ELECTRICAL IMAGING THE KEREPEHI LOW TEMPERATURE GEOTHERMAL SYSTEM, NEW ZEALAND

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ABSTRACT

In-loop transient electromagnetic (TEM) data has been collected from 105 sites in the Kerepehi area to investigate the relationship between the shallow resistivity structure and warm seeps mapped in the area. The area is generally conductive which reflects the clay-rich sedimentary environment, with a low resistivity anomaly (<10 ohm-m) close to Kerepehi Township. This anomaly intensifies between 100 and 200 m below ground and may be associated with thermal fluids interacting with uplifted basement rock and fault structures.

Ten thermal springs (current or historic) are mapped in the Kerepehi area, with many of these springs located in a line, on the eastern side of the low resistivity anomaly. This may indicate that a shallow permeable structure may be facilitating near-surface flow of thermal fluids to the surface.

1. INTRODUCTION

1.1 General

Geothermal systems can provide a source of renewable, sustainable energy that can be used in large scale developments such as power stations (e.g. White and Chambefort, 2016; Fronda et al., 2015) through to small scale direct use applications (e.g. Lund and Boyd, 2015; Climo et al., 2016). The type of development that can occur depends on a number of factors such as resource temperature, permeability, and resource size. Delineating the size, and fluid up-flow zones of low temperature geothermal systems (<125 °C) can be difficult due to a lack of strong geophysical contrasts. This can make sustainable utilisation of these systems difficult and high-risk.

This study presents preliminary results of a transient electromagnetic (TEM) survey to delineate the shallow geothermal resource at the Kerepehi Low Temperature Geothermal System. This study forms part of larger study combining gravity and TEM techniques as used successfully by Soengkono and Reeves (2016) that is located in a similar geological setting.

1.2 Study area

New Zealand lies at the boundary of the Pacific and Australian plates, providing a range of geological conditions such as volcanism and rifting. Hochstein and Balance (1993) describe the Hauraki Rift Zone as a young (10 M year), active, continental rift that lies in the back arc region of the Tonga-Kermadec-NZ "arc trench" system. The rift zone is approximately 250 km long and runs at a strike of 340° beneath three regional features; the Hauraki Gulf in the north, the Firth of Thames in the middle and the Hauraki Depression in the south.

The Hauraki Depression is approximately 150 km long and 23 km wide that extends from Matamata in the south into the Firth of Thames in the north. The land expression of the depression is bound on the west by Jurassic Greywacke (that are also the basement rock in the area) and to the east by Tertiary volcanics (Figure 1). The depression is estimated to be up to 4 km deep (Hochstein and Nixon, 1979) and filled with sediments derived from volcanic deposits (e.g., ash fall, ignimbrite, andesite) and reworked sediments in both terrestrial and marine environments. Strata include clays, pumicious sands, peat, muds, silts and ignimbrite units.

Three main NNW-striking normal, steeply dipping faults are mapped in the study area; the Firth of Thames Fault on the west, the Kerepehi Fault in the middle and the Hauraki Fault on the east (Figure 1). Traces of the Kerepehi Fault are not continuous, with many parts of the surface trace obscured by overlying sediments (Persaud et al., 2016). Inferred offsets to this fault have caused some authors to speculate on the possibility of additional faults running perpendicular to the main faults across the plains (e.g. Hochstein and Nixon, 1979). The main faults are thought to displace the greywacke basement up to 2 km within the Hauraki Depression.

The Kerepehi study area is located near the middle of the Hauraki Plains in the central part of the North Island, New Zealand (Figure 1). The Hauraki Plains are bounded in the west by the Hapuakohe range, to the east by the Coromandel Range, and is at an elevation of approximately 5 m above mean sea level in the main study area. The township of Ngatea is located approximately 6 km northwest of Kerepehi.

Thermal springs (between 23°C to 57°C) have been mapped throughout the region (e.g., Jenkinson (1994), Mongillo and Clelland (1984)) with further discharges located in this study. The Hauraki rifting structure is thought to contain crustal heat at shallow depths enabling fluids to be heated, with faulting structures providing permeability for the fluids to flow to the surface (Hochstein and Ballance, 1993). Reyes et al. (2010) estimates that the total surface discharge of thermal waters in the Hauraki Rift Zone to be ~18 x 10^8 L/year with a total thermal energy of ~6.5 $MW_{Thermal}$. Fluid geothermometers indicate that source water temperatures are less than 200 °C within drillable depths, and that water chemistry shows that recharge water is generally heated meteoric water with minor seawater components in the north, and contains mantle components in the southern part of the rift (Reyes et al., 2010). The springs discharge neutral sodium bicarbonate type waters and are not highly mineralised. Springs generally occur along the eastern margin, western margin, and in the central area near the Kerepehi Fault. However, some shallow bores have encountered warm water in between these areas (Jenkinson, 1994).

Springs in the study area generally have low flows (<1 l s^{-1}) and are usually in the form of diffuse seeps. A number of cold springs (that occur above the regional groundwater table) and cold gas discharges are also observed in the study area; however, it is not clear if these are related to the geothermal system or shallow groundwater processes.

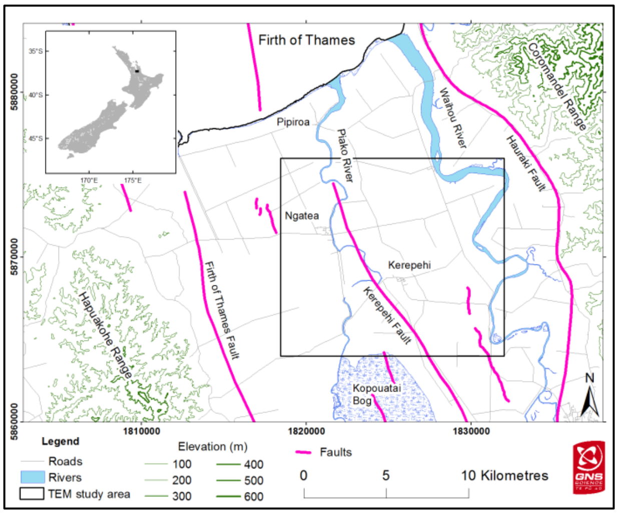


Figure 1: The Kerepehi study area.

2. METHOD

In-loop TEM (Nabighian and Macnae, 1991) data was collected from 105 sites (Figure 2) between October 2015 and April 2016. Sites were selected to focus on a low resistivity zone at Kerepehi (Hochstein and Nixon, 1979) and the Kerepehi Fault area which was suspected of providing a permeable pathway for the thermal fluids to ascend.

A Zonge GDP32 receiver was used with a TEM/3 magnetic coil (effective area 10,000 m^2) and a battery powered ZT-20 transmitter. The transmitting loop was a single loop with a nominal 100 m x 100 m size (unless terrain prevented this) and a 1.8A current. Data were collected at a frequency of 32 Hz with data stacked to provide averaged data at 22 time intervals between 56 us and 6.153 ms. This was repeated several times at each site.

Data were processed using the Zonge software TEMAVG and imported into the WinGLink software. Spurious data points were filtered out, and then smooth 1D resistivity profiles were generated for each site. Model slices and cross-sections were generated from the WinGLink models to interpret.

During the fieldwork, landowners were asked about the occurrence of hot springs on their land. Many landowners had property that had been owned for over a generation, and were able to provide good observations (by them, or comments made by relatives) of current and historically active warm seeps, gas discharges and cold springs. Springs with a water temperature greater than 23°C are assumed to be thermal in this paper.

3. RESULTS AND DISCUSSION

3.1 Surface geothermal features

Ten thermal springs/seeps were located during fieldwork (Figure 2), in addition to numerous cold seeps and gas discharges. This includes two areas where past thermal discharge is suspected based on landowners observations. Most of the thermal springs are mapped in an approximate northwest-southeast line, parallel to the Kerepehi Fault, approximately 3 km east of the Kerepehi Fault. Two warm seeps are mapped close to the western side of the Kerepehi Fault. Eight of the fourteen cold seeps found in this study are located close to the Kerepehi Fault. The cold water seeps may be due to perched groundwater levels in localized near-surface aquifers intersecting the ground surface, or, be related to thermal upflows that have cooled (and/or interacted with groundwater). Further work would be required to investigate the origin of these springs.

3.2 TEM

Smooth model resistivities in the study area range from approximately 1 Ohm-m to >200 Ohm-m between approximately sea level and 250m. The Kerepehi area is generally conductive (<50 Ohm-m) which is consistent with low resistivities that would be associated with clay-rich sediments that are logged in bore holes in this area. This can make interpretations difficult given the possibly small contrasts in resistivitives between geological units.

Figures 2 and 3 show 1D smooth model resistivity slices at 25m below sea level (BSL) and 150m BSL respectively. The slice at 25m BSL shows that low resistivities occur over much of the study area which can have multiple interpretations. The likely interpretation is that these are caused by clay-rich sediments at this elevation which typically have low resistivities. Alternatively, these could be caused by water-rock interactions from the thermal fluids (e.g. alteration) given that many surface thermal features are mapped in, or close to the low resistivity zones. Low resistivity anomalies located close to the Piako and Waihou Rivers (Figure 2) could also be associated with brackish water that has entered the shallow groundwater system through groundwater-surface water interactions. These two rivers are tidally influenced, and have seawater flowing up them at high tide that could possibly seep into the shallow groundwater if permeable pathways between the rivers and the groundwater existed. Geochemical data would be required to confirm this.

A thin northwest/southeast trending medium resistivity (between 20 and 60 Ohm-m) zone is identified at 25m BSL running approximately parallel to the Kerepehi Fault, located approximately 1.3 km to the east of the fault. This is interpreted to be caused by higher-resistivity sediments such as pumice and sands that could represent a groundwater aquifer. Nearby drill holes located in this zone show that a pumice/sand lithology occurs at this depth (Figure 2, bores 63_101 and KE001). A higher resistivity in this lithology would be expected compared to the other clay-rich sediments. The thin nature of this medium-resistivity zone may indicate that this is a palochannel given that this resistivity feature is not uniformly distributed at this elevation. This could indicate that the shallow groundwater aquifers in this area may not be laterally continuous. Alternatively, this zone may indicate the extent of alluvial/coalluvial deposits that have been differentiated from the other surface deposits by Edbrook (2001). These deposits are mapped at Kerepehi Township and approximately 1.5 km to the southeast of Kerepehi (Edbrook, 2001).

The slice at 150m BSL shows that the study area generally has medium resistivities, with a low resistivity anomaly (<12 Ohm-m) in the centre of the study area (Zone A, Figure 3). The centre of the low resistivity anomaly lies approximately 2 km east of the Kerepehi Fault, and encompasses Kerepehi Township and an area north of the town. The location of this anomaly is consistent with a low resistivity anomaly mapped using a DC resistivity survey with AB/2 of 500 m by Hochstein and Nixon (1979).

The low resistivity anomaly at 150 m BSL (Zone A, Figure 3, 4) is interpreted to be caused by hydrothermal alteration of thermal fluids of basement rock and may indicate the location of an upflow of source thermal fluids in the area. A bore located in the low resistivity anomaly (Bore KE001, Figures 3 and 4) is interpreted to have hydrothermally altered greywacke occurring between at least 80 and 160 m depth (Waihi Gold Company, 2006) which supports the above interpretation assuming the thermal fluids are (or were) of a temperature to cause this type of alteration. Extensions of the low resistivity anomaly to the north and west may indicate that the thermal fluids are flowing in these directions or could also represent small, isolated upflow zones. A bore drilled to 92.3 m (Bore Beck, Figure 3) in the north has reportedly (Jenkinson, 1994) used warm water to heat greenhouses indicating warm water exists in this area.

Alternatively, the two other low resistivity zones at 150 m BSL (Zones B and C, Figure 3) may indicate other possible upflow areas. Both zones have, or use to have, thermal bores in these areas confirming the presence of thermal

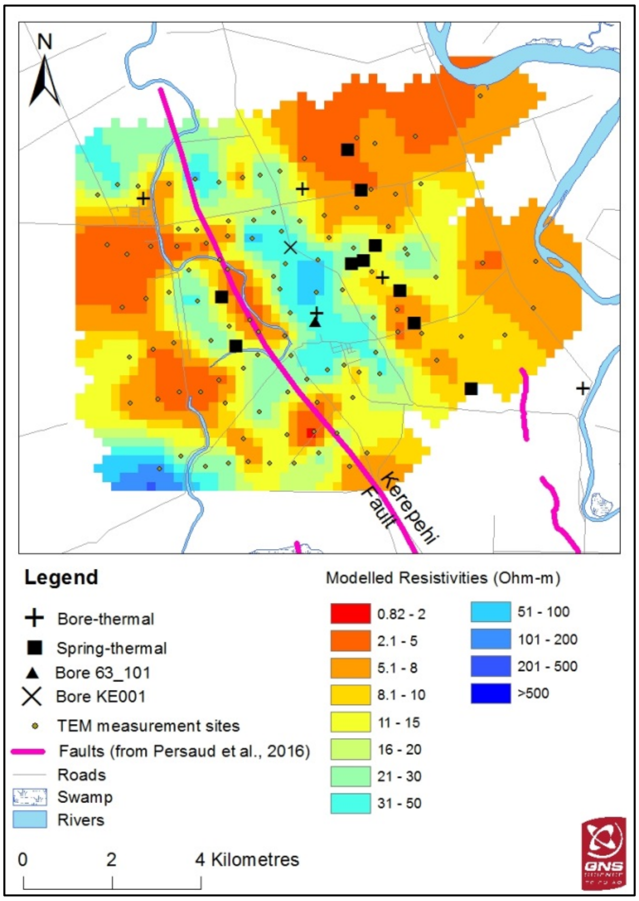
Figure 2 : Smooth model resistivities at 25 m BSL.

fluids. Further exploration work would be required to confirm this.

Many of the mapped thermal features are located in an approximate line along the eastern edge of the low resistivity anomaly at 150m BSL (Figure 3). This line also lies roughly along an extension of a possible fault mapped by Persaud et al. (2016). This indicates that:

- The fault may exist, and continues through the study area even though a surface expression has not been mapped.
- If the fault does exist, may provide a permeable pathway for geothermal fluids to reach the surface. This may be the preferred up flow area at shallow depths, and not the Kerepehi Fault.
- May provide an eastern boundary for the up flowing geothermal fluids in this area.

Figure 4 is an approximately West-East cross-section through the 1D smooth resistivity model with possible flows of source geothermal fluids shown. We interpret that the bulk of the geothermal fluids associated with this study area flow up the unmapped fault located approximately three kilometres east of the Kerepehi Fault, with some thermal fluids also ascending via the Kerepehi Fault. Upflow of the thermal fluids via the Kerepehi Fault may be limited to an area close to this cross-section in the study area.



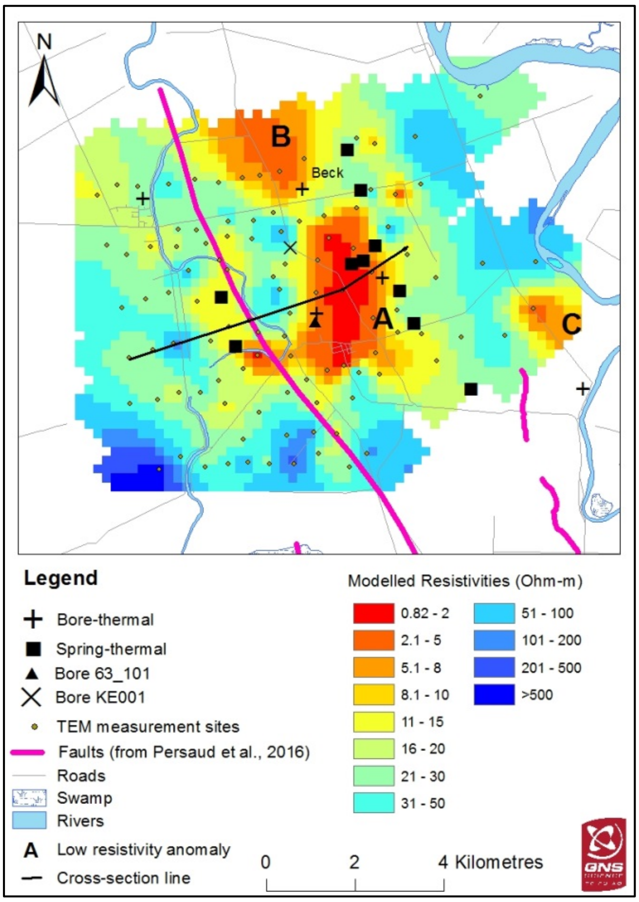


Figure 3 : Smooth model resistivities at 150 m BSL.

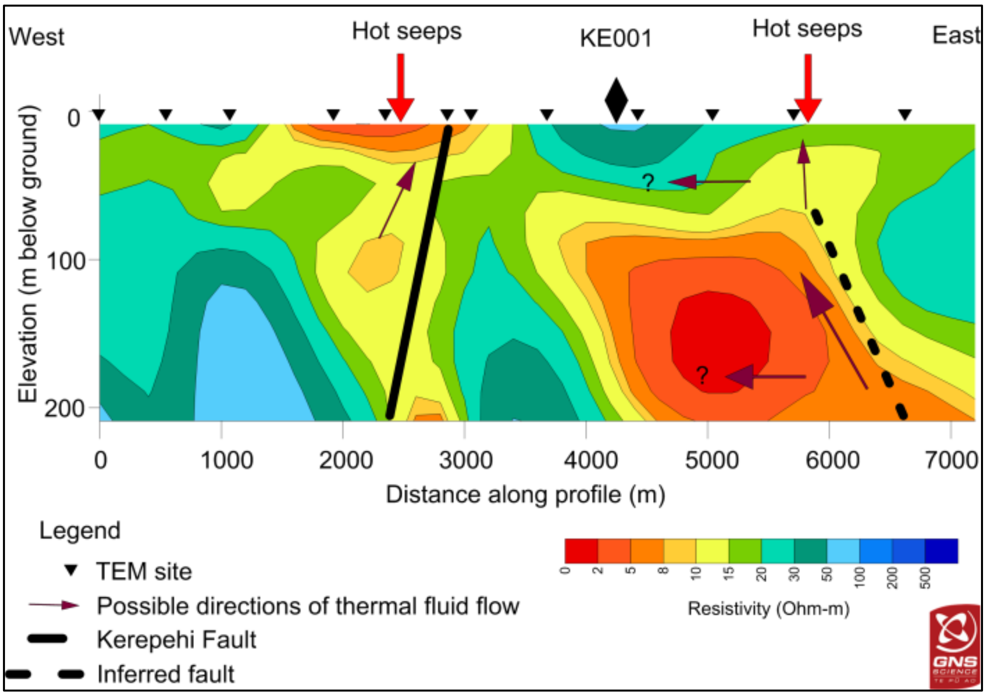


Figure 4. Cross-section of the smooth 1D resistivity model. See Figure 3 for cross-section line. Cross-section is viewed from the south.

4. CONCLUSION

In-loop transient electromagnetic (TEM) data has been collected from 105 sites in the Kerepehi area to investigate the relationship between the shallow resistivity structure and warm seeps mapped in the area. The study found:

- The area is generally conductive which reflects the clay-rich sedimentary depositional environment.
- Low modelled resistivities close to Kerepehi Township may be associated with thermal fluids interacting with uplifted basement rock and fault structures.
- The Kerepehi Low Temperature Geothermal System may be larger than expected. Further work will be required to determine this.

5. ACKNOWLEDGEMENTS

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