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# FLUID CHEMISTRY OF THE NGAWHA RESERVOIR

D. S. Sheppard

Chemistry Division
DSIR, Petone

## ABSTRACT

Analyses of fluids discharged from ten deep wells at Ngawha showed that the wells sampled a fluid which was compositionally rather uniform in all but gas component concentrations. Small variations in water chemistry indicate that waters are diluted in the east of the field and that higher level fluids leak into some wells during discharge. Solute geothermometers reflect the temperature measured in the production zones; higher temperatures (300°C) are indicated by gas ratios, and have been verified by measured temperatures in the deep well NG13. Calcite precipitation in flashing wells may be a problem during exploitation, expecially in wells with a lower gas content.

## INTRODUCTION

The postponement of the Ngawha Project development in 1983 has enabled a review of data obtained so far from geochemical studies. Sheppard and Lyon (1981) published a progress report, unpublished reports on well discharge fluid compositions have been written by Giggenbach and Sheppard (1980) and Sheppard (1982). A compilation of all known fluid chemical analyses from the Ngawha area is in press (Sheppard, Giggenbach and Johnston). A more comprehensive presentation and discussion of the data is available in Sheppard and Giggenbach (in press).

The physical measurements taken from the wells in Table 1 and the chemical compositions listed in Tables 2 and 3 allow a more or less typical discharge for each well to be calculated, although this data is available in the publications listed above. The fluid enthalpy used to calculate the values in Table 2 is taken to be that for pure water at the feed zone temperature, this being a more consistent approximation than any other available.

## WATER COMPOSITION

The fluid compositions presented in Table 2 show little variation, except in gas content, although a small variation in chloride and boron content and temperatures at the feed zones shows a dilution through to the east (wells NG18, NG8). This is illustrated in Figure 1, as contours, and in Figure 2 as profiles. Water isotope composition of the waters also shows a dilution of deep fluid with local groundwaters, in the wells NG18 and NG8.

Enhanced Mg contents were observed at times in the wells NG2, NG4, NG8, NG12 and NG13. This is a small effect (indeed, it was only noticed as a result of the divergence of the silica and K/Mg (Giggenbach, et al, 1983) geothermometer temperature) but in NG12 corresponds to the addition of up to 5% of water containing 2 mg/kg Mg. This effect is surprising for this well as it is cased to within 30m of the well bottom, but it appears that as the discharge progressed and wellhead pressure lowered, a high Mg (and Ca) water was drawn into the well (Figure 3).

|  | Depth<br>m | Cased Depth<br>m | $T_{Max}$<br>°C | $T_D$<br>°C | Feed Depth<br>m |
|---|---|---|---|---|---|
| Ng1 | 590 | - | - | - | - |
| Ng2 | 1234 | 535 | 236 | 229 | 840 |
| Ng3 | 1461 | 563 | 230 | 224 | 840 |
| Ng4 | 1343 | 618 | 239 | 224 | (740)<br>1240 |
| Ng5 | 1280 | 653 | 248 | - | - |
| Ng7 | 1316 | 644 | 189 | - | - |
| Ng8 | 1189 | 540 | 217 | 209 | 900 |
| Ng9 |  |  |  |  |  |
| Shallow | 712 | 590 | 244 | 228 | 670 |
| Deep | 1000 | 857 | 228 | - | 940,970 |
| Ng11 | 1208 | 696 | 225 | 225 | 950 |
| Ng12 | 657 | 626 | 230 | 228 | 626 |
| Ng13 | 2300 | 955 | 301 | 226 | 960 |
| Ng18 | 1330 | 625 | 250 | 220 | 800 |
| Ng20 | 1634 | 492 | 240 | - | - |

Table 1: Details of the deep wells, from Ministry of Works and Development well logs. $T_{MAX}$ - maximum measured temperature. $T_D$ - Discharging temperature of feed zone.

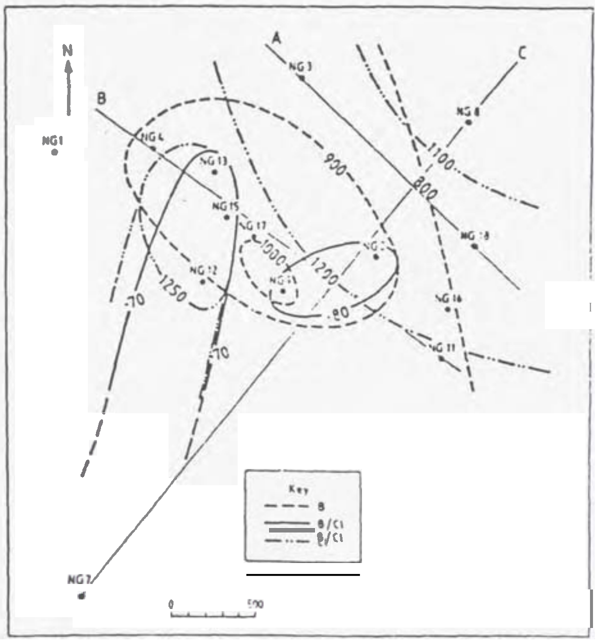


Figure 1: Contours of B, B/Cl and Cl content of fluids at the principal feed zones for the wells. The lines A, B and C indicate the positions of the profiles in Figure 2. Concentrations in mg/kg, total discharge.

| Well | pH | Li | Na | K | Rb | Cs | Mg | Ca | $NH_3$ | $SiO_2$ | B | F | Cl | $SO_4$ | $HCO_3$ | $\delta^{18}O$ ‰ | $\delta D$ ‰ | $CO_2$ Wt % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | mg/kg | | | | | | | | SMOW | | |
| Ng1 | - | 7.5 | 539 | 40 | .46 | .23 | - | - | 84 | 219 | 616 | - | 906 | 18 | 257 | | | |
| Ng2 | 5.6 | 9.8 | 843 | 64 | .29 | .68 | .14 | 2.0 | 188 | 365 | 985 | 1.8 | 1151 | 21 | 239 | 5.57 | -36.7 | 1.63 |
| Ng3 | 5.6 | 9.7 | 854 | 65 | .24 | .55 | .04 | 3.4 | 145 | 370 | 862 | 1.6 | 1179 | 29 | 318 | 5.11 | -37.1 | 1.54 |
| Ng4 | 5.7 | 11.7 | 891 | 77 | .27 | .65 | .09 | 2.5 | 111 | 399 | 929 | 1.8 | 1260 | 40 | 271 | 5.8 | -35 | .85 |
| Ng8 | 5.6 | 9.5 | 762 | 69 | .29 | .66 | .40 | 6.8 | 222 | 363 | 762 | 1.4 | 1054 | 28 | 394 | 4.7 | -35 | 1.39 |
| Ng9S | 5.9 | 10.9 | 890 | 76 | .34 | .78 | .07 | 3.3 | 199 | 455 | 846 | 1.9 | 1229 | 17 | 338 | 5.87 | -35.8 | .88 |
| Ng9D | 5.7 | 10.6 | 873 | 75 | .32 | .75 | .08 | 2.2 | 230 | 433 | 1026 | 2.1 | 1241 | 27 | 327 | 5.89 | -36.1 | 1.09 |
| Ng11 | 5.8 | 10.4 | 876 | 78 | .31 | .73 | .13 | 2.5 | 100 | 394 | 877 | 1.5 | 1211 | 25 | 458 | 5.58 | -36.5 | 1.23 |
| Ng12 | 5.8 | 10.7 | 897 | 78 | .26 | .79 | .09 | 2.7 | 132 | 378 | 889 | 2.6 | 1283 | | 329 | 5.77 | -35.9 | 1.16 |
| Ng13 | 5.7 | 9.4 | 881 | 69 | .24 | .78 | .15 | 3.3 | 148 | 405 | 854 | | 1257 | 15 | 393 | 5.39 | -36.6 | 1.74 |
| Ng18 | 5.3 | 9.7 | 818 | 69 | .26 | .64 | .16 | 5.4 | 293 | 357 | 844 | 1.1 | 1155 | 29 | 258 | 4.84 | -36.1 | 2.37 |

Table 2: Total discharge compositions of fluids from Ngawha wells. pH is the reservoir pH, and $HCO_3$ is $HCO_3$ in the reservoir, both calculated by routines in GEODATA.

| Well No | $CO_2$ | $H_2S$ | $NH_3$ | He | $H_2$ | Ar | $O_2$ | $N_2$ | $CH_4$ |
|---|---|---|---|---|---|---|---|---|---|
| Ng1 | 939 | 7.0 | .647 | - | 5.0 | - | <10 | 10 | 39 |
| Ng2 | 945 | 7.64 | 14.5 | .0066 | 2.92 | - | .014 | 7.89 | 22.4 |
| Ng3 | 948 | 8.10 | 7.2 | .0033 | 3.69 | .009 | <.002 | 4.02 | 29.1 |
| Ng4 | 948 | 10.5 | 9.0 | .004 | 2.81 | .002 | <.002 | 2.5 | 27.6 |
| Ng8 | 949 | 7.48 | 12.1 | .0051 | 3.65 | - | <.002 | 2.87 | 25.3 |
| Ng9 | 947 | 10.5 | 16.2 | .004 | 2.95 | - | <.001 | 1.78 | 21.5 |
| Ng9 | 943 | 10.3 | 15.2 | .004 | 3.49 | - | <.002 | 2.40 | 25.6 |
| Ng11 | 961 | 13.4 | 3.3 | .004 | 2.02 | .0052 | <.002 | 1.94 | 18.0 |
| Ng12 | 963 | 9.67 | 5.4 | .0025 | 2.62 | .008 | .002 | 2.05 | 17.6 |
| Ng13 | 961 | 8.65 | 5.1 | .0025 | 2.92 | .014 | <.005 | 2.97 | 19.5 |
| Ng18 | 935 | 6.86 | 7.4 | .0090 | 7.09 | - | <.028 | 4.66 | 38.8 |

Table 3: Gas composition of selected steam samples from wells, mmol/mol, dry gas.

system at the, reservoir temperatures, probably more rapidly than silica so the Mg is probably entering the well very close to the feed, or through the casing.

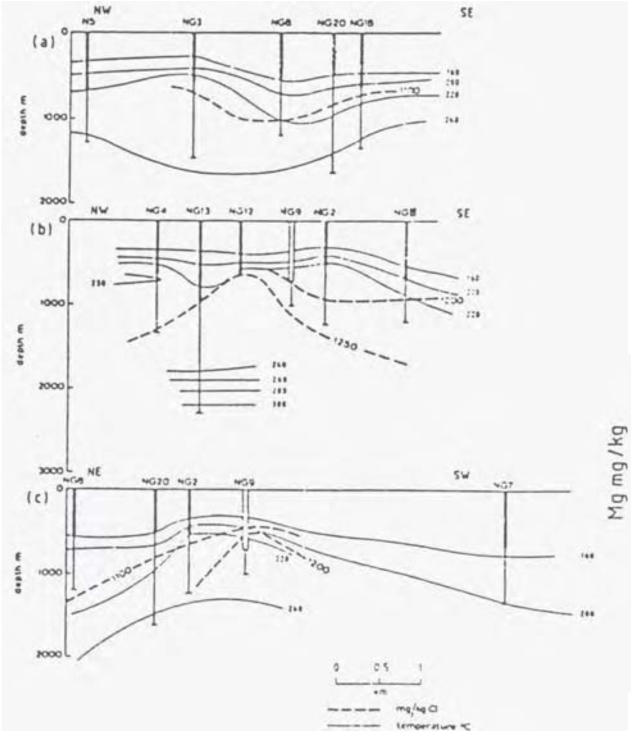


Figure 2: Profiles of chloride in total discharges from well feed zones, and standing well temperatures. (a) (b) and (c) sections are indicated as A B and C in Figure 1. The wells are projected onto the plane of the profile.

## GASES

Giggenbach (1980) has derived a series of equations for deducing from analytical data the dependance of gas compositions on temperature and vapour gain or loss. The calculated values for Ngawha well fluids (Figure 4) show a consistent grouping which indicates that the gases were last in equilibrium at around 300°C (average values of ~295°C for nitrogen species reactions, ~305°C for methane reactions), and that these gases have been added to the sampled reservoir subsequent to equilibration.

The high $CO_2$ and high B content of the fluid has consequences with regard propensity to deposit calcite in the wells upon flashing, since both form weak acids and interact to control pH, a primary control on calcite deposition through the reactions:

$$H_2O + CO_3 \overset{Ca}{\rightleftarrows} CaCO_3 \downarrow$$

$$\begin{array}{ccc} CO_2(g) & & -H^+ \ \uparrow\downarrow \\ \uparrow\downarrow & & \\ H_2O + CO_2(aq) + H_2BO_3^- & \rightleftarrows & HCO_3^- + H_3BO_3 \end{array}$$

The presence of borate moderates the loss of $HCO_3^-$ and $CO_3^=$ upon flash, holding the ionic product of Ca and $CO_3^=$ higher than might be expected if no borate was present, thus increasing the propensity of calcite to precipitate. As Figure 5 shows, this is the dominant effect at higher temperature flashing. Lower temperature flashing results in a

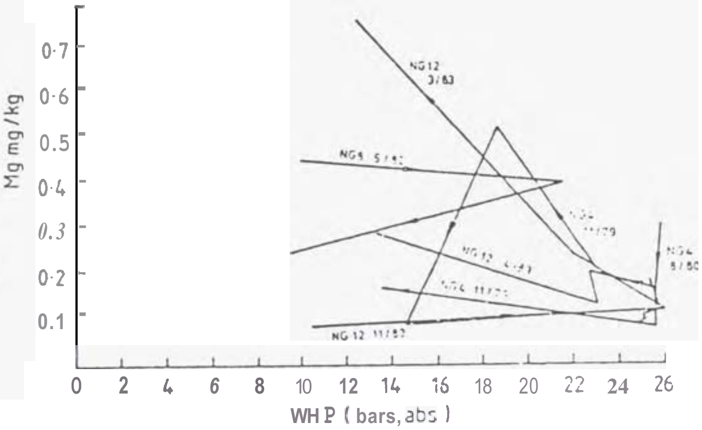


Figure 3: Variation of Mg content of total discharge fluid with well head pressure during discharge tests.

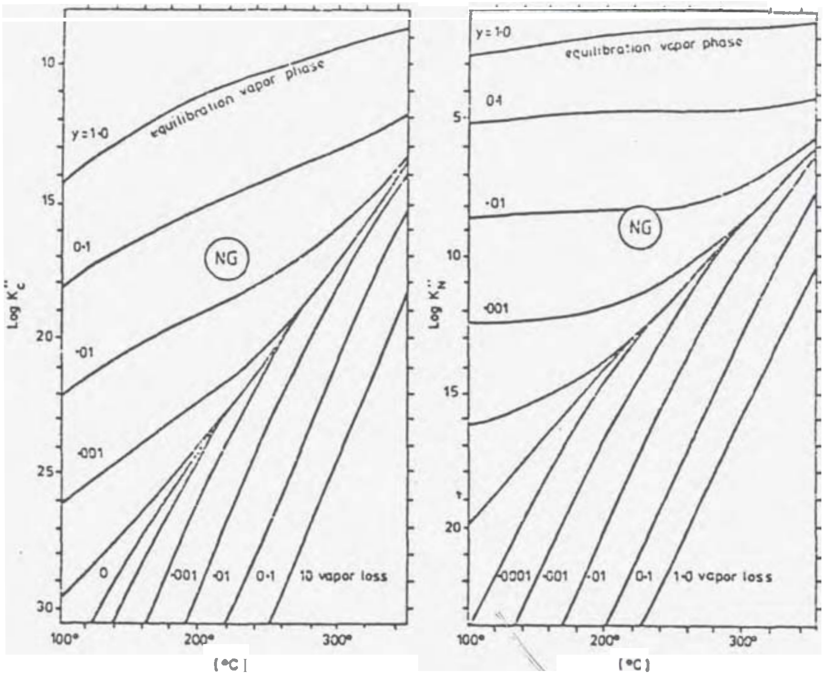


Figure 4: Log $K''_C$ and log $K''_N$, the equilibrium constants for the reactions $CH_4 + 2H_2O \rightleftarrows CO_2 + 4H_2$ and $2NH_3 \rightleftarrows N_2 + 3H_2$ respectively, plotted as a function of temperature (Giggenbach, 1980). Ngawha well compositions and reservoir silica temperatures are indicated, showing the higher temperature origin, and gain of vapour by the sampled reservoir.

reversal of this effect. The degree of saturation of calcite is an inverse function of the total $CO_2$ content, a result of smaller $CO_3^=$ losses due to less $CO_2$ being lost from solution.

## WATER ISOTOPES

The isotopic composition of the water within the sampled aquifer is very uniform at $\delta^{18}O = +5.7‰$, $\delta D = -369$ (Fig.5). Local groundwater composition is taken to be $\delta^{18}O = -5.5‰$, $\delta D = -31‰$. The large (11‰) $\delta^{18}O$ shift from local groundwater has been attributed to a limited interaction of the waters with rock, and/or a young age for the system: perhaps the water is not derived from local meteoric water, but from dewatering of the underlying metamorphosed sediments. Such an explanation might provide for some puzzling geochemical problems, e.g. the large $\delta^{18}O$ shift, the high boron and $CO_2$ content, the high $Ar^{40}/Ar^{36}$. $\delta D$ in the total discharge fluid is 590 lighter than the .local meteoric water; this shift also encourages a search for an alternative source for the water.

## DISCUSSION

There are many aspects of the chemistry of the Ngawha fluids which require further research. The preceding presentation shows some of the conclusions and problems thrown up by the programme to date. It seems that dilution occurs in the east: is this a shallow recharge? Giggenbach and Sheppard (1980) predicted 300° temperatures below the known reservoir; this has been confirmed by the deep well NG13 although no fluid from that depth was sampled. An investigation into the source of the boron and $CO_2$ might well be of value, for any exploitation of the field that results in variation in these will affect the calciting propensity of the wells. A realistic model of the field has yet to be developed: where is the recharge, if any; why is there a relative homogeneity of dissolved species but not gas content within the reservoir; what is the likely composition of the 300° fluid, if it exists; and so on. The Ngawha field is truly chemically fascinating, and its similarities to the Sulphur Bank/Geysers and Larderello systems may indicate a very rewarding economic prospect.

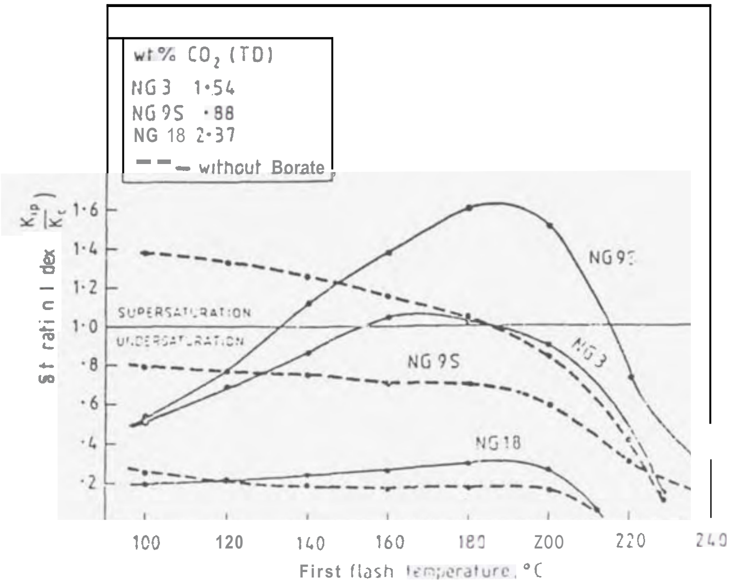
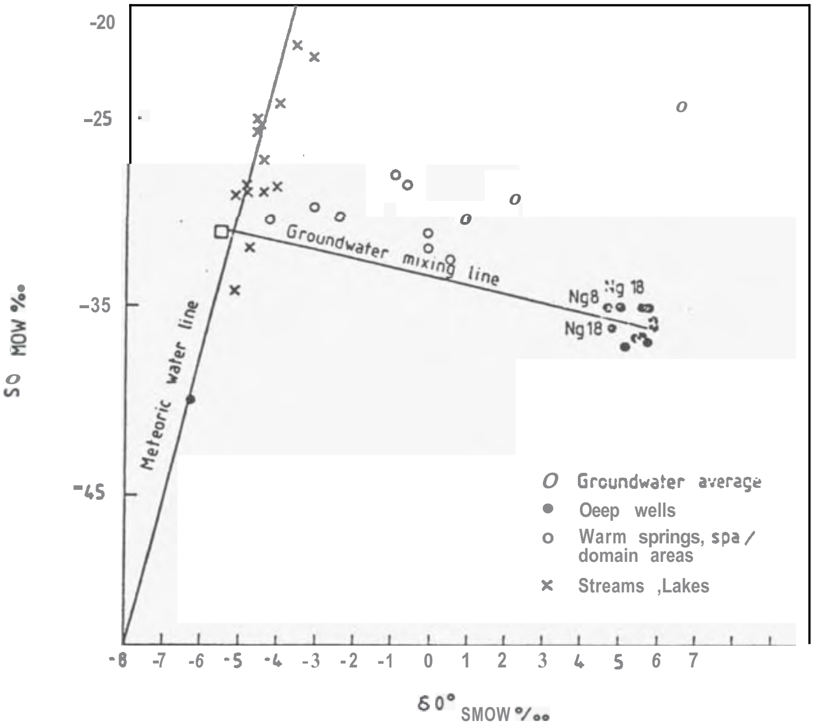


Figure 5: Plot of $K_{ip}/K_c$, against the first flash temperature for three Ngawha wells. $K_{ip}$ is the product $a_{Ca}\cdot a^{2}_{HCO_3^{w}}/P_{CO_2}$, $K_c$ is the solubility product of calcite, calculated by the GEODATA routine, (Palmer, 1976, and updates) and DOWNHOLE (Truesdell and Singers, 1971, and updates), and the FLASH routine contained with GEODATA (Singers, W.A., Giggenbach, W.F., and Henley, R.W. in preparation). Broken lines show saturation index for a fluid from the three wells, but containing no boron.

Figure 6: Water isotope composition for Ngawha wall waters, springs and surface waters.



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