Three-Dimensional Inversion of Magnetotelluric Data from Mt. Ruapehu, New Zealand

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1 Introduction

Mt. Ruapehu (see Fig. 1) in the central North Island of New Zealand is part of the Tongariro National Park. This is a major tourist site with approximately 800,000 visitors each year (Hutchings, H. and Bamford, D., 2017). However, Mt. Ruapehu is also a frequently active volcano and potential hazards may include ash fall, lava flows, pyroclastic density currents and lahars (Leonard et al., 2021). These may put the visitors and the infrastructure in the national park into great danger, e.g. as in the 1953 Tangiwai disaster, where 151 people died when a train plunged into the Whangaehu river after a railway bridge was destroyed by a lahar (NZ History, 2023).
In order to better understand the volcano, high-resolution models of its subsurface structure, e.g. the magmatic system are needed (Leonard et al., 2021). Here, we present a preliminary resistivity model of Mt. Ruapehu including MT data collected this year and from a previous campaign (Ingham et al., 2009).

Figure 1: Aerial photograph of Mt. Ruapehu (Leonard et al., 2021)

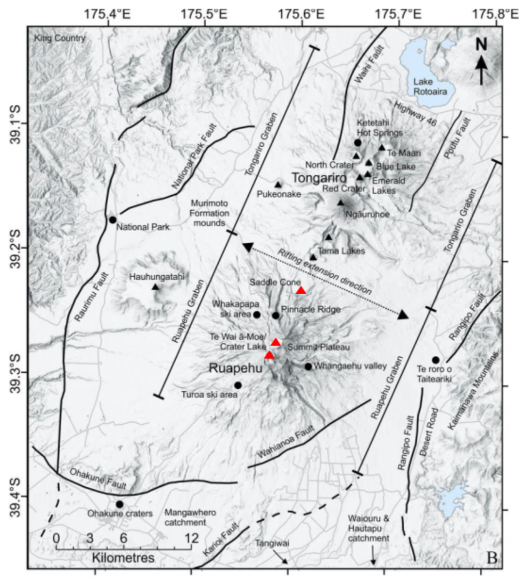


Figure 2: Geological map with major geographic and tectonic features labelled. Annotated lines mark faults and (red) triangles mark eruptive vents (at Mt. Ruapehu) (modified from (Leonard et al., 2021)

2 Geology

Mt. Ruapehu is located at the southern tip of the Taupo Volcanic Zone (TVZ) (Leonard et al., 2021). This is a NNE-SSW trending rifted arc in the central part of the

North Island of New Zealand (see Fig. 2) and formed by the subduction of the Pacific plate beneath the Australian plate at the Hikurangi margin (Wilson & Rowland, 2016).
Mt. Ruapehu itself is a 2797 m high andesite-dacite stratovolcano and forms part of the Tongariro Volcanic Centre whose vents align NNE (see Fig. 2). At the summit of Mt. Ruapehu, Te Wai ā-Moe or Crater Lake forms the uppermost portion of the hydrothermal system (Leonard et al., 2021). According to Leonard et al. (2021), the edifice of the volcano and the ring-plain around it are mainly comprised of volcaniclastic rocks. These are expected to be unaltered and therefore electrically resistive at the surface. In contrast, in the presence of an underlying hydrothermal system, the volcaniclastics can be partially altered to clay, resulting lower electrical resistivity at greater depths. The basement rocks below Mt. Ruapehu are inferred to be resistive metasediments, which outcrop at the surface in the Kaimanawa mountains East of Mt. Ruapehu. South and West of Mt. Ruapehu conductive tertiary sediments can be found at the surface (Leonard et al., 2021).

3 MT Survey

In total a set of 64 MT measurements have been used in this study (see Fig. 3), including new data acquired at 28 sites in March 2023 on and around Mt. Ruapehu, as well as data from 36 sites from a previous campaign (Ingham et al., 2009). The site spacing in the central part is approximately 3 km. The data generally exhibits excellent data quality.

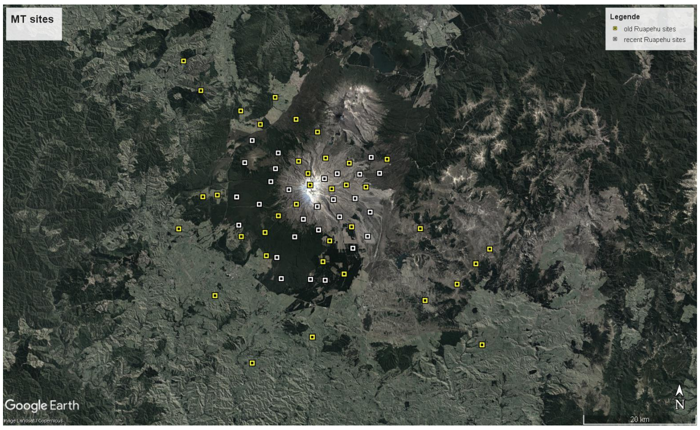


Figure 3: MT site locations: yellow squares mark sites of previous campaign (Ingham et al., 2009) and white squares mark sites from 2023.

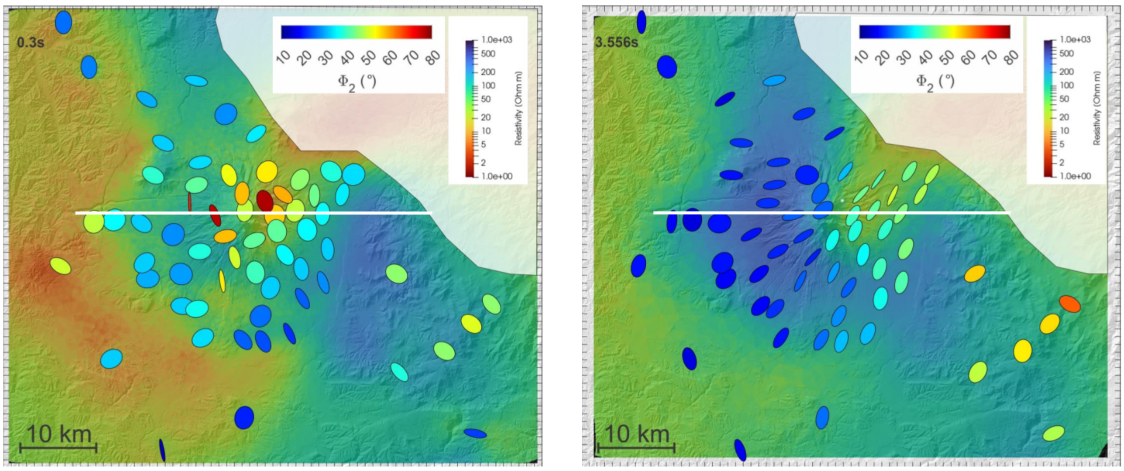
4 Inversion of MT Data

The inversion has been carried out using FEMALY (Finite Element MAtlab LibrarY for Electromagnetics) (Spitzer et al., 2023). The mesh includes the topography and has ca. two million cells. In the inversion, the impedances for 16 periods between 0.012 s and 341 s have been used as input data. A homogeneous half-space of 100 Ωm has been assigned as the starting model. The inversion has been split into four period bands with four periods each, starting with the shortest periods and progressing to the longest periods. The final model of the previous period band has been assigned as the starting model of the new period band. The computational effort has been approximately 30 h and 170 GB RAM per period band for first order Nédélec elements on the TUBAF compute cluster.

5 Inversion Results

The preliminary resistivity model exhibits a conductive layer to the S and W of the survey area at shallow depths, which coincides with the tertiary sediments (see Fig. 4). The model

also shows a highly resistive layer at depth in the western half of the survey area as well as to the S and SE of Mt. Ruapehu (see Fig. 4). This is interpreted as the metasedimentary basement, whose top is located at a depth of approximately 2 km below sea level in the central part of the survey area.
The most interesting structure revealed in the model is the conductive body extending from Mt. Ruapehu towards the Northeast (see Fig. 4), which we interpret as the connection to the magmatic system that feeds heat to Mt. Ruapehu. The NE conductor in the inversion model is supported by the phase tensor ellipses (based on (Caldwell, Bibby, & Brown, 2004)) from the MT measurements, which also indicate a conductive structure in this area. From the W-E profile (see Fig. 5) it can be seen that this conductive zone extends down to at least 12 km below sea level.
In the central part of the survey area, there is also a conductive layer at very shallow depth (see Fig. 5) that we intepret as altered, volcaniclastic rocks. In this area, any young, unaltered and resistive volcanic rocks at surface, may not be imaged well in this particular model, as the shortest periods measured have not yet been included in the modelling.



(a) $z = 1.5\ km$ below sea level **(b)** $z = 6\ km$ below sea level

Figure 4: Depth slices of the preliminary resistivity model with phase tensor ellipses after (Caldwell et al., 2004) overlaid. The white line indicates the position of the W-E profile shown in Fig. 5

6 Conclusions and Outlook

The resistivity structure of the preliminary inversion model of MT data at Mt. Ruapehu varies strongly between the resistive western part and the more conductive northeastern part of the survey area. No conductive structure has been imaged directly below Mt. Ruapehu. In contrast, a conductive zone is imaged that extends from Mt. Ruapehu towards the NE, indicating that the volcano may be fed from a supply zone in the NE outside of the survey area.
Further inversions including the tipper and phase tensor data as well as the data from the shortest periods ($T < 0.012\ s$) will be run in order to improve the model. However, improving the resolution of the hydrothermal system at shallow depths would also require a denser site array.

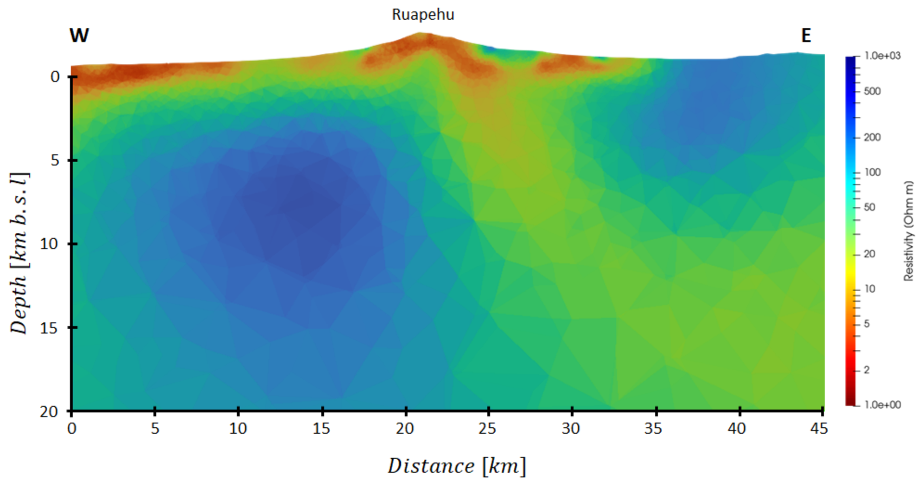


Figure 5: Vertical section through the preliminary resistivity model along W-E profile indicated in Fig. 4

7 Acknowledgments

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References

Caldwell, T. G., Bibby, H. M., & Brown, C. (2004). The magnetotelluric phase tensor. *Geophysical Journal International*, *158*(2), 457-469.

Hutchings, H. and Bamford, D. (2017). *Ruapehu regional development plan.* ([Online; accessed 18-Nov-2023])

Ingham, M. R., Bibby, H. M., Heise, W., Jones, K. A., Cairns, P., Dravitzki, S., ... Ogawa, Y. (2009, 11). A magnetotelluric study of Mount Ruapehu volcano, New Zealand. *Geophysical Journal International*, *179*(2), 887-904.

Leonard, G. S., Cole, R. P., Christenson, B. W., Conway, C. E., Cronin, S. J., Gamble, J. A., ... Wilson, C. J. N. (2021). Ruapehu and Tongariro stratovolcanoes: a review of current understanding. *New Zealand Journal of Geology and Geophysics*, *64*(2-3), 389-420.

NZ History. (2023). *Tangiwai railway disaster.* ([Online; accessed 18-Nov-2023])

Spitzer, K., Blechta, J., Börner, J., Börner, R.-U., Eiermann, M., Ernst, O., & Scheunert, M. (2023). FEMALY: A Finite Element Matlab Library for Electromagnetics. In *7th International Symposium on Three-Dimensional Electromagnetics.* Vancouver, BC, Canada. (13-15-Nov-2023)

Wilson, C. N., & Rowland, J. N. (2016). The volcanic, magmatic and tectonic setting of the Taupo Volcanic Zone, New Zealand, reviewed from a geothermal perspective. *Geothermics*, *59*, 168-187.