Journal of Volcanology and Geothermal Research 176 (2008) 191–198

Contents lists available at ScienceDirect

Journal of Volcanology and Geothermal Research

journal homepage: www.elsevier.com/locate/jvolgeores

U–Pb dating of zircon in hydrothermally altered rocks as a correlation tool: Application to the Mangakino geothermal field, New Zealand

C.J.N. Wilson [a,b,*], B.L.A. Charlier [c], C.J. Fagan [a], K.D. Spinks [d], D.M. Gravley [a,b], S.F. Simmons [a,b], P.R.L. Browne [b]

[a] School of Geography, Geology and Environmental Science, University of Auckland, PB 92019, Auckland 1142, New Zealand
[b] Institute of Earth Science and Engineering, University of Auckland, PB 92019, Auckland 1142, New Zealand
[c] Department of Earth Sciences, The Open University, Walton Hall, Milton Keynes MK7 6AA, United Kingdom
[d] Mighty River Power, PO Box 445, Hamilton, New Zealand

ARTICLE INFO

Article history:
Received 7 January 2008
Accepted 3 April 2008
Available online 24 April 2008

Keywords:
zircon
U–Pb dating
Mangakino geothermal field
Taupo Volcanic Zone

ABSTRACT

Recognition and correlation of rock units within geothermal fields is often hampered by high degrees of alteration that obscure primary mineralogies and lithological boundaries, and preclude direct dating by radiometric techniques. Magmatic zircons are commonly present in silicic volcanic rocks, where zircon saturation was achieved and zircons crystallized 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 heavily altered rocks. Zircon crystallization-age spectra have been obtained by SIMS techniques (SHRIMP-RG) from three samples of cuttings and a core sample from ignimbrite penetrated in 3 drillholes up to ~3.2 km deep at the Mangakino geothermal field in New Zealand. The crystallization ages are similar between the drillcore and cutting samples, indicating that downhole mixing of cuttings has not been important, and showing collectively that volcanic units of closely similar ages are represented between ~1.4 and ~3.2 km depth. This is despite apparent changes in the inferred primary volcanic lithology that had led to earlier inferences that multiple ignimbrites of contrasting age were present in this depth interval. Comparisons of zircon crystallization-age spectra and inferred primary mineralogical characteristics from the drillhole samples with surficial ignimbrites that crop out west of Mangakino suggest that the boreholes have entered a >1.8-km-thick intracaldera fill of ignimbrite generated in the closely-spaced Kidnappers and Rocky Hill eruptions at ~1 Ma.

1. Introduction

Understanding the geological structure of geothermal fields is important in relating the age and physical characteristics of the subsurface rock units to their properties as reservoirs or caps. In many cases, although the generalised origin and stratigraphic ordering of subsurface hydrothermally altered rock units can be discerned, dating them is very difficult (e.g., Dalrymple et al., 1999; Arehart et al., 2002). This is due either to the rocks having been held above closure temperatures for long enough such that significant diffusive loss of Ar has occurred in the relevant minerals, or to alteration of those minerals that are conventionally used to derive eruption age estimates, such as feldspar or biotite. Providing absolute age estimates for buried units in geothermal fields is thus problematic, unless correlations can be made on the basis of physical continuity, or comparison of petrographic characteristics, with fresh surficial correlatives that have had age estimates made on them.

However, many intermediate to evolved volcanic compositions, particularly rhyolites, contain primary zircons that have crystallized in the magma over some time period prior to quenching by eruption (Hoskin and Schaltegger, 2003, for review). In conventional K–Ar or $^{40}Ar/^{39}Ar$ age dating, the age of the host rock is estimated from accumulation of radiogenic argon since the minerals were quenched on eruption. In contrast, zircons yield model ages based, depending on the length of time since crystallization, on the deficit of ^{230}Th or accumulation of Pb isotopes by radioactive decay in the U and Th decay series (Williams, 1998; Condomines et al., 2003). For young volcanic rocks the crystallization age is generally measured by utilising the disequilibrium caused in the ^{238}U to ^{206}Pb decay chain because of the preferential uptake of U over Th in zircons, creating a deficiency in ^{230}Th that then decays back to the equilibrium value. The disequilibrium in ^{230}Th is measurable at most over a period of ~5 half lives of ^{230}Th (i.e., ~350 kyr). Model ages for individual crystals are then calculated as two-point isochrons on a plot of ($^{230}Th/^{232}Th$) versus ($^{238}U/^{232}Th$) (where values in brackets denote activity ratios) between a single value for the whole-rock and individual analyses of the zircon crystals (e.g., Charlier et al., 2005). For older rocks (usually ≥300 ka), relative abundances of the three major radiogenic Pb isotopes (206, 207, 208) are measured directly and the age of the crystal estimated on the basis of accumulation of radiogenic Pb.

* Corresponding author. School of Geography, Geology and Environmental Science, University of Auckland, PB 92019, Auckland 1142, New Zealand. Tel.: +64 9 373 7599; fax: +64 9 373 7435.
E-mail address: cjn.wilson@auckland.ac.nz (C.J.N. Wilson).

0377-0273/$ – see front matter
doi:10.1016/j.jvolgeores.2008.04.010

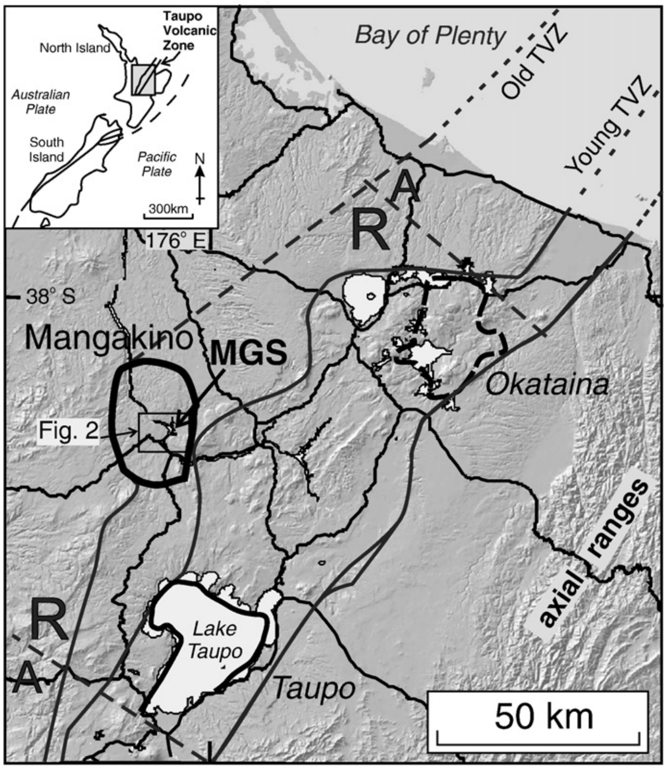

Fig. 1. Setting of Mangakino caldera (thick outline) and the Mangakino geothermal field (MGS). The Taupo Volcanic Zone is divided into 3 segments, dominated by andesitic (A) and rhyolitic (R) volcanism. Mangakino was active from ~1.6 to 0.95 Ma, then infilled by sediments and ignimbrites erupted from volcanoes to the east that were situated within the area outlined as Young TVZ. Taupo and Okataina are the two currently active centres.

However, allowance has then to be made for the initial disequilibrium caused by the preferential partitioning of U into the zircons (Schärer, 1984) that is utilised, as described above, for the dating of young volcanic rocks.

In this paper we report U–Pb age data obtained from a sequence of strongly hydrothermally altered rocks from core and cuttings in wells from the Mangakino geothermal field in New Zealand and compare these data with those from possible correlative material from fresh surface exposures. Despite extensive alteration of the primary volcanic mineral assemblages in the subsurface samples, the zircon crystals appear unaffected by the hydrothermal activity (either in dissolution or by overgrowths visible under cathodoluminescence). We show how model-age data from zircons can be used to constrain interpretations of eruptive units when models of eruption stratigraphy using conventional petrographic information might be ambiguous or inaccurate.

2. Mangakino geothermal field

Mangakino is the westernmost geothermal field identified in the TVZ (Fig. 1: Bibby et al., 1995, for overview). It is contained within a caldera structure identified initially from gravity anomalies (Stern, 1979; Rogan, 1982) and subsequently from geological mapping. The caldera is inferred to be a source for several members of an ignimbrite succession now mostly exposed to the west (Blank, 1965; Wilson et al., 1984; Wilson, 1986) that range in age from ~1.6 Ma to 0.95±0.03 Ma (Houghton et al., 1995). Both the extent of the caldera and volumes of ignimbrites erupted from it are poorly constrained due to erosion and infilling, respectively. However, crude volumes estimated from surface exposures of the ignimbrites and associated fall deposits in total exceed 1000 km^3, and the gravity low covers around 800 km^2. The topographic expression of the caldera after 0.95 Ma has been greatly modified by infilling with lacustrine and fluvial sediments and the 0.32±0.02 Ma Whakamaru ignimbrite (Briggs, 1976) and by down-warping to produce the modern basinal form of the area.

The Mangakino geothermal field was first investigated as a geothermal prospect in 1986 by the New Zealand Department of Scientific and Industrial Research undertaking resistivity surveys within Mangakino caldera. Results indicated that an area of low resistivity, similar to other geothermal fields within the TVZ, occurred within the Mangakino basin. Hot springs were also known to exist in the area prior to their flooding by the filling of Lake Maraetai. The documented gravity and resistivity anomalies, as well as the observed surface manifestations, led to drilling of MA1 well (Fig. 1), to 607 m vertical depth (Wood, 1987).

In 2004 Mighty River Power re-examined the prospect, using new geological information and a MT-TEM resistivity survey along with the previous data from MA1 to delineate the positions of three further wells. These results led to the completion of four drillholes (Fig. 1): MA2 which is vertical and is the deepest well at 3192 m below ground surface; MA2a, which occupied the same site as MA2 but was deviated, to reach 1759 m vertical depth; MA3, deviated and reached 1840 m vertical depth; and MA4, deviated and reached 1574 m vertical depth.

3. Surface and subsurface stratigraphy

The surface stratigraphy around the Mangakino basin was established by Martin (1961) and Blank (1965) and modified by Wilson (1986). Dominant landscape-forming rock types are welded and non-welded ignimbrites (Table 1) ranging in age from 0.32 Ma to ~1.6 Ma (Houghton et al., 1995). To the southeast and east of

Table 1
Summary of ignimbrite stratigraphy in the areas around Mangakino caldera. Compiled from Martin (1961) and Wilson (1986), with ages from Wilson et al. (1995: Kidnappers) and Houghton et al. (1995: all other units; errors are 1σ). **X** = abundant, **x** = common, x = sparse; – = absent. Fe–Ti oxides are present in all units

Ignimbrite	Age	Xtl	Crystal mode					Features in subaerial deposits
	(Ma)	(%)	Plag	Qtz	Bio	Opx	Hb	
Whakamaru	0.32±0.02	35–40	**X**	**X**	**x**	**x**	**x**	Crystal rich, vitroclastic partly welded ignimbrite. Quartz rich, lithic poor.
Waiotapu	0.71±0.06	10	**X**	x	–	x	–	Crystal poor, dense welded ignimbrite. Lithic poor.
Marshall	0.95±0.03	8	**X**	x	–	x	–	Crystal poor, non non-welded to moderately welded ignimbrite. Contains large pumices and rhyolite lithics.
Rocky Hill	1.00±0.05	20	**X**	**x**	x	**x**	**x**	Crystal rich, densely welded ignimbrite. Contains large amphibole pseudomorphs.
Kidnappers	1.01 – 1.02	10–20	**X**	**x**	**x**	**x**	**x**	Non-welded widespread ignimbrite overlying a large phreatomagmatic fall deposit
Ahuroa	1.18±0.02	10–12	**X**	**x**	–	x	–	Crystal poor welded ignimbrite with inverse thermal zonation.
Unit D	1.20±0.04	Not studied in detail						Non-welded ignimbrite overlying a large phreatomagmatic fall deposit
Ongatiti	1.21±0.04	40	**X**	**X**	–	x	x	Crystal rich welded ignimbrite
Unit C	(1.68±0.07)	30–40	**X**	–	–	**x**	–	Crystal rich non non-welded to densely welded andesitic ignimbrite. Abundant andesite lithics.
Unit B	1.53±0.04	<10	**X**	x	–	x	–	Crystal poor partly welded ignimbrite.
Ngaroma	1.55±0.05	1–7	**x**	–	–	x	x	Crystal poor welded ignimbrite, heavily vapour-phase altered.