Magmatic inputs into the Ohaaki geothermal field: An "arc-type" hydrothermal system in the TVZ, New Zealand

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1. Introduction

It is widely acknowledged that the high heat flow in the Taupo Volcanic Zone (TVZ) is fostered by extensional tectonism related to westerly-dipping subduction beneath the North Island (eg. Cole 1990; Stern, 1987). Theoretical heat transfer models have been proposed which try to fit the observed heat flow at the surface (Weir, 2000) and distribution of geothermal systems across the TVZ (Kissling, 1997). All of these models assume the presence of a granitic batholith at a depth of ca. 8 km beneath the TVZ, with the geothermal systems being a natural consequence of stable convective flow regimes over this heat source.

Giggenbach (1995), however, recognised that gases discharged from geothermal systems along the eastern margin of the TVZ (eg. Kawerau, Ohaaki, Waiotapu, Rotokawa) have close affinities to those discharged from TVZ andesitic volcanoes (Fig. 1), and with arc-type volcanoes elsewhere in the world. This observation is consistent with the view that the present-day arc lies along the eastern margin of the TVZ (cf. Cole, 1990), but more importantly, it indicates that subsurface arc-type magmatic systems exist in the TVZ where there is presently no surface expression of recent volcanism. The occurrence of a shallow, 700 ka intrusive diorite at Ngatamariki (Christenson et al., 1998), raises the possibility that some magmatic heat sources along the arc may exist at considerably shallower depths than those residing in the marginal basin further to the west.

Results of comprehensive chemical and isotopic studies of waters and gases discharged from Ohaaki geothermal production wells highlight significant compositional differences across the field, and appear to point to the existence of a relatively shallow magmatic intrusive under the eastern borefield.

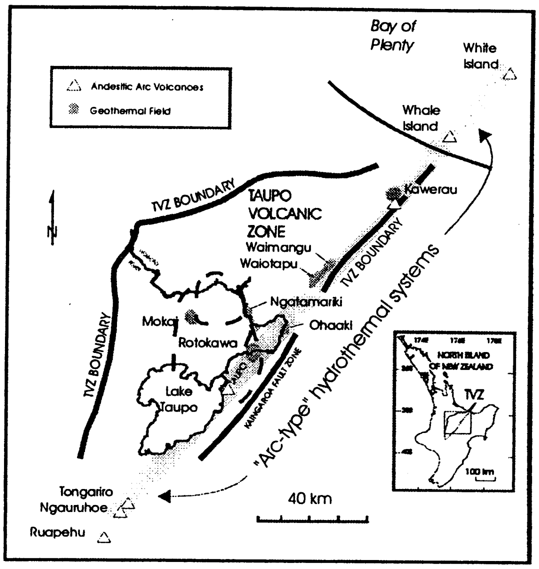

Fig.1 Locations of "arc-type" hydrothermal systems in the TVZ.

2. Charactersitics of reservoir waters

Two thermal plumes have been delineated by drilling, one on the western side of the field (west bank), the other on the eastern side (East Bank). Cl-enthalpy characteristics of fluids across the field show the western upflow to be higher in Cl, which led earlier investigators (eg. Hedenquist, 1990) to conclude that the current heat source underlies the West Bank.

Water isotope signatures across the field indicate variable mixtures of meteoric and up to ca. 20 % arc-type waters in the discharges. In addition, condensation of steam is indicated on both banks, with the steam component on the East Bank comprising up to 40% of arc-type vapour.

Non-volatile solute geo-indicators indicate more or less local equilibrium conditions across the reservoir. More conservative solutes (eg. B, F), on the other

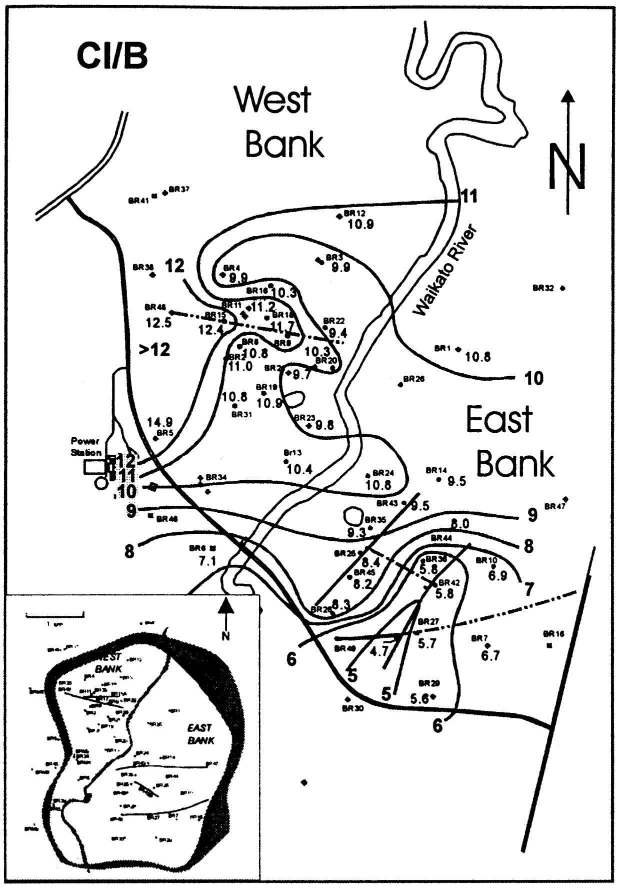

Fig. 2 Molar Cl/B ratios across the field. Inset shows resistivity boundary for the field (in grey).

hand, are strongly enriched on the East Bank. Minimum Cl/B values are found in wells producing from a fault structure which displaces Mesozoic basement rocks in the vicinity of well 42 on the East Bank (Fig. 2), suggesting a B emitting source at depth in this area.

Relative contents of B, Li and Cl in the Ohaaki discharges (Fig. 3) are compared to crater lake waters from White Island and Ruapehu volcanoes, and to relevant TVZ reservoir rock lithologies. Cl/B ratios in rhyolite and andesite lithologies match the Ohaaki compositions most closely, whereas TVZ greywacke is Cl-depleted and the crater lake compositions are Cl-enriched relative to the Ohaaki fluids. Whereas B is readily transported in high temperature magmatic gas streams (Quisefit et al., 1989; Arnorsson & Andresdottir, 1995), the high Cl/B of the TVZ crater lakes suggest that a supplementary source of B must be involved. Evidence suggests that this source is most likely the Mesozoic greywacke basement rocks.

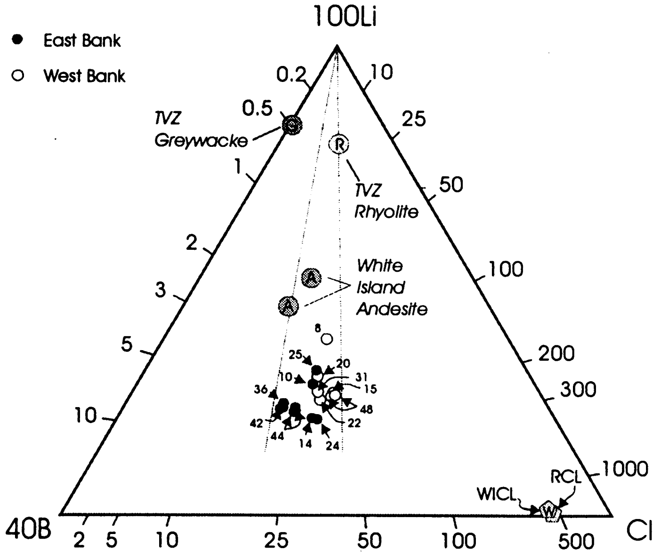

Fig. 3 Relative contents of B-Li-Cl

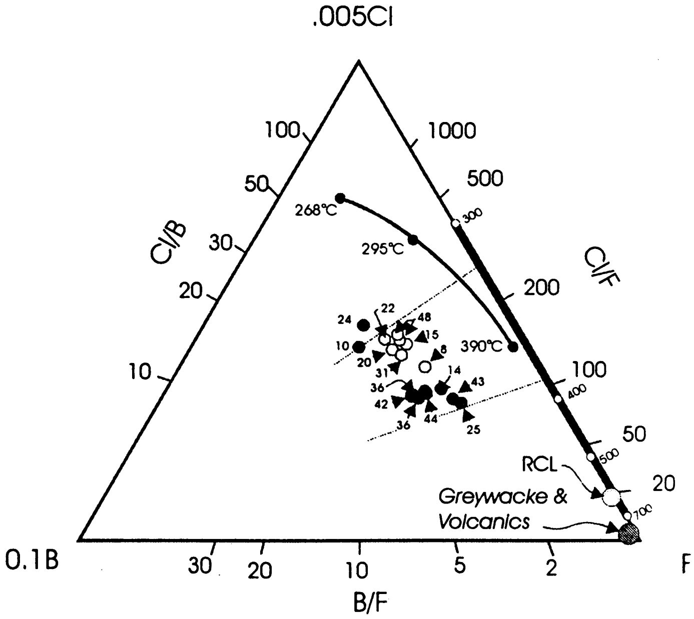

Fig. 4. Relative B-Cl-F contents of Ohaaki discharges, White Island fumaroles and TVZ rock compositions

The East Bank fluids are also relatively enriched in F (Fig. 4). This enrichment is consistent with either a high temperature gas source, or localised dissolution of F-enriched reservoir rock. Once again, the basement greywacke is implicated.

3. Chemical and isotopic composition of gases.

The Ohaaki geothermal system is noted for its relatively high gas contents (source fluid compositions of ca. 1 molal; Sutton and McNabb, 1977). The system is largely 2-phase, hence conventional gas geo-indicators are adversely influenced by excess vapor contributions to the wells.

N_2/Ar values for the discharges are amongst the highest in the TVZ, pointing to the high organic content of the (subduction zone) source materials. Within the field itself, there are three local N_2/Ar highs, the highest being found on the East Bank (Fig. 5).

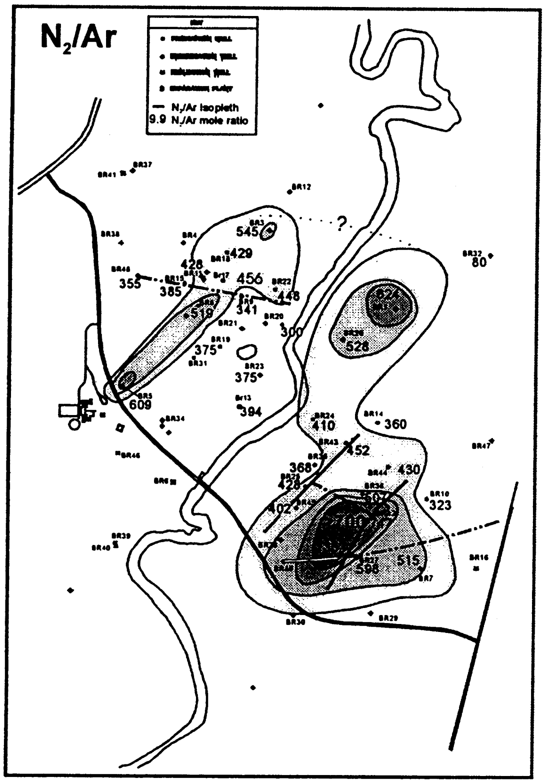

Fig. 5. N_2/Ar in Ohaaki discharges.

The East Bank discharges are also enriched in CO_2 relative to those on the West Bank (Fig. 6). Modelling shows that the CO_2–enriched gases cannot derive from West Bank source fluids, and these East Bank compositions show close similarities to gases discharged from White Island (Giggenbach and Sheppard, 1989).

$\delta^{13}C$ signatures for the CO_2 range between –6 to –9 ‰ consistent with magmatic compositions elsewhere in the TVZ. Equilibrium fractionation temperatures for ^{13}C between CH_4 and CO_2 in the discharges range between ca. 360 and 437 °C.

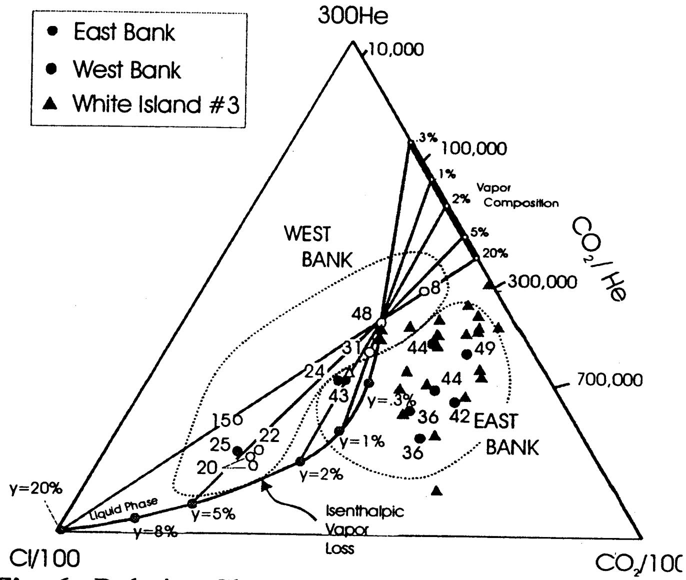

Fig. 6. Relative Cl-He-CO_2 contents.

Equilibrium temperatures on the East Bank are uniformly higher than those op the West Bank, (typically between 400 – 437 °C), with the highest temperature found in the discharge from well 42.

Hulston and Lupton (1996) reported $^3He/^4He$ and $^{40}Ar/^{36}Ar$ results for discharge samples collected between 1978-1986, and found R/R_A.values to be higher on the West Bank than on the East. In addition, they reported more radiogenic $^{40}Ar/^{36}Ar$ compositions on the East Bank. We have expanded the data set, and have identified two end-member source fluids for the system (Fig. 7).

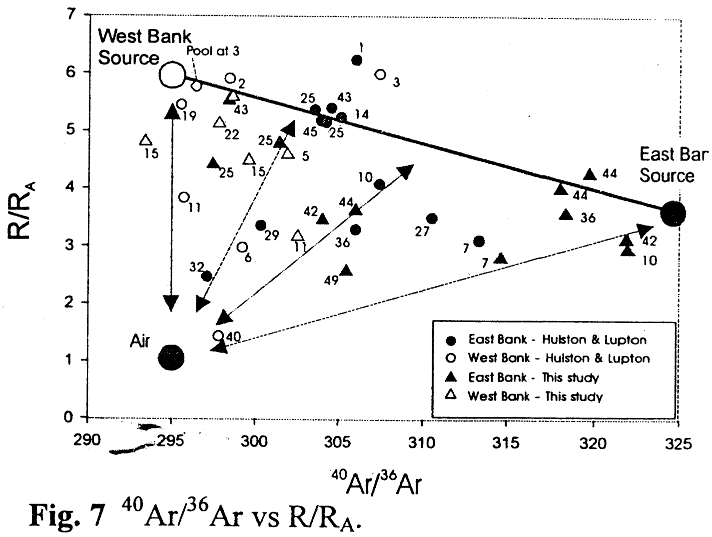

Fig. 7 $^{40}Ar/^{36}Ar$ vs R/R_A.

4 Discussion & Conclusions

The results point to the existence of a relatively young and shallow, degassing intrusion situated under the East Bank production field. Boiling point depth calculations suggest a minimum depth of ca 3100 m to the 370 °C isotherm, the inferred limit of the plastic-brittle transition zone (Fournier, 1999). Calculations based on ^{13}C fractionation kinetics between CH_4-CO_2 provide an estimated depth of ca. 4 km to the 430 °C isotherm. These results indicate that the East Bank heat source is considerably shallower than those considered to exist elsewhere in the TVZ.

The relatively high (ie. >400 °C) equilibrium fractionation temperatures on the East Bank indicate that CH_4 production and isotopic equilibration is taking place within the plastic-brittle transition zone. These reactions probably proceed within 2-phase (ie. vapour-high density brine) fluid segregations which accumulate in the ductile intrusion (eg. Fournier, 1999), and periodic breaching of the brittle-plastic transition releases vapour into the overlying, meteoric-dominated environment.

Although the vapours released across the brittle-plastic transition will be depleted in SO_2, and will therefore have lower hydrolysing capability than H_2S-SO_2 buffered (eg. magmatic) vapours, they will still be HCl- and CO_2-bearing, and hence capable of promoting dissolution of the host rocks (greywacke). As a result, both B and F could be released through dissolution of host rocks, and provide the observed anomalies on the East Bank.

R/R_A values close to 6 on the West Bank are typical of most TVZ hydrothermal systems, and point to the significant quantities of mantle ^3He being discharged through the zone (eg. Giggenbach, 1995). The lower values of R/R_A on the East Bank can best be explained by dilution of the mantle signature by crustal-derived ^4He. This idea is consistent with the view of Stern (1987) who envisions an eastward migration of the arc through time.

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