is being submitted to an international journal.

6. GAS AND STEAM CHEMISTRY

As the heat and mass flow at Karapiti is controlled by the lateral movement of fluid from the vicinity of the production borefield at Wairakei, the gas chemistry observed at Karapiti is also likely controlled by conditions in the reservoir beneath the borefield. The gas chemistry changes between 1952 and 1998 can also be attributed to the effects of continuous extraction from the Wairakei Reservoir. Ellis and Mahon (1977) suggest that steam emitted by fumaroles in an exploited geothermal field may, with time, change in composition. They noted that trends in the steam (gas) chemistry at Karapiti are similar those for steam from the Wairakei bores which indicates a steam supply

Figure 4. A plot of CO_2 concentrations for 8 pairs of fumaroles to illustrate the large concentration changes.



produced by increased boiling of the liquid phase in the reservoir. When the 1961 survey was conducted, Glover (1961) considered that the source of the steam discharged by the fumaroles was a hot chloride water moving beneath the Karapiti area from the N and NW to S and SE, with a consequent decrease of CO_2 in the fumarole discharges across the field. The gas concentrations of the Karapiti Blowhole at that time were consistent with concentrations that would be produced by a 13% flash fiom the hot chloride water.

6.1 Comparison of the 1961 and 1990 Chemical Surveys

To compare chemical data fiom the two surveys, a set of co-ordinates was determined for each fumarole site, based on the New Zealand Map Grid metric reference system (NZMG). Table 1 lists the CO_2 gas chemistry of eight pairs of fumaroles from the 1961 and 1990 surveys, plus 1975 data from fumaroles Fa and Fq and data to July 1998 for K22. The locations of the fumaroles in each pair are not identical but close enough for comparison of the gas data. The concentrations are plotted in Fig 4.

A comparison between the main 1961 and 1990 (initial survey) sets of data for the carbon dioxide concentrations are shown in Fig. 5. This plot was

Figure 5. Scatter plots of 1961 and 1990 CO_2 data with the fumarole sites entered from the N end of Karapiti Thermal Area (left) to the *S* end (right).

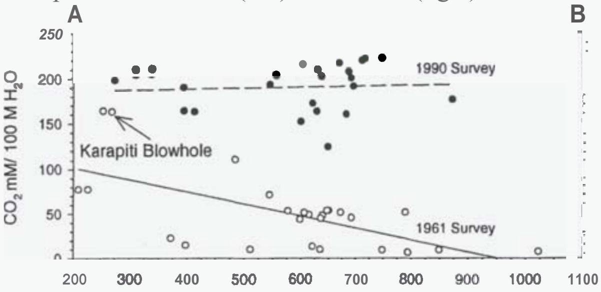
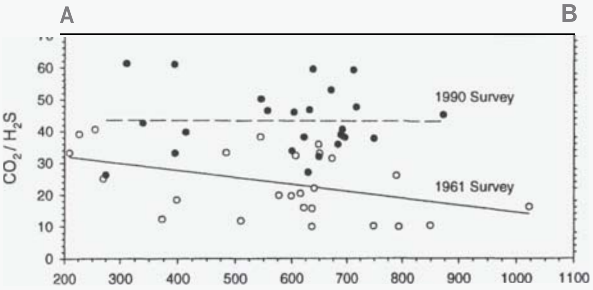


Figure 6. Scatter plot for the 1961 and 1990 CO_2/H_2S data



produced by projecting the data from each sample site onto a NE/SW axis between points A and B on the grid map (Fig. 3). The distances on the **x-axis** (Figs. 5) are relative to point A (zero m) on the NE/SW axis on Fig. 3. A least squares fit to the data was used to produce the linear regression lines drawn through each of the plots. The 1961 CO_2 plot (Fig. *5)* shows a large decrease in concentration across the thermal area, from NE to SW. The 1961 high CO_2 gas data in Fig. 5 at about 260 m from the NE is for the Karapiti Blowhole fumarole which at this time was still the most significant feature. The scatter in the data may be related to localized events, such as the boiling of meteoric ground water in the vicinity of one or more fumaroles. However, the large decrease in the concentration of CO_2 across the thermal area from the NE to the SW, is related to the loss of gas from the hot chloride water flowing under Karapiti (Glover, 1961). A similar change is seen in the CO_2/H_2S ratio (Fig 6). If the flow was steam rather than water separating steam, then there would be a different effect on the gases. Condensation of steam and removal of H_2S by oxidation can increase the CO_2 concentration and the CO_2/H_2S ratio. This would occur as the steam moves toward the margins. As the opposite changes occur in the southerly fumaroles which are toward the margin, then this mechanism does not occur, and the gas is separating from a flowing hot water body.

The 1990 *C02* concentrations and CO_2/H_2S ratios show little variation with change of location and are consistent with a steam zone of uniform CO_2 and H_2S concentration underlying the Karapiti Thermal Area.

It is unlikely that the large differences between the 1961 and 1990 surveys can be attributed entirely to improved methodology. The uncertainty of air contamination during sampling and analysis in the earlier survey led Glover (1961) to recalculate his results to an *air-free* state. These corrections did not affect the CO_2 concentrations. The large increase in gas concentrations between 1961 and 1990 are therefore real, and not perturbations introduced by the collection and analytical methods used.

6.2 Trends in CO_2 Concentrations with Time at Karapiti

An increase in carbon dioxide concentration in the Karapiti Blowhole from 33 to 66 millimoles/100moles of steam appears to have occurred between 1936 and 1958, concomitant with the increase in heat flow. By 1961, this had risen to 170 millimoles/100 moles of steam. All the other fumaroles sampled at that time had much lower gas concentrations. This suggests that the perturbation of the reservoir first affected the most vigorous and northerly of the Karapiti steam vents, i.e. the ones closest to the Wairakei Borefield. A good correlation between the gas concentrations in Karapiti Blowhole, the heat flow, and the formation of a larger steam zone is shown in Figure 2. Two other fumaroles, Fa (equivalent to the 1990's K-21 fumarole) and Fq (equivalent to K-19), which were sampled in 1961 and 1975 indicate that the rise in carbon dioxide concentrations (46 to 252 and 52 to 152 **mM/100M** respectively, had, by 1975, reached values measured in 1990 (Table 1 and Fig **4).** When sampled again in 1975, Karapiti Blowhole gas concentrations had also reached levels similar to the 1990 concentrations.

The continuous drawdown of deep-liquid water levels at Wairakei, with accompanying lowering of deep-liquid pressures during the period between 1961 and 1975 greatly expanded the steam dominated zone in the production reservoir. This may have reached a maximum around 1969, when Glover (1970) found that gas concentrations in wells discharging at that time fitted a multi-stage steam separation processes rather than single-stage steam separation present in the early stages of development of the Wairakei Borefield. He also concluded that many wells were discharging water which had lost steam at some distance from the drillholes. Accordingly, the hot water flowing beneath Karapiti in 1961 apparently was replaced by 1969 (or possibly a few years earlier) with a steam phase drawn from the greatly expanded low pressure steam zone of the Wairakei reservoir.

The 1990 survey data are consistent with the presence of a steam zone of uniform gas concentration underlying the Karapiti Thermal Area. This is shown by the uniformity of CO_2 values along the cross-section line (Fig 5). Glover's (1970) data also suggest that by 1969 there was a tendency for aquifer pressures and gas concentrations in the total discharge of some wells at Wairakei to stabilize. While gas concentrations at Karapiti may have peaked in 1969, it is not known if the concentration levels were similar to those in 1975 (and 1990) or if there was a gradual decline to the concentrations levels of 1975, as in the case of the heat flow which peaked around 1969 and then by 1978, had decreased to the apparently stable heat flow value still present in 1988 (Mongillo and Allis, 1988). The precise times at which the different parameters changed or stabilised are uncertain due to the long period between data sets, e.g. heat flow data in 1964 and 1975. It is likely that, by 1975 or earlier, a similar steam composition occurred in all the fumaroles and these were still at those levels in 1990.

6.3 Evidence from Stable Isotopes

From the slight change in the isotopic composition of the steam from the Blowhole between 1961 ($\delta^{18}O$ = -8.2 ‰, δ D = -45 ‰) and 1974 ($\delta^{18}O$ = -7.84 ‰ and δ D = -43.5 ‰), Giggenbach and Stewart (1983) deduced that some of the vapour zones were present in the aquifer during the early stages or even before fluid withdrawal for power production. Whilst this may be true, their data can only be used for the situation at 1961, 8 years after the first well was drilled and 3 years after the power station was commissioned. By 1961 the CO_2 concentration in Karapiti Blowhole had increased to 170 millimoles/100moles (from 43 in 1953). Increased heat flow from the Karapiti area and increased size of the steam zone had also occurred. Thus the isotope data are in agreement with the other changes in the reservoir and steam at that time. Repeat isotope measurements on Karapiti steam in 1982 showed a slight change from the 1974 data. Stewart (in Allis, 1979) used the changes, mainly between 1961 and 1978, to deduce an increase in the steam formation temperature from about 210°C to 235°C. The increased steam formation temperatures indicate that the depth of steam formation had also increased. This is in agreement with the vertical expansion of the steam zone.

6.4 Data Since 1990

Since 1990, CO_2 concentrations in three monitored fumaroles have decreased with falling steam zone pressures. The southernmost of these (K22) showed small changes between 1990 and 1994 (228 to 207 mM/100M CO_2). However, in April and July 1998 values of 35 and 60 mM/100M were measured (Lawless, pers. comm.). By December 1998 the fumarole was too weak to be sampled. As the most southerly, it is expected to be affected first by a reduction in steam flow. From 1973, when the Rogue Bore ceased to discharge, until 1997, there were no significant geothermal discharges from the area between the borefield and Karapiti. When the McLachlan Power Station was opened in 1997 a further perturbation occurred in the system. The bores supplying this station (WK604, WK605, WK606 and WK610) are approximately the same distance from the site of Karapiti Blowhole as the nearest production well in the main borefield. However, they are closer to the site of the Rogue Bore which was linked to the Blowhole. It is possible that the extra steam drawn off from the low pressure steam zone caused the changes in K22. K20 had a low CO_2 content in April 1998 which was lower than the slow downward trend but then recovered in July 1998. K14, which is the most northerly of the three showed a slow and steady decline. Thus the further away from the steam source, the more drastic the effect. This is tentative but not conclusive evidence for the effect of the extra discharge. Further sampling is planned to test this conclusion.

7. CONCLUSIONS

1. Large increases in the concentrations of C02 between the 1961 and 1990 surveys are related to the continuous utilisation of the Wairakei reservoir.
2. An extensive steam zone at Karapiti fed by the main production steam zone at Wairakei, appears to have replaced the liquid phase (or possibly two-phase) zone that was underlying Karapiti in 1961. This change occurred between 1961 and 1975, probably around 1969 when multistage steam separation became predominant at Wairakei.
3. Since 1990 gas concentrations in steam discharges in the Karapiti area have declined slowly following the pressure in the low pressure steam zone.
4. An apparent greater decline in gas concentrations in 1998 is tentatively associated with the additional steam discharged by the McLachlan Power Station

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