GEOLOGICAL STRUCTURES OF THE OKAUIA LOW-T GEOTHERMAL SYSTEM (HAURAKI RIFT ZONE, NEW ZEALAND) INVESTIGATED USING GRAVITY DATA AND DIGITAL TOPOGRAPHIC MODEL

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ABSTRACT

Okauia Low-T geothermal system is located about 7 km northeast of Matamata in the Waikato Region, North Island of New Zealand. It is situated over the eastern edge of the southern (inland) part of the Hauraki Rift Zone (HRZ). Prior to this study, detailed gravity, ground magnetic, TDEM and DC-resistivity investigations have been carried out over this low-T geothermal system. In this study we investigate further the detailed geological structures across the Okauia Low-T system using the 3-D density model from the previous gravity investigation and a high resolution digital elevation model (DEM) of topography available from the Land Information New Zealand (LINZ).

Natural surface thermal features at Okauia consist of seeps and springs with temperatures up to 40ºC along a half kilometre stretch of the Waihou River. The Okauia Low-T geothermal system is hosted by upper Pliocene alluvium sediments (the Hinuera Formation) and older Tertiary volcanic rocks (the Waiteariki Ignimbrite) which are exposed about 1 km south east of the Okauia warm springs.

Horizontal gradients were calculated from horizontal slices of the 3-D density model and from the high resolution LINZ DEM data. A set of normal faults mainly oriented in the NW/W direction (the HRZ direction) can be recognised from the analyses. Two of these faults form the SW/W boundary of the sub-surface Waiteariki Ignimbrite, but there is another fault that cut through the ignimbrite formation. It appears that these faults and the sub-surface boundary of the Waiteariki Ignimbrite provide permeable paths for ascending warm fluids from deep circulation of ground water facilitated by regional faulting in the HRZ to reach the surface.

1. INTRODUCTION

This paper presents a geological structure investigation of the Okauia Low-T geothermal system using 3D density model from a previous gravity study (Soengkono and Reeves, 2015) and a new analysis of high resolution DEM of topography (8m grid) obtained from the Land Information New Zealand (LINZ). The Okauia Low-T system is located 7 km northeast of Matamata, over the eastern edge of the southern (inland) part of the Hauraki Rift Zone in the North Island of New Zealand (Figure 1). The Hauraki Rift Zone is an active back-arc continental rift parallel to the NW-SE trending Miocene to mid-Pleistocene Coromandel Volcanic Zone (Hochstein and Balance, 1993). Gravity and seismic interpretations by Hochstein and Nixon (1979) indicated that the inland HRZ consists of two sub-parallel fault angle depressions related to the Kerepehi Fault and the Hauraki Fault. The Okauia Low-T geothermal system is situated between the southernmost segments of the Kerepihi and the Hauraki Faults (Figure 2).

The gravity interpretation of Hochstein and Nixon (1979) also suggests that the Mesozoic greywacke basement has been down faulted to a maximum depth of about 2 km along the two fault angle depressions that are now filled with sediments, ranging from unconsolidated in the upper part to quasi-consolidated in the lower part of the sequence. The upper unconsolidated sediments consist mainly of upper-Pliocene alluvium deposits of a large, braided river delta complex named the Hinuera Formation (Houghton and Cuthbertson, 1989). The Hinuera Formation and older Tertiary volcanic rocks (the Waiteraiki Ignimbrite) exposed to the southeast of Okauia (Figure 2) host the Okauia Low-T geothermal system.

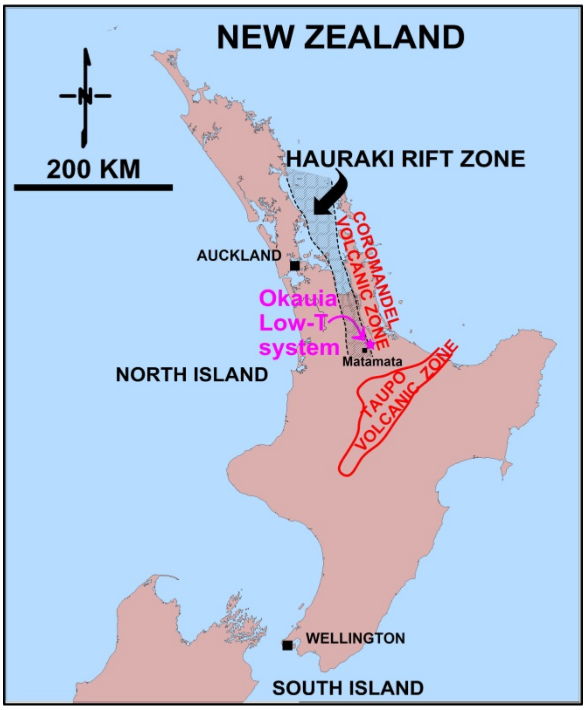

Figure 1: Location map of the Okauia low-T system.

Detailed gravity, ground magnetic, TDEM and DC-resistivity investigations have been carried out over this low-T geothermal system (Soengkono and Reeves, 2015). The approximate boundary of the Okauia Low-T geothermal system (shown in Figure 2) was delineated using the TDEM and DC resistivity surveys.

2. THE GRAVITY DATA OVER THE OKAUIA LOW-T GEOTHERMAL SYSTEM

The detailed gravity measurements over the Okauia Low-T geothermal system were conducted by Soengkono and Reeves (2015) in order to investigate the shallow density variation within the upper unconsolidated alluvium deposits found locally. The survey was carried out using a La Coste and Romberg G-Type (G106) gravimeter (±1 microN/kg reading accuracy). The elevations of gravity stations were determined using Trimble GeoXH Differential GPS with an estimated vertical accuracy of ±0.1m. The Bouguer gravity anomalies obtained from this survey are accurate to at least ±5 microN/kg (±0.5 mgal) (Soengkono and Reeves, 2015).

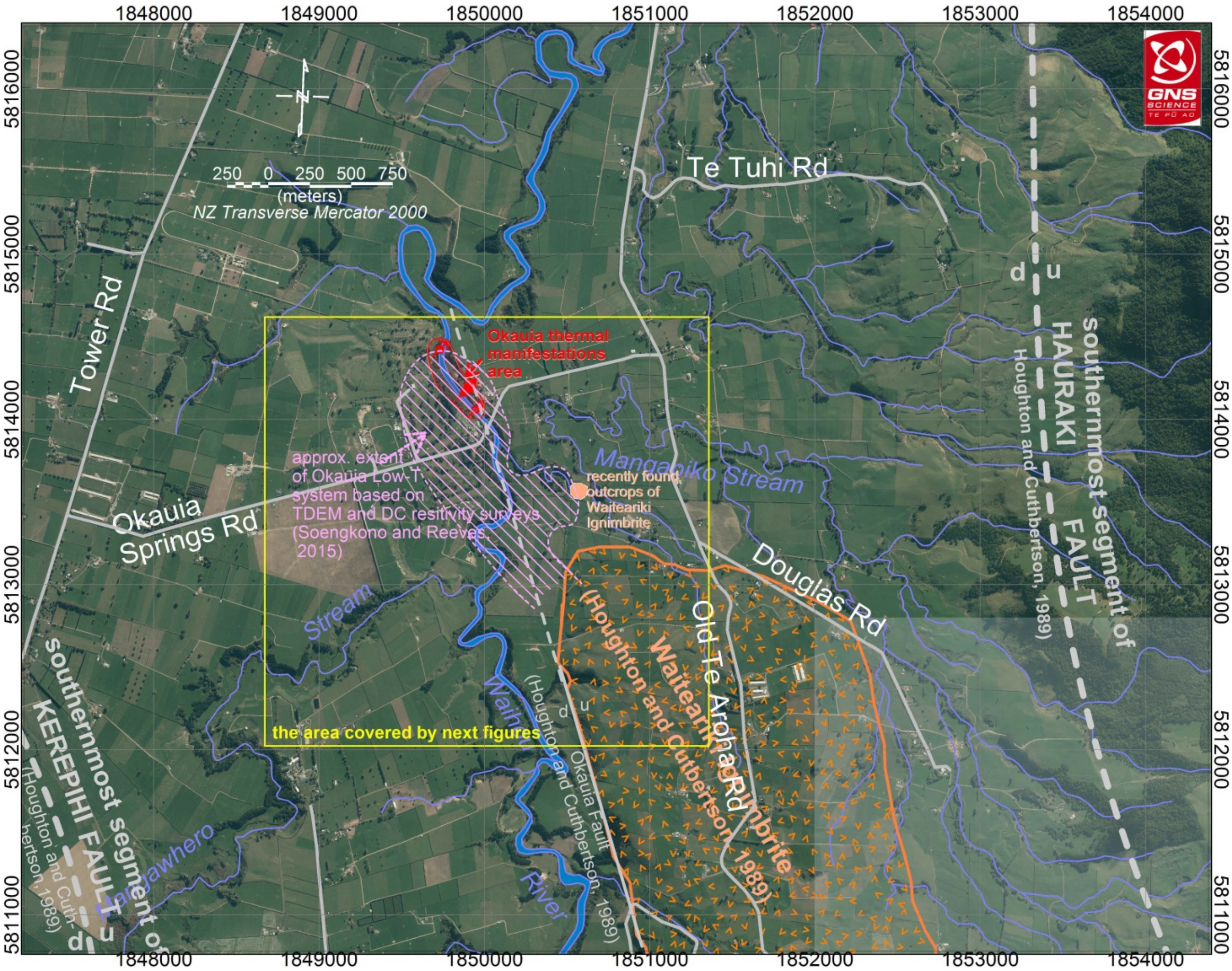

Figure 2: The setting of the Okauia low-temperature geothermal system

3. INTERPRETATION OF THE GEOLOGICAL STRUCTURES

3.1. 3D density model

Soengkono and Reeves (2015) subtracted a regional field defined from anomaly values over outcropping Mesozoic greywacke basement around the Hauraki Depression (GNS gravity database) from the Bouguer gravity anomalies over the Okauia study area to obtain the residual Bouguer gravity anomalies, which represent lateral changes in average density down to the greywacke basement. To obtain the gravity expressions of shallow (< 500 m depths) density variation, which was the aim of the gravity study, they resolved a "local regional" gravitational field by a third order trend of the residual Bouguer anomalies. The values of this "local regional" field were subtracted from the residual Bouguer anomalies, giving "local residual Bouguer anomalies" (Soengkono and Reeves, 2015) shown in Figure 3, which reveal the shallow density variation in the study area. The gravity data in this figure show a gravity high (≥+10 microN/kg) that was interpreted by Soengkono and Reeves (2015) to represent the extension to the north-northwest of the Waiteariki Ignimbrite at shallow depth.

Figure 4 shows a 3D density model obtained from quantitative modeling of the gravity data in Figure 3 (Soengkono and Reeves, 2015). The map of a horizontal

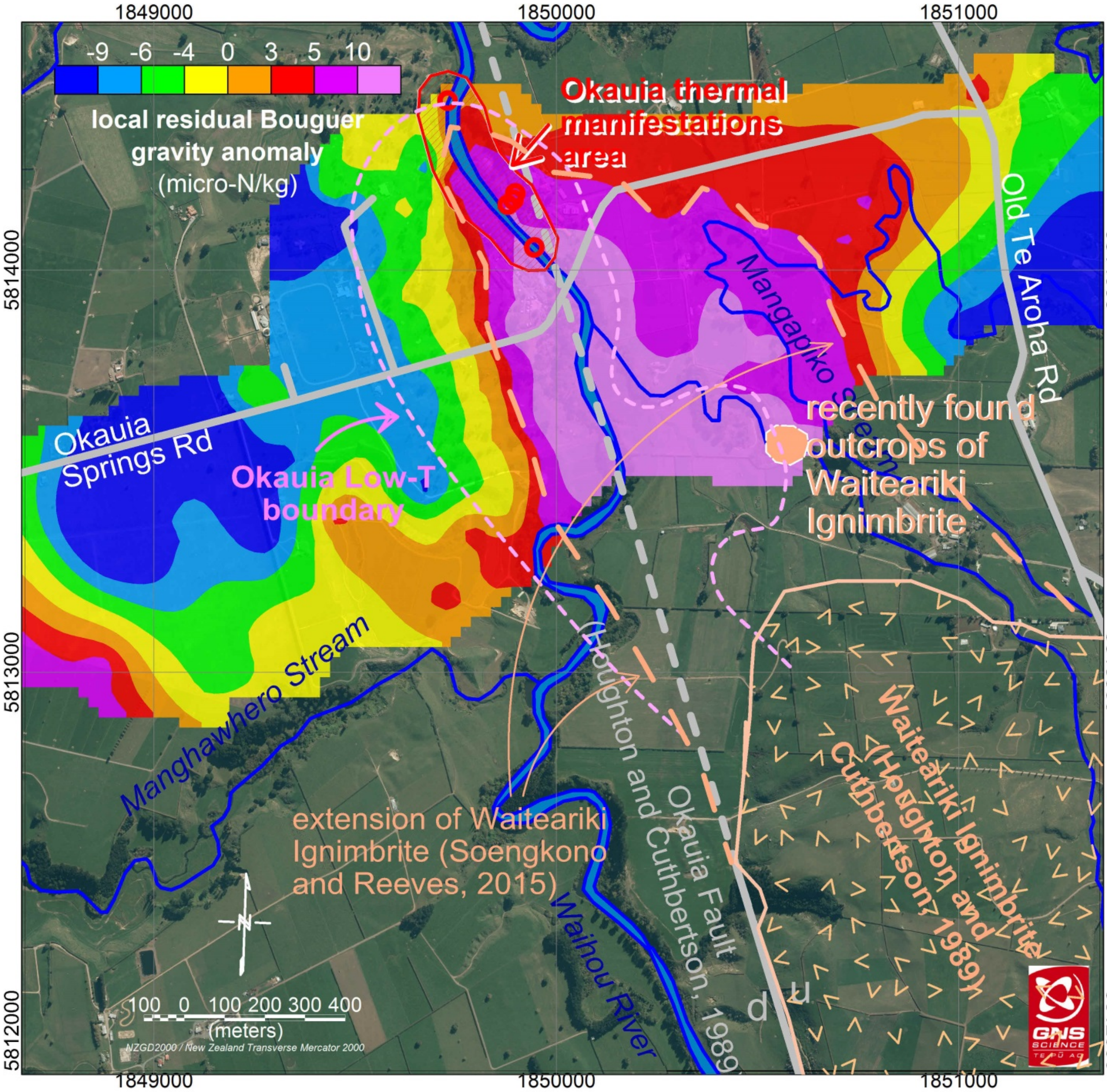

Figure 3: Local residual Bouguer gravity anomalies over the Okauia low-temperature geothermal system (Soengkono and Reeves, 2015).

slice of the density model at 0 m RL (the sea level) is presented in Figure 5. A similar density slice was also made at +25m RL and gives a result very similar to the density slice from 0 m RL in Figure 5.

From a close look at the result in Figure 5, we identify more extensions of the Waiteariki Ignimbrite to the northeast and to the southwest than that indicated by local residual Bouguer anomalies map (Figure 3) alone.

Geological faulting in the study area is in approximately S/SE-N/NW (N337.5˚E) direction (Figure 2) which is also the direction of the Hauraki Rift Zone. The faults are normal faults with the SW/W block moving downwards. Accordingly, a further interpretation of geological faulting from the density model, with a more detailed approach than that of Soengkono and Reeves (2015), is carried out by computing the gradient of density in the NE/E (N67.5˚E) direction (looking perpendicular to the fault plane from the downward block). The normal faults identified from the new interpretation are shown in Figure 5. Three segments of normal faults are identified inside the Okauia Low-T geothermal system. The two segments at 200 m to the west-southwest of the Okauia Fault inferred by Houghton and Cuthbertson (1989), were interpreted by Soengkono and Reeves (2015) as a single segment marking the western-southwestern boundary of the Waiteariki Ignimbrite underneath the Okauia Low-T geothermal system.

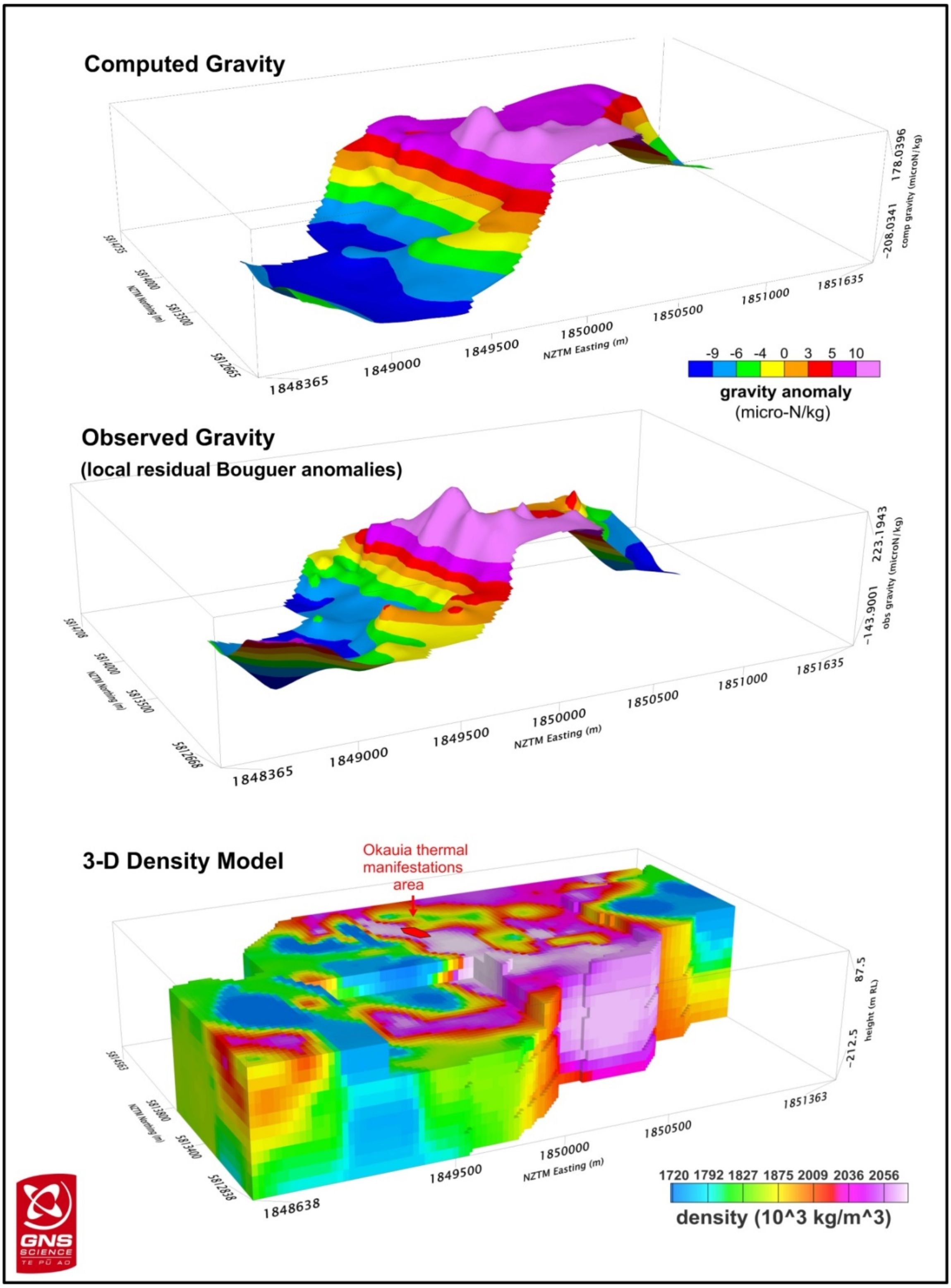

Figure 4: 3D density model of Okauia local residual Bouguer anomalies shown in Figure 3 (from Soengkono and Reeves, 2015).

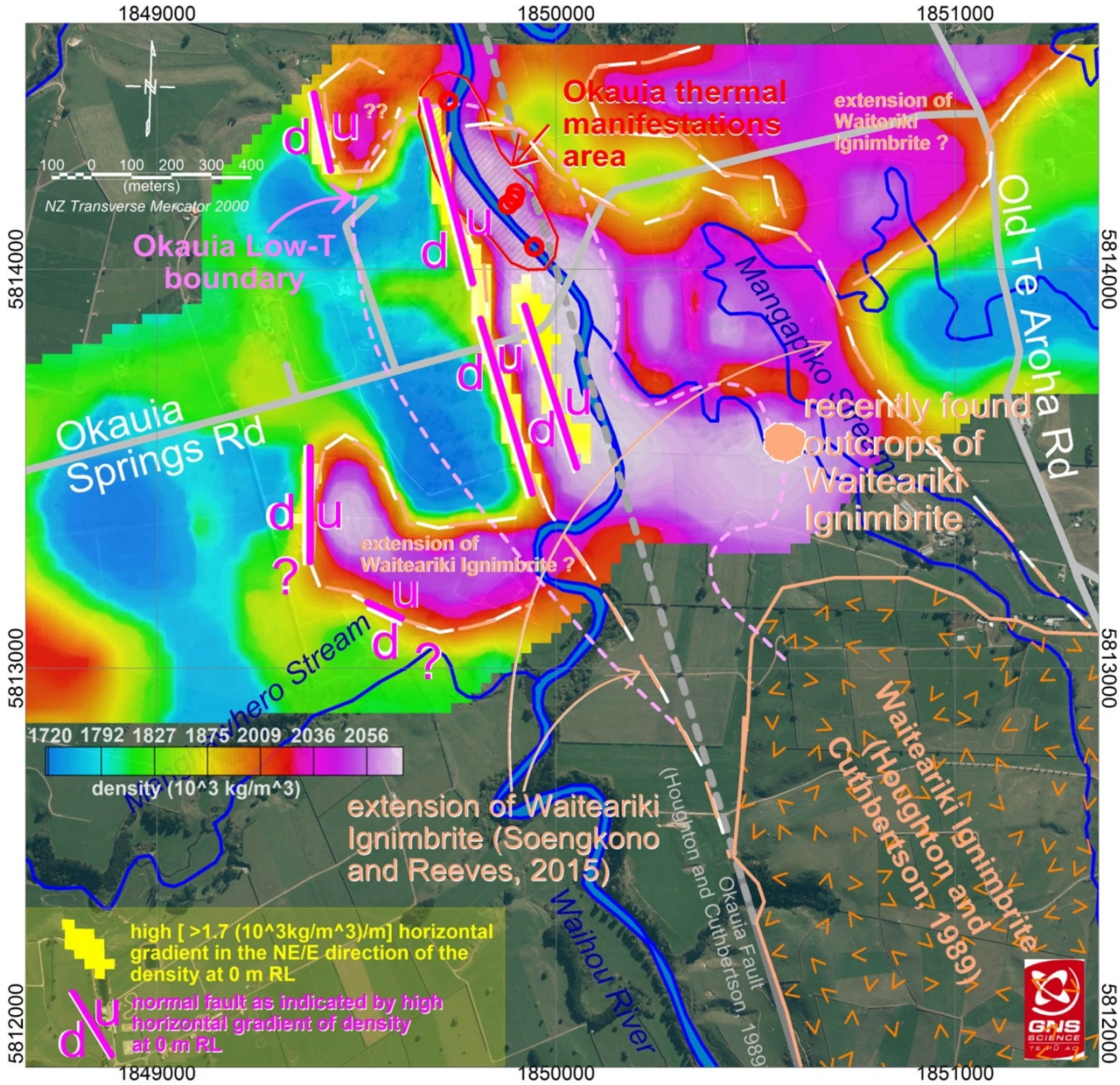

Figure 5: Horizontal slice at 0 m RL of the density model (Figure 4). The density model indicates extensions of Waitearik Ignimbrite that are not detected using only the gravity map (Figure 3). Normal faults as indicated by high (>1.7 (10^3kg/m^3)/m)) horizontal gradient in the NE/E (N67.5˚E) direction of the density at 0 m RL are shown by the thick purple lines.

The third segment located closer (about 100m) to the inferred Okauia Fault of Houghton and Curthbertson (1989) in Figure 5, was not identified by Soengkono and Reeves (2015).

Three other short segments of normal faults are identified in the west outside the Okauia Low-T geothermal system. These were also not identified by Soengkono and Reeves (2015). The three fault segments appear to mark edges of the additional extensions of Waitearik Ignimbrite.

The density model does not extend far enough to the southeast to cover the exposed Waitearik Ignimbrite and the Okauia Fault shown by Houghton and Cuthbertson (1989) as marking the western-southwestern boundary of the ignimbrite. However, high resolution (8m grids) DEM data of New Zealand topography have recently become available at the LINZ website (https://data.linz.govt.nz/). The DEM data for the region covering the Okauia study area were downloaded from the website in ASCII format and were transformed into Oasis Montaj grid format for plotting and further processing.

However, another explanation is plausible for the denser body extending from the SE towards the Okauia thermal manifestation area (Figures 4 and 5). This body might represent depositions of silica or calcite in the pores of the Waitearik Ignimbrite and Hihuera Formation by thermal water that laterally moving in a general NW direction (M.P. Hochstein, pers. comm., 2015). Supporting this suggestion is our field observation that the rocks of the Waitearik Ignimbrite contain a significant amount of pumice, so they do not appear to be overall much denser than the Hinuera Formation. This alternative explanation is attractive in terms of the use of accurate gravity measurements to explore low-T geothermal system. If it is true, the denser body shown in Figures 4 and 5 represents the zone where warm waters are, or have been flowing. Unfortunately, no gravity measurements were made over the large exposure of the Waiteriki Ignimbrite to the south east of Okauia thermal springs.

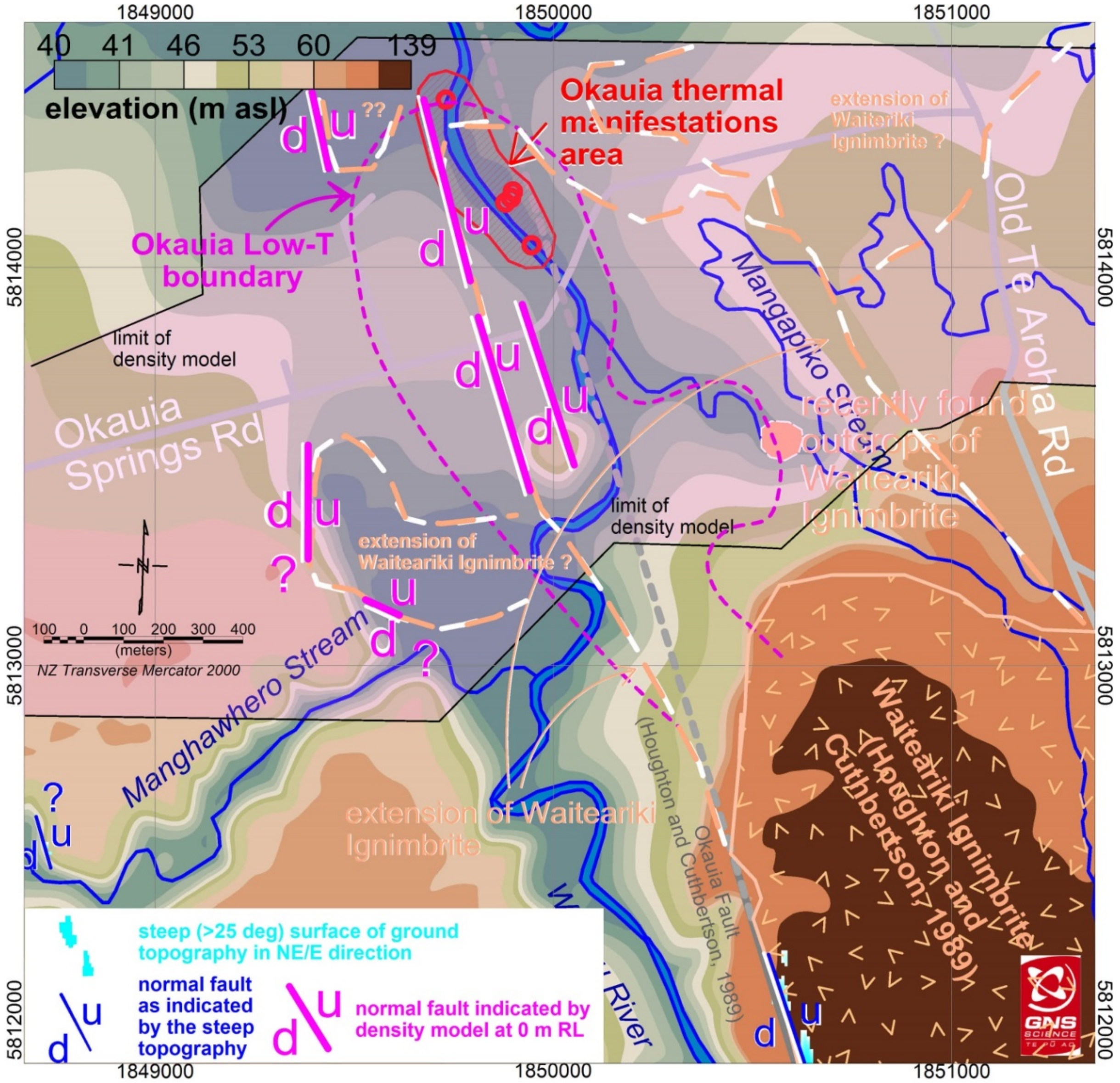

Figure 6: Okauia topography image drawn from high resolution DEM of topography (8m grid) downloaded from the LINZ website. The normal faults in thick blue lines are interpreted from relatively steep (>25˚) topographic gradient in the NE/E (N67.5˚E) direction. The normal faults indicated by subsurface density model (Figure 5) are also shown (thick purple lines).

3.2. High resolution DEM topography

The topography image of the Okauia area drawn from the high resolution DEM from LINZ is shown in Figure 6. It shows that the ground elevation of the area ranges from about 40 m RL along the course of Waihou River to about 150 m RL over the exposed Waiteariki Ignimbrite.

Most of the study area is topographically almost flat which represents the surface of the upper-Pliocene alluvium deposits (the Hinuera Formation). These alluvium deposits would hide topographic expressions of most normal faults that were inactive prior to upper-Pliocene. However, we still computed the gradients of topography in the NE/E (N62.7˚E) direction from the detailed DEM data from LINZ to see what comes out. The result shows that the highest gradient in NE/E direction is 0.57 m/m which is equivalent to a topographic slope of about 30˚. We plotted on the map in Figure 6 the locations of topographic slope ≥25˚. The plot shows a zone which follows the Okauia Fault mapped by Houghton and Cuthberson (1989) along the western/southwestern edge of the exposed Waiteariki Ignimbrite.

Another zone of NE/E topographic slope ≥25˚ also occur along the course of the Manghawero stream near the southwestern corner of Figure 6. However, it is not clear whether this topographic slope reflects a normal faulting or it is just the result of erosion by the stream.

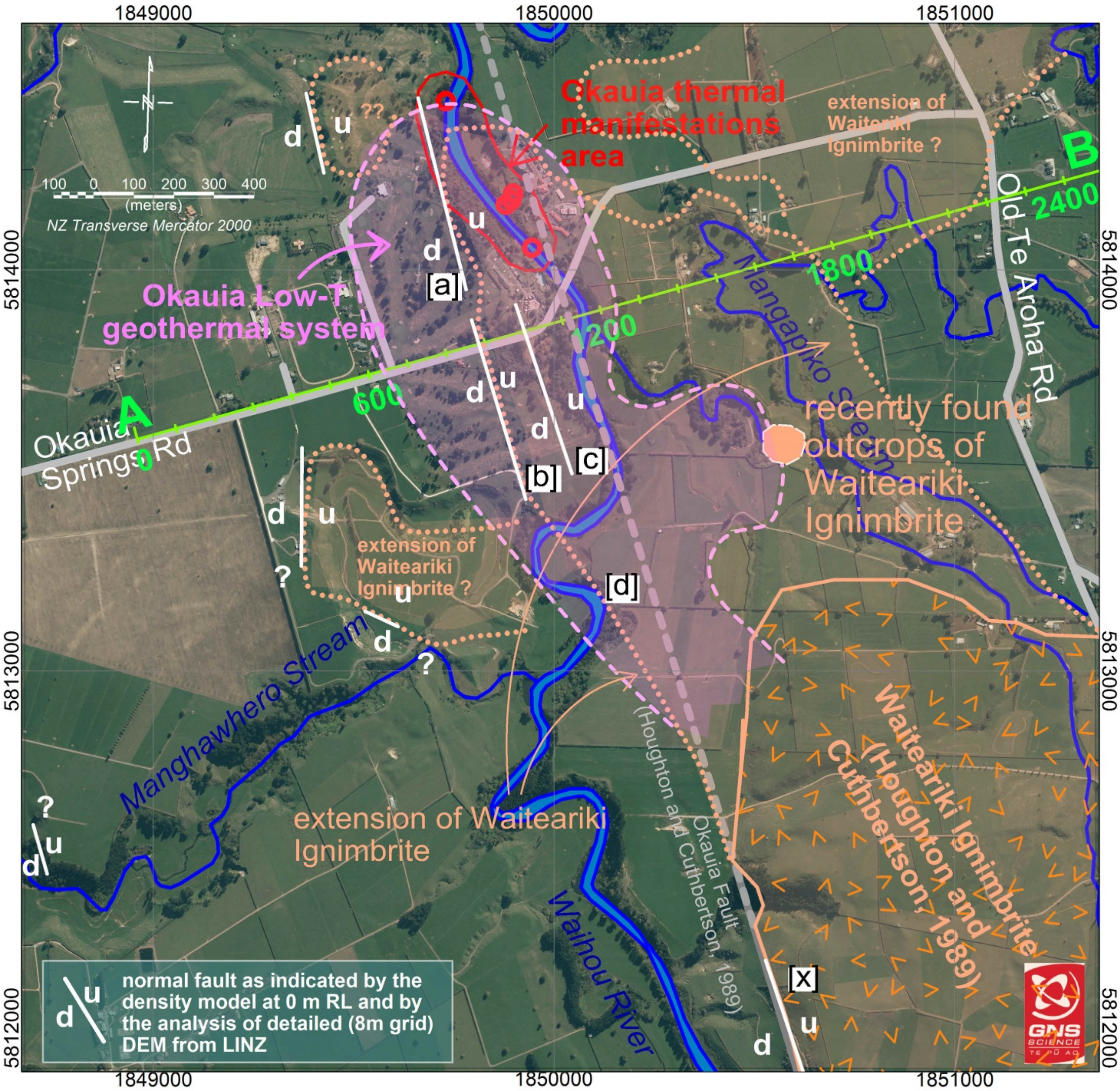

Figure 7: Summary map of the Okauia Low-T geothermal system

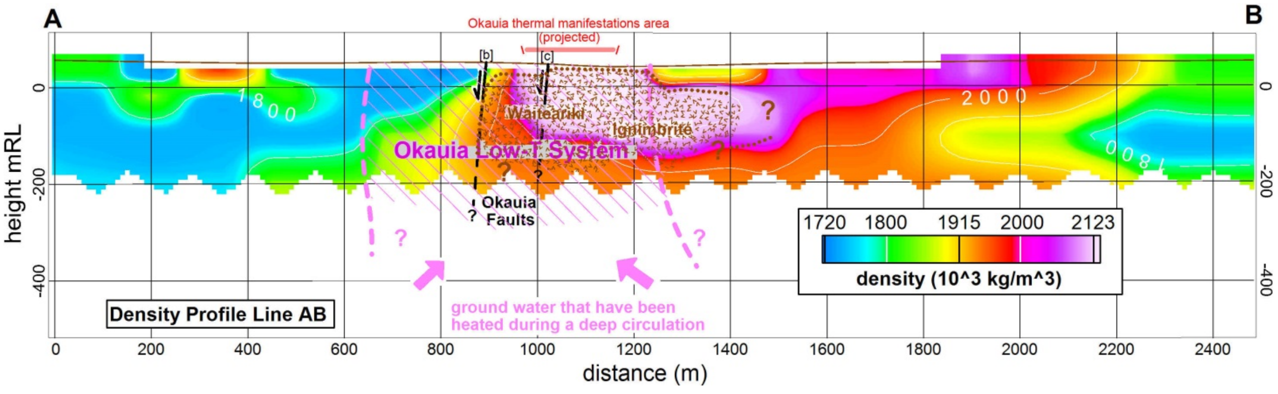

Figure 8: Cross-section of Okauia Low-T system along Line AB. See Figure 7 for the location of Line AB.

4. SUMMARY AND CONCLUSIONS

A summary map of the Okauia Low-T geothermal system is presented in Figure 7. This figure shows a normal fault ([x]) interpreted from an analysis of high resolution DEM which perfectly matches the southern part of the Okauia Fault determined during a geological mapping by Houghton and Cuthbertson (1989) as the southwestern\western edge of the exposed Waiteariki Ignimbrite. Houghton and Cuthbertson also inferred that Okauia Fault extends further to the north, running through the location of the Okauia thermal manifestations. From the analysis of the 3D density model in this study, three segments of normal fault ([a], [b] and [c]) are identified in this area, but these are located 100 m and 200 m to the southeast/east of their inferred north extension of Okauia Fault.

The result in Figure 7 shows that the Okauia Low-T Geothermal system is closely related to the three segments of normal fault ([a], [b] and [c]) and to the southwestern\western edge of the Waiteariki Ignimbrite subsurface extension ([d]), all are identified from the 3D density model. These normal faults and edge of Waiteariki Ignimbrite provide permeable paths for upward movements of warm water.

A cross-section of the Okauia Low-T geothermal system along profile line AB (Figure 7) is presented in Figure 8. The cross-section suggests that the Okauia Low-T geothermal system is the result of upward movements of groundwater that have been heated during a deep circulation facilitated by the Hauraki Fault in the east, and the Kerepihi Fault in the west.

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