CHANGES IN THERMAL ACTIVITY AT THE TE KOPIA GEOTHERMAL FIELD,
TAUPO VOLCANIC ZONE, NEW ZEALAND

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ABSTRACT

The Te Kopia geothermal field has surface manifestations in a zone up to 1.2 km wide that extends for about 3 km along the Paeroa Fault scarp. This fault is normal, has a steep dip, and is still active, with displacements that total 450 m in the Te Kopia area. The fault continues to have an important control on the hydrology of the geothermal field, both by producing steep terrain east of its trace, but also because its successive movements have triggered landslides, hydrothermal eruptions, and variations in the piezometric surface.

Changes that have occurred during the lifetime of the system (>75,000 years) are evident from the geological record and direct observations. For example, beginning in about November 1993, three areas in the north-west part of the field have changed thermally. Temperature surveys at 1.0 m depth in January, February and March 1994 show the areas affected are 10,000 m^2 in total. Vegetation has died, and a vigorously discharging fumarole and then a mudpot formed at one (Murphy's Hill). Petrographic and field evidence of hydrothermal alteration, and fluid inclusion geothermometry, show that the block east of the Paeroa Fault has been upthrown by at least 315 m ± 5 m, exposing reservoir rocks that were once within the Te Kopia reservoir. These are now being altered by steam discharging from this still very active geothermal system.

INTRODUCTION

The Te Kopia geothermal field, the north-eastern section of the larger Orakeikorako and Te Kopia geothermal system (Bignall and Browne, submitted) has been little studied, despite two deep (945 and 1250 m) holes having been drilled there in 1965-66. Te Kopia is located 25 km north of Taupo (Figure 1) and 8 km north-east of the surface manifestations at Orakeikorako. It lies astride the Paeroa Fault, a major tectonic feature of the Taupo Volcanic Zone (TVZ; Figure 1), and at the eastern margin of the Maroa Volcanic Center from which voluminous ignimbrite sheets erupted in Quaternary times. At least three of these sheets are now exposed on the eastern upthrown block of the Paeroa Fault where they form a steep scarp 220 m high at Te Kopia. The two drillholes on the west side of the fault scarp (Figure 2), and four at Orakeikorako, encountered the same ignimbrite sequence, and demonstrate that cumulative vertical displacement on the fault has been at least 450 m.

The Paeroa Fault is normal, dips steeply to the west, but may also have had a component of strike-slip displacement (Grindley, 1959); it has moved during the past 1800 years (Nairn and Hull, 1986) and its displacement rate over 75,000 years averaged 4 m/thousand years (Keall, 1987). The thermal evolution of Te Kopia is clearly linked to episodes of movement along this fault, and there has long been interplay between the hydrology of the field and faulting, thermal activity, hydrothermal alteration, and the landsliding events which have occurred there.

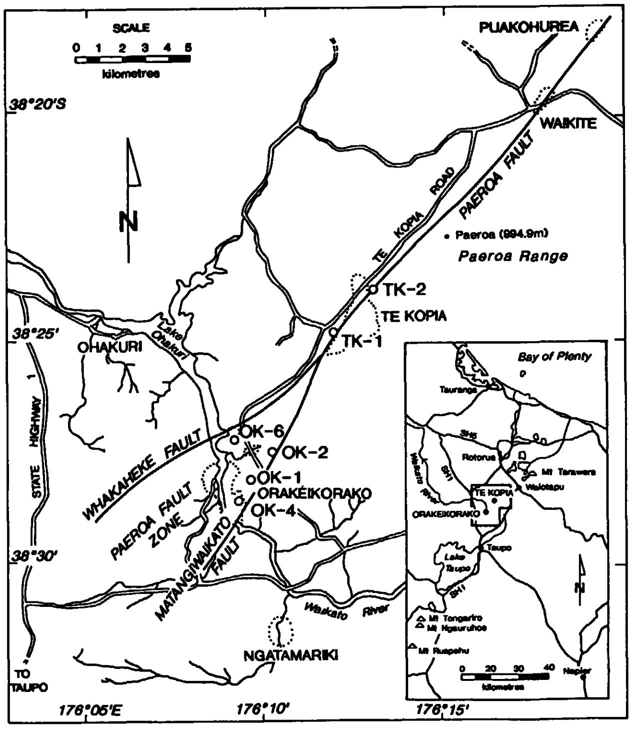

Figure 1: Location of Te Kopia geothermal field in relation to the Paeroa Fault and Orakeikorako. Presently active thermal areas are enclosed by dotted lines. (From Bignall and Browne, submitted).

In this paper we describe some of the changes which have taken place during the lifetime of the Te Kopia system, concentrating mainly on surface manifestations and field evidence. Descriptions of the subsurface geology at Te Kopia and Orakeikorako have been given by Bignall (1994), and the present surface activity at Te Kopia has been described by Bignall and Browne (submitted). Among the few earlier accounts of thermal activity here are those by von Hochstetter (1864), Grange (1937), and Healy (1952, 1974). Sheppard and Klyen (1992) have reported the compositions of some of the fluids now discharging, and Cochrane et al. (1993) and Burns and Leathwick (1993) have studied the types of vegetation present and their distribution with respect to the present thermal regime.

PRESENT DAY SURFICIAL THERMAL ACTIVITY

Thermal manifestations occur over an area extending for about 3 km along the Paeroa Fault Scarp (Bignall, 1994; Bignall and Browne, submitted). The width of the thermally active zone varies up to about 1.2 km in the north (Figures 2 and 3).

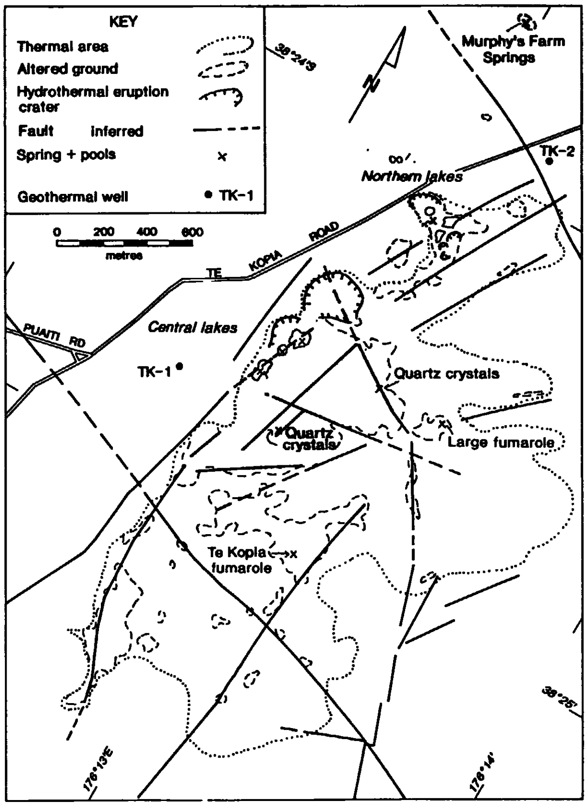

Figure 2: Distribution of main area of thermal activity in the southern part of the Te Kopia field showing distribution of thermally altered ground and location of drillholes; compare with Figure 3. Modifed from Bignall and Browne (submitted).

There are three different types of manifestations:

(1) The most common and widespread are areas of steaming ground accompanied by white clays, disseminated iron oxides, sulfate minerals such as alunite, and silica residue. Also in this category are a few fumaroles discharging superheated steam, including the Te Kopia fumarole itself (Figure 2), located with others along the crest of the scarp but seldom visited. A few smaller steam vents also occur at the foot of the fault scarp.

(2) Small lakes with acid sulfate waters are present in two areas along the foot of the Paeroa Fault scarp (Figure 2). These have low discharge rates but their chloride contents are up to 34 mg/kg (Bignall, 1994). A notable individual feature in the Northern Lakes thermal area is a mud geyser whose periodicity and magnitude largely depends upon the amount of rainfall.

(3) There are several neutral pH springs discharging at the Murphy Farm Springs west of the main thermal area (Figure 3); their flow rates vary from slight to several litres per second at temperatures up to 59°C. The Road Springs (Figure 3) are hotter (75°C) but have discharge rates between 1 and 2 litres per second. None has deposited appreciable amounts of silica but they are probably the surface expression of westward-moving outflows of chloride water that ascends along the fault to the south (Bignall and Browne, submitted).

TEMPORAL CHANGES IN THERMAL ACTIVITY

Field work and petrographic examination of cores recovered from the two drillholes (Figure 2) shows that there have been changes in the magnitude, type and locations of thermal activity at Te Kopia. Since neither well has discharged, except for a brief test period in 1966, the observed and deduced changes in surface activity are not due to any exploitation of the field.

The changes which have occurred are, for convenience, described separately and are considered here as: changes which have taken place in the past 6 months, the past 135 years, and the past 75,000 years. These greatly different scales of resolution are chosen because the rates and magnitude of the changes have varied in both time and space.

Changes in the past 6 months

There have been changes in thermal activity in the north-western part of Te Kopia (Figure 3). These were observed from November 1993 until April 1994. The areas affected by change lies west of the Te Kopia Road and between 500 and 700 m distant from the Paeroa Fault trace (Figure 3). The eastern parts of this area were visited by students making ground temperature and resistivity surveys in September 1993 (Nguyen, 1993; Perez-Ramos, 1993). At that time there was no remarkably high level of thermal activity.

Murphy's Hill: The two long-established mudpots on Murphy's Hill and the nearby chloride springs (Road Springs, Figure 3) seemed to be at the same state of activity as they had been for at least the past 12 years. Sometime in late 1993, however, the following changes started occurring, and these continued until at least April 1994.

(a) A vigorously discharging fumarole formed on Murphy's Hill, a few meters south west of the two long-established mud pots (Figures 2 and 3). In January and February 1994 this was discharging a high volume of gas and very viscous mud. Ground "thumping" was felt up to 100 m away on occasions (M. Murphy, pers. comm.). By late March the mud was less viscous and its surface was within 20 cm of the lip of its vent; ground vibrations had decreased. Hot mud spattered the surround, and all grass within 13 m of the vent had died. Kanuka trees nearby, up to 3 m high, were dying.

(b) Temperatures measured at depths of 0.2 and 1.0 meters changed. Three thermal surveys of the Murphy's Hill area were made: on January 22, February 15 and March 21, 1994, using a thermocouple and meter.

(i) Measurements made on January 22, after vegetation dieback began, outlined an area of above-ambient temperature extending over 2700m^2 (Figure 4). Temperatures were highest in the 1.0 m deep holes closest to the new fumarole, with the 80° isotherm

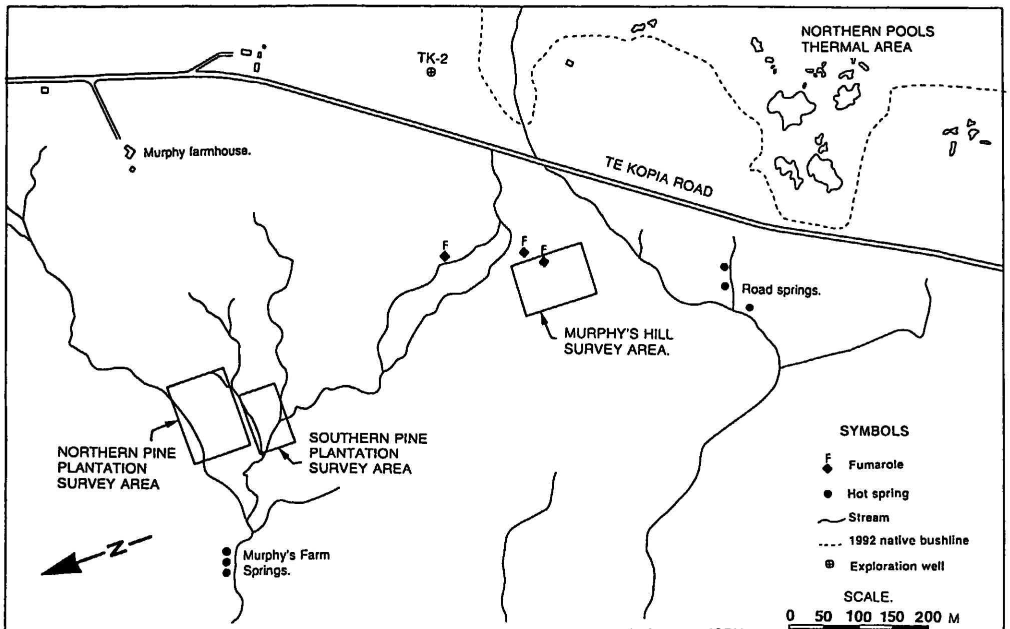

FIGURE 3. MAP OF THE NORTHERN SECTION OF THE TE KOPIA GEOTHERMAL FIELD SHOWING MAJOR EXISTING THERMAL FEATURES AND THE AREAS THAT HAVE UNDERGONE RECENT THERMAL CHANGE.

being on average 20 m distant from it. Two smaller areas with temperatures above 60° were located 30 m and 55 m to the north-west of the fumarole. These have no detectable mass discharge but are also characterised by their recently dead pasture.

(ii) The ground temperature survey made on February 15 extended to the south and west of that measured the previous month. It showed that the isotherm pattern then was very similar to that measured on January 22 but the three hottest areas had each increased in size by several meters, mainly in a north-easterly direction. The maximum temperature in the western thermal high had, however, cooled from 85° to 79° and the central one from 73° to 62°. By contrast, ground temperatures directly to the north-east of the formerly hottest survey holes had increased from 5 to 12° in the 25 days between the two surveys (Figure 5).

(iii) The survey on March 21 showed an overall cooling pattern. This is apparent on all the margins of the area surveyed, and near to the new fumarole where some temperature stations had cooled by 10° to 20° (Figure 6). One station, which 34 days earlier was at 106°, had cooled by 53°. The only temperature increases occurred near to where maxima (63° to 66° and 71° to 78°) were measured on February 15, at a station between them (62° to 67°) and a station close to the vent (71 to 77°C).

The changes in ground temperatures at Murphy's Hill show no simple pattern. Between January 22 and February 15, heating dominated overall, but between February 15 and March 21 almost the whole area had cooled. However, there are stations and small areas where the reverse occurred and some stations showed wide fluctuations in temperature, both increases and decreases. During the survey period the two long-established mudpots on Murphy's Hill and the nearby chloride springs showed no change in their levels of activity or temperatures of discharge. Steaming ground 50-100 m north west of Murphy's Hill also appeared to remain the same.

Pine Plantation: Two areas totalling 7200 m^2 covered by long grass and pine seedlings (Figure 3) showed signs of thermal stress in late 1993. By January 1994 the two areas (southern and northern pine plantations) had temperatures at 1.0 m depth that showed ellipsoid-shaped isothermal patterns whose longer axes were aligned in ESE (southern pine plantation) and NE (northern pine plantation) directions. The smaller southern area had maxima of 52° and 48°C about 33 m apart on January 23. By February 16, the two areas of thermally-stressed vegetation had increased to about 8000 m^2, and the southern plantation had maxima that had increased by 5° (to 57°) and 17° (to 66°); temperatures at 12 of the 13 stations common to the two surveys had cooled to between 51° and 63°, and 10 of the 11 other survey stations had cooled by between 1° and 6°C. Only the most south-easterly station had heated (by only 1.4°) between the two surveys.

The northern pine area had 4 thermal maxima (of 67°, 85°, 86° and 59°) on January 23, aligned in a north-easterly direction and extending over 185 m. By February 16 the three westernmost of these maxima had cooled to 64° (reduced by 3°), 81 (-4°) and 83° (-3°) but the easternmost one had heated to 63° (+4°). Surrounding stations showed slight temperature changes (4.5° to 6°), with 7 recording cooling and 20 heating. In the next 34 days the 4 maxima had again changed, from west to east, by -2°, -5°, +2° and -4°. Cooling dominated in the area overall with 26 other stations recording a reduction in temperature by between 1° and 6°, but only 6 centrally-located stations became hotter.

The changes in thermal activity observed at Te Kopia over the past 6 months are not great in magnitude; indeed, if they had occurred within the main area of thermal activity (Figure 2) they would probably not have been noticed. Their occurrence in farmland made them obvious. However, any changes in natural thermal activity are noteworthy (especially to the farmer) and reflect subsurface perturbations to the thermal regime at

Te Kopia. The area is tectonically active and lies literally in the shadow of the Paeroa Fault Scarp, which strikes in a north-east direction. However, north-west striking faults, albeit of much lesser offset, also occur at Te Kopia (Keall, 1987; Bignall and Browne, submitted). One has an inferred trace that extends through the newly formed hot ground in the pine plantations. On 28 and 29 November 1993, the Te Kopia area was affected by about 100 shallow focus earthquakes; the two largest had magnitudes of 4.3 and 4.5 (B. Scott, pers. comm.), and several were felt in the Murphy farmhouse (Figure 3). The epicentre of these earthquakes is not known but it seems it was within the Te Kopia area itself. There is no direct evidence linking these earthquakes to the onset of the thermal changes described but it is possible that they affected the shallow subsurface hydrology of the northern part of the field. Past fluctuations in the level of thermal activity in this area are recorded by the presence of small patches of steam-altered ground. Some are now at ambient temperatures but one in the pine plantation testifies to an earlier period of thermal activity here.

Alternatively, the changes observed may be only a response to the low rainfall experienced in 1993. Data kindly made available by the National Institute of Water and Atmospheric Research for the Ngakuru Station, 10 km to the north west, show that 1029 mm of rain fell there in 1993 compared with an annual mean of 1193 ±132 mm. That year was, in fact, the driest year at Ngakuru for the past ten years; it is possible that the reduced volume of water runoff from the Te Kopia scarp has allowed these small thermal areas described to heat as the groundwater table descended.

Changes in the past 150 years

Evidence for changes in the intensity and extent of surface thermal activity since 1859 is provided by: (1) the few descriptions made by scientists visiting the area, starting with von Hochstetter (1864) in 1859; (2) comparing the levels and distribution of activity by interpreting aerial photographs made in 1948, 1984, 1991, 1992.

Von Hochstetter (1864) did not map the extent of thermal activity but pointed out the dangers from landslides being triggered by earthquakes. He described the mud geyser, still active today, and apparently in the same state, and reported vigorous steam discharge from the Te Kopia fumarole itself. There is some doubt as to which fumarole he referred to as there are two large fumaroles now discharging on the crest of the scarp. Von Hochstetter made no mention of the presence of sinter or any pools with clear water, which probably indicates that chloride springs were not then discharging.

Grange (1937) reported briefly on the Te Kopia geothermal area, based on his field work in 1929. Unfortunately he made no map, but there is nothing in his account which implies that conditions were greatly different then than they are in 1994. Healy (1974) published the first map showing the extent of thermal activity and the distribution of some of the main discharge features there; his map was mainly a photogeological interpretation and clearly shows some of the craters and the Central and Northern lakes (see Figure 2). We conclude, therefore, that there is no evidence from the few written accounts available that thermal activity at Te Kopia has changed appreciably in intensity or location during the past 135 years. However, there is an unsubstantiated suggestion that a small hydrothermal eruption occurred in the Northern lakes area in 1886 contemporaneous with the basaltic eruption from Mt Tarawera. The two mudpots on Murphy's Hill enlarged in about 1971, but there is no documentation of this event.

Preliminary interpretation and comparison of thermal activity on aerial photographs taken in 1948, 1984, 1991 and 1992 show several differences in the extent and distribution of altered ground and thermally-stressed vegetation in the northern part of the Te Kopia area.

There have also been changes in the chloride contents of the largest pond in the Central lakes region (Figure 2). Grange (1937) reported it as containing 113 mg/kg Cl; by 1965 this had increased to 142 mg/kg Cl (Mahon, 1965), but analyses made in 1993 gave values of less than 33.6 mg/kg Cl (Bignall and Browne, submitted). A small amount of ascending chloride water therefore still reaches the surface in the low elevations of the Central lakes, but the proportion of chloride water relative to steam condensate and meteoric water fluctuates. Not enough alkali chloride water reaches the surface in this area, however, to cause silica sinter to precipitate.

Changes in the past 75,000 years

Evidence for changes in near-surface geothermal activity at Te Kopia is as follows (Bignall, 1994; Bignall and Browne, submitted):

(1) The occurrence of silica sinter in the Central Lakes area, but about 5 m above the present lake levels, which C^{14} dating shows deposited 3026 ±43 years BP. Alkali chloride waters were therefore discharging here at that time.

(2) The presence of at least two separate deposits of hydrothermal eruption breccias, although it is not certain that either derive from craters in the Northern or Central Lakes areas (Figure 2). The relationships between the eruption breccias and interbedded tephras indicate that two eruptions occurred between 186 AD and 22,700 years ago.

(3) Extensive deposits of breccias produced by large landslides. Tephrochronology indicates that these occurred before and after a 22,700-year-old volcanic event at Lake Taupo and since 186 AD. Occasional clasts in these landslide breccias are hydrothermally altered (including mordenite, quartz and adularia), proving that geothermal activity was taking place on the scarp before these landslides occurred. It seems most likely that episodic movement on the Paeroa Fault triggered the landslides.

(4) The widespread overprinting of hydrothermal alteration minerals in rocks exposed on the fault scarp. For example, rocks originally altered in the subsurface to a quartz-illite assemblage are now partly replaced by kaolinite. In the most strongly overprinted rocks, the products are a mixture of quartz, pug, kaolinite, cristobalite and alunite (Bignall, 1994).

(5) The presence of rocks now at the surface containing hydrothermal minerals that formed deep (>250 m) within a geothermal reservoir; for example, adularia, illite and chlorite.

(6) The occurrence of euhedral quartz crystals on the ground in two areas east of the Paeroa Fault. These contain liquid-rich fluid inclusions that homogenise at 196 ±11°C and 188 ±15°C. Consideration of the boiling temperature versus depth conditions indicate that one set of quartz crystals grew at depths at least 170 m below ground surface (trapped fluids are of low apparent salinity, < 0.4 wt % NaCl equivalent). Crystals now occur on the upthrown fault block at elevations 145 ±5 m above the floor of the Te Kopia Valley. These crystals have thus been uplifted by at least 315 m. By similar reasoning, the other set of quartz crystals, now 180 m above the valley floor, have ascended at least 300 m since their formation.

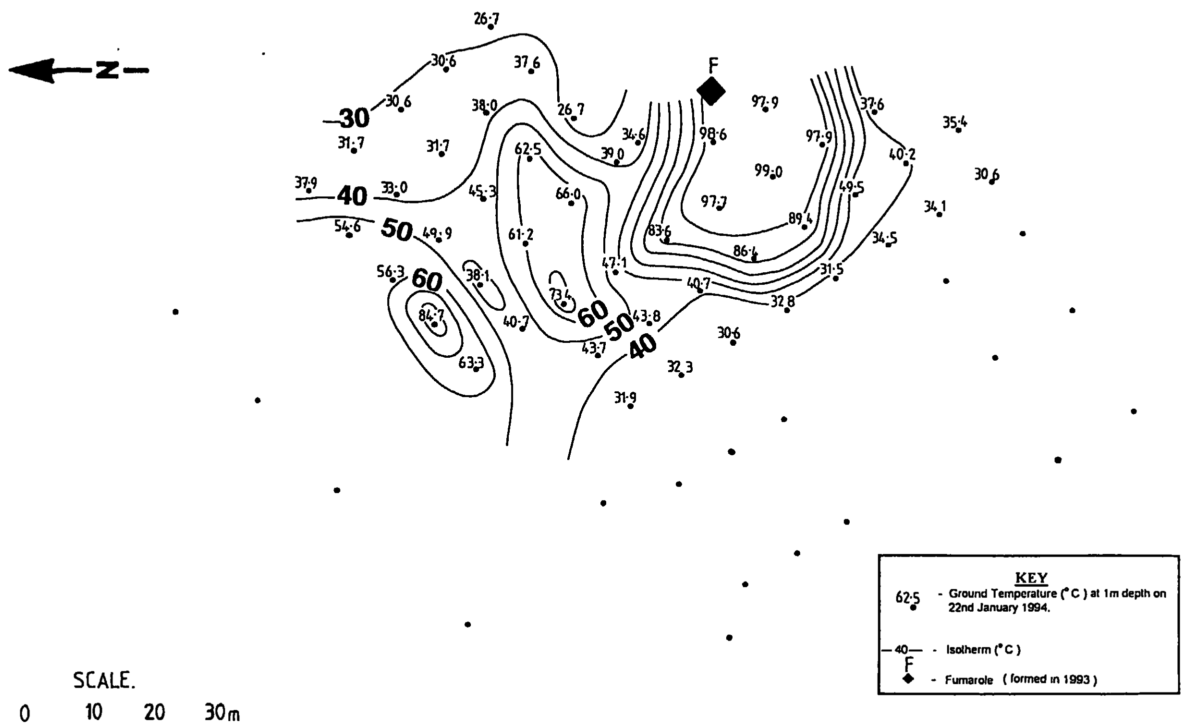

FIGURE 4. Contoured temperature profile map of Murphy's hill area, showing ground temperatures at 1m depth on 22nd January 1994.

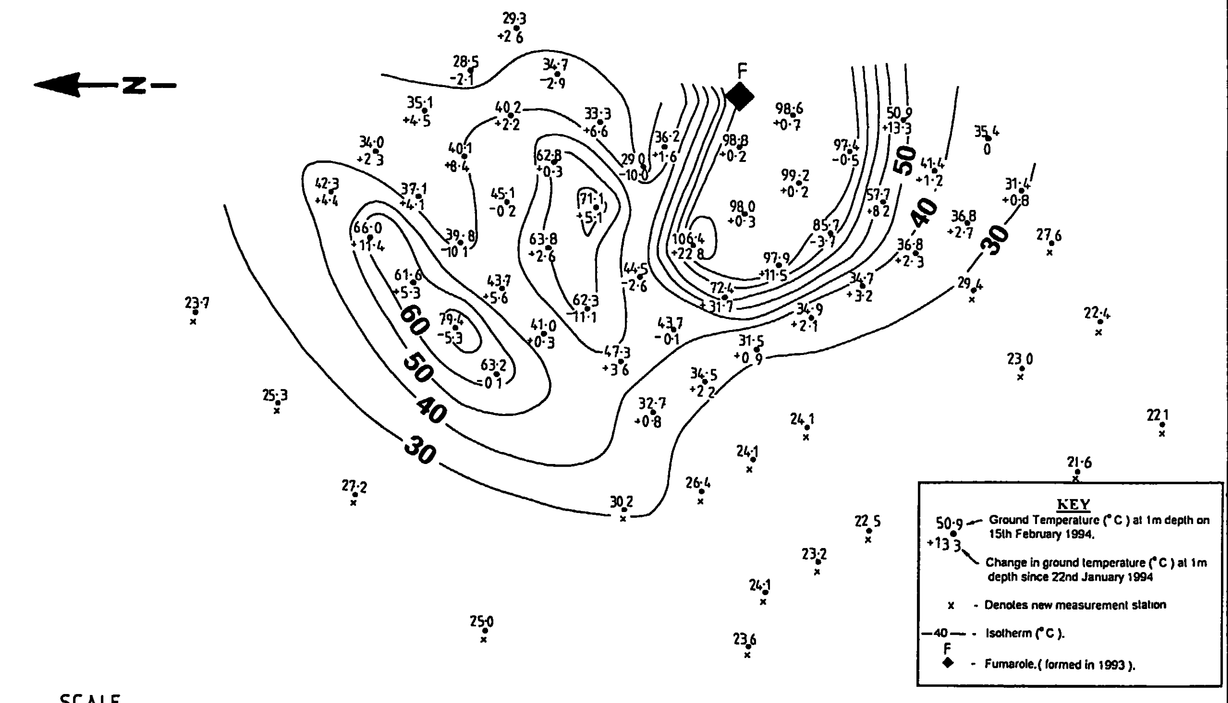

FIGURE 5. Contoured temperature profile map of Murphy's hill area, showing ground temperatures at 1m depth on 15th February 1994 and also changes that have occurred since 22nd January 1994.

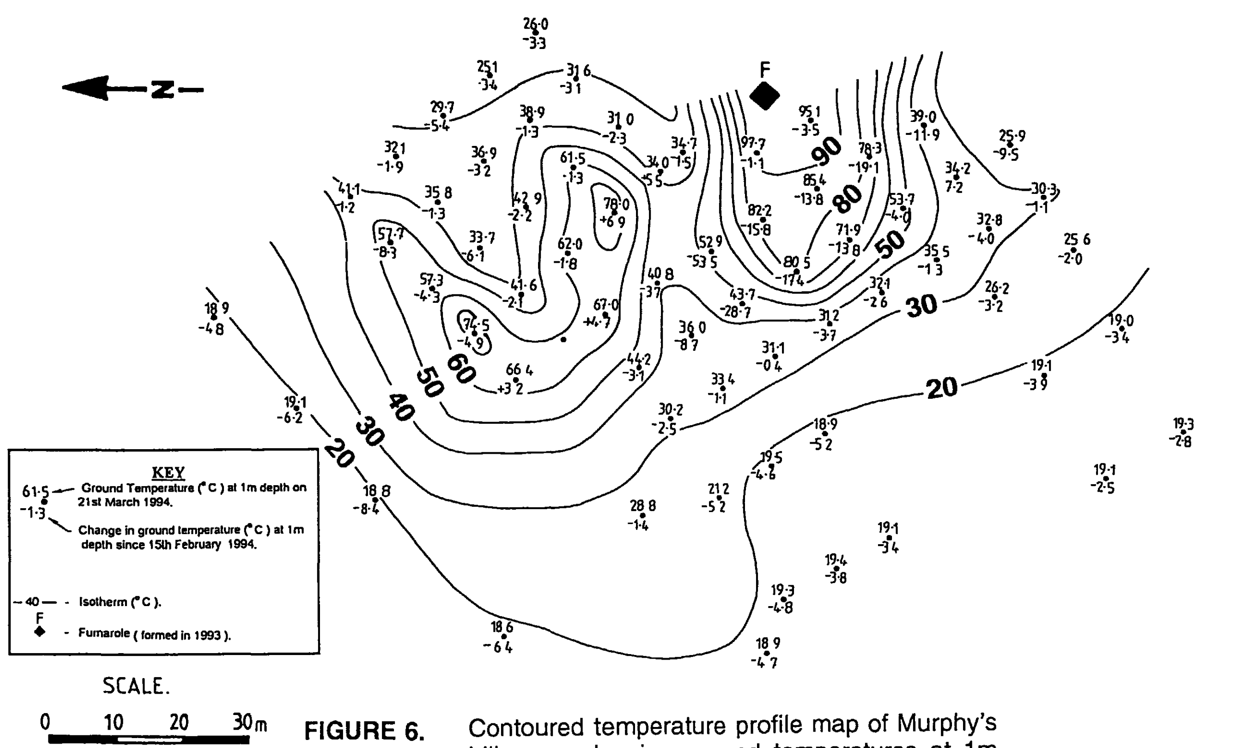

FIGURE 6. Contoured temperature profile map of Murphy's hill area, showing ground temperatures at 1m depth on 21st March 1994 and also changes that have occurred since 15th February 1994.

CONCLUSIONS

Evidence and observations show that surface thermal activity at Te Kopia has changed constantly during the lifetime of the system, believed to be at least 75,000 years but possibly 15,000 years (Bignall, 1994). Many of these changes are slight and have gone unrecorded, but others have left their marks in the geological record. The location of the Te Kopia field on a major active tectonic feature (Paeroa Fault) has allowed interplay between hydrology and fault movement.

Most major displacements on the fault resulted in a change in hydrology of the geothermal field, probably caused landsliding, and perhaps some movements triggered hydrothermal eruptions. Because of the sensitivity of a geothermal system in such steep terrain, short and long term climatic changes also probably affected surface thermal activity, for example, long term and annual differences in rainfall.

Progressive uplift of the eastern block of the Paeroa Fault has now exposed rocks once at least 300 m below ground surface in the bowels of the geothermal reservoir. Their alteration records these changes through textural overprinting, and provides information about temperatures and fluid types then present in the former reservoir.

In the past 3000 years, the piezometric surface has been descending so that chloride waters now mostly discharge only in the most western part of the field, hundreds of meters distant from where they did so formerly. Drilling shows that temperatures in the present reservoir exceed 240° at a depth of 1200 m. The Te Kopia field is still very active despite its longevity.

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