RECENT ISOTOPIC MEASUREMENTS AT OHAAKI

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SUMMARY - Helium isotope measurements have recently been completed on a series of samples collected from a cross-section of wells in the production area of the Ohaaki geothermal field. The results obtained show relatively small changes in $^3He/^4He$ from measurements on the same wells in the late 1970's and mid-1980's. In particular the correlation with changes in B/Cl ratios, predicted by Hulston (1995), have not been in evidence. A correlation has however been observed between the $^3He/^4He$ and $CO_2/^4He$ ratios on the repeat measurements of some wells. Some changes to the hydrogen and carbon isotopes of the methane with time may be evident, but are yet to be confirmed. Although the information from this study is of value to the building up of our knowledge of geothermal systems, it is not yet able to provide an estimation of the recharge of geothermal systems and the sustainability of these systems.

1. INTRODUCTION

Since drilling commenced in the Ohaaki-Broadlands Geothermal field in the late 1960's a number of isotopic studies have been made on the geothermal fluids. Giggenbach (1971) and Stewart (1978) showed from hydrogen and oxygen isotopic measurements that the majority of the water in the geothermal fluids originated from local rainwater but that some shift of oxygen-18 had occurred. Methane, hydrogen and carbon dioxide isotope measurements were reported by Lyon and Hulston (1984) (see section 2.4). Three Ohaaki wells included in the NZ helium isotope survey of Torgersen *et al.* (1982) showed significant differences in $^3He/^4He$, which were confirmed in a more detailed study of Ohaaki by Hulston *et al.* (1986). Hulston and Lupton (in press) placed these 1984-86 helium isotope results within the context of other geothermal fields in the Taupo Volcanic Zone (TVZ). They emphasised the possible link of higher B/Cl ratios on the East Bank with radiogenic helium-4 contributions which resulted in the $^3He/^4He$ ratios decreasing from -6 R_A (where R_A is the $^3He/^4He$ ratio of air) on the West Bank to -3 R_A on the Eastern margin of the East Bank and suggested greywacke as a possible source of both the boron and the radiogenic helium-4. Giggenbach (1989) investigated the chemical and isotopic position of the Ohaaki field within the TVZ, concluding that Ohaaki East fluids were of "arc" type composition whereas Ohaaki West fluids showed "rift" (or "backarc" in some papers) characteristics approaching those of Wairakei and other geothermal fields away from the SE boundary of the TVZ. Giggenbach (1989) also preferred an origin of the high boron content of the arc type discharges in the subducted component of the mantle fluids rather in the greywacke source preferred by Hulston and Lupton (in press). Figure 1 illustrates a model of noble gases within a geothermal system which Hulston and Lupton (in press) used to illustrate the role of deeply circulating groundwater saturated with atmospheric gases which interacts with mantle gases (particularly ^3He) and heat. *En route* to the surface this also picks up radiogenic ^4He from the decay of uranium and thorium series nuclides from crustal material.

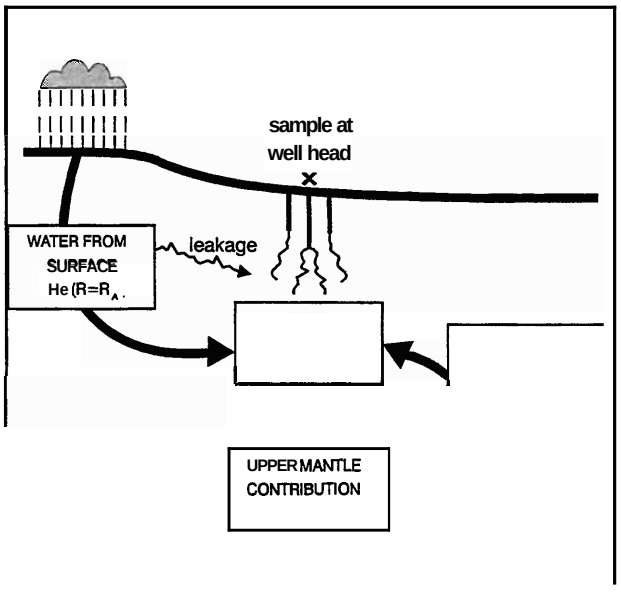

Figure 1 - Model of noble gases in a geothermal system

In the intervening period, the field has been developed with a 110 MWe geothermal power station at Ohaaki. Clotworthy *et al.* (1995) reported on the changes in the Ohaaki Reservoir following seven years of commercial production. These included declines in temperature in the NW of the West Bank and the SW of the East Bank

and a decline in enthalpy in the West Bank reservoir caused by the ingress of relatively shallow groundwater. Hulston (1995) postulated that repeat measurements of B/Cl and the gas isotopes should be capable of determining effects of flushing of fluids through the system and, in particular, in the reduction of boron and radiogenic helium-4 in the discharge. A programme of re-sampling and measurement was therefore set up and the results are reported in this paper. Where possible, the same wells as previously were sampled but, as some were no longer in production, additional wells were chosen to provide a spectrum of B/Cl ratios as well as a reasonable cross section of the field.

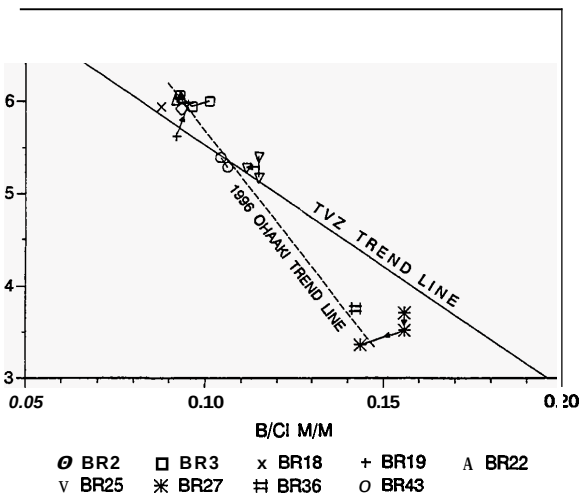

Figure 2 - Helium isotope (R_C/R) v B/Cl ratios for the re-sampled wells. Arrows show changes from earlier measurements.

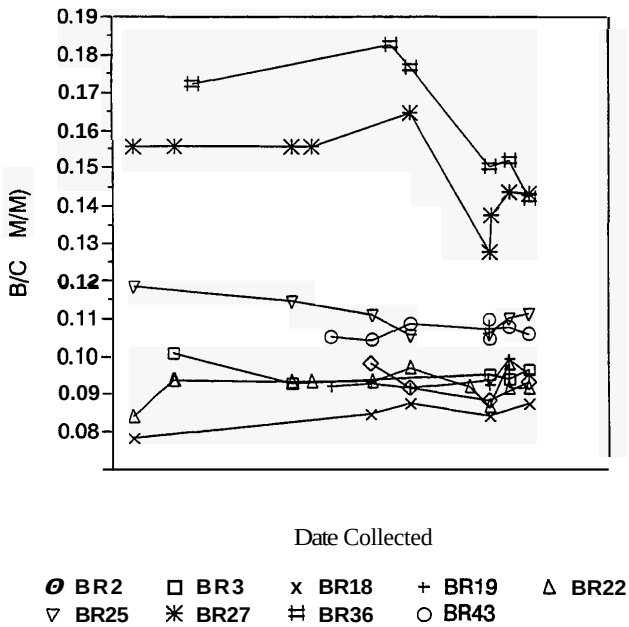

Figure 3 - Changes with time of B/Cl ratio of wells sampled.

2. CHANGES OVER THE PAST DECADE

2.1 Helium isotope and Boron/Chloride ratios

The results obtained from $^3He/^4He$ and B/Cl measurements are shown diagrammatically in Figure 2. It will be seen from these that the change in helium isotope and B/Cl ratios over the last decade have been relatively small when compared with the range of values found across the field. Thus there is minimal evidence for the coupled flushing of boron and helium-4 from the system as postulated by Hulston (1995). The slope of the 1996 Ohaaki best fit line is however somewhat steeper than the TVZ trend line of Hulston and Lupton (in press) suggesting that some flushing of the boron may be in evidence.

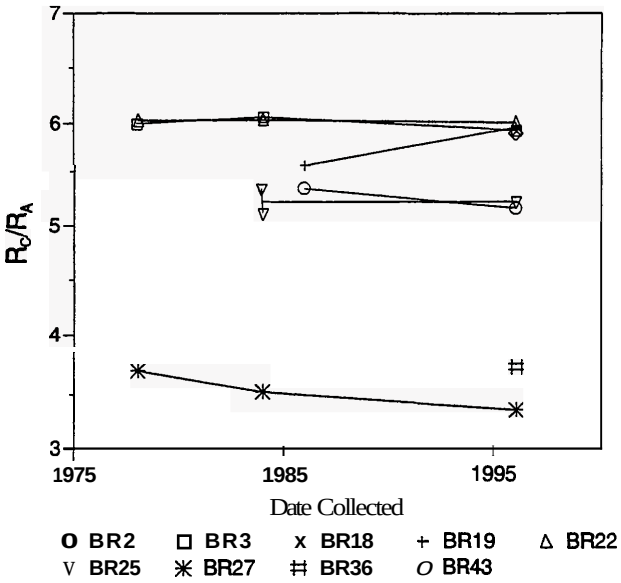

Figure 4 - Changes with time of $^3He/^4He$ in the wells sampled

The change in B/Cl with time for the wells sampled is shown in Figure 3 (the points plotted in this and later plots are restricted to dates which correspond to noble gas collection dates). A reduction of B/Cl over this period in the Eastern wells of the East Bank (BR27 and BR36) is indicated but we have also found a variation of B/Cl ratio with well head pressure (WHP) which is evident even when the well is tested at different flow rate in a single day. Thus this reduction in B/Cl in these wells with time may simply reflect a reduction in WHP as field pressures have declined. Glover (1988) investigated boron distribution between liquid and vapour in geothermal fluids but the proportions of boron found in the steam phase at the temperatures encountered in these wells is much less than the changes shown in Figure 3. It is thus probable that this effect is related to more efficient extraction of boron by the higher temperatures and lower flow rates occurring at higher WHPs. Wells with B/Cl below 0.12 do not appear to be affected by WHP or to have varied significantly with time. (It should be noted that the 1996 collection from BR36 was accidentally collected from a pipeline

containing ~10% of fluid from the adjacent well BR42. This is not however considered to have affected the discussion in this paper as recent chemical measurements of BR42 are very similar to those of BR36).

The change with time of the $^3He/^4He$ data is shown in Figure 4. It will be noted that both increases and decreases have occurred since the earlier measurements. Figure 5 shows a plot of $^3He/^4He$ against $CO_2/^4He$ ratios. This plot shows a consistent family of parallel lines for these re-measured wells indicating that the $CO_2/^4He$ ratio has an influence on the $^3He/^4He$ ratio. At this stage it is not clear if this correlation is a result of helium isotopic fractionation during liquid/vapour fractionation processes during boiling or to radiogenic helium-4 being carried by carbon dioxide-rich fluids.

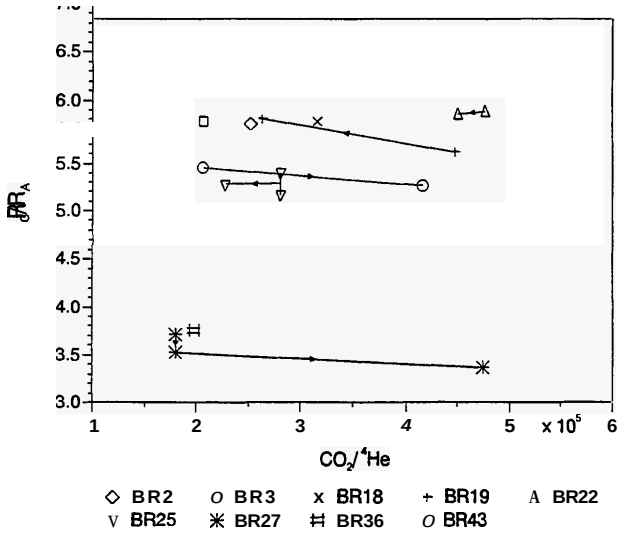

Figure 5 - Plot of $^3He/^4He$ against $CO_2/^4He$ ratios. Repeat measurements of a well are joined by lines with arrows pointing towards later measurements.

2.2 Argon content of total discharge

The argon content of the total geothermal discharge should, provided no phase separation occurs *en route,* be equal to that of air saturated groundwater (see Figure 1). This atmosperic origin is confirmed by the near atmospheric $^{40}Ar/^{36}Ar$ ratios found at Ohaaki by Hulston *et al.* (1986). The initial argon content varies according to the temperature at which the groundwater leaves the surface but for the purpose of this paper it is adequate to use the value of 0.3 μmol/mol. Hulston (1994) and references therein, discuss the way in which sub-surface boiling can affect this value.

Figure 6 shows a plot of argon in the total discharge against the date of sample collection. Prior to the commencement of these measurements by DSIR, phase separation had already occurred as a result of the drawdown test over the 1968-71 period. Well BR3, which is a relatively shallow well and is probably partially fed by the CO_2-rich steam heated groundwater described by Hedenquist and Stewart (1985), in particularly shows signs of steam phase enrichment of argon, while most of the other wells show a depletion in argon due to a loss of steam phase. BR22 which is one of the hottest wells on the West Bank has shown consistently low argon content while its equivalent on the West Bank, BR43 maintained a value close to atmospheric until after 1988 and has since dropped to a third of that value.

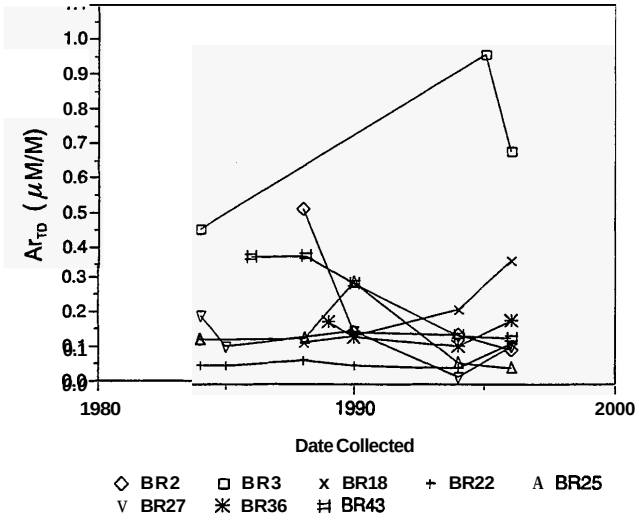

Figure 6 - Change of argon content of the total well discharge with time.

2.3 Helium-3/heat ratios

Hulston (1994) calculated helium-3/heat ratios for Wairakei and pointed out that these ratios were within an order of magnitude of those reported for mid ocean ridge vents. Giggenbach (1995) has estimated TVZ helium-3/heat ratios at 1.5 - 5 pmol/MJ for "arc" type fluids and 6 - 15 pmol/MJ for "rift" type fluids (900-3,000 and 3,600-9,000 atom ^3He mJ^{-1} respectively) and Hulston and Lupton (in press) calculated 400-10,000 atoms ^3He mJ^{-1} for several TVZ geothermal fields including Ohaaki. Figure 7 shows a plot of helium-3/heat variations of the wells sampled from 1984 to 1996. This indicates that this ratio continues to be in the mid-ocean ridge range of ~3500 atoms ^3He mJ^{-1} (values of up to five times this have been reported for some mid-ocean ridge vents by Lupton *et al.*, 1989). However it should be noted that by sampling wells used for steam production for the power station we have made an uneven survey of the field. It will also be noted from Figure 7 that there has been no consistent trend over the past decade other than for the recent values to be closer together than the earlier values.

2.4 Methane isotopes

Lyon and Hulston (1984) measured the isotopic composition of carbon and hydrogen in the methane and carbon dioxide phases of a number of geothermal areas of New Zealand including a collection from the Ohaaki-Broadlands area made during 1978. These showed very

little variation in isotopic composition across the Ohaaki field. Lyon and Hulston (1984) considered the possibilities that isotopic exchange was occurring between carbon dioxide and methane in these areas. However the equilibrium temperatures obtained were some 100°C higher than measured well temperatures. Two possible explanations existed for this. Firstly that the equilibrium was so slow that the apparent temperatures represented an equilibrium at considerably greater depth than the bottom of the well and, alternatively, that the methane and carbon dioxide had entirely separate origins which accidentally gave these apparent equilibrium temperatures. They were not able to distinguish between these processes for their paper. Since almost two decades has elapsed since these measurements were first made, it was felt that it would be useful to re-measure these isotopic compositions in a selection of the wells used for helium isotopic measurements.

The results obtained from this re-measurement still fall in a relatively tight band with $\delta^{13}C(CH_4)$ between -25.5‰ and -26.5‰ and $\delta H(CH_4)$ between -144‰ and -160‰. Slight changes in the results for individual well results over the 18 years may be present but it was considered prudent to repeat some of these measurements before releasing the detailed data. The data show no significant correlation with factors such as B/Cl which vary across the field. This would suggest a common origin for the methane. We must therefore, conclude that the methane is sourced somewhat deeper in the system, than the effects which produce the variations in $^3He/^4He$ and B/Cl or alternatively that it arises from organic material which exists in the source rocks on both banks of the field. In either case the methane source appears to have changed only minimally over the past 20 years.

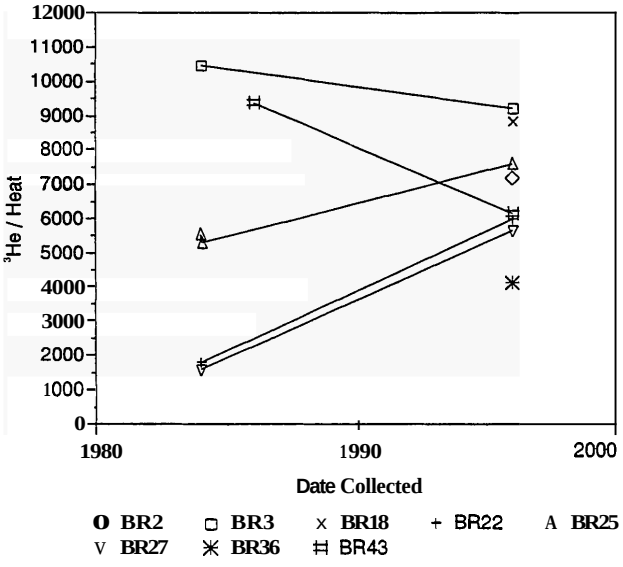

Figure 7 - Changes in $^3He/heat$ ratio (atoms $^3He\ mJ^{-1}$) with time for the wells sampled.

3. RELEVANCE TO THE ORIGIN AND SUSTAINABILITY OF GEOTHERMAL FIELDS

3.1 Relevance to Ohaaki Field

Various suggestions have been made as to the origin of the Ohaaki-Broadlands system. These have been reviewed by Glover and Hedenquist (1989) who concluded that "in the past upflows of deep fluids occurred to a greater degree on the eastern portion of the near surface (<2000 m depth) system. Boiling in the upper 1500 m resulted in the formation of marginal steam-heated fluids that subsequently diluted the ascending chloride fluid. With time this dilution occurred at deeper level, particularly in the East bank. This decreased permeabilities in the East Bank by deposition of illite and may have shifted the focus of the upflow towards the West Bank." Lovelock (1990) however, on the basis of the contrasts in Br/Cl and $^3He/^4He$ ratios across the field and other data, favoured a model of more deeply sourced, chemically distinct upflows.

With the continued commercial production from the field the distinction in the B/Cl, Br/Cl and $^3He/^4He$ ratios between the East and West Banks has remained, with the sustained temperature highs over 1 km apart. Thus it appears as if the hot recharge is occurring independently on each bank.

3.2 Relevance to other geothermal fields within TVZ

While fields away from the margin of TVZ, such as Wairakei and Mokai, have relatively low boron content, several other fields such as Kawerau and Rotokawa have B/Cl ratios similar to that of Ohaaki. In particular it is interesting to note that the Waikato River, which by its nature follows the lowest local elevation, intersects both Ohaaki and Rotokawa fields with the lowest B/Cl ratios on the NW Bank and the highest on the SE Bank. It is useful to ask if this is a coincidence or if there is a more fundamental reason related to the origin of the geothermal fluids.

4. CONCLUSIONS

Despite the decline in field output over the past decade the mantle derived helium-3 signal has remained relatively unchanged over the period, with the differences between the East and West Banks persisting.

Although the information from this study is of value to the building up of our knowledge of geothermal systems, it is not yet able to provide an estimation of the recharge of geothermal systems and the sustainability of these systems.

5. ACKNOWLEDGEMENTS

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