Chemical Structure of the Ngatamariki Geothermal Field, Taupo Volcanic Zone, N.Z

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ABSTRACT

A review of the chemistry of the Ngatamariki geothermal field has enabled the source fluid composition and the natural state reservoir processes to be characterized.

The cation and anion relationships and chloride enthalpy mixing models show that Ngatamariki shallow fluids are related to the deep fluids by dilution (mixing). The processes are in agreement with the conceptual model developed by Mighty River in 2010. Deep fluid composition at Ngatamariki was characterised from 5 deep exploration wells and shows typical neutral chloride composition with ~950 mg/l Cl and silica and Tnkc geothermometer temperatures of ~280˚C. Gas chemistry from the geothermal wells suggests that the Ngatamariki fluids have degassed evenly across the field and record equilibrium geothermometry temperatures of 275˚C.

As the fluids ascend out of the reservoir they enter an intermediate aquifer through a zone in the central part of the field which appears to be the main upflow from the reservoir to the surface. These fluids can be classified into three distinct types of water within the aquifer 1) Local groundwater, 2) Dilute geothermal fluids mixed with groundwater and 3) a steam heated groundwater. Based on the enthalpy chloride relationship of samples taken from wells drilled into the upflow suggest that the fluids are 60% deep reservoir fluid mixed with regional cold groundwater. These fluids then variably mix with ~140˚C steam heated ground waters as they travel towards the Orakonui stream springs where they discharge at the surface.

1. INTRODUCTION

1.1 Overview

This review summarises the fluid composition at the Ngatamariki geothermal field in order to characterise the source fluid geochemical signatures and processes occurring within the reservoir, including chemistry from new wells drilled between 2009 and 2010.

Ngatamariki geothermal field is located within the Taupo Volcanic Zone (TVZ) about 20 km north-west of Taupo with the Orakei Korako geothermal field a further 7 km to the north (Figure 1). The field sits on the edge of the 340 ka Whakamaru Caldera, with the inferred boundary running through the western part of the field (Wilson et .al, 1986). Whakapapataringa dome marks the north western boundary of the field, a product of the nearby Maroa Volcanic Centre. The surface manifestations at Ngatamariki are minor with perhaps about a dozen features including seeps. The fluids discharge primarily in two main locations in the Orakonui stream ("South Orakonui" and "North Orakonui") 1-1.5 km from the confluence with the Waikato River but there are also hot springs on the banks of the Waikato River. The major thermal feature is a large hydrothermal eruption crater situated at the South Orakonui area. The crater measures 50 x 30 m and outflows via a small channel into the Orakonui Stream.

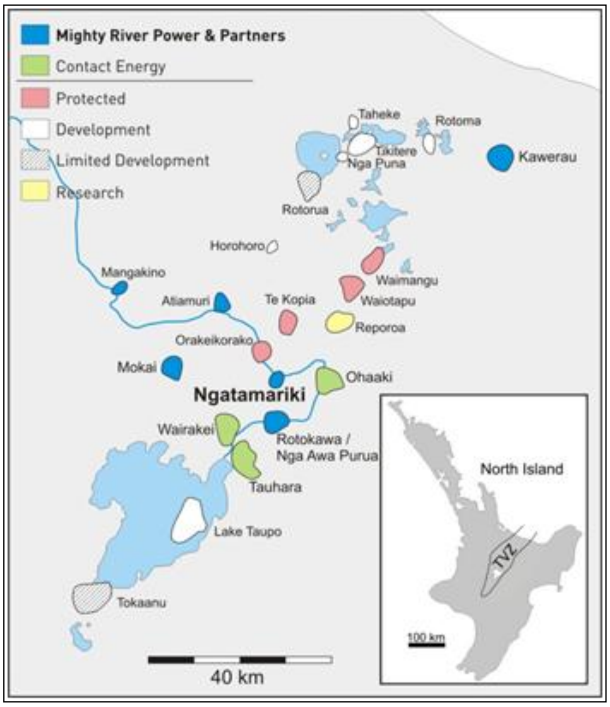

Figure 1:Location of the Ngatamariki geothermal field within the TVZ.

1.2 Ngatamariki

First documentation of thermal features at Ngatamariki is by Grange (1937). Lloyd (1972) was the first to create a geological map of the area in his bulletin on the Orakei Korako field. Hedenquist (1986A and B) was the first to provide a summary of the chemistry of thermal features and NM2 and 3 discharges. From this he deduced that the parent fluid at Ngatamariki was ~290 ˚C and 1200 mg/l chloride and that the major upflow for the field was in the vicinity of NM2 and NM3.

He also inferred that cooler shallow lateral flows extend north towards the Waikato River Seeps and west towards the Orakonui Stream. Mixing relationships suggested variable dilution of the deep fluids by a steam heated bicarbonate fluid of ~140 ˚C. Subsequent studies (Brotheridge, 1995; Urzua, 2008; O'Brien, 2010) have also examined the chemistry of the springs and came to similar conclusions and estimates for reservoir temperatures and mixing relationships. Urzua (2008), Bignall (2009) and O'Brien (2010) all present hydrological models for the area with the latter also completing an isotopic study of the springs and selected well waters.

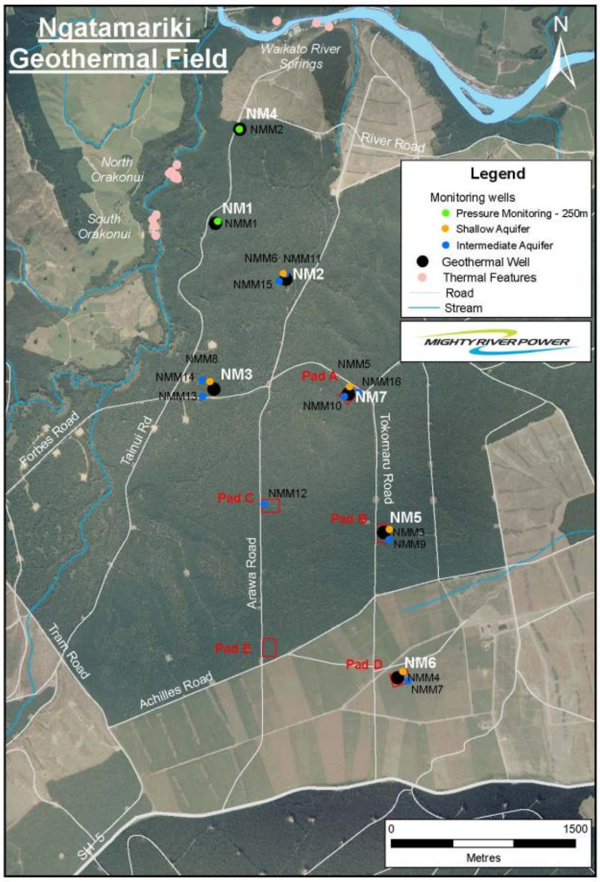

Figure 2: Current layout of the Ngatamariki Geothermal Field. The white line running through the section is the line of section for the conceptual model cross section.

The following outlines the changes to this interpretation with new data from 3 new exploration wells and intermediate wells on each pad (Figure 2). It is known that the Ngatamariki geothermal field is composed of three distinct aquifers (Boseley et.al., 2010):

1. The deep 'reservoir' containing the primary geothermal fluids.

2. An 'intermediate aquifer' sitting directly above the reservoir above the clay cap hosted in rhyolite,

3. An unconfined 'shallow aquifer' located in the shallow formations, with its base being the top of the Huka Falls Formation (aquitard) which separates it from the intermediate aquifer.

The interaction between these aquifers and the mechanisms producing the fluids found in the field is discussed in this paper.

2. FLUID TYPES

The following section identifies the four main fluid types encountered within the Ngatamariki field and their relationship to each other. Previous studies mentioned above had identified these fluid types but had not detailed the chemical interactions between three different aquifers mentioned above. A simple plot of Cl vs. HCO_3 allows us to easily distinguish these fluids from each other (Figure 4).

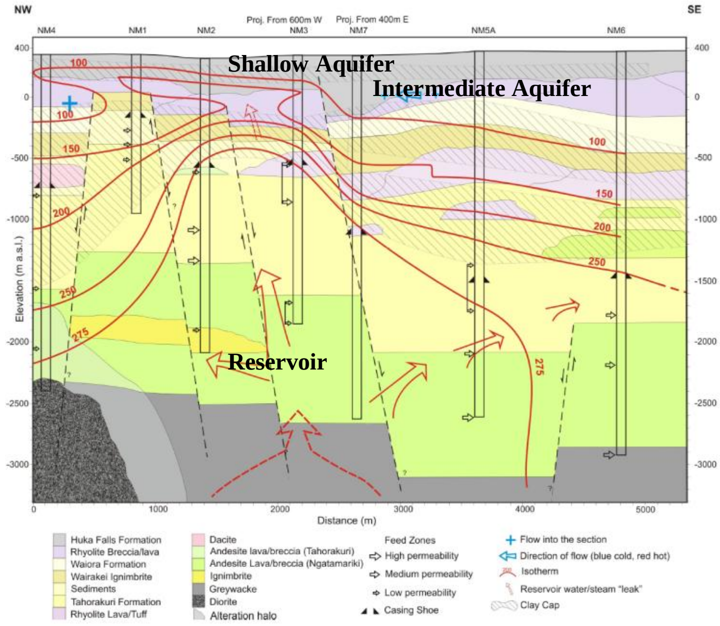

Figure 3: Conceptual model of the Ngatamariki Geothermal Field showing the three aquifers separated by clay zones. (Boseley et al, 2010).

2.1 Reservoir Fluids

Reservoir fluids at Ngatamariki are typical neutral chloride waters seen in geothermal systems throughout the TVZ with concentrations ranging from 998 mg/l chloride in NM3 to 954 mg/l chloride in NM7. Liquid samples for the reservoir have been obtained from NM2, NM3, NM5, NM6 and NM7. Gas samples have also been taken from all of the above wells and are used in this paper.

2.2 Mixed Geothermal Fluids

These geothermal fluids occur in the north of the field within the rhyolite hosted intermediate aquifer. Fluids exiting the reservoir mix with meteoric waters flowing to the north within the intermediate aquifer producing this fluid which is approximately 60 % geothermal. The Orakonui Stream springs are sourced from these fluids and mix with steam heated groundwater to produce the chemistry we see at the surface. Samples from this mixed fluid have been obtained from intermediate wells on NM1 (NMM1), NM2 (NMM11 and NMM15), NM3 (NMM13 and NMM14) NM4 (NMM2) and NM7 (NMM10) pads (Figure 2).

2.3 Steam Heated Groundwater

Meteoric water steam heated as it travels into the centre of the field through the intermediate aquifer. These waters are most likely soured from rhyolite domes in the north of the field as there is no evidence of this fluid in the intermediate aquifer in the south of the field. These fluids have not actually been encountered in any wells but the Waikato River springs give the best approximation of their chemistry as they have relatively low chloride but high silica.

2.4 Local 'meteoric' Groundwater

Local 'meteoric' groundwater is found in both the shallow (NMM3) and intermediate aquifers (NMM12 and NMM16) at Ngatamariki, these waters are representative of meteoric water as shown by their similarities to the Orakonui stream composition. These waters appear to enter the system from the south through a series of rhyolite domes.

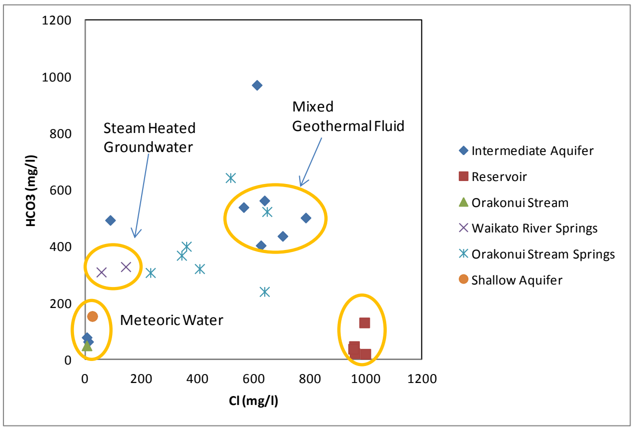

Figure 4: Cl vs. HCO_3 plot for Ngatamariki waters. The yellow circles encompass the four different water types within the field.

4. CHEMICAL STRUCTURE

The concentrations of conservative constituents can give clues into reservoir processes. This section details the interactions

4.1 Deep Reservoir

The chemical composition of reservoir fluids shows an east west gradient across the Ngatamariki field. Liquid and gas compositions both suggest the upflow to the field is probably located to the west of NM3 (Figure 7). Chloride concentrations show a gradient from 954 mg/l chloride in NM7 to 998 in NM3. The Na-K-Ca geothermometer (NKC) (Figure 5) suggests temperatures of ~280 ˚C in the western and central wells (NM3, NM2 and NM7) with gas CO_2-NH_3-H_2S ratios suggesting fluids in NM3 are the least degassed (they contain the highest concentrations of CO_2), which also suggests the west part of the field is the the closest to the upflow for the field (Figure 6). Tqtz geothermometer temperatures also suggest temperatures of ~280 ˚C with NM7 having the highest temperature of 290 ˚C.

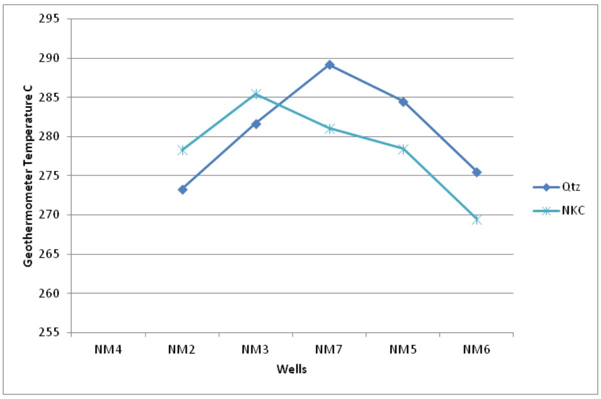

Figure 5: Quartz and NKC geothermometers for Ngatamariki reservoir fluids. Both methods agree within 5 ˚C suggesting reservoir temperatures of ~280 ˚C

CO_2/Ar vs. H_2/Ar (CAR/HAR) gas geothermometry (Giggenbach and Goguel, 1989) also agrees with these temperatures. When using the CAR/HAR geothermometer it indicated that all the Ngatamariki reservoir fluids are in equilibrium with liquid at 275 ˚C. This is consistent with the Tqtz and Tnkc geothermometer temperatures shown above.

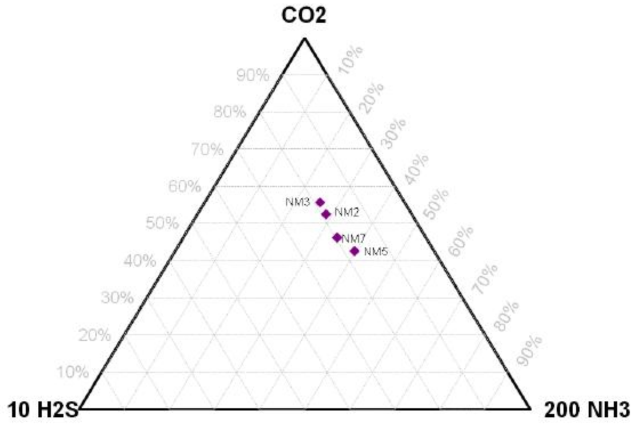

Figure 6: CO_2-H_2S-NH_3 ternary diagram for Ngatamariki reservoir fluids. The diagram suggests that NM3 produces the least degassed fluid, suggesting it may be the closest to the upflow of the system.

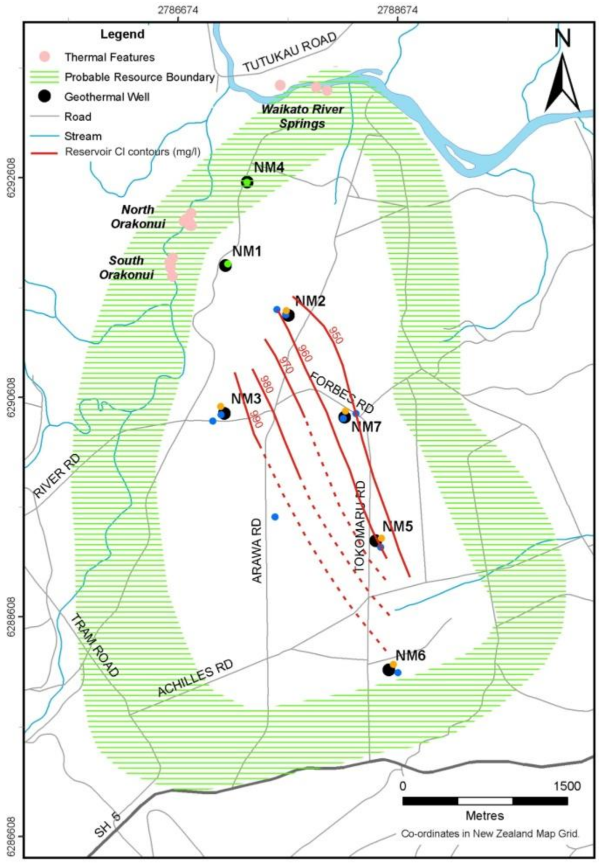

Figure 7: Contours of reservoir Cl at Ngatamariki. An east-west gradient is seen across the field suggesting the most concentrated fluids are to the west of the currently drilled wells.

4.2 Intermediate Aquifer

There appear to be two distinct groups of waters within the intermediate aquifer:

1. Regional groundwater derived from regional meteoric recharge, uninfluenced by the deep geothermal reservoir.

2. Dilute geothermal fluids mixed with regional groundwater.

The distinction between these two types appears to be spatially controlled with wells south of NM7 showing the signature of a typical ground water. The wells north of NM7 show a geothermal signature with significantly higher concentrations of both chloride and bicarbonate than those in the south (regional groundwater).

The location of the geothermally affected area of the intermediate aquifer can be clearly mapped out using contours of chloride and bicarbonate concentrations (Figure 9). Both of these constituents show a strong gradient to the north to south away from the main upflow from the deep reservoir. The contours also show the gradient is stronger to the south An intermediate aquifer testing programme in 2009 confirmed that there was no hydraulic connection between the north and south of the intermediate aquifer (Boseley et.al, 2010 B).

The highest chloride concentrations represent the main upflow between the intermediate aquifer and the deep geothermal reservoir. Hydrothermal alteration of the Ngatamariki reservoir rocks also reflects the processes indicated from the fluid chemistry. High temperature alteration is recognized by the occurrence of epidote, illite, illite-smectite and smectite. The alteration appears to dome upwards around the NM2 area which is consistent with the high concentrations of chloride seen in the fluid chemistry in the intermediate aquifer (Figure 8).

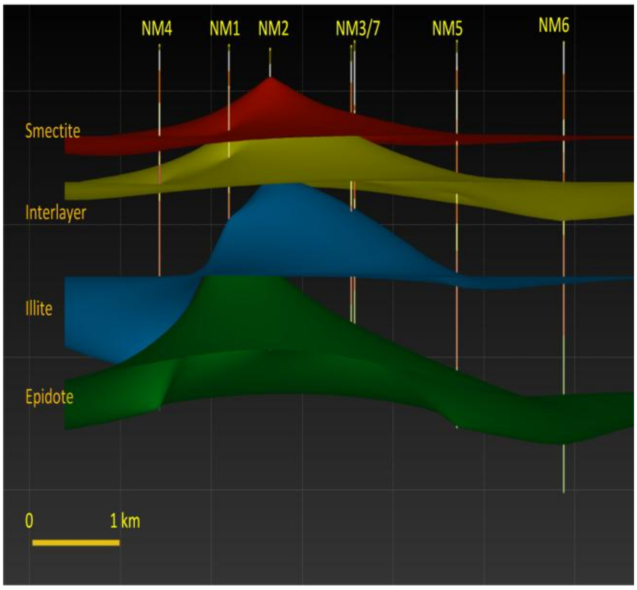

Figure 8: 3D visualization of hydrothermal alteration at Ngatamariki. The layers represent the first occurrence of these minerals in the wells as delineated by XRD and visual analysis. The alteration mineralogy domes upwards around

4.3 Unconfined Aquifer

The shallow (50-100 m deep) unconfined aquifer at Ngatamariki is hosted in volcanic units overlying the Huka Falls aquitard (Boseley et.al, 2010 A). Water in this aquifer is derived from rainfall in the area and the chemistry of the water in the aquifer reflects this (Figure 4).

Chloride contours for the whole reservoir show the same shape and nature as the measured temperatures (Figure 10). High chloride concentrations in the reservoir are diluted as they enter the intermediate aquifer and flow to the north as is reflected in the intermediate aquifer temperatures (Figure 3).

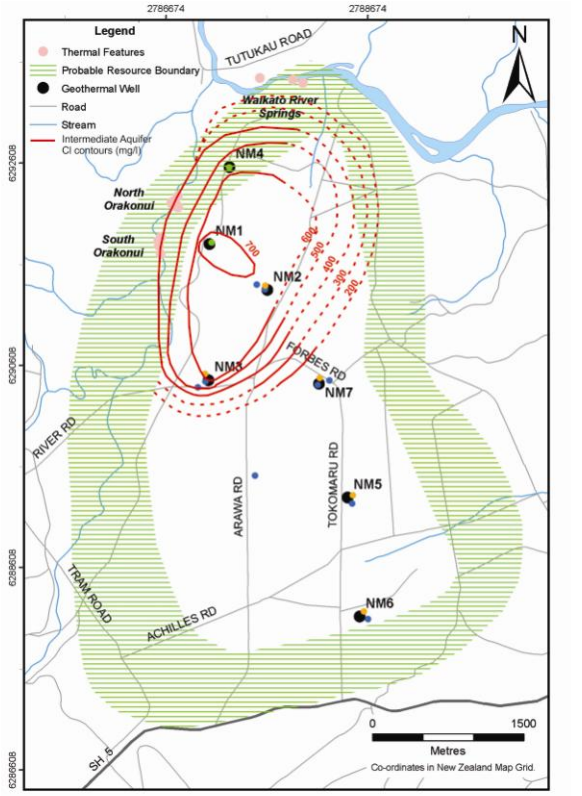

Figure 9: Contours of Cl in the intermediate aquifer. The contours outline the proposed location of the connection between the reservoir and the intermediate aquifer and shows the dilution of the fluids as the spread away from the connection (pads with two well finished in the intermediate aquifer have an average Cl value for the pad)

5. ENTHALPY-CHLORIDE RELATIONSHIPS

The field wide processes described earlier can be simply represented using a chloride enthalpy relationship. The four water types outlined in the above section and their interactions can be explained using the diagram (Figure 11).Reservoir fluids show similar chemistry with chloride values of around 970 mg/l and quartz enthalpies of ~1250 kJ/kg. It appears no significant mixing or boiling is occurring within the deep Ngatamariki reservoir.

Figure 11 also shows that as the fluids exit the reservoir they are diluted with groundwater within the intermediate aquifer to produce a 60 % geothermal fluid mix. These mixed fluids have chloride concentrations of ~600 mg/l and quartz enthalpy of ~800 kJ/kg. The Orakonui Stream Springs are sourced from this mixed fluid which is evident from two samples plotting within the same area as the intermediate aquifer wells. The spring fluids mix variably with a steam heated groundwater most likely produced by waters entering the field from the north-west through rhyolite domes like Whakapapataringa and steam heated as they travel into the field across the top of the reservoir to a temperature of ~140 ˚C.

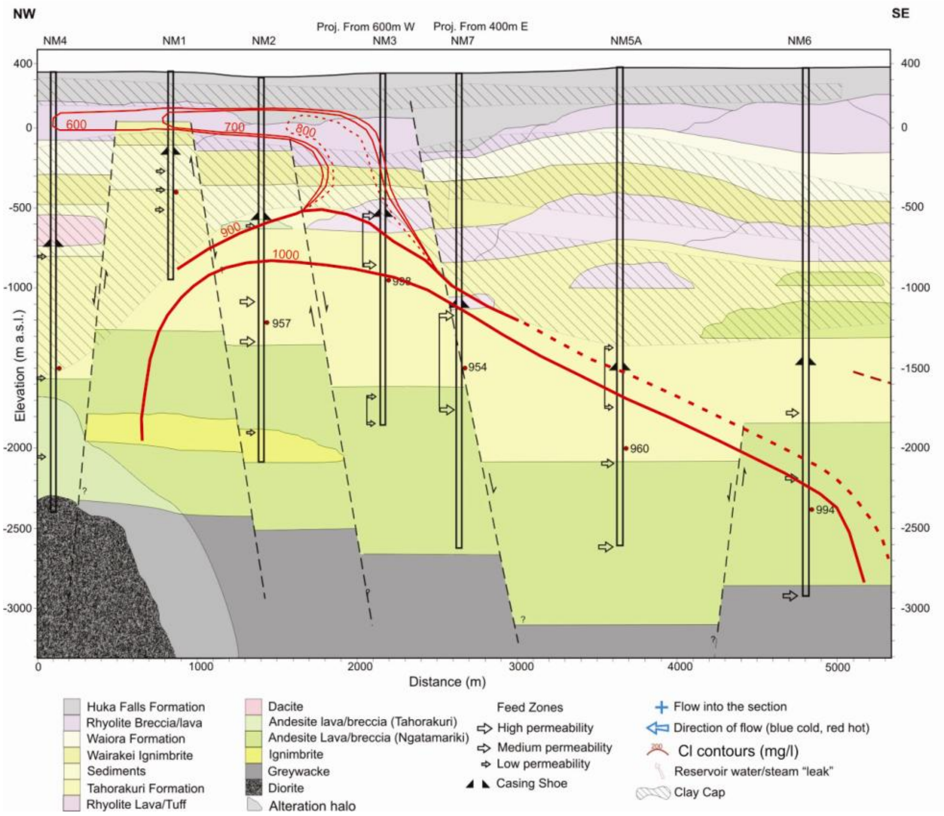

Figure 10: Field wide chloride concentrations for the Ngatamariki reservoir. The nature of the chloride contours is very similar to the temperature contours seen in Figure 3.

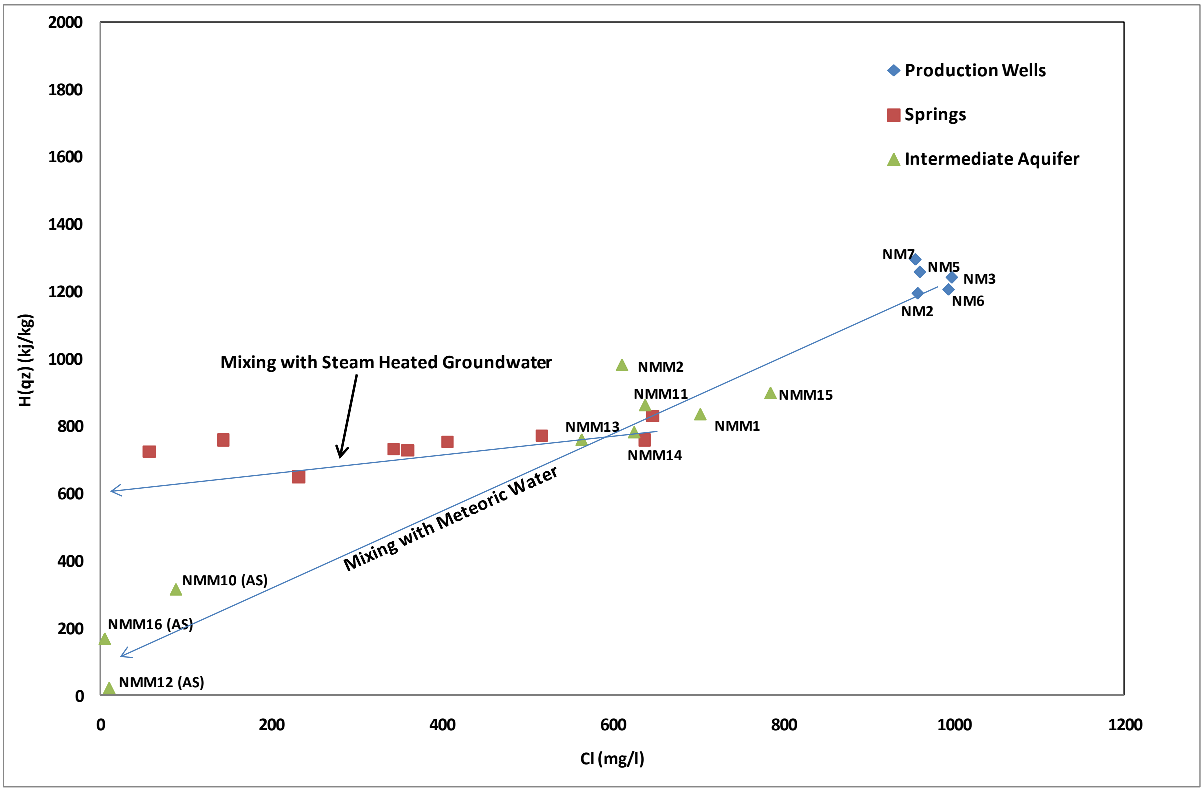

Figure 11: Enthalpy (at Tqtz) – Chloride diagram for the Ngatamariki Geothermal Field. Two simple trends can define the field-wide processes 1) mixing of reservoir fluids with meteoric water in the intermediate aquifer and 2) dilution or mixing of a mixed geothermal fluid with a steam heated groundwater to produce the chemistry of the Orakonui stream springs. (AS stands for amorphous silica geothermometer where temperatures were not in equilibrium with quartz).

The NMM10, NMM12 and NMM16 samples represent the southern uncontaminated part of the Intermediate aquifer. There samples are plotted using the enthalpy at the amorphous silica geothermometer temperature rather than the normal quartz geothermometer as the cooler fluids are not in equilibrium with quartz. These samples represent the fluid mixing with geothermal fluid as it exits the reservoir.

6. CONCLUSIONS

Four distinct fluid types can be mapped out using chemical constituents including reservoir fluids, mixed geothermal fluids, meteoric groundwater and steam heated groundwater.

As fluids leave the reservoir they mix with local ground water to produce a 60% geothermal fluid restricted to the north part of the field within the intermediate aquifer. The fluids are located in three aquifers separated by clay horizons across the field. Hydrothermal alteration reflects the processes suggested by the chemistry with high temperature alteration doming upwards around NM2 (Figure 8).

These conclusions suggest the Ngatamariki reservoir is a liquid dominated reservoir with its fluids in chemical equilibrium.

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