OHAAKI WEST BANK PRODUCTION FLUID COMPOSITIONS

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SUMMARY - During 2006 and 2007 Contact Energy undertook a successful well drilling programme to increase the resource capacity and power production from the Ohaaki Geothermal Field with eight new wells drilled on the West Bank. This enabled a doubling of nett generation from about 30 to 60 MWe. A conservative production management approach has been taken seeking to avoid deleterious calcite scaling and drawdown of cooler surficial fluids.

Of the eight new wells, two discharge fluid similar in terms of T_{QZ}, Cl_{QZ} and SO_{4QZ}, to the fluid initially produced (in 1995) and presently discharging from BR48; that is relatively cool at ~260°C and dilute. Three of the remaining six new wells discharge aquifer fluids at T_{QZ} ~290°C which is hotter than any of the presently discharging wells, indeed hotter than wells at the commencement of production in 1988. The last three wells discharge fluid with reservoir T_{QZ} temperatures of ~280°C which was similar to those observed at the commencement of production. That six of the new wells discharge reservoir fluids which have been minimally affected by both dilution as well as boiling as a consequence of previous production is a good outcome for the future generation from Ohaaki.

1 INTRODUCTION

The Ohaaki Geothermal Resource, which is bisected on the surface by the Waikato River into the East and West Banks, is located some 27 km north east of Taupo on the Eastern Margin of the Taupo Volcanic Zone (Bibby et al., 1995). Field exploration and development at Ohaaki occurred over a period 30 years, influenced by government policy, uncertainty in the resource potential, and uncertainty about the potential effects of injection. The DSIR commenced scientific work in the 1960's. The first well was drilled in late 1965 and 24 wells were drilled before government interest in geothermal energy waned in the early 1970's due to the discovery of gas in Taranaki. Geothermal investigation work recommenced in 1974 following an "oil crisis", and by 1985 a total of 46 wells had been completed at Ohaaki to an average depth of 1200m.

The Ohaaki power station was commissioned in late 1988 - early 1989 and was officially opened on 31st October 1989 generating about 100MWe (nett). Since 1993 generation slowly decreased to about 30 MWe in 2001. The decrease was caused by cooling of production fluids by surface waters in combination with severe calcite scaling and lack of make-up production well drilling. In 2006-2007 a successful drilling programme enabled new production to double generation to over 60 MWe.

2 PREVIOUS WORK

2.1 Introduction

Comprehensive geochemical reviews of the geochemistry of Ohaaki fluids have been undertaken by Giggenbach (1995) and Christenson et al., (2002). Giggenbach (1995) was interested in the pre-exploitation state of the field and inferred that on the West Bank the reservoir compositions were a mixture of deep water such as discharged by well BR15 and a co-existing vapour phase with composition corresponding to a vapour-liquid equilibrium of about 300°C. However he suggested that the major upflow of heat and thermal fluids was on the East Bank due to the accumulation of vapour there. Christenson et al., (2002) showed that the chemical and isotopic composition differences, which were not due to physical reservoir processes, implied a younger and more shallow seated intrusive beneath the East bank field compared to the West.

2.2 West Bank Reservoir

Drilling and discharge testing was undertaken on the West Bank between 1966-1971 and proved a productive area of about 1.5 km^2 with temperatures between 240-280°C. Changes in the chemistry of some wells was observed in this field testing, most notably in the shallow cased West Bank wells. Decreases of 400-500 mg/kg chloride in BR2, 4, 8, 11 were observed though changes in temperature (indicated by geothermometry) were relatively minor (Mahon and Finlayson, 1972; Wood et al., 1998). The chemical changes were attributed to the influx of steam-heated water (<200°C) from the shallow Ohaaki Rhyolite formation. These shallower waters were low chloride, CO_2-rich, sodium bicarbonate in composition and could be recognised on temperature profiles in some wells by temperature inversions and downflows after a period of production.

Pre development, the cooler fluids within the Ohaaki Rhyolite had little effect on the deep reservoir because the deep reservoir was over-pressured with respect to the shallower aquifers containing these cooler fluids. A comprehensive summary of the geological formations and permeable zones is given by Wood et al. (1995).

Temperatures in the reservoir have generally fallen with pressures. Nearly all the production zone is at boiling point hence as pressure decreased the temperature also decreased. There has also been development of inversions associated with the entry of colder waters into shallow producing zones. In some wells sharp localised inversions have appeared at shallow feedzones; for example BR2, where a downflow from 520m occurred when the well was shut. Water at around 190°C entered at this depth. In addition increased cooling with time has been observed in temperature surveys at 510-570m behind the casing in BR15.

2.3 Compositional Trends

2.2.1 Introduction

In almost all shallow-cased wells on the West Bank, the high temperature (250-260°C) reservoir waters have become diluted (with respect to chloride) and cooled by the influx of water from the overlying Ohaaki Rhyolite.

Changes are manifested in the discharge chemistry as declining chloride concentrations and quartz geothermometer temperatures, increasing Na/K ratios, increasing magnesium and increasing bicarbonate. Typical compositional trends are demonstrated by BR20 in Figure 1.

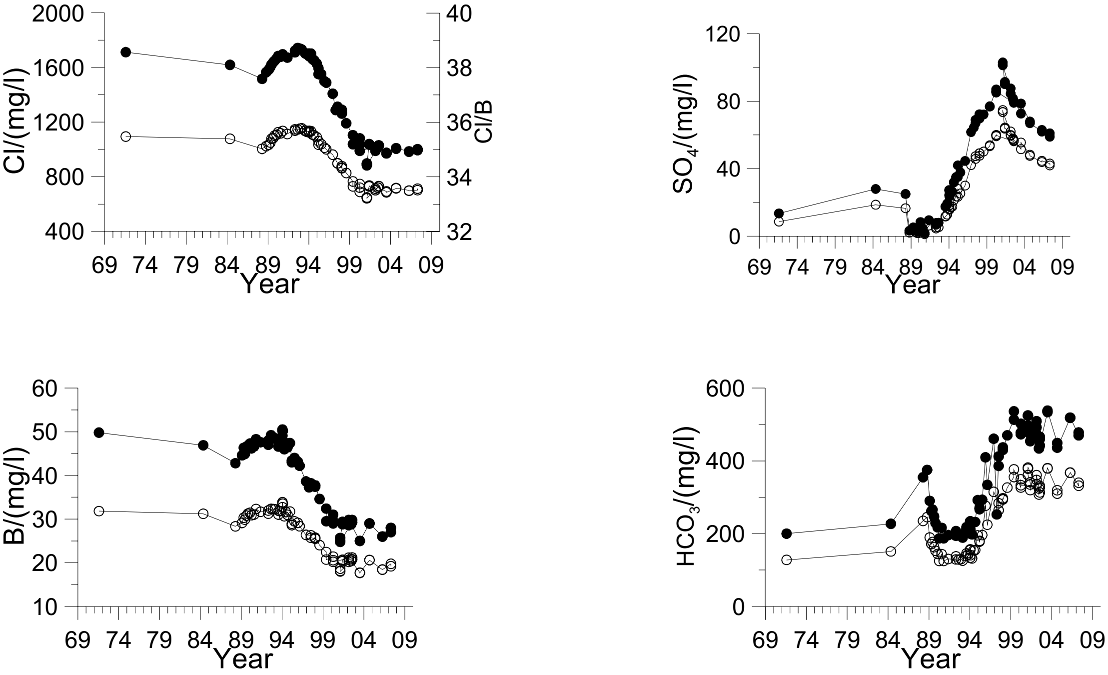

Figure 1: BR20 Compositions

2.2.2 Chloride-Enthalpy Plot

This dilution and cooling is also evident on the enthalpy-chloride diagram (Figure 2; to reduce clutter in this and following figures only selected wells are included). The chloride-enthalpy diagram is used to infer changes due to aquifer boiling, mixing (dilution) and conductive heat gain or loss. The aquifer enthalpy (H_{QZ}) is derived from the inferred reservoir temperature, which is calculated using the quartz geothermometer (T_{QZ}). The chloride composition (Cl_{QZ}) is recalculated to reservoir conditions at T_{QZ}. The features of the chloride-enthalpy diagram are that H_{QZ} and Cl_{QZ} both decrease with dilution by cool low mineralized fluids, H_{QZ} decreases and Cl_{QZ}, increases with adiabatic cooling (boiling) and with reservoir boiling at constant temperature the Cl_{QZ} increases at constant H_{QZ}. Although most wells on the West Bank have shown progressive cooling and dilution since the commencement of production a few (e.g. BR20) have shown dilution with little change in reservoir temperature. This “heat mining” eventually results in a rapid decline in reservoir temperature. The “parallel” dilution trend also suggests there may be a low temperature diluting fluid at about 195^{o}C. Indeed in some wells the end-member shallow water has been evident under shut-in conditions as an internal downflow; for example a sample of the 193°C downflow in BR2 had a chloride concentration of 200 mg/kg.

The result of incursion of shallow, cooler waters on the West Bank has been declining discharge enthalpies, increased calcite scaling and in some cases increases in gas content in the separated steam.

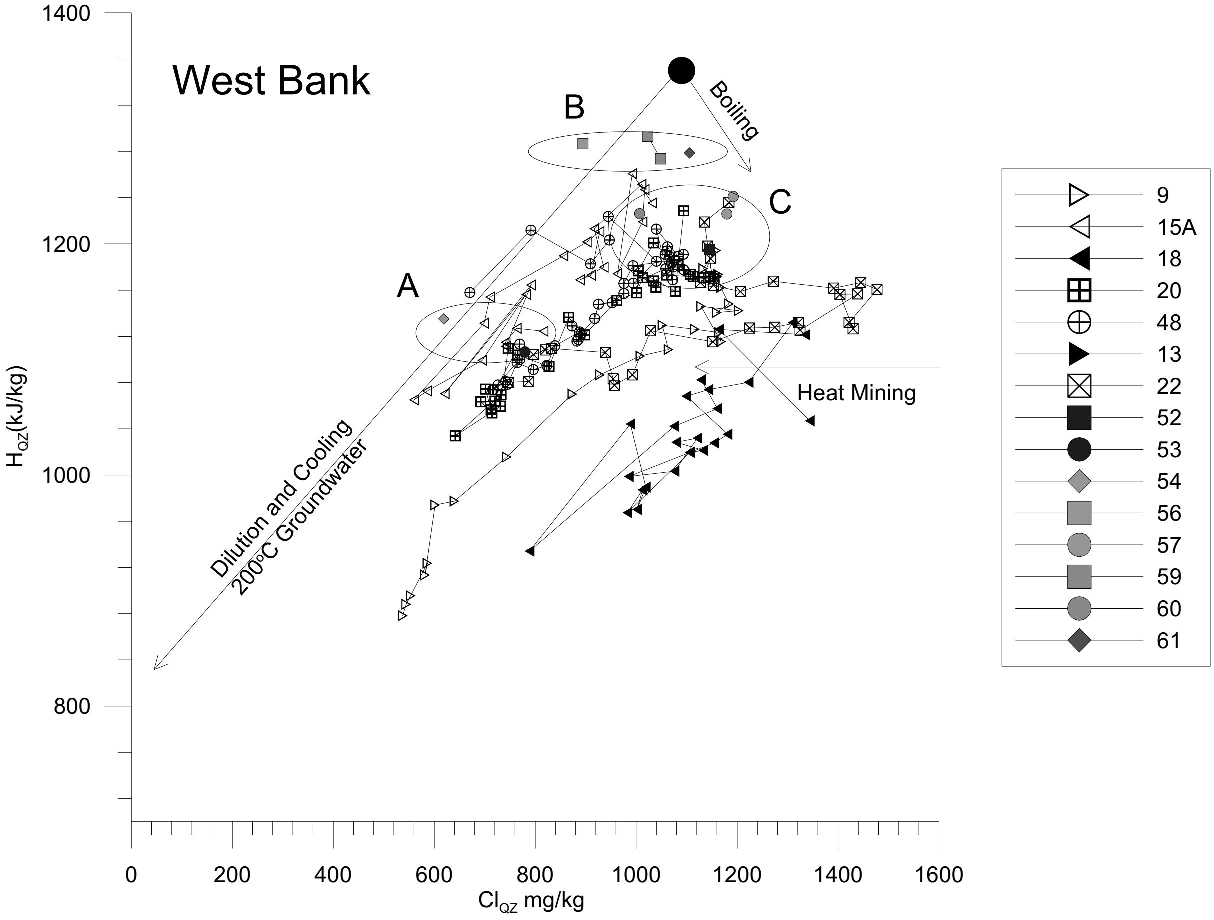

Figure 2: Chloride-Enthalpy Plot

2.2.3 Temporal Trends in Cl_{QZ} and T_{QZ}

Dilution and cooling trends have been evident in West Bank wells which produce from all depths. West Bank deeper wells, BR15A and BR48 have maintained their quartz temperatures well above what might have been expected from the degree of dilution evidenced by declining chlorides (Figures 3 and 4).

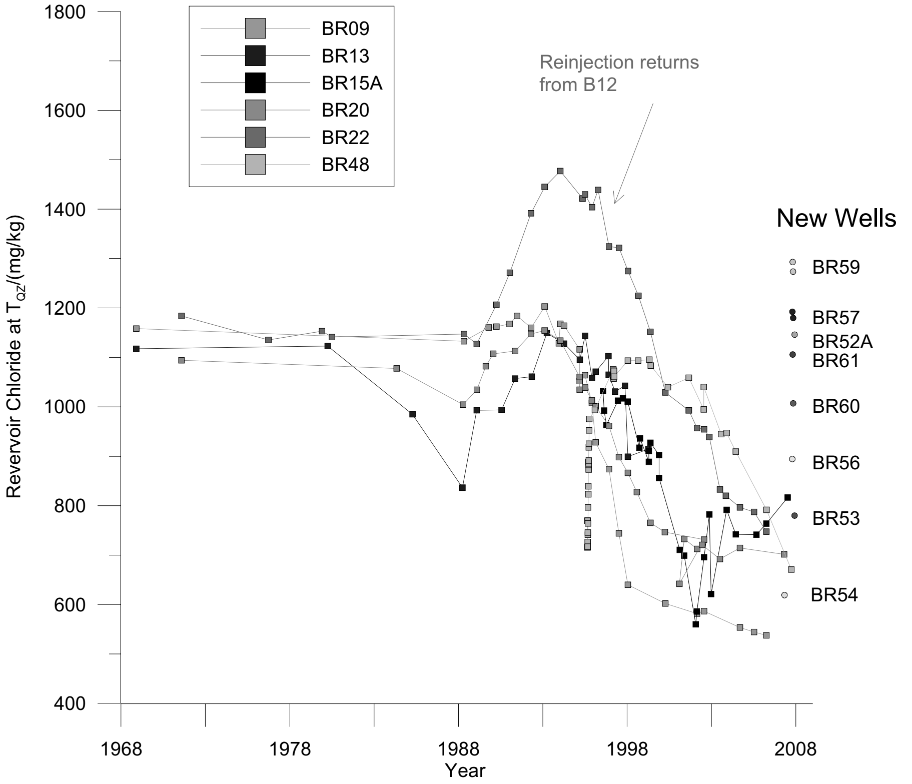

Figure 3: West Bank Chloride Concentration with Time

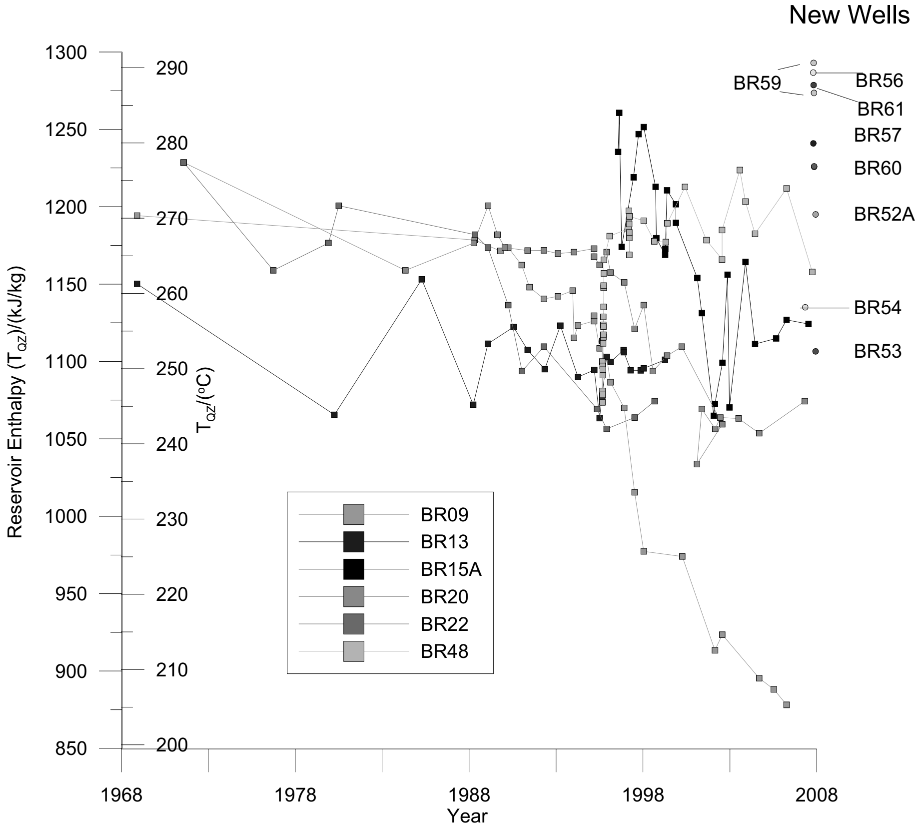

Figure 4: West Bank Quartz Temperature with Time

3 WEST BANK PRODUCTION WELLS DRILLED 2006-2007

Introduction

The composition and reservoir chemistry of the eight recently drilled wells (BR52 to BR61) is compared to the existing wells in Figures 2 to 4. Relative concentrations between selected anions are shown in Figures (5 to 8).

Of the eight new wells, BR53 and BR54 (group A in Figure 1) discharge fluid similar in terms of T_{QZ}, Cl_{QZ} and SO_{4QZ} to the fluid initially produced (in 1995) and presently discharging from BR48; that is, relatively cool at ~260°C and dilute. Three of the remaining six new wells BR56, BR59 and BR61 (group B), listed in order of increasing Cl_{QZ} at similar T_{QZ} of about 290°C, discharge aquifer fluids with higher T_{QZ} than any of the presently discharging wells, indeed hotter than wells at the commencement of production in 1988. The last three wells, BR60, BR52 and BR57 (group C) discharge fluid with reservoir temperatures of ~280°C, similar to those observed at the commencement of production. That six of the new wells have reservoir compositions which appear to have been unaffected by both dilution as well as boiling as a consequence of production to date is an encouraging result for future generation from Ohaaki.

It is interesting to speculate as to why these wells have been relatively unaffected by the nearby production. Geological interpretation is underway which may shed light on the possible reasons but one explanation may be that calcite deposited by reservoir boiling has reduced the permeability and connection between these wells and the existing production reservoir.

Relative Compositions

The reservoir temperatures, chloride, sulphate and gas compositions are listed in Table 1.

Table 1: New well inferred reservoir temperatures and compositions

Well	Date	T_{QZ}	E-H_{QZ}	$T_{Na/K}$	Cl_{QZ}	SO_{4QZ}	CO_2TD
		°C	kJ/kg	°C	mg/kg	mg/kg	mmol/100 mol
BR52	6/12/2007	281	628	303	1289	6.2	1425
BR53	5/12/2007	259	179	280	828	26	575
BR54	6/03/2007	262	230	260	617	35	389
BR56	17/10/2007	289	297	309	894	18	1017
BR57	19/10/2007	281	399	305	1192	15	755
BR59	25/10/2007	291	332	313	1023	6.8	949
BR60	5/11/2007	278	147	300	1007	19	838
BR61	25/10/2007	288	262	311	1106	3.7	1829

The high gas in total discharge is indicative of boiling in the reservoir at small steam fractions. A plot of CO_2(TD) versus excess enthalpy (the difference between the discharge enthalpy and inferred reservoir enthalpy at T_{QZ}) in Figure 5 shows how much higher the gas content of the new wells is compared to the other West Bank wells. Typically historical changes in CO_2(TD) are correlated with excess enthalpy. Although very dependent on the accuracy of the measured enthalpy, results indicates that the increases and decreases in the CO_2 concentration are due to addition or loss of steam after the liquid equilibrates with quartz.

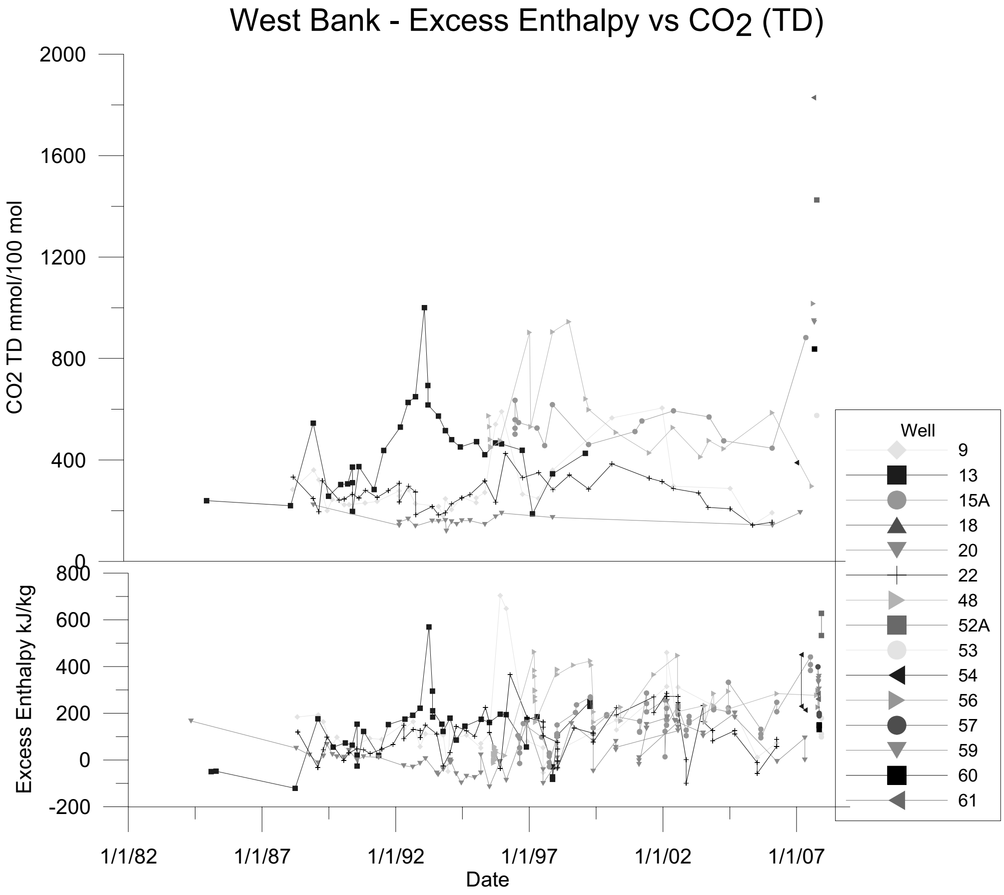

Figure 5: Excess enthalpy versus CO_2(TD)

The effect of boiling on the proportion of methane, which is much less soluble compared to CO_2 and H_2S is shown in Figure 6. The plot includes data for the recent wells as well as limited early historical data. Not surprisingly well 61, which has the highest CO_2(TD), is the most enriched with respect to methane but for all wells the CO_2/H_2S ratio ~ 60. This suggests that the steam is supplied to all the wells from the same source ("generalized aquifer") with dilution and a small amount of boiling leading to the observed differences in gas and liquid compositions.

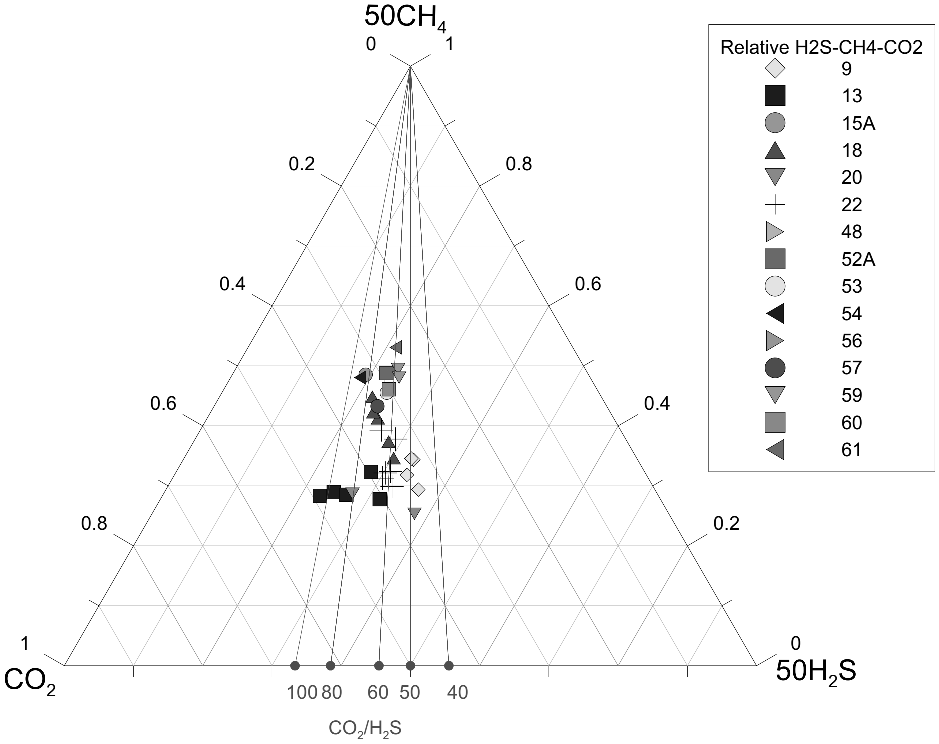

Figure 6 : Relative concentrations (molar) H_2S-CH_4-CO_2

Boron (B) and chloride (Cl) are conserved in geothermal fluids while SO_4 primarily originates from shallow reservoir processes due to oxidation of H_2S. Similarly HCO_3 is not typically conserved and arises at relatively shallow depths due to steam containing CO_2 being quenched and then being neutralized to HCO_3 by water rock interaction. Boiling and flashing to release CO_2 gas also gives rise to HCO_3. A plot of the relative concentrations of B-Cl-SO_4 for the recent wells as well as for all the data on the West Bank wells is shown in Figures 7A & 7B. The one mixing line at a uniform Cl/B ratio ~ 30 for all wells suggests they are derived from one source reservoir fluid. The trend toward the SO_4 apex of the plot is indicative of the progressive effects of mixing of the deep geothermal water with a low chloride - high sulphate surficial fluid.

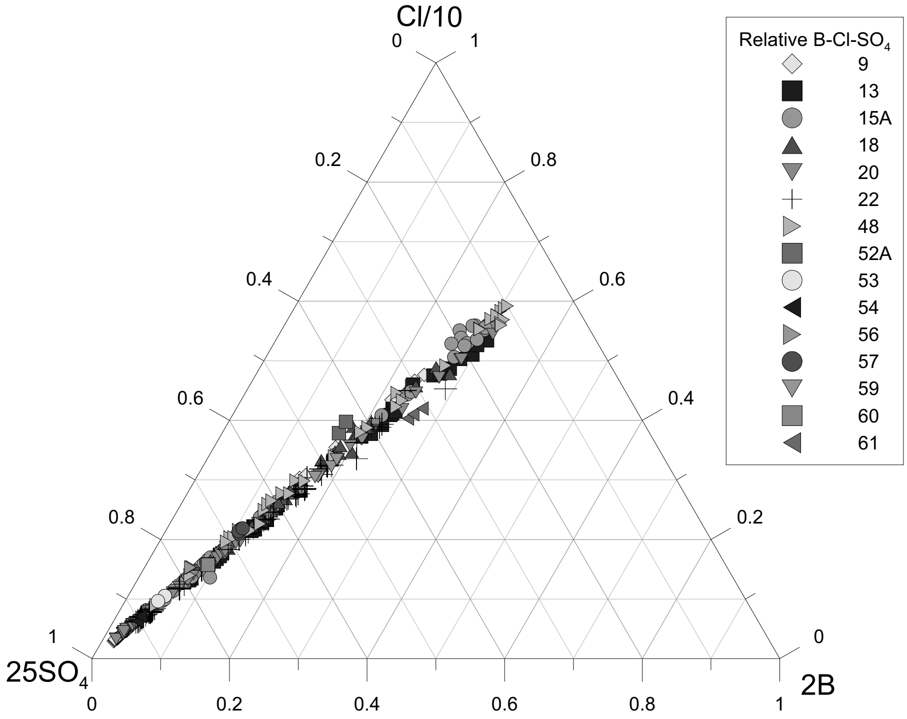

Figure 7A: B-Cl-SO$_4$ relative concentrations – All Data

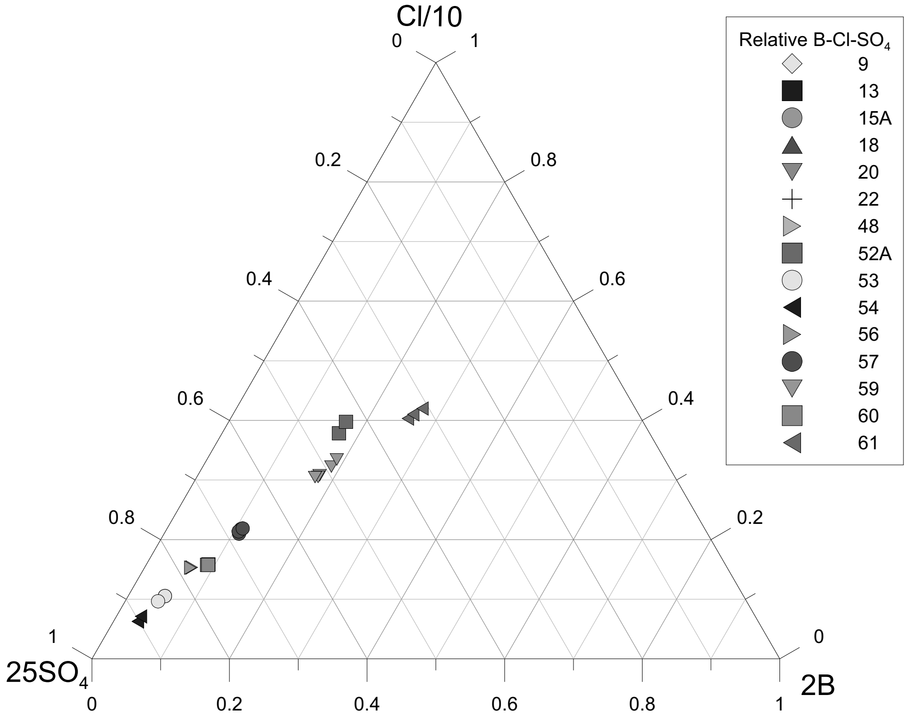

Figure 7B: B-Cl-SO$_4$ relative concentrations - New Wells

The relative concentrations of HCO_3-Cl-SO_4 in Figure 8 show a different trend. Of the older wells, only data from BR9, BR20 and BR48 is included to make the plot less cluttered. The excluded well data follows a similar trend. The trend is a mixing line from high to low HCO_3/SO_4, with initially relatively constant HCO_3/Cl ratio up to ~ year 2000, when the dilution with high bicarbonate water reduced in many wells. The coloured lines approximately delineate pre and post 2000 data with pre 2000 to the right of each line at lower relative proportions of SO_4. This puts the recent well data in perspective, plotting at much lower HCO_3/Cl and higher HCO_3/SO_4 than the presently discharging old wells. It is unknown whether the recent wells will be affected by high bicarbonate rhyolite fluids drawn down from above, as has occurred in other West Bank wells. If not, then it is expected that the calcite scaling will be less severe.

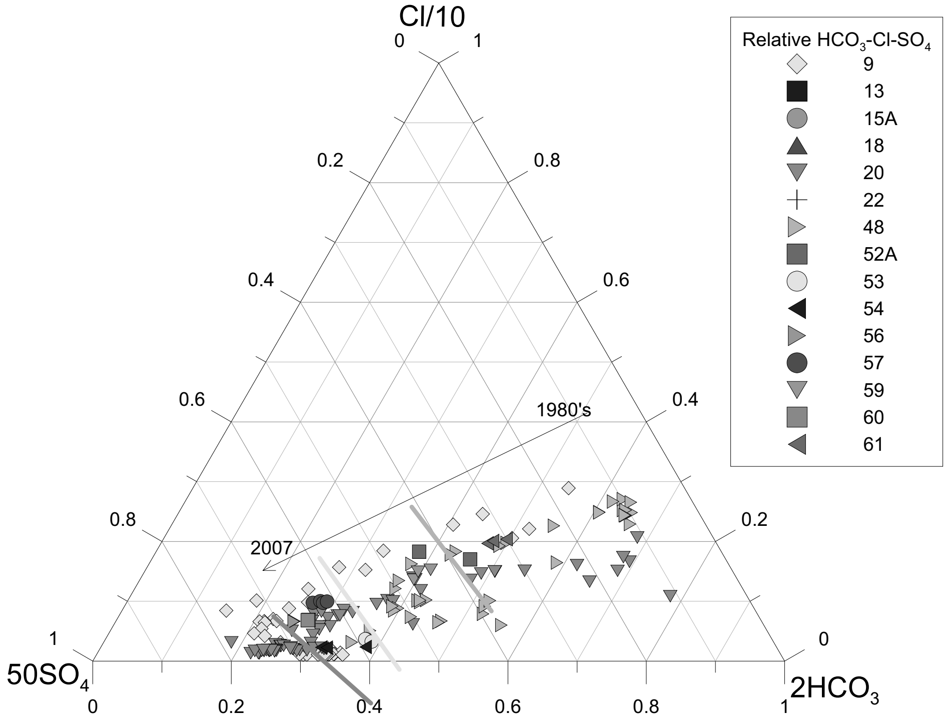

Figure 8: HCO3-Cl-SO_4 relative concentrations
New Wells and Selected West Bank Wells

4 CALCITE SCALING

Calcite ($CaCO_3$) scaling at Ohaaki has been a serious impediment since the commencement of production. Scaling occurs in wellbores at the boiling point and although inconvenient and costly to rectify can be controlled by well workovers and downhole injection of antiscalant chemicals through capillary tubing. Antiscalant dosing has been used to successfully control scaling at Ohaaki. Deposition retreated to the feed zones due to higher enthalpies, cementing the sinker bars in place and dosing was discontinued in 2000 due to difficulties of recovering and maintaining the injection tubing.

Scaling in the reservoir, away from the well, has serious implications for maintaining production. If the fluid withdrawal causes flashing in the formation then it is certain that calcite will deposit. How quickly the flow paths block depends on the local reservoir properties. Although boiling is the primary deposition mechanism at Ohaaki calcite scaling in surface plant has been caused by mixing of high bicarbonate with high calcium fluids.

Figure 9 shows the change in calcite saturation assuming a one step flash from reservoir conditions to various temperatures for three wells; BR56, BR59 and BR61. It shows that, for the first two, the fluid undersaturates with respect to calcite just under 200°C and for BR61 at about 225°C. To avoid scaling it will be necessary to manage the field conservatively, to limit drawdown of dilute bicarbonate fluids and minimize reservoir boiling to avoid calcite scaling away from the wellbore in the formation. Associated near well-bore scaling has had an effect on production and appears that it might be an issue with some of the recent deep production wells. Recovery is very difficult although well acidizing and stimulation techniques have met with some success overseas, particularly in the Philippines.

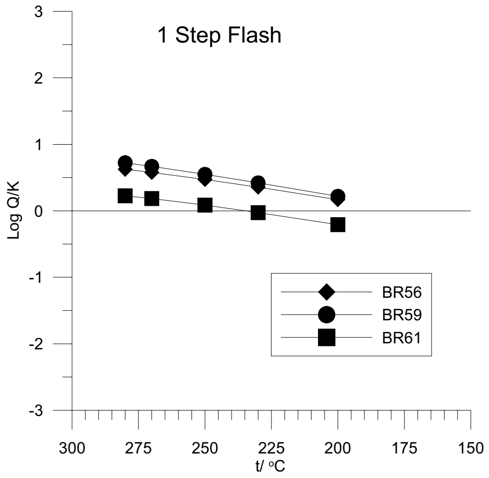

Figure 9: Calcite Saturation vs. temperature for wells BR56, BR59 and BR61 (calculated using WATCH geothermal code)

5 CONCLUSIONS

Since the commencement of production in 1988 the composition of the West Bank fluids has been characterized by cooling and dilution with a decrease in reservoir chloride from about 1200 mg/L to 700 mg/L and in reservoir temperatures (in some wells) from 280°C to 250°C. Recent drilling on the West Bank to increase generation capacity has been successful. Five of the eight new wells discharge fluids with similar reservoir temperatures and chloride concentrations observed at the commencement of production however high gas (total discharge) suggests that there has been a small amount of reservoir boiling. The reason these fluids appear to have been minimally affected by the surrounding production is not understood but may be due to the flow paths being blocked by calcite scale deposited during the initial production or perhaps even during the extensive testing prior to commissioning.

6 ACKNOWLEDGEMENTS

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