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U–Pb dating of zircon in subsurface, hydrothermally altered pyroclastic deposits and implications for subsidence in a magmatically active rift: Taupo Volcanic Zone, New Zealand

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A B S T R A C T

Recognising and correlating hydrothermally altered rock units within buried volcanic sequences in the Taupo Volcanic Zone (TVZ) in New Zealand is difficult. This is because of broad similarities in the lithologies of many major ignimbrite units, and the destruction by hydrothermal alteration of distinctive chemical and mineralogical characteristics. However, magmatic zircons are commonly present, are highly resistant to hydrothermal alteration and yield crystallisation ages in intensely altered rocks. Crystallisation-age spectra have been obtained by SIMS techniques (SHRIMP-RG) on zircons extracted from cores from altered ignimbrites penetrated by drillholes at the Waiotapu, Te Kopia and Orakei Korako geothermal fields in the central TVZ.

At Waiotapu, the thick (up to 350 m) densely welded Waiotapu Ignimbrite returned a zircon age spectrum with a probability density function (pdf) peak of 0.79 Ma, consistent with an eruption age (from $^{40}Ar/^{39}Ar$ techniques) of 0.71 ± 0.06 (1 s.d.) Ma. Three older ignimbrite sheets yielded age spectra that were consistent stratigraphically. The shallowest of the three yielded sparse zircons that gave a pdf peak of 1.24 Ma and it may correlate with the 1.18 ± 0.02 Ma Ahuroa ignimbrite. The middle sheet, although 220 m thick, yielded an age spectrum identical to that obtained from pumice in the widespread 1.21 ± 0.04 Ma Ongatiti ignimbrite, extending earlier estimates of the likely volume of this large deposit. The deepest sheet has a spectrum consistent with an eruption age of 1.45 ± 0.05 Ma; it has no surficial correlative, but its likely coeruptive ash forms part of a concentrated group of primary or secondary tephra in sediments on the ocean floor east of New Zealand and in sedimentary basins across the North Island. These three ignimbrites were previously correlated with either major ignimbrites exposed on the Paeroa Fault scarp, 10 km to the west, or the Akatarewa Ignimbrite that occurs in drillholes at Te Kopia and Orakei Korako, but these correlations are disproved from our age data.

Drillholes at Te Kopia (TK) and Orakei Korako (OK), reach, but do not penetrate the base of, one or more deposits collectively termed the Akatarewa Ignimbrite. Samples from 62 (TK) and 165 m (OK) below the top contact of this unit yielded closely similar age spectra and pdf maxima of 1.00 (TK) and 1.02 Ma (OK), implying that the same deposit was penetrated at both fields. This ignimbrite is not correlated with a specific surface equivalent; several candidate deposits exist, but all are areally restricted. The Akatarewa Ignimbrite at TK and OK is, however, not the same deposit as those earlier correlated with it at Waiotapu.

The age data are consistent with there being two zones of subsidence on both sides of a horst aligned with the three geothermal fields sampled. The eastern zone is the Reporoa Basin, which has high heat flow but little surface faulting, and the western one is the axis of the Taupo Rift, currently with low heat flow but abundant surface faulting. Overall subsidence rates at the three geothermal fields studied vary between 2 and <0.2 mm/yr and imply that subsidence is uneven in time and with position along and across the strike of the TVZ. Such complex patterns will complicate distinctions between background regional subsidence and more localised effects due to exploitation in the TVZ.

1. Introduction

In many volcanic arc environments hosted in continental crust, there are complex relationships between the processes of arc-related magmatism, volcanism and rifting. The thermal influence of magmatism controls the overall rheology of the crustal cross-section, which

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influences the styles and timing of the crustal thinning and rifting processes. Volcanism in turn is strongly influenced (obviously) by the scale and nature of the magmatism, and can often act in tune with rifting (e.g. Rowland et al., 2010). An important element in disentangling the history of magmatism, volcanism and tectonism is the dating and correlation of once surficial deposits now buried. In particular, large silicic eruptions may generate widespread and/or voluminous pyroclastic units that can serve as chronostratigraphic markers to assess the rates of faulting and subsidence. However, correlating these marker planes in the subsurface environment is sometimes difficult because the only material available to do so is cuttings and cores from holes drilled into geothermal systems.

The central segment of the Taupo Volcanic Zone (TVZ) in New Zealand is a locus of intensive silicic volcanism and geothermal activity driven by crustal magmatism and undergoing extension at rates of 3 to 15 mm/yr (e.g., Wilson et al., 1995a; Rowland and Sibson, 2001; Villamor and Berryman, 2001; Wallace et al., 2004; Rowland et al., 2010). There are at present 3 disparate pieces of information pertinent to reconstructing the dynamic evolution of this area.

1. A chronostratigraphy of the surficial rock record within and on the margins of the TVZ, particularly the largest and most widespread ignimbrite sheets that form marker horizons (Houghton et al., 1995; Wilson et al., 2009). However, this record is incomplete due to burial and/or erosion of key units.
2. A chronostratigraphy of primary volcanic and secondary re-sedimented volcaniclastic deposits (collectively labelled as tephras) in contemporaneous sedimentary basins (e.g., Alloway et al., 2004; Pillans et al., 2005) and of primary ash deposits on the ocean floor (e.g., Carter et al., 2003, 2004; Allan et al., 2008). This record is, in principle, more complete, but many of the individual tephras have not been correlated with onshore sequences and the nature and volumes of the parental eruptions are poorly constrained.
3. A lithostratigraphy of hydrothermally altered rock units penetrated by drillholes down to 3 km in geothermal fields. Although detailed stratigraphies have been constructed for individual fields, a regional chronology is generally lacking. Bignall et al. (1996), however, attempted to correlate three ignimbrites between five geothermal fields. The correlations were mainly based upon the characteristic concentrations of 'immobile' constituents, especially rare-earth elements present in altered drillcores. However, there is uncertainty in chemical and mineral fingerprinting of individual ignimbrites that are intensely altered. The only deeply buried marker unit to be correlated between multiple fields is the widespread deposits grouped together as the Whakamaru-group ignimbrites, dated at 320–340 ka with uncertainties of 10–40 kyr (Wilson et al., 1986; Pringle et al., 1992; Houghton et al., 1995; Brown et al., 1998). Otherwise, few pre-30 ka stratigraphic units have been correlated between fields, and only a few examples are known at individual fields where dated surficial units are confidently identified at depth (e.g., Browne, 1978; Wood, 1992, 1994; Grindley et al., 1994; Bignall et al., 1996).

Here we report U–Pb ages from zircons separated from hydrothermally altered rock units drilled at three geothermal fields in the central TVZ (Fig. 1). The age spectra of zircon crystallisation we obtain are used either to match the rock units to surficial equivalents dated by $^{40}Ar/^{39}Ar$ techniques, or to constrain the eruption ages and thus enable correlations and/or comparisons with other sources of information on silicic activity in the TVZ. The depths to which these newly dated units are buried also give first-order constraints on subsidence rates and their variations in time in areas of the TVZ where such information has previously been missing.

2. Geological controls and sample base

During the first phase (1949–1965) of geothermal exploration in New Zealand, several fields with significant surface manifestations (i.e., hot springs, geysers) were explored by drilling. Three of those fields, now slated for preservation because of their conservation value, are considered here: Waiotapu, Te Kopia, and Orakei Korako (Figs. 1 and 2).

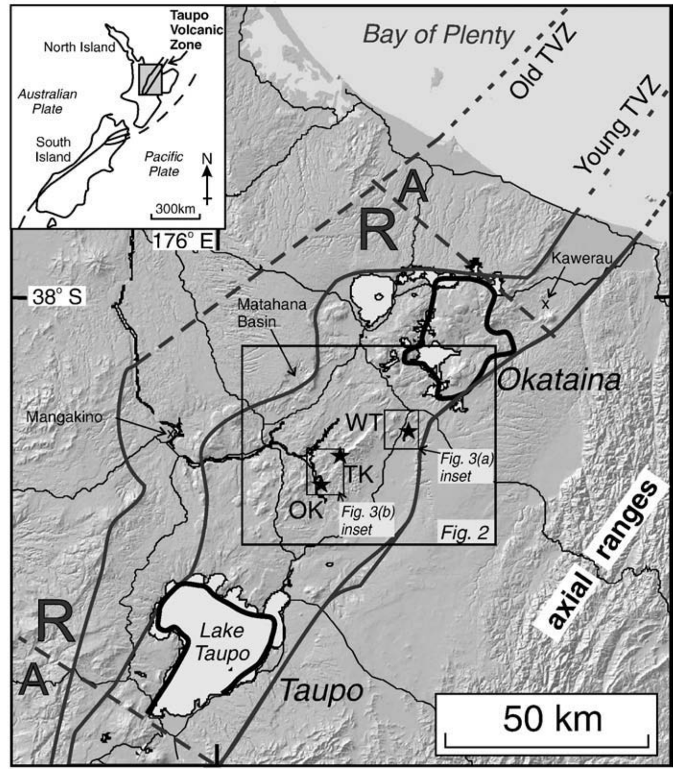

Fig. 1. Locality map for the Taupo Volcanic Zone (TVZ), and the three geothermal fields (WT = Waiotapu, TK = Te Kopia; OK = Orakei Korako) studied for this paper. Old (1.6 Ma to 340 ka) and Young (340 ka to present) boundaries to the TVZ are shown, with its subdivisions into andesite-dominated (A) extremities and the rhyolite-dominated (R) central segment. Okataina and Taupo volcanoes are the highly active modern silicic centres; other names referred to in the text are marked.

2.1. Waiotapu

Seven holes were drilled at Waiotapu (Fig. 3(a) inset). Steiner (1963; Fig. 3(a)) presented a summary subsurface stratigraphy later utilized by Hedenquist (1983) and Hedenquist and Browne (1989) but subsequently modified by Grindley et al. (1994). The thickest unit penetrated in the field is a densely welded tuff named the Waiotapu Ignimbrite; it is also exposed nearby (Grindley, 1959; Martin, 1961). This ignimbrite was correlated with a tuff exposed to the west of TVZ dated by $^{40}Ar/^{39}Ar$ techniques at 0.71 ± 0.06 Ma (all uncertainties for $^{40}Ar/^{39}Ar$ ages are 1 s.d.) by Houghton et al. (1995). Below the Waiotapu Ignimbrite, Steiner (1963) correlated three sheets of weakly to moderately welded ignimbrite (themselves separated by other tuffs and volcaniclastic sedimentary units: Fig. 3(a)) with three ignimbrites exposed in the ~600 m high Paeroa Fault scarp ~10 km to the southwest. The latter units were at that time believed to be among the oldest rocks exposed in the TVZ (Grindley, 1959; Martin, 1961), and so the three sheets at Waiotapu were labelled Paeroa A (youngest), B and C (oldest) by Steiner (1963; Fig. 3(a)). However, subsequent radiometric and fission-track dating has shown that the three ignimbrites exposed on the Paeroa Fault scarp are only ~340 ka in age (Keall, 1988; Pringle et al., 1992; Grindley et al., 1994; Houghton et al., 1995) and correlate with the Whakamaru group of ignimbrites. Thus the ages of the subsurface 'Paeroa' sheets at Waiotapu and their correlations are uncertain. Grindley et al. (1994) proposed that the two youngest 'Paeroa' sheets (A and B) in the Waiotapu drillholes correlated with an ignimbrite drilled below Te Kopia and Orakei Korako and so re-labelled Steiner's (1963)