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THE ROLE OF THE TE MIHI UPFLOW AT WAIRAKEI

K.J. Youngman

Hiruzen Research Institute
Okayama University of Science, 1-1 Ridai-cho, Okayama 700, Japan

Abstract

Evidence obtained from the discharge chemistry of wells in the western Wairakei borefield during the period 1964 to 1969 indicate that they draw their supply of hot fluid from the east in the region of the Uaiora fault and not from the Te Mihi area to the west as previously supposed. Lateral flow of fluid from the Waiora fault towards wells to the west of the Waiora fault results in a pressure loss of 3-4 bars at those wells compared to wells that are located on the Waiora fault itself.

Introduction

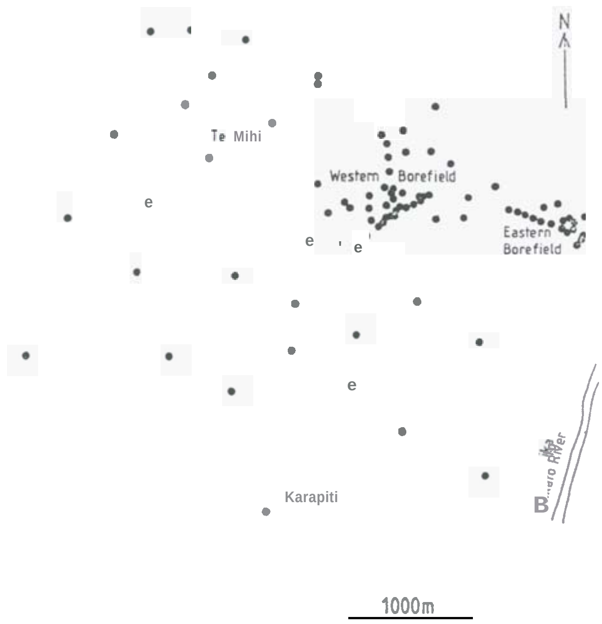
The Wairakei geothermal borefield has always been subdivided into a number of different geographic sectors, the most common subdivision has been into the eastern borefield, the western or main borefield, and the Te Mihi area (Figure 1). It is in the western borefield along an alignment called the Waiora fault that the largest concentration of wells in the Wairakei field occurs (Figure 3a). Evidence of this alignment is easily seen in early maps of the geothermal field (Grange 1955, Studt 1958) as an intermittent series of elongated zones of steaming and altered ground.

The original rational for placing wells along this particular alignment was that greatest production occurred from wells that successfully intersected fluid ascending the permeable structure of these fault fissures (Grindley 1965). A rational that has been supported by more than 30 years of commercial production from this zone.

More recently, however, it has been suggested that the Te Mihi area to the west of the main borefield may be the origin of the fluid that is intersected at the Waiora fault and that fluid moves laterally eastwards from a principal upflow at Te Mihi towards the western borefield. This inference is based upon evidence of higher well pressures and temperatures at Te Mihi compared to those of the western borefield.

Grant (1982) in a review of the historic physical data sought to describe the origin of the recharge to the Wairakei reservoir. He inferred, from steam and liquid zone temperatures and from the pattern of upflows and downflows in wells, that the location of the recharge to the western borefield was to the northeast at Te Mihi. Similarly, Brown et al. (1988), in a review of the historic discharge chemistry, inferred, on the basis of highest well temperatures, that the principal upflow was also to the west of the present production borefield.

The interpretation of a major upflow to the west of the main borefield must, however, be tempered with the reservation expressed by Grindley (1986) that the maintenance of of local pressures and temperatures at Te Mihi might, in fact. only reflect the absence of sustained local production there. Indeed, the concentration of production in only one section of the field makes sucn comparative analyses very difficult and. therefore. other methods must be examined in the hope of obtaining a less equivocal result.



Wairakei Geothermal Borefield

Figure 1. Location map of the bores drilled at the Wairakei geothermal field.

If the principal upflow is indeed at Te Mihi with lateral outflow towards the western borefield, then some expression of this might be expected in the characteristics of the well discharge chemistry or well performance at the western borefield. As it has been interpreted that the hottest wells lie to the west of the main borefield then, as a first assumption, it might be expected that within the main borefield discharge temperatures will increase towards the west.

The first indication that there may indeed be some variation in temperature across the western borefield was the appearance of a systematic trend in the difference between the silica geothermometer and the sodium/potassium geothermometer values obtained for various bore discharge histories. However, this requires a large amount of data for each bore, and a more simple demonstration can be achieved by using the silica geothermometer alone. As this requires less data per bore, it allows more bores to be considered and is. therefore. more indicative of field wide changes. This paper examines the evidence for the existence of an upflow at Te Mihi based upon silica geothermometry and offers a new interpretation that is consistent with the data.

Method

With over 30 years of fluid discharge chemistry available for Wairakei (Henley et al. 1984) care must be taken to reduce the data to meaningful sets. In this analysis only wells in the western borefield have been considered and only during the period 1964-1969. This time frame was chosen because it includes the period of greatest pressure drop at Wairakei from when the first reliable silica data are available until just before dilution begins to increase substantially and complicates the matter.

Between 1964 and 1969 a series of field-wide surveys were carried out on the silica contents of the well discharges at Wairakei (Mahon 1964. 1965, 1966. 1969). This followed the finding that the silica content in the fluid was controlled by saturation with respect to quartz and that equilibrium was sufficiently fast that the silica content accurately indicated the temperature of the bore fluid (Mahon 1964). Three of these four surveys, 1965, 1966, and 1969, provide the basis for examining changes in the well temperatures during this early period of exploitation.

The silica temperatures of Mahon were originally corrected graphically for additional steam entrainment, or so called "excess enthalpy", and thus the reported silica temperatures take into account the effects of additional steam. In addition, the chloride concentrations in the well discharges at the surface for 1969 have here been recalculated back to downhole concentrations iteratively using the silica geothermometer of Fournier and Potter (1982) and the measured well discharge enthalpy. This also accounts for the effects of additional steam entrainment.

The resultant chloride data have been presented in terms of the amount of pure water dilution that must have occurred at the silica geothermometer temperature to reduce the chloride concentration in the fluid from the original western borefield value to the present one. The original borefield concentration used here is that of Youngman (1989) which is derived for any temperature by adiabatic expansion from a value of 1595mg/kg Cl^- at 255°C.

Table 1. Western Borefield Well Data

Well No.	Well depth[a] (m rsl)	Casing depth: (m rsl)	Silica Temp. (°C) 1964[b]	1965[c]	1969[d]	% Dil.	Relativt Press. (bars)
Waiora Fault Wells							
28	-186	-23	252	249	244	4.5	2
88	-229	-53	250	249	247	4.4	0
86	-222	-14	241		240		5
46	-229	-90	245	244	242	2.2	3
83	-243	-53	249	245	245	4.2	2
82					243	4.5	3
72	-210	-67	251	249	244	5.2	2
30	-273	-50	250	246	242	5.8	3
71	-255	-69	250	246	242	5.3	3
70				244	242	5.7	3
48	-812	-145	250	244	240	4.8	5
68	-249	-56			238	5.2	6
67	-261	-67	250	249	243	5.5	3
27	-208	-19	248	248	243	6.8	3
66	-218	-218	247	2G4	243	6.5	3
ai	-186	-79	250	246	243	9.5	3
55	-268	-79	248	244	241	8.4	4
Non-Waiora Fault Wells							
78	-239	-66	237				
80	-241	169	230	220	202	29	
74	-295	-76	241	244	242	0	3
47	-287	-184	251	242	238	0.4	6
22	-19s	-63	240	237	233	7.4	8
107	-224	143	241	240	238	4.7	6
108	-224	108		239	238	5.9	6
24	-407	79	247	246	243	8.1	3
29	-247	48	245				
109					212	13	
26A			248	242	237	4.4	6
76	-210	-33	249	240	236	3.9	7
268			248	242	237	3.0	6
101	-258	84		230			
50	-240	-22	246	242	238		6
103				239	238	1.2	6
57	-233	11	241	239	235	5.3	7
118				246	170	77	
116					239	0.7	5
105	-216	73		239	239	1.1	5
56	-21/	-43	251	239	231	13	
44	-275	-106	247	243	243	1.7	3
92	-249	-67	245	239	232	2.7	9

a, Healy 1984
b, Mahon 1964 c. Mahon 1965 d. Mahon 1969

Evidence from the Discharging Wells

Data for 39 western borefield wells (Figure 3a) are available (Table 1) and although not all wells provide data for all periods, it was felt that it was best to use as large a sample as possible. The borefield has been divided into two groups, one group consists of all available wells on the Waiora fault and the other group consists of all other available western borefield wells that are off the fault.

Probably the most effective way to present the silica temperatures in the western borefield is as simple histograms (Figure 2a,b,c). The actual rrequency of samples in any one class is probablv not of great importance'because well siting is not a random process. however, the range of values for a particular area is important.

This simple analysis shows that in 1964 temperatures ranged from 240 to 252°C across the western borefield with no apparent differentiation between values for wells on the Waiora fault and those for wells off the fault. However, just one pear later, in 1965, it is apparent that the temperature distribution has changed

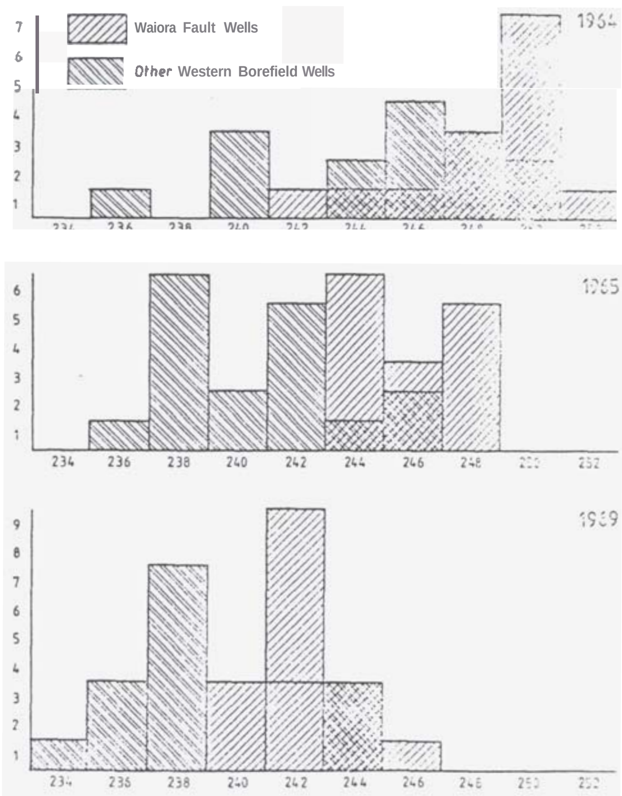


Figure 2 (a.b.c) Histograms or silica temperature distribution for the years 1964. 1965, & 1969 respectivelp at the western borefield.

significantly. Not only has the temperature dropped for all wells in the western borefield, in response to pressure drawdown across the field (Bolton 1970). but temperatures have dropped at a faster rate in wells to the west of the Waiora fault than those wells on the Waiora fault.

By 1965 there are two distinct temperature distributions for the two areas of concern. wells to the west that are off the Waiora fault have become cooler than wells on the fault. This differential cooling was recognised at the time by Mahon (1965) who noted that during the preceding year temperatures had decreased along the Wairakei fault to a greater extent than they had along the Waiora fault.

By 1969 the temperatures across the western borefield had dropped even further, but the two areas still remained as distinctly separate temperature distributions. The spatial relationships of the temperatures in 1969 are also shown (Figure 3b).

It would appear from this simple data that during the early years of pressure drawdown the temperature distribution of the western borefield was relatively uniform, however, as production proceeded fluids west of the Waiora fault cooled and remained cooler than fluids at the Waiora fault. The distribution of these temperatures across the borefield indicates that the lowest temperatures extend far from the Waiora fault.

The occurrence of the coolest wells to the west, closest to Te Mihi, is opposite to the expected result assuming an upflow exists to the west at Te Mihi and a number of possible explanations must be investigated in order to explain it. In fact, there are three possible explanations for the lower temperatures west of the Waiora fault. The first is that the wells there might be more shallow and thus tap a more shallow and cooler fluid. Unfortunately, an examination of the distribution of well depths (Healy 1984a) of the two areas shows that this is not the case. With the exception of well WK24, a deep well to the west, the wells off the fault are as evenly distributed between -180m and -300m rsl as are those on the Waiora fault. Thus the possible occurrence of shallow wells to the west of the Waiora fault can not be used to explain the lower temperatures there.

Secondly it might be argued that the cooling is the result of the influx of cold groundwaters into the system, however, it would appear from the values for relative dilution across the system (Figure 3c) that many of the cooler western-most wells such as WK116, 105, 103, 26B, 74, & 47 are, in fact, less dilute than wells on the Waiora fault. This implies that lower temperatures to the west cannot be ascribed to the affects of cold water dilution.

Neither of these first two alternative suggestions seem to account for the lower temperatures to the west of the Waiora fault. The only other alternative is that the vertical permeability, and therefore the fluid flux, below wells to the west, and off the Waiora fault, is lower than those on the Waiora fault itself. Thus, there is insufficient fluid available for the number of wells in operation there and this manifests itself as lower saturation pressures in these wells. Furthermore, given the high lateral permeability across the western borefield (Bolton 1970) and the lower relative saturation pressures to the west it would seem most likely that the hotter fluid ascending the Waiora fault is drawn off laterally to the west.

In any case it can be demonstrated that there are no hotter wells on the western side of the western borefield. neither is there any demonstrable flow from Te Mihi to the western borefield. In fact, given that the lowest saturation pressures must also exist to the west, flow can be expected to be in the opposite direction. The Te Mihi upflow is, therefore. not the source of fluid for the western borefield, and the very existence of the Te Mihi upflow as the source of any significant fluid flow must be seriouslv doubted. It is undoubted that the Waiora fault is the major upflow at the western borefield and in all probability the whole of the field, therefore, it is worthwhile to reiterate that it has been the source of commercial production for more than 30 years.

Discussion

The prospect that fluid must flow under the influence of a pressure differential away from the Waiora fault towards the west raises some important points. The saturation pressure differences relative to the hottest well in the borefield during the 1969 survey, WK88, are given (Figure 3d). The implication is that fluid flowing across from the Waiora fault to the west must lose steam as it does so.

The steam zone at Wairakei is the result of four possible processes, the first is simply the void left by the receding liquid zone, the second is due to the additional steam rising off the increase in hot recharge, the third is the increasing distance of the boiling front away from the well, and the forth is the steam formed dynamically as a unique result of the position of the wells at Wairakei in relation to the upflow. It would seem that the expansion of the steam zone into previously cooler areas (Grant 1982) may have been, in part, a consequence of vapour loss from the deep reservoir during lateral migration of fluid from the Waiora fault to the west.

The loss of steam from the upflow may not appear. in the first instance, to be of much economic importance as a significant proportion of it will eventuallv be utilised by more recent wells that tap into the steam zone, albeit a much lower grade resource. Of more importance, however, is the pressure loss that wells in the west experience as a result of the steam loss. Given that the fluid reaching Waiora fault wells in 1969 had a temperature of about 244°C and the wells to the west of the Waiora fault had temperatures of 236-238°C, then it appears that each well west of the Waiora fault has a pressure loss of 3-4 bars due to lateral migration of the fluid through the country rock. Well pressure decline is an important consideration in the operation of the Wairakei power station (Grant and Horne 1980, Stacey and Thain 1983) and it would appear that well positions west of the Waiora fault suffer an additional pressure loss due to their location.

Although a westward flow from the Waiora fault out into the western borefield seems most likely, this is at first appearance contrary to the results obtained in 1979 from isotope tracer studies (McCabe et al. 1983) and it needs to be addressed. In the isotopic tracer study, tracer was placed down well WK107 to the west of the Waiora fault and returns were detected from this well after 4-5 days in wells WK 66, 67. 48, 70, & 30 on the Waiora fault. The indicated flow direction from the tracer results is west to east. the opposite to the inference from the discharging well chemistry which is from east to west.

An eastward flow direction is, however, consistent with the interpretation of Healy (1984a,b) and Youngman (1989) for the existence of the lateral inflow of cold water from the periphery of the field eastwards towards the main borefield. It seems most likely that the tracer returns which indicate an eastward flow are, for the most part, simply entering the cold water aquifers that are known to exist under the field and flow in towards the main upflow to cause the dilution that is observed along the Waiora fault.

Conclusions

Maintenance of temperatures and pressures at Te Mihi is, at best, equivocal evidence of an upflow at Te Mihi and the only real indication of the relative importance of the fluids from each area is in the chemistry of the western borefield discharges. Here it can be shown that silica temperatures and consequently saturation pressures of wells to the west of the Waiora fault are lower than those wells that

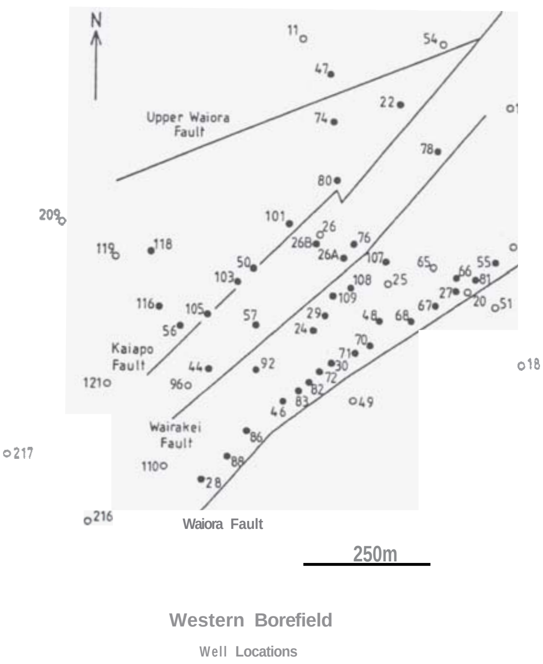


Figure 3a Map of well locations in the western borefield of the Wairakei geothermal system. Approximate fault locations are drawn from Grindley ***(1965)****.*

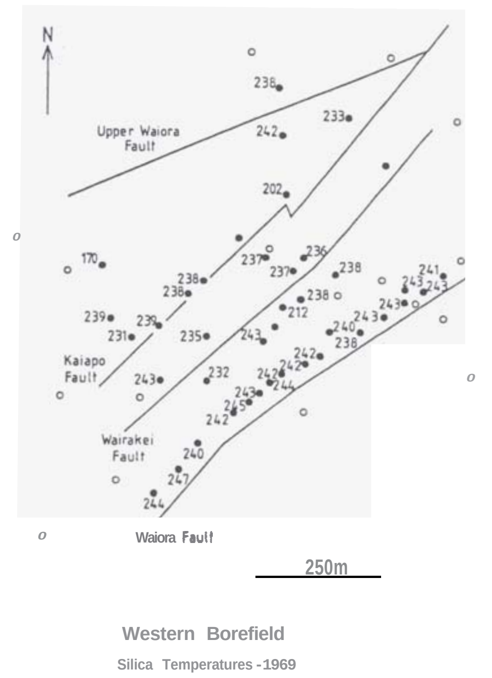


Figure 3b Map of silica geothermometer temperatures for well discharge fluids from the data of Mahon ***(1969)****.*

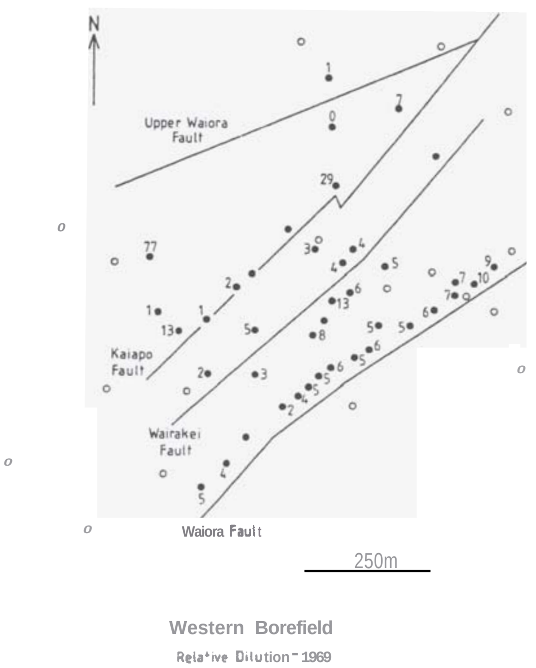


Figure 3c Hap of relative dilution for the western borefield calculated as the difference between well chloride concentrations and the initial chloride concentration for the unexploited system.

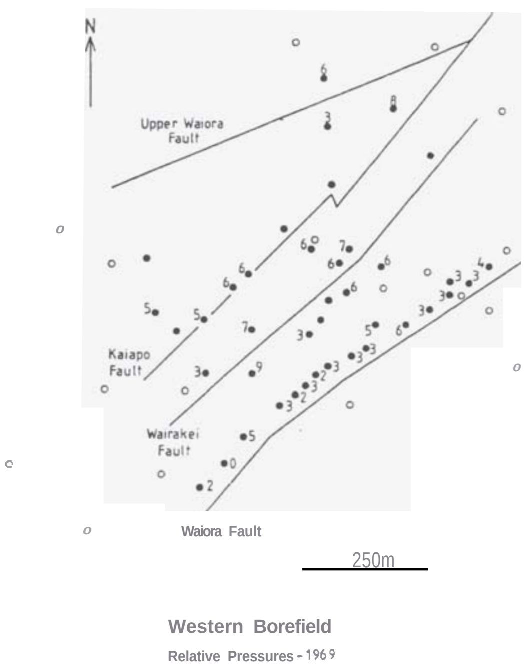


Figure 3d Map of relative pressures. calculated as the dirference in saturation pressures (bars) between individual wells and the highest temperature well WK88.

occur on the Waiora fault. It is, therefore, concluded that there is a mass flow from the Waiora fault westwards to other wells in the western borefield. Tnis is the opposite direction to a fluid derived from Te Mihi and thus we must conclude that the Te Mihi upflow has little or no role in the hydrology of the western borefield. Furthermore, fluids flowing off the Waiora fault in response to the lower pressure to the west lose 3-4 bars of pressure in the process.

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