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MULTI-ELECTRODE RESISTIVITY SURVEYS AROUND THE HOT LAKES OF THE WAIMANGU GEOTHERMAL AREA, NEW ZEALAND

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SUMMARY – We conducted a series of multi-electrode surveys around the Waimangu thermal area, using 1.26 km of cable with 20 m electrode spacing. A Wenner configuration gave the most consistent results, producing a detailed image of the electrical resistivity in the top 200 metres.

There were very low resistivity zones under recently active thermal areas, including the Warbrick Terrace-Iodine Pool area, Raupo Pond, Inferno Crater, Frying Pan Lake, which had the largest and deepest low resistivity zone, and also under the inactive Southern Crater. Surface low resistivity areas were globally well correlated with high 1 metre ground temperatures and high CO_2 fluxes.

We repeated a profile past Inferno Crater 7 days later, and could see resistivity changes near the crater, indicating fluid movement associated with the cycling of Inferno Crater, which was overflowing during the first survey, but was a couple of metres lower by the time of the second survey.

1. INTRODUCTION

The Waimangu hydrothermal area, known as Waimangu Volcanic Valley, is within the Taupo Volcanic Zone, on the North Island of New Zealand. The current thermal features of the valley are extremely young, being formed since the Tarawera Eruption of 10 June 1886, although there were thermal features in the area before then, notably the Pink and White (silica) Terraces, which were destroyed by the eruption. After the 1886 eruption, there was violent hydrothermal activity for about 30 years, including the famous Waimangu geyser which played to several hundred metres when in its prime in 1900-1904, and a substantial eruption from Echo Crater on 1 April 1917. Although the system appears to have calmed down somewhat in recent years, with the hot lakes of Inferno Crater and Frying Pan (in the old Echo Crater) dissipating a large amount of energy, there were small eruptions as recently as 1973 and 1981 in this area.

The active thermal areas are aligned roughly in a north-east direction from Frying Pan through Inferno Crater to the shores of Lake Rotomahana. (Fig 1). Inferno Crater Lake is only about 80 metres in diameter, but it is notable for its substantial changes in level, with up to 9 metres change in a cycle which generally takes about 40 days (Scott 1994). Vandemeulebrouck et al (2005) showed that this cycling could be explained as a consequence of a thermal instability in the two-phase region under the lake. During the cycle, the ratio of steam to water in the two-phase region under the lake changes, with the lake rising as steam pushes water up out of the region, then the steam condenses and allows water to return and the lake to fall.

The resistivity survey described here had two aims, firstly to obtain a better picture of the structure and thermal state underlying the current thermal activity, and secondly to see whether we could detect changes in resistivity under Inferno Crater Lake associated with its cyclic behaviour. Previous resistivity measurements in the Waimangu area have been large-scale, using mainly Schlumberger arrays with electrode spacing of 500 and 1000 metres (Bibby et al, 1994). They recorded an apparent resistivity of about 10 Ω.m across the whole of the Waimangu thermal area.

2 METHOD

Direct current electrical resistivity measurements (Wenner-a) were performed along the two profiles shown in Fig 1, with a resistivity-meter ABEM SAS 4000. The topography and vegetation around Waimangu essentially limit the possible cable routes to the roads and tracks. It was not therefore possible to conduct any straight profiles in a north-south direction across the line of the thermal features. We tested different layouts (Wenner-a, Dipole-Dipole, Schlumberger), but finally we retained Wenner-a, which provided the least noisy dataset. We used a set of 64 brass electrodes, with a spacing of 20 m along the ground surface. The main electrode profile (A) was 3840 metres long, i.e. a total of 24 lengths of 160 metres cable, and ran from near Lake Rotomahana to the far side of the Waimangu Tea Room, following the Bus Road.

The second one (B), was 1580 metres long, and ran from Raupo Pond to Southern Crater, along the footpath. Two surveys were conducted on the B profile, at different stages of the Inferno cycle (respectively when the level was high, and during recession). This approach was relevant as Tosha et al (1996) measured remarkable self-potential changes with time, at different stages of the cycle, probably linked to the change of subsurface condition. As far as possible the same electrode locations were used, with location differences less than a metre. For the second survey on profile B, we just repeated the measurements around Inferno Lake and we added the roll-over data from the first survey on the western part of the profile. The addition of roll-over data allowed to restrict side effects and to keep the same sounding depth.

Electrical resistivity tomographies were obtained using RES2DINV code, which uses a finite-element method for the forward analysis. Topography was included in the inversion.

These readings were compared with CO_2 fluxes, using the accumulation chamber method, in which an open-bottomed collecting chamber is put directly on the ground, and 1 metre depth ground temperatures, which were generally taken at the resistivity electrode locations (Fig 1).

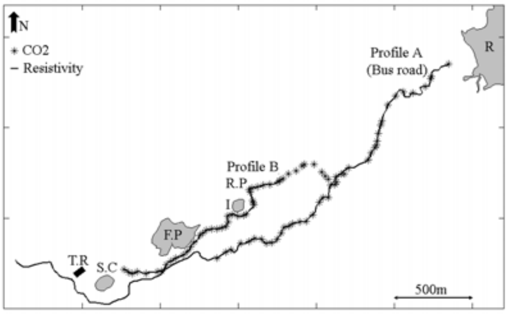

Figure 1. Location of outlines A and B. R: Rotomahana lake, R.P: Raupo Pond, I: Inferno lake, F.P: Frying Pan lake, S.C: Southern Crater, T.R: Tea Rooms.

3 RESULTS

Profile A (figure 2a): Along the bus road, the profile ran a few hundred metres south of the two active hot lakes of Frying Pan and Inferno. We describe below the spatial changes observed on a profile starting from the Rotomahana Lake and going up to the Tea Room. In these profiles, light shading indicates low resistivity.

There is a clear structural feature at a distance of 700-800 m from the lake, quasi vertical, which separates the high-resistivity area around the Lake Rotomahana, from a low-resistivity area, corresponding to the north-eastern thermal area, including Iodine Pool, a small and very active geyser. The resistivity ratio between the two areas is around 40; this contrast is not surprising as the thermal place is supposed to be very conductive, with a very high water temperature in the Iodine Pool (between 75°C and 97°C) and a strong hydrothermal activity on both sides of the geyser. Around the Iodine Pool, this low conductivity matches high ground temperatures and CO_2 fluxes.

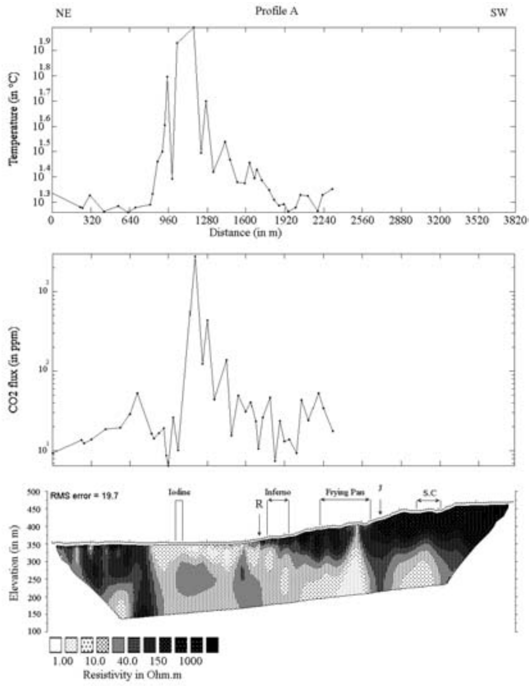

Figure 2a. Profile A: Electrical tomography, CO_2 and temperature along the Bus Road. R: River, J: Junction between the bus road and tourists track, S.C: Southern Crater.

From Iodine Pool onwards, both CO_2 and temperature tend to decrease. Field observations revealed hydrothermal activities on the side of the road, less numerous but still present, and a large discharge of steam in the river. Where the road crosses the stream, point "R" on the figure, marks a change in shallow ground properties, as the medium becomes more and more resistive (between 180-1000 Ω.m) towards the south-western part of the area. There is a clear decoupling between the shallow and the deep parts; particularly surprising is the sloping lithology of the resistive zone, which suggests a covering process. The largest deep low-resistivity zone is seen as the profile passes to the south of Frying Pan lake, with values down to 2 Ω.m at a depth of about 100-150 metres. The bus road is very close to the western part of Frying-Pan lake (see figure 1), so it is likely that a conductive spring appears at depth. There is also a very obvious low-resistivity area under Southern Crater, which is somewhat surprising as there has been no thermal activity here since soon after the 1886 eruption. This possibly could indicate highly conductive altered material, but this is not apparent at the other old thermal craters in the area. At this higher end of the profile, the resistivity is fairly high in the surface layers, with resistivity values reaching 1000-2000 Ω.m.

Profile B (figure 2b): The profile ran along the footpath from the Raupo Pond to Southern Crater, across the main geothermal features of the area, which are the Inferno Lake, the Old Geyser site and the Frying Pan lake.

When Inferno was overflowing, all these places appeared as clearly conductive (with a resistivity around 5 Ω.m), except at Inferno where the geometry of layers seem more complex: there is a shallow conductive layer, over a resistive body which slopes towards the south-west. Note that Inferno is not so large as it seems in figure 2b, but the profile went round the lake, so we represent it here in terms of electrode locations and it is effectively extended. The geyser site and Frying Pan lake are associated with high peaks of CO_2 and temperature, as it is expected for geothermal features.

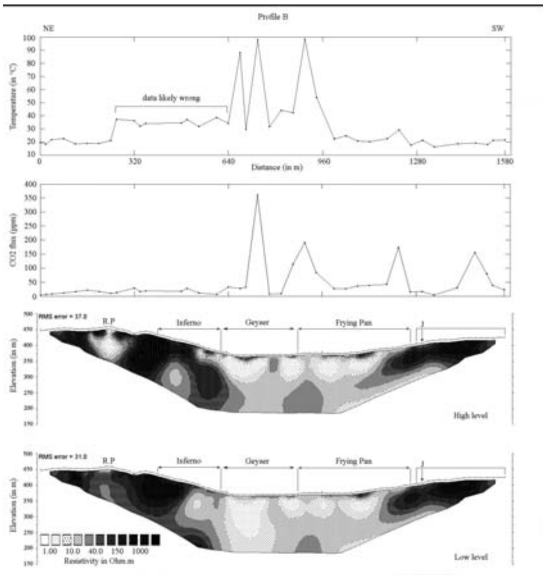

Figure 2b. Profile B: Electrical tomographies (associated with the cycling of Inferno Crater Lake), CO_2 and temperature along the footpath. Roll-overs are shown at the furthest right of resistivity outlines, and start close to the junction. R.P: Raupo Pond.

The high resolution available from the multi-electrode system suggested that we might be able to detect apparent resistivity changes associated with the cycling of Inferno Crater Lake. Indeed, between two stages of the cycle (over an interval of 7 days within the about 35 day cycle), noticeable temporal changes occurred: at Raupo Pond, the conductive body vanished at depth, and became clearly more resistive (from a resistivity previously smaller than 10 Ω.m to 68 Ω.m). Close to Inferno, the shallow layer previously conductive became resistive, and the resistive body at depth is conductive at the beginning of recession, with a less obvious resistivity gradient. The boundary between Inferno and the geyser is slightly different, as if the resistive body was pushed out. At the Geyser site, the conductive body (4 Ω.m) spread downward at depth, and laterally between the geyser site and Frying Pan Lake the medium became slightly more conductive (the ratio between the resistivity in the first and second surveys is lower than two). At depth, a large resistive body at the boundary between the geyser and Frying Pan was present when overflowing. This body diminished at the beginning of recession, and is only present in the deepest part of the area.

4 DISCUSSION

We can observe a large conductive structure between the 3 geothermal features. At the upper slope of Inferno, the change in resistivity is very consistent with the model proposed by Vandemeulebrouck et al., 2005: during recession, as steam at depth is replaced by liquid, it is normal to see a downwards migration of conductive layers.

Concerning Inferno Lake and Raupo Pond, the previously mentioned results suggest interdependence between the two lakes: during the change from overflow to recession, behaviors at the two places were exactly inverted. As Raupo pond is located at the farthest east side of the outline, these results could be due to edge effects, but sensitivities and uncertainties are similar to the values obtained elsewhere. As far as we know, there is no obvious relationship between Raupo Pond and Inferno, the literature only describes one event which occurred at both places during the night of 23-24 February 1978: when Inferno Crater Lake was completely discoloured, while at Raupo Pond Crater the Mud Rift was in eruption (Scott, 1992).

At Inferno, the main difficulty in the interpretation of the data is linked to the geometry, in that the profile is not straight, and the fact that we represent in 2D a three-dimensional medium. Hence, some parts of this zone may be misrepresented, but the inversion method allows us to see changes with time.

5 CONCLUSION

The resistivity results are well correlated with hydrothermal activity. A large conductive body lies between Inferno and Frying Pan including the old Geyser site. Clear structural features appear on the bus road profile.

Clear differences triggered by changes at Inferno have been observed; these first results are very promising, and such studies should be continued, to follow the evolution of the sub-surface resistivity structure during all the different stages of an Inferno Crater water level cycle.

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