Proc. 10th New Zealand Geothermal Workshop 1988

SOIL GAS TRACE METAL TRANSPORT - THE GEOGAS METHOD APPLIED TO NZ EPITHERMAL AND GEOTHERMAL ENVIRONMENTS

B.W. Christenson*, L. Malmqvist+, K. Kristiansson+, and J.B. Finlayson*

*Chemistry Division, DSIR, Wairakei, New Zealand
+Dept of Nuclear Physics, Lund Institute Technology, Lund, Sweden

ABSTRACT

A relatively new soil gas collection technology has been tested on two New Zealand epithermal gold deposits and one active hydrothermal system with the aim of ascertaining its usefulness as an exploration tool in these environments. The method successfully identified the trace levels of base metal mineralisation associated with hydrothermally altered units at both the Golden Cross deposit in the Coromandel Peninsula and the Ohakuri prospect in the Taupo Volcanic Zone, and detected gold in a single site over the Golden Cross deposit.

Two surveys at the Rotokawa hydrothermal system have proven the method to be successful at delineating both zones of shallow permeability and areas of sulphide mineralisation.

INTRODUCTION

The analysis of key soil gases overlying buried ore deposits is a common exploration technique in the minerals industry, particularly in terranes where there is extensive overburden (e.g. the review paper of McCarthy and Reimer, 1986). Such techniques have also been applied to the study of geothermal systems with the aim of defining both the structure and the boundaries of geothermal reservoirs (see Koga and Mahon, 1982; Hinkle, M.E. 1980; and Whitehead, 1984).

This paper reports on the NZ application of a passive collection technique which has been used successfully in the exploration for base metal sulphide deposits in Europe, the United States and Saudi Arabia. Here we apply the so called GEOGAS method (Kristiansson and Malmqvist, 1988) to two known epithermal gold deposits in the Taupo Volcanic Zone and Coromandel Peninsula, and to the Rotokawa geothermal field, a well studied active hydrothermal system located about 20 km northeast of Taupo. The aim was to test its usefulness not only from an epithermal metals exploration standpoint, but also as a guide to shallow, permeable structures in the active hydrothermal environment.

GEOGAS BACKGROUND AND CONCEPTS

The GEOGAS method is founded on the premise that there exists in the upper earths crust a small but measurable, upwardly streaming microflow of free gas which is capable of serving as a carrier for trace quantities of rock matter. The existence of such a non-diffusive transport mechanism has been demonstrated both indirectly in controlled soil gas Rn experiments (Kristiansson and Malmqvist, 1982), and by direct measurement of the carrier flux in drill holes at three mining areas in central Sweden (Malmqvist and Kristiansson, 1984).

Analysis of the carrier gases at two of the three study areas in Sweden showed them consisting of varying ratios of air constituents, with nitrogen dominating (from 77.9 and 94 vol. %), argon ranging from 0.9 to 1.2%, and oxygen contents varying between 5.2 and 19.6%. Methane was also present as a minor or trace constituent at these locations, but was found to be a major constituent in the third study area where it comprised as much as 54.4% of the total flow, and varied inversely with oxygen.

The origins of these carrier gases are largely atmospheric, but with local contributions of methane from biogenic reactions, or interactions between pore fluids and graphitic shale units as in the methane rich example above (Malmqvist and Kristiansson, 1984). However, the possibility of a small, but hitherto undetected mantle contribution cannot be excluded.

Local exsolution of these gases from saturated groundwater is predicted as a response to meteoric flow along pressure gradients, pressure shocks or other disturbances (Kristiansson and Malmqvist, 1982). Flow rates of up to 4 $cm^3/min\ m^2$ were recorded in the above studies in central Sweden, a very old and tectonically inactive cratonic terrane. Higher flows were expected in more juvenile terranes such as the Taupo Volcanic Zone where there are also hydrothermal and/or volcanogenic components in the flow.

The transport mechanism is portrayed schematically in Fig. 1. Below the water table, the upwardly streaming bubbles are presumed to possess sufficient binding energy at their gas-liquid interface to effectively scavenge a small but significant quantity of dissolved constituents from solution. The bubbles then stream upward to the pisometric surface, from where the dissolved constituents are carried via a less efficient aerosol mechanism. A special ^{222}Rn study over a large underground mine in Central Sweden revealed transport velocities of as high as 10 m/day (Kristiansson and Malmqvist, 1982), although these rates are not necessarily representative of unperturbed, steady state systems.

Evidence from the ^{220}Rn studies also suggests that flow is restricted to the more permeable fracture channels rather than intergranular pore networks which would tend to be inherently "sticky" to such bubble transport. The primary usefulness of the method, from a metals exploration standpoint, stems from the fact that flow through fractures penetrating an ore body at depth will necessarily pick up not only the traditional indicator or tracer constituents associated with the ore, but also the ore metals themselves, ultimately delivering the ore matter to the surface environment.

COLLECTION AND ANALYSIS

The collection system consists of an inverted funnel apparatus which focuses the flow of geo gas past a 20 ug/cm polystyrene membrane. The polystyrene, which serves as an adsorption surface for the transported matter, is mounted on a glass backing to facilitate handling, and is housed inside a moulded plastic beaker assembly which is designed to channel flow past the membrane. To guard against atmospheric contamination, the entire apparatus is

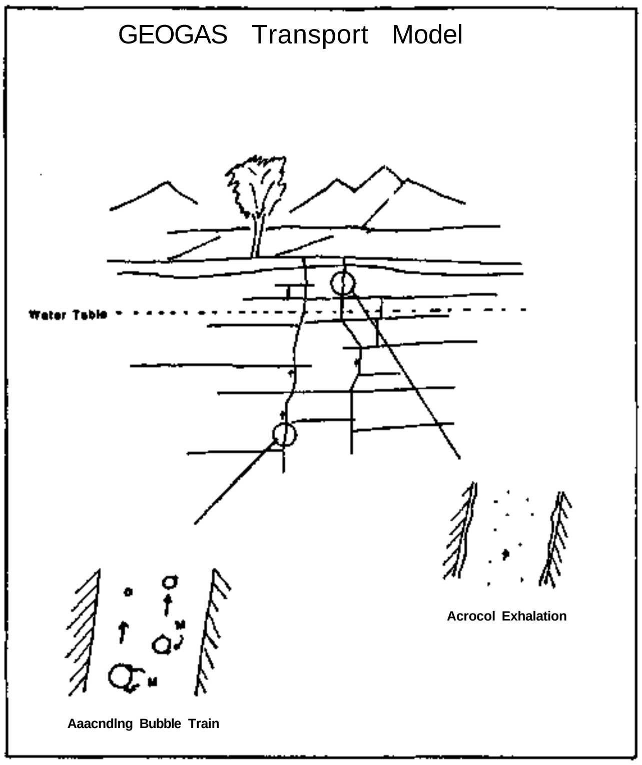


Fig. 1. Schematic diagram of GEOGAS transport mechanism. Below the water table, ascending bubbles carry individual atoms and/or atom clusters m along the gas-liquid interface. Above the water table, the gas flux carries the matter in an aerosol suspension.

buried at a depth of ca. 50 cm for exposure periods ranging from 22 to 91 days in fossils systems, but for periods as short as two hours in active areas such as Rotokawa where the carrier flux is locally extraordinarily high.

The trace amounts of matter thus collected are analysed by by the PIXE method (Johansson and Johansson, 1976). The exposed membranes are bombarded with protons having an energy of 2.55 MeV, which is sufficient to excite inner electron shells of the collected matter, thus generating characteristic X-ray spectra. The analytical method is most sensitive for elements in the atomic number range $14 < Z < 33$; data for atom numbers < 14 are unobtainable due to absorption of their characteristic X-rays by the detector windows on the instrument. Data are obtainable for those elements having $Z > 34$, but with somewhat diminished sensitivity.

As this is an ultra-trace, analytical method (sensitivity is on the ng/cm^2 level), the possibility of contamination is a constant concern. Therefore utmost care is taken to guard against contamination during transport to and from the exposure sites, and unexposed control samples provide correction factors on background contaminations.

DATA HANDLING

An indication of the total flux which passes through a collector system is gained from the amounts of common rock forming elements which are retained by the membrane. Therefore, the analytical quantities of Si, K, Ca and Fe are summed into a parameter which is subsequently used to normalise trace metal contents to flux independent values. In this way, the metal values are directly comparable and indicative of metal anomalies encountered along the flux path.

All data are normalised to 45 collection days so to facilitate inter-study comparison.

NEW ZEALAND EPITHERMAL ENVIRONMENTS

Studies were made at two well known epithermal deposits in New Zealand, namely at Golden Cross in the Waitekauri Valley, northwest of Waihi (Cyprus Minerals Inc.), and at Ohakuri in the Central TVZ (a B.P. Minerals holding).

The Golden Cross deposit is characterised by a lobate ore body of high grade stockwork mineralisation carrying up to 7.2 g/T gold and 17.3 g/T silver. This is unconformably overlain by up to 140 m of late to post mineralisation andesite (Fig. 2; de Ronde, 1985; Keith Hay, pers. comm., 1988) which thins to the west. The gold is hosted by quartz/calcite veins, and is accompanied by trace amounts of sulphide mineralisation.

The GEOGAS traverses were designed to cross the present day regional structures at high angle, so to increase the likelihood of intersecting high flux rates. The main traverse (shown in Fig. 2) was some 1.5 km long with sensor spacings ranging from 10 to 200 m apart, being more densely concentrated over the main ore zone. Results for the base metals Cu and Zn show very strong anomalies at roughly 3200E and 3260E, over the main stockwork zone, and another at about 3800E (Fig. 2). There were locally anomalous levels of Cl, Br and As over the ore zone, as well as a single occurrences of gold, tin, tungsten and silver at the 3200E m grid site. As depicted in Fig. 2, this location directly overlies the highest grade gold ore at depth.

The method appears to have accurately detected the mineralisation over the 3100E to 3300E interval where the base metals prove an association with gold. The nearest drill hole to the 3800E Cu anomaly, on the other hand, revealed only sulphide bearing argillic alteration underlying the unaltered andesite with little or no gold over this drilled interval (Keith Hay, pers. comm, 1988). Whether the method indicates a deeper, hitherto unrecognised gold mineralisation, or simply a wider aureole of base metals surrounding the gold anomaly will require further study.

Similar base metal and halogen group anomalies were recorded at the Ohakuri prospect. Here the mineralised units breach the surface, and although the method successfully detected the boundaries of the mineralisation, gold was not identified on any of the membranes making the base metal - gold association less defined.

Since the target element in the epithermal environment, ie. gold, has a high atomic number ($Z = 79$), the PIXE analytical method is somewhat less sensitive to its detection than, for example, the lighter base metals. This, coupled with the fact that most epithermal gold deposits are economic at relatively low levels of Au content (often at a few ppm Au) indicates that further studies will be required to:

1. further delineate the association between the commonly detected elements and gold occurrence; and
2. determine the sensible gold concentration - exposure time - flux relationship so to facilitate the estimation of gold content in prospective ore body. The fact that gold was detected at Golden Cross suggests that we are close to some threshold detection limit with our present approach, and that further work will improve our abilities to "see" this metal of interest.

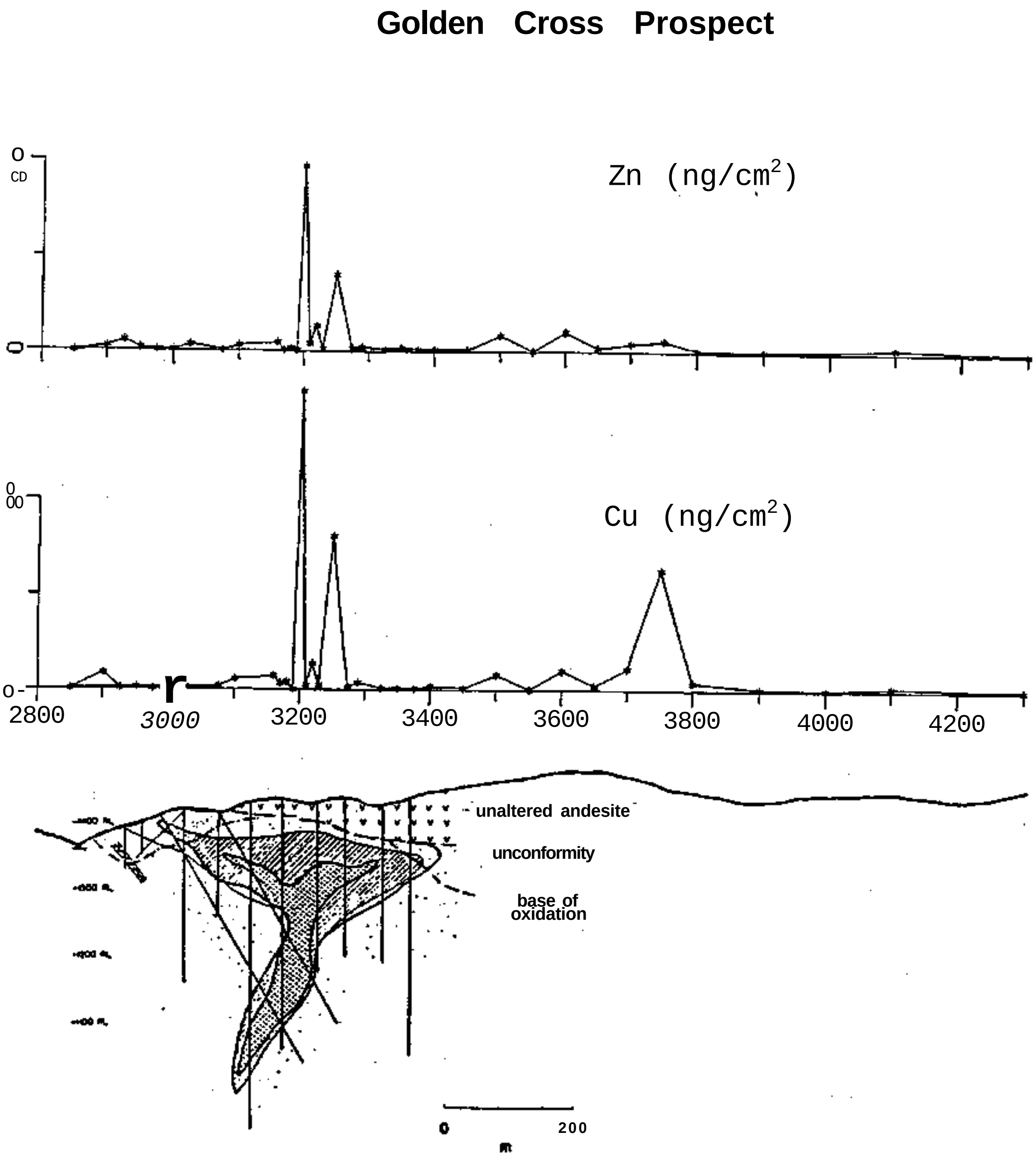


Fig. 2. Copper and zinc anomalies over the Golden Cross deposit. Alteration schematic after de Ronde (1985) shows the location of the main ore body.

ACTIVE SYSTEMS STUDY - THE ROTOKAWA GEOTHERMAL FIELD

Application of this method to the active hydrothermal system at Rotokawa (Fig. 3a) is of interest not only because the system is presently ore forming (Krupp and Seward, 1987), but also the high gas flux from the field makes the method amenable to the study of shallow reservoir structures and processes.

Two surveys have been completed at Rotokawa thus far. A preliminary study was carried out in October of 1987 to determine suitable membrane exposure times. Here a total of just 20 sensors were placed at 11 stations having approximately 1 km spacings. The sampling locations were chosen along a NW-SE line so as to: 1) cross the regional NE structural trends at high angle; 2) fall along existing roadways both within and outside the apparent resistivity anomaly; and 3) cross areas of both thermal and non-thermal ground within the anomaly. The exposure times were set at 10 days, with the exception of a single sample placed for two hours at a site on the shore of Lake Rotokawa.

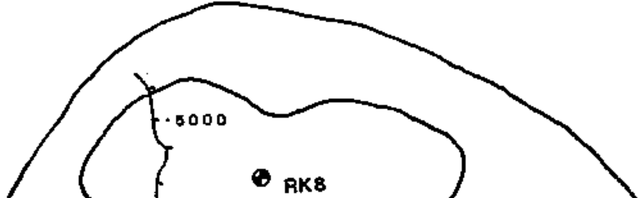
Notable findings of the first test were: 1) the large flux values over the system generally; and 2) the *very* large quantity of matter collected on the membrane placed in thermal ground adjacent to Lake Rotokawa. Here the collector hole was dug into the highly mineralised, olive green siliceous muds described by Krupp and Seward (1987). There was a high local discharge of gas in this area, as evident from the very ebullient pools located within a few metres of the sample site. The sample site was also very close to the local water table, as hot (65°C) fluids were intersected at 30 cm depth. On collection, there was noted a small but sustained bubbling of gases from the bottom of the sample pit.

Although the membrane was exposed at this locality for just 2 hours, the analysis revealed, after normalisation to a common residence time of 45 days, roughly two orders of magnitude more metals than observed at any of the other sample localities.

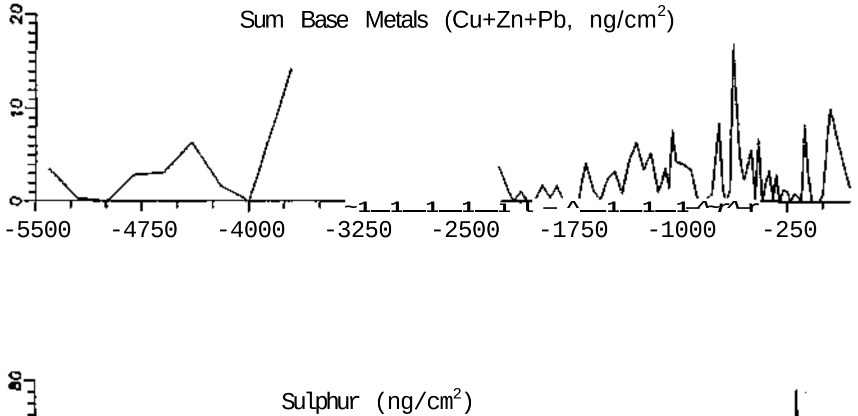
Rotokawa Geothermal Field

GEOGAS Sample Traverses

a.



b.



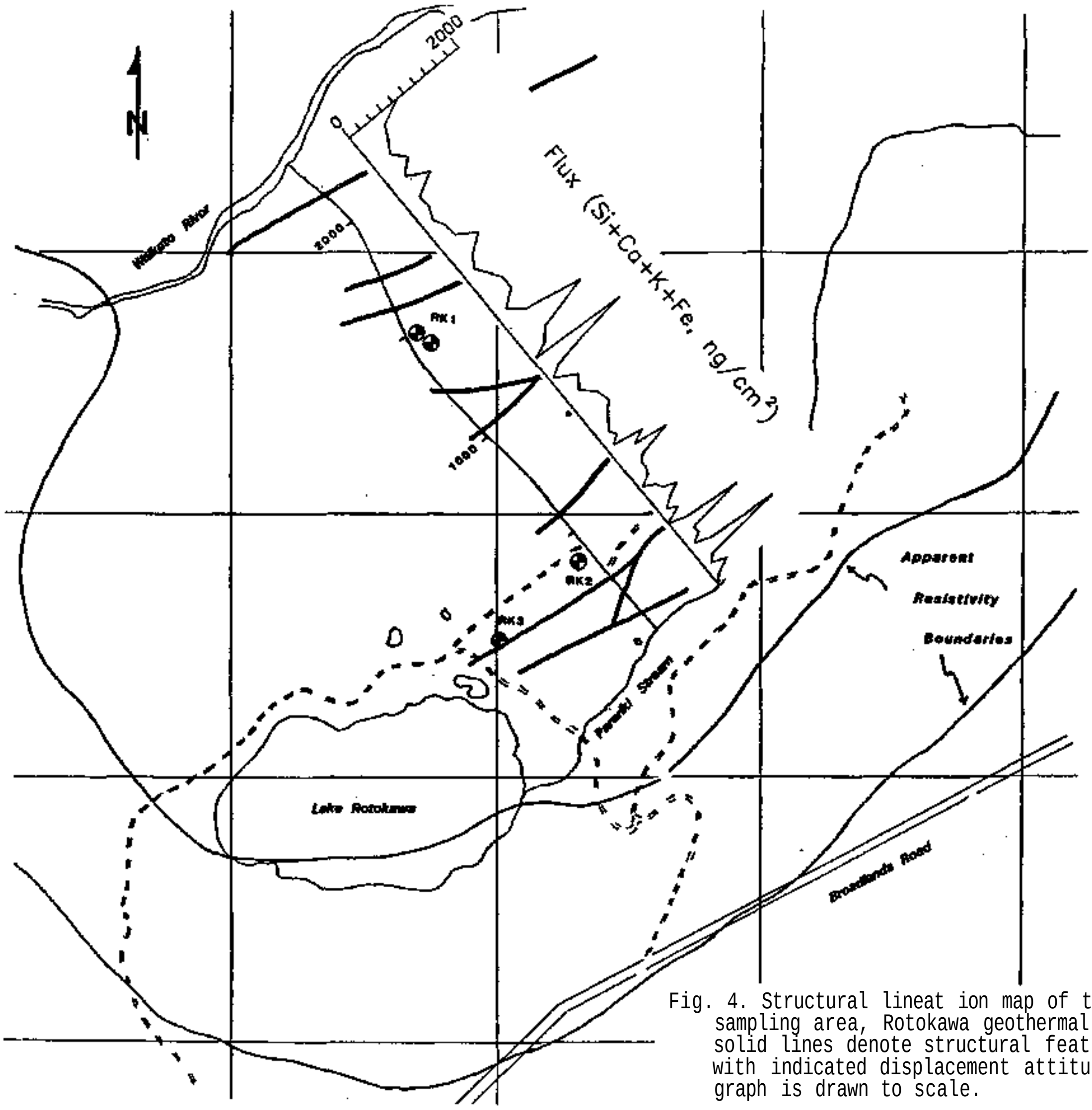
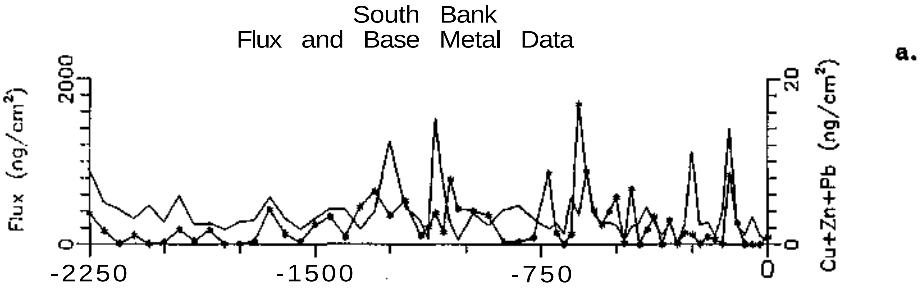


Fig. 4. Structural lineation map of the south bank sampling area, Rotokawa geothermal field. Heavy solid lines denote structural features, some with indicated displacement attitudes. Flux graph is drawn to scale.



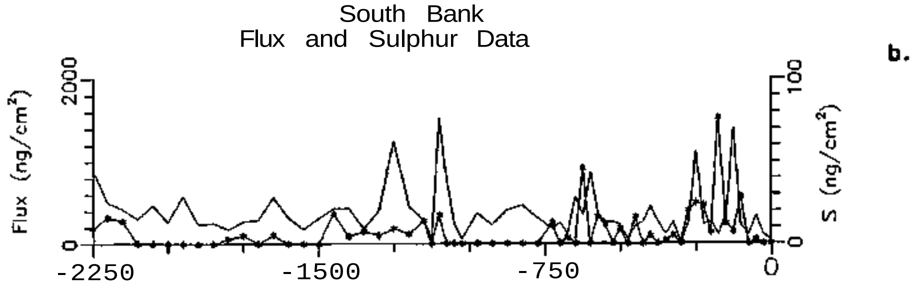


Fig. 5. Comparison of flux parameter (solid lines) with total base metals (a.) and sulphur (b.; both plotted with * symbols).

In order of decreasing abundance, anomalies were recorded for S, Pb, Cl, Zn, Ti, Cu, As and Ni. This provides strong support for the non-diffusive transport mechanism described earlier.

The second survey was completed in February along the same transect (shown in Fig. 3a). The main focus of this study was on changes accompanying the transition from thermal to non-thermal ground south of the Waikato River. A fairly high density survey was laid out starting at the Parariki Stream and extending NW, with 25 m spacings along the first 1200 m and 50 m spacings thereafter. Sensors were also placed north of the River, but along a much wider, 200 m spacing (Fig. 3a). Background stations were located along the Broadlands Highway, and extending up onto the Kaiangaroa plateau, a distance of some 12 km east of the Parariki Stream location. Exposure times were reduced to 6 days for the south bank samples, 10 days for the north, and the background membranes were exposed for 14 days.

Data for the high density survey are summarised in Fig. 4. South of the River, the flux parameter reveals three main zones of elevated gas flow between Parariki Stream and the deep exploration well RK1, two of which correspond to areas of warm, altered ground. A fourth anomaly occurs immediately adjacent to the Waikato River, near an area where numerous low volume seeps have been reported (Khabar et al., 1986).

North of the River, the widely spaced array detected just one very strong flux anomaly at 5200 m, positioned close to margins of the resistivity anomaly, and there are numerous significant anomalies recorded for sulphur and total base metals on both sides of the River.

Geologic structures along the southbank transect are shown in Fig. 4. The lineations plotted here are derived from combined air photo mapping and field observations of the thermal features. The flux anomalies correspond surprisingly well to the inferred structures, considering that a 25 m sensor spacing is fairly broad and thus prone to missing finer scale features. The apparent ability of the flux measurements to delineate structures on such a scale must point to both the relatively large size of the shallow structures, and the large flux of hydrothermal gases (principally CO2) emanating through them.

The total amounts of base metals collected at each station are compared to their associated flux parameters in Fig. 5a. Note that three relationships arise from the data; namely, that in some places, large flux anomalies occur locally without associated base metal anomalies, large base metal anomalies may occur with low associated flux and third, large coincident anomalies occur locally for both flux and metals.

Although the origins of the base metal anomalies are at present somewhat speculative, noting that boiling leads to the focused deposition of base metal sulphides from these dilute TVZ fluids (Brown, 1986; Christenson, 1987) and that the high measured flux rates necessarily imply boiling at depth, it is possible that we are observing different stages of development of the individual ore forming fracture systems. The large flux anomaly at 250 m may correspond, for example, to a relatively new fracture system which is at present barren of ore phases. Coinciding anomalies at 125 m, on the other hand, may portend a "middle aged", highly mineralised environment that has sustained permeability, whereas the situation at 750 m is suggestive of a mineralised zone which now largely sealed.

Sulphur values, plotted in Fig. 5b, show similar relationships. However, interpretation of the sulphur results is complicated by the fact that sulphur exists in at least two states in the system, as H_2S gas and as native (crystalline) sulphur. The latter is restricted to ca. the upper 20 m of the reservoir (where ascending h^S gas had, in the past, oxidised to S_c in the openly aerated vadose zone). That this process continues today is evident in mine workings located just north of Lake Rotokawa.

Although the locations showing large sulphur anomalies with low associated flux values in Fig. 5b probably indicate the presence of sulphur ore (as at ca. 175 m), those with high flux and sulphur values may reflect either high H_2s emission, shallowly seated native sulphur or possibly both. Further study of these environments may reveal an independent parameter which will help to resolve these questions.

CONCLUSIONS

The application of the GEOGAS method to epithermal and hydrothermal systems looks promising. Although there are at present some detection problems for the low levels of gold encountered in the NZ epithermal deposits, the method quite successfully delineates associated mineralisation. In the more active environments, the method is quite adept at defining zones of enhanced permeability, zones of sulphide mineralisation and with further investigations, may even provide some insights into processes operating in the mineralising environment.

REFERENCES

Brown, K.L., 1986, Gold deposition from geothermal discharges in New Zealand. Econ. Geoi., 81, p 979-983.

Christenson, B.W., 1987, Fluid -mineral equilibria in the Kawerau Hydrothermal System, Taupo Volcanic Zone, New Zealand. Unpub. PhD. Dissert., Auckland Univ., NZ., 452 p.

de Ronde, C.E.J., 1985, Studies on a fossil hydrothermal system at Golden Cross, Waihi, New Zealand. Unpub. MSc, Thes., U. Auckland, NZ, 166 p.

Hinkle, M.E., 1980, Survey of helium in soils and soil gases and mercury in soils at Roosevelt Hot Springs Known Geothermal Resources Area, Utah. Rep. US Geological Survey USGS-OFR-80-613.

Johansson, S.A.E. and Johansson, T.B., 1976, Analytical application of particle induced X-ray emission. Nucl. Instr. Meth. 137, p 473-516.

Khabar, D., Browne, P.R.L. and Renner, N., 1986, Note on the composition of river bank springs, Rotokawa Geothermal Field. Proc. 8th NZ Geothermal Workshop, p 193-194.

Koga, A., Taguchi, S. and Mahon, W.A.J., 1982, The use of volatile constituents in geothermal fluids for assessing type, potential and near surface permeability of a geothermal system: The Broadlands geothermal area, N.Z. Proc. Pacific Geothermal Conf., U. Auckland, N.Z. 1, p 135-138.

Kristiansson, K. and Malmqvist, L., 1982, Evidence for non-diffusive transport of 222Rn in the ground and a new physical model for the transport. Geophysics 47, p 1444-1457.

Kristiansson, K. and Malmqvist, L., 1988, Trace Elements in the geogas and their connection to the bedrock composition. In press Geoexploration.

Krupp, R.E. and Seward, T.M., 1987, The Rotokawa Geothermal System, New Zealand: An active epithermal gold-depositing environment. Econ. Geol. 82, p 1109-1129.

Malmqvist, L. and Kristiansson, K., 1984, Experimental evidence for the microflow of geogas in the ground. Earth Plan. Sci. Lett. 70, p 407-416.

McCarthy, J.H. Jr., and Reimer, G.M., 1986, Advances in soil gas geochemical exploration for natural resources: Some current examples and practices. J. Geoph. Res., 91, p 12,327-12,338.

Whitehead, N.E., 1984, Geothermal Prospecting by ground radon measurements. J. Vole. Geoth. Res. 20, p 213-229.