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TAUHARA FIELD - TWO GEOTHERMAL SYSTEMS?

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ABSTRACT

Although the four deep wells in the Tauhara Field indicate over 15 bar of drawdown due to exploitation of Wairakei Field, there have been no significant thermal or chemical changes to surface features on the south side of the Tauhara Field. The extent and concentration of chloride outflows in the Waipahihi seepage zone along the shores of Lake Taupo do not appear to have changed since the drawdown began in the late 1950s and 1960s. The absence of significant changes to the south contrasts with the disappearance of chloride outflows along the banks of the Waikato River and increased steam-heating of groundwaters on the northern half of Tauhara Field. These differences suggest the southern side of Tauhara Field has not been drawn down and therefore may be considered as a separate geothermal system. Subsidence trends are consistent with this interpretation.

INTRODUCTION

The effects of the exploitation of Wairakei Field on the adjacent Tauhara Field are well documented. Pressures were found to be decreasing rapidly when the first deep well was drilled in Tauhara Field in the early 1960s. Later analysis of the pressure changes, and comparisons with the original maximum elevation of chloride waters in the field, suggested that the original pressure regimes in Wairakei and Tauhara Fields were very similar (Allis, 1983). The total pressure decline at 1 km depth in the early 1980s was estimated to be around 18 bars in Tauhara Field compared to around 25 bars in Wairakei Field. Most of the drawdown at Tauhara Field has been confined beneath the relatively impermeable Huka mudstone units, which are providing a cap to a steam zone in the hotter parts of the field. The drawdown of the deep chloride reservoir has meant that shallow aquifers are no longer being charged with chloride-rich water. In particular, the previously intermittent geyser and hot spring activity in the Spa Sights thermal area along the banks of the Waikato River has dried up, and decreases in the chloride content of some shallow thermal groundwater wells have occurred (Allis, 1983). Concomitant increases in steam-heated thermal activity and increases in groundwater temperatures have also occurred (Figure 1). A published review of the chemical characteristics of fluids in Tauhara Field is given by Henley and Stewart (1983). Wooding (1981) has modelled the pressure response of the deep wells to fluid extraction from the Wairakei borefield; and Donaldson (1982) has published an overview of all the abovementioned papers.

In 1987, the Waikato Valley Authority commissioned the D.S.I.R. to carry out an integrated review of the response of Tauhara Field to exploitation (D.S.I.R., 1988). Although most of the data discussed in the report belongs to the D.S.I.R., the report as a whole is confidential to the W.V.A. (now the Waikato Catchment Board). The purpose of this paper is to expand on one of the conclusions reached in that report. This is the assertion that the southern side of Tauhara Field may not have experienced significant drawdown due to exploitation of Wairakei Field. The basis for this assertion is discussed below, along with more recently acquired thermal infra-red imagery. The imagery shows the dramatic differences that now exist between the original, two chloride outflow zones in the north and the south of the field.

EVIDENCE FROM THERMAL ACTIVITY CHANGES

A comparison of the thermal areas of Wairakei and Tauhara Fields which have undergone obvious heat output changes since the 1950s and 1960s is shown in Figure 1. At Wairakei Field, virtually all thermal areas have experienced an increase in heat output due to pressure drawdown and steam zone formation at depth (Allis, 1981; the only exception is in a 1 km^2 area on the north side of the production borefield where substantial groundwater level declines have occurred). At Tauhara Field, similar increases have occurred only in the northern half of the field. The greatest increases have been centred on the Pony Club area where hydrothermal eruptions occurred in 1973 and 1981 (Scott and Cody, 1983). In the Spa Sights thermal area there has been a mix of areas of decreased activity, especially along the banks of the Waikato River, and areas of increased steaming ground. One minor hydrothermal eruption occurred here in 1974 (Allis, 1983). Over the southern half of Tauhara Field, nu obvious changes in thermal activity have occurred. The thermal areas here are relatively small, scattered, and of low heat output. There is very little well data from this part of the field, but it is likely that groundwater temperatures here are below the boiling point.

The differences between the northern and southern halves of Tauhara Field are evident in the temperature histories of the main hot springs (Figure 2). Temperatures of northern springs have increased by around 40°C since the mid 1960s. However, in the south of the field, the source of the Waipahihi Stream and the nearby Iron Bath Spring have not shown major temperature changes. The history of the Iron Bath is complicated by excavation and pumping of the spring since the 1970s. At least 2 wells have been drilled in the area since 1985 to provide hot water to the Baths Complex and to the Hotel, and the Iron Bath Spring has dried up.

EVIDENCE FROM CHEMICAL CHANGES

The pattern of thermal changes discussed above is similar to the chemical changes (Henley and Stewart, 1983; Glover, in D.S.I.R., 1988; Glover et al., 1989). The

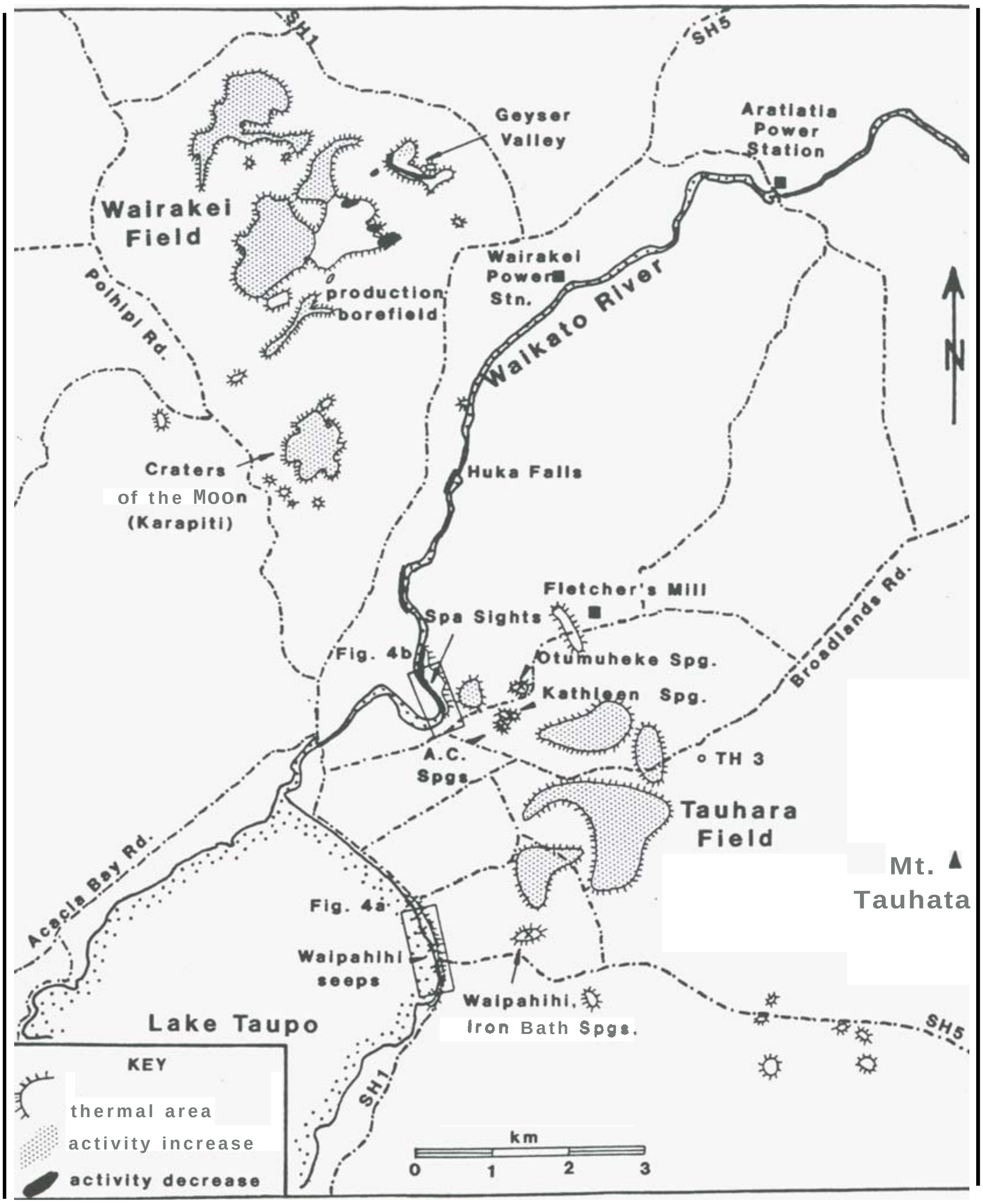


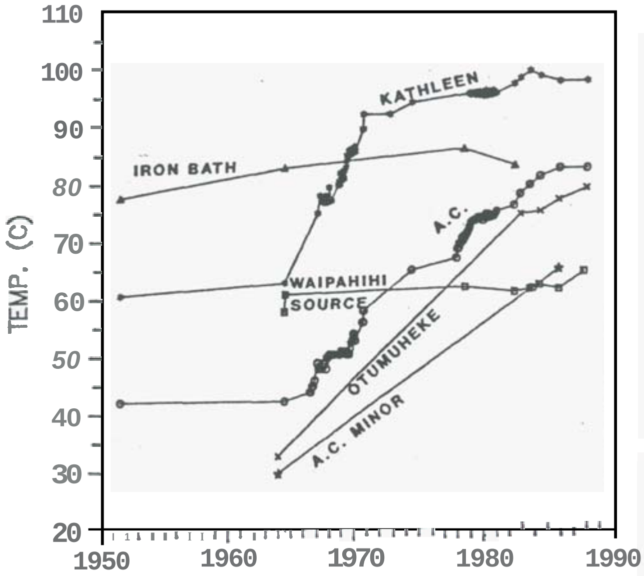
FIGURE 1: Distribution of thermal areas in Wairakei and Tauhara Fields. The areas which have experienced significant changes in thermal activity due to fluid withdrawal from the Wairakei production borefield are depicted.

northern springs (Kathleen, **A.C.,** Otumuheke) continue to have increasing sulphate contents, which is indicative of increased steam-heating (Figure 3a). The chloride concentrations of waters with significantly above-background values in the 1960s have decreased by more than 50% (Figure 3b). The feature with the best history of analyses (Kathleen Spring) is consistent with an exponential decay curve having a 50% decay ("half-life") of the order every 10 years. If the shallow aquifer is considered to have been suddenly cut off from its upflow of chloride (possibly around 1960) then the decay rate is simply exp(-mt/M) where

- m = step change in chloride inflow rate
- M = initial mass of chloride in the shallow aquifer
- t = time since step change.

Inserting realistic figures (m = 0.1 kg/s; t = 10 y for 50% decay) gives **M = 4** x 10^7 kg. If the average Cl of the groundwater was originally around 100 mg/kg, and the groundwater aquifer is 100 m thick, then its area would be around **4** km^2. **A** higher original Cl concent ration reduces the inferred groundwater aquifer area. The uncertainties in these calculations mean only that the observed rate of decay of chloride has been consistent with known characteristics of the groundwater aquifer.

The southern springs, seepages and wells indicate €ew chemical changes since sampling began in 1962. Chloride concentrations are typically in the range 200-500 mg/kg. The small shift towards the bicarbonate corner for one of the Waipahihi points in Figure 3a is due to a higher bicarbonate concentration in the most recent sample (Cl



was not significantly different). Recent isotopic data suggests a minor increase in dilution may have occurred between 1979 and 1989 (Glover et al., 1989). More work is required to confirm this suggestion, which is not seen in the major element chemistry.

PRESENT LIQUID OUTFLOWS

Apart from the major springs already mentioned, Tauhara Field originally had seepage areas along a 700 m length of the shore of Lake Taupo, and along a similar length of the right bank of the Waikato River (Spa Sights thermal area, Figure 1). The liquid outflows from the Spa Sights have always been noted for their sensitivity to river level changes. In the 1950s and early 1960s this outflow ranged between 10 and 20 kg/s (Fisher, 1964; Cl concentrations ranged up to 1300 mg/kg). The last stimulated geyser eruption at Spa Sights was probably in the early 1960s (pers. comm. R.F.Keam). Although steaming ground persists, the last hot water seepages may have ceased in the early 1980s. In 1979 the Witches Cauldron at Spa Sights contained a pool of 75°C water with a Cl concentration of 175 mg/kg (Henley and Stewart, 1983). Sometime between 1980 and 1985 the pool dried up, and subsurface seepage to the river is now inferred to be minimal.

The area of thermal seepages along the Taupo foreshore have not had notable longterm changes in thermal activity. Early thermal maps show a similar length of seepage to that present today (refer to Mongillo, 1989a, for a detailed map). The exposure of the seepage is strongly influenced by the lake level, with a low lake level being the best time to delineate the seeps.

Confirmation of the absence of seepages from the Spa Sights thermal area and the extent of seepage along the Taupo foreshore was recently obtained with a thermal infrared survey. The thermal imagery (8-12 μm) was acquired at dusk using a FLIR Systems 1000A

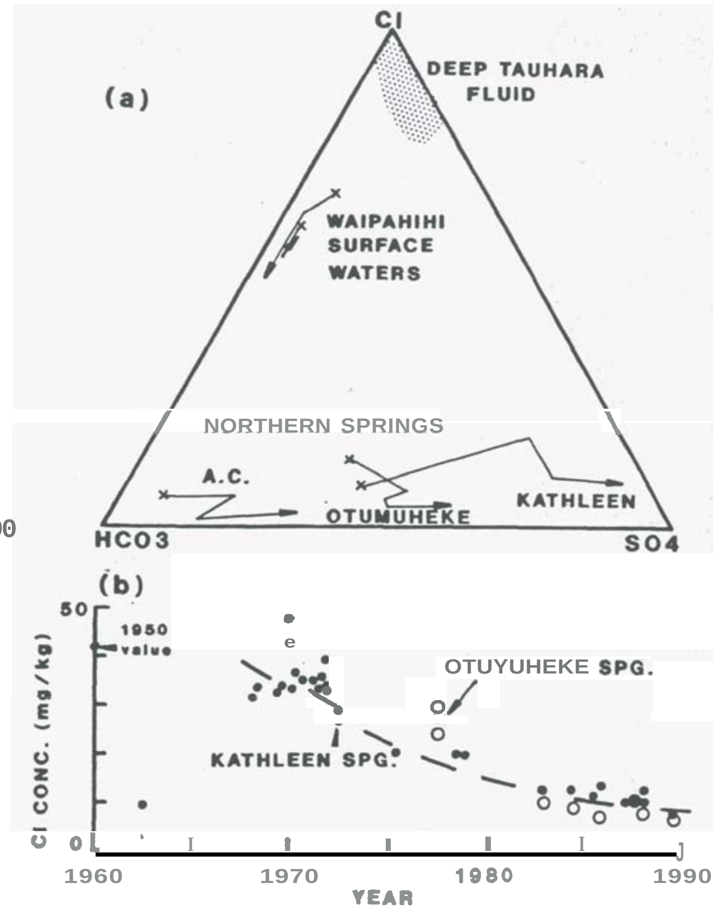


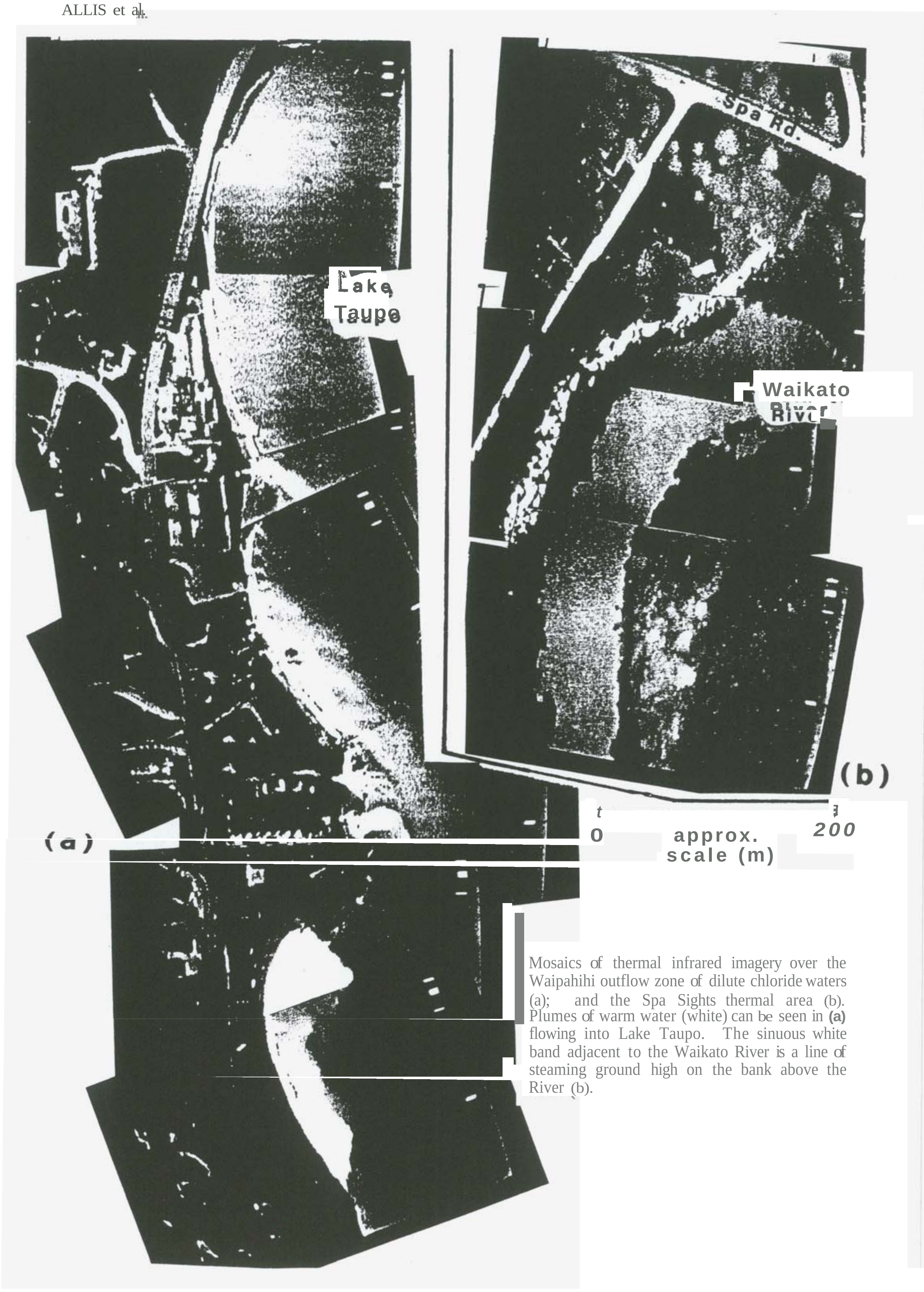
FIGURE 3(a): Trilinear plot of mole percent compositions of Cl, SO, and HCO,. Each component is 100% at its labelled apex of the plot.

(b): Trend in chloride concentrations with time for two springs in the northern portion of Tauhara Field.

instrument vertically mounted beneath a helicopter (Mongillo, 1989b). A flight path up the Waikato River and along the Taupo foreshore was specially planned to investigate the extent of geothermal seepages. The imagery was recorded as grey tones on video tape, and was available for immediate review on a standard TV-VCR system. Subsequent image processing techniques including pseudo-colour enhancement have been carried out but unfortunately cannot be demonstrated in this paper.

Unprocessed, black and white mosaics of the two original hot seepage areas are shown in Figure 4. Extensive hot seepage is clearly evident along the Taupo foreshore, whereas there is no evidence of seepage along the right bank of the Waikato River. However, a small thermal anomaly does appear to be present on the left bank (inside corner) of the river. There originally were isolated seeps on this side of the river as far upstream as Cherry Island, so such a seep is not impossible. The anomaly needs to be verified before being considered further.

A notable feature of the thermal imagery along the Waikato River is the strong lineation in the steam-heated thermal areas high up on the right bank. This appears to be due to steam flowing out underneath a low permeability layer which is exposed in the bank.



Mosaics of thermal infrared imagery over the Waipahihi outflow zone of dilute chloride waters (a); and the Spa Sights thermal area (b). Plumes of warm water (white) can be seen in **(a)** flowing into Lake Taupo. The sinuous white band adjacent to the Waikato River is a line of steaming ground high on the bank above the River (b).

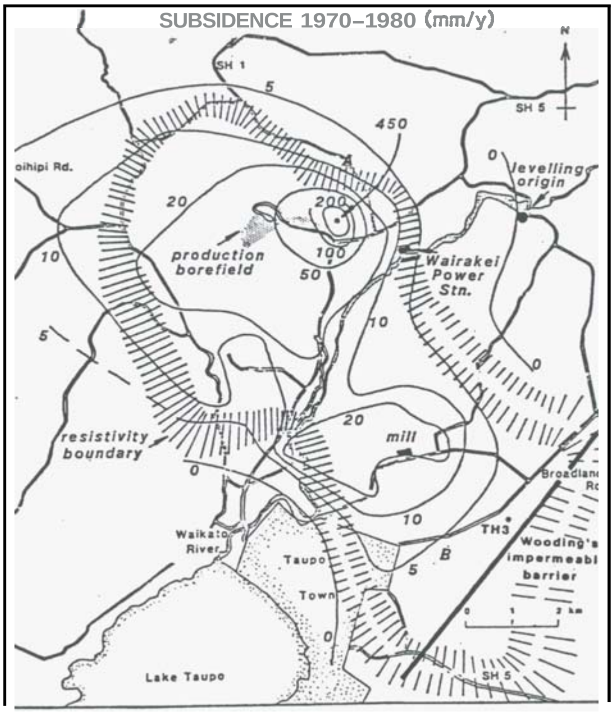


FIGURE 5: Average subsidence rates over Wairakei and Tauhara Fields. The resistivity boundary zone applies to about 500 m depth; the location of this zone is uncertain in the southeast of Tauhara Field. The solid line is the impermeable barrier implied by Wooding's (1981) modelling of the pressure response of Tauhara Field to fluid production from Wairakei Field.

SUBSIDENCE

The pressure decline caused by fluid extraction from the Wairakei production borefield has caused subsidence over at least 30 km^2 (Figure 5; Allis and Barker, 1982). The areas of greatest subsidence coincide with accumulations ofpumice breccia within local basins in the Huka mudstone formation. However, more pertinent to this paper are the outer limits of the subsidence anomaly which largely appear to be due to compaction within the deeper formations (especially the Waiora formation). Figure 5 shows that the eastern and southern sides of Tauhara Field have not been affected by significant subsidence.

Figure 5 must be interpreted cautiously because all subsidence data are referred to an origin near the Aratiatia Dam. This is 5 - 10 km from the far margins of the subsidence anomaly, so some tectonic Subsidence may be superimposed. 'The dominant tectonic component in the region is a northeast-trending subsidence zone with a maximum of around 10 mm/y coinciding with the centre of the Taupo Volcanic zone (Otway, 1986). A tectonic component is certainly present on the western side of Wairakei Field where at least 5 mm/y of Lhe subsidence shown in Figure 5 is likely to be tectonic (P. Otway, pers. comm.). Whether as much as 5 mm/y of tectonic uplift is occurring in the southeast of Tauhara field (relative to the levelling origin) is less certain. Evidence from repeat levelling around Lake Taupo suggests the tectonic component across Taupo town area is unlikely to exceed 2 mm/y (Otway, pers. comm.).

Given the available subsidence and tectonic deformation data, the amount of geothermally induced subsidence in the southeast of Tauhara Field is surprisingly small, if over 15 bars of drawdown has occurred throughout the low resistivity anomaly. The resistivity boundary zone depicted in Figure 5 is uncertain in the southeast of Tauhara Field but it is unlikely to enclose a significantly smaller area than that depicted. One deep well at Tauhara Field (TH3) is situated outside the 5 mm/y contour, and this well has experienced drawdown at feedzone depths (at R.L. -450 m, Allis, 1983). Therefore the very low subsidence around this well is either due to relatively incompressible rocks or to the pressure decline being restricted to a narrow depth range. The stratigraphy in TH3 is similar to that in TH1 and TH4.

It is interesting that Wooding's (1981) modelling of the pressure drawdown in Tauhara required an impermeable barrier in the southeast of the field (shown in Figure 5). The barrier was though to coincide with a sharp resistivity boundary shown on an old map (Banwell and Macdonald, 1965). However, more recent measurements suggest that the original resistivity boundary was due to high resistivity volcanics near surface on the lower flanks of Mt Tauhara. Low resistivity probably extends eastward at depth beneath Mt Tauhara. The impermeable barrier along the southeast side of Tauhara Field implied by Wooding's (1981) modelling appears to be supported by the subsidence data rather than the resistivity data.

DISCUSSION

The northern half of Tauhara Field has shown a predictable response to drawdown as a result of fluid extraction from Wairakei Field. There has been an increase in steam-heated thermal activity; a decrease in chloride outflow from this part of the field; and subsidence due to the pressure decline at depth. In addition, precise gravity decreases (corrected for elevation changes) confirm a steam zone has formed beneath the main subsidence anomaly over the northern half of Tauhara Field (D.S.I.R., 1988; unpublished Geophysics Division data).

In the southern half of Tauhara field, none of the above-mentioned changes has occurred. The simplest explanation is that the drawdown in the southern half of Tauhara Field is insignificant. However, let us first consider the alternative explanations. The lack of a deuterium anomaly in these southern, dilute chloride thermal waters is an indication that steam loss or steam addition are not important processes along their upflow/outflow path (Henley and Stewart, 1983). Therefore pressure drawdown here would not necessarily produce a steam-heating pulse because temperatures may be too far below the boiling point. It might also be argued that subsidence is insignificant because the rocks here are incompressible and atypical of the rest of Tauhara Field. The absence of gradually declining chloride concentrations with time in the groundwaters over the southern half of the field is more difficult to explain away. If drawdown has affected this part of the field, then the chloride-bearing groundwaters here have a very long outflow path compared to northern Tauhara Field. If so, it must be argued that the chemical front due to the cessation of upflowing chloride water has not yet reached the wells and seepages in the south of the field.

In the north of the field the subsidence histories of key benchmarks indicates that drawdown was affecting this part of the field by the late 1950s (D.S.I.R., 1988). Both thermal and chemical changes had been detected in the groundwater aquifer by the mid-late 1960s. Why have similar changes not been detected in the southern part of Tauhara Field, some 20 years after the changes further north? Very simplistically this means that the outflow path of the chloride in the south of the field is over 3 times longer than that in the north. This points towards the chloride coming from a part of Tauhara Field far from the known drawdown area. Our conclusion is that the chloride is probably originating from a part of Tauhara Field which has in fact not been affected by the drawdown of Wairakei Field. The conclusion implies that the rock beneath Mt Tauhara **is** impermeable, but probably very hot (TH3 is the closest deep well to Mt Tauhara; it is also the hottest of Wairakei-Tauhara wells, at around **280°C).** This situation may be analogous to that beneath Mt Edgecumbe on the southeast side of Kawerau Field (in the NE part **of** the TVZ). Like Mt Tauhara, Mt Edgecumbe is also a dacite cone. Deep wells drilled in the southeast corner of Kawerau Field have found very high temperatures but very low permeability.

The conclusion about a second upflow zone in the south of Tauhara Field must remain speculative until proven by new drillhole evidence. Based on the shallow hydrologic gradient across the south side of Tauhara Field, the chloride water is flowing from the south side of Mt Tauhara. Patches of weakly steaming ground exist here, so the flow could conceivably originate from even further east. Unfortunately the resistivity data on the southern and eastern flanks of the field are scarce and the boundaries are poorly delineated. Additional resistivity mapping around the south side of Mt. Tauhara should reduce much of the uncertainty.

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