Proceedings of 9th NZ Geothermal Workshop 1987

RECONNAISSANCE OF THE TIKORANGI GEOTHERMAL PROSPECT (HAROHARO-OKATAINA CALDERA), NEW ZEALAND

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ABSTRACT

Geological, geochemical and geophysical reconnaissance surveys of the Tikorangi Geothermal Prospect (previously described as Lake Rotoma Geothermal Field) has shown that a major high temperature (>210°C) hot water system occurs beneath the Tikorangi watershed area. The system is concealed by young rhyolites of the Haroharo Centre which probably covered the near surface reservoir about 5500 to 7500 yrs ago. The reservoir can still be recognized from a characteristic magnetic anomaly pattern caused by demagnetized reservoir rocks. Hot water from the upper reservoir is drained by a shallow outflow to the north towards Lake Rotoehu and Lake Rotoma, which can be traced by resistivity surveys, There is some evidence for a deeper, almost 8 km long, outflow to the south beneath the Kaipara Stream valley. Both outflows and the high resistivity cover of the young rhyolites conceal any deeper resistivity structure; the lateral extent of the reservoir could not be determined.

INTRODUCTION

The Tikorangi geothermal prospect lies in the NE part of the young Haroharo-Okataina caldera. It is associated with minor solfatara patches at Tikorangi; outflows of neutral bicnrhonnte-chloride water occur at the Waitangi Soda Springs and at Lake Rotoma (Otei Springs) about 4 km N and NE from Tikorangi respectively. There is little information about the prospect. Grange (1937) called this area "Sulphur Gully" because of minor sulphur mining at the solfataras which continued into the 1950s. Healy (1969) described the geology and thermal activity of the Tikorangi area and refers to five shallow exploratory wells drilled for sulphur prospecting of which two encountered hot water (> 100°C) at DO to 40m depth (see Fig. 1). Nairn (1974) compiled the few data known and presented a more detailed geological map of the area. A structural geological map of the NW part of the caldera is shown in Fig. 1 (from Nairn, 1981b)

Because of the rather low natural heat discharged (Tikorangi solfataras about 0.2 MW, Waitangi Soda Springs about 8 MW), the prospect was given a low ranking for future prospecting (Nairn, 1974). An airborne magnetic survey of the whole Okataina Caldera undertaken by the Geothermal Institute in 1984 (Salt, 1985), augmented by additional flight-lines flown in 1986 (flight elevation 800m asl), showed that the Tikorangi prospect is associated with a pronounced negative magnetic total force anomaly (see Fig. 2). Salt (1985), and Salt and Caldwell (1985), found that this anomaly cannot be explained in terms of topographic effects and that it is probably caused by demagnetized thermally altered rocks. The lobe structure of the magnetic low towards the Waitangi Springs and towards Lake Rotoma was tentatively associated with partially demagnetized rocks in an inferred concealed outflow from the Tikorangi area. The magnetic low also extends from Tikorangi towards the south up to the Tarawera River where diluted chloride waters are discharged near the Mangakotukutuku Strcnm (Nairn, 1981b), about 7 km to the SSW of Tikorangi.

There were, therefore, indications that a major, deeper geothermal system might occur in the Tikorangi area; an extended reconnaissance survey of the prospect was made in September 1985 to check whether this inferred system exists.

The fieldwork consisted of detailed geological mapping of the surface thermal features, a geochemical study, and a 1m temperature survey (Yamada, 1985). In addition, the resistivity structure of the prospect was investigated by a few traverses and soundings using the Schlumberger array with AB/2 up to 1200m (Doens, 1985; Kohpina, 1985).

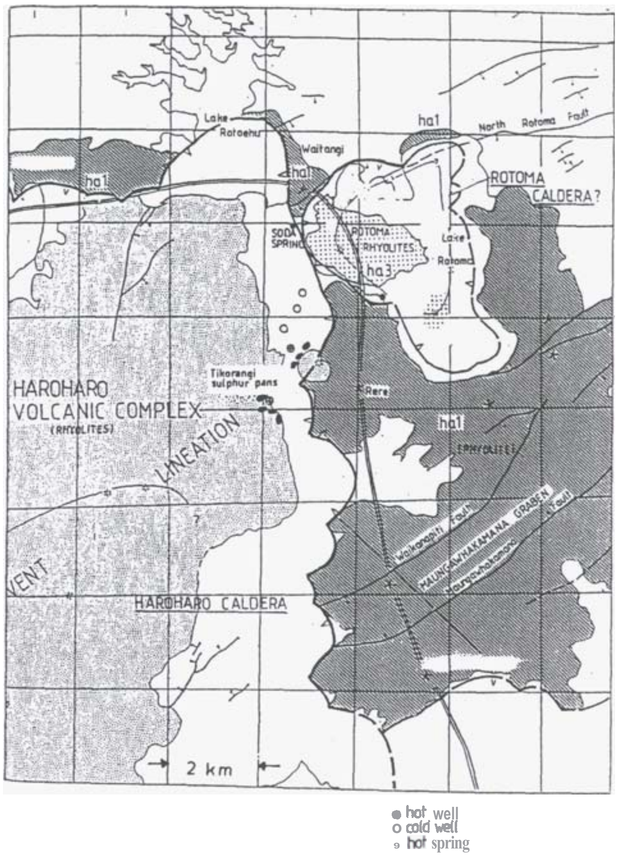

Fig. 1: Structural geological map showing the NE part of the Haroharo-Okataina Caldera (from Nairn, 1981b).

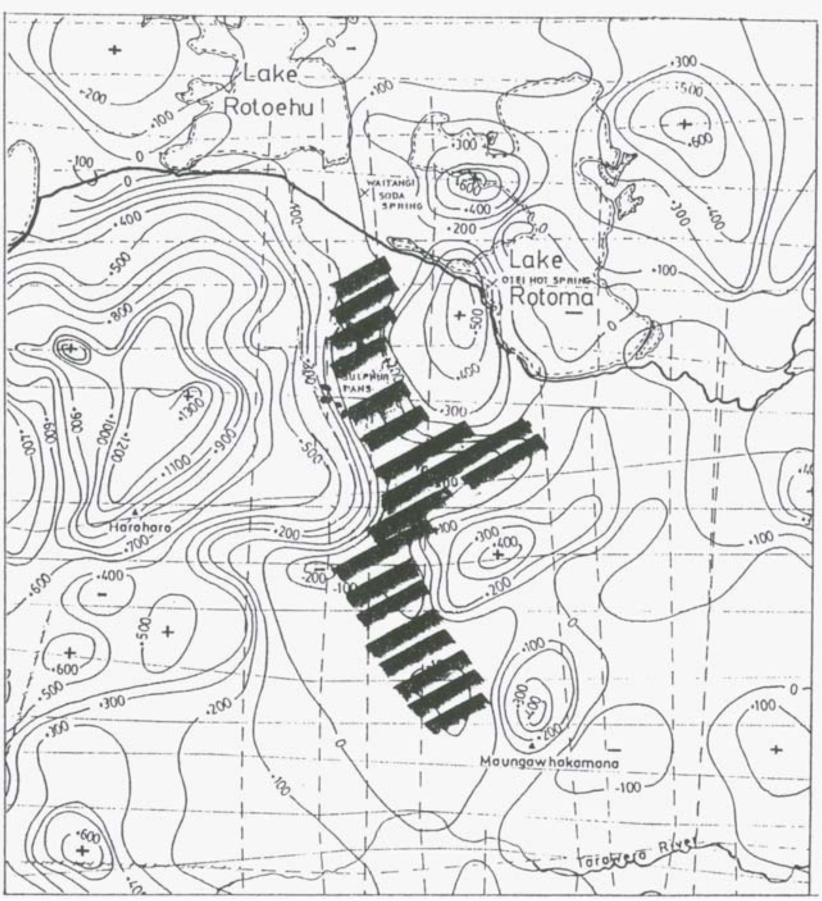

Fig. 2: Airborne total force magnetic anomaly map of the NE part of the Haroharo-Okataina Caldera; flightlines are shown by thin solid and dashed lines. The toned area outlines a magnetic low which is not controlled by topographic effects.

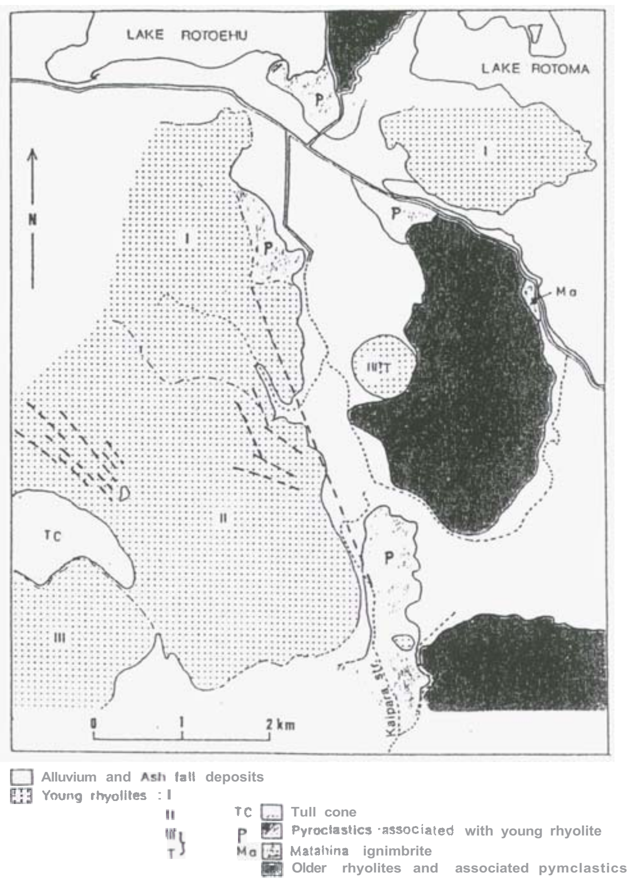

Fig. 3: Geological map of 1985 reconnaissance survey of Tikorangi prospect taken from Yamada (1985) Lineaments visible on air photos are shown by dashed line segments.

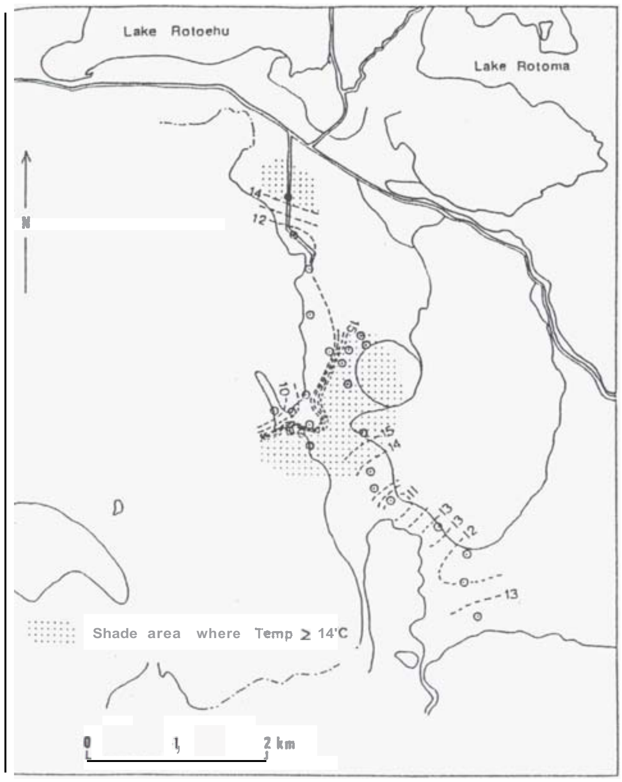

Fig. 4: Ground temperature survey of Tikorangi prospect (from Yamada, 1985). Mean annual temperature at 1m depth is 12°C for whole survey area (Sept. 1985).

Geology

The Tikorangi prospect lies near the E boundary of the Haroharo Caldera as defined by Nairn (1981a), which is infilled with young Holocene rhyolites and pyroclastics; to the E outcrop Pleistocene glassy rhyolites unconformably overlain by Matahina Ignimbrites (200,000 yrs BP according to Nairn, 1981a) at the W shore of Lake Rotoma. A geological map of the 1985 field survey is shown in Fig. 3 which is rather similar to the map of Nairn (1974) but Fig. 3 contains a few new details. Rhyolite I in Fig. 3 is about 9000 yrs old, rhyolite II about 7500 yrs, and rhyolite III and probably the Tikorangi Dome (T) about 5500 yrs old (assessed from correlation with dated tephra layers in Nairn, 1981a). Although the young rhyolites are autobrecciated they are probably rather impermeable as indicated by numerous swamps (Including a small lake) on top of rhyolite 11. Only a few lineations are visible on air photos; these are shown in Fig. 3. Some deeper permeability is probably associated with a N-S trending rim fracture zone beneath Tikorangi. The Haroharo Caldera is also outlined by a gravity low (Rogan, 1980; Wilson et al., 1985).

There are 8 small solfatara fields at Tikorangi covering a total area of about 19000 m^2; minor steam is still discharged today with temperatures between 80 to 97°C at the surface. Sulphur sublimation can be noticed and acid alteration has leached the surface rocks producing porous siliceous material. In sheltered places, incrustations of alunogen, tamarugite and some potassium sulphate can be found.

No other surface alteration products were found in the whole area apart from a 0.3m thick lens-shaped layer of hydrothermal eruption material at the S side of State Highway 30 about 3 km N of Tikorangi (N 77/011 149). This layer contains thermal alteration minerals such as smectite, chlorite, clinoptilolite, and altered rhyolite fragments (fresher in centre). The hydrothermal eruption deposit occurs between two tephra layers (5000 and 7000 yr old; I. Nairn, pers.comm.). The bed is fine grained, thus ruling out a nearby local source. Since the Tikorangi system is the only thermal prospect in the area it was inferred that the deposit originated from a hydrothermal eruption in the Tikorangi area.

A 1m depth temperature survey showed that a 1 km wide strip at Tikorangi exhibits slightly anomalous ground temperatiires (more than 2°C above normal); see Fig. 4. The 1m temperature survey was also used to map temperatures in the solfatara fields but no coherent pattern was Found although temperatures were slightly higher than surface temperatures (up to 103.5°C was observed in one small area).

Geochemistry

Geochemical studies were restricted to stream sampling and gas sampling. No representative gas sample could be obtained from the solfatara patches; a gas sample from the Waitangi Springs showed almost the same composition (97% CO_2 and 2.9% N2) as that found in 1964 (R. Glover, pers.comm.) except that in 1985 no traces of H_2S were detected.

The geochemistry of a few thermal springs and of Lake Rotor-hu and Lake Rotoma are listed in Table 1. Analyses of the lakes and the Mangakotukutuku Springs are incomplete and show poor ionic balance. It can be seen that the Waitangi Springs discharge a mixed neutral chloride-bicarbonate water; the temperature of the concealed outflow feeding the springs is probably less than 100°C in the immediate vicinity of the springs as indicated by the K-Mg geothermometer of Giggenbach (1986). Since resistivity surveys have traced an outflow from the Tikorangi area to the Waitangi Springs, it can be inferred that temperatures higher than 210°C as indicated by the Na-K geothermometer (Giggenbach, 1986) prevail in the deeper Tikorangi system which is a hot water system.

Additional thermal water is also discharged by this outflow into Lake Rotoehu which contains a large fraction of thermal water, and also into Lake Rotoma (see analyses in Table 1) where minor springs (Otei Springs) occurred at the lake shore before the lake level rose. Further hydrological balance studies are required to assess the actual input of the northern outflow from the Tikorangi system into both lakes.

From the hydrological setting it is possible that the Mangakotukutuku warm springs discovered by Nairn (1981b) also discharge a diluted deep thermal water which originates .from a deep outflow from the Tikorangi system (distance about 7 km); the Na-K equilibrium temperature of the Mangakotukutuku Springs is similar to that of the shallow outflow at Waitangi Springs and would indicate a position for the centre of the Tikorangi system which is about half way between the two springs. The Cl/B molecular ratios of waters from both springs are of the same order of magnitude but do not give sufficient support for the inference that both springs are fed by separate outflows from the system; only the magnetic anomaly pattern and the hydrological setting allow such an inference.

To check whether traces of deeper fluids enter the streams which drain the Tikorangi area, especially the Kaipara Stream catchment lying to the S of Tikorangi (see Fig. 5), a total of 8 stream samples were taken and carefully analyses for B, Cl, and SiO_2. The results are listed in Table 2 which shows that all streams and creeks contain a slightly anomalous concentration of SiO_2 indicating that groundwater encounters heated rocks at shallow depths; slightly anomalous B concentrations occur at site No. 8 and probably No. 3, both located in the upper reaches of the Kaipara Valley. However, there is no evidence for any major leakage of thermal fluids to the surface.

Resistivity surveys (traverses)

In contrast to other geothermal prospects in the Taupo Volcanic Zone, access to the Tikorangi prospect is very limited and the topography is steep. Only the valley between Lake Rotoehu and Tikorangi is farmland; there is a watershed about 2 km S of Tikorangi with a steep drop into the Kaipara Stream catchment which is only accessible by a single bush path. The Ilaroharo rhyolite domes are flat on top (about 800m asl), and the Pleistocene rhyolites to the E are not accessible. This setting controlled the layout of resistivity traverses in 1985 which were restricted to a N-S trending profile and a NW-SE profile intersecting at Tikorangi; a few stations lying on top of the Ilaroharo Domes and a station in the lower part of the Kaipara Stream were also occupied (see Fig. 6). Resistivity traverses were made using a combined Schlumberger array with AB/2 = 600m and 1200m.

Prior to 1985 only a single resistivity traverse had been made by Geophysics Division, DSIR, along State Highway 30 with AB/2 = 500m and 1000m arrays (H. Bibby, pers.comm.). The data are disturbed between Lake Rotoehu and Lake Rotoma; only undisturbed data are shown in Fig. 6. The results plotted in Fig. 6 indicate that low resistivity rocks with apparent resistivity of less than 25 ohm-m occur in a triangle between Tikorangi, the Waitangi Soda Springs, and the now-flooded Otei Springs. This triangle outlines the shallow N outflow from Tikorangi to Lake Rotoehu and Lake Rotoma which also feeds the thermal springs at these lakes. South of the Tikorangi watershed some intermediate to low resistivity rocks occur at greater depths as indicated by the few values observed with the AB/2 = 1200m array and by resistivity soundings. The station near Lake Rotokohu was occupied to test the hypothesis whether the Tikorangi system is associated with a major vent of the Haroharo rhyolites; the data indicate that these rhyolites are unaltered at depth.

TABLE 1: Geochemistry of natural and thermal features around the Tikoranei Geothermal Prospect

(all constituents in mg/kg, T values in "C)

Locality	T_{max}	pH	Na	K	Mg	Ca	HCO_3	SO_4	Cl	F	SiO_2	$T_{K\ Mg}$	$T_{Na\ K}$
Waitangi Springs	49.5	6.5	304	23	11	21	278	49	365	1	190	86	210
Lake Rotoehu	-	8.3	64	6.5	3.2	3.6	72	7.5	112.4	n.d.	7	-	-
Lake Rotoma		7.4	25	3.5	1.7	1.9	29	4.3	36	n.d.	6		
Mangakotukutuku warm springs	24	8.5	149	10.3	n.d.	n.d.	14	6.2	173	n.d.	86	-	204

Sources: Waitangi Springs from Grange (1937)
Lake Rotehu and Lake Rotoma from McColl (1975)
Mangakotukutuku Springs from Nairn (1981b).

TABLE 2: Results of analysis of stream samples in Tikorangi area

(all constituents in mg/kg, T values in "C)

Locality/ elevation (m)	pH	Flowrate (kg/s)	T (°C)	Cl	SiO_2	B
No. 11275	n.d.	100	10.6	4.23	28.1	n.d.
2/240	n.d.	880	11.5	3.98	30.1	0
31395	7.0	2.1	n.d.	2.68	21.9	0.07
41425	7.0	1.5	8.2	5.19	24.5	0.04
5/395	│	27	10.2	4.94	25.3	n.d.
6/365	│	n.d.	12.3	5.42	27.1	0.04
7/625	│	0	12.9	3.26	0	n.d.
81340	7.0	4(?)	n.d.	4.08	33.9	0.12

Analytical errors from reproducibility tests: SiO_2 = ± 0.5 mg/l (ammonium molybdate method)
B = ± 0.01 mg/l (azomethine method)

For the traverses, the direction and magnitude of the electrical (E) field were measured which usually are not observed in routine traverses. The results indicate that for all stations lying outside the Tikorangi area the E field was parallel to the current density (± 10°); only for stations within 0.5 km of the solfataras did the E field change (up to 27°). This points to an irregular 3D structure of conductive rocks and indicates that the resistivity structure near Tikorangi cannot be interpreted in terms of a layered 1D structure.

Natural potentials (SP) were also observed along the N-S traverse line; the survey showed that SP values continuously decrease up to the Tikorangi watershed indicating that the SP anomalies are associated with streaming potentials in the outflow (SP values decrease from an arbitrary level of 0 mV at Lake Rotoehu to -200 mV at the Tikorangi watershed).

Resistivity surveys (soundings)

A total of 10 traverse stations were re-occupied and the vertical resistivity structure was determined from DC soundings using the Schlumberger array with AB/2 up to 1200m. The important findings are:

(i) Moderately altered rocks (27 ohm-m) and thermal fluids occur in the northern outflow to depths greater than 200m at station B5 which lies about 0.5 km S of the Waitangi Springs.

(ii) Unaltered young Haroharo rhyolites are at least 700m thick (true resistivity greater than 700 ohm-m) at stations A7, 01 and W1 (see Fig. 6 for locality). There is no evidence for the hypothesis that these rhyolites are underlain by low resistivity rocks.

(iii) At the Tikorangi watershed (stations A14 and B16), i.e. 2 km SE of the S solfatara field, 125 to 250m thick young Haroharo rhyolites and associated pyroclastics overlie low resistivity rocks with true resistivities of less than 15 to 30 ohm-m which most likely constitute the central part of the Tikorangi reservoir (see Fig. 7).

(iv) Low resistivity rocks (less than 10 ohm-m) occur beneath the S solfatara field at about 100m depth but are probably confined to a 3D vertical structure.

(v) Intermediate resistivity rocks (≲ 30 ohm-m) can be found below 200m depth in the lower Kaipara Valley (station R1) and might be part of the S outflow structure.

Summary:

Reconnaissance studies of the Tikorangi geothermal prospect have shown that there is good evidence for a concealed major hot water system beneath the Tikorangi sofatara area. Our studies indicate that the old system was most likely covered by up to 250m thick, almost impermeable rhyolites and associated pyroclastics about 5500 to 7500 yr ago which explains the lack of significant surface manifestations. Geochemical evidence points to a hot water system; hot water and steam is still ascending today beneath the Tikorangi prospect but moves away laterally in a shallow broad outflow structure towards Lake Rotoehu and Lake Rotoma which feeds the thermal springs of these lakes. Another, deeper outflow most likely occurs beneath the Kaipara Valley where hot water moves to the south below 200m depth; the Mangakotukutuku Springs are probably fed by this deeper outflow. These outflows and the higher terrain to the W and E effectively conceal any boundary structure of the deeper altered reservoir rocks. The best evidence for a deeper reservoir is still given by the observed magnetic total force anomaly which can be interpreted in terms of a coherent demagnetized reservoir whose centre lies beneath the Tikorangi watershed.

The thermodynamic Na-K geothermometer of Giggenbach (1986) indicates that temperatures of more than 210°C will be encountered near the top of the concealed reservoir. The Tikorangi system occurs inside the young Okataina-Haroharo Caldera. This caldera is underlain at shallow crustal depths by magma chambers as indicated by its Holocene volcanic activity (Nairn, 1981a). In this setting the lack of thermal systems associated with the caldera was anomalous (Nairn, 1981b). However, the reconnaissance of the Tikorangi prospect has shown that at least one major geothermal system exists but it has been concealed by young volcanics. Other concealed major systems might also exist elsewhere within the caldera.

Acknowledgement

Mr G Caldwell (now Geophysics Division, DSIR) assisted with field work and supervised the interpretation of the magnetic and resistivity surveys. Mr Suprijadi Soengkono (Geothermal Institute) analysed the 1986 airborne magnetic survey. Mr J Bottomley (Fletcher Challenge Ltd) provided a grant-in-aid for the field work and the 1986 follow-up airborne survey.

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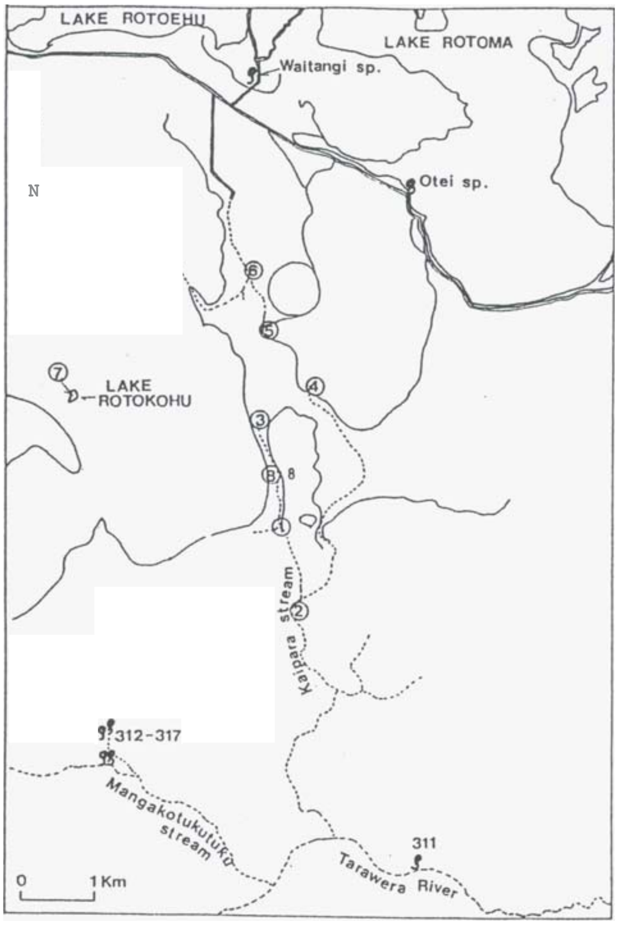

'ig. 5: Locality map of stream sampling survey of Tikorangi prospect (from Yamada, 1985). Sample number of springs at Mangakotukutuku Stream and Tnrawcra River from Nairn (1981b).

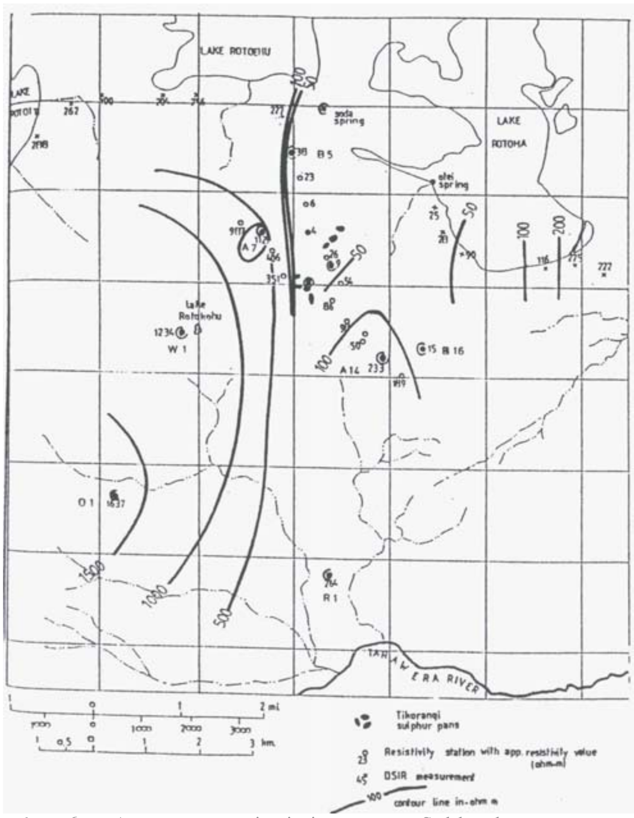

Fig. 6: Apparent resistivity map; Schlumberger traverse with AB/2 = 600m. Stations re-occupied for soundings are shown by dots. Sounding stations referred to in the text are shown by capital letter/number (i.e. B5). Stations marked by crosses are DSIR stations (figure taken from Kohpinn, 1985).

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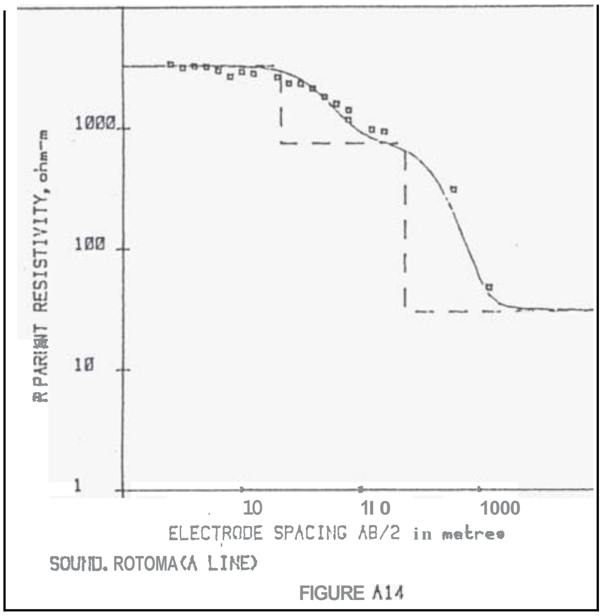

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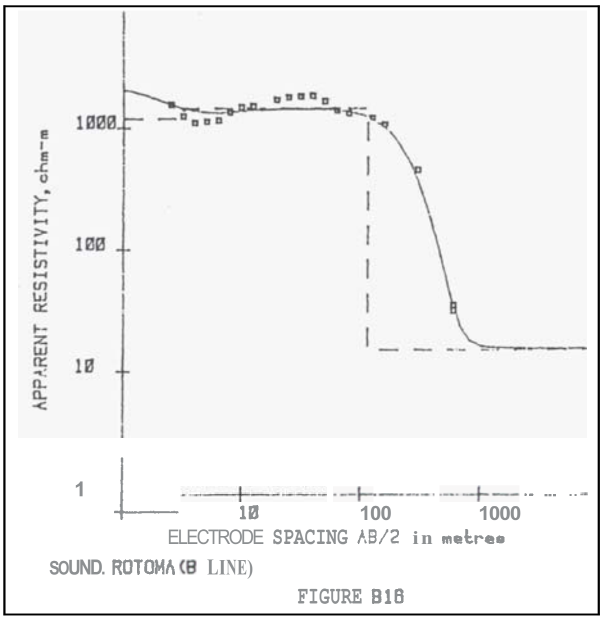
1	3300.00	21.30
2	740.00	215.00
3	< 30.00	INFINITY



Layer #	Resistivity	Thickness
1	2210.40	.86
2	1191.90	122.18
3	1450.00	
4	≤ 15.00	INFINITY

Fig. 7a, 7b: Resistivity sounding curves for stations A14 and B16 near Tikorangi watershed (From Doens, 1985); For position, see Fig. 6.