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PRECOMMISSIONING SAMPLING TO ESTABLISH A BASELINE FOR GEOCHEMICAL MONITORING AT BROADLANDS-OHAAKI GEOTHERMAL SYSTEM, NEW ZEALAND

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ABSTRACT

Discharge and/or downhole sampling of production, injection and monitor wells has been conducted at Broadlands-Ohaaki to establish a precommissioning baseline; this will allow changes related to future production to be assessed. Changes related to long term discharge testing have been essentially due to two processes, (1) steam gain or loss from the formation and (2) dilution by shallow and marginal steam-heated waters. These changes are predicted to continue once full scale production is started, but the interpretation may be complicated by returns of high chloride reinjection waters.

There appears to be similar concentrations of CO_2 in the production liquid and the steam-heated waters; however, the H_2S is greatly depleted in the steam-heated waters, causing a strong increase in CO_2/H_2S ratios when dilution occurs. This signature may nelp to predict the incursion of dilution waters, and also to distinguish these fluids from trends related to reinjection returns. The planned assessment of monitoring results of production wells will greatly assist in the reservoir management of the system.

INTRODUCTION

The Broadlands-Ohaaki geothermal system is located 25 km northeast of the Wairakei geothermal system in the Taupo Volcanic Zone of New Zealand. A 110 MW power station will be commissioned in early 1989; first exploratory drilling began in 1965. After final separation of steam at 4.8 b.g., all waste water will be reinjected along the southwest to southeast margins of the system. Several changes in the production reservoir may occur subsequent to commissioning, including (1) an increase in discharge enthalpy due to depressurisation within the reservoir, (2) an eventual decline in discharge enthalpy due to the extraction of heat from the reservoir, (3) dilution of reservoir fluids by marginal, steam-heated waters and (4) return of reinjected fluids.

In order to predict and monitor these changes to the production reservoir, a programme of regular sampling and analysis of discharging wells, separation plants and reinjection lines has been established. This report describes the results of the sampling programme conducted in late 1987 and early 1988 to provide a present day baseline of chemistry against which to assess production-related changes.

This monitoring programme and the continual assessment of results will be essential to reservoir management. Some chemical indicators may help to predict changes before they occur; the data will also be useful in testing the results of reservoir modelling and related predictions.

Background

Figure 1 shows the locations of production, reinjection and monitor wells at Broadlands-Ohaaki.

The steady state (pre-drilling) geochemical structure of the system was deduced by Hedequist and Stewart (1985) from initial discharge chemical and stable isotope patterns. These data are summarised in an enthalpy-chloride diagram (Figure 2); the enthalpy was determined from quartz geothermometry and the chloride concentration has been corrected to reservoir conditions.

Hedenquist and Stewart (1985) identified a steam-heated water as being the principal natural diluent of both East and West Bank deep chloride fluids. This steam-heated water is CO^-rich due to the high gas content of the deep chroride fluids and, subsequently, the steam which forms during boiling.

The steam-heated waters are present at shallow (200 to 400 m) depths over the deep upflow, and drape downwards along the margins of the system, like a discontinuous umbrella. They are often associated with both shallow and (on the margins) deep thermal inversions of 150 to 175°C.

Hedenquist and Stewart (1985) determined that the shallow CO_2-rich, steam-heated waters were the cause of cemenr and casing corrosion; also, these cool, dilute fluids were drawn down into the production reservoir during long term discharge testing. The present state of the reservoir fluids,

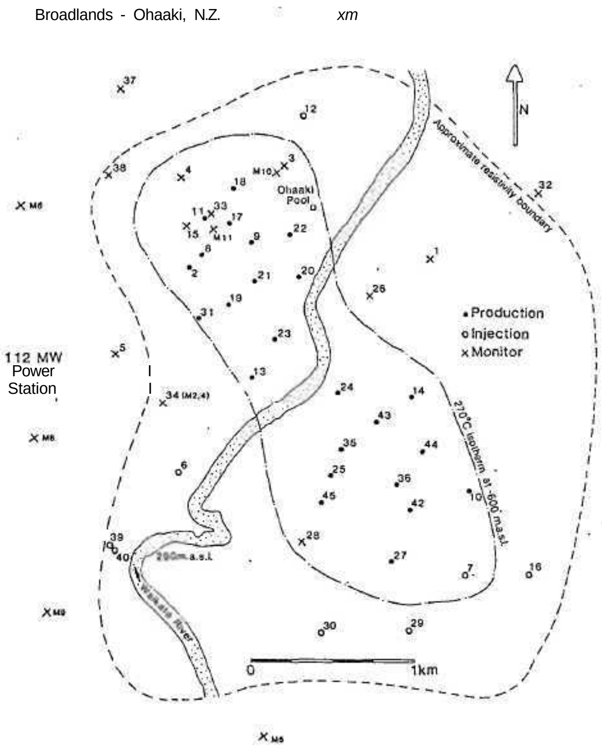

Figure 1: Plan of Broadlands-Ohaaki geothermal system showing the location of production, injection and monitor wells.

somewhat modified from the initial, natural conditions, is discussed here. This present state will be used as a baseline in the future monitoring programme.

RESULTS OF THE BASELINE SAMPLING OF WEST BANK PRODUCTION WELLS

Enthalpy-Chloride Relations

The West Bank production wells were discharged in turn from late February to early May, 1988; weirbox and Webre water and Webre gas samples were collected, and discharge enthalpies measured. East Bank wells have yet to be sampled in the present programme, as these wells are part of the second stage of commissioning.

The results have been compiled along with previous sample data for West Bank producers (initial sample conditions denoted by a tick mark). Three diagrams are used to present the data and look at trends; total discharge enthalpy versus chloride (Figure 3), enthalpy of the quartz geothermometer versus reservoir liquid chloride (Figure 4), and total discharge CO_2 versus CO_2/H_2S ratio (Figure 5).

Two principal trends are observed in the enthalpy-chloride variation. One is due to steam gain or loss from the formation and the other is dilution; in the case of the dilution trend, extrapolation to nil chloride indicates an endmember enthalpy of 600 to 700 kJ/kg (-145 to 165°C), i.e. the same steam-heated fluid identified from initial conditions in Figure 2 (Hedenquist and Stewart, 1985).

There is much variation in total enthalpy (Figure 3), though this is largely due to steam gain to or loss from the reservoir (due to production testing). However, when only the liquid phase in the reservoir in considered (Figure 4), a strong component of dilution is evident. In many wells, the 1988 sample is more dilute than the initial discharge (shown by tick mark); once dilution begins, it seldom reverses, even when the well is not discharged for long periods.

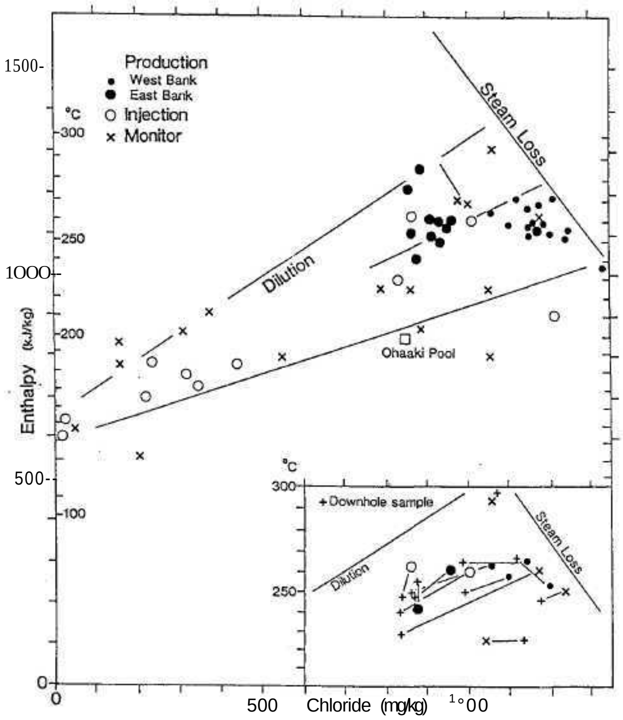

Figure 2: Enthalpy of the quartz geothermometer versus the reservoir liquid chloride concentration for the initial state of the Broadlands-Ohaaki system. East and West Bank production wells are slightly different in reservoir composition, while marginal and injection well chemistry define a dilution trend towards steam-heated waters (from Hedenquist and Stewart, 1985). Insert shows variation from the initial state for some wells recently sampled downhole.

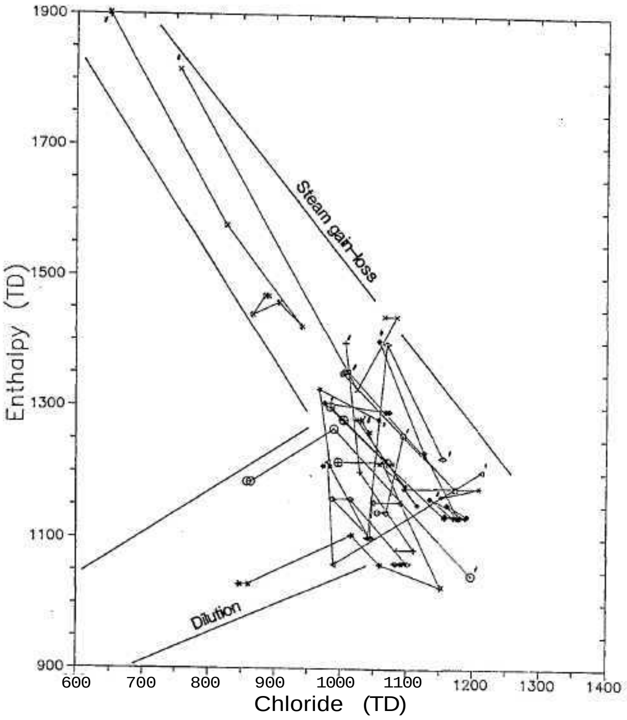

Figure 3: Total enthalpy versus total chloride for all available West Bank production well samples since initial discharge (initial designated by tick marks).

Trends in Gas Chemsitry

The trends in gas chemistry of the total discharge are shown in Figure 5. A model curve has been calculated for changes in dissolved gas in a liquid boiling from 290 to 270°C (based on an initial gas content determined from some high temperature liquid-feed wells); a portion of the corresponding vapour composition curve is also shown.

Wells with liquid feeds should show compositional variations approximately along the liquid trend, while those showing excess enthalpy (i.e. a two phase feed) will have more gas in the discharge, and will plot between the two curves. Most data, particularly for initial discharges, do fall between these curves, with trends parallel to the curves (except where a well undergoes a large variation in discharge enthalpy).

However, several wells deviate from these trends for recent, and particularly 1988, samples. There is a large increase in the CO_2/H_2S ratio without the necessary increase in total CO_2 required by gas fractionation from a single fluid. These trends indicate the presence of a component of fluid distinct from the production fluid; this component has a similar CO_2 concentration to the production fluid, but is depleted in H_2S (i.e. has a much higher CO_2/H_2S ratio).

The greatly increased CO_2/H_2S ratios in some wells are most likely due to the presence of a component of steam-heated waters (i.e. reflecting dilution). These steam-heated waters can have CO_2 concentrations similar to those of the deep chloride liquid (Hedenquist and Stewart, 1985); however, their CO_2/H_2S ratios can range from 300 to 1000, as evidenced" from downhole gas samples.

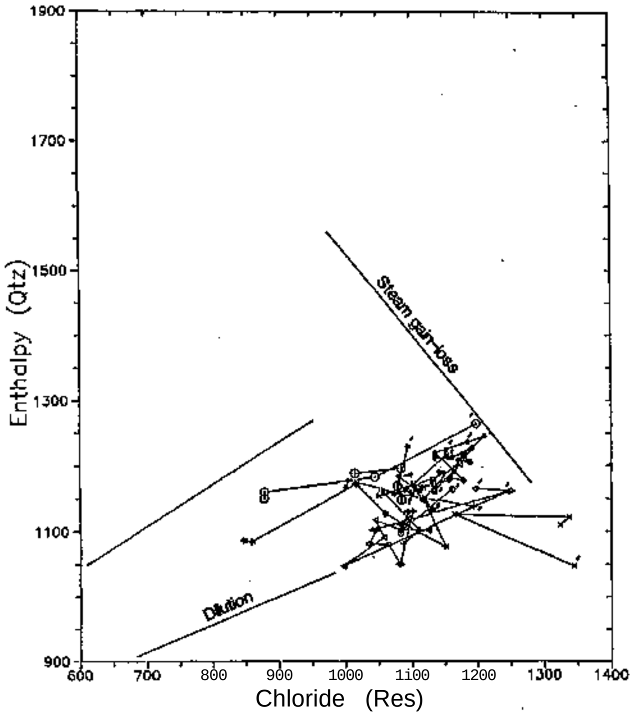

Figure 4: Enthalpy of quartz geothermometer versus the reservoir liquid chloride for all available West Bank production well samples since initial discharge (initial designated by tick marks).

This relative depletion in H_2S in the steam-heated waters may be caused by one or more of at least three processes: (1) H_2S is more soluble in the liquid being boiled such that CO_2 is enriched in the initial steam, and therefore will be enriched in the condensate; (2) H_2S is partly oxidised upon condensing into the steam-heated waters (elevated sulphates are noted, but not to the extent of producing acid conditions); (3) some of the H_2S is fixed as pyrite (iron sulphide is a common alteration mineral associated with the CO_2-rich steam-heated waters).

A 10 to 20% dilution of the production liquid by a steam-heated water with a (X^/H^S ratio of 300 and a CO_2 content similar to the production liquid would easily explain the trends in Figure 5. This would also conform to the dilution trends (well and magnitude) noted from enthalpy-chloride trends (Figure 3).

Steam Fraction Estimates from Gas Chemistry

Total discharge gas data have been used to calculate the log K of the reaction

$$CO_2 + 4H_2 = CH_4 + 2H_2O,$$

and this compared with the log K for equilibration at the reservoir temperature (reservoir temperature estimated by quartz and Na-K-Ca geothermometers). These data are plotted on the Giggegram of Figure 6. Where the apparent equilibrium is different from the reservoir temperature, the amount of steam lost (or gained) from the equilibrium state may be approximated. This departure from equilibrium is caused by the differential fractionation of gases into steam, which disturbs their relative proportions (as well as total amount) in the total discharge (Giggenbach, 1980).

Data lying below the equilibration curve indicate steam and gas loss from the formation, whereas data above indicate steam plus gas gain. The former is due to boiling, whereas the latter is due to steam gain, resulting in excess enthalpy of discharge.

The two wells with the largest log K are also noted to have the greatest degree of excess enthalpy; all other wells are close to or are at saturation. There is generally a 20 to 30°C spread between the quartz and Na-K-Ca geothermometer temperature, with quartz being the lowest. Using either geothermometer, the overall qualitative relationship is consistent with measured enthalpies. If the Na-K-Ca temperature is used as a reservoir maximum, a boiling curve projects back to the equilibration curve at about 300°C, suggesting this is a maximum temperature where steam loss is affecting the reservoir; it could be as low as about 275°C.

Monitoring of this parameter will allow a qualitative assessment of the degree of steam loss from the reservoir subsequent to commissioning. Comparing with 1976 data, as reported by Giggenbach (1980), two wells have had decreases in log K by two log units, consistent with approximately 1% steam loss in the formation of one of the wells, and the decrease in excess enthalpy noted for the other.

DOWNHOLE SAMPLING OF MONITOR WELLS

All monitor wells (Figure 1) were sampled at the end of 1987 by means of a Klyen downhole sampler modified to seal in gases; several reinjection and some production wells were also sampled. Samples were often collected at more than one depth to assist in interpretation of any production-related changes.

The results of some of the downhole sampling are shown in the inset of Figure 2, with trends from initial (often discharge) conditions shown, where available. Regular sampling of the monitor wells will assist in detecting changes in fluid chemistry (either dilution by steam-heated waters or returns of injected waters) before they reach production reservoirs, and may allow for modifications in reservoir management.

Sampling was conducted in static wells, closed from bleed for several months; these are the conditions under which monitor wells will be maintained during production. In contrast, many of the previous downhole samples (and all of the

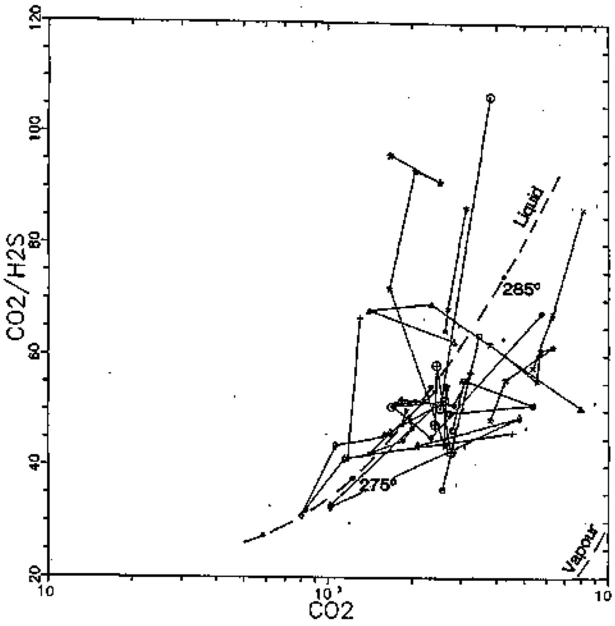

Figure 5: Total CO_2 versus CO_2/H_2S ratio for all available samples from West Bank production wells since initial discharge. The liquid and steam gas composition trends for equilibrium separation are shown, modelled on an assumed initial liquid composition at 280°C.

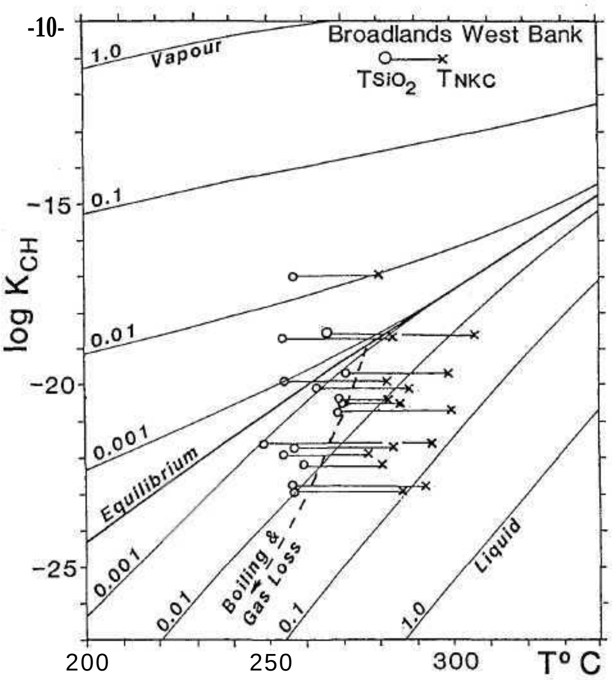

Figure 6: Equilibrium values for the $C0_2$-CH»-$H_?$ reaction plotted versus quartz and Na-K-Ca geothermometer temperatures, showing the effect of steam gain or loss on the equilibria of gases sampled from West Bank production wells. Most wells show a steam loss trend, except for two wells with large excess enthalpies, which show steam gain.

discharge samples) were taken under some form of flow in the well, making comparisons with present data difficult. However, again most changes (Figure 2, inset) follow dilution trends towards a steam-heated water.

DISCUSSION

The 1968 to 1971 long term discharge testing at Ohaaki-Broadlands produced a total of 33.6 million tonnes of fluid (Hitchcock and Bixley, 1976), while subsequent tests prior to 1988 brought this total to 57.5 million tonnes, of which 4.5 million tonnes (8%) has been reinjected. This total discharge over the past 19 years is equivalent to about two and a half years of the planned production, while the reinjection is equivalent to only four months of the future separated water.

Grant et al. (1983) reviewed the effects of the long term discharge testing, and noted a large pressure drop in the reservoir associated with this production. They estimated that during the pressure recovery after shutdown in 1971, approximately half of the discharged fluids were replaced by flow from the East Bank to the West Bank reservoir (of the 16 wells discharged during the long term test, all but two were located on the West Bank, hence the great majority of discharge and depressurisation originating in the West). However, Grant et al. (1983) also estimated that a further third of the discharge was replaced 'by downflow from the rhyolites above the reservoir^1, and 'most of the 10 million tonnes loss from the rhyolite was in turn made up by return of water disposed at surface^1.

Once the first and second stages of commissioning are complete, the drawdown and dilution of 1968 to 1971 can be expected to resume. A complicating factor to the dilution patterns in enthalpy-chloride (Figure 4) will be present if high chloride reinjected waters return to any of the production zones.

The reinjection scheme at Broadlands has been designed to reduce the potential for reinjection returns to the production zones. Interference tests in West Bank wells (McGuinness, 1985) has shown that the shallow permeable rhyolite which will receive much of the reinjected water (to the southwest) is not in good hydrological connection with the zone of production. However, the presence of steam-heated water in this reinjection zone is evidence for there being some degree of interconnectedness (perhaps only to vapour) with the production reservoir. The degree of permeability between the south and southeast reinjection wells with the East Bank production zone is not well known at present.

Dilution by steam-heated waters, even to very small degrees such that enthalpy-chloride changes are not clearly detected, should be identified by noticeable increases in CO_2/H_2S ratios without a corresponding total C0~ increase. Reinjection returns will show up as a mirror image trend to dilution, in that they will be very high in chloride but also about 155°C (the reinjection temperature); reheating of reinjected waters in the formation may produce a buffered trend of increasing chloride with little enthalpy decrease.

A combination of steam-heated water dilution and reinjection return may largely cancel each other in terms of chloride balance. However, in this situation an increase in the COn/H^S of production fluids from the affected reservoir should indicate the presence of dilution. Returns of high chloride reinjected water in conjunction with an enthalpy decline may be seen as a trend related to steam loss. Some thermal buffering of the reinjected water by the formation should result in trends distinct from those due to steam loss.

CONCLUSIONS

At present the baseline of the West Bank production zone and the marginal reinjection and monitor zones is well established; that for the East Bank is reasonably understood, and will soon be confirmed through discharge testing. Any changes in production fluid chemistry subsequent to commissioning should be readily identified through the planned monitoring programme.

However, despite the predictions of possible changes, a rigorous understanding of how the reservoir will react to production and reinjection, and the factors that will indicate this reaction, will only be fully appreciated once the system has been in production for some time. During this period of learning it will be necessary to assess over short periods of time reservoir changes and related indicators so that reservoir management may be as interactive as possible.

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The rest of this page is for the taking of copious notes.