CHANGES IN THERMAL ACTIVITY OF THE NORTHERN TE KOPIA GEOTHERMAL FIELD (NZ) DURING 1993-94

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SUMMARY - In late 1993 three small areas in the northern section of the Te Kopia geothermal field began to heat up; this was first recognised by dead and dying vegetation. Three ground temperature surveys were conducted there and showed that all of these areas heated up between late January and mid February 1994 but had started to cool by late March. The rapid changes indicate that heating of the soil was caused by small steam fluxes which might have been triggered by an increase in permeability in the deeper reservoir caused by a local earthquake swarm in November 1993 and/or a decrease in condensation as a result of a local decrease in rain water infiltration during an exceptionally dry summer.

INTRODUCTION

The Te Kopia geothermal field lies just outside the eastern margin of the Maroa Volcanic Centre (Bignall and Browne, 1994), and is about 10km to the north-east of the Orakeikorako field (Figure 1). At Te Kopia there is a strong structural control on surface activity, particularly by the dominant structure, the Paeroa Fault which is downthrown to the west by at least 450m (Bignall and Browne, in press). The dominant structural trend at Te Kopia is NE, however, several NW trending lineaments, interpreted as basement faults (Cochrane and Wan, 1983), also might provide some vertical permeability.

Present day thermal activity is dominated by fumaroles, mud pools and steaming ground, although several small thermal springs discharge to the west of Te Kopia road (Figure 2). Changes in thermal activity have occurred at Te Kopia in historic and pre-historic times. Comparison between 1948 and 1991 aerial photographs indicates the Te Kopia field has generally cooled in the south, as shown by the extensive recent rejuvenation of vegetation there. Evidence for pre-historic thermal change at Te Kopia includes the occurrence of 3000 yr old silica sinter deposits (Bignall, 1994) and overprinting of hydrothermal alteration. Significant changes in thermal activity also occurred during 1993-94 in the northern part of the field.

In 1993, either in late October or early November, a small section of the northern part of the Te Kopia field started undergoing changes which were initially recognised by the enlargement of a mudpot (on the southern side of Murphy's Hill (Figure 2)), which later changed (January, 1994)

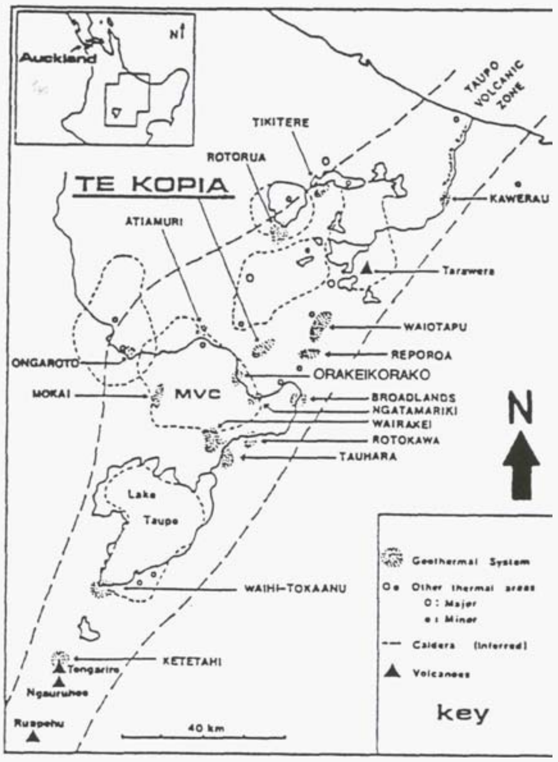

Figure 1. Location of the Te Kopia Geothermal Field, Taupo Volcanic Zone, New Zealand. MVC=Maroa Volcanic Centre (modified from Bignall, 1991).

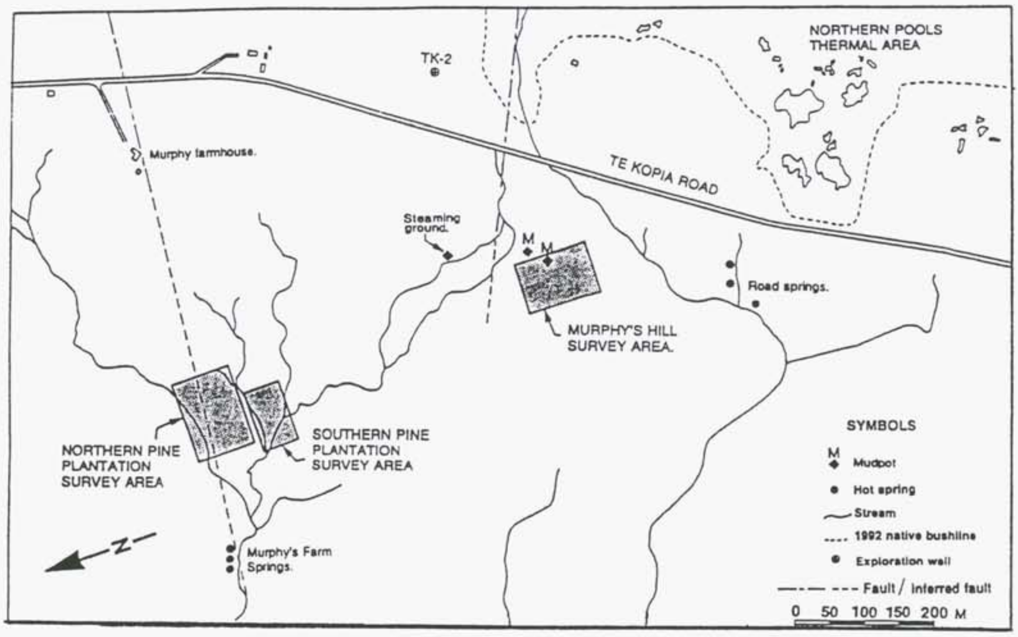

Figure 2. Map of the northern section of the Te Kopia Geothermal Field showing major thermal features and the areas that have undergone recent thermal change.

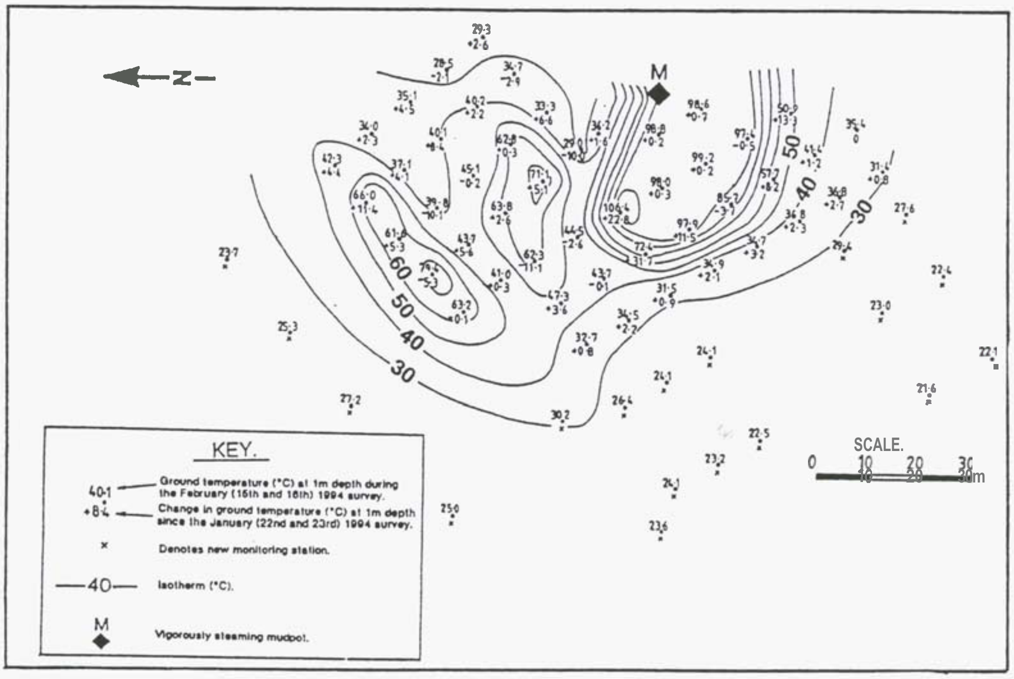

Figure 3. Contoured temperature profile map of the Murphy's Hill area, showing ground temperatures at 1m depth on 15 February 1994 and also changes that had occurred since 22 January 1994.

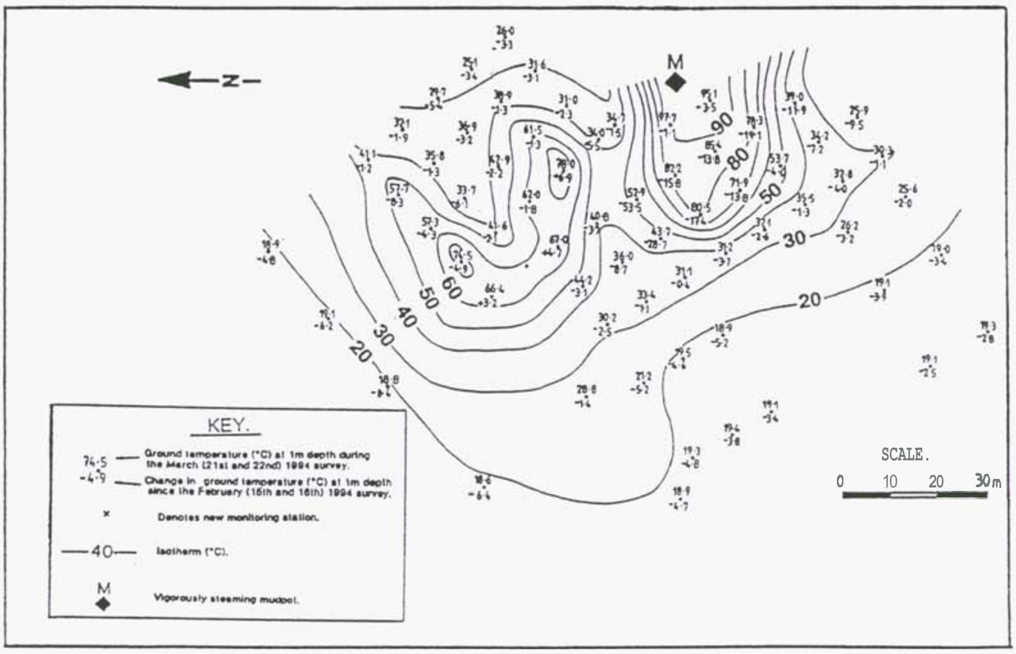

Figure **4.** Contoured temperature profile **map of** the Murphy's Hill **area,** showing ground temperatures **at** 1m depth on 21 March **1994 and** also changes that **had** occurred since 15 **February** 1994.

to become vigorously bubbling and frequently discharged lumps of hot, wet mud around its periphery (this mudpot had a surface temperature of 99°C throughout the period of study, hence it was vigorously discharging steam). Thermal ground appeared over a larger area, as indicated by vegetation die off around Murphy's Hill, and in two other areas called here the "Northern Pine Plantation" and the "Southern Pine Plantation" (Figure 2). Resistivity and ground temperature surveys made by Ngugen (1993) and Perez-Ramos (1993) in September 1993 did not reveal any new areas of anomalously hot ground around Murphy's Hill. An analysis of a 1:5000 scale aerial photograph of the northern part of the field taken in February 1992 also showed no sign of geobotanical stress in the vicinity of the thermal ground discovered in late 1993. Repeated ground temperature surveys were therefore conducted to determine the areal extent of the new thermal ground, to monitor changes in ground temperature and to relate the onset of vegetation stress to ground temperatures.

METHODS

(1) Field Methods and Instruments.

A series of monitoring stations were sited within a rectangular grid in each of the new thermal areas using a compass and tape measure with stations usually being either 10m or 15m apart. A dial type thermometer was used to record near surface (1cm and 20cm) temperatures. Temperatures at 1m depth in hand augered holes were measured using a thermistor and multimeter.

The thermistor was calibrated using a water bath heated over the range of 0° to 100°C. The dial gauge was calibrated for fixed point temperatures of 0" and 100°C only. Within the range of temperatures from 0°C and 100°C. The accuracy was found to be about ±0.1°C for the thermistor and better than ±1°C for the dial gauge.

(2) Effect of periodic temperature variations.

Soil temperatures are affected by diurnal, other short periodic, and seasonal temperature variations (Dawson and Fisher, 1964). Since no base station recordings were available, the temperature readings at 1cm and 20cm depth could not be reduced The effect of daily variations at 20cm depth, however, is small. According to the theory which describes periodic heating in soils (*Turcotte* and Schubert, 1984, for example), the "skin-depth", d, where the amplitude of such variations decreases to 1/e of the surface value is:

$$d = (2\alpha/\omega)^{1/2} \quad ..... (1)$$

where α is the thermal diffusivity (here taken as $0.4 \times 10^{-6}\ m^2/s$, as observed by Drolia et al. (1981) near Rotorua in a similar setting), and ω is the radian frequency ($\omega = 73 \times 10^{-6}$ rad/s for daily variations). Using these values, d = 0.1m. The temperature at 20cm depth contains therefore an uncertainty of a few degrees (assuming an amplitude of 10 to 15°C for daily temperature changes) if unreduced readings are used.

Surface temperatures were found to be not much affected by daily variations in ground where T>40°C at 1cm depth.

The "skin-depth", d, for annual variations ($\omega = 0.2 \times 10^{-6}$ rad/s) according to equation (1) is about 2m. Temperatures at 1m depth are therefore *affected* by these variations, which at depth z are given by:

$$T(z,t) = T_o + \Delta T_o \exp[-z(\omega/2\alpha)^{1/2}] \cos[\omega t - z(\omega/2\alpha)^{1/2}] \quad ..... (2)$$

In equation (2) T_o is the mean annual temperature and ΔT_o is the amplitude of the annual temperature wave; t is the time (in *seconds)* after the summer maximum (15 January). Using climatological data from the nearby Ohaaki Power Station and allowing for a vertical lapse rate, values of T_o = 11.5°C and ΔT_o = ±5.55°C are indicated for Te Kopia (elevation = 405m a.s.l.). For the period of the surveys (22 January to 21 March) the predicted ground temperatures at 1m depth decreased from 15°C to 14.3°C. Temperature changes at 1m depth which are greater than -0.7°C reflect, therefore, temperature changes which are not caused by *seasonal* temperature variations. Restricting discussion of observed data to changes > |1°C| quires, therefore, no reduction of the data.

(4) Estimate of conductive losses.

Since no steam was discharged at the surface over the hot ground, apart from steam discharged by the existing discharge features (steaming mudpools), it *can* be *inferred* that heat transfer close to the surface was mainly by conduction. The heat, Q, discharged per unit area is in *this case:*

$$Q = \lambda\ \Delta T/\Delta z \quad .....(3)$$

where λ is the *thermal* conductivity of the soil (here taken as ≈ 2W/m "C), and $\Delta T/\Delta z$ the temperature gradient. For high temperam ground (T>40°C at surface) the gradient of the upper 20cm *can* be used, for low temperature ground, the gradient between 0.2 and 1m depth was used.

RESULTS

MURPHY'S HILL AREA

Murphy's Hill is a small (<20 metres high) feature comprised of pre- Taupo eruption (1800 yr old) landslide deposits covered by hydrothermal eruption breccia Until late 1993 hydrothermal activity around the Murphy's Hill area was apparently stable although it is possible that the two mudpots, that have long existed on the northern si& of Murphy's Hill, enlarged in 1971, although this event was no& documented (Browne et al, 1994).

On 15 December 1993 it was apparent that Murphy's Hill was undergoing thermal change leading to a vigorous steam discharge in a mudpot, approximately 2m in diameter, on its southwestern si&. A southwest protruding lobe of dead and dying grass and surrounding Leptospermum (manuka, kanuka) showed that heating at this location had been recent.

By 22 January 1994, the mudpot (M in Figures 3 and 4) had changed markedly not only in character, but also in size, increasing to about 4m in diameter and also in steam discharge; it had developed an extensive mud rim. Forty eight ground temperature monitoring stations were sited around the western and northwestern sides of Murphy's Hill. Measurements at 1m depth indicated that thermal ground was present over the entire 3000m^2 survey *area, since* the lowest temperature recorded (27°C) was well above normal ground temperature at 1m depth, which far this time of the year according to equation (2) should be 15°C. The temperature survey on 22 January 1994 delineated three distinct thermal highs, the largest and hottest of which was adjacent to the recently enlarged mudpot, where the 90°C isotherm extended up to 25m from it. The two other highs were 40m and 55m northwest of the mudpot. A near surface heat flow calculation, assessing conductive heating, showed that during 22 January nearly 0.3 ± 0.01MW of heat was discharged on the western si& of Murphy's Hill.

By 15 February 1994 steam activity on the southwestern si& of Murphy's Hill had increased, associated with extensive gas discharge and intermittent ground vibrations which could be felt and heard at most places within the survey area Eighteen new ground temperature monitoring stations were drilled and although this extended the total survey area from 3000 m^2 to about 7550 m^2 elevated ground temperatures at 1m were still encountered throughout, with the lowest temperature being 22°C, indicating that the whole area was being heated (Figure 3).

An overall heating trend *can* be recognised between 22 January and 15 February with the stations common to both surveys increasing in temperature by 2.6°C on average (annual temperature variations account for a change of + 0.1°C). At one station, about 20m from the mudpot, a 1m temperature of 106°C was recorded (Figure 3); steam discharged from this shallow hole. The recordings at 1cm and 20cm depth made at this station yielded temperatures of 40°C and 44°C respectively, indicating that heating at 1m depth had been recent.

By 21 March 1994 steam activity from the mudpot on the south-western *side* of Murphy's Hill had decreased and the level of mud within it had risen to within 2m of its southern rim. Ground vibrations were more intermittent and less intense with mud being thrown out only occasionally. As shown in Figure 4 the entire Murphy's Hill survey area underwent cooling between 15 February and 21 March 1994 with 61 out of 65 monitoring stations recording decreased temperatures, on average by 5.3°C (the annual temperature variation accounts for a temperature change of -0.7°C). It was estimated that on the western side of Murphy's Hill, heat discharged by conduction decreased only slightly from 0.34 ± 0.01MW to 0.32 ± 0.01MW between the February and March surveys.

A visit to the Murphy's Hill area made on 18 April 1994 showed that the area was continuing to undergo thermal change with a rise in the mud level within the mudpot to within 20cm of its southern rim.

SOUTHERN PINE PLANTATION AREA
(*see* Figure 2)

The thermal ground m this area, first recognised during a visit to the area on 15 December 1993, was identified by stressed vegetation which included flattened dead and dying grass, pine seedlings and lupins. Temperatures of up to 55°C were recorded at 20cm depth.

The Southern Pine Plantation survey area, is small by comparison with the Murphy's Hill and Northern Pine Plantation areas. The 23 January 1994 survey covered only an area of *525* m^2 but this was expanded to 1125 m^2 with the establishment of four new measurement stations during the 16 February survey. The area of thermally heated ground was elliptical in shape, with east-south-east elongation, and contained two distinct areas with thermal highs, approximately 35m apart with 1m temperatures of 52°C and 49°C. A conductive heat flow of 0.08 ± 0.01MW was calculated and, in combination with the isotherm patterns, indicated that the focus of steam heating in the subsurface was very local.

Although the survey area was expanded to 1125 m^2 on 16 February, no station yielded ambient ground temperatures at 1m depth (ie. about 15°C) with the coolest being 26°C. While the isotherm pattern had virtually the same *shape* as that of 23 January, almost the whole survey area had been heated.

The 22 March temperature survey of *the* Southern Pine area revealed that the whole area, apart from one station, had cooled with an overall average decrease in temperature at 1m of 3.3°C. There was a marked decline in heat output in March to **0.058 ± 0.01MW** emphasising the overall cooling that had occurred. The temperature drops throughout the survey area were remarkably uniform ranging between 1°C and 6°C.

NORTHERN PINE PLANTATION AREA.

The Northern Pine Plantation survey area is located 100m to the north of the southern Pine

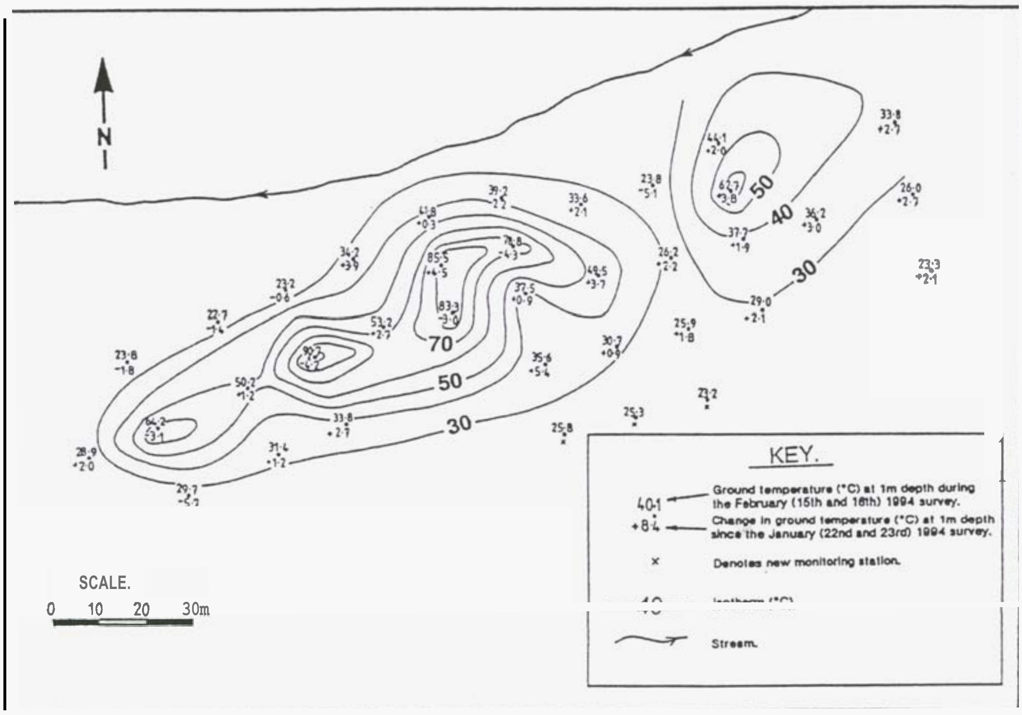

Figure 5. Contoured temperature profile map of the Northern Pine Plantation area, showing ground temperatures at 1m depth on 16 February 1994 and also changes that had occurred since 23 January 1994.

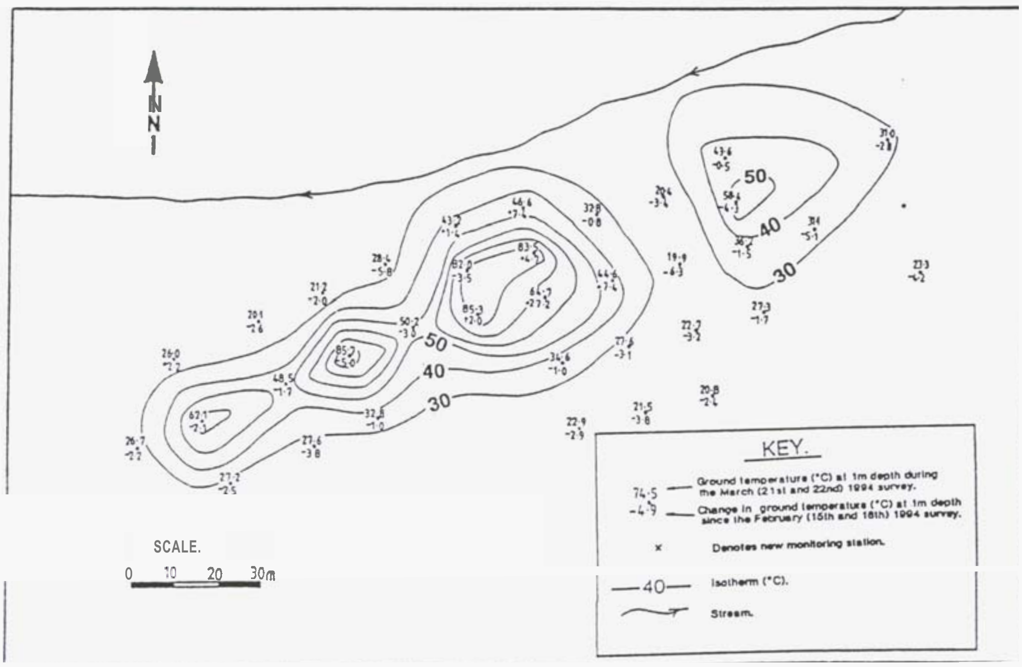

Figure 6. Contoured temperature profile map of the Northern Pine Plantation area, showing ground temperatures at 1m depth on 22 March 1994 and also changes that had occurred since 16 February 1994.

Plantation survey area (Figure 2). The major difference between the two areas is that the northern pine area shows signs that thermal activity has occurred there in the past, with some racks on the steep north facing hill side within the area being hydrothermally altered. These rocks are now at ambient temperature, but their alteration suggests they were hot in the past.

On 15 December 1993 the botanical signs of anomalously hot ground were much more pronounced here than in the southern pine survey area. At least five distinct areas, averaging between 15-20m^2 in size, were characterised by severely stunted dead and dying grass, lupin and pine seedlings. The boundaries between stressed and unstressed vegetation were sharp, and the thermal 'patches' were aligned along a trend striking 064° indicating that they were structurally controlled.

Thirty three temperam monitoring stations were drilled on 23 January 1994; the results showed the extent of thermal ground to be at least 4800m^2. Four areas with thermal maxima, aligned m a north-easterly direction over a distance of *about* 140m, were identified, and coincided with patches of dead vegetation. *An* assessment of conductive heat loss for the Northern Pine Plantation thermal area was made; the value obtained of 0.29 ± 0.01MW was similar to that at Murphy's Hill.

A temperature survey umducted on 16 February 1994 revealed that about two thirds of the survey area had undergone heating since January 23, although the areas with thermal maxima, apart from the easterly one, had cooled by between 3-4°C (Figure 5). Changes in *the* vegetation appeared to be slight with only the *small* pine trees showing any obvious deterioration from the previous month. Similar to the Murphy's Hill survey, eight reference pegs were established to mark the extent of dead vegetation of the large heart-shaped thermal patch near the centre of the survey area, which more or less follows the isotherm pattern. Pegs placed to mark the edge of the dead zone, recorded temperatures of between 52°C and 58°C (average *55°C)* at 20cm depth. It was found that grass started to show signs of thermal stress where 20cm ground temperatures exceeded 42°C (as at Murphy's Hill) and was usually dead when temperatures greater than *55°C* occurred at this depth.

The temperature survey conducted on 22 March 1994 showed that almost the entire survey area had cooled since the 16 February (Figure 6). Although assessing change in the areal extent of thermally affected vegetation was difficult, there was a distinctive change in the *grass* appearance with an increase in size of a halo of lush grass surrounding the dead patches. This is similar to the change recognised around Murphy's Hill during the same survey, and is probably caused by an increase in the supply of moisture to the *grass* roots by steam condensation. The 20cm deep temperature measurements made adjacent to the reference pegs showed that there had been an average cooling in ground temperature of about *5°C.*

DISCUSSION

The study shows that short periodic changes in natural heat output can occur locally on top of a high temperature reservoir without being caused by extraction of hot fluids from bores. There is good evidence that the soil heating observed at Te Kopia was caused by some minor steam upflow which probably lasted only for a few months. This *steam* was not discharged at the surface except for an increase in steamflow in a nearby mudpool; in the heated ground the steam condensed, causing new patches of lush *green* grass to form at the end of a *dry* summer. The additional episodic steamflow in the three areas surveyed (total 13500m^2) was *small,* probably less than 0.26 kg/s corresponding to a heat transfer of 0.7MW, even at the peak of activity. The soil heating, however, was structurally controlled, especially in the Northern Pine Plantation Area Figures 5 and 6) where the structure which allowed the *escape* of steam runs obliquely (070°) to the younger regional faults, trending NE. As for the cause of this heating episode which we witnessed by accident it is possible that both changes in local seismicity and regional climatology were responsible.

On 28 and 29 November 1993, the Te Kopia-Reporoa area experienced over 100 shallow level (<5km depth) earthquakes, with the two largest events having magnitudes of 4.3 (8.14 pm, 28 November) and 4.5 (1250 am, 29 November) (IGNS data). The epicentres of these earthquakes was not determined, however, from local reports it seems likely they were close to the Te Kopia area. It is probable that the thermal changes observed in December 1993 were related to these seismic events, through the generation of some additional vertical permeability, and that subsequent cooling was related to "relaxation"(permeability reduction).

Another contributing factor for the thermal changes that occurred in late 1993 may be the low level of rainfall m the Te Kopia region that year, which was 135mm less than the average (1165mm/yr). Rainfall data for the Ngakuru Station, 10km to the north-west, indicate that the period from July to October 1993 had less rain than the average and that 1993 was the driest year for the last ten. This may have led to a lowering of the watertable resulting in the formation of a shallow steam zone, with the highest steam upflow occurring above and adjacent to the lineaments described previously. An analogous situation might have occurred at Wairakei, although on a much larger scale, where the formation of a two phase zone followed upon production of hot water caused a drop in the watertable. This was the main cause of the heating that occurred at Karapiti between 1958 and 1964 (Allis, 1981).

The overall cooling that occurred between February and March can not be attributed to rainfall since precipitation in the region was still low over this period (with 76mm and 50mm being below monthly averages), but could be related to a reduction in vertical permeability along faults due to "relaxation" following intense seismicity.

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