

Rhyolite of the Tauhara Geothermal Field: insights and correlations from geochemistry

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ABSTRACT

Since 1965, numerous subsurface rhyolite lavas have been drilled at the Tauhara Geothermal Field, Taupō Volcanic Zone. These, and additional rhyolite lavas, were intercepted in 12 geothermal wells drilled from 2019–2022 for the Contact Energy Tauhara II (174 MWe) power development project. Some rhyolites had already been characterised and formally named (e.g., Racetrack Rhyolite), but others were only affiliated to broad groups based on phenocryst type and abundance. To validate stratigraphic correlations, portable X-ray fluorescence (pXRF) analysis was trialled during the drilling campaign to geochemically ‘fingerprint’ the rhyolites by their immobile element concentrations (i.e., elements unaffected by hydrothermal alteration). Of the elements robustly quantified by pXRF, only Zr, Y, and Ti were useful to distinguish the rhyolites. Since concentrations of Zr, Y, and Ti overlap it is typically not possible to identify a given unit exclusively based on chemistry with few exceptions (e.g., Tauhara Moana rhyolite). However, by evaluating pXRF geochemical data combined with spatial and stratigraphic information, plus mineralogy, this technique was able to confirm previous correlations for several rhyolites. It also distinguished rhyolite lavas that are not the same despite their spatial proximity and similar mineralogy (e.g., Racetrack and Kauri rhyolites) resulting in new correlations.

1. INTRODUCTION

The Wairakei–Tauhara geothermal system is comprised of two fields that lie northeast of Lake Taupō (Fig. 1), in the Taupō Volcanic Zone. They occur within an 85–124 km² apparent resistivity anomaly (Fig. 1) that outlines the ‘shallow’ (<0.5 km depth) extent of hot water and clay alteration (Risk, 1984). Both the Wairakei and Tauhara geothermal fields have chemically and isotopically distinct up-flow zones (Henley and Stewart, 1983), although historic pressure drawdown at Tauhara indicates a shallow hydrological connection with Wairakei (Hunt and Graham, 2009). The geology of the Tauhara Geothermal Field includes many different rhyolite units with additional rhyolite lavas intercepted during the 12-well drilling campaign from 2019–2022 (Fig. 2). The rhyolites had been distinguished by mineralogy (phenocryst type and abundances), and/or by spatial and stratigraphic relationships. However, correlations between wells are not always robust and rhyolite identification can be impeded by hydrothermal alteration that destroys the primary igneous

minerals. To help differentiate and correlate rhyolites a pilot geochemical programme was undertaken in 2020 using portable X-ray fluorescence (pXRF) that investigated immobile elements to ‘fingerprint’ the rhyolites. The successful study resulted in a further three geochemical surveys that analysed newly drilled rhyolite, plus those from earlier wells. Here we document how pXRF geochemical analyses have aided in the identification, differentiation, and correlation of rhyolite units across the Tauhara Geothermal Field. Correlations by evaluation of immobile elements (Zr, Y, and Ti) have been made in conjunction with mineralogical, spatial, and stratigraphic considerations. To further validate geochemical correlations a representative sub-set of 35 samples was analysed by flux-fusion digest followed by inductively coupled plasma mass and atomic emission spectroscopy (ICP-MS and -AES) at ALS Geochemistry, Brisbane, Australia. This adds to the number of immobile elements, including important rare-earth elements (REE).

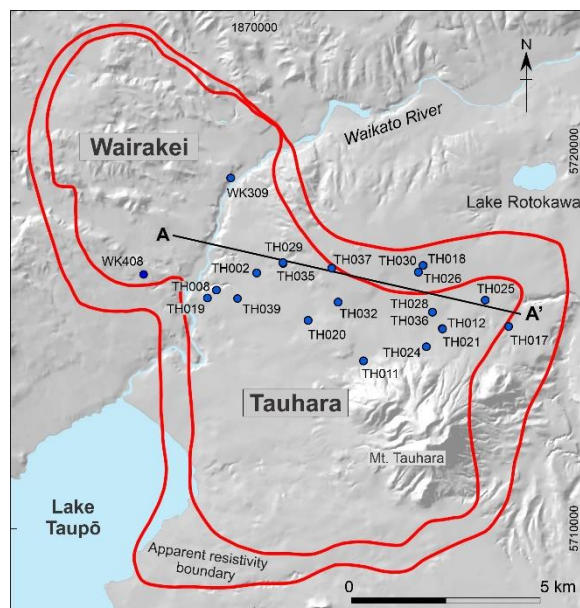


Figure 1: The Tauhara and Wairakei Geothermal Fields showing wells studied and the DC-resistivity-defined field boundary zone (Risk, 1984).

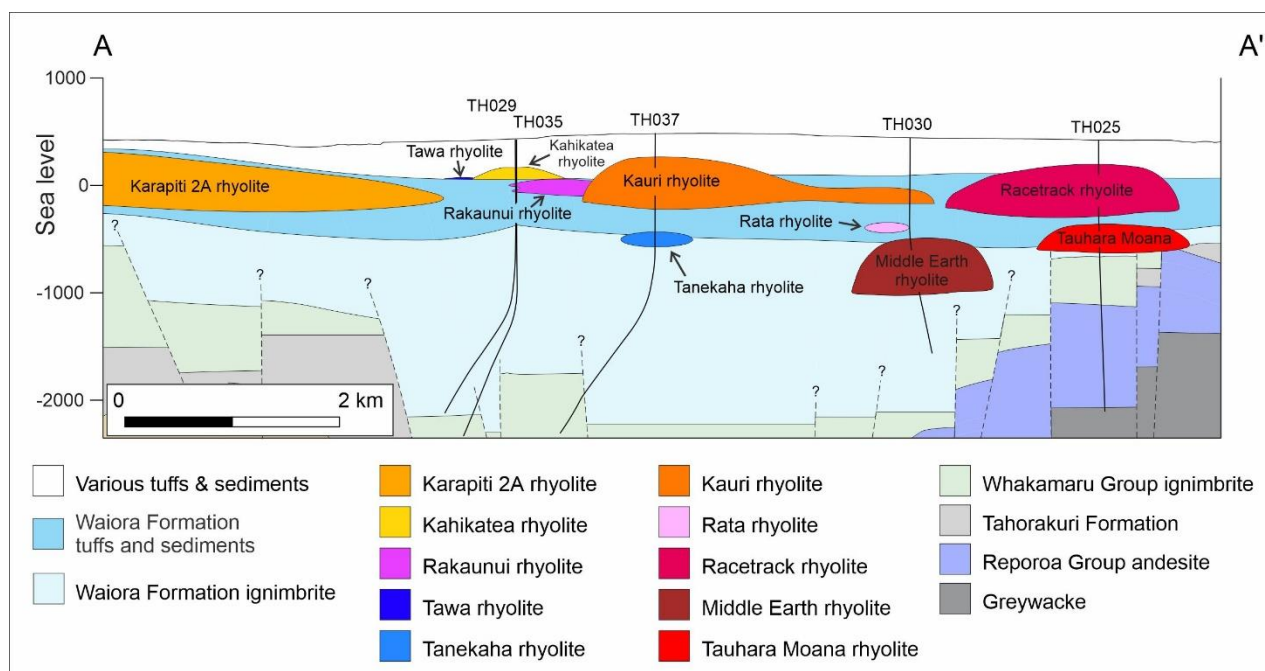


Figure 2: ENE-SSW cross section mostly through the Tauhara Geothermal Field showing simplified geology and structure. Section trace shown in Figure 1.

2. TAUHARA GEOTHERMAL FIELD

The geology of the Wairakei–Tauhara geothermal system is detailed in Grindley (1965), Steiner (1977), and Rosenberg et al., (2009, 2020). Recent drilling of 12 wells (TH024–TH039; deepest 2,792 m) at Tauhara has substantially added to the understanding of the field stratigraphy. Overall, the subsurface rocks are dominated by voluminous rhyolitic airfall and pyroclastic deposits that are interlayered with smaller volumes of lacustrine and fluvial sedimentary rocks (>2.7 km thick; Fig. 2). Domes of dacite prominently form Mount Tauhara, while numerous rhyolite units of varying extent and thickness (~30–500 m) occur within the upper 1.5 km of the succession, most of which are interbedded with Waiora Formation tuffs and sediments (Fig. 2).

Several rhyolites have been formally named and include Racetrack, Middle Earth, Trig 9471/Rubbish Tip, and Crowbar (Rosenberg et al. 2009, 2020). Other rhyolites have only been broadly grouped as quartz-free ‘Karapiti’-type or quartz-bearing ‘Te Mihi’-type initially identified from the Wairakei Geothermal Field (Grindley 1965; Steiner 1977). The quartz-bearing rhyolites have ~5–10 volume % phenocrysts of quartz, plagioclase, hornblende, and rare pyroxene. Quartz-free rhyolites are sparsely porphyritic with <2 volume % feldspar phenocrysts, rare hornblende or pyroxene but have no quartz. Rhyolite textures include massive, porphyritic (<1–10 vol.% phenocrysts), spherulitic, flow banded (cm-to-mm scale), perlitic, and pumiceous, though are seldom unique to a given unit. Combined textural and stratigraphic information are interpreted to indicate most rhyolites are extruded lavas (cf. Cas and Wright 1987; McPhie et al. 1993). A rhyolite dyke occurs at depth in TH019.

3. NAMING OF RHYOLITES

Due to complex spatial and stratigraphic relationships it is deemed confusing for units drilled in the Tauhara Geothermal Field to retain a geographic association with the Wairakei field. Based on mineralogical, spatial,

stratigraphic, and rock chemistry considerations we propose and introduce here the following new rhyolite formation names: Kauri, Rata, Kahikatea, Totara, Tawa, Tanekaha, and Ramarama (after New Zealand indigenous trees), plus Tauhara Moana and Rakaunui (geographic).

4. PORTABLE XRF INSTRUMENT, CALIBRATION, TESTING PROCEEDURE, DATA CORRECTION

Geochemical analyses of rhyolite from 19 Tauhara wells and from 2 Wairakei wells were made by pXRF. Analyses were made using an Olympus Vanta C-series pXRF instrument equipped with a 4 W, 8–40 kV, Rh X-ray tube. The standard reinforced polypropylene window (6 µm with 25 µm Kapton mesh) on this instrument reduces the detection sensitivity for atomically light elements (e.g., Mg, Al, Si). To make it suitable for geochemical applications, Geochem mode software was installed and the signal for light elements improved by replacing the reinforced window with a non-reinforced 6 µm polypropylene window (e.g., Gazley and Wellnitz 2019). A correction factor for each element was determined and applied via the analyses of certified reference material (see Fisher et al. 2014; Gazley and Fisher 2014).

Analyses were made on drilled rock fragments (‘cuttings’) that range in size from <1–10 mm in diameter (most <2 mm) and represented 5-m intervals. Cuttings were analysed on average every 10 m, although contaminated samples with mixed lithology (‘cavings’), casing cement, or lost circulation material (e.g., wood/mica) were avoided. A limited number of core samples were analysed (TH002, TH018). However, multiple analyses of the same core sample resulted in variable results due to some elements (e.g., Zr) being hosted in single minerals (e.g., zircon) heterogeneously distributed in the rock (‘nugget’ effect). Subsequently, these cores were crushed to cutting equivalent material and analysed with homogenisation resulting in more consistent element concentrations.

Portable XRF analyses were made using a field stand with cuttings placed in a plastic cup that has a 4 µm thick

polypropylene base. A pilot study established that cutting samples were homogenous and thus only a single analysis was required per sample (cf. Gazley and Fisher 2014; Fisher et al. 2014). These were analysed for 20 s per beam (40 s total analysis time) with analyses made according to a set analytical procedure. Five certified reference material samples were analysed at the start and end of each session (OREAS 20a, OREAS 24b, OREAS 30a, OREAS 151b, and OREAS 620; <https://www.oreas.com/>). A single certified reference sample was tested after every 25 samples. A replicate (repeat analysis of the same sample without moving) and a duplicate (analysis of the same sample but different fraction) were made after every 50 samples. These were undertaken for data quality assurance and quality control. Certified reference material analyses were further used for data set correction.

All analyses were collected in Geochem mode with an uncollimated beam. Elements reported by the instrument include (in order of increasing atomic mass): Mg, Al, Si, P, S, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Y, Zr, Nb, Mo, Pd, Ag, Cd, Sn, Sb, Ba, Hf, Ta, W, Re, Hg, Pb, Bi, Th, and U. Some elements were not detectable since their amounts were below their limits of detection or are subject to inter-element interferences. Elements with concentrations above the limit of detection included Al, Si, S, K, Ca, Ti, Mn, Fe, Zn, As, Rb, Sr, Y, Zr, Nb, Pb, and Th. A total of 479 cutting samples were analysed.

In addition, the chemistry of 35 representative least altered samples of different rhyolite units were analysed by flux-fusion followed by inductively coupled plasma mass spectrometry and atomic emission spectroscopy (ICP-MS (ME-MS81) and -AES (ME-ICP06) at ALS Geochemistry (Brisbane, Australia). Selected (chalcophile) elements were analysed after four-acid digestion (ME-4ACD81). Elemental oxides and elements quantified include, SiO₂, Al₂O₃, Fe₂O₃, CaO, MgO, Na₂O, K₂O, Cr₂O₃, TiO₂, MnO, P₂O₅, SrO, BaO (ME-ICP06). Ba, Ce, Cr, Cs, Dy, Er, Eu, Ga, Gd, Hf, Ho, La, Lu, Nb, Nd, Pr, Rb, Sc, Sm, Sn, Sr, Ta, Tb, Th, Ti, Tm, U, V, W, Y, Yb, Zr (ME-MS81). Ag, As, Cd, Co, Cu, Li, Mo, Ni, Pb, Sc, Tl, Zn (ME-4ACD81).

5. IMMOBILE ELEMENTS

Whole rock chemistry can be used to identify different rock types. However, hydrothermal alteration of variable intensity (<5–100%) results in removal or addition of mobile elements, including major elements (e.g., Si, K, Ca, Mg, Rb, Sr). Consequently, only immobile trace elements can be used to geochemically identify the rock (MacLean and Barrett 1993; Li et al 2015). Of the elements in our pXRF dataset, only Ti, Zr, Y, Nb, Th, and U are immobile in neutral-pH fluid environments (e.g., MacLean 1990; Madeisky 1996). However, with the addition of laboratory analyses, the REE are added to our dataset which assists with discrimination.

To confirm that Zr and Y are immobile, their concentrations have been compared against the intensity of alteration for individual variably altered rhyolite units. An example is shown in Figure 3 that compares Zr concentrations for variably altered Racetrack rhyolite in TH025. Despite variable alteration (20–100 %) there is no corresponding systematic variation in Zr concentrations. Similar plots for other rhyolites that compare Zr and Y with alteration intensity likewise show there is no systematic change with increasing alteration intensity and confirms that they are immobile. From this study we found Zr and Y are the most

useful immobile elements for distinguishing the rhyolites; although two units are distinguishable based on Ti.

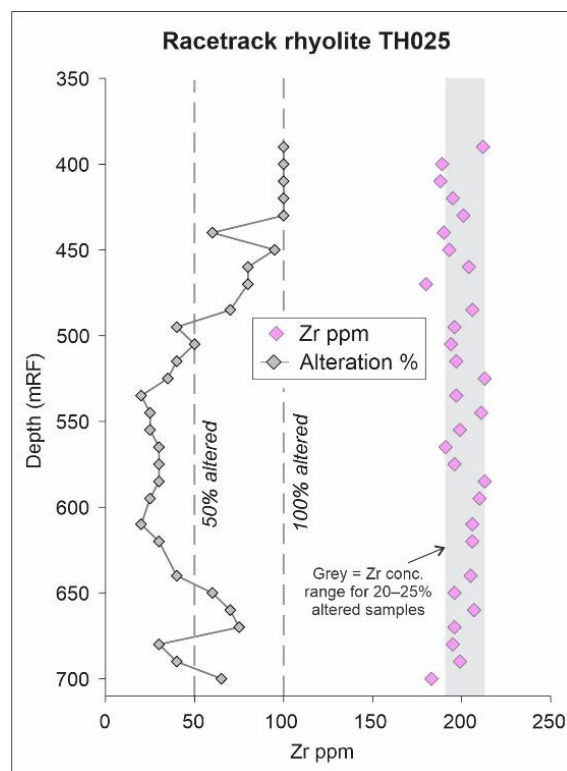


Figure 3: Alteration intensity compared against Zr concentrations for the Racetrack rhyolite in TH025 (pXRF data).

6. TAUHARA RHYOLITE GEOCHEMISTRY

Geochemical analyses were made on 30 intervals of rhyolite from 19 Tauhara wells. For reference, Karapiti 2A rhyolite from 2 Wairakei wells (WK309 and WK408) was analysed. Portable XRF chemistry data is plotted as a series of Harker variation plots (Fig. 4) and ICP chemistry data as REE C1 chondrite-normalised plots (Fig. 5). Because there is considerable overlap between Zr, Y, and Ti concentrations it is not possible to identify individual rhyolites from chemistry alone (Fig. 4A).

By evaluating mineralogical, spatial, and stratigraphic relationships coupled with immobile element concentrations, twelve rhyolite units have been identified. A further two rhyolite units (Trig 9471/Rubbish Tip and Crowbar) are recognised in the Tauhara Geothermal Field (Rosenberg et al. 2009, 2020), but were not analysed in this study. The largest rhyolite units by area and volume are Karapiti 2A, Kauri, Middle Earth, Racetrack, and Tauhara Moana (Fig. 2). Smaller units include Rakaunui, Kahikatea, Totara, Tanekaha, Tawa, Rata, and Ramarama. Geochemical characteristics and correlations of these rhyolites are detailed below.

6.1 Karapiti 2A rhyolite (Wairakei and Tauhara)

Quartz-free sparsely porphyritic (1–2 vol.% phenocrysts) Karapiti 2A rhyolite occurs mostly in the Wairakei Geothermal Field; but potentially extends eastwards into the Tauhara Geothermal Field (Fig. 2). This rhyolite is the largest by area and volume covering ~6.5 x 4.0 km (~7.2

km³) and is up to 470 m thick. Portable XRF analyses of samples from Wairakei wells WK309 and WK408 were made for reference. Rhyolite analyses from Tauhara wells TH002, TH008, TH019, and TH039 determined that their Zr, Y (Fig. 4B), and REE concentrations (Fig. 5A) overlap with the Karapiti 2A rhyolite of the Wairakei wells. Since geochemically equivalent and spatially correlated, rhyolites in these Tauhara wells are interpreted as also Karapiti 2A; thus, confirming its extension into the Tauhara Geothermal Field.

6.2 Kahikatea rhyolite

Strongly altered quartz-free rhyolite in TH029 and TH035 has overlapping but typically lower Zr and Y concentrations compared to nearby Karapiti 2A rhyolite (Fig. 4B). Different REE concentrations confirm that these units are not the same (Fig. 5B). In contrast, Zr and Y for Kahikatea, and the nearby Kauri rhyolite overlap and are inseparable (Figs. 4B vs 4D) based on these elements alone. However, REE concentrations are sufficiently different to confirm that Kahikatea and Kauri rhyolite are not the same lava (Fig. 5B).

6.3 Rakaunui rhyolite

Quartz-bearing rhyolite lava with 5–10 volume % phenocrysts of quartz, plagioclase, hornblende, and rare pyroxene occurs in wells TH020, TH029, TH032, and TH035. This rhyolite is up to 105 m thick and extends ~1.2 x 2.0 km (Fig. 2). It occurs locally above and east of quartz-free Karapiti 2A rhyolite from which it is separated by Waiora Formation tuffs and sediments. In wells TH029 and TH035 the rhyolite is overlain by quartz-free Kahikatea rhyolite and separated from it by a thin interval (25 m) of Waiora Formation. This rhyolite, named Rakaunui rhyolite, has lower Zirconium and Y concentrations than the Karapiti 2A rhyolite (Fig. 4C) and lower REE (Fig. 5C) confirming that they are different. By contrast, concentrations of Zr, Y, (Figs. 4B vs 4C) and REE (Fig. 5D) for the Rakaunui rhyolite are indistinguishable from Kahikatea rhyolite. The Rakaunui and Kahikatea rhyolites are petrographically distinct and stratigraphically separated units but are geochemically inseparable.

6.4 Tawa and Totara rhyolite

Quartz-bearing rhyolite lavas occur in TH002 and TH008 above and boarding the edge of the Karapiti 2A rhyolite and separated by units of the Waiora Formation. They occur at higher stratigraphic level than quartz-bearing Rakaunui rhyolite to the east. Based on limited analyses the strongly altered rhyolite in TH002 has marginally higher Zr and strongly altered rhyolite in TH008 has marginally lower Zr concentrations than Rakaunui rhyolite (Fig. 4C). Both rhyolites have REE concentrations indistinguishable from Rakaunui rhyolite (Fig. 5B). Though geochemically these cannot be differentiated from Rakaunui rhyolite, based on spatial relationships the rhyolites in TH002 and TH008 are considered separate and identified here as the Tawa and Totara rhyolites, respectively.

6.5 Kauri rhyolite

The quartz-free, sparsely porphyritic rhyolite in TH018 and TH030 was initially considered to be the Racetrack rhyolite. Despite identical petrography and overlapping depths the rhyolite from these wells has distinctively lower Zr and Y (Fig. 4D) and REE concentrations (Fig. 5E) than Racetrack rhyolite, and it is thus not geochemically equivalent. Due to significant distance, the thick rhyolite body in TH037 (~2.3

km to the west; Fig. 2) was not initially linked to TH018 and TH030, but similar well pressure profiles hinted to a possible connection. Zirconium and Y concentrations for rhyolite in TH037 and TH032 are indistinguishable from those for TH018 and TH030 (Fig. 4D), and likewise REE concentrations (Fig. 5B). Rhyolite in these wells is now identified as the Kauri rhyolite. It has lower Zr and Y content than neighbouring Racetrack and Rata rhyolites (Fig. 4D), and different REE concentrations than the Rata, Racetrack, and Kahikatea rhyolites (Figs. 5B & 5E). The Kauri rhyolite is up to 495 m thick and covers an estimated area of ~1.8 x 3.8 km, albeit defined by widely spaced wells. Most Kauri rhyolite textures support an extrusive emplacement, but in TH018 there are local hyaloclastite and peperite intervals indicating part of the unit was intrusive (Cattell et al. 2016; Rosenberg et al. 2020).

6.6 Tanekaha rhyolite

Tanekaha is a quartz and hornblende-bearing rhyolite lava intercepted only in TH037 where it is separated from the overlying Rakaunui rhyolite by ~200 m thickness of Waiora Formation (Fig. 2). With respect to rock chemistry, concentrations of Zr, Y, and REE are indistinguishable from mineralogically comparable quartz-bearing Rakaunui rhyolite (Fig. 4C). The distinction is purely based on the stratigraphic separation between the two rhyolites.

6.7 Rata rhyolite

A strongly altered, quartz-free rhyolite has been intercepted only in TH018 occurring beneath two intervals of Kauri rhyolite, from which it is separated by Waiora Formation tuffs and sediments (Fig. 2). It has a core of lava with outer hyaloclastite contact zones and may be an intrusive unit. It is named the Rata rhyolite, and is mineralogically identical to the Kauri rhyolite, but has higher Zr concentrations (Fig. 4D). The rhyolite also has higher Al concentrations compared to other rhyolites (~8.1–9.5 vs ~4.0–6.0 wt.% pXRF; Fig. 4G). The Rata rhyolite has markedly higher concentrations of REE confirming it is different from Kauri rhyolite (Fig. 5E).

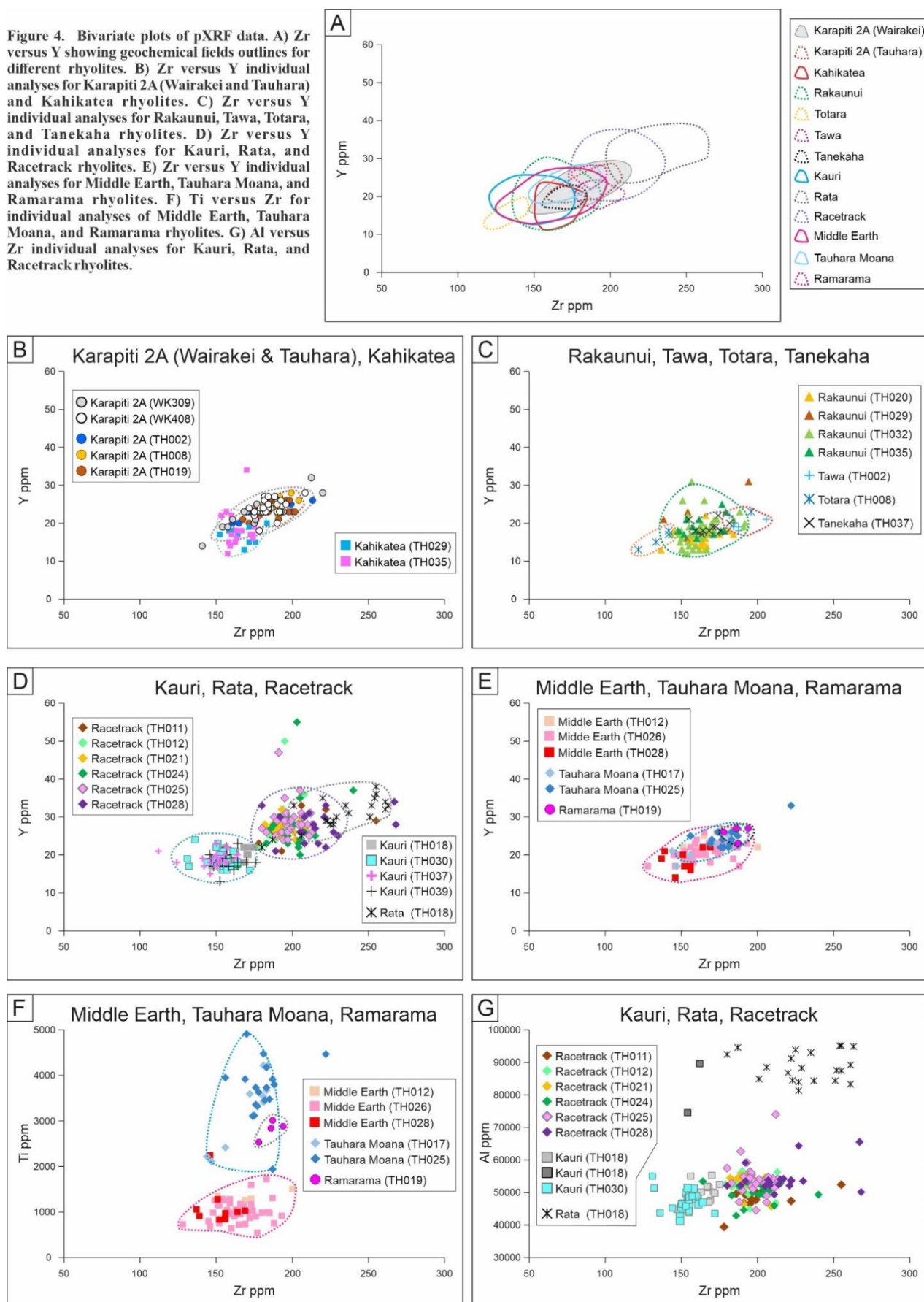
6.8 Racetrack rhyolite

The quartz-free Racetrack rhyolite has sparse phenocrysts (1–2 vol.%) of plagioclase and rare pyroxene. It is up to 485 m thick and is ~2.0 x 5.0 km in extent (Fig. 2). This rhyolite is massive to finely flow-banded, includes autobreccias, and is interpreted to be an extruded lava. It occurs S to SE of the Kauri rhyolite at comparable and deeper elevations but has distinctively higher concentrations of Zr, Y (Fig. 4D), and REE (Fig. 5E).

6.9 Middle Earth rhyolite

The Middle Earth rhyolite was intercepted in six eastern Tauhara wells and is modelled as ~1.2 x 2.7 km unit that is up to and >485 m thick. It is quartz-free and sparsely porphyritic with 1–2 volume % plagioclase and pyroxene phenocrysts set in a micro-spherulitic, vitreous or flow-banded groundmass. Middle Earth rhyolite occurs ~175 to 200 m beneath the Racetrack and Kauri rhyolites and separated by Waiora Formation. This rhyolite overall has lower concentrations of Zr and Y than Racetrack rhyolite (Fig. 4E) and lower concentrations of REE (Fig. 5F). By contrast, Zr, Y, and REE concentrations are indistinguishable from the Kauri rhyolite (Figs. 5E vs 5F); but, based on stratigraphic separation they are not the same unit.

Figure 4. Bivariate plots of pXRF data. A) Zr versus Y showing geochemical fields outlines for different rhyolites. B) Zr versus Y individual analyses for Karapiti 2A (Wairakei and Tauhara) and Kahikatea rhyolites. C) Zr versus Y individual analyses for Rakaunui, Tawa, Totara, and Tanekaha rhyolites. D) Zr versus Y individual analyses for Kauri, Rata, and Racetrack rhyolites. E) Zr versus Y individual analyses for Middle Earth, Tauhara Moana, and Ramarama rhyolites. F) Ti versus Zr for individual analyses of Middle Earth, Tauhara Moana, and Ramarama rhyolites. G) Al versus Zr for individual analyses for Kauri, Rata, and Racetrack rhyolites.



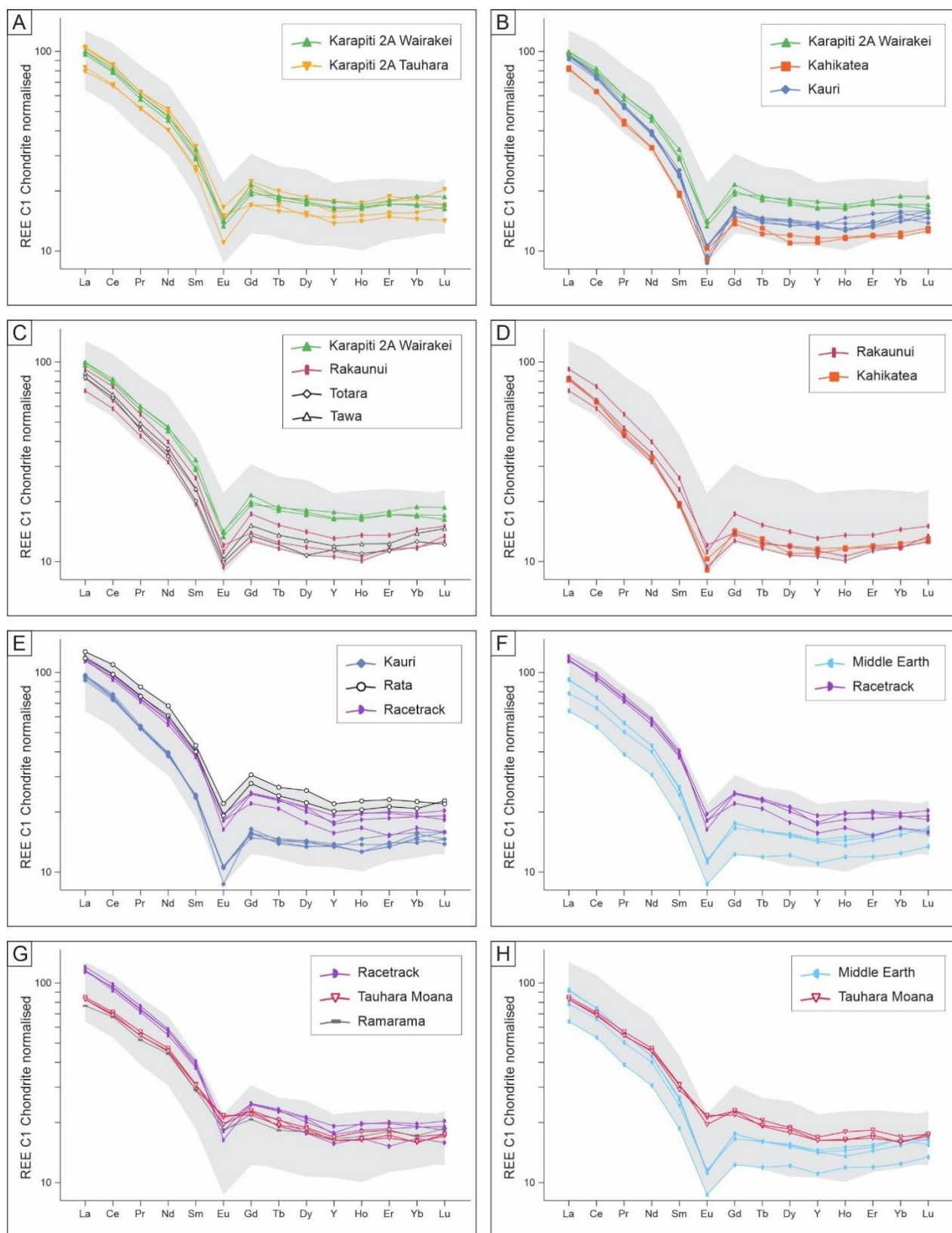


Figure 5: Rare earth element (REE) C1 chondrite normalised (Sun and McDonough, 1995) plots for selected rhyolites. A) Karapiti 2A Wairakei and Karapiti 2A Tauhara. B) Karapiti 2A Wairakei, Kahikatea, and Kauri. C) Karapiti 2A Wairakei, Kahikatea, Rakaunui, Totara, and Tawa. D) Rakaunui and Kahikatea. E) Kauri, Rata, and Racetrack. F) Middle Earth and Racetrack. G) Racetrack, Tauhara Moana, and Ramarama. H) Middle Earth and Tauhara Moana. The grey shaded area outlines the range of values for all samples analysed.

6.10 Tauhara Moana rhyolite

Tauhara Moana rhyolite in TH017 and TH025 occurs beneath Racetrack rhyolite and is separated from it by Waiora Formation tuffs and sediments (Fig. 2). It is a sparsely porphyritic lava with 2 volume % phenocrysts of plagioclase, quartz, and rare pyroxene in a massive to finely vesicular, or locally flow-banded, groundmass. The Tauhara Moana rhyolite is unique with high distinct Ti concentrations (0.3–0.5 wt.%) that is twice that of other rhyolites (Fig. 4F). It has lower concentrations of light REE compared to the overlying Racetrack rhyolite (Fig. 5G), and higher concentrations of heavy REE elements compared to the nearby deeper Middle Earth rhyolite (Fig. 5H).

6.11 Ramarama rhyolite

A dyke in TH019 (1772–1827 m; Fig. 2) is the deepest known rhyolite-like rock intercepted to date in the Tauhara field and is hosted in densely welded ignimbrite. This strongly altered fine-grained porphyritic rhyolite has phenocrysts of quartz, feldspar, and ferromagnesian mineral pseudomorphs (pyroxene and/or amphibole). Titanium concentrations (0.25–0.3 wt.%) are higher in Ramarama rhyolite than in most other analysed rhyolites (Fig. 4F). It shows closest geochemical affinity with the Tauhara Moana rhyolite (~7 km E and ~700 m shallower) based on high Ti concentrations (Fig. 4F) and has overlapping REE concentrations (Fig. 5G).

7. SUMMARY

In the Tauhara Geothermal Field, rhyolites are important to define, as they have a strong influence on the shallow hydrology of the geothermal system (Milloy and Lim 2012). Since 2019 many new rhyolite units have been recognised and now distinguished using combined mineralogy,

stratigraphic, and geochemical constraints. Some rhyolites had formal or accepted names (e.g., Racetrack, Middle Earth), but many were simply designated as either quartz-free ('Karapiti'-type) or quartz-bearing ('Te Mihi'-type). In this study, rhyolite chemistry obtained by pXRF analyses of 479 samples has been used to confirm known or establish new correlations based on immobile element concentrations of Zr, Y, and Ti (Fig. 4). Subsequent evaluation of a greater number of immobile elements (e.g., REE; Fig. 5) from laboratory analyses validate and have slightly refined correlations determined from pXRF data. While it is not possible from Zr, Y, and Ti concentrations alone to unequivocally identify a given rhyolite, they have been used to confirm or reveal new correlations between neighbouring units. The only exception is the Tauhara Moana rhyolite that has elevated, and diagnostic, concentrations of Ti. Nonetheless, based on pXRF determined immobile element concentrations in conjunction with mineralogical, spatial, and stratigraphic constraints, 9 new rhyolites units have been differentiated in the Tauhara Geothermal Field wells studied (Fig. 6).

Geochemistry by pXRF has confirmed the earlier provisional correlation that the extensive Karapiti 2A rhyolite of the Wairakei Geothermal Field extends into the western side of the Tauhara Geothermal Field (Fig. 6). Immobile element concentration evaluation has further revealed that neighbouring rhyolites with identical mineralogy and at comparable elevations may not be the same, as determined for the Kauri and Racetrack rhyolites (Figs. 4D & 5E). Zirconium, Y, and REE concentrations similarly reveal that the quartz-free Karapiti 2A, Kauri, Rata, and Kahikatea rhyolites are all different from each other (though the difference between Kauri and Kahikatea is from REE).

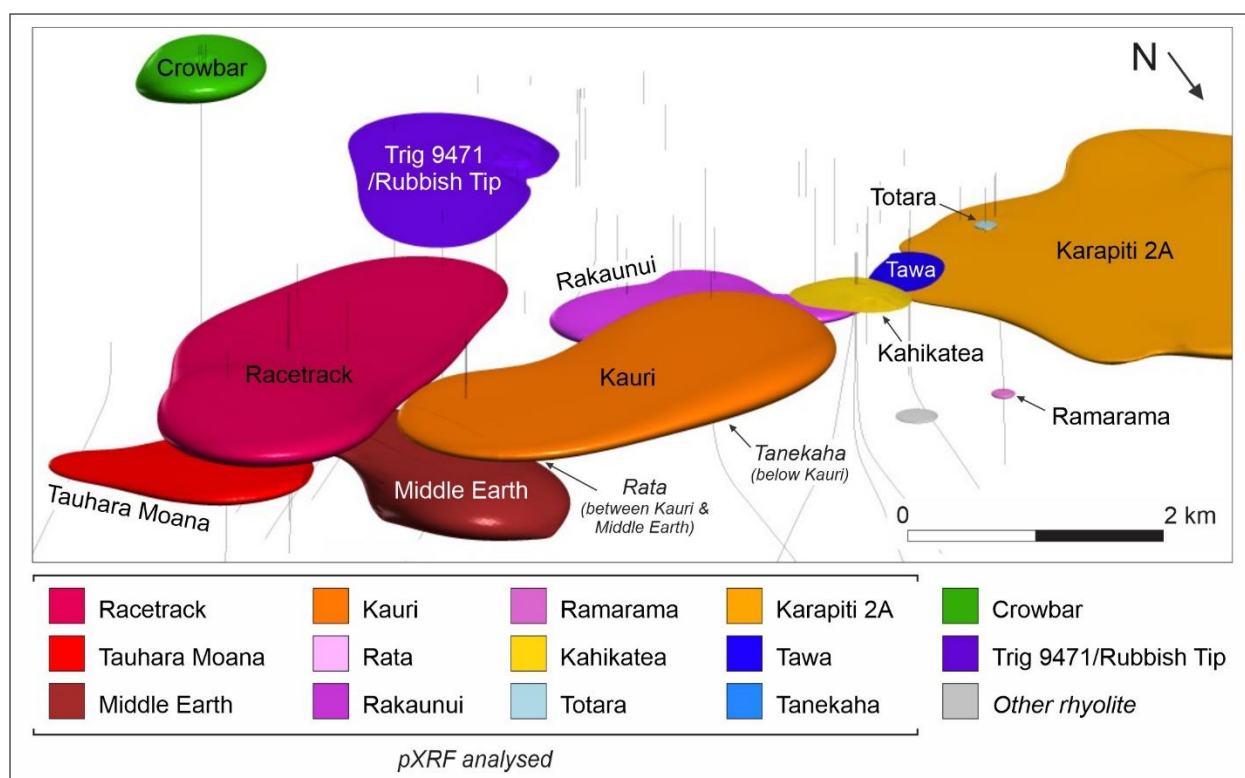


Figure 6: 3D view of the rhyolites of the Tauhara and portion of the Wairakei geothermal fields.

For some rhyolites, immobile element concentrations have not helped in unit differentiation. For example, the Rakaunui and Kahikatea rhyolites have overlapping Zr and Y concentrations (Figs. 4B & 4C) despite different mineralogy (quartz-bearing vs quartz-free) and stratigraphic separation (Figs. 2 & 6). Similarly, the quartz-bearing Rakaunui, Totara, and Tawa rhyolites are indistinguishable by their immobile element concentrations (Fig. 5C). Although all three rhyolites occur in the same general area, spatial separation (Totara vs Tawa) and different elevations (Rakaunui vs Totara) are the key factors for them being considered separate lavas.

Despite limitations (geochemical overlap for some units), we have found that pXRF immobile element concentrations when carefully evaluated with mineralogical, spatial, and stratigraphic considerations has significantly aided in the identification and correlations of rhyolites across the Tauhara Geothermal Field. The advantage of pXRF has been rapid collection of numerous geochemical measurements at low cost acquired during drilling.

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