Buried rhyolite in the Kawerau Geothermal Field, Taupo Volcanic Zone, New Zealand: sources of a rejuvenated geothermal system

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ABSTRACT

Fractured rhyolite lava domes and flows occur between 0 and 1000 m depth in the Kawerau Geothermal Field (New Zealand), with several rhyolite bodies intersected by drilling. Differentiating between the rhyolite lavas has helped resolve an important part of the Kawerau stratigraphy, and enhanced our knowledge of the geological history of the Taupo Volcanic Zone. Onepu Rhyolite flows underlie the ~320 ka Matahina ignimbrite and are composed of a series of flows interspersed locally with rhyolite breccia, tuff and fluviatile pumiceous sediments of Onepu Ash, particularly in peripheral parts of the dome complex. The Caxton Rhyolite has previously been inferred to be extruded from multiple vents, and forms a large rhyolite complex interbedded with Kawerau Andesite and ignimbrite units. Quartz porphyry dikes occur in some wells (e.g. KA28, KA30 and KA31), where they separate ignimbrite and andesite at depths between ~500 and 1000 m.

Recent age determinations obtained from these rhyolite groups using U-Pb dating of zircons has indicated a complex magmatic (and structural) history at Kawerau. The Caxton Rhyolite represent a common series of intrusions (rather than surface flows) with inferred ages clustering around 410 ka. Some of these intrusions have ages similar to those of the buried Onepu Rhyolite lava flows (~400 ka, from stratigraphic relationships to the 320 ka Matahina ignimbrite) and are inferred to be part of a feeder system for the rhyolite. The ages provide insight into the temporal evolution of rhyolitic magmatic activity at Kawerau, with the intrusive complexes representing past heat sources that are likely to have rejuvenated the geothermal system beneath Kawerau.

1. INTRODUCTION

The Kawerau Geothermal Field is located in the northern TVZ, near its eastern boundary (Figure 1). The geothermal activity is at the southern end of the NE-trending Whakatane Graben, in a zone where the NE-striking active rift of the TVZ intersects the N-trending strike-slip faults of the North Island Shear Belt (Nairn and Beanland, 1989; Mouslopoulou et al., 2007). This graben structure is evident east of the Kawerau Geothermal Field, where the 320 ka Matahina Formation ignimbrite (Bailey and Carr, 1994; Leonard et al., 2010) is exposed at the ground surface, but occurs 10 to 130 m depth beneath the field itself. During the last one million years, Mesozoic basement greywacke within the Whakatane Graben has been downfaulted to 1-2 km below sea level, with the resulting structural depression infilled by Quaternary volcanic rocks and sediments.

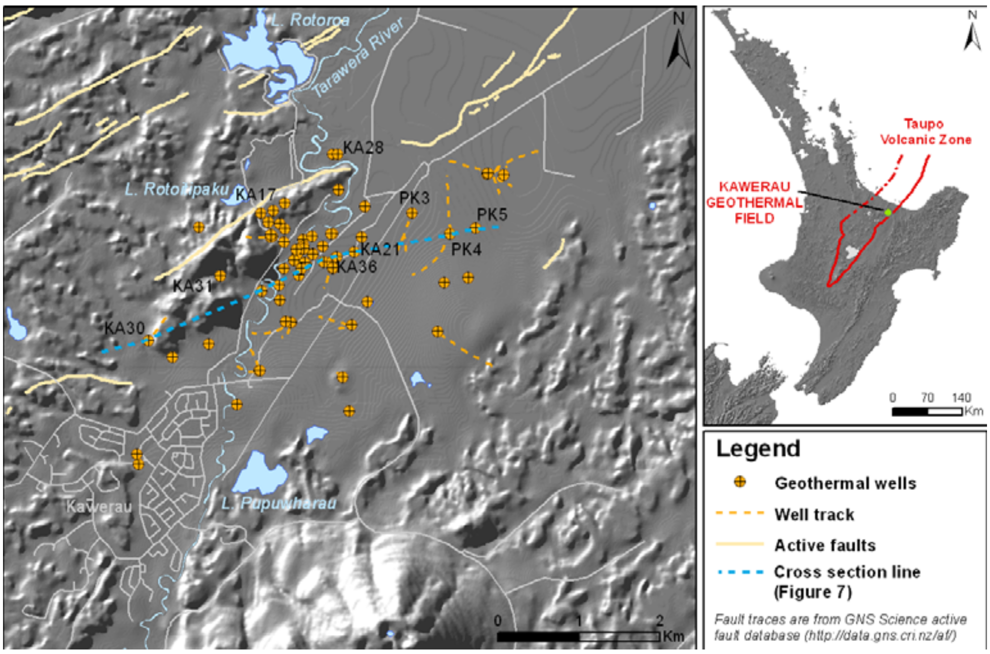

Figure 1: Location map of Kawerau Geothermal Field, with location of wells. Blue dashed line is the approximate location of Figure 7 cross section.

More than 60 wells have now been drilled in the field for various purposes, although no more than 6 or 7 have been in production at any one time. Some of the older wells are now used as monitor wells.

As part of a field wide revision of the stratigraphy, samples were collected for U-Pb dating of zircons from selected units. Amongst these were samples of the Onepu and Caxton Rhyolites. Here we present some of the U-Pb ages and the implications these have on the field stratigraphy.

2. DATING

High degrees of hydrothermal alteration of rock units within geothermal fields can obscure primary mineralogies and lithological textures, and preclude direct dating by radiometric techniques. Magmatic zircons are commonly present in silicic volcanic rocks. Where zircon saturation was achieved, zircons generally crystallise up to the point of eruption. Young zircons are highly resistant to hydrothermal alteration and can yield a record of their crystallization ages in otherwise intensely altered rocks, allowing crystallization ages of rocks to be inferred

Zircon crystallization-age spectra have been obtained by SIMS techniques (SHRIMP-RG instruments at the joint USGS-Stanford University facility and at the Australian National University) from eight samples of core from Onepu and Caxton rhyolite at different stratigraphic levels in drillholes at the Kawerau Geothermal Field.

Age determinations used the techniques described in Wilson et al. (2010). The presence of common Pb was evaluated by monitoring for ^{204}Pb, and a correction applied using the recorded ^{207}Pb/^{206}Pb values and an average common Pb isotopic composition for a bulk Earth value (^{207}Pb/^{206}Pb = 0.8357; Stacey and Kramers, 1975). Although all the Caxton and Onepu samples contained large amounts of common Pb, the best fit lines for data from individual samples formed consistent linear arrays on inverse concordia plots. Raw ages were corrected for initial ^{230}Th disequilibrium using the U and Th concentrations in the zircon from the SIMS analysis and a whole-rock value Th/U of 4.4 (Wilson and Charlier, 2009).

Summary histograms with the associated probability density function (pdf) curves from Isoplot (Ludwig, 2003) are given for 3 representative samples in Figs. 2 to 4. The other five samples of Onepu or Caxton Rhyolite return peak PDF ages within uncertainty of the same values as those for the two KA36 samples.

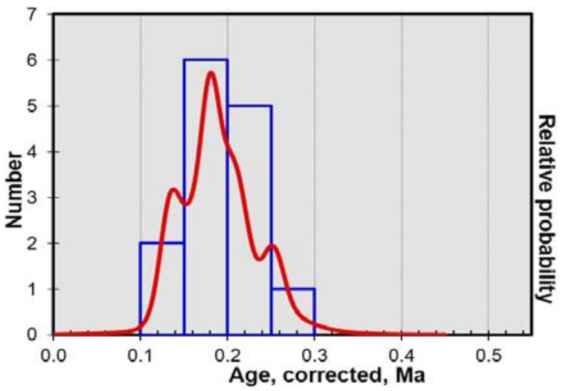

Figure 2: Cumulative probability density function curves and histograms for zircons analysed from a -845 mRSL core sample in drillhole KA30. Peak PDF age of 0.17±0.02 Ma.

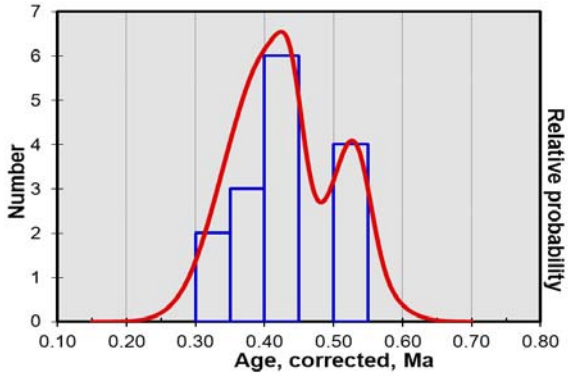

Figure 3: Cumulative probability density function curves and histograms for zircons analysed from a -655 mRSL core sample in drillhole KA36. Peak PDF age of 0.41±0.03 Ma.

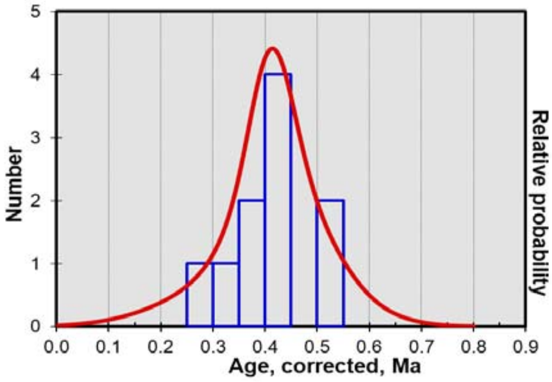

Figure 4: Cumulative probability density function curves and histograms for zircons analysed from a -944 mRSL core sample in drillhole KA36. Peak PDF age of 0.42±0.03 Ma.

2. STRATIGRAPHY

The stratigraphy encountered during drilling at Kawerau is differentiated based on descriptions by Nairn (1977, 1982 and 1986), Grindley (1986), Christenson (1987) and Allis et al. (1995). These authors differentiated the Onepu and Caxton Rhyolite primarily on a basis of their stratigraphic relationships.

Onepu Rhyolite lavas underlie the Matahina Formation ignimbrite and are composed of a series of flows interspersed locally with (probable dome-margin) breccia, tuff and fluviatile pumiceous sediments of Onepu Ash, particularly in peripheral parts of the dome complex. The Caxton Rhyolite has been inferred to be extruded from multiple vents, and forms a large rhyolite complex interbedded with Kawerau Andesite and ignimbrite units. Quartz porphyry dikes occur in some wells (e.g. KA28, KA30 and KA31), where they separate ignimbrite and andesite at depths between ~500 and 1000 m.

The zircon age estimates obtained from these rhyolite groups using U-Pb dating indicate that the magmatic (and structural) history at Kawerau for these units requires major revision. The Caxton Rhyolites represent a series of intrusions (rather than surface flows) with peak pdf ages clustering around 400 ka (Figures 3 & 4) and one at around 170 ka (Figure 2). All but one of the samples of these intrusions have ages which make them probable feeders to the buried Onepu Rhyolite lava flows. The age of the Onepu Rhyolite flows is estimated at ~400 ka, from stratigraphic relationships to the overlying 320 ka Matahina Formation ignimbrite and an underlying pyroclastic unit which has a weighted average corrected age of 0.43 Ma.

2.1 Petrography

The nomenclature used in the following petrographic descriptions is based on the rhyolite names in the old stratigraphy. Their positions in the revised stratigraphic framework will follow in the discussion.

2.1.1 Onepu Rhyolite

The buried Onepu Rhyolite has two distinct petrographies. The first has well developed flow banding and spherulitic texture with minor (5%) phenocrysts of plagioclase and quartz (Figure 5 [1A,B]). The phenocrysts are small and generally have a diameter of < 2 mm.

The second petrography, from a stratigraphically deeper unit of the Onepu Rhyolite (separated by sedimentary units) is represented in KA17 by a rhyolite breccia, with clasts of spherulitic, flow banded and perlitic rhyolite lava. This is distinct from the shallower Onepu Rhyolite flow and has a moderate phenocryst content (Figure 5 [2A,B]) (15%) of quartz (3%; <4 mm diam.), plagioclase and rare mafic minerals (amphibole?). The quartz crystals have deep embayments.

2.1.2 Caxton Rhyolite

The Caxton Rhyolite material has three distinct petrographies. The first petrography, represented by the material dated from KA36 (Figure 5 [3A,B]), has minor (5%) phenocrysts of quartz (<2 mm diam.) and plagioclase (<1 mm diam.). Phenocrysts are hosted in a recrystallized groundmass that has diffuse flow banding.

The second petrography (Figure 5 [4A,B]) contains a moderate phenocryst content (15%) of quartz (typically <2

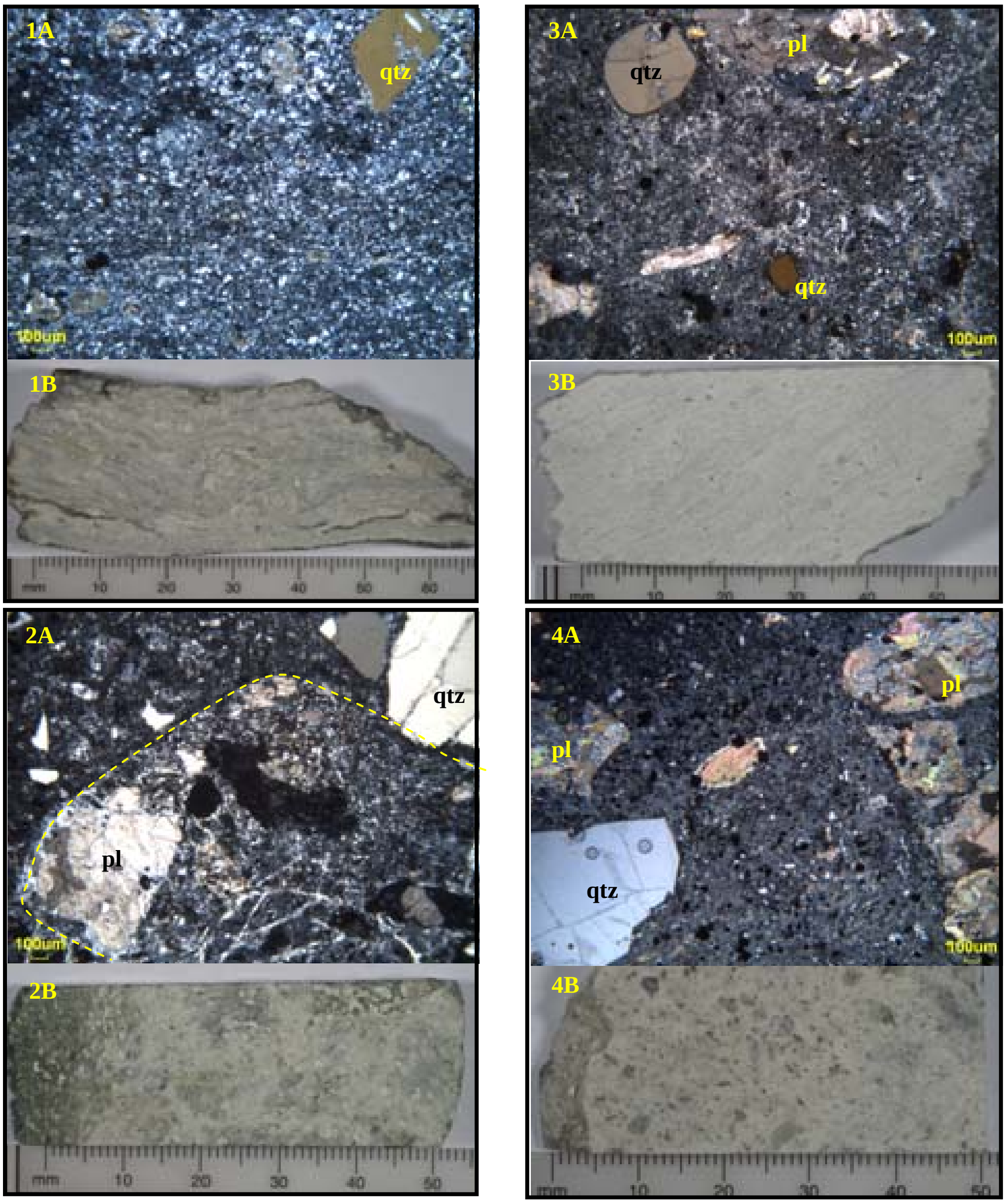

Figure 5: 1A. Photomicrograph, KA21, -418 mRSL; cross polarised light. Flow banded rhyolite lava with a quartz phenocryst (qtz). 1B. Hand specimen of flow banded rhyolite lava. 2A. Photomicrograph, KA17, -408 mRSL; cross polarised light. Brecciated rhyolite, with a clast of perlitic rhyolite (outlined in dashed yellow). Phenocrysts are of qtz and plagioclase (pl). 2B. Hand specimen of rhyolite breccia. 3A. Photomicrograph, KA36, -655 mRSL; cross polarised light. Fine-grained rhyolite with minor phenocrysts of qtz and pl. 3B. Hand specimen of poorly porphyritic, flow banded rhyolite. 4A. Photomicrograph, KA28, -631 mRSL; cross polarised light. Rhyolite with moderate phenocryst content of embayed and fractured qtz and altered pl. 4B. Hand specimen of porphyritic rhyolite.

mm, but up to 4 mm; embayed, fractured), plagioclase (<2 mm length) and amphibole (<1 mm long). Phenocrysts are hosted in a devitrified groundmass with diffuse flow banding.

The third petrography (Figure 6) has abundant phenocrysts of plagioclase and quartz (together ~30% of the rock), amphibole (~5-10%), pyroxene and magnetite. Quartz crystals are embayed, fractured and subrounded (0.5 – 5 mm diam.). Plagioclase crystals frequently form glomerocrysts. Phenocrysts are set in a crystalline groundmass including laths of plagioclase, amphibole and quartz. Xenolithic agglomerates of plagioclase, amphibole and pyroxene are a minor component.

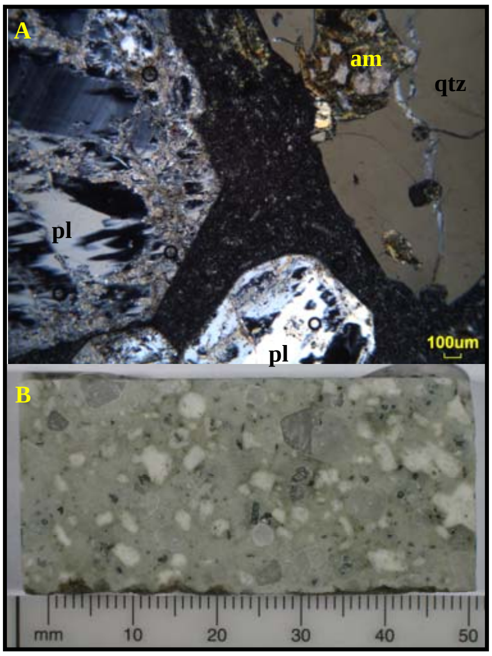

Figure 6: A. Photomicrograph, KA30, -845 mRSL; cross polarised light. Rhyolite with abundant large phenocrysts of quartz (qtz), plagioclase (pl) and amphibole (am). B. Hand specimen of strongly porphyritic rhyolite.

3. DISCUSSION

Petrographic assessment of the rhyolite bodies dated in the Kawerau Geothermal Field represent several episodes of magmatic activity, whereas the zircon age dating implies that the majority of these differing magmas were erupted over a time period that is within the uncertainties of the dating method (i.e. a few tens of thousands of years). Consequently, we can now recognise two distinct time periods of magmatic activity at Kawerau.

The older period of magmatism is characterised by a series of rhyolite bodies with ages close to ~400 ka. These are represented by the buried Onepu Rhyolite and a series of Onepu intrusive bodies (diagrammatically reported on Figure 7) previously mapped as Caxton Rhyolite (Grindley, 1986; Allis et al., 1995). Both the Onepu Rhyolite (extrusive lavas) and the intrusives belonging to this Onepu Group of rhyolite correlate with the first two of the petrographies described in the previous section. These are the crystal poor variant (Figures 5[1] & 5[3]) and moderately crystal rich variant with mafic minerals (Figure 5[2] & 5[4]). The intrusive units are inferred to be part of a feeder system for the two buried rhyolite lava bodies.

The younger intrusive rhyolite is dated at 170 ka (Figure 7, KA30 well track) and is nominally called the Caxton intrusives. This rock is petrographically distinct from all other dated rhyolites bodies at Kawerau, with abundant phenocrysts and containing xenoliths, forming the third petrographic variant described above (Figure 6). This unit, however, is also texturally and petrographically similar to the intrusive units encountered in the greywacke basement in PK8, KA28, and KA42.

The surficial domes to the northwest of the Kawerau Geothermal Field are composed of petrographically similar rhyodacite lavas. The lavas are flow banded, with plagioclase, minor quartz, amphibole, pyroxene, biotite and magnetite. The lavas pre-date the Rotoiti Formation (61 ka; Wilson et al., 2007; Cole et al., 2010), but post-date the Matahina Formation ignimbrite. No tephrochronological age is available for young pyroclastics that overlie the domes, so the upper age limit of the surface Onepu domes is unknown. Grindley (1986) suggested the rhyodacites represent the

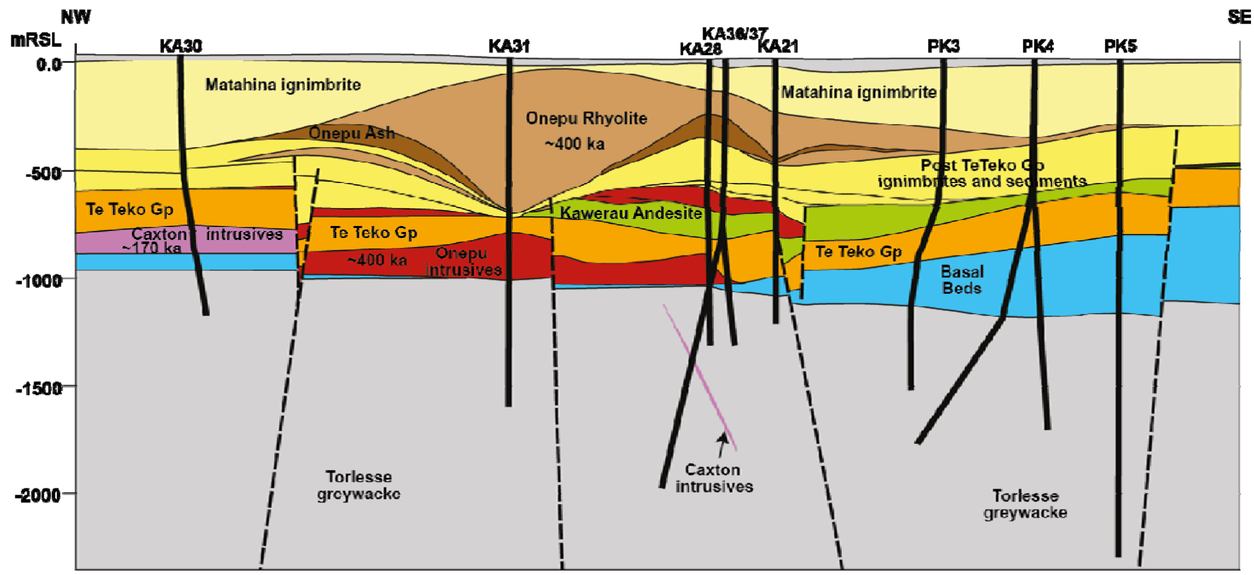

Figure 7: NW-WE geological 2-D cross section of the Kawerau Geothermal Field, based on well logging. The approximate location of this cross section is given in Figure 1. The geology has been simplified to allow for easier interpretation.

youngest domes of the Onepu Rhyolite dome complex. We infer that the 'Caxton Rhyolite', dated from KA30 at ~170-200 ka, is part of a feeder system for this dome complex, though further dating and petrographic work needs to be undertaken to confirm this hypothesis.

The existence of buried rhyolite complexes is consistent with local, shallow rhyolite magmatic heat sources, which have underlain the Kawerau area for >400,000 years. Putauaki volcano is younger than the Kawerau geothermal system, with field studies pointing to the Putauaki area being the likely (present-day) heat source for the Kawerau geothermal system. The ages provide insight into the temporal evolution of rhyolitic magmatic activity at Kawerau, with the intrusive complexes representing past heat sources that are likely to have rejuvenated the geothermal system beneath Kawerau in a previous incarnation reported by Browne (1979). The state of the field between these two episodes of local magmatic heat flux has yet to be determined.

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