Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Preliminary Assessment of the Ohinewai Low Enthalpy Geothermal System, New Zealand

Irene Cheptum[1], Katherine Luketina[2*] and Sadiq J. Zarrouk[3]

1 Geothermal Development Company, Kenya

2 Waikato Regional Council, Private Bag 3038, Waikato Mail Centre, Hamilton East 3240, New Zealand

3 Department of Engineering Science, the University of Auckland, New Zealand

*kluketina@waikatoregion.govt.nz

Keywords: Ohinewai, low enthalpy, geothermal system, Waikato, New Zealand

ABSTRACT

Low enthalpy geothermal systems are widely spread in New Zealand although their exploration and utilization has been relatively limited. There are approximately 105 low-temperature geothermal systems in New Zealand. Approximately thirty of them are found within the Waikato region, which is also host to most of the high-temperature systems in New Zealand.

This study focuses on Ohinewai low-enthalpy geothermal system, which is located to the North West of the Waikato region in the central north island of New Zealand. A field survey was carried out in Ohinewai geothermal prospect to assess the field potential. Geothermal water samples were collected from self-discharging and pumped warm-water wells. The samples were analyzed for their geochemical signature.

The geothermal waters have been classified with respect to their anion and cation contents. The Cl-SO_4-HCO_3 ternary diagram classifies the geothermal water as dilute alkali chloride waters with relatively lower concentrations of sulphate and bicarbonates. Geothermometers were used for the determination of subsurface or reservoir temperature by assuming equilibrium between specific minerals and the geothermal fluids at depth. Calculated temperature from the geothermometers shows the temperature in the range of 60-100 °C. A geological cross section was developed based on drilling logs/records showed that the Greywacke basement (which is the source of the hot fluid) is located at about 300 to 360 m from ground surface. Isotherm map based on well data indicated that the up-flow zone is likely to be located towards North to North-West of the prospect (with respect to springs in the area).

From the geochemical analysis it is inferred that the resource might be small in size. This needs to be confirmed by deep drilling and further detailed geo-scientific studies.

1. INTRODUCTION

1.1 Background

New Zealand is endowed with a wide range of geothermal resources ranging from high to low enthalpy resources. However, the exploration and development of the vast low enthalpy geothermal resources have been limited due to the abundance of high enthalpy geothermal resources (Thain et al., 2006).

There are approximately 105 low-enthalpy (low temperature) geothermal systems in New Zealand, about thirty of which are found within the Waikato region (Luketina, 2012). Reyes and Jongens (2005) detailed hot spring systems with discharge temperatures of less than 90 °C scattered throughout the North and South Islands, and concentrated on the edges or boundary of high-enthalpy geothermal systems in the Taupo Volcanic Zone (TVZ) and Northland. Temperatures ranging from 120 to 160 °C waters at depths greater than 3.5 km are observed in abandoned hydrocarbon wells and natural heat flow from about 15 m below the surface and deeper.

1.2 Waikato Region Geothermal Systems

Waikato regional council has classified the region's geothermal systems into five categories with a different management approach for each category. Classification is based on system size, existing uses, and the presence of vulnerable surface geothermal features. The council aims to balance the development through the protection of highly valued surface features. The five categories are:

- Development systems
- Limited Development systems
- Research systems
- Protected systems
- Small systems

Among the 30 already known small systems in the region is Ohinewai geothermal field.

1.3 Aim of the Study

The purpose of the study is a preliminary assessment of the size and potential uses of the Ohinewai low enthalpy geothermal system. The field survey in the area of study involved sampling water bores in the resource area. The preliminary geochemical analysis is reported and interpreted in this work.

2. OHINEWAI GEOTHERMAL FIELD

2.1 Location

Ohinewai geothermal field is located equidistant between two main cities of Hamilton and Auckland, and immediately SW of Lake Waikare (see . It is situated in the lower part of Waikato lowlands in Waikato region (highlighted box in Figure 1). It has several springs and warm wells drilled to shallow depths for domestic, farm and industrial uses.

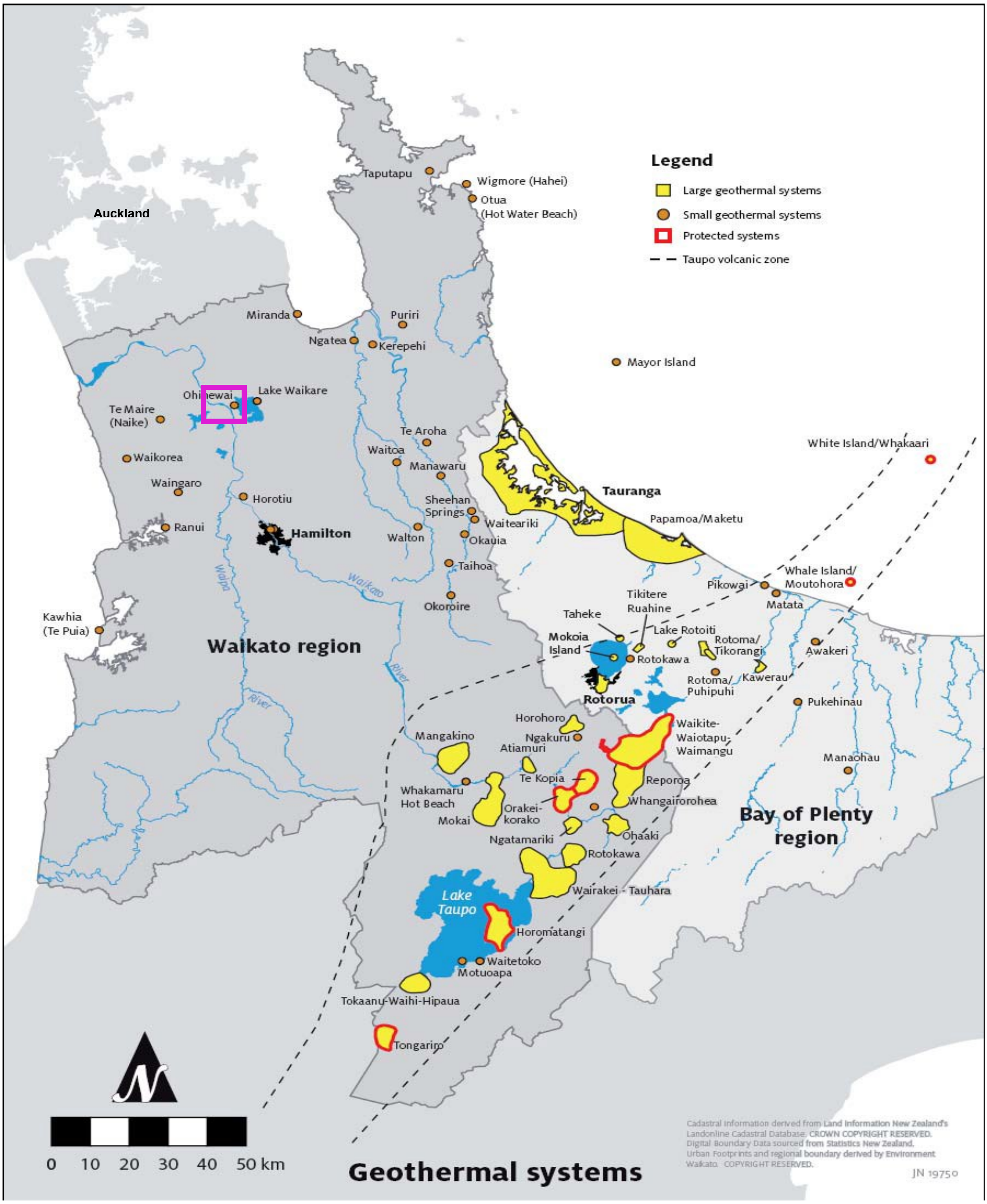

Figure 1: Map showing the location of Ohinewai geothermal field (map courtesy of Waikato Regional Council).

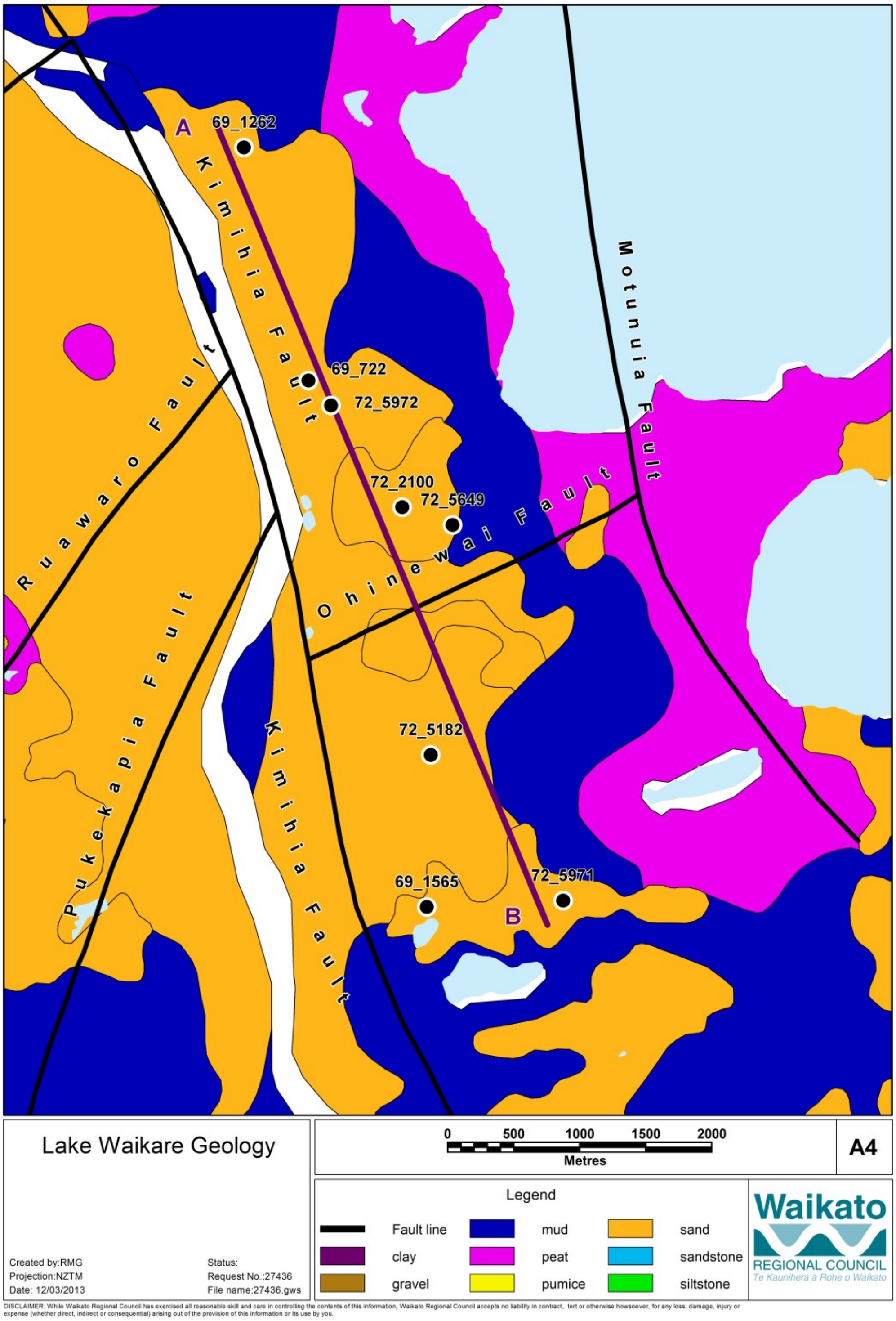

Figure 2: Surface geological map of Ohinewai geothermal field (map courtesy of Waikato Regional Council).

2.2 Geological background

The surface geology of Ohinewai geothermal field is dominated by sandstone on the western and south-eastern part of the field. Mudstone dominates the central part of the field and extends to the east towards Lake Waikare. Patches of sand are distributed across the field. The geological map (Figure 2) shows two main structures trending in the NW–SE direction, probably indicating that the field is permeable.

A geological cross section of the field (Figure 3) was developed using bore log records of the daily log sheets prepared by Drillwell Exploration NZ Ltd during the exploration for coal mining in the field. It was found that the rock types of Ohinewai field are sedimentary.

In Ohinewai, most of the 200 m of overburden on Paleogene coal measures comprises of terrestrial sediments of the late Neogene Tauranga Group. Tauranga group sediments are heterogeneous, including gravel, sands, silts, muds and peats of fluvial, lacustrine and distal ignimbritic origin (Edbrooke, 2001). They are dominated by silicic volcanic deposits derived from the Coromandel Peninsula and lately from central North Island (TVZ) sources, with persistent and locally abundant mineral assemblages from weathered or fresh "greywacke" or coal measure local sources. At least five distal ignimbrites occur in the Ohinewai cores (Campbell et al., 1988). Studies done by Zarrouk and Moore (2007) and Hochstein (1986) indicate that the Greywacke basement is encountered at about 300 to 400 meters.

Previous work by Vucetich et al., (1978) points out that Ohinewai Ash Member forms a section near Huntly as the lowermost member of Hamilton Ash Formation. Moreover, palynology dating of the formation of Ohinewai indicates an age range of late Miocene to late Pliocene (Edbrooke, 2001).

2.4 Land use

The sedimentary surface geology (Figure 2) renders the area suitable for grazing purposes, mainly dairy farms, with limited horticultural potential due to high water table.

3.BACKGROUND WORK TO THE STUDY

Few geoscientific studies have been undertaken at Ohinewai geothermal resource apart from those done for coal mining regional-scale assessments.

In previous assessments on the possible renewable energy targets for geothermal energy in New Zealand, some fields in Waikato region, including Ohinewai, were identified as possible targets. However, little is known about Ohinewai's utilization potential and heat assessment apart from a few existing domestic and farm uses (GNS Science, 2007; White, 2006).

Hochstein and McKee (1986) carried out a survey that involved boron analysis in thermal springs in the greater Auckland area over a distance of about 100 km between Huntly and Leigh (north of Auckland). This showed that the springs in the south discharge mainly from greywacke basement rocks, while those in the north discharge through a sequence of Tertiary sediments of variable thickness that rest upon greywacke. Warm bores and thermal springs in Ohinewai discharge through tertiary cover rocks. Geochemical analysis shows that the waters from the thermal bores are of neutral pH with Boron concentration in the springs is of the same order of magnitude as in the high-temperature systems of the TVZ, which are also connected to the greywacke basement.

Studies at Huntly, south of Ohinewai, show that the Waikato region has a good potential for sustainable low temperature geothermal direct heat applications for an extended future use. The greywacke basement is the source of the geothermal fluid that is of significant interest for low enthalpy heat production in the Waikato region with a measured thermal gradient of 52 to 55 C/km (Zarrouk and Moore, 2007).

4. GEOCHEMISTRY

In our study we were unable to find any natural thermal springs in Ohinewai geothermal field although some may have existed in the near past. Lake Waikare is maintained by Waikato Regional Council at artificially low levels for flood control and farming activities. This may affect the natural spring flows. Warm bore water produced to the surface using is pumps, apart from the Ohinewai spring (well) where water discharges to the surface (artesian flow). Water samples were collected during the field survey for geochemical analysis. Figure 2 shows the site where samples were collected in the field in the same direction of the NNW-SSE Kaimihia Fault.

4. 1 Sampling

Water chemistry data is essential information required for the characterization of geothermal fluids and the evaluation of the energy potential of geothermal fields by geothermometry (Malimo, 2009). The usefulness and credibility of any geochemical data greatly depends on the methods used during sampling and the care it is given during the collection process to avoid contamination or degradation of the sample. During the primary investigation of a field with hot water, the most useful chemical data for interpreting the subsurface conditions are obtained from boiling springs with flows greater than 0.5l/s. In the absence of boiling springs, springs of low temperature with small flows or even stagnant springs may give very useful information about the field (Nkunda, 1999).

During the field survey that was done on 23rd October 2012, temperatures and electrical conductivity were measured at the sites where samples were taken. Water samples were collected in rinsed plastic bottles for analysis of different components. Samples were filtered through 0.45 μm membrane filter. This is essential in ensuring that the samples do not have any particles and also to reduce algal growth and bacteria action.

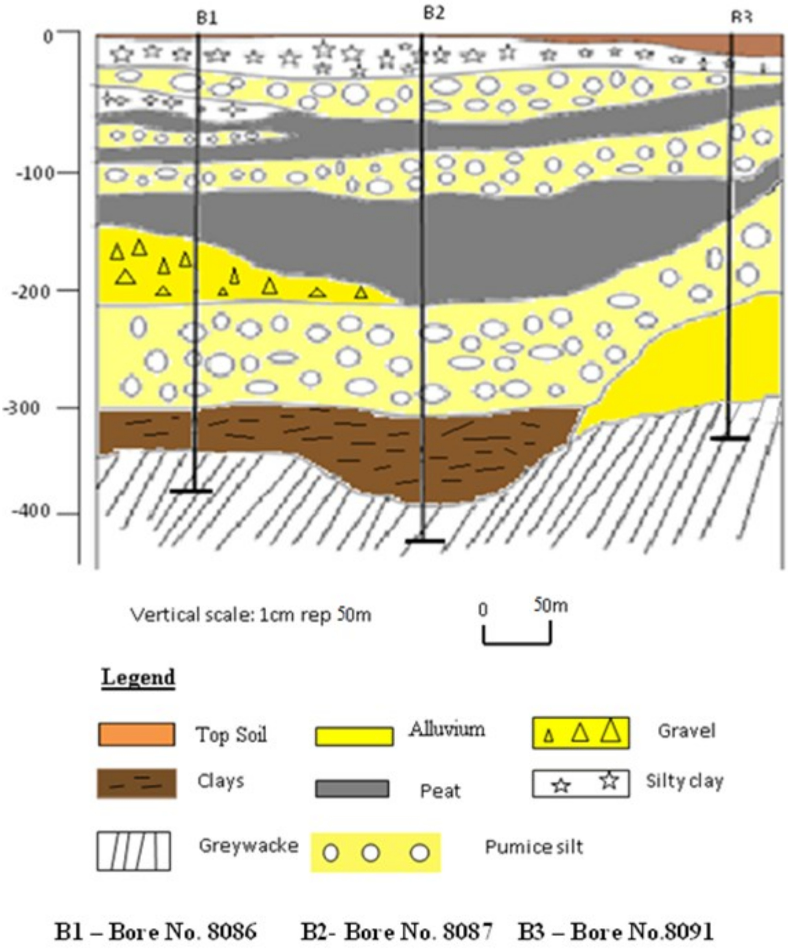

Figure 3: Generalized geological cross section of Ohinewai field.

Figure 4: Map showing locations of bores and springs sampled during field survey in Ohinewai, 1:56000 (Google earth)

4.2: Analytical methods

Analytical results with good quality are the key to accurately evaluating the sub-surface conditions of any geothermal resources. Table 1 summarises the methods that were used when analyzing the collected samples during the field survey for different chemical components.

Table 1: The analytical methods used for the different elements in the collected samples.

Analysis Component	Method	Analysis Component	Method
pH	pH meter	B	ICP-MS
Conductivity/TDS	Conductivity meter	HCO_3	Titration
Na	ICP- MS	Cl	Ion Chromatography
K	ICP-MS	Li	ICP-MS
Mg	ICP-MS	SO_4	Ion Chromatography
Ca	ICP-MS	SiO_2	Heteropoly blue colorimetry

4.3. Results

The results of the chemical analysis of the water samples are shown in Table 2 below. Analysis obtained in this study are presented by the use of ternary diagrams and geothermometers. These will be discussed later.

Some analytical results of samples taken during the study were still in progress, resulting in incomplete data. Previous chemical results were also used in this study to provide a fuller sample selection.

Table 2: Chemical composition of geothermal ground waters in mg/kg

Sample No.	Sampling date	pH	Temp (°C)	Na	Ca	K	Cl	Mg	B	SO_4	HCO_3	Li	SiO_2
69_5972 (B) Ohinewai	23/10/12	9.4	21.4	250	10.2	2.0	-	0.081	20	-	20	-	-
72_5972 (C) Ohinewai	23/10/12	9.2	21.1	220	13.2	1.84	-	0.042	18.8	-	38	-	-
72_2100 (D) Ohinewai	3/8/09	9	21.3	280	6.1	2.0	390	0.14	22	1.3	19	0.72	25
	23/10/12	9	23.2	280	7.6	1.87	-	0.088	20	-	44	-	-
72_5649 (E) Ohinewai	11/7/12	8.9	23	280	8.2	2.0	410	0.25	21	0.5	66	0.63	19.4
72_5971 (G) Ohinewai	23/10/12	6.4	16.9	18.2	2.8	3.2	-	1.97	0.013	-	30	-	-
69_1565 (H) Ohinewai	23/10/12	6.4	17.1	17.2	3.7	4.0	-	3.5	0.0198	-	62	-	-
72_2118 (I) Te Maire	11/7/12	9.3	44	153	3.1	1.17	152	0.02	12.7	6.2	54	0.11	6.2
72_4292 (J) Waingaro	11/7/12	9.6	52	82	1.34	0.64	57	0.02	5	1.5	61	0.066	61
72_4290 (K) Miranda	3/8/09	9.2	53.6	120	2.7	1.7	150	0.04	4.5	1.6	78	0.18	61
72_2980 (L) Hamilton	11/7/12	8.1	22	1250	300	6.8	2500	4.1	24	0.036	49	2.8	13.8

4.4 Classification of geothermal waters

4.4.1 Cl-SO_4-HCO_3 ternary diagram

Cl-SO_4-HCO_3 ternary diagram plots enable several types of thermal water to be distinguished: mature waters, peripheral waters, steam-heated waters and volcanic waters. The diagram provides an initial indication of mixing relationships. Chloride, which is a conservative ion in geothermal fluids, does not take part in reactions with rocks after it has dissolved. As a most conservative element in geothermal waters, Cl is the most useful diagnostic solute and is commonly used in ratios with other elements in the interpretation of water chemistry. Concentrations can range from 10 to 100,000 mg/kg (Nicholson, 1993).

The complete chemical data (Table 2) was plotted in the Cl-SO_4-HCO_3 ternary diagram (Figure 6) in order to classify the geothermal water based on the relative concentrations of Cl, SO_4 and HCO_3 (Giggenbach,1991). The Ohinewai geothermal waters (D and E) plotted in the mature region close to the Cl apex. Relative to the abundance of chloride, sulphate and bicarbonate concentrations in the springs and warm bores, the Cl-SO_4-HCO_3 ternary shows the waters are NaCl type water with relatively low sulphate and bicarbonate concentrations.

Chemical result from other small systems in Waikato Region were also plotted in the Cl-SO_4-HCO_3 ternary diagram in Figure 5 for comparison. Water from fields I, K and L have the same chemistry as the waters from Ohinewai geothermal field, possibly indicating the same fluid source.

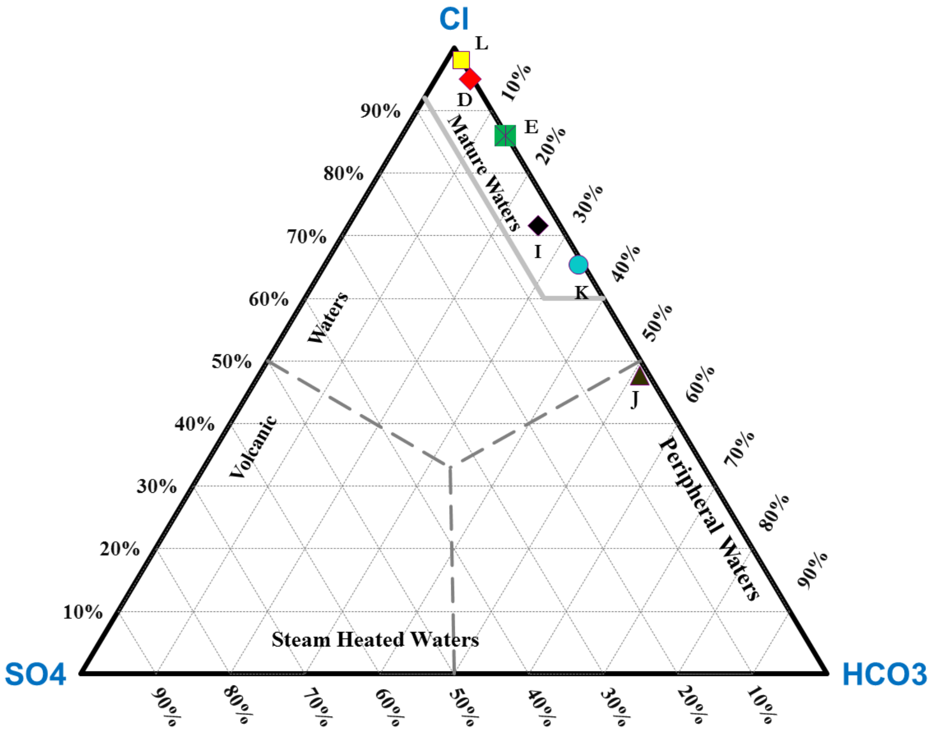

Figure 5: Comparative plot of relative Cl-SO_4 -HCO_3 contents of Ohinewai thermal waters

4.4.2 Na-K-Mg ternary diagram

The Na-K-Mg triangular diagram is used to classify waters into fully equilibrated, partially equilibrated and immature waters. It has been used to predict the equilibrium temperature and also the suitability of thermal waters for the application of ionic solute geothermometers. It is based on the temperature dependence of the full equilibrium assemblage of potassium and sodium minerals expected to form after the isocheimal recrystallisation of average crustal rock under conditions of geothermal interest (Giggenbach, 1988). The use of the triangular diagrams is based on the temperature dependence of the three reactions (equations 1- 3):

$$\mathrm{K-feldspar + Na^{+} \leftrightarrow Na-felspar + K^{+}} \quad (1)$$

$$\mathrm{0.8\,muscovite + 0.2\,clinchlore + 5.4\,silica + 2Na^{+} = 2\,Albite + 0.8K - felspar + 1.6water + Mg^{2+}} \quad (2)$$

$$\mathrm{0.8\,muscovite + 0.2\,clinochlore + 5.4\,silica + 2K^{+} = 22.8\,K - felspar + 1.6\,water + Mg^{2+}} \quad (3)$$

The Na-K-Mg triangular diagram (Figure 7) shows attainment of the water-rock equilibrium if the data point plots are on the full equilibrium line. Data plotting below the “immature water curve” indicates an initial dissolution of minerals before equilibrium reaction sets in. No geoindicators can be used in the latter case. The field of partial equilibrium lies between the curves, and suggests either:

• A mineral that has dissolved, equilibrium reactions have set in but equilibrium has not been reached,

• Or a mixture of water that has reached equilibrium, e.g. a geothermal water, with dilute unequilibrated water such as cold groundwater (Giggenbach et al., 1983). Geothermometer temperatures may often be deduced from such a position. Points close to the √Mg corner usually suggest a high proportion of relatively cold groundwater, not necessarily “immature” (Giggenbach et al., 1983).

The results of springs and warm bores (Figure 6) indicate that the waters are partially equilibrated, plotting close to the equilibrium line in relation to the Na/K and K/√Mg geothermometers. This is an indication that the deep geothermal waters are probably mixed with shallow ground waters. It gives a temperature of 60 to 100 °C, confirming the field to be a low temperature geothermal system.

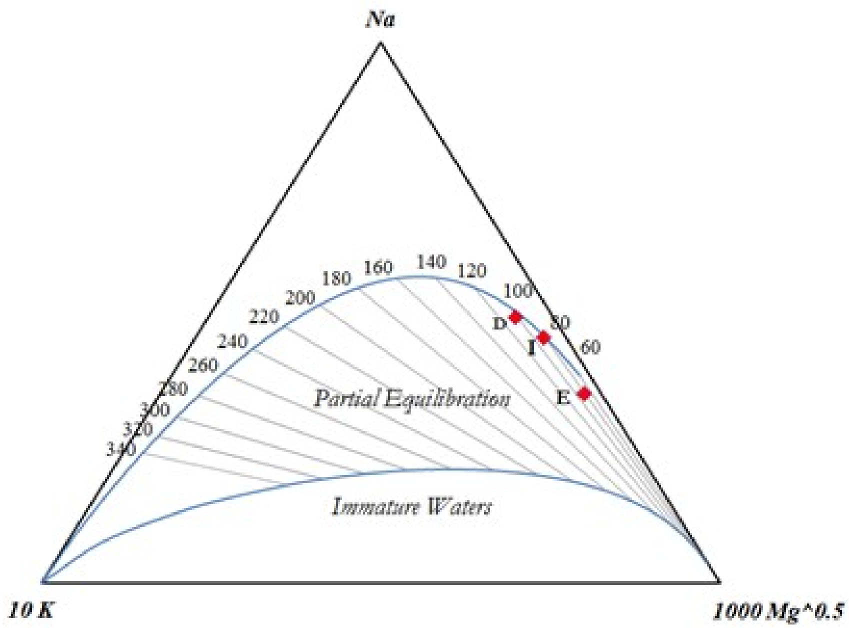

Figure 6: The Na-K-Mg ternary diagram

4.5 Geothermometry

Geothermometers enable the temperatures of the reservoir fluid or subsurface to be estimated, based on the assumption that specific temperature-dependent mineral-solution equilibria are attained in the geothermal reservoir. Various geothermometers may provide different values. The following processes may interfere and affect different geothermometers differently: lack of equilibration with particular mineral, different rates of equilibration reaction between minerals and water, mixing with cold groundwater, boiling and condensation during up-flow (Malimo, 2009). The silica concentration in the water samples was too low for the silica geothermometers to be used.

4.6 Cation geothermometers

Cation geothermometers are based on ion exchange reactions, with a temperature-dependent equilibrium constant. An example is the exchange reaction between alkali feldspar and Na+ and K+ in aqueous solution (Fournier and Truesdell, 1973):

$$K^+ + NaAlSi_3O_8 = KAlSi_3O_8 + Na^+ \tag{4}$$

The equilibrium constant for reaction (iv) is:

$$K_{eq} = (KAlSiO_8)(Na^+)/NaAlSi_3O_8)(K^+) \tag{5}$$

Taking the solids to be pure (unit activity), no or equal complexing of Na+ and K+ in aqueous solution, and the activity coefficients to be the same for both ions, equation (v) reduces to:

$$K = [Na^+]/[K^+] \tag{6}$$

Where $[Na^+]$and $[K^+]$ = the molalities of respective ions

Giggenbach (1988) suggested Na-K geothermometer, which works well in estimating temperatures above 200˚C and is expressed as:

$$T(°C) = [1390/1.75 + \log(Na/K)\ ] - 273.15 \tag{7}$$

Fournier and Truesdell (1973) developed the Na-K-Ca geothermometer specifically for calcium-rich waters that give anomalously high calculated temperatures by the Na-K method. This geothermometer has been applied to both low and high temperature reservoirs. It is expressed by;

$$T(°C) = [1647/\log(Na/K)\ + \beta(\log(\sqrt{Ca}/Na) + 2.06 + 2.47] - 273.15 \tag{8}$$

Where β = 4/3 when calculated temperature is >100 °C;

β = 1/3 when calculated temperature is < 100 °C.

However, the Na-K-Ca geothermometer may give erroneous calculated temperatures, as a result of boiling and mixing with cold water, hence, it should be used with caution.

The results of chemical analysis were used to calculate subsurface temperatures and are summarized in Table 3. The solute geothermometers adopted in this study give inferred temperatures ranging between 62 and 102 °C, typical for a low-temperature geothermal system. All sampling were collected from shallow bores, and the sampling temperatures recorded are lower than the calculated temperatures, hence, these values should be used with caution subject to confirmation from deep wells.

Table 3: Inferred subsurface temperatures from chemical geothermometers

Sample ID	Na-K-Ca	Na/K (Fournier)	Na/K (Giggenbach)
D (Ohinewai spring) 72_2100	83	62	84
E (72_5649)	77	62	84
I (72_2118)	86	81	102

5 TEMPERATURE DISTRIBUTION

Figure 7 shows the contour map of temperature and locations of the sites covered during the field survey. The highest temperature recorded in the area was 23.2 °C at Ohinewai spring (D), while warm bore G and the warm irony bore H were at ambient temperatures. Warm bore (B) and C were above ambient, indicating that they are thermal waters.

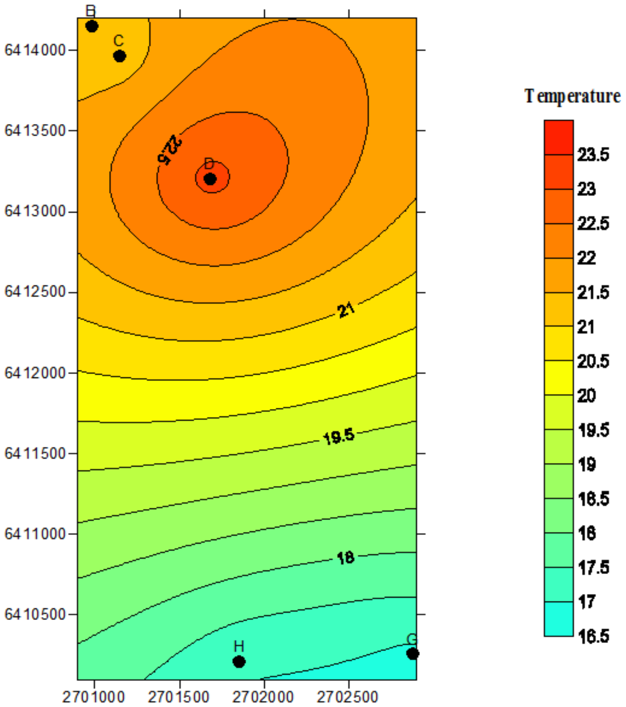

Figure 7: Isotherm map of the surveyed bore location and their respective measured surface water temperatures °C.

The temperature contour map (Figure 8) gives an indication that NNW part of the field has some thermal input from shallow depth compared to the SSE which is relatively cold, probably due to incursion of cold water to the south (Figure 8) at shallow depths. This is an indication that the resource could be concentrated near Ohinewai spring as indicated by the isotherm map.

6 CONCEPTUAL MODEL

Geochemistry analysis (Table 2) of geothermal waters from bores in Ohinewai field indicates that according to the SSE of the field there is a lot of dilution by the ground waters. This is seen in bore G and H, which have higher concentration of Magnesium than other bores in the NNW of the field. Fresh groundwater is relatively rich in Magnesium.

Bores B, C and D to the NNW of the field have higher concentrations of Boron than the bores G and H to the SSE of the field. High boron concentrations are associated with heated water from the greywacke basement infiltrating the sedimentary layer.

The same scenarios as discussed above are experienced in Miranda area. The springs discharge fluids with high concentration of Boron and low concentration of Magnesium (Peter, 2010). By analogy this could be an indication that the resource is concentrated to the NNW of the field around Ohinewai spring.

A NNW –SSE (A-B) cross section of Ohinewai geothermal field was taken since the bores seems to be aligned in this orientation, implying that there could be an hidden fault in the subsurface allowing the surface upwelling of the fluids, especially as seen in Ohinewai spring (D) as shown in Figure 2.

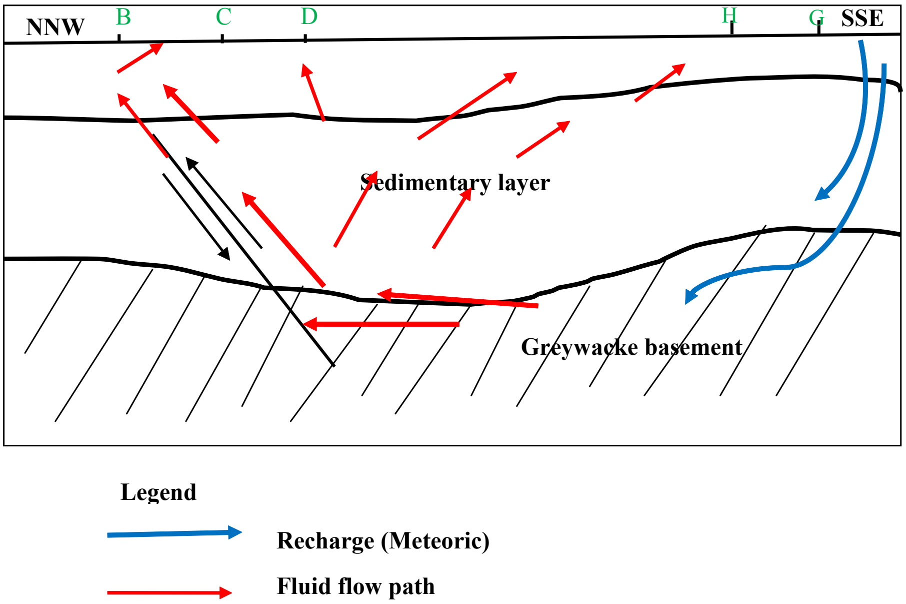

Figure 8: Generalized conceptual model of Ohinewai field showing the fluid flow paths.

The generalized conceptual model in Figure 8 shows the recharge of the SSE of Ohinewai geothermal field. The recharge water is heated from below by hot greywacke basement, rises through the sedimentary layer to shallow depth and is tapped by shallow drilled bores. The fluid path shows the water bores of the SSE with diluted waters compared to the fluids in the NNW of the field as shown in the chemical composition of the waters in Table 2.

7. DISCUSSION AND CONCLUSIONS

Relative Cl-SO_4-HCO_3 contents of fluids from Ohinewai geothermal field indicate that the fluids are dilute alkali chloride waters. The geochemistry data indicates that there is little themal input from deep source and the waters could have been mixed with surface ground water as they/were plotted in the partial equilibrated region.

The geothermometers indicates that the inferred sub-surface temperatures range from 60 to 100 °C. These temperatures are typical for a low enthalpy geothermal system. The isotherms indicate that the resource is concentrated to the NNW part of the field. This is further confirmed by low Magnesium and high Boron in the NNW and high Magnesium and low Boron of the SSE of the field.

Currently there is little direct utilization of the resource apart from the normal domestic, farm and industrial uses. Due to limited data available for the field, water chemistry shows that this resource could be very small but more work to assess its size is needed.

8. RECOMMENDATIONS

- Detail geo-scientific work would be needed to assess the size of the geothermal resource, but the early indications are that it is small.
- Deep drilling work is needed to confirm whether the NaCl waters as inferred by the ternary diagrams are from a deep source.
- Annual monitoring of the bores would enable establishment of a comprehensive data base for this field.

REFERENCES

Campbell, S. Nelson, Dallas C. Mildenhall, Andrew J. Todd & David T. Pocknall (1988): Subsurface stratigraphy, paleo environments, palynology, and depositional history of the late Neogene Tauranga Group at Ohinewai, Lower Waikato Lowland, South Auckland, New Zealand, New Zealand Journal of Geology and Geophysics, 31:1, 21-4

Vucetich, C. G., Birrell, K. S. and Pullar, W. A. (1978): Ohinewai Tephra Formation; a c. 150000-year-old tephra marker in New Zealand, New Zealand Journal of Geology and Geophysics, 21:1, 71-73

Edbrooke, S. W., 2001: Geological map of Auckland area, 1:250 000 geological map (3), pp 45

Fournier, R. O. and Truesdell, A. H., 1973. An empirical Na-K-Ca geothermometer for natural waters. Geochim. Cosmochim. Act, 37, 1255-1275

Giggenbach, W. F., 1991: Chemical techniques in geothermal exploration. In: D'Amore, F. (coordinator), Application of geochemistry in geothermal reservoir development. UNITAR/UNDP publication, Rome, 119-142.

Giggenbach, W. F., 1988: Geothermal solute equilibria. Derivation of Na-K-Mg-Ca geoindicators. Geochim. Cosmochim. Acta, 52, 2749-2765.

Giggenbach, W. F., Gonfiantini, R., Jangi, B. L. and Truesdell, A. H. (1983): Isotopic and chemical composition of Parbati valley geothermal discharges, NW-Himalaya, India, Geothermics, 12: 199-222.

GNS Sciences and East Harbour Management Services (2007): Assessment of Possible Renewable Energy Targets – Direct Use: Geothermal

Hochstein M. P. and McKee, G. A. M. C (1986): Boron I N Thermal Spring systems i n the greater Auckland area, (New Zealand), Proc. 8th NZ Geothermal Workshop 1986, pp. 219-223.

Luketina, K. 2012: The Waikato regional geothermal resource. Waikato Regional Council Technical Report 2012/10, Document #: 1767056

Malimo, S.J, 2009: Interpretation of geochemical well test data for wells OW-903b, OW-904b and OW-909 Olkaria domes, Kenya, report 17. Geothermal Training in Iceland 2009. UNU-GTP, Iceland, pp. 319-344

Nicholson Keith, 1993: geothermal fluids. Chemistry and exploration techniques. pp 48.

Nkunda. L, 1999: Geochemistry of hot springs of the Tokaanu domain, Tokaanu geothermal field. Report no. 99. 17

Peter, A.T 2010: Low Enthalpy Geothermal Resources - Miranda-Kaiaua Area. Waikato Regional Council Technical Report 2012/19. Doc # 2179231

Reyes, A. and Jongens, R. 2005. Tectonic settings of low enthalpy geothermal systems in New Zealand: an overview. Proceedings World Geothermal Congress, April 2005, Antalya, Turkey. pp 24-29.

Thain, I., Reyes, A. G. and Hunt, T. 2006: A practical guide to exploiting low temperature geothermal resources. GNS Science Report 2006/09. June 2006. 76p. ISSN 1171-2425.

White, B., 2006: An assessment of geothermal direct heat use in New Zealand.

Zarrouk, S. J and Tim A. Moore, 2007: Preliminary assessment of the geothermal signature and ECBM potential of the Huntly Coalbed Methane field, New Zealand.