WHAKAREWAREWA NATURAL FEATURES – UPDATE OF CHEMICAL AND ISOTOPIC COMPOSITIONS AND COMPARISON WITH HISTORICAL DATA

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SUMMARY - A geochemical survey of 17 selected Whakarewarewa natural features was undertaken for comparison with historical data. The purpose was to provide an overall assessment of the recovery of the springs following the 1986 bore closure programme and implementation of resource management plan polices for the Rotorua field. The features show a range of chemical and isotopic changes ranging from continuing decline to recovery with aquifer re-heating. The most outstanding recovery is at Parekohoru which is now discharging less-dilute fluids and at Pohutu where re-heating of the shallow aquifer is indicated by a significant increase in dissolved silica. Pohutu fluid composition is now comparable to that discharged in 1937. Possible increases in the temperature of the deeper water component are indicted by THC Blowout fluid compositions and by the Okianga Geyser.

1. INTRODUCTION

Progressive decline in natural thermal activity in the Rotorua geothermal field occurred as a result of fluid draw off from the shallow aquifers, by commercial and domestic users, between 1950 and 1985. In response to this decline central government enforced a bore closure programme in 1986 and introduced a user royalty regime to discourage use of the geothermal resource. Following the 1986 bore closure water levels in the field recovered. In 1991 responsibility for the management of the field shifted to Environment Bay of Plenty (regional council) with the passing of the Resource Management Act 1991. In 1993 Environment Bay of Plenty developed a resource management plan for the field, which after Environment Court appeals became operative in 1999.

The recovery of the Rotorua natural surface features has been ongoing with the greatest period of recovery from 1992-2000 with resumption of fluid flow to many previously dormant springs (Gordon et al., 2001). Over that time water levels and natural activity has been intensively monitored by Environment Bay of Plenty, however chemical analysis of the discharging fluids was essentially discontinued in 1993 when central government funding for field monitoring was withdrawn. From 1993 only sporadic sampling and analysis of a few wells and springs has occurred, usually during significant events such as well failures or spring outbreaks. Nevertheless the changing chemical and isotopic composition of the fluids and the relationships between them are the most important indicators of the hydrology of a geothermal system. In conjunction with physical monitoring this enables a comprehensive understanding of the current state of the field as well as the field’s response to exploitation and recovery. The chemistry data also provides constraints for the complex mathematical models that have been developed for the field. This geochemical study is a component of a continuing field management monitoring and research programme undertaken by Environment Bay of Plenty to support the objectives and polices of resource management plan for the field. The study has been divided into a manageable three part programme. Part one was to conduct a geochemical survey of selected Rotorua natural features, compare the results to historical data and provide an overall assessment to highlight any changes (Mroczek et al., *2002).* In this paper we report results only for the Whakarewarewa area.

2. DATA

The recent analytical chemical and isotopic data is presented in Table 1

The historical analytical data was abstracted from compilations given by Zeng (1981), Stewart and Taylor (1985), Bradford et al., (1987), Glover (1993) and unpublished data held in GNS files.

Glover (1967) published the only comprehensive compilation of historical analytical data. This included samples collected between 1878 and 1955. Glover (1967) also undertook an analytical survey between 1961 and 1963, which included many wells but only a few of the natural features.

The comparison of the recent results with historical data presents two major difficulties. The first is the sheer volume of data to compare and the second is the need to compare samples over 40 years, where the changes in absolute concentrations may appear to be erratic and could be influenced by local effects such as high rainfall episodes and other disturbances to the shallow aquifers. The technique used was to compare the changes in the relative concentrations of both chemically inert non-reactive species and chemically reactive species using triangular diagrams originated by Giggenbach (1991).

Comparison of relative rather than absolute concentrations has many advantages. The relative proportions of constituents remain constant during steam loss or dilution, in the absence of mineral dissolution/precipitation. Furthermore, mixing trends between end-members are always straight lines so that relationships between different groupings of features are easily discerned.

The triangular diagrams for all springs may be found in Mroczek et al., (2002) but diagrams for only Parekohoru spring (S284) are presented here. The historical data will be published elsewhere.

3. RESULTS

3.1 Chemical Compositions

Descriptions of spring activity are of necessity very brief but detailed accounts may be found in Mahon (1985), Glover (1993), Cody (1998), Scott and Cody (2000) and Gordon et al., (2001).

Papakura geyser (S28)
This feature was always active until March 1979, when boiling and geysering stopped. Thereafter, water levels and temperatures declined and this feature shows no recovery. The relative proportion of SO_4 with respect to Cl and B has increased progressively since the 1960s, as the temperature and pH have declined.

Ngawharua spring (S55)
There is essentially no change in the fluids discharged by this spring since the 1980's when the first detailed sampling was made. The latest samples have slightly more absolute Cl and SiO_2 but also more SO_4. The higher Mg suggests equilibration at a lower temperature which is at odds with the observed increase in SiO_2 of 13 ppm, just over the likely uncertainty in the analysis (±5%). Use of silica concentrations to calculate geothermometer temperature in hot-spring fluids must be interpreted with caution due to the unknown fraction of steam separation during boiling and conductive cooling and possible deposition.

Prince of Wales Feathers geyser (S72)
Data from this sampling show there is little change between the 1991 and 1997 samples. No data are available pre-1991 to examine longer trends. There is slightly more Cl and relatively more K, perhaps indicative of deeper hotter fluid feeding this geyser, but no increase in SiO_2.

Pohutu geyser (S75)
Only one sample (from 1984) is available to compare with the present sample. The relative proportions are similar but there has been a significant increase in absolute concentration of Cl, 549 to 600 ppm and particularly SiO_2, which increased from 374 to 462 ppm. This represents a change from 207°C to 226°C in the chalcedony/quartz geothermometer (assuming maximum steam loss), which is a substantial increase. The chemistry of Pohutu is now very similar to Prince of Wales Feathers, suggesting similar fluids feed both geysers. Cody (1998) pointed out that features on Geyser Flat (Pohutu, Te Horu, Waikorohihi and Mahanga) previously all had similar waters based on dye tracing experiments. Analyses compiled by Glover (1967), as well as data for the 1984 and 2002 samples are given in Table 2. Increasing Cl relative to SO_4 and decreasing Na/K compared to 1984 all indicate deeper-sourced fluids are being erupted by Pohutu. Pohutu now discharges a fluid with compositions comparable to that recorded by Grange in 1937 (as reported by Glover, 1967).

Te Horu (S76)
The composition of this water is now very similar to Pohutu and there have been increases in Cl, cations and silica compared to the early 1990s. The temperature is low (53.7°C) and Gordon et al., (2001) suggest this feature is receiving discharge fluids from Pohutu, which is supported by these results.

Wairoa geyser (S79)
This geyser has not erupted naturally since 1940, however human induced eruptions did occur during 1958-59. In 1982 the fluid was an acid-chloride mixture of deep and steam heated waters, SO_4 (450 pprn), pH 3, and Cl (442 pprn). A dramatic reversal occurred in 1987 coincident with local earthquakes, resulting in an inflow of alkaline-chloride fluids (Glover, 1993; Cody, 1998). This was not sustained and the fluid is now substantially more acidic than the previous sample collected in 1997; SO_4 is up from 325 to 1903 ppm, Cl down from 451 to 108 ppm and pH down from 3.4 to 1.7.

Table 1. Analytical and isotopic data for Whakarewarewa Springs*.

Name	CT	AT		mg/l											‰	‰
	°C	°C	pH	Li	Na	K	Ca	Mg	SiO_2	B	Cl	SO_4	HCO_3	H_2S	δ^2H	$\delta^{18}O$
Parekohoru	96.2	21	9.28	4.2	483	52	1.6	0.02	379	5.5	610	63	162	16	-32.6	-3.52
Korotiotio	99.5	20	9.16	3.9	438	43	1.5	0.01	324	5.7	571	68	157	11	-32.3	-3.55
Okianga Gey.	97.7	20	9.16	3.2	486	33	5.1	0.02	202	5.5	638	156	34	20	-31.7	-3.43
Ororea	75	21	8.38	4.2	589	72	5.4	0.11	282	5.4	746	256	161	12	-27.8	-2.01
NO 377	70.2	21	7.22	3.1	433	44	4.6	0.14	236	4.6	533	250	69	6		
THC Blowout	88.5	22	8.48	3.8	681	60	3.4	0.01	310	8.6	1052	48	120	1.3	-30.3	-1.96
Papakura	37	21	6.3	2.8	343	40	2.2	0.15	253	4.7	456	170	38	<0.2		
Ngawharua	95	21	9.35	3.9	434	35	1.3	0.07	214	5.9	575	75	81	9.8	-32.2	-3.82
Prince of Wales	100	20	9.73	3.5	439	61	1.9	0.03	461	5.1	591	77	37	12.1	-31.1	-3.42
Pohutu	100	22	9.73	3.4	463	61	1.9	<0.01	462	5.2	600	79	48	10.9	-29.9	-3.32
Te Horu	53.7	22	9.67	3.5	467	63	1.9	<0.01	469	5.3	619	86	71	2.2		
Waiora Gey.	95	22	1.69	0.65	93	22	11.5	1.4	378	1.2	108	1903	-	0.34		
Puapua	100	21	8.22	3.4	485	67	2	0.01	403	5.2	619	80	217	7.2	-29.9	-3.63
Waikite Geyser	100	22	2.02	<0.05	2.5	1.7	0.72	0.04	196	0.4	<3	1155	-	<0.20		
Kereru	100	21	8.99	3.4	439	53	1.7	0.01	397	5.3	566	87	142	2.9	-26.6	-3.58
S506	90	22	9.09	3.2	409	33	2.1	<0.01	202	5.8	551	73	85	3.3	-30.7	-3.65
Ngararatua-tara	95	20	8.15	2	385	52	1.8	<0.01	344	5.5	523	78	138	1.3	-29	-2.86

*CT & AT = Collection and analysis temperatures respectively, Samples numbers in order were 2200634 – 2200639, 2200647-2200657, sampled on 23/4/02 and 24/4/02 respectively.

Table 2. Analyses of water from Pohutu Geyser, 1937-2002.

	mg/l							
Year	Na	K	Cl	SO_4	SiO_2	Na/K	Cl/B	Cl/SO_4
1937	466	65	600	106	439	7.1		5.6
1955	412	70	579			5.9	108	
1961	485	58.5	560	88	490	8.2	105	6.3
11984	462	56	549	76	1374	8.3	102	17.2
2002	1463	79	1600	77	1462	17.6	115	17.6

Puapua spring (S81)

The relative proportion of SO_4 has decreased suggesting a greater portion **of** high chloride deep water is present. In absolute terms the SO_4 concentration is similar to that measured in the early **90's** but the Cl and cation concentrations have increased. There is no change in SiO_2. The Cl at 619 ppm is now higher than any sample back to the first collected in 1969 (554 ppm).

Waikitegeyser (S130)

This was the highest discharging feature at Whakarewarewa. Eruptions ceased in 1967 and the vent remained *dry* until the early 1990s when a collapse allowed fluids to come back into the vent. The first sample from this feature was collected in 1996 (Cody, 1998) and was shown to be acid sulphate fluid, pH 2.3 and SO_4 1760 ppm. The latest sample shows a reduction in SO_4 to 1180 ppm but there is still negligible chloride at 1.5 ppm indicating it is still essentially steam heated water.

Kereru geyser (S2 78)

Eruptions recommenced at this geyser in 1988, the first in over 16 years. The latest sample is very similar to that collected in 1993 which was more concentrated than the average at that time (Glover, 1993).

Korotiotio spring (S283)

This spring ceased reliable overflow into the Oil Baths in 1978. Water levels have gradually risen since 1996, but overflow has not been established. Between 1982 and 1993, this feature had stable chemistry and the latest sample is very similar to that collected in 1993. However there has been a slight increase in SO_4, from 59 ppm to 68 ppm and a drop in silica from 350 ppm to 325 ppm. These are relatively minor changes, but do suggest less deep geothermal aquifer fluid is present. Glover (1967) reports a 1878 analysis of 585 ppm Cl and 72 ppm SO_4, in comparison with 571 ppm Cl and 68 ppm SO_4 in 2002.

Parekohoru spring (S284) – Figure 1.

This pool has always overflowed but during the winter of 1986 several cessations occurred. By the late 1990s strong overflows and boiling surges were again occurring. Glover (1993) noted that this feature has displayed stable compositions between 1969 and 1993. The 2002 sample shows

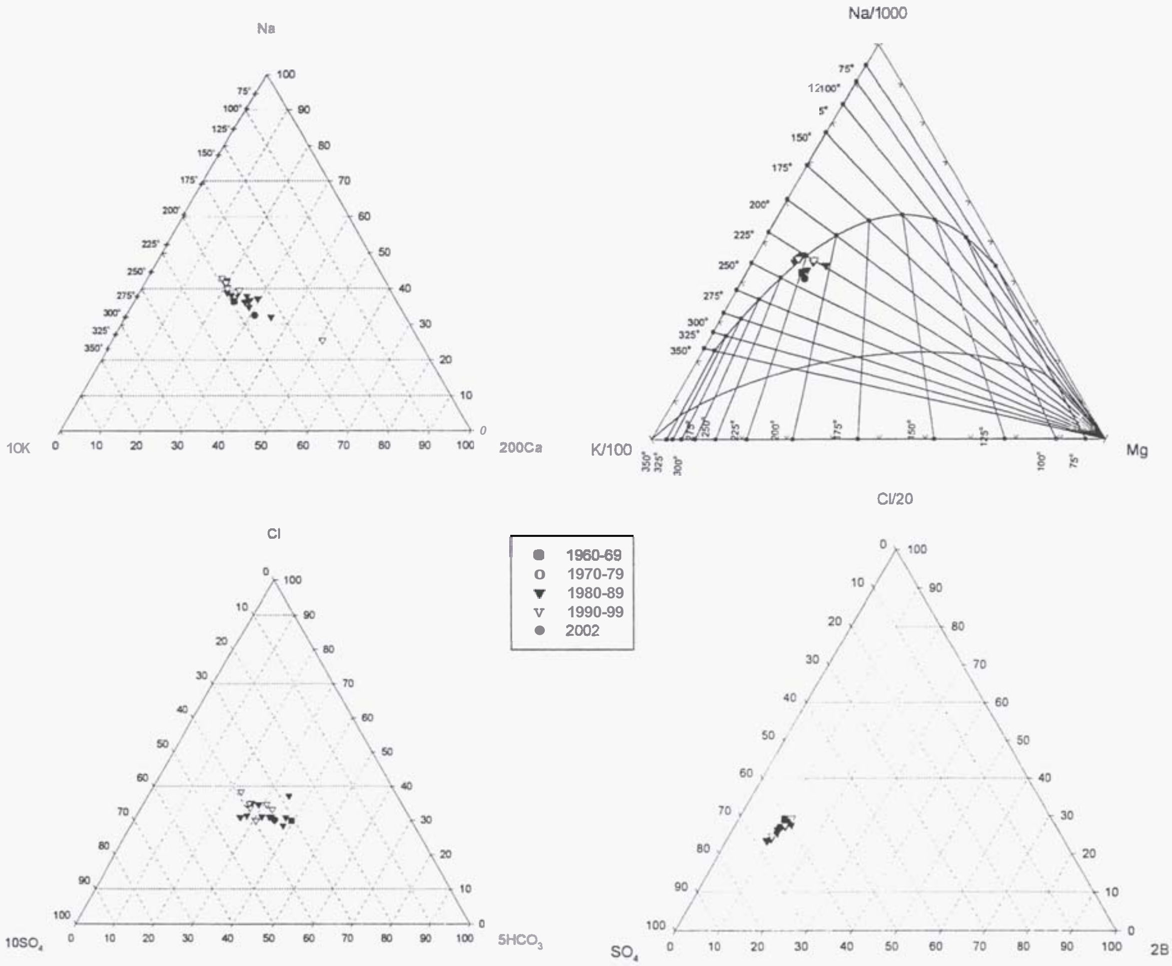

Figure 1. Parekohoru spring (S284), relative concentrations (wt%)

compositional changes very similar to those observed at Puapua (over 250 m away). There is little change in SO_4 and SiO_2 but significant increases in absolute concentrations of Cl (561 pm to 610 ppm), Na, K and HCO_3, although the relative proportions have not changed much. This indicates higher chloride, deeper aquifer fluid is now reaching the surface, consistent with recent increases in spring activity.

Ororea springs (S351, S352)

This group of springs has shown variable activity since the 1930s when they were used to supply the Ward Baths in Rotorua city. This was discontinued after cessation and eruptions between 1938 and 1943. Activity recommenced in 1982 and boiling overflows continued until 1996. Water levels and temperatures are now low, similar to those during a period of low activity (65-85°C) between 1983 and 1986 with reduced chloride and increased sulphate. Between 1987 and 1993 the composition of the Ororea S351 fluids was stable and less dilute than prior to 1987 (Glover, 1993). The latest sample (Ororea S352) is similar to those collected during the 1983-86 low activity period. The change in absolute concentrations since 1993 has been large, Cl decreasing from 835 ppm to 746 ppm and sulphate increasing from 52 ppm to 256 ppm.

Spring 377

This is one of several springs along the western side of Lake Roto-a-Tamaheke, which showed recovery in the 1980s. However, boiling and overflowing stopped in March 2001. In 1983 this spring was a near neutral chloride-sulphate spring (Cl 613 ppm , SO_4 147 ppm) spring at 98°C. The latest sample shows a decline in temperature to 70°C with increasing dilution with steam heated fluids with SO_4 increasing to 250 ppm and chloride declining to 533 ppm. There has also been a drop in silica, 282 ppm to 236 ppm. The chemistry changes are consistent with decreased spring activity.

Okianga geyser (S488)

During the 1980s-90s this small geyser erupted about once an hour to about 4 m height. In 1999 many small vents opened in the area and the geyser activity stopped. Compared to samples collected in 1983 and 1984 the latest sample shows dilution in Cl, SO_4 and B but the relative proportions of these components have not altered significantly and the silica concentration is unchanged. However the Na has decreased compared to K, suggesting an increase in temperature of the deeper water component. For the 1983 and 1984 Okianga spring samples the Na/K geothermometer temperatures were 184°C and 183°C respectively, while the 2002 sample now gives a value of 203°C. The isotopic composition (see section 5.1) suggests this geyser is fed by deep water, which is now more dilute.

Spring 506

This feature was selected for sampling as it represents a small continuously discharging hot chloride feature in the western portion of Whakarewarewa. No previous analyses appear to exist for this feature. It is a hot (90°C) alkaline chloride spring with low sulphate (pH 9.1, Cl 551 ppm, SO_4 73 ppm). The composition is like the way Ngararatuatara (S529) was, and like Korotiotio spring (S283) is now. The cooler aquifer temperatures of S506 and lower bicarbonate indicate different subsurface processes/sources than Ngararatuatara, where it appears the groundwater dilution takes place at a deeper level.

Ngararatuatara (S529)

This continuously discharging feature has been sampled regularly since 1979 and has shown relatively stable Cl compositions. The latest sample (523 ppm) is similar to the previous sample collected in 1993 (522 ppm). Between 1979 and 1993 the average Cl was 528±9 ppm (24 samples) with a high of 544 ppm measured in 1982 and a low of 512 ppm in 1990. Glover (1967) reports values of 580 ppm and 568 ppm in samples collected in 1937 and 1955 respectively.

However, the Na has decreased while K has remained essentially constant as for the Okianga Geyser. In Ngararatuatara the geothermometer temperature increase is much smaller, from an average of 248±3°C between late 1984 an 1993 to 257°C in 2002, a value which had not been exceeded since 1984.

THC Blowout (S952)

This feature formed in 1987 as a result of problems with a nearby bore. Between 1991 and 1993 the "blow-out" discharged fluid with a stable concentration higher than any other Whakarewarewa spring (Glover, 1993). The latest sample shows a slight increase in Cl (1024 ppm to 1052 ppm) and lower sulphate (66 ppm to 48 ppm). Again as for Okianga and Ngararatuatara springs there is a decrease in Na but an increase in K. Between 1988 and 1993 the average Na/K geothermometer temperature was 215±2°C and for the 2002 sample this is now 222°C

3.2 Isotopic Compositions

Ngawharua (S55) shows a slightly higher (less negative) $\delta^{18}O$ and increase in SO_4 since the 1980s indicating extra surface evaporation or steam heating, consistent with the chemical observations. Prince of Wales Feathers and Pohutu geysers have higher $\delta^{18}O$ and chloride supporting chemical indications of higher-temperature, deeper-sourced fluid now feeding these features. Puapua has a significantly lower $\delta^{18}O$ indicating less surface or near-surface evaporation, also shown by less sulphate. The higher chloride and bicarbonate values also indicate greater input of diluted deep water. Kereru has unchanged $\delta^{18}O$. There are no previous analyses for Spring 506. Ngararatuatara has higher $\delta^{18}O$ and slightly higher sulphate suggesting evaporation combined with dilution.

Korotiotio has higher $\delta^{18}O$ and sulphate indicating more steam heating/surface evaporation like Ngawharua. Parekohoru has $\delta^{18}O$ within the range of previous values, but higher chloride and bicarbonate show greater input of diluted deep water like at Puapua.

Ororea shows increased steam heating even compared with the 1983 sample. Okianga Geyser has higher $\delta^{18}O$ but lower chloride and sulphate indicating more groundwater is mixing with boiled deep water to dilute it. THC Blowout accesses deeper water with higher chloride concentrations. The higher $\delta^{18}O$ is consistent with higher chloride, but no earlier results are available for comparison.

4. DISCUSSION

In the Whakarewarewa area features show a range of chemical and isotopic changes with apparently no consistency to geographical location. These changes range from continuing decline or no recovery to stable or recovery with aquifer re-heating. In summary, the features can be grouped as:

- **Stable** – Kereru, Korotiotio (but slight increase in **SO_4**),
- **Declining or dominantly acid chloride fluids** - Papakura, Wairoa, Waikite Geyser, Ororea,
- **Minor recovery** - Ngawharua (increase in Cl but also **SO_4**), Prince of Wales Feathers, Te Horu, Puapua,
- **Significant recovery** - Parekohoru (less dilute fluids), Pohutu – substantial heating of the shallow aquifer indicated by the increase in dissolved silica and the composition (Cl and Na/K) now appears to be similar to fluids discharged in 1937,

- **Possible increase in temperature of the deeper water component -** Okianga Geyser, Ngararatuatara (small), THC Blowout (especially).

The isotope analysis indicates that Ngawharua, Korotiotio, Ororea and Ngararatuatara fluids have an increase of steam heating, whereas Prince of Wales Feathers and Pohutu geysers have a greater input of "boiled" (i.e. bicarbonate-poor) deep water. Puapua and Parekohoru springs have a greater input of "diluted" (bicarbonate-rich) deep water, and Okianga Geyser is fed by deep water, which is now more dilute. Kereru shows no change and springs S506 and THC Blowout have no previous data.

5. CONCLUSIONS

Features in Whakarewarewa continue to show changes in chemical and isotopic compositions. These results support the observations of Gordon et al., (2001) that complex changes are occurring in this area, with inconsistencies in both physical changes and geographical distribution of the changes.

The most outstanding recovery is at Parekohoru which is now discharging less dilute fluids and at Pohutu where re-heating of the shallow aquifer is indicated by a significant increase in dissolved silica. The evidence is that the Whakarewarewa springs are only now beginning to respond with decreasing influence of the surficial steam heated waters and increasing aquifer geothermometer temperatures.

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