Geochemistry of Buried Rhyolite Lavas, Western Steamfield, Wairakei Geothermal Field, Taupo Volcanic Zone, New Zealand

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ABSTRACT

Fractured rhyolite lava domes and flows provide geothermal production and injection targets at 500 – 1500 m depth in the Wairakei geothermal field (New Zealand). Differentiating between the rhyolites will resolve an important part of the Wairakei stratigraphy, that is of regional significance for the geologic history of the Taupo Volcanic Zone, and may also have applications for geothermal well targeting. To date, several buried rhyolite bodies have been intersected by drilling. Karapiti (IIa, IIb and III) Group rhyolites are stratigraphically separated by pumiceous pyroclastics and sediments of the Wairoa Formation from recently discovered, deeper Poihipi (I, II) Rhyolites. All rhyolites are spatially clustered in the western part of the geothermal field beneath the Te Mihi sector and were erupted during the time span of the Waiora Formation, which post-dates the ~330 ka Wairakei Ignimbrite (Whakamaru Group).

The Karapiti and Poihipi rhyolites are calc-alkaline with homogenous major and trace element compositions. At Wairakei, there is a general increase of hydrothermal alteration intensity with depth where K, Na and Ca gain is geochemically observed and attributed to adularia, albite, calcite, illite, epidote and wairakite precipitation. The REE distribution patterns, especially the magnitude of the Eu anomaly, can distinguish Karapiti from Poihipi rhyolites (Eu/Eu*= 0.21-0.34 for Karapiti; Eu/Eu*= 0.17-0.19 for Poihipi). Such differences can be explained by variable plagioclase ± amphibole crystal fractionation. Age determination of each rhyolite group, using zircon U/Pb isotope systematics, will provide valuable insights into the temporal and chemical evolution of rhyolitic magmatic activity at Wairakei that occurred post-eruption of the Whakamaru Group ignimbrites, but prior to deposition of the pre-26.5 ka Huka Falls Formation lake deposits.

Introduction

Fractured rhyolite lava domes and flows provide geothermal production and injection targets at 500 – 1500 m depth in the Wairakei geothermal field New Zealand (Figure 1). Differentiating between the rhyolites will resolve an important part of the Wairakei stratigraphy, which is of regional significance for the geologic history of the Taupo Volcanic Zone, and may also have repercussions for geothermal well targeting. To date, several buried rhyolite bodies have been intersected by drilling. Karapiti (IIa, IIb and III) Group rhyolites are stratigraphically separated by pumiceous pyroclastics and sediments of the Wairoa Formation from recently discovered, deeper Poihipi (I, II) Rhyolites. All rhyolites are spatially clustered in the western part of the geothermal field beneath Te Mihi and were erupted during the time span of the Waiora Formation at Wairakei, which post-dates the ~330 ka Wairakei Ignimbrite (Whakamaru Group).

Here we present geochemical characterization of these rhyolites, centred on the chemical differentiation, in order to understand

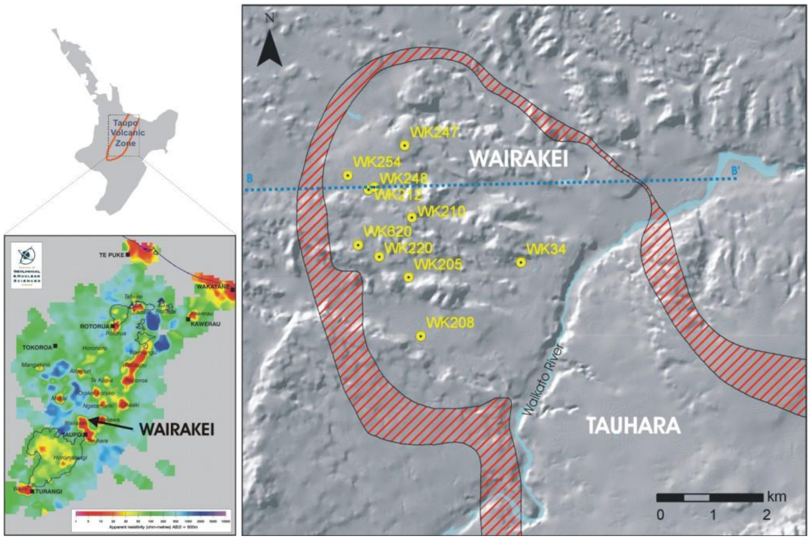

Figure 1. Location map of Wairakei geothermal Field. Sampled wells at Wairakei are shown. Red hatch area is the electrical resistivity field boundary. Blue dashed line is the approximate location of Figure 2 cross section.

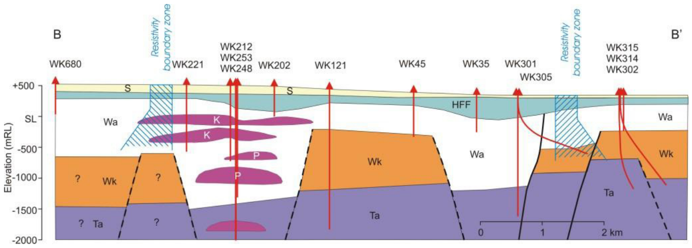

Figure 2. West to East geological 2-D interpretation of structural elements at Wairakei, based on well stratigraphy and interpreted seismic reflection data (Rosenberg et al., 2009). The approximate location of this cross section is given in Figure 1. No vertical exaggeration. Faults are simplified (and dashed where inferred). Superficial formations (S); Huka Falls Formation (HFF); Waiora Formation (Wa), Karapiti Rhyolites (K) and Poihipi Rhyolites (P); Wairakei Ignimbrite (Wk) and Tahorakuri Formation (Ta).

the evolution of rhyolite magmatism in the western Wairakei area, and the chemical effect of the hydrothermal alteration in these rocks.

Geology of Wairakei Geothermal field

Recently, Rosenberg et al. (2009) reported a detailed overview and update of the geology of the Wairakei-Tauhara geothermal system (Figure 2). Based on their work, we present a short summary of the geological units at Wairakei, focusing on the rhyolite lavas located in the western part of the field.

The Tahorakuri Formation is one member of the Reporoa Group. The other, the Waikora Formation, is a greywacke pebble conglomerate, but is absent at Wairakei. The Tahorakuri Formation is a composite unit of at least 650 m thick, of sedimentary and volcanic/volcaniclastic strata. It is similar to the younger Waiora Formation, but includes more andesitic lava/lava breccia layers.

The Wairakei Ignimbrite, overlies the Tahorakuri Formation, and is a member of the ~ 0.32-0.34 Ma old Whakamaru Group of ignimbrites (Grindley, 1960, Wilson et al., 1986). It is weakly to moderately welded, with abundant 1-5 mm long, feldspar, and deeply resorbed quartz crystals, accessory orthopyroxene, biotite and hornblende, and minor pumice, volcanic and sedimentary lithics.

The Waiora Formation (Grindley, 1965) is a thick and varied sequence of volcanic deposits, with interlayered mudstones and sandstones. The formation comprises all strata, except rhyolite and andesite lavas, that lie between the top of the Wairakei Ignimbrites and the base of the Huka Falls Formation (Grindley, 1965). Rhyolite and andesite lavas that occur within the Waiora Formation were excluded by Grindley (1965), who assigned rhyolite lavas to a previously established Haparangi Rhyolite Group (Grindley, 1959), and the andesite lavas to a then new formation (Waiora Valley Andesite). The Waiora Formation contains the main geothermal aquifers at Wairakei.

The Huka Falls Formation (HFF, Grindley, 1965) includes all the lacustrine sediments and water-deposited tuffs that lie between the base of the Oruanui Formation and the top of the Waiora Formation. Prior to the Oruanui eruption of Taupo volcano 26,500 years ago, the HFF accumulated in a long-lived (>150 ka?) shallow lake that occupied a basin stretching north-eastwards at least 50 km from the modern Lake Taupo to the Waiotapu Geothermal Field (20 km southeast of Rotorua) (Steiner, 1963).

Superficial formations into the Wairakei area include material related to the 1.8 ka Taupo eruption (Wilson, 1993), Oruanui Formation (26.5 ka) and layers that pre-date that eruption but post-date the Oruanui Formation. The younger group comprises pyroclastic fall units and non-welded ignimbrite of the Taupo eruption, minor fluvial and lacustrine pumiceous sand and pebble alluvium (derived mostly from the eruption deposits). The post-Oruanui sequence includes surface mantling of volcanic ash and pumice fall units, derived from small- to moderate-scale eruptions of silicic magma (Wilson, 1993), intercalated paleosol horizons, and locally dispersed basaltic tephra and cryptotephra from andesitic sources. Sedimentary and aeolian sequences are also recognised in boreholes and outcrops. The Oruanui Formation (Wilson, 1993) comprises the products of a catastrophic eruption that occurred beneath a former Lake Taupo some 26,500 years ago (Wilson, 1993). The formation, produced by a single eruption episode, comprises several pyroclastic density current deposits interbedded with ash tuff units of airfall and/or flow origin (Wilson, 2001).

Several rhyolite lava domes and flows have been intersected by wells at Wairakei. Most of the rhyolites are spatially clustered within the Waiora Formation in the west part of the Wairakei field (see Figure 2). Steiner (1977) defined seven different rhyolite units: four Te Mihi Rhyolites (quartz-phenocryst bearing) and three Karapiti Rhyolites (quartz-free). Te Mihi Rhyolite lavas have been intersected in wells near the western and eastern margins of the Wairakei geothermal field. They are known individually only from a few wells (sometimes only one or two) and have not proved to be significant to the field's hydrology (Rosenberg et al., 2009).

West Wairakei Rhyolite Lavas

The largest rhyolite at Wairakei, named Karapiti Rhyolite by Grindley (1965) and later Karapiti II Rhyolite by Steiner (1977), is also hydrologically the most significant. This rhyolite is now known as Karapiti 2A Rhyolite, to distinguish it from an older, smaller rhyolite (Karapiti 2B) that occurs only in the far west of Wairakei. (Rosenberg et al., 2009). Beds from Waiora Formation separate both rhyolites. Within the geothermal field, Karapiti 2A Rhyolite has the form of a lava dome, which extruded from a vent in the south into a broad valley or basin in which Waiora Formation deposits were actively accumulating. It is permeable, and acts as a storage reservoir for much of the low-pressure steam zone. It has also been used as an injection target in areas where it contains water, not steam. This rhyolite has a significant impact on field hydrology as it has good fracture permeability, particularly in its margins, where it is likely to be flow-brecciated (Rosenberg et al., 2009).

There are no distinctive mineralogical differences between any of the Karapiti lavas, which are rhyolites with spherulitic, flow-banding textures and rare, relict perlite fractures. Phenocrysts are relatively minor (< 2-5 vol.%), small (<1 mm long) and consist mainly of plagioclase feldspar and accessory quartz.

A flow-banded rhyolite encountered in few wells, Karapiti 3 Rhyolite (Steiner, 1977), has a shallower occurrence compared to Karapiti 2B Rhyolite. A breccia of probable autoclastic origin comprises the lower portion of the unit in WK247 and is a clast-supported, brecciated, flow-banded and porphyritic (rare feldspar and quartz) rhyolite, and silicified vitric tuff.

The Poihipi Rhyolites, are an older group of rhyolites, located in the same western part of the geothermal field, at the base of the Waiora formation. The Poihipi 1 Rhyolite is a >130-m thick lava, petrographically distinct from the shallower crystal-poor Karapiti lavas. Poihipi 1 lava has common quartz, pyroxene and subordinate plagioclase phenocrysts, and pumiceous, brecciated and flow-banded textures. The Poihipi 2 Rhyolite lava, occurs beneath Poihipi 1 Rhyolite and is separated by Waiora formation beds. It is a porphyritic (plagioclase-quartz-pyroxene) flow-banded, spherulitic, and perlitic textured lava.

Geochemistry of Rhyolite Lavas

Six samples from Karapiti 2A, three samples from Karapiti 2B, one sample from Poihipi 1 and two samples from Poihipi 2 rhyolites were analyzed for major and trace elements by XRF at University of Otago, New Zealand.

Based on the immobile element classification of Winchester and Floyd (1977), Karapiti and Poihipi lavas are high silica rhyolites (Figure 3A). Both are calc-alkaline and present homogenous major and trace element compositions and based on major elements, is not possible to differentiate between them. However, the REE distribution patterns, especially the magnitude of the Eu anomaly (Eu*), can distinguish Karapiti from Poihipi rhyolites (Eu/Eu*= 0.21-0.34 for Karapiti; Eu/Eu*= 0.17-0.19 for Poihipi; Figure 3B,D,E,F). Some trace element contents (e.g. Ba) may also be useful for differentiation (Figure 3C).

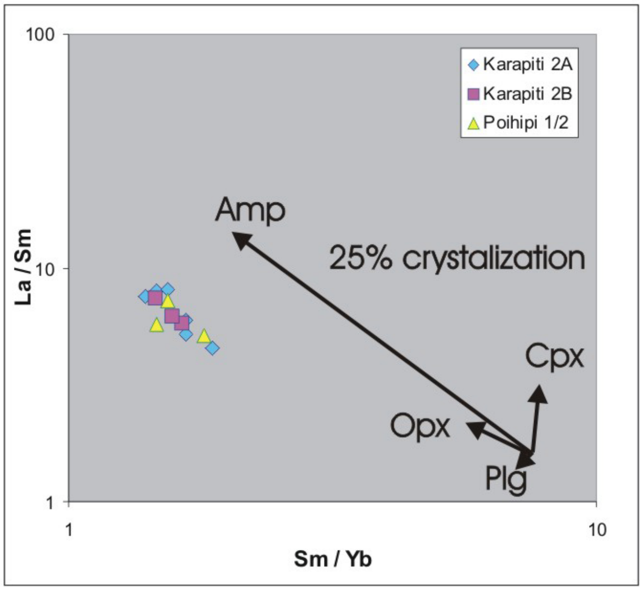

Figure 4. La/Sm v/s Sm/Yb plot. All samples are constrained to a small area, suggesting a similar evolution. The direction and magnitude of the Rayleigh FC vectors (25% crystallization) suggest an evolution dominated by amphibole fractionation. Kd's and vectors from FC-modeler (Keskin 2002).

Although the genesis/evolution of Poihipi rhyolites are influenced by plagioclase fractionation (as suggested by the Eu anomaly), both Karapiti and Poihipi rhyolites are likely dominated by amphibole fractionation, as suggested by the direction and magnitude of the Rayleigh FC vectors (Figure 4).

Hydrothermal alteration of the analysed samples is moderate to intense. Generally, at Wairakei, there is an increase of hydrothermal alteration intensity with depth. Karapiti 2A is altered by an argillic assemblage (smectite, illite-smectite, illite, quartz, calcite, iron oxides and pyrite), while Karapiti 2B and Poihipi rhyolites are altered by a propylitic assemblage (quartz, illite, chlorite, epidote, wairakite, albite, adularia, calcite, pyrite and iron oxides). K, Na and Ca gain/loss is geochemically observed and attributed to the precipitation of different hydrothermal alteration assemblages. The shallow part of the field (Karapiti 2A), is dominated by an argillic alteration assemblage, and the chemical effects are Ca, Na and K loss in the shallower samples. With depth, it is possible to observe an increase in the molar content of Ca, Na and K (Figure 5, overleaf), which is related to adularia, albite, calcite, illite, chlorite, epidote and/or wairakite precipitation.

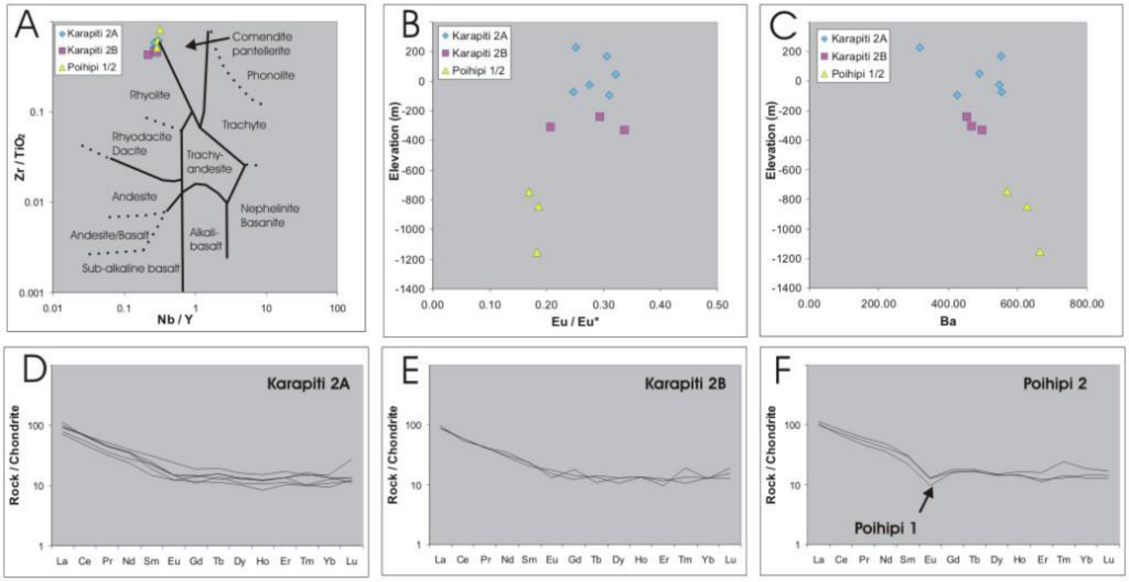

Figure 3. A. Immobile element classification of Winchester and Floyd (1977), showing a similar rhyolite composition for all samples. **B.** Magnitude of Eu anomaly (calculated as Eu/Eu*, where Eu* is $(Sm*Gd)^{1/2}$) versus depth, showing two groups of rhyolites. **C.** Ba (ppm) versus depth. **D. E. F.** REE distribution patterns of sampled rhyolites (normalized to Sun and McDonough (1989) chondrite).

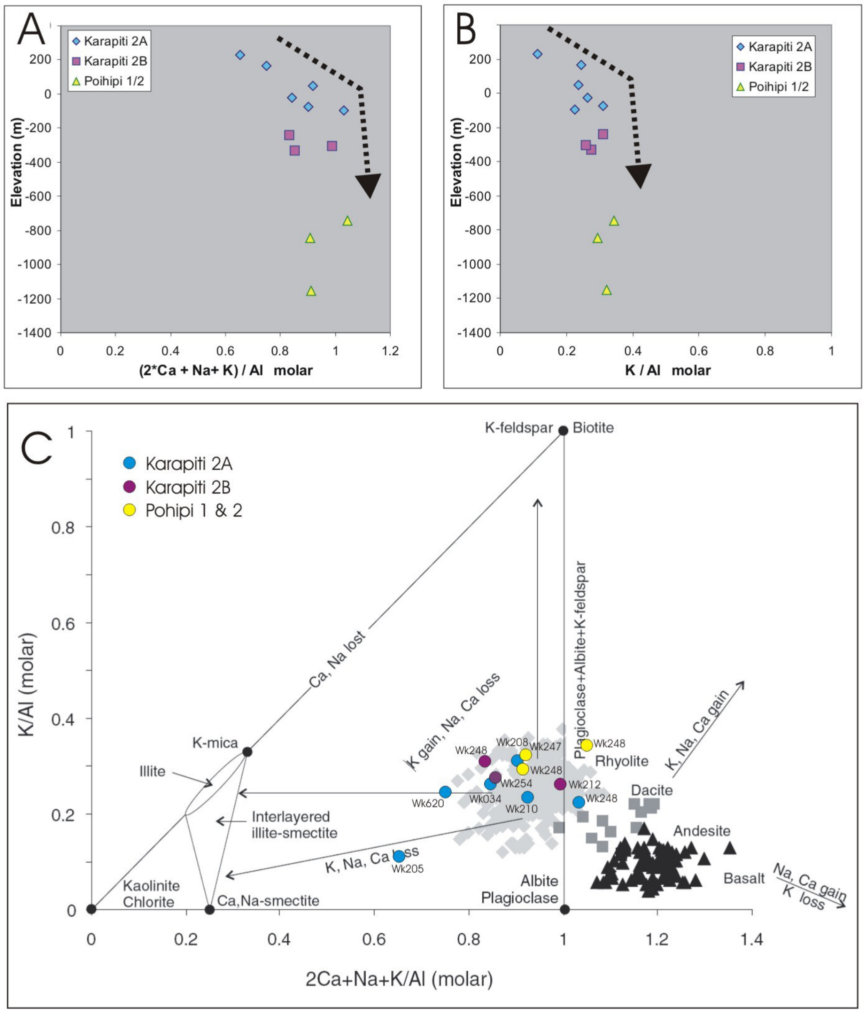

Figure 5. A. Molar element ratio plot of (2Ca + Na + K)/Al vs depth. **B.** Molar element ratio plot of K/Al vs depth. **C.** Molar element ratio plot of (2Ca + Na + K)/Al vs K/Al. Mass transfer processes are shown with arrows that vector toward associated alteration minerals. The portion of the plot occupied by typical fresh rocks is illustrated with data from fresh volcanic rocks of the Taupo volcanic zone, New Zealand (Graham et al., 1995; modified after Warren et al., 2007).

Conclusions

Based on major elements, it is not possible to differentiate between Karapiti and Poihipi rhyolites, but few trace elements (e.g. Eu, Ba) may be useful. Poihipi rhyolites are influenced by plagioclase fractionation, whereas the evolution of Karapiti rhyolites is likely dominated by amphibole fractionation.

Hydrothermal alteration of the analysed samples is moderate to intense. Karapiti 2A is altered by an argillic assemblage, which is reflected in a Ca, Na and K loss of the shallower samples. Karapiti 2B and Poihipi rhyolites are altered by a propylitic assemblage, and reflected in a slight increase (gain) of K, Na and Ca with depth.

Age determination of each rhyolite group, using zircon U/Pb isotope systematics, will provide valuable insights into the temporal and chemical evolution of rhyolitic magmatic activity at Wairakei that occurred post-eruption of the Whakamaru Group ignimbrites, but prior to deposition of the pre-26.5 ka Huka Falls Formation lake deposits.

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