

SOIL GAS SURVEYS: A CHEAPER ALTERNATIVE TO GEOPHYSICAL SURVEYS: THREE EXAMPLES FROM THE TAUPO VOLCANIC ZONE

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ABSTRACT

Soil gases have been used for some time to attempt to delineate geothermal reservoirs. Soil, CO₂ and mercury surveys carried out in the well studied Wairakei/Tauhara Corridor, the Waiotapu/Reporoa outflow and at Mokai, to test techniques and compare results with geophysical resistivity surveys. Areal concentration variations of these gases were similar in pattern, and similar to resistivity contours, and so have potential for detailed interpretation of shallow sub-surface hydrology.

INTRODUCTION

Geothermal systems are dynamic hydraulic systems which exsolve gases. The dominant gases evolved are CO₂, H₂S, H₂, CH₄, and N₂, while other components such as Hg must be regarded as trace gas components. Enhanced mercury on soil has long been used to delineate ore bodies and, more recently, geothermal systems, although the differentiation between background and elevated levels is sometimes subtle, especially above ore bodies. Few studies have been made on soil gases overlying geothermal systems in New Zealand and most of these have concentrated on radon, and derived radioisotope studies, with some interesting but mostly inconclusive results (Whitehead, 1981, 1984, 1985; Koga, Taguchi and Mahon, 1982; Whitehead, Gingencho and Fisher, 1983).

The hypothesis underlying the method assumes that gases, and volatiles such as metallic mercury, evolve from the deep geothermal fluid during boiling in response to pressure and temperature changes, which occur during upflow. Chemical reactions will tend to remove reactive components of the gas in the overlying rocks and soils (eg. NH₃ and H₂S), and water soluble gases will be depleted should the upflowing gases interact with cold groundwaters. There is thus the potential for deriving structural and hydrologic information about the reservoir, as a result of these properties, and as a result of the differing solubilities of different gases, should they be able to be determined and mapped in the soils.

One of the major problems in using soil gases is the influence of sources other than the geothermal system. Such sources can be the lithology, the atmosphere, and biological activity. Isotopic analyses can usually be used to differentiate these sources.

Surveys were made, in 1988, in three areas in the Taupo Volcanic Zone (Sheppard, Orange and Humphries, 1988), using some techniques developed by French scientists, for looking at volcanic CO₂ in soils, the flows of this CO₂ (Tazieff, Chevrier, Faivre-Pierret and le Guern, 1987).

This report is a summary of the work done in 1988 and fully reported in Sheppard, Orange and Humphries, 1988.

METHODS

A number of traverses were made in each field, sampling at approximately 500 m intervals. The locations of the area surveyed are shown on Figure 1, and were:

- (1) the Waiotapu outflow (Healy and Hochstein, 1973) being from the southern edge of the Waiotapu geothermal field, to Golden Springs;
- (2) Mokai, from Mokai village north to the Waikato River, over the northward sub-surface outflow (Lloyd, 1978; Henley and Glover, 1980; Henley and Plum, 1985; Bibby et al, 1981);
- (3) the Tauhara/Wairakei "corridor" or the connecting neck between these two fields (Banwell and MacDonald, 1965; Henley and Stewart, 1983; Risk et al, 1983).

Each of these features has been subjected to resistivity surveys, the results of which are available (Figures 2a, 3a, 4a). This is one reason why they were chosen as study areas.

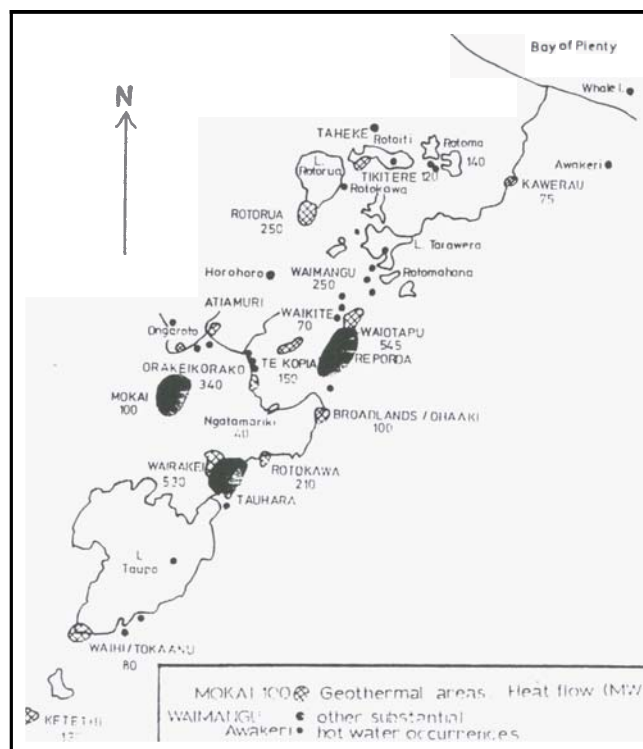


Figure 1: Location of study areas in the Taupo volcanic zone (solid). Other geothermal fields and their approximate heat flows are also indicated.

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We attempted to sample for mercury vapour, mercury in soil, and soil gas CO_2 . Samples for mercury were collected and analysed later; CO_2 analyses were performed on the spot, using either an IR CO_2 analyser (Reporoa, Mokai) or a portable gas chromatograph (Tauhara/Wairakei). Mercury vapour was collected on gold traps and analysed on the same day, but gave erratic or nil results. Soil mercury was determined in the laboratory by heating the samples to 360°C and collecting the evolved mercury for analysis.

Soil samples were taken from the bottom of a 0.6 m, 2.6 cm diameter hole, while gas samples were pumped from a sealed 1 m deep 2.6 cm diameter hole (Reporoa, Mokai) and the bottom 20 cm of a 1 m deep hole (Tauhara).

Gases were pumped and analysed until constant compositions were obtained in sequential analyses. The instruments were calibrated in the field.

RESULTS

The concentrations for soil mercury and CO_2 contours interpolated from the measurements are displayed in Figures 2b, 3b and 4b, and Figures 2c, 3c and 4c respectively.

Attempts were made to ascertain statistical correlations between factors such as weather, soil texture, vegetation and the concentrations. The only strong correlations were between CO_2 and Hg concentrations and the resistivity. The conclusion must therefore be that in these systems, for these variables, the anomalies are large so that possible interferences (such as those above) have relatively minor influences.

Figure 2 compares the 600 m resistivity contours and geothermally active areas, both mercury concentration contours and soil CO_2 content contours, for the area between Waioatapu and Golden Springs. The contour maps have a number of similarities:

- (1) distinct North to South elongation;
- (2) areas of high concentrations match the areas of low resistivity, more or less, and these tend to be near (but not necessarily superimposed on) geothermally active areas;
- (3) all maps indicate flow structures, from west to east, most strongly in the CO_2 contour map.

Differences between the maps are of considerable interest. For instance, the displacement of maxima or minima from the areas of geothermal activity differs on the three maps. Resistivity lows coincide with the Opaheke geothermal area, northwest of Reporoa, and do not indicate the smaller features at all. These resistivities are soundings to 500 m, and indicate the structure at that depth. Soil mercury contents are elevated to the east of the active areas while high CO_2 contents seemingly corresponding to the active areas are superimposed or displaced to the east or west. It is interesting to speculate on what these mean by way of sub-surface hydrology.

The Mokai contours (Figure 3) tell a similar story, with a south to north lobate structure seemingly closely associated with the fault's structures as illustrated in Figure 3a, especially in the east of the field. The reliability of the soil gas contours are adversely affected by the sparsity of the data in some areas, but the general shapes are similar. Worth noting in all three maps is the definite closing of the anomaly to the south (where the fluid is thought to upwell at depth (Henley and Plum, 1985)).

A strong resistivity trough at 500 m depth, to the northeast to the Waipapa Springs site, is shown also by mercury contours, but much less distinctly by the CO_2 contours. The Mokai system is relatively low in gas (Henley and Plum, 1985) which may be the explanation for the small range in mercury and CO_2 concentrations measured. Despite

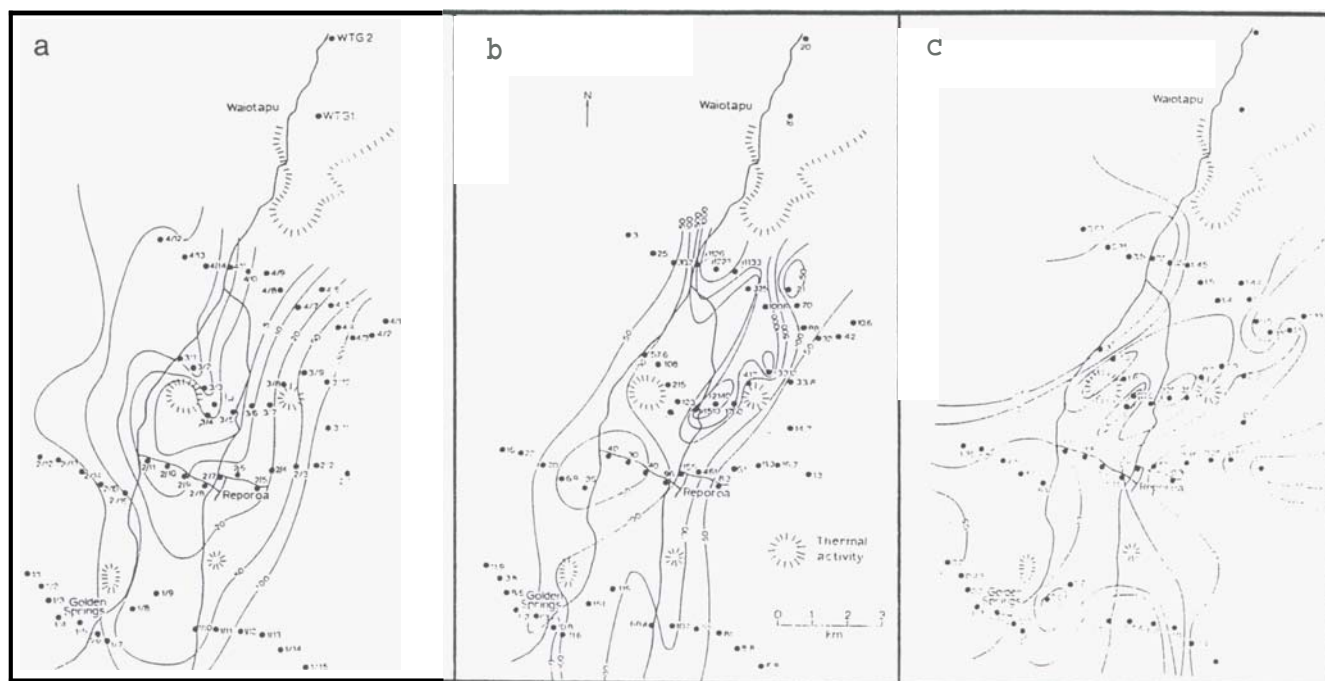


Figure 2: Reporoa area

- (a) 500 m resistivity contours (MacDonald, pers. comm., 1988) sampling points and areas of thermal activity
- (b) soil mercury contours. Measured values are indicated in ng/g
- (c) soil CO_2 contours; values are vol %

this, the concentrations are measurable and reasonably easily contoured.

The complex pattern of contours near the lake may be an artifact of a concentration interval close to background, or it may be related to outflows **into** the river, **known** at one place, and tapped by a well west of the Waipapa Stream. The conclusion could be drawn, from the evidence of the three maps, that hot water is upwelling in the south and flowing at depth, northeast, controlled largely by structural features, and spreading north and west at shallower depths, as a sheet, towards the topographic low of the Waikato River valley. This shallow structure is not revealed by the 500 m resistivity survey.

The Wairakei/Tauhara situation (Figures 4a, 4b and 4c) is **more** complex than either of the previous examples. The resistivity pattern (Figure 4a) is elongated north and south, with a complex western boundary, comprising a ridge between Tauhara and Karapiti/Wairakei. Soil gas surveys were carried out over and to the east and north of this zone. Quite complex patterns are revealed, matching the tight changes in resistivities in the area of the river valley. Of particular interest is the resistivity high about Huka Falls, associated perhaps with the tight ignimbrites in this area. The resistivity soundings show a low resistivity trough between Huka Falls and Karapiti (Banwell and MacDonald, 1966) whereas the soil gas components are low over this region, and are high along the river valley. This information can be interpreted as indicating that while at depth (500 m) the geothermal fluid **flows** west and east of the river valley, skirting the ignimbrites perhaps, at shallower levels it upwells along the river valley for quite **some** distance. The detail of this area may be instructive and the results of a resurvey with finer intervals will be reported **at** the meeting.

A zone of elevated soil gas concentrations is evident on the hills east of the Wairakei Power Station, indicated by only one soil Hg analysis, but also by two elevated soil CO₂ concentrations. There is a little evidence of high CO levels north of the power station; this may only be a remnant of the original field boundary, or an artifact of the contouring exercise. Both of these features will **be** investigated before the meeting.

Other gases could be of use. An obvious one is hydrogen, which should permeate rapidly from the deeper reaches of a system. By using a selection of gases with differing properties, aspects such as **flow** direction, deep upwelling zones and overlying groundwaters, should be apparent.

CONCLUSIONS

Soil gas determinations over geothermal systems would **seem** to be of considerable potential usefulness, as a compliment to and alternative to expensive geophysical techniques such **as** resistivity surveys, for delineating the structure and hydrology of the systems. Considerable work remains to be done, to gain **an** understanding of the behaviour and properties of **exsolved** gases, and **so** being able to interpret the results of the surveys.

ACKNOWLEDGEMENTS

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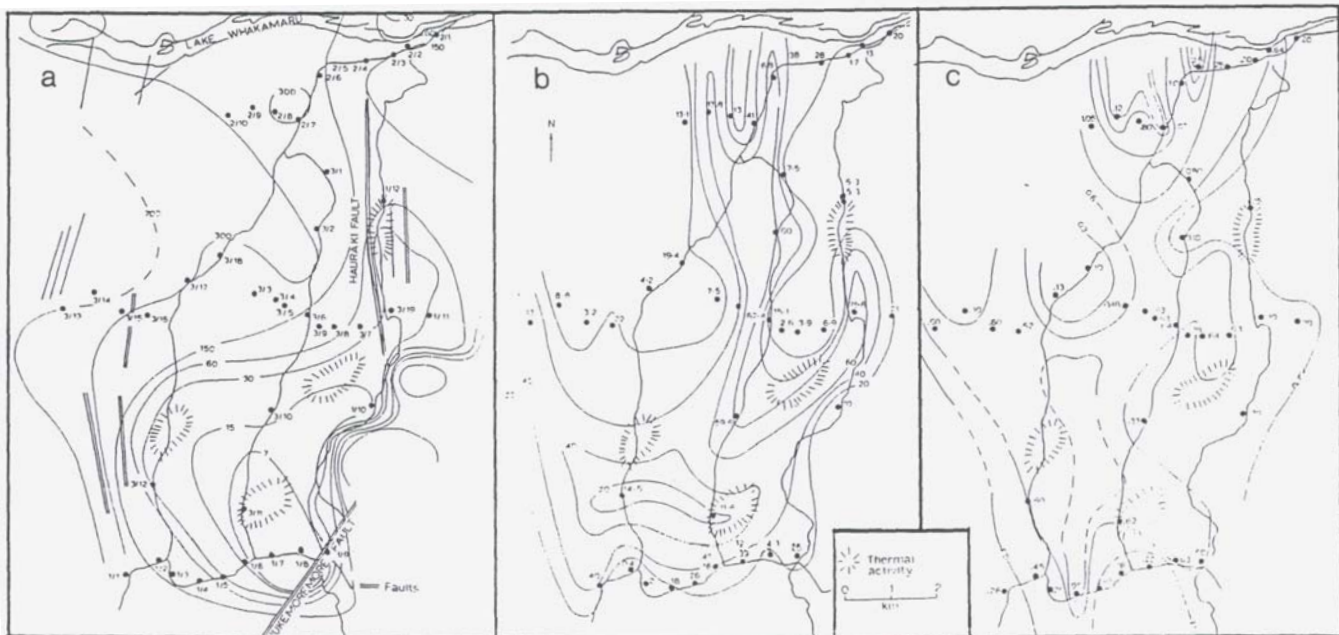


Figure 3: Mokai area

- (a) 500 m resistivity contours (Bibby et al, 1981), fault locations (E.F. Lloyd, pers. comm., 1988), areas of thermal activity and sampling point locations
- (b) soil mercury contours, in ng/g
- (c) soil CO₂ contours, in vol %

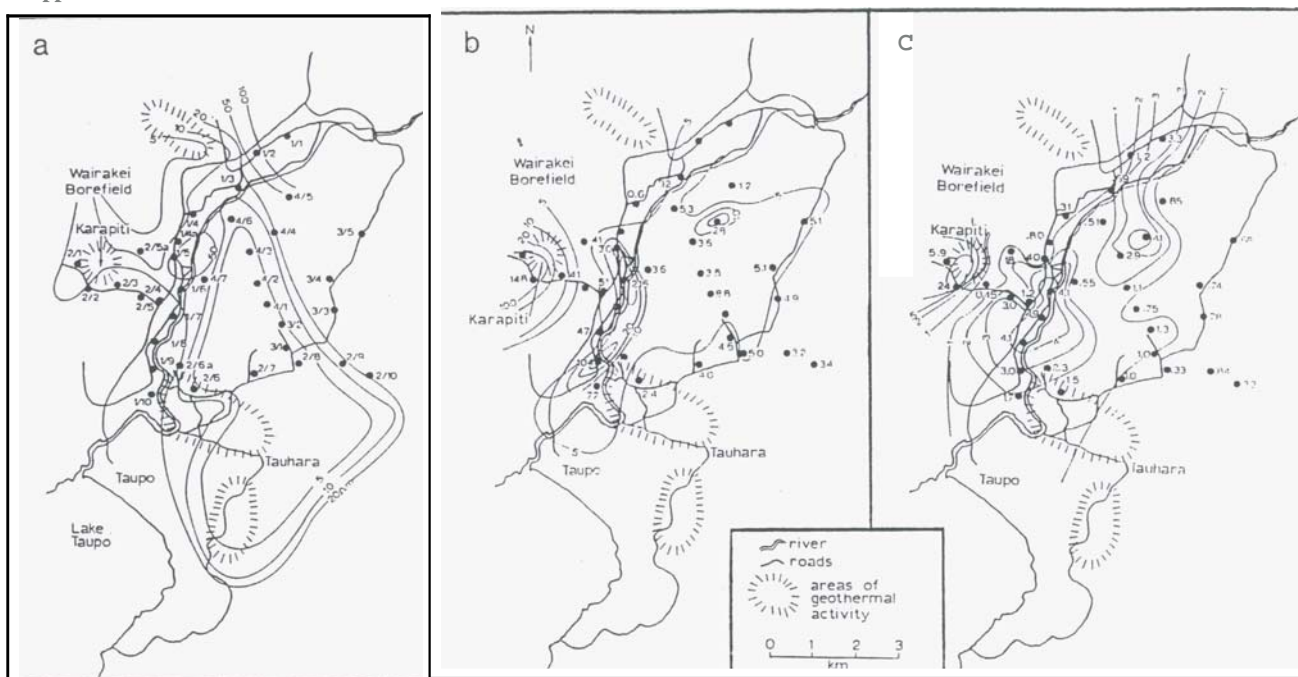


Figure 4: Wairakei\Tauhara area

- (a) smoothed resistivity contours (500 m at Wairakei - Risk et al, 1983; 560 m at Tauhara - Banwell and MacDonald, 1966), sampling points and areas of thermal activity
- (b) soil mercury contours. Measured values are indicated in ng/g
- (c) soil CO₂ contours, values are in vol %

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