Waikato Regional Council Technical Report 2013/08

Preliminary assessment of low enthalpy Ohinewai geothermal system

www.waikatoregion.govt.nz
ISSN 2230-4355 (Print)
ISSN 2230-4363 (Online)

Prepared by:
Irene Cheptum
The University of Auckland

For:
Waikato Regional Council
Private Bag 3038
Waikato Mail Centre
HAMILTON 3240

February 2013

Document #: 2292575

Peer reviewed by:
Katherine Luketina February 2013

Approved for release by:
Ed Brown Date February 2013

PRELIMINARY ASSESSMENT OF LOW ENTHALPY OHINEWAI GEOTHERMAL SYSTEM

BY

IRENE CHEPTUM

November 2012

ABSTRACT

Although low-enthalpy geothermal systems are widely spread in New Zealand, their exploration and utilization has been limited. There are approximately 105 low-temperature geothermal systems in New Zealand, with approximately thirty of them found within the Waikato region. This study focused on Ohinewai geothermal field, which is a low temperature small geothermal system located in Waikato region.

A field survey was carried out in Ohinewai geothermal prospect to assess the resource. Geothermal water samples were collected from cold and warm bores and analyzed for their chemical properties.

Geothermal waters have been classified with respect to their anion and cation contents. The Cl-SO4-HCO3 ternary diagram classified the geothermal waters from this prospect 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 geothermometers gave a temperature range of between 60 and 100 °C. Isotherms gave an indication that the resource could be concentrated towards NNW of the prospect.

With limited data available for the study field, it is difficult to determine the extent of the resource, however, from the geochemical analysis it is inferred that the resource might be small but this is subject to confirmation by deep drilling and detailed geoscientific studies.

ACKNOWLEDGEMENTS

This report is an adaptation of a project prepared in part-fulfilment of the requirements for the University of Auckland Post-graduate Certificate in Geothermal Technology programme. The report is based on data obtained in the field with the assistance of Waikato Regional Council, and existing data obtained from Waikato Regional Council, University of Auckland, and other sources.

I am deeply grateful to the University of Auckland and the Government of New Zealand for having awarded me the opportunity of attending the Post-graduate Certificate in Geothermal Technology programme.

My special regards goes to the course coordinator and my supervisor, Dr. Zarrouk J. Sadiq. It has been a great honour to be under his guidance and to share his experience and knowledge during the realization of the project. I thank all the lecturers and staff members for their willingness to share their knowledge and experience.

I owe special thanks to Katherine Luketina and John Hughey from Waikato Regional Council for their assistance in the field and provision of information and data for my report and GNS for providing the geological units through Waikato Regional Council.

I thank Geothermal Development Company for granting me an opportunity to be able to pursue this specialized training.

TABLE OF CONTENTS

List of figures

List of tables

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 because of the abundance of high enthalpy geothermal resources (Thain et al., 2006).

There are several sources of low-enthalpy heat in New Zealand. Reyes and Jongens (2005), noted that heat can be from hot spring systems with discharge temperatures of less than 90 °C in the North and South Islands, edges or boundaries of high-enthalpy geothermal systems in the Taupo Volcanic Zone (TVZ) and Northland. Temperature ranging from 120 to 160 °C waters at depths greater than 3.5 km is observed in abandoned hydrocarbon wells and natural heat flow from about 15 m below the surface to deeper levels. There are approximately 105 low-temperature geothermal systems in New Zealand, with approximately thirty of them found within the Waikato region (Luketina, 2012).

1.2 WAIKATO REGIONAL 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 ranking each system's characteristics and aims to balance development with the protection of highly valued surface features. Individual geothermal systems have been classified into five categories as follows:

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

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

1.3 Aim of the study

The purpose of the study is to do a preliminary assessment of Ohinewai low enthalpy geothermal system and give the size of the resource in the prospect.

The field survey was conducted in the area of study and it involved sampling of water from the water bores in the resource area. The preliminary geochemical analyses are looked into and their interpretation is presented in the report.

2.OHINEWAI GEOTHERMAL FIELD

2.1 Location

Ohinewai geothermal field is located North East of Te Maire field and South West of Lake Waikare in the lower part of Waikato lowlands in Waikato region (highlighted box in Figure 1). This field is among the number of fields that have been categorized as low enthalpy geothermal resource in Waikato region. It has a number of springs and warm wells drilled to shallow depths basically for domestic, farm and industrial use.

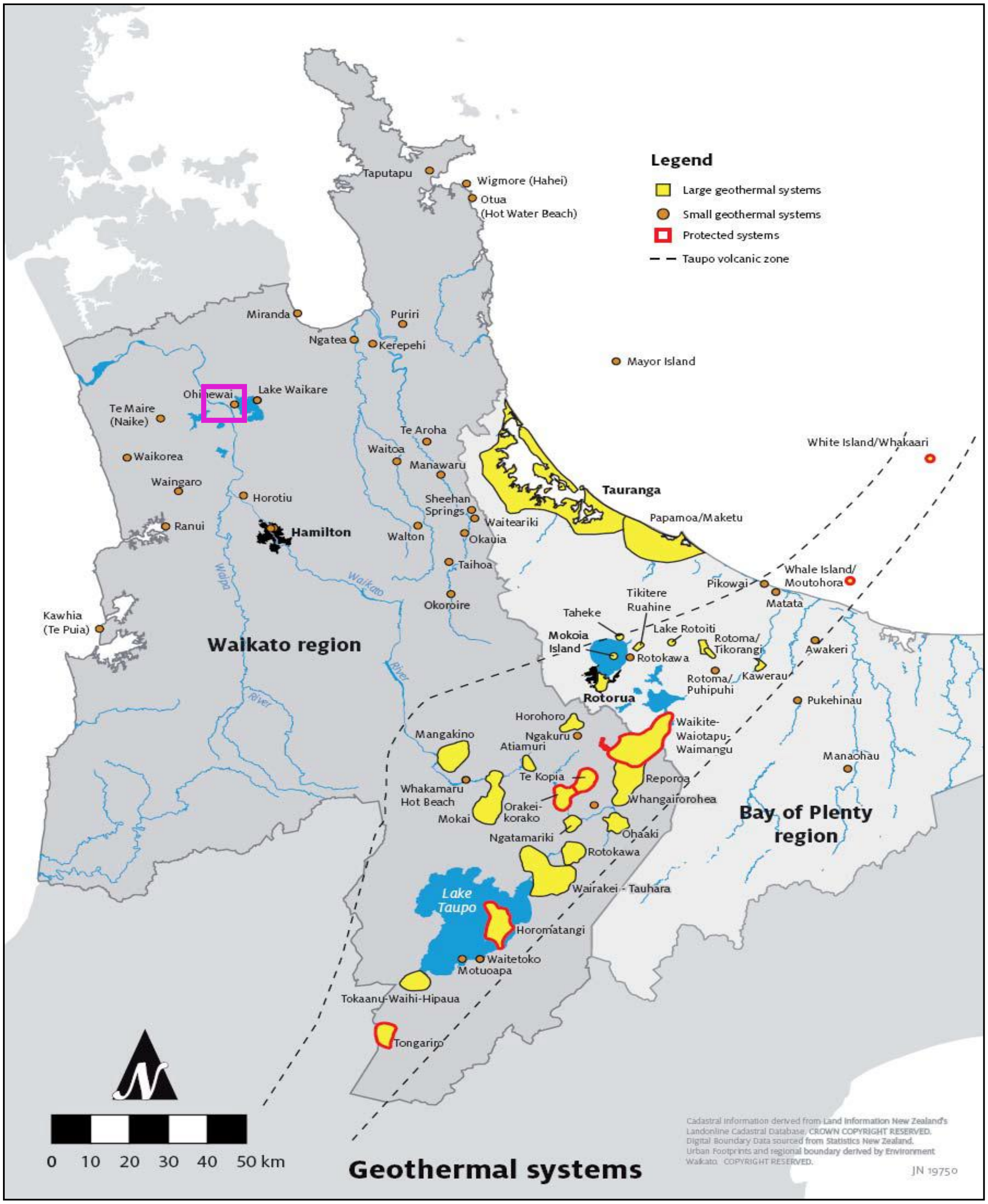

Figure 1: Map showing the location of Ohinewai geothermal field (map courtesy of Waikato Regional Council).

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 on the central part of the field and extends to the east towards Lake Waikare. Patches of sand are distributed across the field. Noted from the geological map (Figure 2) are two main structures trending in the NW–SE direction probably indicating that the field is permeable.

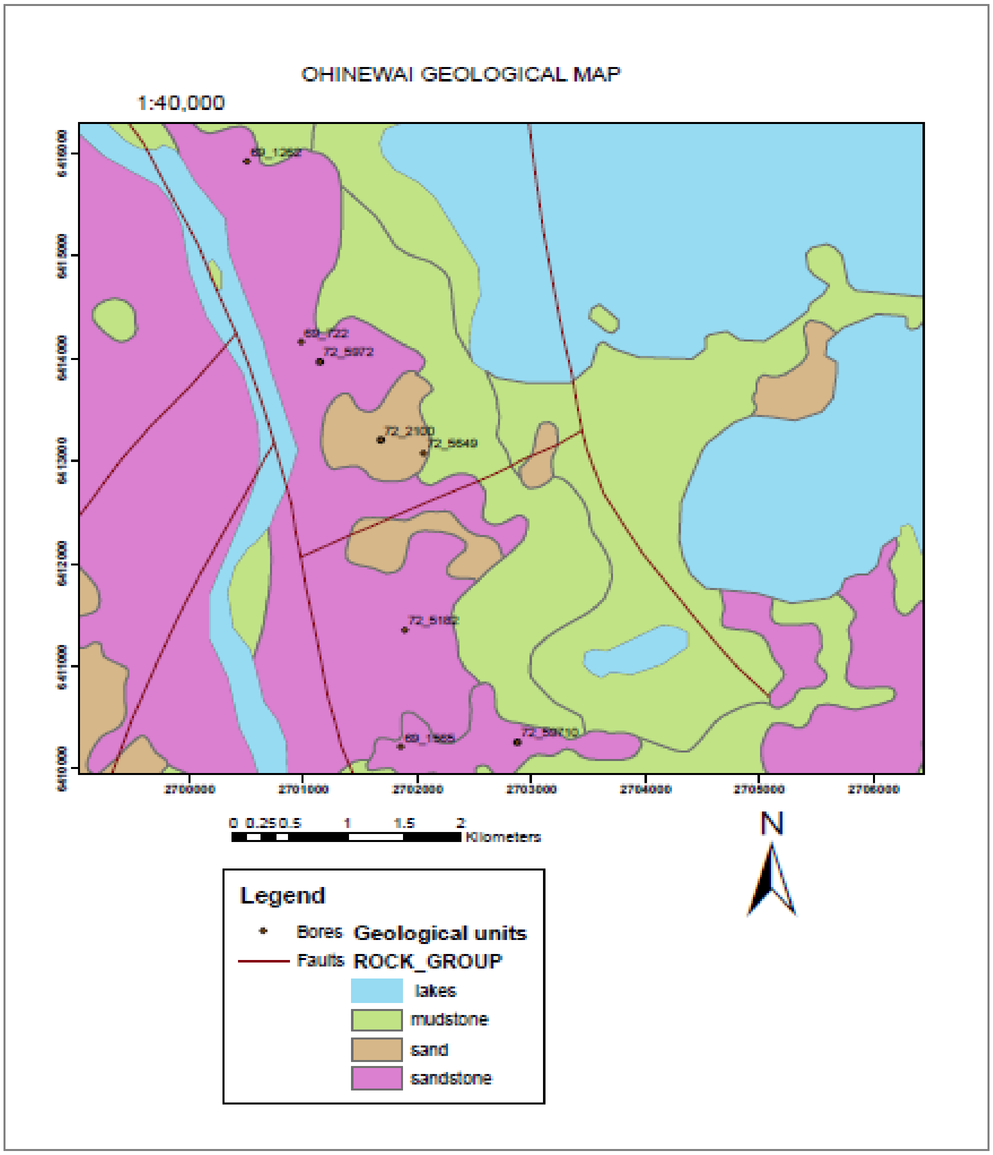

Figure 2: Surface geological map of Ohinewai geothermal field (Geological units from GNS)

2.3 Geological cross section of Ohinewai field

A geological cross section of the field was done using the bore log records obtained from daily log sheets that were prepared by Drillwell Exploration NZ Ltd during the exploration for coal mining in the field. The rock types of Ohinewai field are sedimentary as shown from the obtained Ohinewai geological cross section (Figure 3) with the basement rock being greywacke.

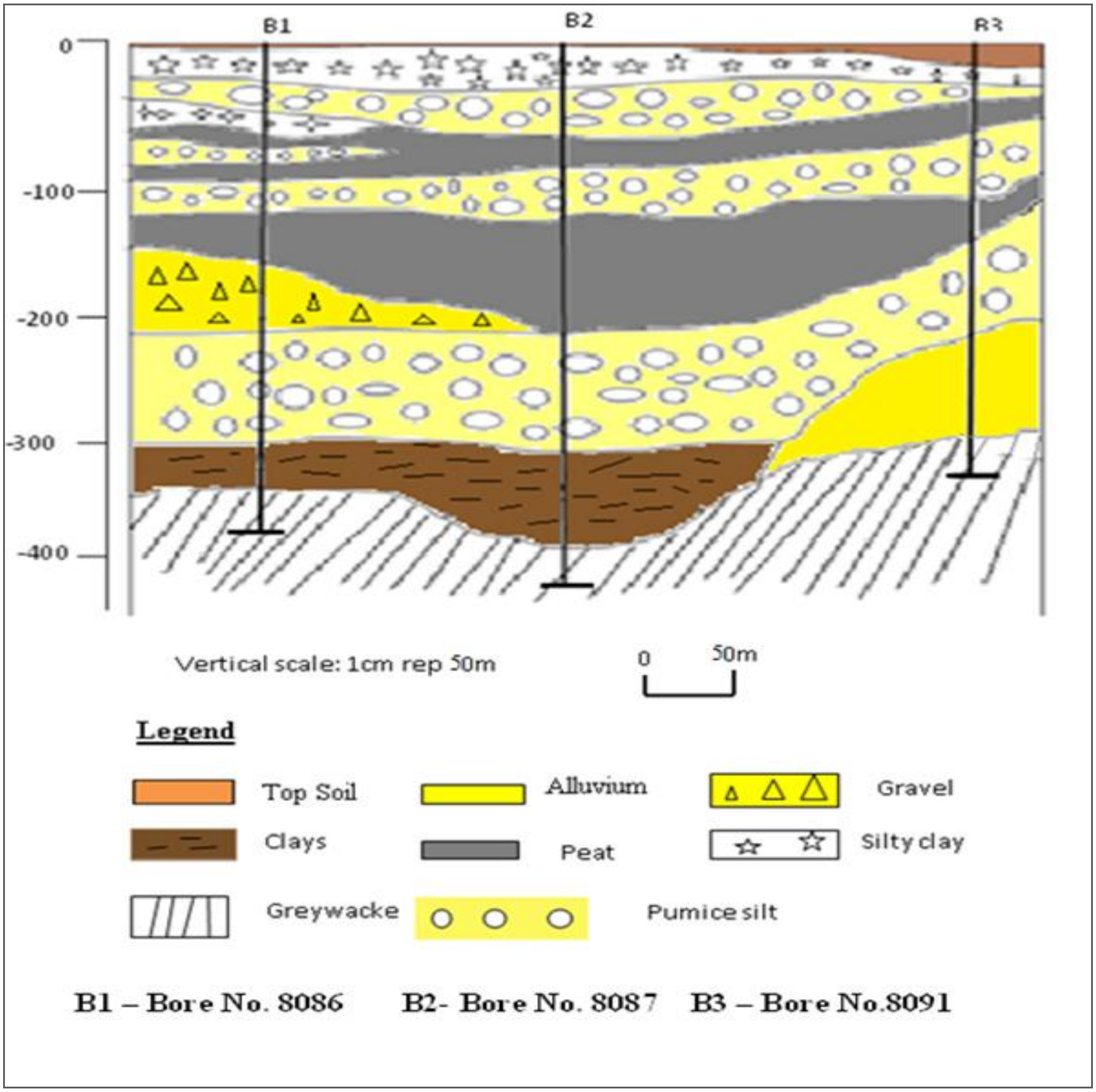

Figure 3: Generalized geological cross section of Ohinewai field.

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 S. W., 2001). They are dominated by silicic volcanic materials derived from Coromandel Peninsula and, latterly, central North Island 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 S. J. *et al.*, (2007) and Hochstein (1986) indicate that greywacke is the basement rock.

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, S. W., 2001).

2.3.Land use

From surface geology (Figure 2) it shows that the area is covered by sediments,, hence, it is suitable for grazing purposes. It is generally farmland consisting of mainly dairy farms with limited horticultural potential due to high water table.

3.Background work to the study

There are few geoscientific studies that have been done that could be helpful in assessing the size of Ohinewai geothermal resource apart from studies that were done for coal mining and those assessments done on regional scale.

Assessments have been done on the possible renewable energy targets for geothermal energy in New Zealand. Some fields in Waikato region, including Ohinewai, were identified as possible targets, though little is known about Ohinewai’s utilization potential and heat assessment apart from the normal domestic uses mostly in the farms (GNS Science, 2007; White. B. 2006).

Hochstein (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 (Figure 4). The study shows 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 rocks. Warm bores and thermal springs in Ohinewai discharge through tertiary cover rocks. From geochemical analysis; it shows that the waters from the thermal bores are of neutral pH. Boron concentration in the springs is of the same order of magnitude as B in hot water systems that occur in the Taupo Volcanic Zone. The deeper reservoirs of the Taupo systems also stand within greywacke basement rocks.

Studies done in Huntly, a field 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. It is further noted that the greywacke basement is the source of the geothermal fluid that is of significant interest for low enthalpy heat production and development in the Waikato region (Zarrouk S. J. *et al.,* 2007).

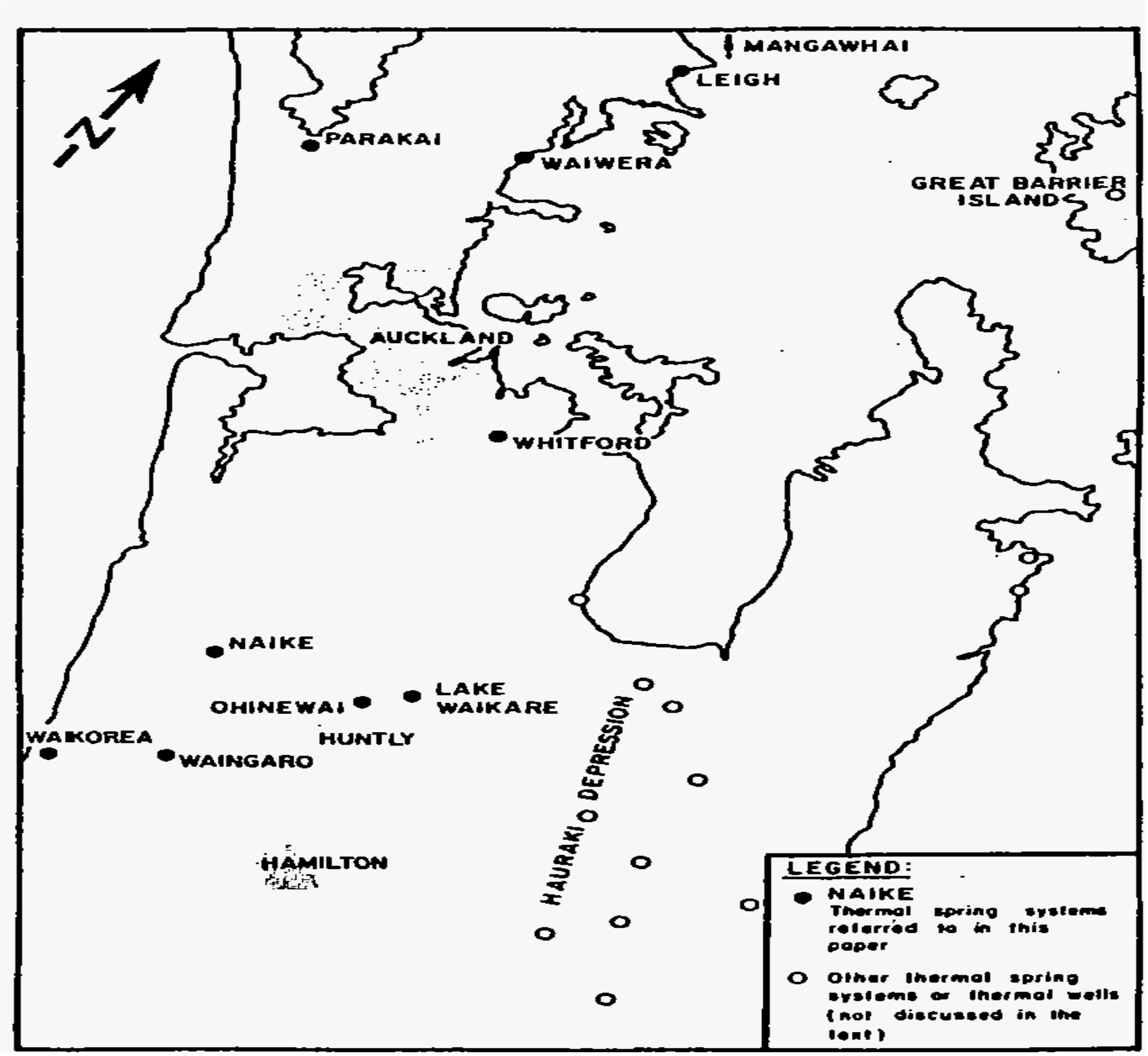

Figure 4: Location map of thermal springs in the greater Auckland area (Hochstein *et al.*, 1986).

4. Geochemistry

In the current 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 at artificially low levels for the purpose of flood controls and farming. This may have affected the natural spring flows. Water from the warm bores is pumped to the surface, apart from Ohinewai spring (well) where water discharges to the surface. Water samples were collected during the field survey for geochemical analysis. The map in Figure 5 shows the site locations where samples were collected in the field (NNW-SSE) and the site description sheets are attached to Appendix 1.

1:56000

Figure 5: Map showing locations of bores and springs sampled during field survey in Ohinewai (photo source, Google maps)

5. METHODS

5. 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 tampering with 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 flows 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. Plastic sampling bottles were rinsed with the sample water before the actual water samples were collected for analysis of different components. Sample filtering was done through 0.45 μm membrane filter. This is essential in ensuring that the samples do not have any particles and also reduce algal growth and bacteria action.

5. 2: Analytical methods

Analytical results with good quality are the key to accurately evaluating the sub-surface conditions of any geothermal resources. There are different methods that are used in analysis geothermal waters. Table 1 gives the summary of the methods that were used at R J Hill Laboratories Limited in analyzing the samples collected during the field survey for different chemical components.

Table 1: Methods used for analysis of different elements in collected samples.

Analysis Component	**Method**
pH	pH meter
Conductivity/TDS	Conductivity meter
Na	ICP- MS
K	ICP-MS
Mg	ICP-MS
Ca	ICP-MS
B	ICP-MS
HCO3	Titration
Cl	Ion Chromatography
Li	ICP-MS
SO4	Ion Chromatography
SiO2	Heteropoly blue colorimetry

6. RESULTS

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

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_722 (B) Ohinewai	23/10/12	9.4	21.4	250	10.2	2.4	-	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	0.0098	-	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

Noted from the table of chemical analysis are missing data points. This is because at the time of compiling the report the analysis of these components were still in progress, hence, resulting into incomplete data. Hence the past chemical results which are complete were used in this study.

6.1 Classification of geothermal waters

6.1.1 Cl-SO4-HCO3 ternary diagram

Cl-SO4-HCO3 ternary diagram is a plot that has been used to primarily classify the types of geothermal waters in a given field under investigation. Several types of thermal water can 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 diagnostic solute and is commonly used in ratios with other elements in the interpretation of water chemistry. Concetrations can range from 10< to >100,000mg/kg (Nicholson 1993).

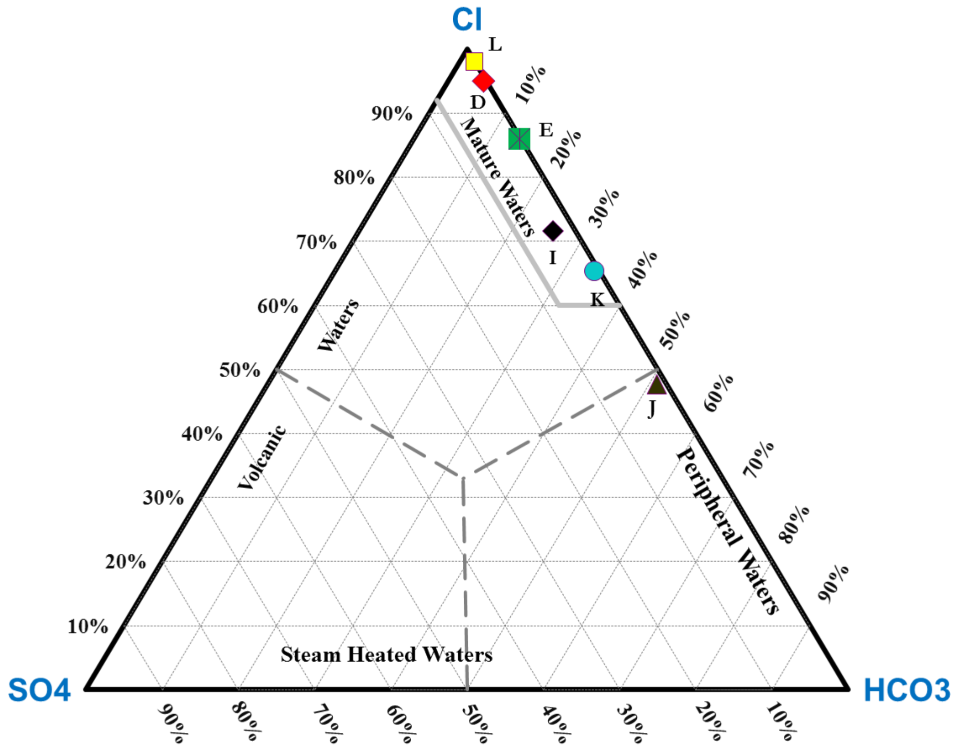

Figure 6: Comparative plot of relative Cl-SO4 -HCO3 contents of Ohinewai thermal waters

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^{2-} and HCO_3 (Giggenbach,1991). The ternary diagram obtained shows that the waters from Ohinewai geothermal field (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-SO4-HCO3 ternary shows the waters are Na-Cl type 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 6.This was done so as find out if the waters from Ohinewai prospect is comparable to some other fields within the region. Water from fields I, K and L have the same chemistry as the waters from Ohinewai geothermal field, hence, using exploration by analogy this could indicate that this field could be having the same fluid source.

6.2 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 that are 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 i-iii):

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

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

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

The Na-K-Mg triangular diagram (Figure 7) shows attainment of the water-rock equilibrium if the data point plots on the full equilibrium line, or suggests a field of immature water below the "immature water curve" which 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 a water that has reached equilibrium (e.g. a geothermal water) with a dilute unequilibrated water e.g. cold groundwater (Giggenbach *et al.,* 1983). Geothermometers 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).

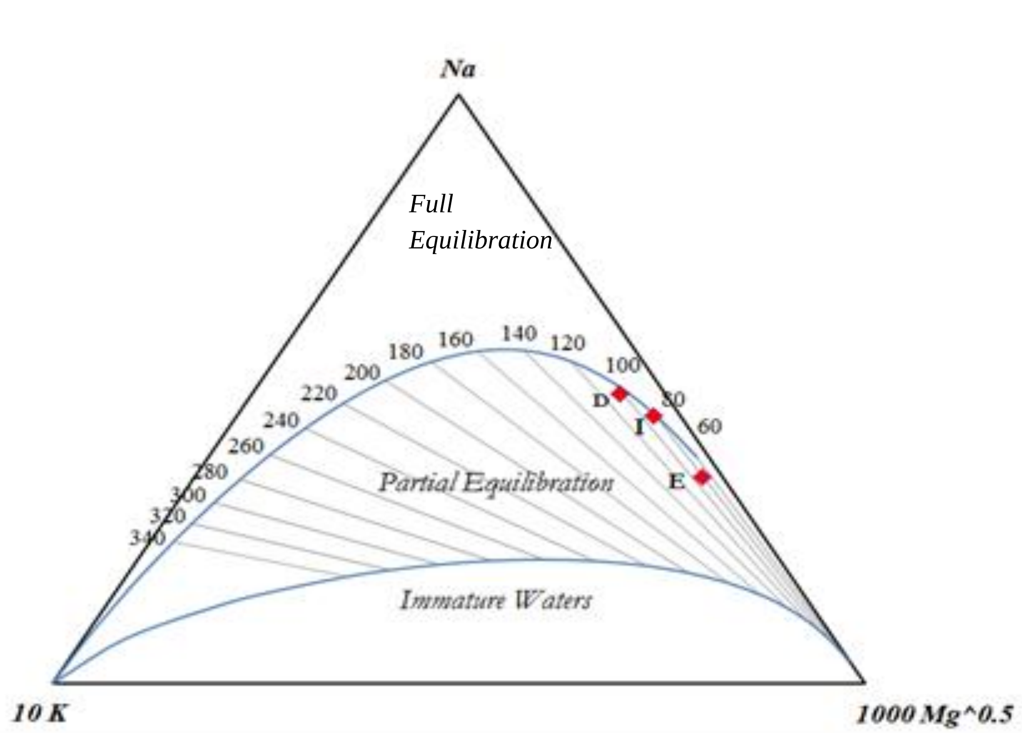

Figure 7: Na-K-Mg ternary diagram

The results of springs and warm bores (Figure 7) indicate that the waters are partially equilibrated and plots close to the equilibrium line in relation to the Na/K and K/√Mg geothermometers as shown in Figure 7.This is an indication that the waters are probably mixed with surface ground waters. It gives a temperature of 60 to 100 °C, which basically qualifies the field to be a low temperature geothermal system.

6.3 Cl-B-HCO3 ternary diagram

Cl-B-HCO3 ternary diagram was constructed using the data in Table 2 in order to determine the source of the fluid in Ohinewai prospect. The diagram in Figure 8 shows that the fluids could be from the basement based on the complete data available.

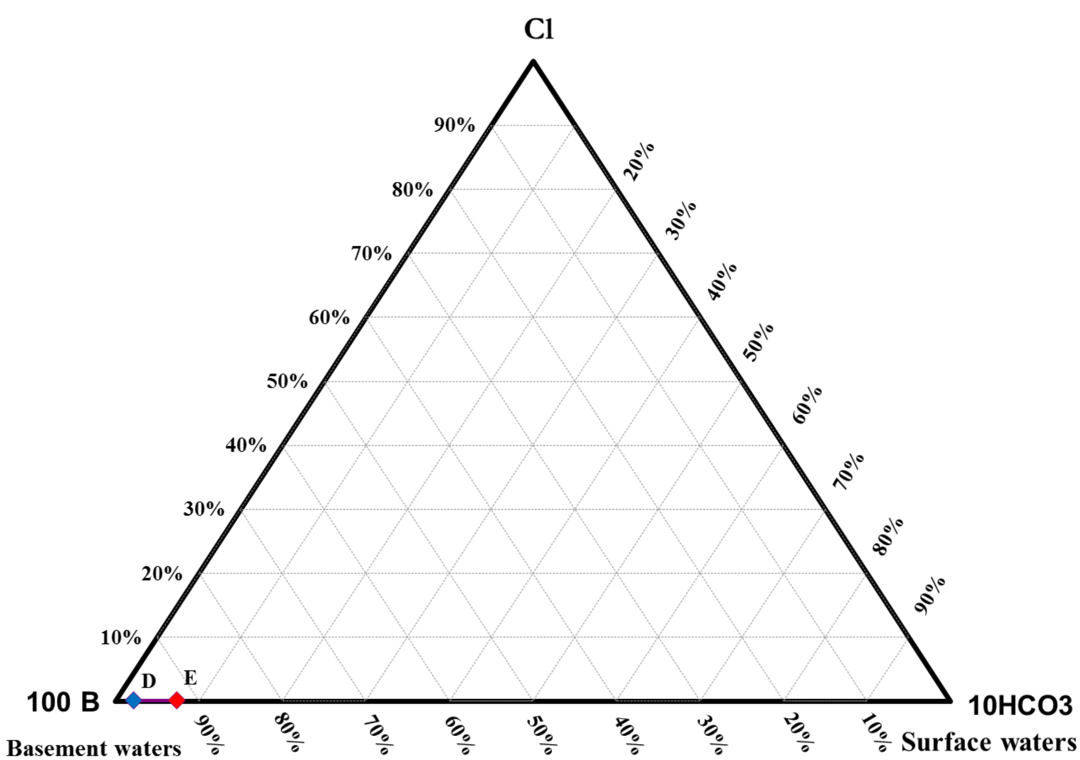

Figure 8: Cl-B-HCO3 ternary diagram

6. 4 GEOTHERMOMETRY

Geothermometers enable the temperatures of the reservoir fluid or subsurface to be estimated. These geothermometers are all 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). This report shall not consider silica geothermometers since the concentrations of silica is little to be used for the calculations of sub-surface temperatures and is mostly applicable in high temperature geothermal systems.

6.4.1 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):

$$K^+ + NaAlSi_3O_8 = KAlSi_3O_8 + Na^+ \qquad \text{(iv)}$$

The equilibrium constant for reaction (iv) is:

$$K_{eq} = (KAlSiO_8)(Na^+)/NaAlSi_3O_8)(K^+) \qquad \text{(v)}$$

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:

$$K = [Na^+]/[K^+] \qquad \text{(vi)}$$

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:

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

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;

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

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. The solute geothermometers adopted in this study give inferred temperatures ranging between 62 and 102 °C, typical for a low-temperature geothermal system. Temperatures recorded during sampling are relatively lower than the calculated temperatures, hence, these values should be used with caution subject to confirmation from deep wells since all the sampling was done from shallow bores. The results of the geothermometers calculations are summarized in Table 3.

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

6.5 Temperature distribution

Temperature contours were plotted so as to get a preliminary analysis of the measured temperature distribution of the field. Figure 9 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.

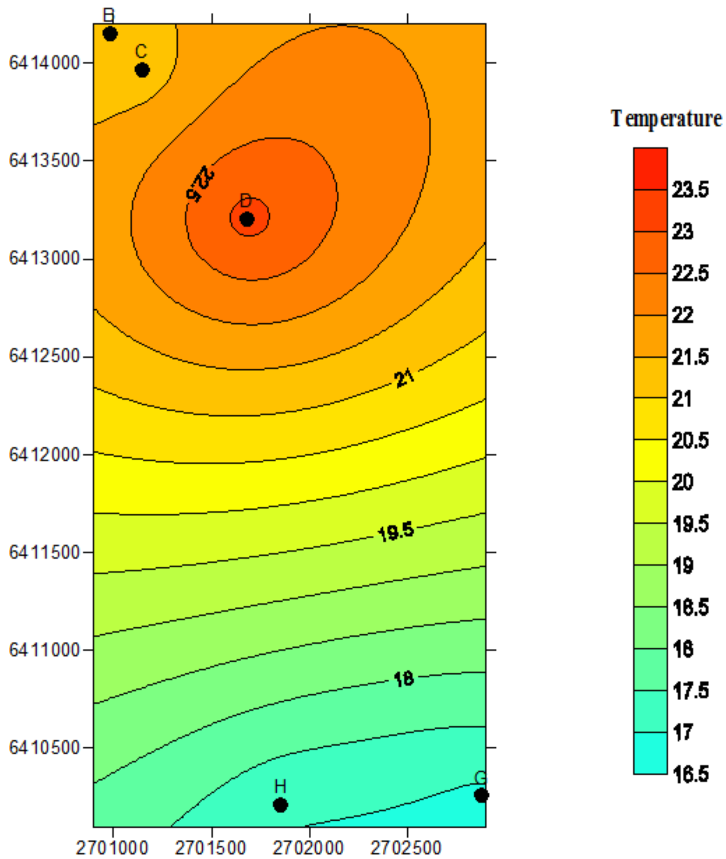

Figure 9: Isotherm map of the surveyed bore location and their respective measured surface water temperatures °C.

The temperature contour map (Figure 9) 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 5) at shallow depths. This is an indication that the resource could be concentrated near Ohinewai spring as indicated by the isotherm map.

6.6 Conceptual model

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

NNW of the field and this is an indication that the waters have been diluted by groundwater which is relatively rich in Magnesium.

Bores B, C and D to the NNW of the field have relatively higher concentrations of Boron as compared to the bores G and H to the SSE of the field. High boron concentrations are associated with heated water from the greywacke basement to 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. A., 2010). By analogy this could be an indication that the resource is concentrated to the NNW of the field around Ohinewai spring.

In developing a generalized conceptual model of Ohinewai geothermal field a NNW –SSE (A-B) cross section 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 upwelling of the fluids at the surface especially as seen in Ohinewai spring (D) as shown in Figure 10.

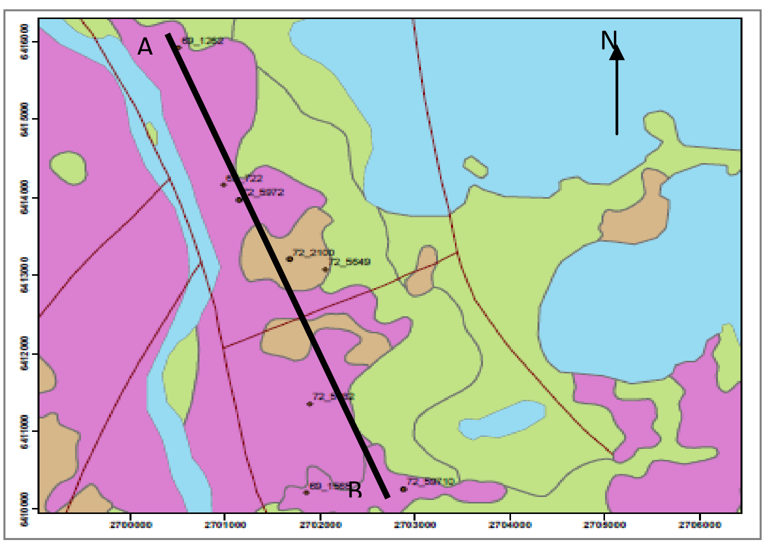

Figure10: NNW-SSE cross section of Ohinewai geothermal field (Geological units from GNS).

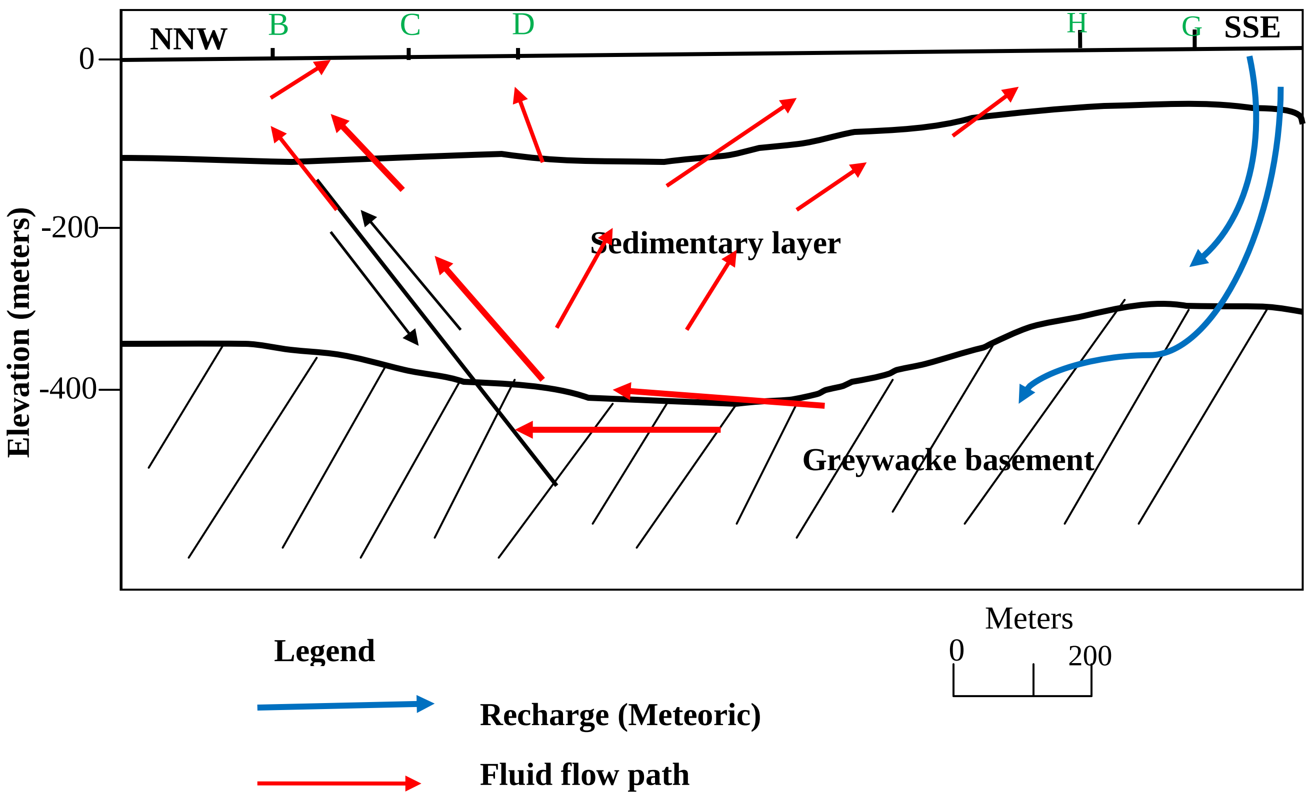

Figure 11: Generalized conceptual model of Ohinewai field showing the fluid flow paths.

From the generalized conceptual model in Figure 11, it shows that the recharge is to 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 that the water bores to the SSE have diluted waters in comparison to the fluids in the NNW of the field and this is confirmed by 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 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 plotted in 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. From isotherms it indicates that the resource could be concentrated to the NNW part of the field. This is further confirmed by low Magnesium and high Boron concentrations in comparison to high Magnesium and low Boron concentrations to 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, chemistry of waters show that this resource could be very small but more reseach needs to be done to assess its size.

8. RECOMMENDATION

i. Detail geoscientific work needs to be done for this field since there is little data available to be able to assess the size of the geothermal resource.

ii. Deep drilling should be done to confirm whether the Na-Cl waters as inferred by the ternary diagrams are from a deep source for a conclusive decision to be made.

iii. Continuous monitoring of the bores at least twice a year needs to be done to ensure 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

C. G. Vucetich, K. S. Birrell & W. A. Pullar (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), pg 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 G. A. M. C McKee (1986): Boron I N Thermal Spring systems i n the greater Auckland area, (New Zealand), Proc. 8th NZ Geothermal Workshop 1986, pg 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, 319-344

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

Appendix 1: Geothermal Water Quality Site Description Sheet

Site Number:	72_2100	Geothermal field:	Ohinewai
Feature Type:	Open warm bore	Map Reference:	E2701679, N6413205

Description/sample method

Sample site is a muddy spring in a flat paddock

Comments/Precautions

Though technically a bore, site is effectively a spring as casing is buried in mud. A spade and some plastic piping will be helpful for sampling. Bottom photo shows view from spring. Solid Energy drilled it many years ago but never capped it.

Site Map

Site Number:	72_5649	Geothermal Field:	Ohinewai
Map Reference:	E 6415912 N 6413070	Feature type:	Warm bore

Description

From 72_2100 take races in a SE direction .Bottom photo shows the view of the site

Site Map

Site Number:	72_5972	Feature Type:	Warm bore
Geothermal Field:	Ohinewai	Map Reference:	E 2701144 N 6413963

Description/sample method

Bore is in a large shed across the yard, in the far right corner of the shed in the picture below, behind the green cover.

Site Map

Site Number:	69_722	Map Reference:	E 2700978 N 6414154
Geothermal Field:	Ohinewai	Feature Type:	Warm bore

Description/sample method

The warm bore is located beside the cow shed. Sample from the top of the water tank by the cowshed. Photo below is the view of the site

Site Map

Site Number:	72_5182	Map Reference:	E 2701892 N 6411348
Geothermal Field:	Ohinewai	Feature Type:	Monitoring bore

Description

At the paddock there is a well that is used for monitoring.

Site Map

Site Number:	69_1262	Map Reference:	E 2700506 N 6415912
Geothermal Field:	Ohinewai	Feature Type:	Cold irony bore

Description/sample method

Bore is in paddock next to the railway fence SE of the house, in extreme LHS of the picture by the post. Pump is behind the shed on the other side of the driveway. Sample from the pump.

Comments/Precautions

Bore is cold and irony.

Site Map

Site Number:	72_5971	Map Reference:	E 2702880 N 6410258
Geothermal Field:	Ohinewai	Feature Type:	Slightly warm bore

Description/sample method

Bore is beside pump house halfway up hill. Sample from inlet pipe at top of tank.

Site Map

Feature Name:	Balemi Rd Spring	Geothermal Field:	Ohinewai
Feature Type:	Monitoring bore	Map Reference:	-

Description/sample method

Opposite bend in Balemi Rd. Needs the right sized allen key to open it.

Site Map