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$^{40}Ar/^{39}Ar$ age of the Rotoiti Breccia and Rotoehu Ash, Okataina Volcanic Complex, New Zealand, and identification of heterogeneously distributed excess ^{40}Ar in supercooled crystals

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A B S T R A C T

Co-magmatic granitoid clasts erupted as part of the Rotoiti Ignimbrite (Rotoehu Tephra) contain euhedral K-feldspar and biotite crystals that protrude into miarolytic cavities and show textural evidence for growth in super-cooled conditions and are thus interpreted as growing during eruption. $^{40}Ar/^{39}Ar$ stepped heating experiments on single K-feldspar crystals reveal the presence of heterogeneously distributed excess ^{40}Ar, preferentially released at lower temperature steps (most likely from fluid/melt inclusions), which cannot reliably be characterised by, or corrected for using isotope correlation diagrams due to mixing between three reservoirs of ^{40}Ar (radiogenic, atmospheric and excess). This excess ^{40}Ar component is common, but not ubiquitous, and an age population unmixing algorithm applied to single-crystal fusion data identifies a younger group of K-feldspar and biotite crystals that appear to be largely unaffected by excess ^{40}Ar. This population gives a statistically robust weighted mean age of 47.4 ± 1.5 ka (1σ, n = 13) and an indistinguishable inverse isochron age of 50 ± 3 ka for this historically difficult to date eruption. The weighted mean age is significantly younger than previous age estimates of the Rotoiti eruption obtained by K/Ar and $^{40}Ar/^{39}Ar$ dating of bracketing lavas, but is indistinguishable from recent ^{14}C and (U–Th)/He dates and estimates based on orbital tuning and sedimentation rates constrained by ^{14}C ages.

1. Introduction

The Rotoiti Ignimbrite (also referred to as the Rotoiti Breccia) and Rotoehu Ash, erupted from the Okataina Volcanic Complex in the Taupo Volcanic Zone (TVZ) and immediately followed by the eruption of the Earthquake Flat (EQF) ignimbrite, is an important regional stratigraphic marker on the North Island of New Zealand and in the SW Pacific Ocean which has been used to correlate numerous stratigraphic sections both onshore and offshore (e.g. Berryman, 1992; Molloy et al., 2008; Nilsson et al., 2011; Shane et al., 2006). It occurs at the base of a remarkably well constrained tephra record in which all deposits have been correlated to their source vents and their distribution is well known (Shane, 2000) and so an accurate age for this deposit is particularly important for calculating both sedimentation rates and magma production and eruption rates in the TVZ and surrounding areas. Furthermore, the climatic conditions before and after the eruption are well constrained and the ash is interpreted to have been deposited during an interstadial, most likely in the middle of Marine Isotope Stage (MIS) 3 (Mcglone et al., 1984; Shane and Sandiford, 2003). However, despite 45 years of study and numerous attempts to date the eruption, the age of the Rotoehu ash still remains controversial, with recent published ages ranging from ~45 to 61 ka. In this paper we present $^{40}Ar/^{39}Ar$ stepped heating and total fusion data for single crystals of K-feldspar and biotite from co-magmatic granitoid lithic clasts erupted as part of the Rotoiti Ignimbrite and show that the eruption most likely took place at ~47 ka.

1.1. Geological context

The 60 km wide TVZ extends ~300 km north-eastwards from the centre of the North Island of New Zealand into the Bay of Plenty

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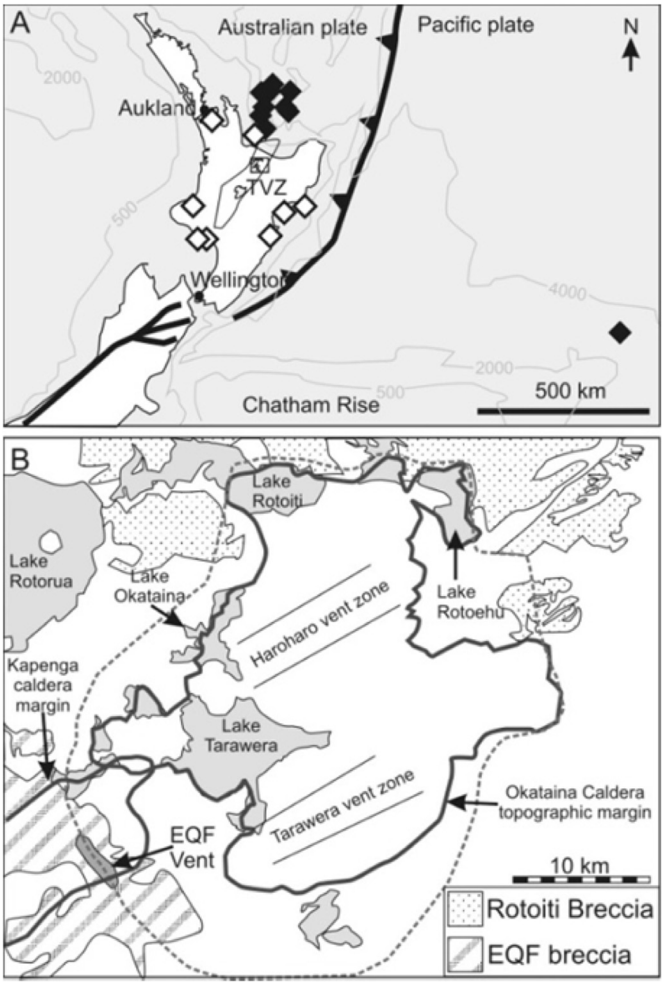

Fig. 1. (A) – Map showing the tectonic setting of the Taupo Volcanic Zone (TVZ), related to the subduction of the Pacific plate beneath the Australian plate, with onshore (white diamonds) and offshore (black diamonds) occurrences of the Rotoiti Ignimbrite and/or Rotoehu Ash (Allan et al., 2008; Berryman, 1992; Danišík et al., 2012; Molloy et al., 2009; Nairn and Kohn, 1973; Santos et al., 2001; Shane et al., 2006; Shane and Sandiford, 2003). Square box shows the location of Fig. 1B. (B) – Structural map of the Okataina Volcanic Complex, the source of the Rotoiti eruption (after Charlier and Wilson, 2010). Dashed line represents the cryptic structural boundary of the Okataina caldera as suggested by Burt et al. (1998).

and the south Pacific Ocean (Fig. 1). Volcanism in the TVZ began at ~2 Ma, becoming dominated by silicic volcanism after ~1.6 Ma and it is currently the most active region of silicic volcanism on Earth, with rhyolite eruption rates of 12.8 $km^3\ kyr^{-1}$ over the last 61 ka (Wilson et al., 2009). There are at least 8 caldera complexes that have been active over the lifetime of the TVZ, with at least 34 caldera forming eruptions identified as having occurred since 1.6 Ma (Wilson et al., 1995). The Okataina Volcanic Complex (also referred to as the Haroharo Caldera complex, Charlier et al., 2003; Shane et al., 2012; Smith et al., 2010) is one of the most productive silicic volcanoes known with rhyolite production rates quoted as being 2.5 $km^3\ kyr^{-1}$ over the last 65 ka (Wilson et al., 1995). The Rotoiti Ignimbrite and Rotoehu Ash were produced during the most recent caldera collapse eruption at Okataina. The eruption began with an explosive basaltic eruption, producing the Matahina Tephra (Pullar and Nairn, 1972) and was immediately followed by the Rotoiti eruption which produced non-welded ignimbrite, interbedded with and overlain by phreatomagmatic ash, with the combined ignimbrite and ash equating to a magma volume of at least 80 km^3 (Wilson et al., 2007). The Rotoiti eruption was followed almost immediately (within months) by the smaller volume (7 km^3 of magma) EQF ignimbrite and associated Rifle Range ash (Nairn and Kohn, 1973; Wilson et al., 2007), which is generally considered to originate from the Kapenga caldera complex, although Burt et al. (1998) suggested that the EQF vent lineament represents a cryptic ring-shaped structural boundary of the Okataina Volcanic Complex (Fig. 1B).

Plutonic lithic fragments brought to the surface during ignimbrite eruptions have been observed in many TVZ volcanic deposits (Brown et al., 1998; Burt et al., 1998; Charlier et al., 2003; Ewart and Cole, 1967; Shane et al., 2012). However, a notable class of felsic plutonic clasts contained in a lithic lag breccia facies of the Rotoiti Ignimbrite contain volcanic glass, indicating that they were incompletely crystallised at depth and so are referred to as granitoids (Brown et al., 1998; Burt et al., 1998). The most common type of these granitoid clasts, Group 1 granitoids (the subject of this study), tend to be highly friable, exhibit quench textures, such as volcanic glass, micrographic intergrowths and miarolytic cavities lined with euhedral crystals, and often contain two populations of biotite (Brown et al., 1998; Burt et al., 1998; Charlier et al., 2003). Importantly, the glass in these granitoid fragments often co-exists with euhedral crystals, implying that the glass represents quenched residual melt, rather than melt infiltration and remobilisation of a previously solidified magma body, which would result in rounded and resorbed crystals (Brown et al., 1998; Burt et al., 1998). Based on contrasting chemical and isotopic signatures, the granitoid clasts are generally considered to be co-magmatic, rather than cognate or xenolithic, to the Rotoiti Ignimbrite magma, forming from a spatially close but petrogenetically distinct magma batch (possibly derived from the Matahina magmatic system) that was emplaced at a high crustal level and subsequently disturbed during the caldera-collapse phase of the Rotoiti eruption (Brown et al., 1998; Burt et al., 1998; Charlier et al., 2003; Shane et al., 2005). Cooling and crystallisation of the Group 1 granitoids is generally considered to have taken place in at least two stages, with most crystallisation taking place at 10–15 km depth, followed by volatile-loss, undercooling and crystallisation at < 3 km, associated with upheaval caused by migration of the Rotoiti magma towards the surface (Brown et al., 1998; Burt et al., 1998).

1.2. *Previous age estimates for the Rotoiti eruption*

The range of published ages for the Rotoiti eruption is given in Table 1, along with pertinent details, and in Fig. 2 (all ages in this paper are quoted as ± 1σ, where known). The earliest attempts to assign an age to the Rotoiti eruption utilised radiocarbon dating and were plagued by difficulties relating to the age limit for ^{14}C dating (generally considered to be ~40–50 ka) and contamination with younger carbon material (Froggatt and Lowe, 1990; Grant-Taylor and Rafter, 1971; Lowe and Hogg, 1995; Nairn and Kohn, 1973; Nathan, 1976; Pillans and Wright, 1992; Pullar, 1976; Pullar and Heine, 1971; Shane, 2000; Thompson, 1968; Vucetich and Pullar, 1969; Whitehead and Ditchburn, 1994). For many years, Wilson et al.'s (1992) age of 64 ± 4 ka, based on K/Ar dating of overlying (67 ± 11 ka) and underlying (63 ± 5 ka) obsidian lava flows on Mayor Island was considered to be the most reliable age for the Rotoiti eruption. This age was subsequently revised to 61.0 ± 1.4 ka based on a $^{40}Ar/^{39}Ar$ stepped heating plateau age of 58.5 ± 1.1 ka for the overlying Mayor Island obsidian lava flow and supported by stepped heating experiments on biotite and plagioclase from the Rotoiti and EQF ignimbrites, which showed a high level of xenocrystic contamination (Wilson et al., 2007). Indeed, $^{238}U–^{230}Th$ disequilibrium dating of both Rotoiti pumice and granitoid clasts and of the EQF ignimbrite indicates a prolonged crystallisation