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HYDROLOGY AND HYDROTHERMAL ALTERATION, REPOROA WELL (1), REPOROA, NEW ZEALAND

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ABSTRACT

The Opaheke-Reporoa thermal system has surface activity that consists of hot, neutral pH, alkali chloride-bicarbonate pools; minor sinter, mudpools; steaming ground and hot water seepage.

Regional resistivity measurements and fluid chemistry surveys suggest that the Reporoa system is a lateral outflow of hot water from the Waiotapu Geothermal System 9km to the north-east.

A 1338m deep exploratory drillhole, RP1, encountered a sequence of lacustrine sediments, volcanic, tuffaceous and ignimbritic rocks. The well was discharged in October 1966, but was shut down after 5 hours during which time wellhead pressure fell from 289.6kPa to 82.7kPa. Downhole temperatures in RP1 were measured after 47 days of heating and showed a significant temperature inversion between 400m and 670m which is interpreted to be caused by hot water at about 300m depth flowing above a cooler water influx.

The temperature interpretation from clay and calc-silicate mineralogy and calculated chemical geothermometers is consistent with the bore hole temperatures. A minor maximum of 204°C occurred at 305m (interlayered illite-smectite encountered), a minimum of 166°C at 549m (smectite), and a maximum of 225°C at 853m to 975m (illite + rare epidote), bottom hole temperature was 219°C.

Intensity of hydrothermal alteration generally increases with depth below about 700m with the mineral assemblage of quartz, albite, adularia, titanite, illite, chlorite and calcite produced by near neutral pH, chloride-bicarbonate fluid. The scarcity of epidote and absence of wairakite and other calc-silicate minerals is consistent with alteration by a geothermal fluid moderately high in dissolved CO_2.

Fluid inclusion homogenisation temperatures, up to 254°C at 741m depth (average 225°C Th) are slightly higher than measured temperatures at the same depth (eg. 202°C at 741m) and indicate that the geothermal fluids are cooler now than at some earlier time.

Based on the occurrence of adularia and reported circulation losses, the main permeability occurs between about 1050m and 1120m and may be controlled by microfractures which are common in cores from RP1.

INTRODUCTION

Evaluation of drillhole data provides an opportunity to study active and extinct geothermal systems. The Reporoa thermal area has been regarded as an outflow plume of the Waiotapu Geothermal System by Healy and Hochstein (1973) and more recently by Goff et al (1988). A single exploration well (RP1) was drilled in the area in 1966 and information obtained from downhole temperature measurements and related studies were used by these and other workers to establish a hypothetical model for the Waiotapu-Reporoa system.

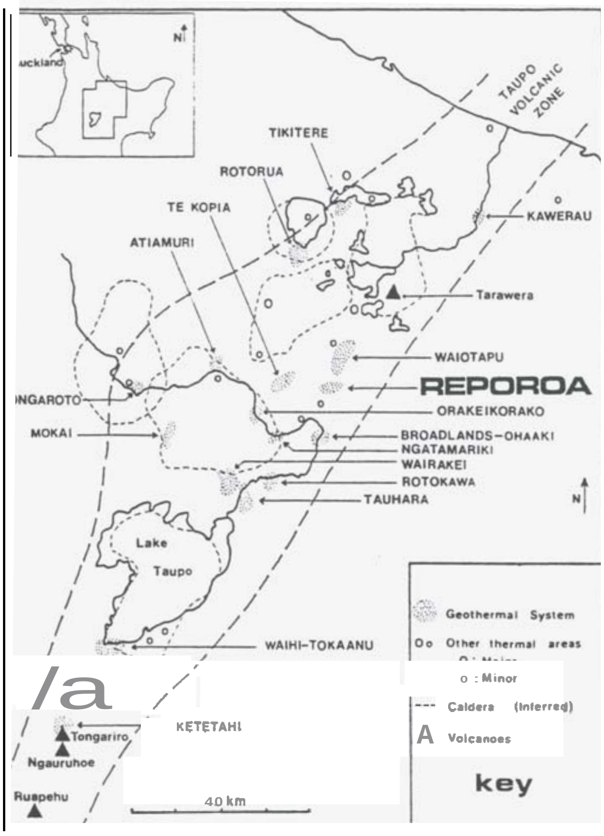

Figure 1: Location of the Reporoa geothermal area, Taupo Volcanic Zone, North Island, New Zealand.

The Opaheke-Reporoa thermal system is located in the Taupo Volcanic Zone (TVZ), North Island, New Zealand (Figure 1), 30km south of Rotorua and 9km southwest of Waiotapu. The Opaheke thermal springs (grid reference U17/012046) occupy an area approximately 700m in diameter bounded by State Highway 21 and Wharepapa Road. Another thermal area, 500m in diameter, is located 2.5km to the east near Longview Road and Loop Road (grid reference U17/037046).

A detailed petrological study of cores and cuttings taken from RP1 was made using thin sections kindly loaned by the NZ Geological Survey, DSIR, supplemented by examination of the cores and cuttings held at Wairakei, to assess alteration mineralogy and attempt to understand fluid/rock interactions. In addition X-Ray fluorescence, X-Ray diffraction and fluid inclusion studies were undertaken to facilitate the interpretation of hydrothermal alteration, reservoir conditions and potential for epithermal mineralisation.

GEOLOGICAL SETTING

The Opaheke-Reporoa springs are located in the Reporoa Basin, a tectonic basin filled with breccias and sediments of the Huka Group and with rhyolite volcanic rocks (Grindley, 1959). The thermal area is flat lying with surface geology characterised by current-bedded rhyolite, pumice and ignimbritic sands and gravels (Hinuera Formation), that overly undifferentiated Huka Group-Waiora Formation pumiceous pyroclastic and lacustrine sediments.

The [illegible]ctural pattern of the Reporoa thermal system is similar to the regional structural pattern of the TVZ, with the main axis of the Reporoa Basin being orientated in a NE-SW direction. **Inferred** normal faults predominate in the area and form graben-like structures. Although no faults have been located at the surface or can be directly related to the features observed at Repoma they may control regional hydrology and possibly provide permeable channels for hydrothermal **fluids.**

The surface activity at Reporoa was surveyed by Mahon (1966) and was found to consist of several clear, hot, neutral pH alkali chloride-bicarbonate pools with minor sinter and mudpools. Minor areas of steaming ground and seepage of hot water into drainage channels also occur.

GEOPHYSICS

Although the Reporoa system has been incorporated into regional geophysical studies of the TVZ, few surveys have been directed specifically towards the Opaheke-Reporoa region.

A resistivity survey of the Taupo-Waiotapu area was conducted by Macdonald (1967). He concluded that there was a connection between Waiotapu and Reporoa and that the Reporoa system could be a "run off', perhaps at "reasonable depths" of a column of water rising in the Waiotapu area.

A map of apparent resistivity in the Waiotapu-Reporoa area (Healy 1974) indicates an elongated pattern of low resistivity which suggests the existence of a lateral plume of hot water derived from the Waiotapu thermal area (Figure **2).** The area enclosed by the **5** and 10 **ohm.m.** contour lines at Reporoa are $10km^2$ and $14km^2$ respectively.

SUBSURFACE STRATIGRAPHY

The subsurface stratigraphy at Reporoa can only be interpreted from cores and cuttings recovered from RP1, the only exploratory well drilled in the area (Figure 3).

Flat lying Huka Falls Formation extends to about 310m and consists of grey to cream coloured, interbedded pumiceous pyroclastic and lacustrine sediments. The rocks are generally friable, well sorted and composed of pumice, rhyolite and **crystal** fragments set in a weakly clay-altered ash **matrix.**

The tuffaceous rocks are underlain by a porphyritic, flow banded **and** occasionally spherultic rhyolite which is 330m thick. The grey coloured rhyolite lava is commonly fractured, **quartz** veined and occurs to a depth of about 640m.

A 10m thick **quartz** sandstone unit was encountered beneath the volcanic **rocks** and overlies a pale grey, poorly **sorted** pumice-crystal tuff which is 15m thick and occurs to **675m** depth..

A 25m thick, poorly sorted, dacitic breccia incorporates crystal fragments, abundant dacitic-rhyolitic and crystal tuff

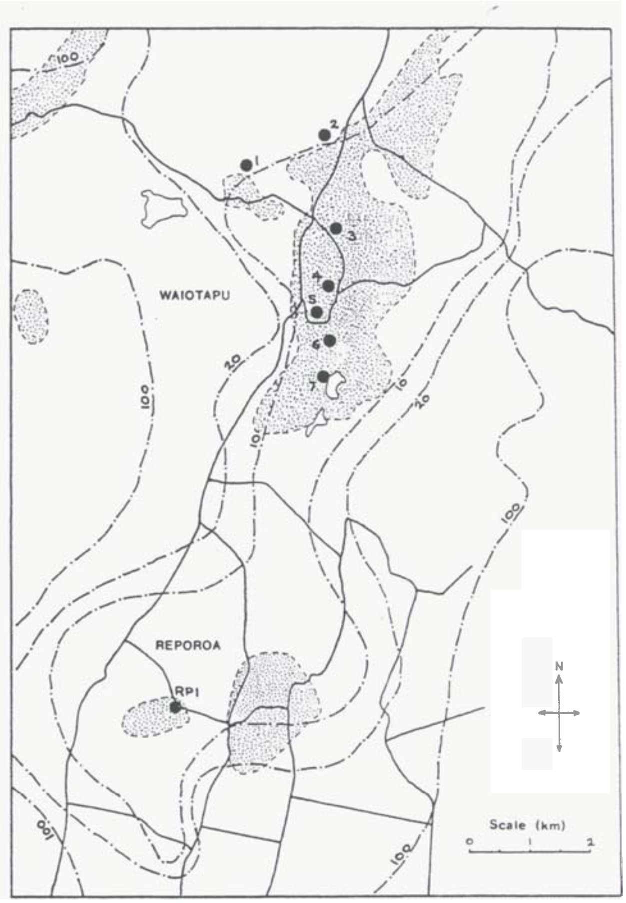

Figure 2 : **Apparent** resistivity map of the Waiotapu-Reporoa area. **From** Healy **(1974).**
02 = Waiotapu Well **2**
0RP1 = **Reporoa** Well 1
▨ = **thermal area**
— · — = resistivity contour **(ohm.m.)**

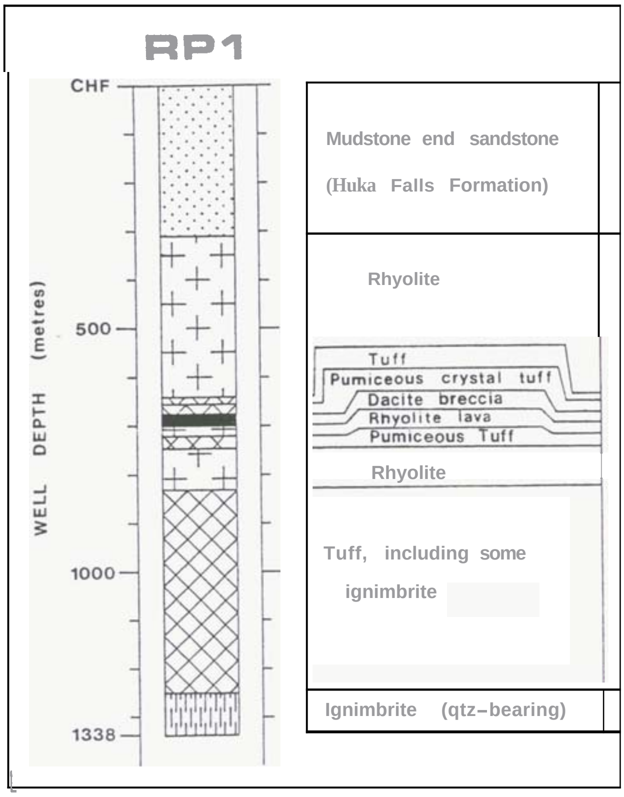

Figure 3 : Subsurface stratigraphy of Reporoa Well 1.

clasts. These are set in a microcrystalline clay altered matrix which has been cut by pyrite+quartz veinlets.

Below 700m a perlitic textured rhyolite lava, 20m thick, overlies a quartz veined pumiceous crystal tuff which extends 25m to 745m depth.

Flow banded, spherulitic and occasionally perlitic textured rhyolite occurs to 830m. The porphyritic rhyolite lava is 85m thick and typically shows a weakly developed banding, devitrified glass matrix and characteristically abundant quartz and quartz+pyrite veinlets.

Pumiceous crystal tuff and pumice breccia, including interbedded ignimbrite occurs to a depth of about 1250m. The pale grey coloured rock is moderately indurated, generally unfractured and shows no obvious bedding or layering. The clay altered matrix supports rhyolite and tuffaceous clasts, quartz and relict plagioclase. The unit overlies a quartz-bearing ignimbrite composed of grey, banded rhyolite clasts; green, perlitic textured rhyolite; clay altered tuffaceous clasts and quartzo-feldspathic fragments set in an indurated, cryptocrystalline matrix which occurs to well bottom at 1338m.

GEOCHEMISTRY

Mahon (1966) conducted a chemical survey of the hot spring waters in the Opaheke area and found that they were mainly of the neutral pH chloride-bicarbonate type. Glover and Ellis (1967) further showed that the chloride contents and salinity were similar to springs at Waiotapu. Comparison of the Cl/F, Cl/B, Cl/SO_4 and Na/Li ratios of the Opaheke waters to that in the Postmistress and Champagne Pools at Waiotapu demonstrate the similarity (Table 1).

The low temperature, low chloride spring that occurs at Golden Springs, 9km south of Reporoa, may be supplied from the same chloride water that occurs at Opaheke. The water reaching Golden Springs has been considerably diluted by meteoric water; however the Cl/B ratio in both waters is similar.

The chemistry of RP1 water was discussed by Glover and Ellis (1967) who showed that silica concentrations of water samples from the well indicated quartz equilibrium temperatures of 197°C to 220°C. The Na/K geothermometer gave temperatures of 200°C to 230°C.

In this study silica and Na/K geothermometers were applied to the main, high discharging neutral pH, chloride-bicarbonate springs which were analysed by Mahon (1966). The silica geothermometer gave an estimate of 195°C to 210°C (T_{SiO_2} adiabatic). The Fournier Na/K geothermometer gave an estimate of 170°C to 185°C. However the calculated temperatures are lower than the borehole temperatures measured by the MOW in 1966.

The high concentration of bicarbonate and low calcium content in spring and well discharges may indicate a high CO_2 concentration in the underground waters.

HYDROTHERMAL ALTERATION

The process of hydrothermal alteration includes the interaction between geothermal fluids and primary rock forming minerals. Hydrothermal alteration often produces changes to the properties of rocks by altering their porosity, permeability, density, magnetisation and resistivity.

The intensity of alteration is a measure of how completely a rock has reacted to produce new hydrothermal minerals. Primary rock forming minerals in RP1 show a moderate degree of alteration intensity with the order of replacement of primary minerals similar to the other systems of the TVZ as

	Concentrations in water (mg/kg)													
Sample	pH	(°C)	Li	Na	K	Ca+Mg	F	Cl	I	SO_4	HBO_2	SiO_2	NH_3	HCO_3
RP-1/A	7.95	-	0.14	32	10.8	3	2.2	21	1.2	15	0.8	<10	0.6	90
RP-1/B	8.0	-	0.14	32	11.1	3	2.7	21	1.2	15	1	<10	0.6	90
RP-1/C	7.95	-	0.14	32	10.8	4	0.6	21	1.2	29	1	<10	0.55	90
RP-1/C	8.45	-	2.35	313	63	Nil	-	312		34	20.9	325	0.8	229
RP-1/D	8.55	-	2.85	342	46	Nil	-	468	2.5	46	28.9	455	0.3	234
RP-1/E	8.35	-	2.7	315	55	Nil	-	454		17		395	2.5	-
RP-1/F	9.3	-	2.7	302	41	Nil	6.0	312	3.4	52	19.3	425	0.15	211
N85/6/150	8.55	88	4.2	555	29	3.1	5.2	624	0.6	54	43	245	1.3	403
N85/6/151	7.8	99	4.8	660	44	<0.5	6.4	767	1.05	46	52	300	1.6	460
N85/6/152	8.55	99	4.8	660	35	<0.5	6.4	766	1.05	25	53	255	1.1	276
N85/9/1	6.7	40	0.7	175	18	22	1.1	42		9	3.1	155	0.2	698
N85/9/2	8.35	-	0.7	160	18	22	1.1	42		7.5	3.1	122	0.1	420
Golden Springs	8.15	40	0.75	187	16	16	0.7	43	-	10	3.3	144	<0.1	464
Waiotapu Postmistress Pool	8.6		4.0	450	22	9	5.2	688	0.8	93	27	380	0.4	58
Waiotapu Champagne Pool	5.7		9.0	1220	166	35	5.5	2000	0.4	145	117	490	11.5	235

indicated by Browne **(1982);** however, the degree of replacement **also** *appears* to depend on lithology.

The processes of fluid-rock interaction in RP1 has altered the mineralogy **and** overall chemistry of the rock by replacement, deposition of secondary minerals (in veins and vugs) and minor leaching. Replacement of **primary** mineralogy is the most common form of alteration. Intensity of alteration and occurrence of hydrothermal minerals in the Reporoa well is summarised in Figure **4.**

The hydrothermal silicate minerals in RP1 cores include **quartz,** albite, cristobalite, accessory adularia, titanite, rare mdymite and epidote. Clay minerals include kaolinite, smectite, interlayered illite-smectite **and** illite.

The mineral assemblage at depth is indicative of neutral pH waters. The presence of kaolinite in a thin, shallow layer (90-180m) does not imply that the waters are acidic. Browne and Ellis (1970) ***report*** that although kaolinite is a typical product of acid alteration it has been observed in near neutral pH ***or*** alkaline geothermal systems as a result of groundwater mixing. ***This*** process causes sulphide oxidation and generates low temperature acid conditions necessary for kaolinite formation.

A hydrothermal mineral zonation is often recognised in geothermal wells and is frequently compared to the zonation concept of porphry copper deposists. However, no systematic vertical distribution of hydrothermal alteration can be recognised in RP1.

Secondary quartz *occurs* throughout the **well and is** commonly **associated with** cristobalite and, at greater depth, **with** calcite. The **quartz** occurs in microveins, infilling **vugs** and most frequently **as a** replacement of the rhyolite glass and **crystal** laths both in **the** volcanic and tuffaceous **rocks.**

The main occurrence of cristobalite and tridymite is between about 500m and 650m. Their abundance decreases with increasing depth but neither is observed below 1070m. Cristobalite may result **from** the devitrification of the rhyolite **glass** and **also** occurs filling cavities and **as** feldspar replacement.

Albite, with variable abundance, **occurs** from 350m to the bottom of the well; adularia is evident between 680m and 1120m. **Both** occur **as** replacement minerals for primary plagioclase **and are** usually in inverse abundance **to** each **other.**

Titanite is widely, albeit irregularly, distributed throughout the well and its shallowest presence is near the top of the upper rhyolite at about 320m. The mineral grains **are** typically **small,** anhedral and increase in abundance towards the base of the well especially from 960m to the bottom.

Chlorite is ubiquitous, and **occurs as** an alteration product in the volcanic **glass** of the rhyolite, clay matrix of the tuffaceous rocks and **as a** replacement of plagioclase and ferromagnesian minerals.

Calc-silicate minerals such **as** clinozoisite and wairakite **are** absent from the cores, but rare epidote occurs, notably at about 1095-1100m as *small* anhedral **grains.**

The main secondary carbonate mineral **discovered** in the well was calcite, occasionally associated with anhydrite. The occurrence of calcite is confined to three major zones. The upper **occurs** between 335m and **400m,** second between 680m and 770m and the lower **from** about 850m to the base of the well. The calcite typically occurs as a replacement or overprinting of volcanic **glass,** plagioclase and ferromagnesian minerals. Occasionally **small** bladed calcite **crystals** occur in the altered feldspar which **are** sometimes themselves altered to secondary quartz. **Some** calcite-filled veins *are* **also** present.

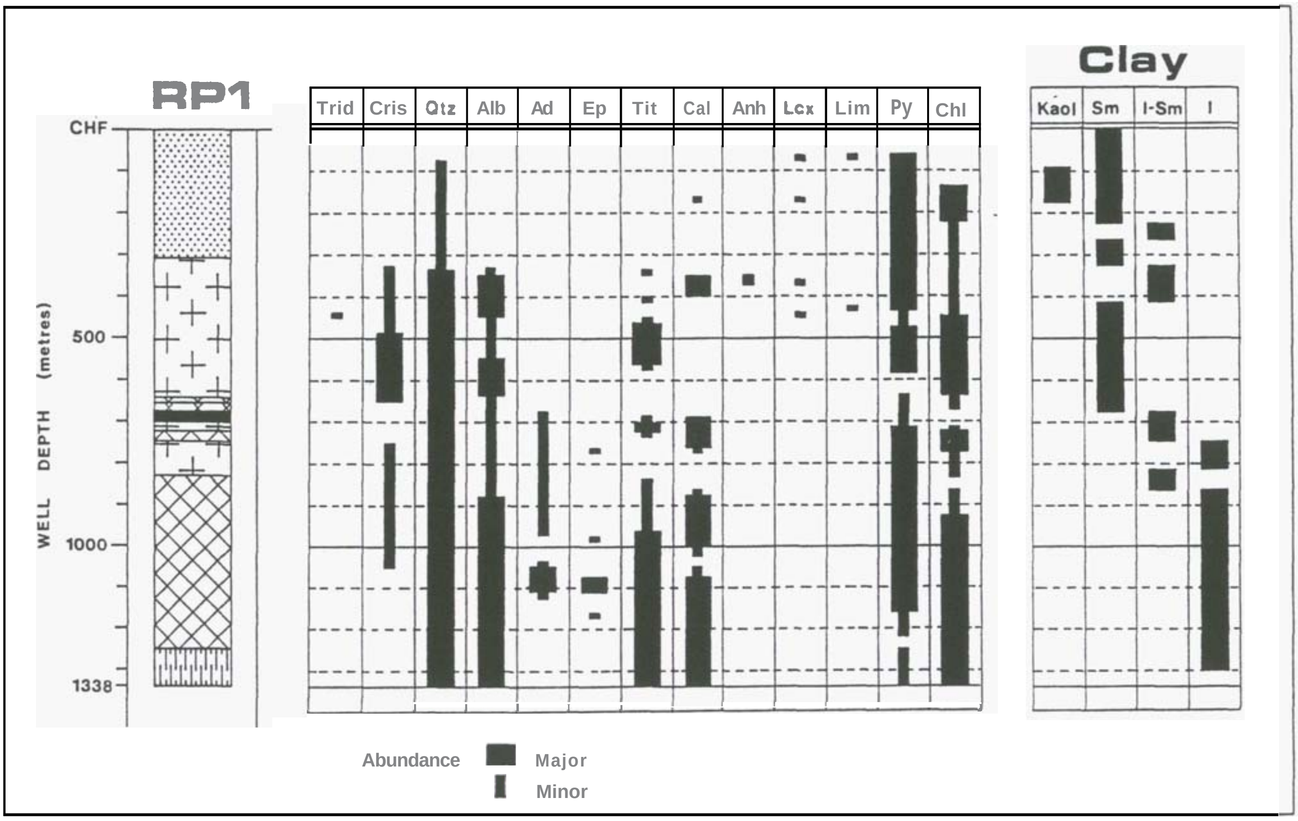

Figure 4 :Occurrence of hydrothermal **minerals and** clay **zonation** in RP1.
Abbreviations :Trid=Tridymite, **Cris=Cristobalite, Qtz=Quartz,** Alb=Albite, Ad=Adularia, Ep=Epidote, Tit=Titanite, Cal=Calcite, Anh=Anhydrite, Lcx=Leucoxene, Lim=Limonite, Py=Pyrite, Chl=Chlorite, Kaol=Kaolinite, Sm=Smectite, I-Sm=Interlayered illite-smectite, I=Illite.

Oxide minerals in RP1 *arc* leucoxene and limonite. The abundance of the oxide minerals decrease with depth; leucoxene is most common above 450m.

The only sulphide mineral is pyrite which can be found in all of the core samples. High **As** content (658ppm) in GB579.1m (sample/depth) may reflect the Occurrence of arsenopyrite.

Measured Bore Temperatures

Downhole temperatures in RP1 were measured by **MOW** on 5/10/66 after 47 days of heating and showed a significant temperature inversion between 400m and 670m with **a** minor maximum of 204°C at 304.8m (interlayered illite-smectite encountered), a minimum of 166°C at 548.6m (smectite encountered) and a maximum of 225°C at 853.4 to 975.4m (illite encountered). The bottom hole temperature at 1338m was 219°C.

Mineral Temperature Indicators

Browne (1984) showed that hydrothermal minerals which provide information on the temperature of their formation **are** mostly those that contain, in their structure, either (OH) or nH_2O. Progressive dehydration with increasing temperature has been shown by Elders er *al* (1984) to produce a sequence of temperature dependent calc-silicate minerals. With increasing temperam clay minerals lose interlayer water and structural changes occur. It is the progressive dehydration processes and temperature dependence that ***makes*** the clay and calc-silicate minerals useful in the geothermal setting as temperature indicators.

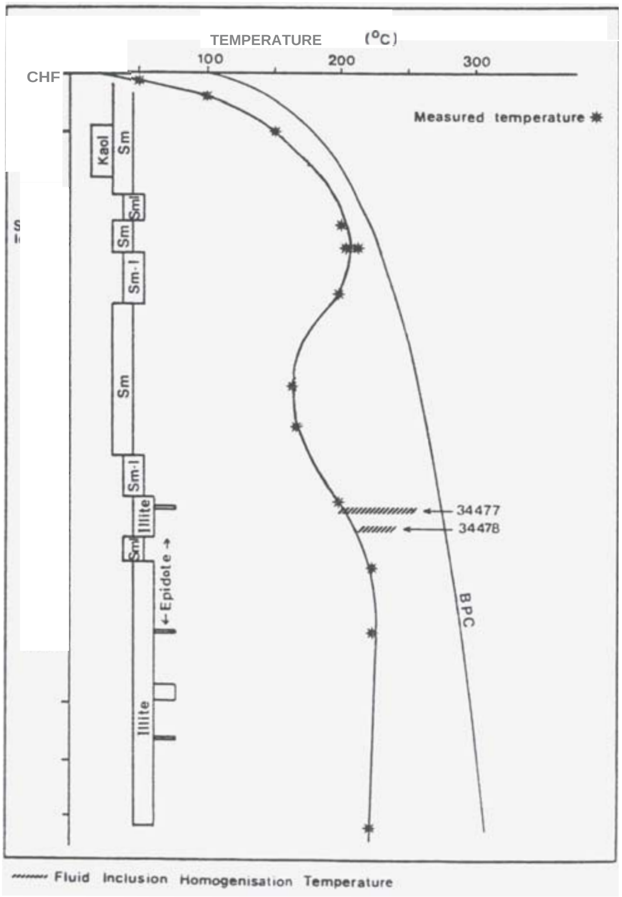

Figure **5** : Clay Zonation related to measured bore hole temperatures and fluid inclusion geothermometry in RP1.
kaol = kaolinite, Sm = smectite, Sm-I = interlayered smectite+illite, I = illite.
34477, 34478 = ***NZGS* Core** samples/thin sections numbers.

Calc-silicate Temperature Indicators

Typical calc-silicate minerals which commonly occur in geothermal systems include epidote, clinozoisite, wairakite, prehnite and pumpellyite. ***Of*** these only epidote is found in the core samples from Reporoa, and then only rarely.

Epidote is commonly regarded **as** a high temperature alteration mineral **(>250°C)** and is found in many geothermal fields (Browne, 1978). The occurrence of epidote in RP1 is towards the bottom of the well where measured bore temperatures attain a maximum of 225°C but where fluid inclusion studies indicate temperatures **as** high **as** 254°C at some **unknown** time in the past.

Clay Mineral Temperature Indicators

Clay minerals which occur in RP1 cores and record their mineral formation temperature are kaolinite, smectite, illite-smectite **and illite.**

The temperature of formation for the different clay **minerals** is **summarised** below -

Hydrothermal Mineral	Stability Temperature
kaolinite	<120°C
smectite	**<140-**150°C
interlayered illite-smectite	140-220°C
illite	>220°C

The temperature interpretation from clay mineralogy is consistent with the measured bore hole temperatures shown in Figure **5.** The temperature inversion recognised in downhole measurements are reflected by the Occurrence of different clay minerals and is interepreted to be caused by a cooler water influx at about 600m.

FLUID INCLUSION GEOTHERMOMETRY

Several secondary **quartz** samples were collected for fluid inclusion analysis but only **two** proved useful. Fluid inclusion homogenisation temperatures for primary two phase liquid inclusions were determined for samples from 741.4m and 789.4m depth (NZGS **Nos.** 34477, 34478).

The homogenisation temperature measurements for the samples ranged from 201.8°C to 254.7°C and 215.4°C to **240.4°C,** but showed a similar distribution and average value.

Depth	Number	Range (OC)	Average (°C)	Bore (°C)
741.4m	11	201.8-254.7	225.7	202
789.4m	8	215.4-240.4	228.6	211

The homogenisation temperatures determined for the two samples **are** higher than the measured bore temperatures at the corresponding depth. Although it is not conclusive since the number of samples is too small, this does suggest that perhaps the geothermal fluid is slightly cooler now than when the fluid inclusions **were** trapped.

The inclusions indicate apparent salinities of 2.0-2.1 wt% NaCl equivalent, although the possible effects of CO_2 content which would reduce the apparent salinity have not been considered. No daughter minerals were seen.

PERMEABILITY

Several workers have indicated a control on the deposition of hydrothermal minerals due to permeability. A knowledge of the mineralogy of the cores from a drillhole can be used to interprete the subsurface permeability.

Adularia mainly occurs between about 1050m and 1120m depth with accessory Occurrence between 680m and 950m depth. Albite occurs with variable abundance between 350m and the bottom of the well. Generally the relationship between adularia and albite is an inverse one. In less permeable parts albite is more abundant and adularia is rare or absent.

Hole 1 was opened and discharged for the first time on 12/10/66. Initially the wellhead pressure was 289.6kPa but fell to 82.7kPa after 5 hours at which time the well was shut. Drilling circulation losses occurred at 41.8m and 74m below CHF in the Huka Falls Formation and were cemented. Partial losses occurred from 386m to 525m in rhyolite with maximum loss being at 407m. All levels at which circulation loss occurred were cased out with no further losses below 525m.

Healy (1974) suggested "that small discharges were coming from the levels of minimum and maximum temperatures but relative amounts changed during the discharge test". The rocks in RP1 are commonly quartz veined and contain joints and this is the source of permeability.

REPOROA - AN OUTFLOW FEATURE?

Interpretation of temperature reversals and petrology in RP1 and regional resistivity surveys support the idea of a lateral flow of hot water to Reporoa from Waiotapu. However, the chemical structure of the Reporoa geothermal system has not been considered in detail.

Henley and Ellis (1983) showed a schema of a geothermal system typical of active island-arc andesite volcanoes and noted the increasing HCO_3/SO_4 ratio of water away from the centre of the upflow. Although the regional topography is almost flat a parallel can be seen in the Waiotapu-Reporoa system whereby there is an increase of the HCO_3/SO_4 ratio of discharge water from Waiotapu through Reporoa to Golden Springs.

A subhorizontal flow is envisaged and produces the neutral pH, chloride-bicarbonate springs and minor sinter at Reporoa (Figure 6).

Well discharge and spring chemistry have been applied to an enthalpy-chloride diagram to predict the underground conditions in the Reporoa system and relate them to conditions at Waiotapu. Fluid chemistry from well and spring waters at Waiotapu have been recalculated to reservoir conditions following the procedures of Henley et *al* (1984). These analyses were used with data from RP1 (Glover and Ellis, 1967) and the Opaheke Springs (Mahon, 1966) and shown on the enthalpy-chloride diagram to show the trend of boiling and vapour loss at Waiotapu (Figure 7). The figure indicates a hydrological connection between Waiotapu and Reporoa.

The Opaheke spring compositions can be related to a parental fluid by the following mechanisms -

i) Ascending fluid could boil and then mix with a dilute groundwater fluid to produce the different spring compositions.

ii) Ascending fluid could mix with dilute steam heated waters along the dilution trend shown by the well discharge compositions and then boil to produce the spring compositions.

iii) Conductive cooling to produce the spring compositions from the diluted reservoir fluid may also be involved.

The hot spring waters that reach the surface at Opaheke are probably mixed waters that may have equilibrated chemically in shallow reservoirs or aquifers.

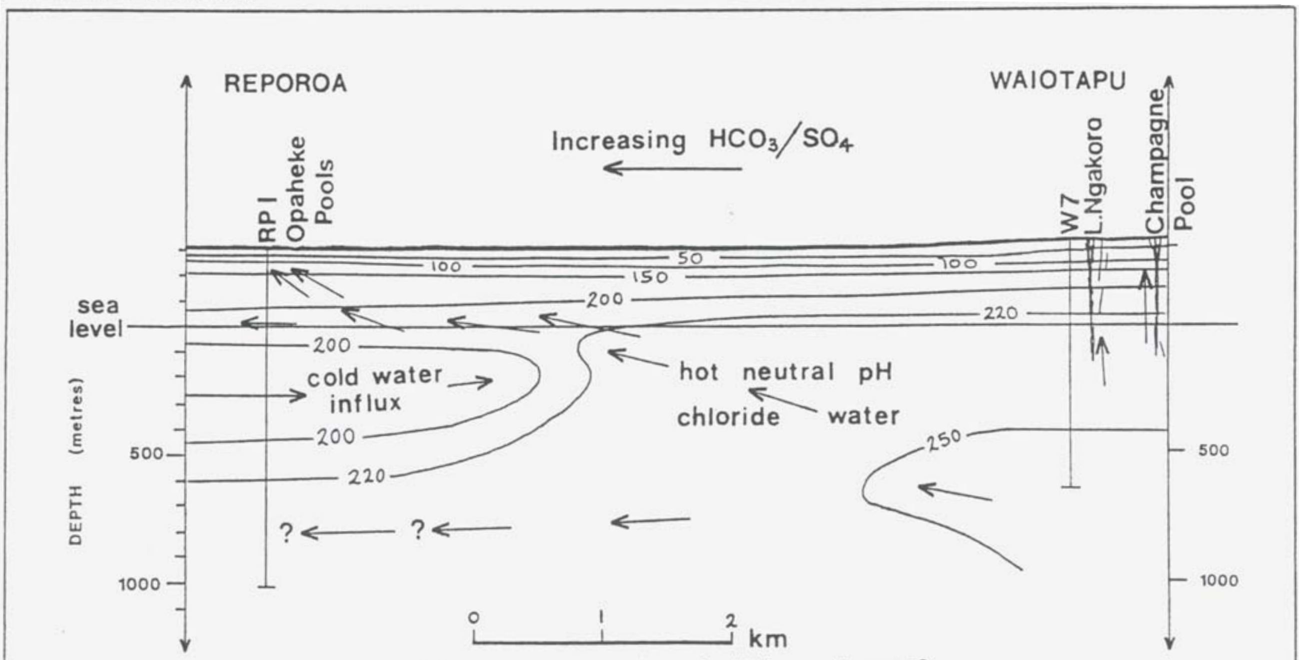

Figure 6 : Proposed schema for Waiotapu-Reporoa?

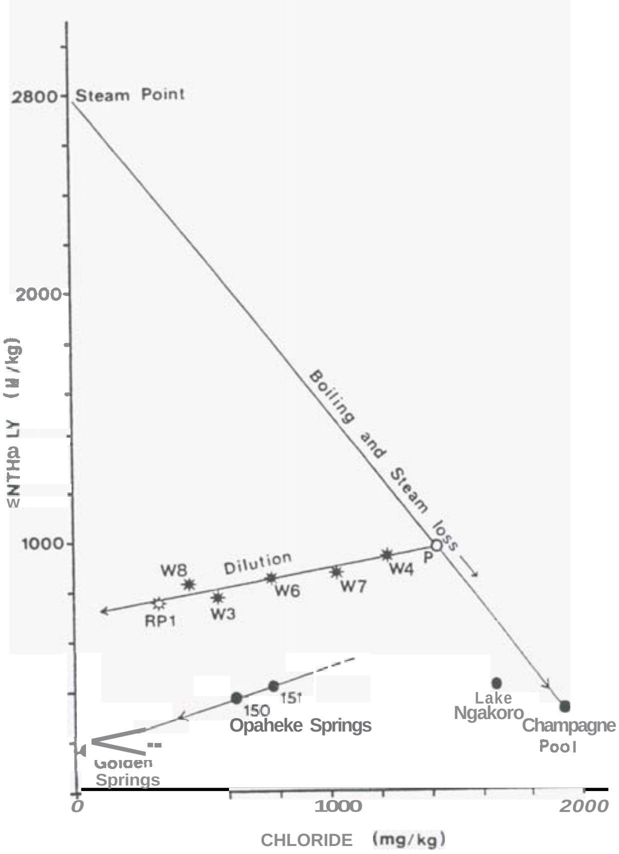

Figure 7 : Enthalpy-chloride diagram for Reporoa and Waiotapu wells and spring fluids - after Hedenquist and Henley (1985).

CONCLUSIONS

- Regional geophysical measurements and chemistry studies of RP1 borehole fluid suggest that the Reporoa system is a lateral flow of hot water from the Waiotapu Geothermal System.

- Hydrothermal alteration in RP1 generally increases in intensity with depth below about 700m but above this depth a temperature inversion is indicated by the mineralogy, due to an influx of hot water at about 300m depth and cooler water at 500-650m. Below 800m hydrothermal alteration is produced by near neutral pH chloride-bicarbonate fluid.

- The mineral assemblage at depth in cores from RP1 is quartz, albite, adularia, titanite, illite, chlorite and calcite. The scarcity of epidote and absence of wairakite and other calc-silicate minerals is consistent with a geothermal fluid moderately high in CO_2.

- Calculated chemical geothermometers and clay/mineral stability temperatures agree reasonably well with the pattern of downhole measurements while fluid inclusion temperatures are somewhat higher indicating that the geothermal fluids are cooler now than at the time of their trapping.

ACKNOWLEDGEMENTS

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Appendix

ROCK CHEMISTRY

Hydrothermal alteration characteristically produces changes between altered and unaltered rocks. This is true of volcanic and pyroclastic rocks of the TVZ (Steiner, 1977). Replacement, leaching and deposition from solution are the main cause of chemical changes although sometimes isochemical changes occur.

Six cores from RP1 were analysed for major and trace elements, two from the upper rhyolite, two from the lower rhyolite and two tuff.

Analyses are presented in Appendix 1 and were compared to unaltered rocks from the TVZ and observed alteration mineralogy in RP1 to assess the intensity of alteration and chemical changes that may have occurred.

	GB394.7m Rhyolite	GB579.1m Rhyolite	GB752.2m Rhyolite	GB761.4m Rhyolite	GB947.3m Tuff	GB1159.7m Tuff
SiO_2	77.67	73.67	70.10	75.83	72.53	71.53
TiO_2	0.10	0.09	0.28	0.24	0.24	0.25
Al_2O_3	11.92	12.31	13.86	12.46	13.16	13.10
Fe_2O_3	0.82	1.48	1.72	1.48	2.21	2.25
MnO	0.03	0.02	0.18	0.03	0.07	0.06
MgO	0.18	0.23	0.74	0.35	0.41	0.45
CaO	0.14	0.26	2.76	1.14	1.50	1.95
Na_2O	1.07	2.00	1.34	2.24	4.36	4.32
K_2O	5.40	3.01	3.46	2.61	3.29	3.35
P_2O_5	0.01	0.01	0.05	0.03	0.03	0.04
H_2O^-	0.84	2.21	1.54	0.99	0.20	0.22
LOI	1.99	4.36	3.80	2.21	1.54	1.89
TOTAL	100.18	99.65	99.85	99.60	99.50	99.41
Nb	9	10	9	9	9	9
Zr	119	117	257	228	196	205
Y	54	43	37	33	34	35
Sr	26	17	157	148	134	138
Rb	209	103	119	89	110	113
Th	13	17	13	13	11	15
Pb	25	32	24	23	24	21
As	29	658	14	39	12	11
Zn	212	81	47	55	47	49
Cu	-1	-1	-1	-1	-1	-1
Ni	4	4	-1	-1	4	-1
Cr	7	7	12	8	20	23
V	-1	-1	-1	8	12	14
Ba	952	551	1311	756	675	692
La	34	33	31	29	30	25

Appendix 1 : Major and trace element chemistry of selected rocks from RP1.
-1 = Below detection limits.
Major element abundances given in wt% oxide, trace elements abundances given in ppm.