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GEOCHEMICAL SOIL SURVEYS: AN EXPLORATION TECHNIQUE FOR LOW-ENTHALPY GEOTHERMAL RESOURCES

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ABSTRACT

A geochemical soil survey was conducted over a sediment-hosted low-enthalpy resource at Naike, New Zealand. Samples were taken on a 250m x 250m grid, covering about $2.5 km^2$, from both the A and B horizons. Soil ammonia (or, more smctly, ammonium) was selected as the pathfinder species since this attains high levels in geothermal fluids from sedimentary-hosted reservoirs. The ammonia content was determined by a gas-sensing ammonia-selective electrode following a potassium chloride leach. The A horizon showed a stronger anomaly contrast than the B horizon. In the A horizon, the mean background concentration, as determined by probability plots, was 2 mg NH_3/kg, with anomalous values up to 25 mg NH_3/kg and a threshold of 4 mg NH_3/kg. The results define a pattern of anomalies which parallel known faults, thereby implying a fracture dominated hydrology - a conclusion supported by previous geophysical surveys. This study demonstrates that soil surveys can be useful in the exploration for low-enthalpy resources, and shows that ammonia is an effective pathfinder to this type of geothermal field.

INTRODUCTION

Geochemical soil surveys have been successfully employed in the exploration for geothermal resources for over a decade. The surveys undertaken to date have concentrated on high-temperature geothermal fields (Table 1), typically using mercury to delineate areas of geothermal activity and fluid flow. Although mercury has been used most frequently, other elements which are relatively volatile (and are therefore transported to some extent in the vapour phase) can also define areas of geothermal activity and fluid flow. In this respect it has been shown that arsenic, antimony and bismuth can be effective pathfinders to geothermal resources (eg. Zhu et al., 1986, 1989). By contrast, the use of soil surveys over low-enthalpy systems has been largely neglected by exploration geochemists. Similarly, the use of ammonia as a determinand in geochemical soil surveys has not been investigated. However, this soluble gas is known to attain high concentrations in fluids from sedimentary-hosted geothermal reservoirs. Since low-enthalpy aquifers are commonly situated in such lithologies, ammonia would appear to be an ideal candidate for use as a pathfinder to these geothermal fields.

This study evaluates the use of soil surveys as an exploration technique for low-enthalpy geothermal resources, and examines the use of soil ammonia (or more strictly ammonium) as a geothermal pathfinder species.

SURVEY AREA

To fulfil the objectives of this study, a sedimentary-hosted, low-enthalpy resource was required. The selected area had to have good topographic and geological control to aid interpretation and evaluation of the technique. Similarly, land-use and anthropogenic influences on the area needed to be known and well defined. The Naike geothermal system fulfilled these requirements and was therefore selected as the target area.

Naike geothermal system

The Naike hot springs, which have also been known as the Te Maire, Whangape, Awaroa and Waiora springs (Rockel, 1986), are located about 70km south of Auckland in the North Island of New Zealand (Fig. 1). Naike was considered to be an ideal area for the study as the geothermal field had been the subject of earlier geological, geochemical and geophysical investigations (Petty, 1972; Waterhouse, 1978; Siswojo et al., 1985). Furthermore, the land use is relatively consistent over the area as a whole; there are few lithological boundaries, and these are known; nor are there any large variations in topography or complex drainage patterns.

Topography. The area is characterised by a rolling topography, which attains a height of 120m to the north and south of the study area, declining gently to 15m above sea-level in the central portion, rising to around 70m in the east and west (Fig. 2).

Climate and drainage. The Te Maire stream forms the principal drainage feature in the area, which is fed by tributaries in the north and south-west (Fig. 2). The records for 1986 for the area show a mean annual rainfall of 1090mm with an annual extreme temperature range of about -2°C to 29°C (NZMS, 1986).

Land-use. The area is largely in grass for cattle and sheep grazing, with some deer farming and localised pine-tree plantations. Valley bottoms contain isolated patches of native bush. Tracks throughout the area, which are both unsealed and unmetalled, are marked on Figure 2, along with farm buildings.

Geology. The geology of the Naike area (Fig. 3) has been described by Waterhouse (1978) and Siswojo et al. (1985), and is only summarised here. Jurassic siltstones and greywackes, which form the basement group, outcrop in the southwest of the study area. This sequence is overlain unconformably by Upper Eocene and Oligocene sediments of the Te Kuiti Group. Recent deposits of alluvium cover areas flanking the steams. The area is transected by north-east and north-north-west trending faults and lineaments

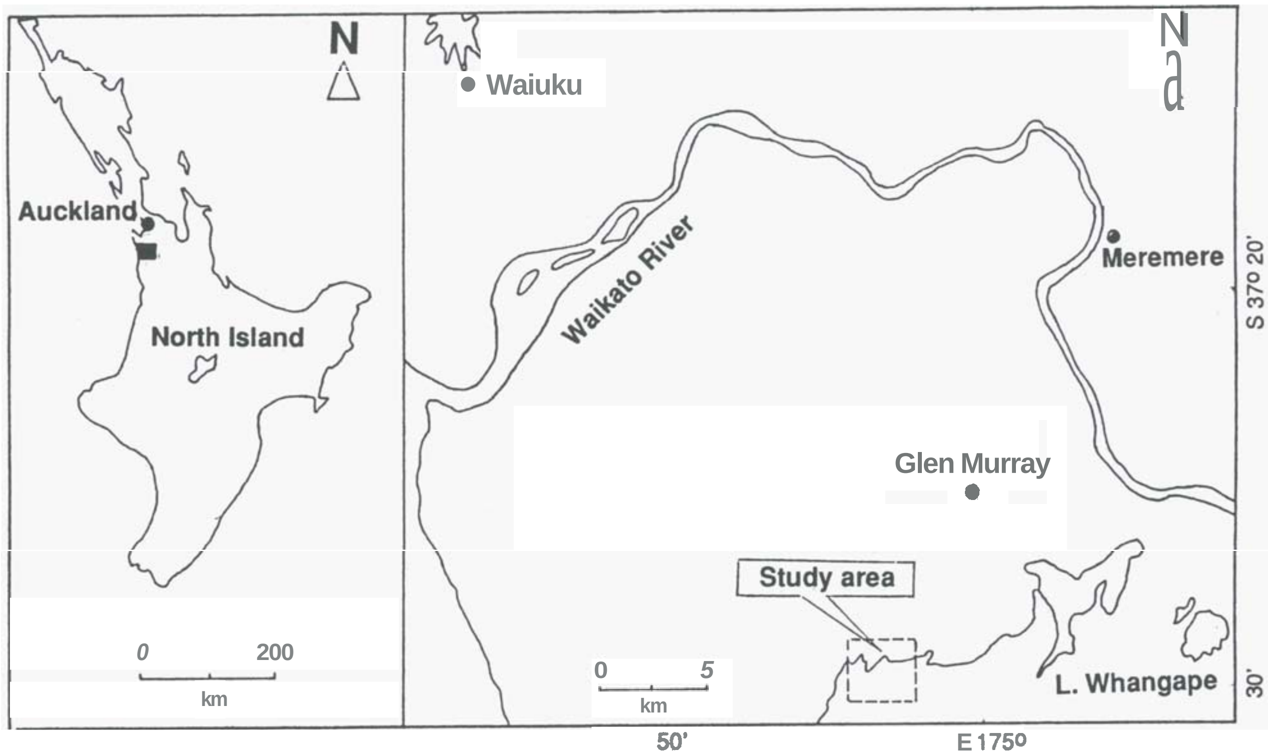

Fig. 1. Location of Naike geothermal area, North Island, New Zealand

seen on aerial photographs, which have been interpreted as faults (Siswojo et al., 1985).

Geothermal discharge features. In addition to numerous seepage areas along the banks of the Te Maire stream, there are two principal hot-pools which discharge into the stream and a third which was partly overgrown, but following recent excavations now has a discharge of *0.5* L/s. Siswojo et al. (1985) calculated that the total volume of geothermal water discharged into the stream in April 1985 was 29 L/s. Since the combined flow rate of the discharging springs is much less than this figure (Table 2), the majority of this fluid must enter the stream through seepages or springs on the stream bed. Studies on the stream water chemistry show that these thermal discharges are limited to a length of about 500m downstream from Pool 1 (Siswojo et al., 1985). The waters are of the dilute-chloride type (Table 2, Figure 4) and although temperatures of up to 93°C have been recorded (Petty, 1972), figures around 65°C are more usual.

SOIL SURVEY PROGRAMME

Sampling procedure. The geochemical soil survey was conducted on a 250m x 250m grid centred around the thermal manifestations, and covering an area of about 2.5 km^2 (Fig. 2). Samples were collected from both the A and B soil horizons at each sample station, using a stainless-steel auger. These were placed in new, self-sealing polythene bags. Duplicate samples from both horizons were taken at every tenth station.

Samplepreparation. Samples were dried in an oven at 30°C prior to disaggregation in a ceramic pestle and mortar. To negate the effects of lithological changes on the soil composition, an extraction procedure was adopted. This is designed to release ammonia adsorbed onto organic and mineral substrates, leaving intact any structural ammonia held in primary soil minerals. Ten grammes of sample were leached with 100mL of 2M potassium chloride for one hour with constant shaking, Aliquots, 10 mL, of the settled solution were taken for analysis.

Analytical method. The ammonia content of the sample solutions was determined with an Orion 95-12 gas-sensing ammonia-selective electrode by direct potentiomentry using a calibration graph (Orion, 1987). All samples were randomised prior to analysis to avoid any false anomalies produced by trends in systematic errors. Successive aliquots of the sample solution were taken until two equilibrium-emf readings within 1.00 mV were obtained. This was taken as the equilibrium potential and used to determine the ammonia concentration from the calibration graph.

RESULTS AND DISCUSSION

The results of the survey from the A horizon are illustrated in Figure 4. The B horizon showed anomalous areas with the same spatial distribution as those in the A horizon. However, as the anomaly contrast in the B horizon is poorer, only the results from the A horizon will be discussed. Ammonia concentrations ranged from 1.0 to 25 mg NH_3/kg, with a mean background value of

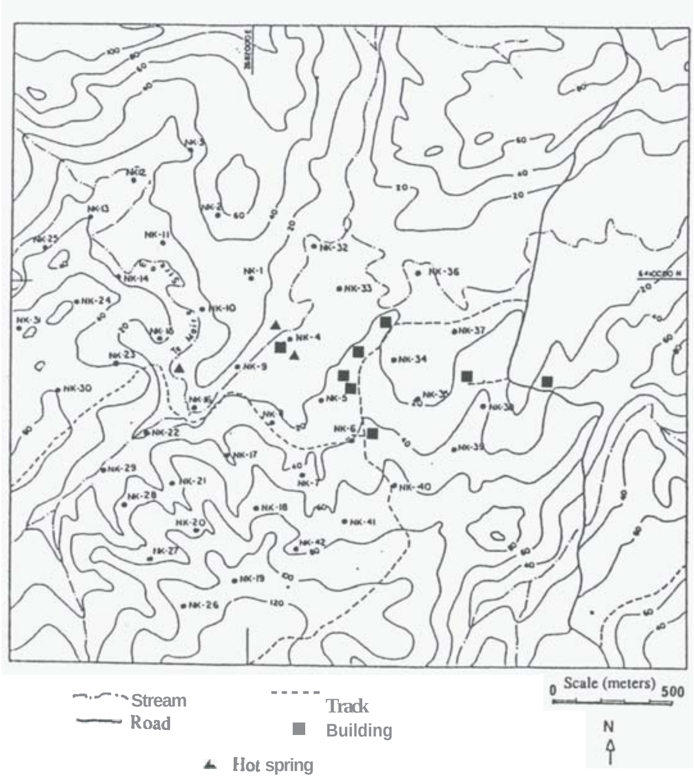

Fig. 2. Topography and sampling stations over the Naike area.

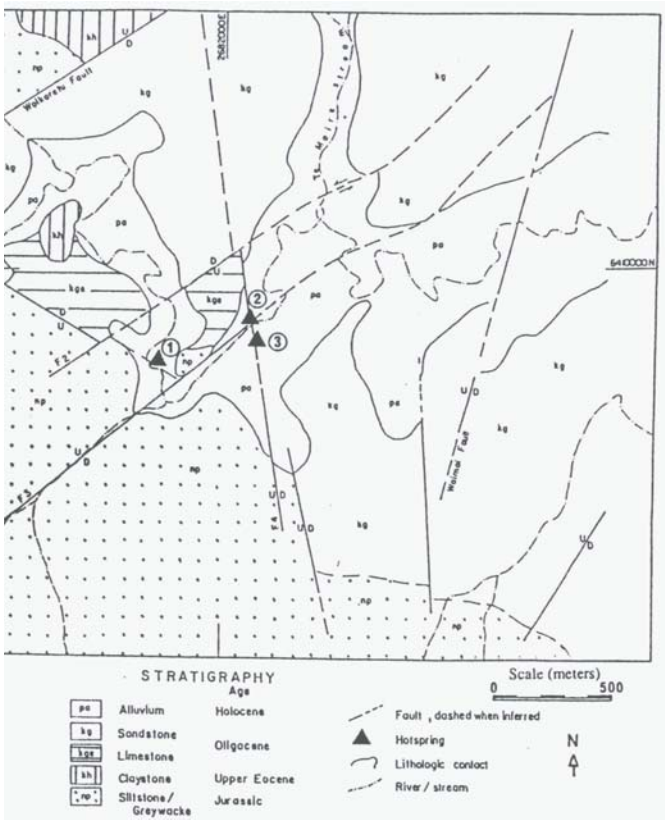

Fig. 3. Geology of the Naike area (after Siswojo et al., 1985)

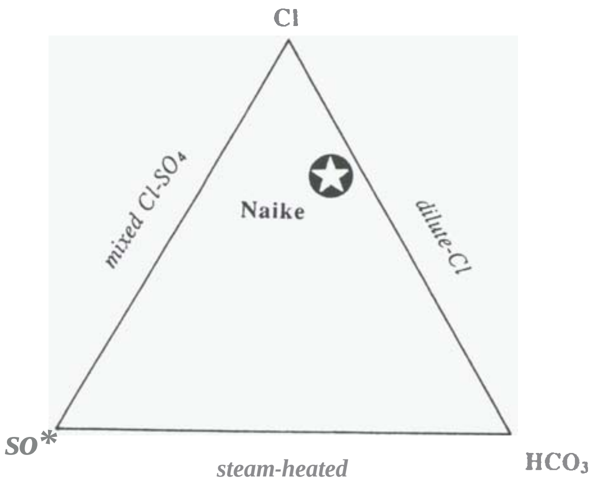

Fig. 4. Classification of geothermal fluids with composition of discharges from Naike hot springs plotted

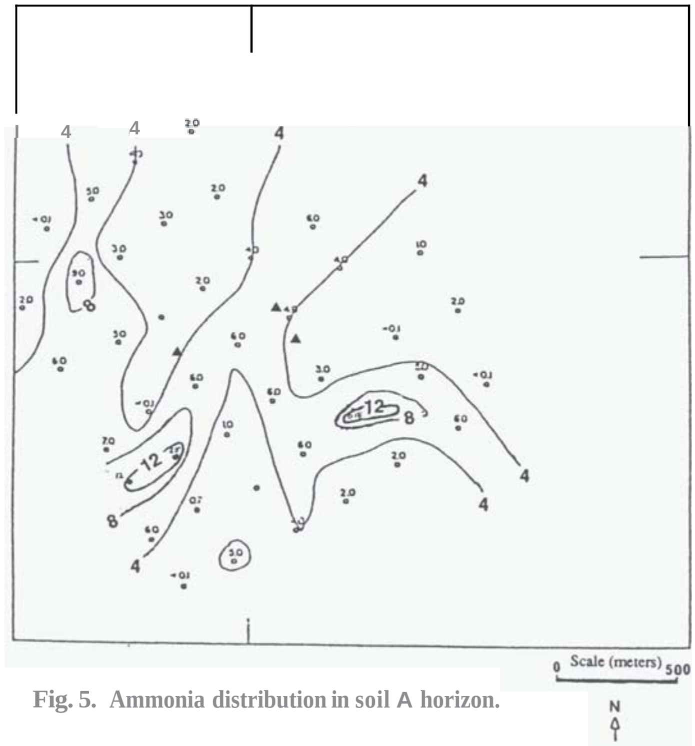

Fig. 5. Ammonia distribution in soil A horizon.

TABLE 1
Geothermal fields covered by geochemical soil surveys

Country/Region	Field/Area
CANADA	
British Columbia	Meager Creek
CHINA	
Beijing	Xiaotangshan
Tengchong	Rehai, Reshuitang
Tibet	Yangbajing
COSTA RICA	Ricon de la Vieja
INDONESIA	
Java	Sikidang
JAPAN	
Honshu	Ogachi, Onikobe, Narugo
Kyushu	Beppu, Kirishima, Noya, Otake
MEXICO	
BCS	Las Tres Virgenes
Michoacan	Los Azufres
Nayarit	Ceboruco
NEW ZEALAND	
Northland	Ngawha
Taupo	Broadlands-Ohaaki, Mokai, Wairakei
USA	
Alaska	Mt Spurr, Unalaska Is
California	Coso, Eagle Lake, Imperial Valley, Medicine Lake, Lassen, Long Valley
Colorado	Animas Valley, Cottonwood, Glenwood, Idaho Springs, Mt Princeton, Poncha, Routt, Steamboat Springs,
Hawaii	Maui, Puhimau, Puna
Nevada	Antelope Valley, Aurora, Cuprite Hills, Desert Peak, Dixie Valley
New Mexico	Socorro
Oregon	Breitenbusch, Klamath Falls. Mickey Alvord Valley, Summer Lake, Vale
Utah	Roosevelt
Wyoming	Yellowstone

2 mg NH_3/kg, as determined by probability plots, and a threshold figure of 4 mg NH_3/kg.

A comparison of the anomaly pattern (Fig. 5) with the topographic and geological maps (Figs 2 and 3) illustrates several points. Firstly, it is clear that anomalies traverse lithological boundaries and are therefore not restricted to soils developed over a single sediment type. Further, there are no obvious topographic controls as the anomalies cross contours and are not restricted, for example, to ridges or low-lying areas. Although the tracks do not exert any influence on the anomaly pattern, it is clear that the ammonia high to the east is centred around some farm buildings. Subsequent discussions with the farmer revealed that this area was the site of buried offal pits, clearly the source of the anomalous concentrations. Elimination of this false anomaly therefore leaves a pattern of intersecting north-easterly and north-north-westerly trending *anomalies,* with increasing concentrations to the south-west of the study area. This pattern closely follows the distribution of known faults (*cf* Figs 3 and 5), and may have identified an additional north-south fracture zone to the west. A fracture-dominated hydrology is therefore indicated, with a possible upflow area in the south-west. This model agrees well with geophysical surveys by Siswojo et al. (1985). who also considered the fluid flow to be fracture controlled. These authors cited faults 2 and 3 (F2, F3 on Fig. 3) as the principal feed zones, a conclusion independently supported by the geochemical soil survey anomaly pattern which places the upflow zone on the trend of fault 3.

CONCLUSIONS

The survey over the Naike geothermal field demonstrates that geochemical soil surveys are an effective tool in the exploration for low-enthalpy geothermal resources, and .are not restricted in their application to high-temperature systems. Furthermore, ammonia is a reliable pathfinder species which delineates areas of thermal activity and fluid flow. The primary source of the ammonia is assumed to be the vapour which evolves from ascending geothermal fluid. However, this may not be so, and the ammonia could be generated by the thermal degradation of the organic matter within the soil profile itself. If this is the case, then soil ammonia could be a geothermal pathfinder species which can be universally applied, regardless of the temperature or geological setting of the system.

TABLE 2
Geochemistry of Naike geothermal waters

(All concentrations in mg/kg; nd = not determined)

Feature/date	Flow (L/s)	T(°C)	pH_T	Na	K	Ca	Mg	B	SiO_2	Cl	SO_4	HCO_3	Ref.
Pool 1 (c.78)	10	nd	9.15	150	2.5	2.6	7.9	18.6	70	159	4.0	34	(1)
Pool 1 (8/83)	3	64	9.7	155	2.1	5.2	0.01	12.3	48	160	5.0	nd	(2)
Pool 2 (8/83)	4.5	60	9.7	150	2.2	4.7	0.02	12.8	70	163	7.0	nd	(2)
Pool2 (4/85)	nd	65	9.1	143	2.0	nd	nd	nd	67	154	6.7	47	(2)
Pool 3 (8/83)	nil*	59	9.7	145	2.1	4.5	0.01	12.4	72	153	8.0	nd	(2)

References: (1) Waterhouse (1978); (2) Siswojo et al. (1985)

* Flow rate now 0.5 L/s (06/89)

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REFERENCES

NZMS (New Zealand Meteorological Service) (1986). *Meteorological observations for 1986.* Misc. publ., 101, 45pp.

Orion (1987). *Ammonia 95-12 gas sensing electrode instruction manual.* Boston. USA, 37pp.

Petty, D.R. (1972). *Springs of the Auckland region.* NZ Geological Survey Report 57, DSIR. Wellington, 56pp.

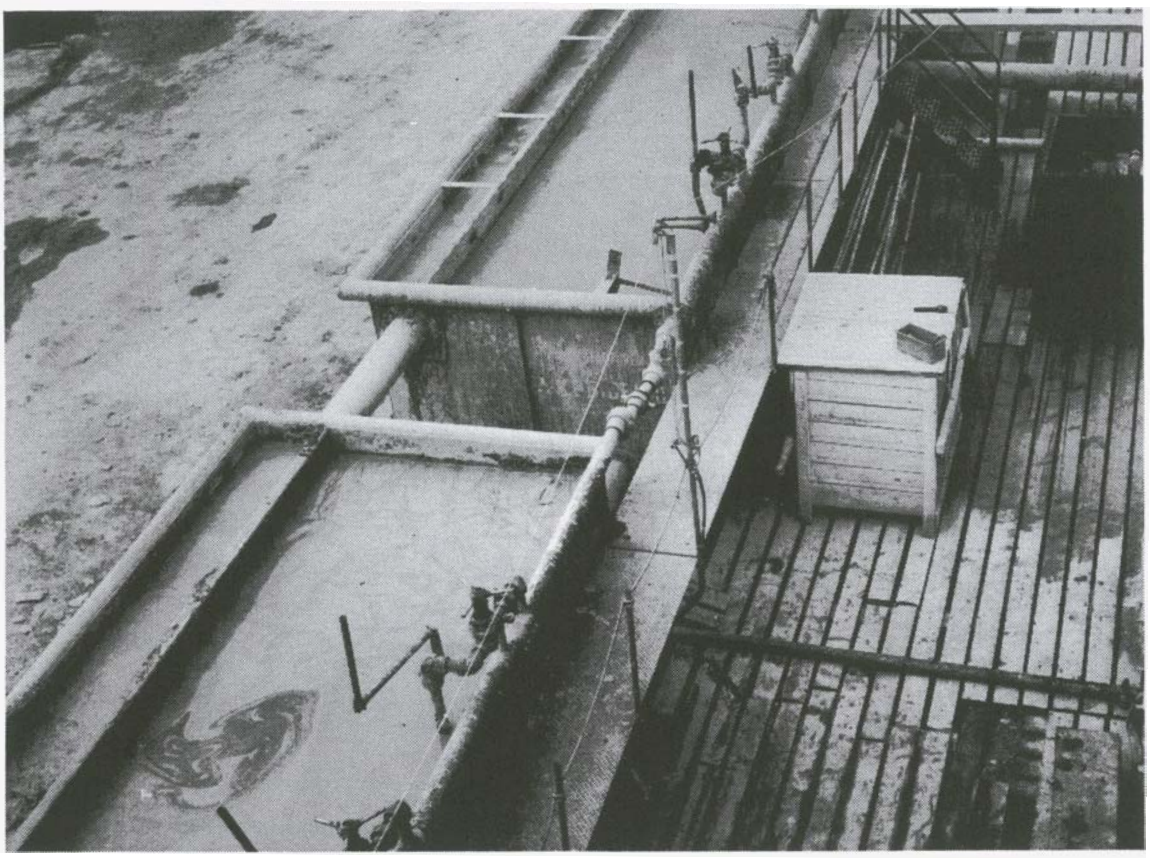
Rockel, I. (1986). *Taking the waters. Early spas in New Zealand.* Government Printing Office, Wellington. NZ, 195pp.

Siswojo, S.. Kasonta, A.S. and Hochstein. M.P. (1985). Naike hot springs: A hot spring system (North Island. New Zealand). *Proc. 7th NZ Geothermal Workshop,* 181-187.

Waterhouse, B.C. (1978). *Sheet N51, Onewhero (1st edition).* Geological map of New Zealand 1:63 360, DSIR, Wellington. 32pp.

Zhu, B., Zhang, J., Zhu, L. and Zhang, Y. (1986). Mercury, arsenic, antimony. bismuth and boron as geochemical indicators for geothermal areas. *J. Geochem. Explor.*, 25: 379-388.

Zhu, B., Zhu. L.. Shi, L., Yu. H. and Wang, G. (1989). Application of geochemical methods in the search for geothermal fields. *J. Geochem. Explor.*, 33: 171-183.



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