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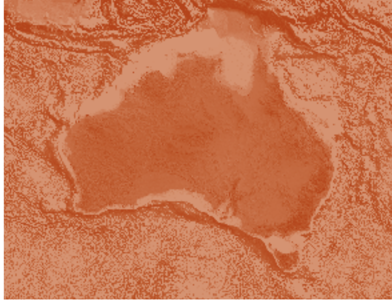

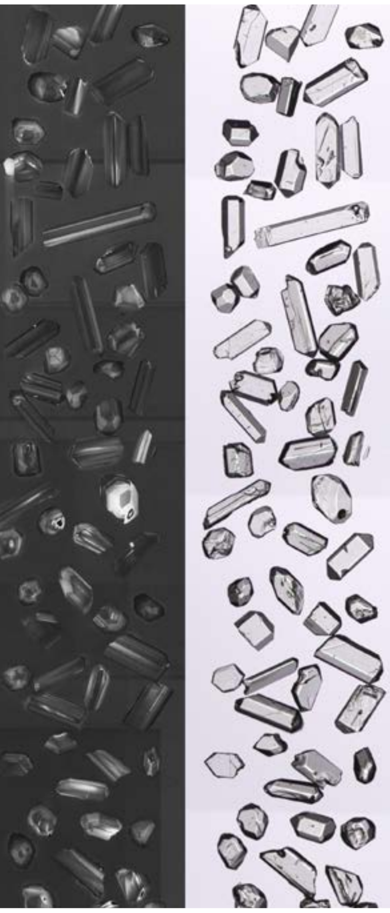

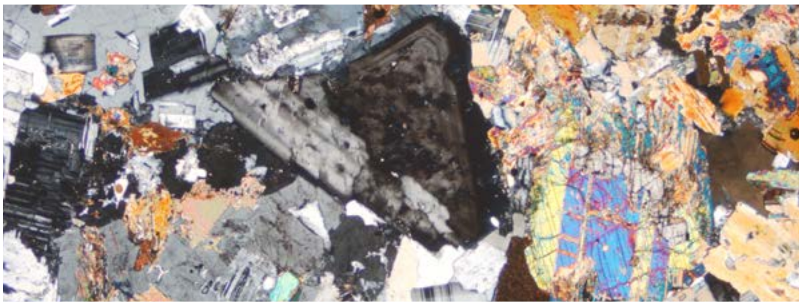

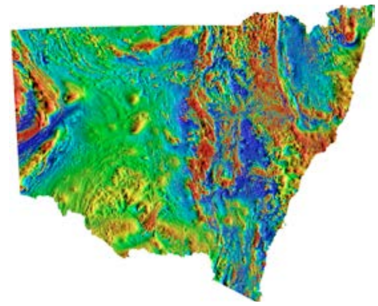

Record 2014/13 | **GeoCat** 76460
Geological Survey of New South Wales Report GS2013/1838

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Geological Survey of New South Wales

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ISSN 2201-702X (PDF)

ISBN 978-1-925124-02-6 (PDF)

GeoCat 76460

Bibliographic reference: Chisholm, E. I., Blevin, P. L. & Simpson, C. J., 2014. *New SHRIMP U–Pb zircon ages from the New England Orogen, New South Wales: July 2010–June 2012*. Record 2014/13. Geoscience Australia, Canberra. Report GS2013/1838. Geological Survey of New South Wales, Maitland. http://dx.doi.org/10.11636/Record.2014.013

Contents

Executive Summary

This Record presents new zircon U–Pb geochronological data, obtained using a Sensitive High Resolution Ion Micro Probe (SHRIMP), for nine samples of plutonic and volcanic rocks of the southern New England Orogen, New South Wales. The work was carried out under the auspices of the National Geoscience Accord, as a component of the collaborative Geochronology Project between the Geological Survey of New South Wales (GSNSW) and Geoscience Australia (GA) during the reporting periods 2010/11 and 2011/12. It is part of a larger collaborative effort between GA, the GSNSW and the Geological Survey of Queensland to better understand the geological evolution of the New England region through a targeted geochronology program (Cross et al. 2009, 2010, 2012, 2013; Brownlow and Cross, 2010, Chisholm et al. in prep).

Summary of results and significance

In the southern-most New England Orogen (NEO), the Nerong Volcanics (near Morna Point at Port Stephens) yielded a magmatic crystallisation age of 340.5 ± 2.0 Ma (all uncertainties are quoted at the 95% confidence level). This constrains the onset of Carboniferous volcanism and accords with a previous low-level age of 338.6 ± 3.8 Ma (Roberts et al., 1995). Sedimentary rocks interbedded with the ignimbrites at Soldiers Point host the Carboniferous flora *Rhacopteris* (White, 1994), extending the age of *Rhacopteris* back to at least as far as ~340 Ma.

The remaining samples are from the south-central region of the southern NEO. The Balala Granodiorite yielded an older than expected magmatic crystallisation age of 295.0 ± 1.7 Ma, despite being geochemically and petrographically indistinguishable from the Late Permian I-type Uralla Supersuite. This new age, together with that of the Glenburnie Adamellite (295.2 ± 2.3 Ma; Black, 2007) confirms 'older' I-type magmatism in the southern New England Orogen, presaging emplacement of the S-type Bundarra Supersuite at ~285 Ma.

Following excision of the underlying and geochemically distinct 264.4 ± 2.5 Ma Drake Volcanics by Cross and Blevin (2010), three samples were dated from the newly defined base of the Wandsworth Volcanic Group (WVG) in order to constrain the onset of Late Permian volcanism. The three informally-named units yielded indistinguishable magmatic crystallisation ages: 256.0 ± 1.5 Ma for the 'Uralla volcanics', 255.8 ± 1.5 Ma for the 'Attunga Creek volcanics', and 256.3 ± 1.5 Ma for the 'Kurrajong Park volcanics'. These dates extend the known timeframe of WVG magmatic activity, and are consistent with previous determinations on the 254.1 ± 2.2 Ma Dundee Rhyodacite (Brownlow and Cross, 2010; Cross and Blevin, 2013) and the 252.3 ± 2.0 Ma Emmaville Volcanics (Cross and Blevin, 2013) higher in the WVG succession.

Three Late Permian granitic rocks were also dated: the 254.9 ± 1.5 Ma Yarrowyck Granodiorite (which intrudes the Balala Granodiorite), a 255.0 ± 1.5 Ma component of the Regional Felsic Dyke Swarm (RFDS), and the 253.3 ± 1.4 Ma Khatoun Tonalite (which intrudes the WVG 'Uralla volcanics'). The first two are mutually indistinguishable, despite cross-cutting relationships between the granodiorite and member units from the RFDS. However, this new RFDS date is distinguishably older than a previous SHRIMP age on the same unit (252.5 ± 1.8 Ma, Cross and Blevin, 2010), which reveals an expanded chronology for RFDS emplacement and indicates the new date is from an earlier flush of intrusive activity in the region. The 253.3 ± 1.4 Ma Khatoun Tonalite is also cut by the RFDS, but is distinguishably younger than the new RFDS date reported herein. Presumably the cross-cutting unit is a younger phase of the swarm (cf. Cross and Blevin, 2010).

The youngest of the units reported herein is the Triassic ‘Kindee Creek tonalite’ that intrudes the Carboniferous Nevann Siltstone within the Hastings Block. The magmatic crystallisation age of 227.3 ± 1.3 Ma compares well with 231–228 Ma ‘coastal granitoids’ in Cross and Blevin (2013).

1 Introduction

This Record presents new zircon U–Pb geochronological data, obtained using a Sensitive High Resolution Ion Micro-Probe (SHRIMP), for nine samples of plutonic and volcanic rocks of the New England Orogen, New South Wales (Table 1.1 and Figure 1.1). The work was carried out under the auspices of the National Geoscience Accord, as a component of the collaborative Geochronology Project between the Geological Survey of New South Wales (GSNSW) and Geoscience Australia (GA) during the reporting periods 2010/11 and 2011/12.

Of the nine samples, seven were analysed from MANILLA: the Yarrowyck Granodiorite from BUNDARRA (northeastern MANILLA; small and large capitals refer to map sheet names in the 1:100 000 and 1:250 000 Topographic Series respectively) and six from BENDEMEER (southeastern MANILLA) including three from the Wandsworth Volcanic Group (undifferentiated, one each from Uralla, Attunga Creek, and Honeysuckle Hills at Kurrajong Park), the Balala Granodiorite, the Khatoun Tonalite and a porphyritic granodiorite dyke from the Regional Felsic Dyke Swarm. One sample, the 'Kindee Creek tonalite' was analysed from COWARRAL (north-central HASTINGS), and one sample, the Nerong Volcanics, was analysed from PORT STEPHENS (south-central NEWCASTLE).

Table 1.1 Summary of sample identifiers, locations, stratigraphic units and results (magmatic crystallisation age for all samples and associated 95% confidence limits) for the GSNSW–GA Geochronology Project 2010–2012 (New England Orogen). Single quotes denote informal identifiers; n = number of analyses included in the weighted mean age.

GSNSW Site ID	GA SampleNo	MGA94 Zone	MGA94 Easting	MGA94 Northing	Stratigraphic Name / Informal Identifier	$^{206}Pb/^{238}U$ Age (Ma)
PB-12-URA-02	2129545	56	343993	6625448	Yarrowyck Granodiorite	254.9 ± 1.5 (n = 32)
BB-10-WVG-05	2120074	56	349223	6609425	Wandsworth Volcanic Group: 'Uralla volcanics'	256.0 ± 1.5 (n = 25)
BB-10-WVG-07	2120076	56	307330	6579351	Wandsworth Volcanic Group: 'Attunga Creek volcanics'	255.8 ± 1.5 (n = 25)
BB-10-WVG-08	2120077	56	336136	6623259	Wandsworth Volcanic Group: 'Kurrajong Park volcanics'	256.3 ± 1.5 (n = 25)
PB-10-BL-01	2121504	56	341800	6611300	Balala Granodiorite	295.0 ± 1.7 (n = 25)
PB-12-URA-01	2129544	56	348551	6609801	Khatoun Tonalite	253.3 ± 1.4 (n = 34)
PB-12-URA-03	2129546	56	347687	6610095	Regional Felsic Dyke Swarm porphyritic granodiorite dyke	255.0 ± 1.5 (n = 28)
PB-10-BWD-01	2121505	56	441234	6531839	'Kindee Creek tonalite'	227.3 ± 1.3 (n = 26)
PB-12-PTS-01	2129547	56	416308	6371829	Nerong Volcanics	340.5 ± 2.0 (n = 31)

This Record documents detailed results for each sample, encompassing sample location, geological context, petrography, zircon descriptions, an evaluation of the relevant analytical data, and a brief geochronological interpretation. The data and age interpretations are also available via GA's Geochron Delivery system (accessible at http://www.ga.gov.au/geochron-sapub-web/).

This record does not attempt to present the new SHRIMP U–Pb results in the context of an exhaustive regional assessment, nor does it consider all of the relevant and available geological and geochronological information. Comprehensive geological interpretations stemming from this data will be documented elsewhere.

A comprehensive description of sample acquisition and processing procedures, preparation and analysis of SHRIMP mounts, and data reduction and presentation methods are included in the Appendix, along with analytical session-specific details of the calibration data collected on the reference $^{206}Pb/^{238}U$ and $^{207}Pb/^{206}Pb$ zircons. Session specific calibrations are summarised in Appendix Table A.1.

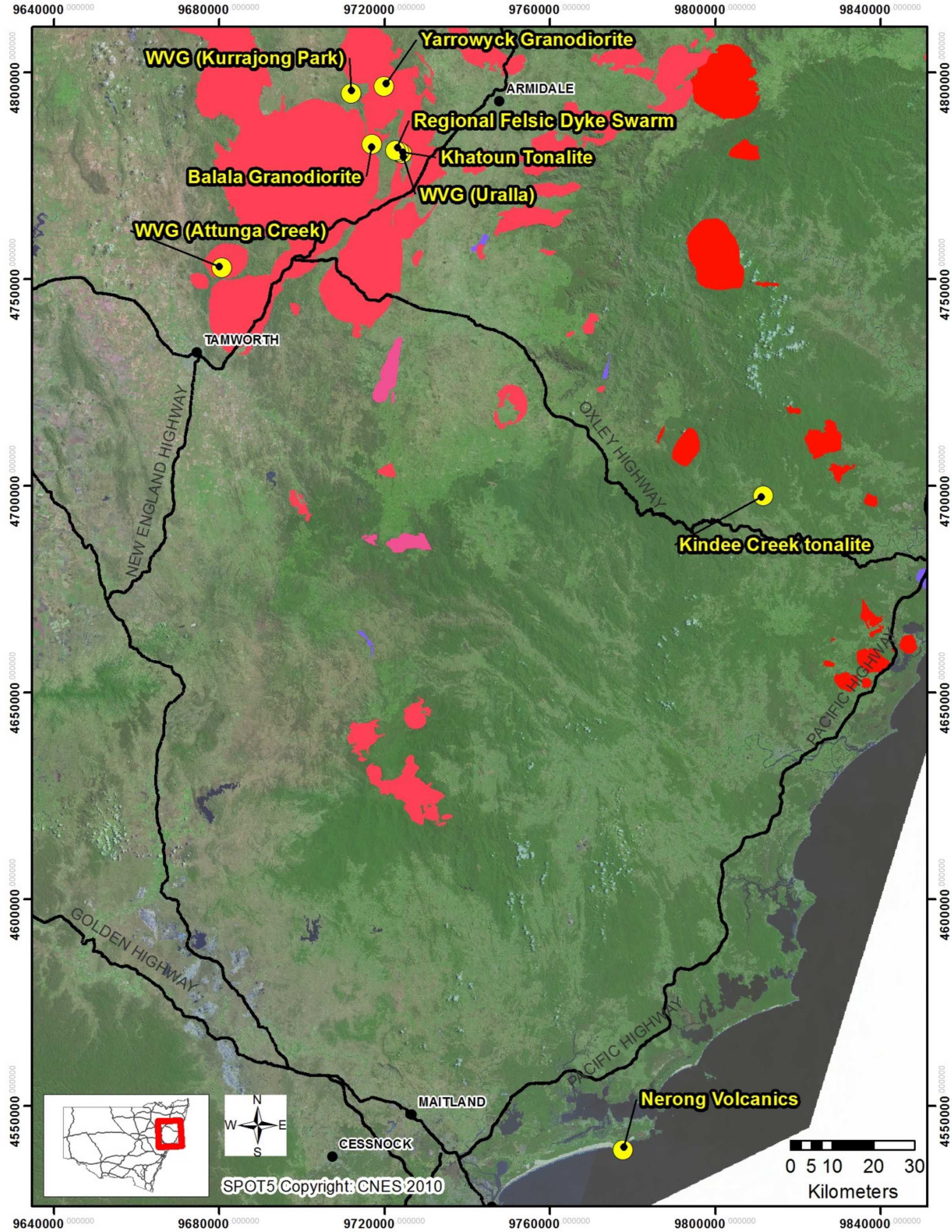


Figure 1.1 Map showing locations for the SHRIMP U–Pb geochronology samples presented in this report. Yellow circles represent the locations of samples presented in this Record, polygons represent outcropping intrusive units in the region: orange-red = granodiorites, red = granites, pink = monzogranites, purple = mafic intrusives.

2 Yarrowyck Granodiorite

Table 2.1 Summary of results: Yarrowyck Granodiorite (GSNSW: PB-12-URA-02, GA: 2129545).

GA SampleNo	2129545
GSNSW SiteID	PB-12-URA-02
Parent Unit	Uralla Supersuite, Yarrowyck Suite
Stratigraphic Unit	Yarrowyck Granodiorite
Informal Identifier	—
Lithology	Granodiorite
Province	New England Orogen
1:250 000 Sheet	MANILLA (SH/56-9)
1:100 000 Sheet	BUNDARRA (9137)
Location (GDA94)	30.493138°S, 151.374480°E
Location (MGA94)	Zone 56; 343993 mE, 6625448 mN
Analytical Session No	120062 (see Appendix Table A.1 for parameters derived from concurrent measurements of $^{206}Pb/^{238}U$ and $^{207}Pb/^{206}Pb$ reference zircons)
Interpreted Age	254.9 ± 1.5 Ma (n = 32)
Geological Attribution	Magmatic crystallisation
Isotopic Ratio used	$^{206}Pb/^{238}U$ (^{204}Pb-corrected)

2.1 Sampling Details and Geological Relationships

A sample of Yarrowyck Granodiorite (Flinter et al., 1972) was taken from fresh, medium-sized boulders 10 m off the eastern side of the Uralla–Bundarra Road at the extreme southern end of a long low road cutting. Minor aplites and rare small pegmatite segregations occur in outcrop and small sparsely distributed mafic microgranular enclaves are also present. The granodiorite is medium-grained, and intermediate–felsic in hand specimen.

The Yarrowyck Granodiorite cuts the Balala Granodiorite (295.0 ± 1.7 Ma, this volume) immediately to the south of the sample area, and is cut by the Regional Felsic Dyke Swarm (RFDS; 252.5 ± 1.8 Ma, SHRIMP, Cross and Blevin, 2010; 255.0 ± 1.5 Ma, this volume), and the Gwydir River Adamellite (252.3 ± 1.5 Ma, SHRIMP, Cross and Blevin, 2010), which in turn truncates the RFDS.

Phillips et al. (2011) obtained a $^{206}Pb/^{238}U$ age of 249 ± 3 Ma for the Yarrowyck Granodiorite that is inconsistent with the ages of other dated plutons in the region and mapped geological relationships.

An age for the Yarrowyck Granodiorite of the Uralla Supersuite will confirm: (1) local intrusive relationships between it, the Balala Granodiorite, and the RFDS; (2) regional magmatic relationships including with the Gwydir River Adamellite; and (3) together with the Khatoun Tonalite (this volume) will contribute additional age information for plutons of the Uralla Supersuite.

2.2 Petrography

The sample is a virtually unaltered, medium-grained but inequigranular and hornblende-bearing granodiorite (Figure 2.1). It is characterised by well-formed, subhedral and tabular plagioclase crystals (~55% of the overall mode) up to 5.5 mm in size. Many of the larger crystals display fine concentric zoning; however, an andesine composition (An40–42) was obtained on a couple of grains. The rock also contains long (to 4.5 mm) bladed, anhedral crystals of hornblende (~3–4 modal %) and a similar quantity (~6–7 modal %) of smaller laths of tan- to chocolate-coloured biotite. The remainder of the mode consists of much finer grained quartz (20 modal %) and alkali feldspar (15 modal %) which, along with a small quantity of small plagioclase, form fine crystal aggregates between larger grains. The quartz and feldspars in these aggregates have a polygonal, equilibrium texture. A weakly perthitic texture in the alkali feldspar is partly obscured by very fine dusty alteration. The granodiorite contains accessory apatite and zircon.

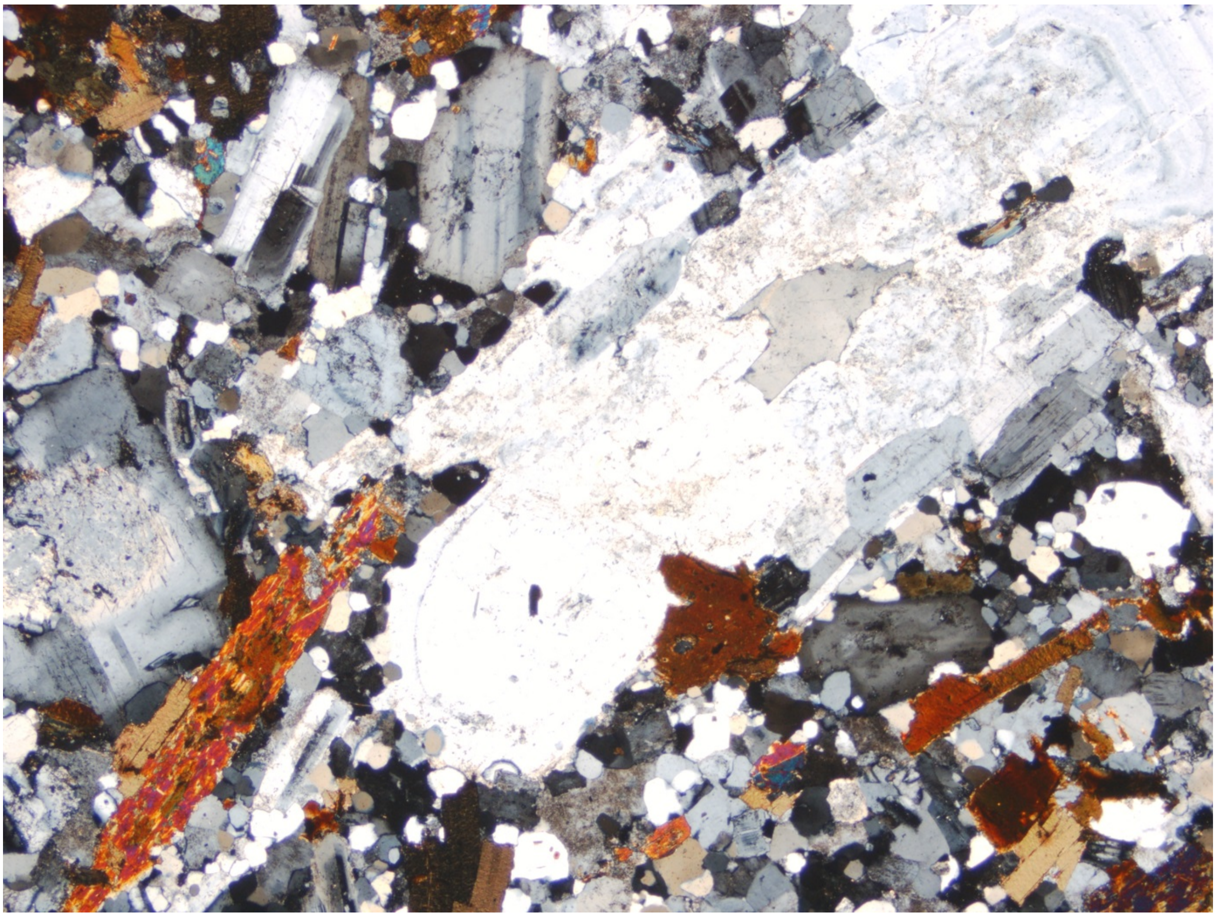


Figure 2.1 Representative photomicrograph of the Yarrowyck Granodiorite (GSNSW: PB-12-URA-02, GA: 2129545) in cross-polarised light. Inequigranular granodiorite showing scattered outsized plagioclase crystals and the bladed but anhedral hornblende crystals (lower left). Elsewhere, smaller crystals of plagioclase, biotite, fine-grained quartz and alkali feldspar typically form polygonal aggregates. Long axis of image is ~6 mm. Image supplied by Geological Survey of NSW.

2.3 Zircon Description

The zircons are predominantly euhedral elongate to stubby prismatic grains with well-formed facets, with lesser sub-rounded and fractured grains (Figure 2.2). Long axes are 60–200 µm. Grain length to width is variable between 1:1 and 4:1.

In transmitted light (TL) the zircons are predominantly transparent to slightly translucent and colourless. There are minor clear inclusions present as acicular and anhedral rods that are variably disoriented to axially oriented. Cracks are variable across the population ranging from major crazing in some grains to solitary large cracks and crack-free grains (Figure 2.2).

Cathodoluminescence imaging reveals a range of internal structures that do not appear to be specific to grain morphology. Many grains, both transparent and translucent in TL, show moderate emission and a broadly diffuse axially zoned core region with a narrow (<5 µm) low response rim. Stubby prismatic grains tend towards strong oscillatory zoning with conformable oscillatory zoned cores. A minority of grains have cores that are convolutedly zoned and disconformable with narrow, dark rims (Figure 2.2).

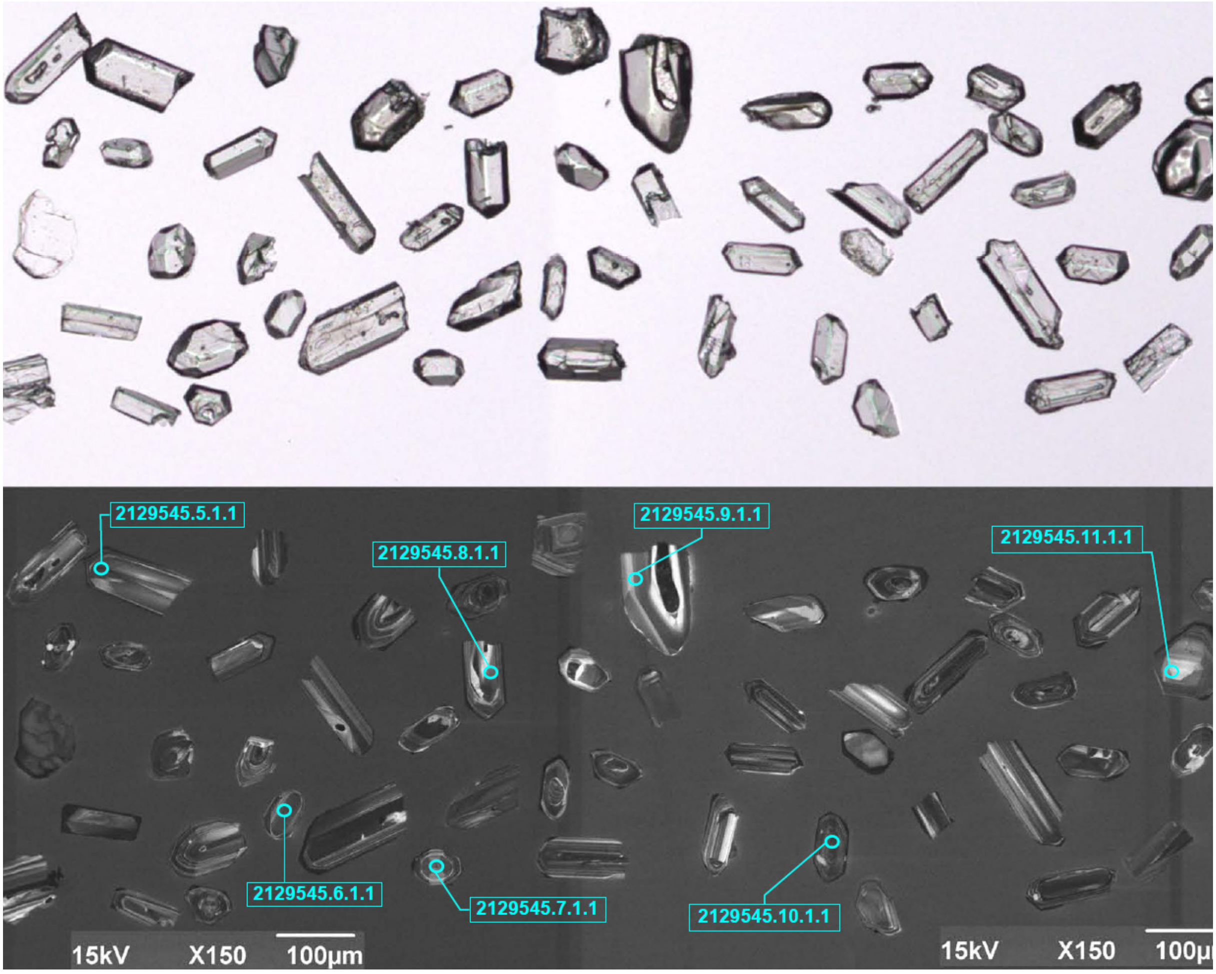


Figure 2.2 Representative zircons from the Yarrowyck Granodiorite (GSNSW: PB-12-URA-02, GA: 2129545). Transmitted light image is shown in the upper half; Cathodoluminescence image is shown in the lower half. SHRIMP analysis sites are indicated, and labelled with sample, grain, spot and replicate number.

2.4 U–Pb Isotopic Results

Thirty-three analyses were obtained from 33 individual zircon grains; the results are presented in Table 2.2 and illustrated in Figure 2.3. Grain labels 18–22 were not used (see Appendix A.4.2).

The 33 analyses are characterised by varied U concentrations (144–1611 ppm, median 501 ppm), moderate Th/U (0.41–1.27, median 0.66) and $^{206}Pb_c$ less than 1.16% (median 0.09%).The analyses can be divided into two groups:

- Group 1: Thirty-two analyses (Figure 2.3, pink fill; Table 2.2) with individual $^{206}Pb/^{238}U$ ages between ~248 Ma and ~262 Ma, which combine to produce a weighted mean $^{206}Pb/^{238}U$ age of 254.9 ± 1.5 Ma (95% confidence, MSWD = 1.22, probability = 0.19).
- Group 2: One analysis (2129545.35.1.1; Figure 2.3, yellow fill; Table 2.2) with an individual $^{206}Pb/^{238}U$ age of ~298 Ma.

2.5 Geochronological Interpretation

The weighted mean $^{206}Pb/^{238}U$ age of 254.9 ± 1.5 Ma for the 32 analyses in Group 1 is interpreted as the best estimate of the magmatic crystallisation age of the Yarrowyck Granodiorite.

The single analysis in Group 2 is interpreted to reflect Early Permian (~298 Ma) inheritance.

This new SHRIMP age, along with other new ages from this volume, and pertinent geological relationships are considered in the discussion.

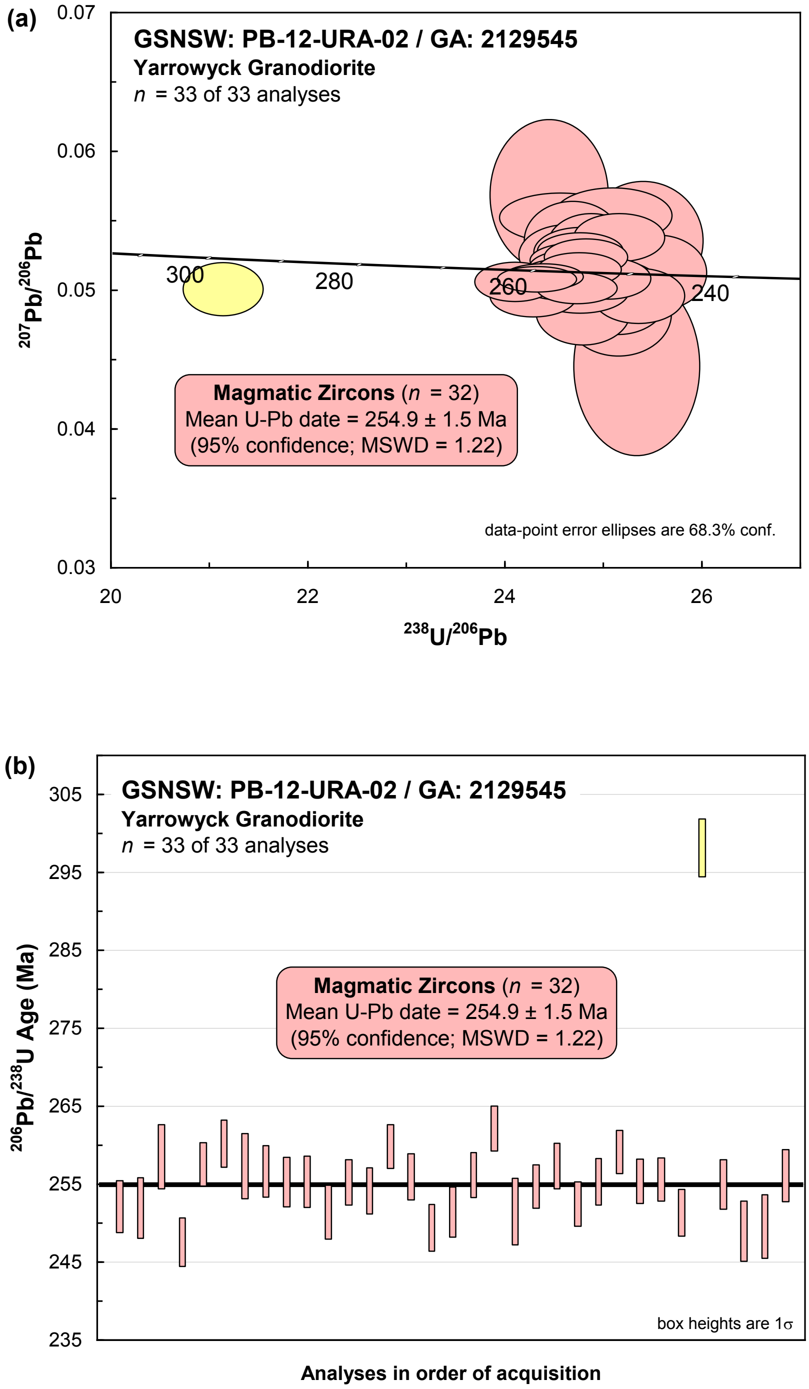


Figure 2.3 SHRIMP U–Pb data for zircons from the Yarrowyck Granodiorite (GSNSW: PB-12-URA-02, GA: 2129545). Pink fill denotes Group 1 (magmatic crystallisation), and yellow fill denotes Group 2 (Early Permian inheritance). (a) Tera-Wasserburg concordia diagram; (b) $^{206}Pb/^{238}U$ ages in order of acquisition. Heavy black line denotes the weighted mean $^{206}Pb/^{238}U$ age of the magmatic population.

Table 2.2 SHRIMP U–Pb isotopic data for zircons from the Yarrowyck Granodiorite (GSNSW: PB-12-URA-02, GA: 2129545). All ages are $^{206}Pb/^{238}U$.

Session No.	Sample. Grain. Spot. Replicate	$^{206}Pb_c$ (%)	U (ppm)	Th (ppm)	$^{232}Th/^{238}U$	$^{238}U/^{206}Pb$	±1σ (%)	$^{207}Pb/^{206}Pb$	±1σ (%)	Age (Ma)	±1σ (Ma)
Group 1: Magmatic zircons (n = 32)											
120062	2129545.25.1.1	0.25	910	667	0.76	24.098	1.1	0.05062	1.9	262.1	2.9
120062	2129545.6.1.1	0.09	576	457	0.82	24.285	1.2	0.04959	2.0	260.1	3.0
120062	2129545.14.1.1	0.13	1611	1978	1.27	24.320	1.1	0.05079	1.2	259.8	2.8
120062	2129545.31.1.1	0.04	1264	1107	0.90	24.389	1.1	0.05100	1.2	259.0	2.8
120062	2129545.3.1.1	-0.91	161	64	0.41	24.445	1.6	0.05692	6.3	258.5	4.1
120062	2129545.5.1.1	0.34	1139	994	0.90	24.538	1.1	0.05079	1.9	257.5	2.8
120062	2129545.7.1.1	-0.06	453	261	0.59	24.559	1.7	0.05526	2.1	257.3	4.2
120062	2129545.28.1.1	-0.11	731	637	0.90	24.560	1.2	0.05087	1.7	257.3	2.9
120062	2129545.8.1.1	0.16	348	272	0.81	24.625	1.3	0.05255	2.8	256.6	3.3
120062	2129545.24.1.1	0.07	693	477	0.71	24.672	1.2	0.05163	1.7	256.1	2.9
120062	2129545.17.1.1	-0.42	315	131	0.43	24.682	1.3	0.05360	3.5	256.0	3.3
120062	2129545.15.1.1	-0.04	776	521	0.69	24.694	1.2	0.05219	1.6	255.9	3.0
120062	2129545.33.1.1	0.15	1233	844	0.71	24.728	1.1	0.05017	1.5	255.6	2.7
120062	2129545.32.1.1	-0.07	785	617	0.81	24.752	1.1	0.05151	1.6	255.3	2.9
120062	2129545.10.1.1	0.30	874	424	0.50	24.759	1.3	0.04994	2.1	255.2	3.3
120062	2129545.30.1.1	0.10	501	511	1.05	24.761	1.2	0.05137	2.1	255.2	3.0
120062	2129545.12.1.1	-0.04	664	379	0.59	24.763	1.2	0.05283	1.7	255.2	2.9
120062	2129545.9.1.1	-0.07	404	259	0.66	24.764	1.3	0.05275	2.3	255.2	3.2
120062	2129545.36.1.1	0.29	400	230	0.59	24.789	1.3	0.04845	3.3	254.9	3.2
120062	2129545.27.1.1	-0.17	940	537	0.59	24.818	1.1	0.05241	1.6	254.7	2.8
120062	2129545.13.1.1	-0.14	611	338	0.57	24.875	1.2	0.05327	2.8	254.1	3.0
120062	2129545.29.1.1	0.18	728	329	0.47	25.044	1.1	0.05086	2.0	252.4	2.8
120062	2129545.1.1.1	0.27	292	166	0.59	25.078	1.3	0.05228	3.4	252.1	3.3
120062	2129545.2.1.1	-0.22	496	311	0.65	25.099	1.6	0.05540	2.4	251.9	3.9
120062	2129545.26.1.1	-0.15	346	265	0.79	25.143	1.7	0.05218	2.7	251.4	4.3
120062	2129545.11.1.1	0.33	258	112	0.45	25.150	1.4	0.04830	4.2	251.4	3.5
120062	2129545.23.1.1	0.33	331	258	0.80	25.152	1.3	0.04947	3.5	251.3	3.2
120062	2129545.34.1.1	-0.11	479	256	0.55	25.159	1.2	0.05383	2.1	251.3	3.0
120062	2129545.38.1.1	1.16	144	84	0.60	25.337	1.7	0.04453	9.6	249.5	4.1
120062	2129545.16.1.1	0.23	526	390	0.77	25.357	1.2	0.04959	2.6	249.3	3.0
120062	2129545.37.1.1	-0.50	161	90	0.58	25.404	1.6	0.05360	5.3	248.9	3.8
120062	2129545.4.1.1	0.43	378	267	0.73	25.552	1.3	0.05129	3.5	247.5	3.1

Session No.	Sample. Grain. Spot. Replicate	$^{206}Pb_c$ (%)	U (ppm)	Th (ppm)	$^{232}Th/^{238}U$	$^{238}U/^{206}Pb$	±1σ (%)	$^{207}Pb/^{206}Pb$	±1σ (%)	Age (Ma)	±1σ (Ma)
Group 2: Inherited zircon (n = 1)											
120062	2129545.35.1.1	0.17	396	216	0.56	21.124	1.3	0.05009	2.5	298.2	3.7

3 Wandsworth Volcanic Group: ‘Uralla volcanics’

Table 3.1 Summary of results: Wandsworth Volcanic Group ‘Uralla volcanics’ (GSNSW: BB-10-WVG-05, GA: 2120074).

GA SampleNo	2120074
GSNSW SiteID	BB-10-WVG-05
Parent Unit	Wandsworth Volcanic Group
Stratigraphic Unit	Wandsworth Volcanic Group (Undifferentiated)
Informal Identifier	‘Uralla volcanics’
Lithology	Crystal-rich rhyolitic ignimbrite
Province	New England Orogen
1:250 000 Sheet	MANILLA (SH/56-9)
1:100 000 Sheet	BENDEMEER (9136)
Location (GDA94)	30.638020°S, 151.426452°E
Location (MGA94)	Zone 56, 349223 mE, 6609425 mN
Analytical Session No	110005 (see Appendix Table A.1 for parameters derived from concurrent measurements of $^{206}Pb/^{238}U$ and $^{207}Pb/^{206}Pb$ reference zircons)
Interpreted Age	256.0 ± 1.5 Ma (n = 25)
Geological Attribution	Magmatic crystallisation
Isotopic Ratio used	$^{206}Pb/^{238}U$ (^{204}Pb-corrected)

3.1 Sampling Details and Geological Relationships

The sample for the Wandsworth Volcanic Group (WVG; Barnes et al., 1991) ‘Uralla volcanics’ was taken from blast site boulders 6.6 km west of Uralla on the western side of Uralla–Kingston Road, immediately adjacent to the intrusive contact with Khatoun Tonalite. The unit sampled is a felsic hornfelsed crystal-rich ignimbrite of probable rhyolitic composition (Figure 3.1).

The WVG ‘Uralla volcanics’ are intruded by granites of the Uralla Supersuite (Uralla Granodiorite, Wilhelmshohe Tonalite and Khatoun Tonalite [253.3 ± 1.4 Ma, this volume]). The Uralla Granodiorite and Wilhelmshohe Tonalite are interpreted to be Late Permian in age, based on: (1) Rb–Sr ages of 251–246 Ma for the Uralla Granodiorite (Shaw et al., 1994); and (2) their association with other Uralla Supersuite granites immediately to the northwest that yielded Rb–Sr ages (251–244 Ma; Shaw et al., 1994) comparable to SHRIMP U–Pb ages obtained by Cross and Blevin (2010): Gwydir River Adamellite (252.3 ± 1.5 Ma), Parlour Mountain Granite (254.7 ± 1.6 Ma) and the Tingha Adamellite (251.3 ± 1.7 Ma).

A SHRIMP U–Pb age for the WVG ‘Uralla volcanics’ will determine its relationship to: (1) previously dated WVG units (about 254–252 Ma:, Cross and Blevin, 2010; 2013); and (2) previously undated WVG units (‘Kurrajong volcanics’ and ‘Attunga Creek volcanics; this volume). These dates will constrain the timing of commencement of WVG magmatism, and constrain the ages of plutons undated by SHRIMP U–Pb techniques (e.g. Uralla Grandiorite and Willhelmshohe Tonalite).

Figure 3.1 Representative photographs of the Wandsworth Volcanic Group 'Uralla volcanics' (GSNSW: BB-10-WVG-05, GA: 2120074) showing sample site at left and hand sample on right.

3.2 Petrography

The sample is a medium-grained, moderately crystal-rich rhyolitic ignimbrite with a weakly recrystallised matrix and contact metamorphic texture (Figure 3.2). The ignimbrite contains phenocrysts of quartz (~3 modal %) to 3 mm, mostly sericitised plagioclase (15%) and 5–6% weakly perthitic alkali feldspar. There is also a small amount of fine-grained secondary fibrous chlorite that has replaced regular laths (1%), presumably biotite phenocrysts to 1 mm in size. The degree of crystal fragmentation appears to be low. The matrix is a mostly massive granophyric aggregate of quartz, feldspar and minor chlorite, but rarely preserved elongate rods of slightly coarser microcrystalline material are probably welded shards. Furthermore, the matrix includes abundant, usually elongate, crystal-poor lenses that are probably flattened pumice clasts. There is rare preservation of poorly defined spherulitic texture in a few of these lenses. The ignimbrite contains rare black opaques and zircon.

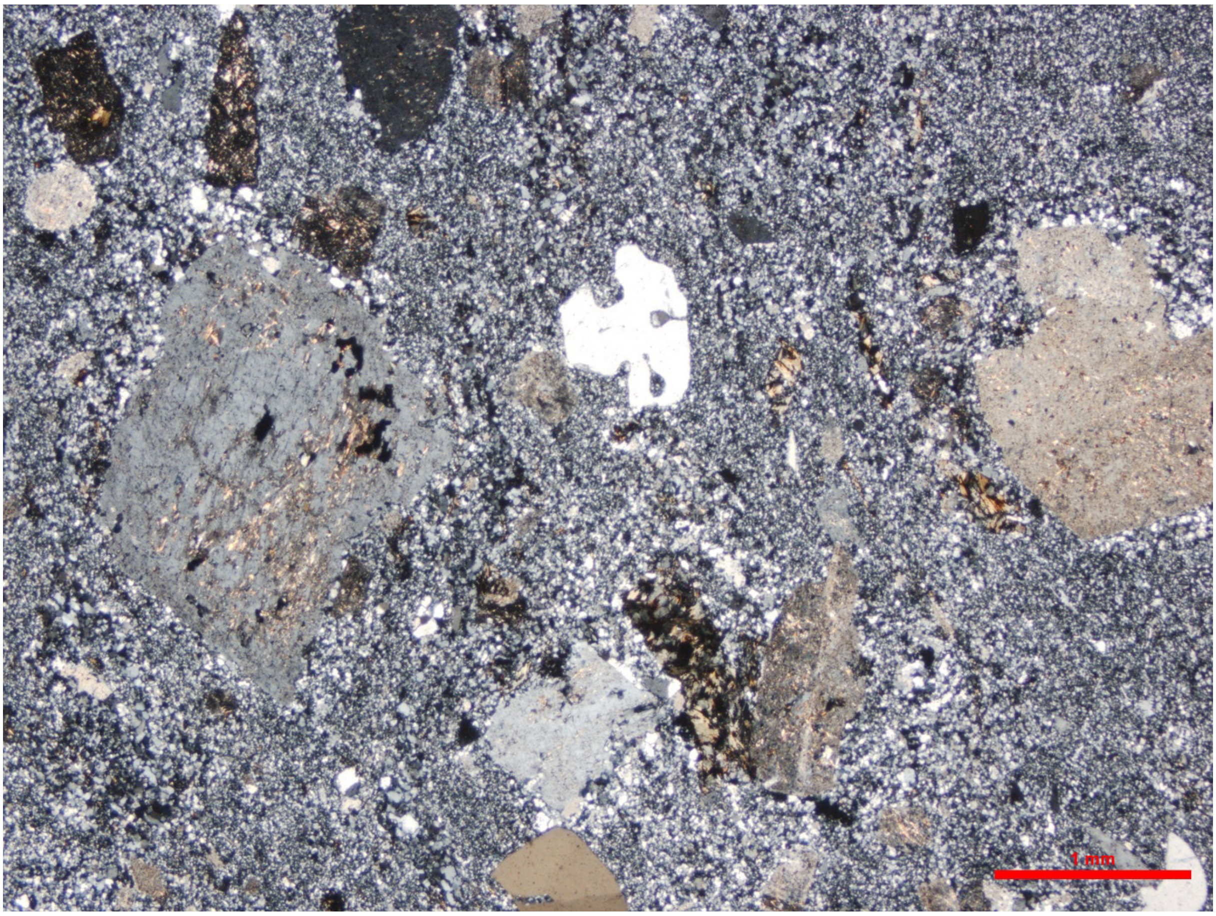


Figure 3.2 Representative photomicrograph of the Wandsworth Volcanic Group 'Uralla volcanics' (GSNSW: BB-10-WVG-05, GA: 2120074) in cross-polarised light. Weakly contact metamorphosed, moderately crystal-rich rhyolitic ignimbrite, characterised by phenocrysts of sericitised plagioclase (e.g. top left and right side), alkali feldspar (left side), quartz, and minor chlorite (after probable biotite; lower centre). Scale bar is 1 mm. Image supplied by Geological Survey of NSW.

3.3 Zircon Description

The zircons consist predominantly of euhedral prismatic grains with well-formed facets, fragmented grains and fewer elongate grains (Figure 3.3). Long axes are 70–400 µm. Grain length to width is variable between 1.5:1 and 4:1.

In transmitted light the zircons are predominantly transparent, and colourless to pale amber in colour. Common acicular clear inclusions are present as anhedral and axially-oriented rods. Cracks are variable between grains, presenting as hairline cracks or axially-oriented fractures (Figure 3.3).

Cathodoluminescence imaging reveals strong concentric oscillatory zoning around broadly zoned cores. This zoning is defined by moderate contrast emission and fine to moderate banding relative to grain size and core banding. Core regions are variable across the sample and significant in some grains; large cores (up to 200µm) with broad banding and high contrast, or small dark cores (up to 100 µm) with fine low-contrast banding (Figure 3.3). Core and overgrowth interfaces are generally sharp; some with pronounced disconformity. Recrystallisation textures, present as convolute zoning, are evident in some grains.

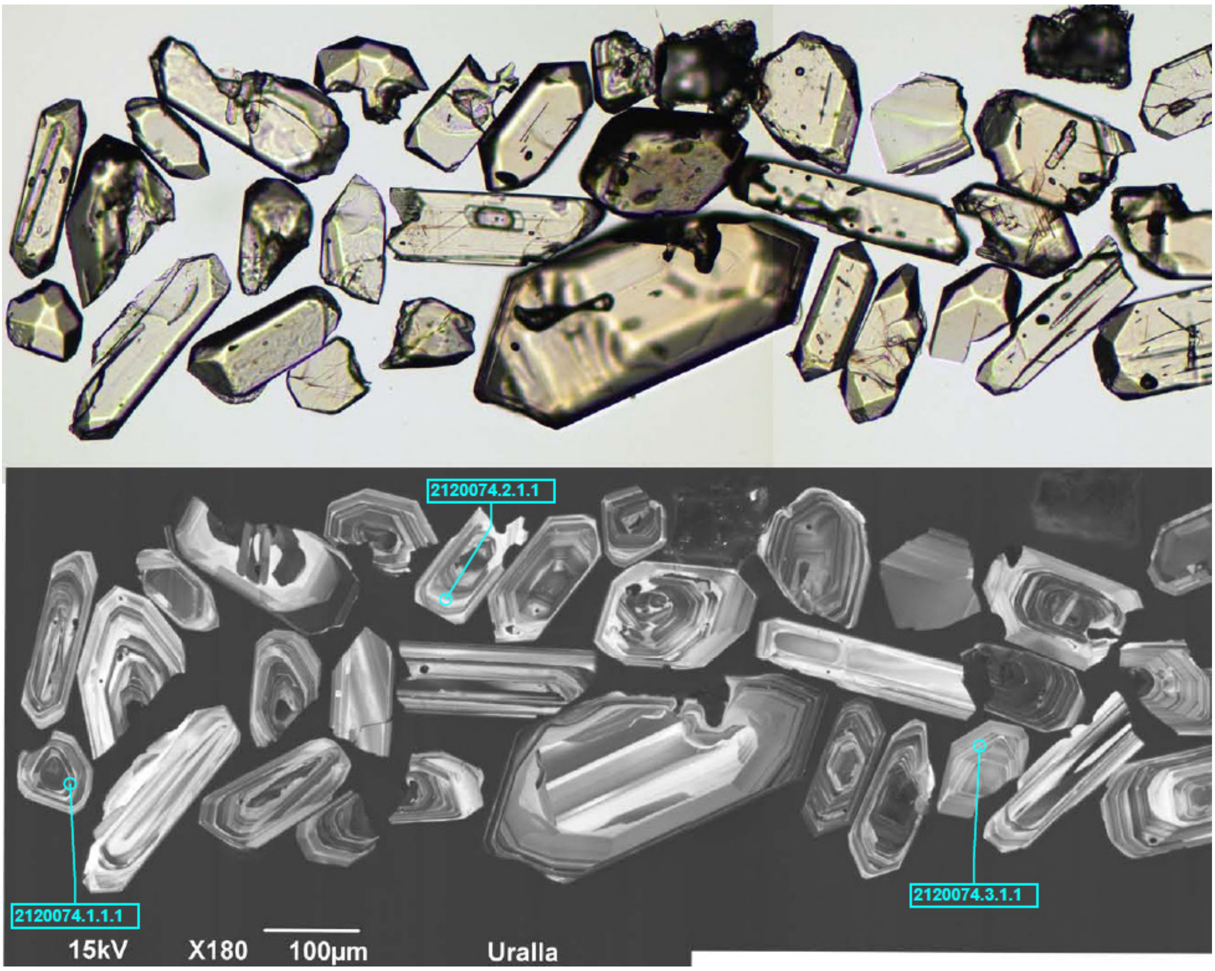


Figure 3.3 Representative zircons from the Wandsworth Volcanic Group 'Uralla volcanics' (GSNSW: BB-10-WVG-05, GA: 2120074). Transmitted light image is shown in the upper half; Cathodoluminescence image is shown in the lower half. SHRIMP analysis sites are indicated, and labelled with sample, grain, spot and replicate number.

3.4 U–Pb Isotopic Results

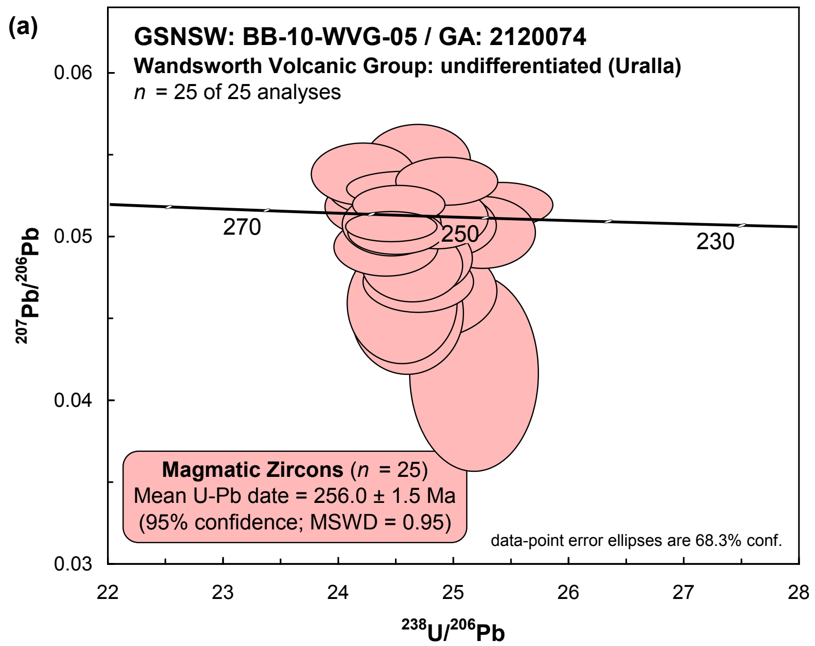
Twenty-five analyses were obtained from 25 individual zircon grains; the results are presented in Table 3.2 and illustrated in Figure 3.4. The analysed zircons are characterised by low to moderate U concentrations (112–772 ppm, median 272 ppm) and consistent Th/U (0.41–0.89, median 0.56).

The 25 analyses (Group 1 in Table 3.2; pink ellipses in Figure 3.4) have $^{206}Pb_c$ less than 1.66% (median 0.19%) with individual $^{206}Pb/^{238}U$ ages between ~249 Ma and ~261 Ma, which combine to produce a weighted mean $^{206}Pb/^{238}U$ age of 256.0 ± 1.5 Ma (95% confidence, MSWD = 0.95, probability = 0.53).

3.5 Geochronological Interpretation

The weighted mean $^{206}Pb/^{238}U$ age of 256.0 ± 1.5 Ma is interpreted to be the magmatic crystallisation age of the Wandsworth Volcanic Group Uralla volcanics.

This new SHRIMP age, along with other new ages from this volume, and pertinent geological relationships are considered in the discussion.



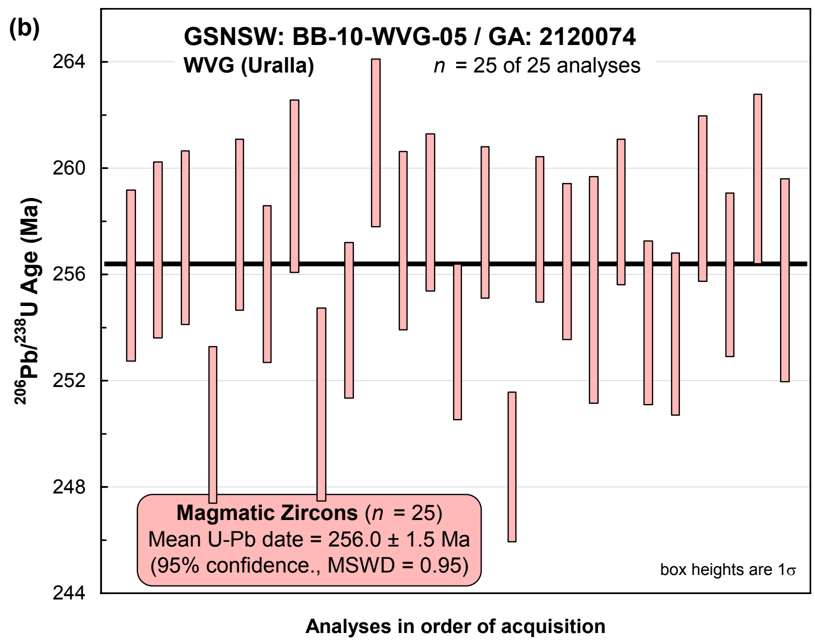


Figure 3.4 SHRIMP U–Pb data for zircons from the Wandsworth Volcanic Group 'Uralla volcanics' (GSNSW: BB-10-WVG-05, GA: 2120074). Pink fill denotes Group 1 (magmatic crystallisation). (a) Tera-Wasserburg concordia diagram; (b) $^{206}Pb/^{238}U$ ages in order of acquisition. Heavy black line denotes the weighted mean $^{206}Pb/^{238}U$ age of the magmatic population.

Table 3.2 SHRIMP U–Pb isotopic data for zircons from the Wandsworth Volcanic Group 'Uralla volcanics' (GSNSW: BB-10-WVG-05, GA: 2120074). All ages are $^{206}Pb/^{238}U$.

Session No.	Sample.Grain. Spot.Replicate	$^{206}Pb_c$ (%)	U (ppm)	Th (ppm)	$^{232}Th/^{238}U$	$^{238}U/^{206}Pb$	±1σ (%)	$^{207}Pb/^{206}Pb$	±1σ (%)	Age (Ma)	±1σ (Ma)
Group 1: Magmatic zircons (n = 25)											
110005	2120074.10.1.1	0.12	214	99	0.48	24.207	1.2	0.05388	2.3	260.9	3.2
110005	2120074.24.1.1	0.07	201	151	0.77	24.336	1.3	0.05190	2.4	259.6	3.2
110005	2120074.7.1.1	0.00	176	75	0.44	24.363	1.3	0.05303	2.1	259.3	3.2
110005	2120074.22.1.1	0.12	229	119	0.54	24.407	1.2	0.04944	2.4	258.9	3.1
110005	2120074.19.1.1	0.08	772	474	0.63	24.456	1.1	0.05068	1.2	258.4	2.7
110005	2120074.12.1.1	0.33	310	180	0.60	24.458	1.2	0.05081	2.5	258.3	3.0
110005	2120074.14.1.1	0.15	427	278	0.67	24.493	1.1	0.05035	1.8	258.0	2.8
110005	2120074.5.1.1	0.40	182	85	0.48	24.503	1.3	0.05111	3.3	257.9	3.2
110005	2120074.16.1.1	0.22	698	560	0.83	24.520	1.1	0.05202	1.5	257.7	2.7
110005	2120074.3.1.1	1.03	185	93	0.52	24.549	1.3	0.04599	5.3	257.4	3.3
110005	2120074.11.1.1	-0.03	487	263	0.56	24.560	1.3	0.05298	1.3	257.3	3.4
110005	2120074.2.1.1	0.87	165	76	0.48	24.595	1.3	0.04539	5.4	256.9	3.3
110005	2120074.17.1.1	0.56	325	193	0.61	24.638	1.2	0.04832	3.0	256.5	2.9
110005	2120074.23.1.1	-0.29	235	127	0.56	24.686	1.2	0.05475	2.6	256.0	3.1
110005	2120074.1.1.1	0.53	480	413	0.89	24.690	1.3	0.04732	2.6	256.0	3.2
110005	2120074.25.1.1	0.11	363	206	0.59	24.707	1.5	0.04975	1.9	255.8	3.8
110005	2120074.6.1.1	0.51	306	205	0.69	24.721	1.2	0.04875	3.0	255.6	2.9
110005	2120074.18.1.1	0.77	241	152	0.65	24.742	1.7	0.04674	4.1	255.4	4.3
110005	2120074.9.1.1	0.30	310	132	0.44	24.856	1.2	0.05123	2.5	254.3	2.9
110005	2120074.20.1.1	0.19	212	102	0.50	24.865	1.2	0.05091	2.7	254.2	3.1
110005	2120074.21.1.1	0.18	228	121	0.55	24.907	1.2	0.05075	2.6	253.8	3.1
110005	2120074.13.1.1	-0.05	289	193	0.69	24.937	1.2	0.05343	1.8	253.5	2.9
110005	2120074.8.1.1	1.66	112	45	0.41	25.175	1.5	0.04174	9.5	251.1	3.6
110005	2120074.4.1.1	0.39	272	147	0.56	25.255	1.2	0.05032	2.9	250.3	2.9
110005	2120074.15.1.1	-0.04	355	205	0.60	25.419	1.2	0.05200	1.7	248.7	2.8

4 Wandsworth Volcanic Group: ‘Attunga Creek volcanics’

Table 4.1 Summary of results: Wandsworth Volcanic Group ‘Attunga Creek volcanics’ (GSNSW: BB-10-WVG-07, GA: 2120076).

GA SampleNo	2120076
GSNSW SiteID	BB-10-WVG-07
Stratigraphic Unit	Wandsworth Volcanic Group (Undifferentiated)
Parent Unit	Wandsworth Volcanic Group
Informal Identifier	‘Attunga Creek volcanics’
Lithology	Hornfelsed crystal-rich dacite hosting granite fragments
Province	New England Orogen
1:250 000 Sheet	MANILLA (SH/56-9)
1:100 000 Sheet	BENDEMEER (9136)
Location (GDA94)	30.903532°S, 150.984157°E
Location (MGA94)	Zone 56; 307330 mE, 6579351 mN
Analytical Session No	110005 (see Appendix Table A.1 for parameters derived from concurrent measurements of $^{206}Pb/^{238}U$ and $^{207}Pb/^{206}Pb$ reference zircons)
Interpreted Age	255.8 ± 1.5 Ma (n = 25)
Geological Attribution	Magmatic crystallisation
Isotopic Ratio used	$^{206}Pb/^{238}U$ (^{204}Pb-corrected)

4.1 Sampling Details and Geological Relationships

A sample of the Wandsworth Volcanic Group ‘Attunga Creek volcanics’ was taken from the east side of New England Gully Road, ~20 km north-west of Moonbi. Site access was via Minbalup Hostel private property. The sampled unit is a hornfelsed crystal-rich dacite hosting fragments of mica-rich granite (Figure 4.1).

This sample represents the southern-most occurrence of the Wandsworth Group volcanics (Vickery et al., 2010) and was taken from the base of the local sequence. The sample is intruded and metamorphosed by the Attunga Creek Monzogranite of the Moonbi Supersuite (~249 Ma, Rb–Sr, Shaw et al., 1994).

The Rb–Sr age of ~249 Ma on the intrusive Attunga Creek Monzogranite (Shaw et al., 1994) aligns with previous Rb–Sr ages on other Moonbi Supersuite granites (250–243 Ma, Shaw et al., 1994), the same units that yield U–Pb SHRIMP ages between ~254 and ~248 Ma. These previously SHRIMP dated Moonbi Supersuite units include the:

- Inlet Monzonite (252.6 ± 1.9 Ma, Black, 2007; 251.3 ± 2.6 Ma, Jeon, 2012)
- Walcha Road Monzogranite (253.8 ± 1.8 Ma, Black, 2006; 251.8 ± 3.0 Ma, Jeon, 2012)
- Red Range Leucoadamellite (253.2 ± 1.5 Ma, Cross and Blevin, 2013)
- Oban River Leucoadamellite (252.1 ± 1.4 Ma, Cross and Blevin, 2013)
- Bendemeer Monzogranite (247.5 ± 1.6 Ma, Jeon, 2012).

A SHRIMP U–Pb age for the WVG 'Attunga Creek volcanics' will determine its relationship to: (1) previously dated WVG units (about 254–252 Ma, Cross and Blevin, 2010; 2013); and (2) previously undated WVG units ('Kurrajong volcanics' and 'Uralla volcanics; this volume). These dates will constrain the timing of commencement of WVG magmatism and the age of the intrusive Attunga Creek Monzogranite.

Figure 4.1 Representative photographs of the Wandsworth Volcanic Group 'Attunga Creek volcanics' (GSNSW: BB-10-WVG-07, GA: 2120076) showing outcrop (left) and hand sample (right).

4.2 Petrography

The sample is a medium-grained, moderately crystal-rich dacite with a strongly recrystallised groundmass (Figure 4.2). The phenocrysts are unaffected and consist of equant to tabular euhedral to subhedral plagioclase (~15 modal %) and tabular laths of mid- to dark-brown biotite rarely altered to chlorite (7–8%). There are no obvious quartz phenocrysts, however, minor small patches of recrystallised quartz may have originally been small phenocrysts. The dacite includes a 3 mm equigranular fine-grained enclave composed of the same mineralogy as the phenocryst phases. Trace minerals include black opaques, allanite, apatite and zircon. Some of the more tabular phenocrysts of plagioclase and biotite are crudely flow aligned. The groundmass/matrix is a massive, recrystallised aggregate of quartz, feldspar and minor, very fine, biotite in which any primary volcanic textures have been obliterated. At one end of the thin section the moderately crystal-rich dacite described above is in diffuse and irregular contact with finer grained and much less crystal-rich material of similar composition. Most of this finer grained zone contains more abundant fine groundmass biotite, as well as elongate rounded patches that are biotite-poor but rich in very fine black opaques. These patches do not look well enough defined to be lithic clasts unless they are very similar in composition to the rest of the rock e.g. possible pumiceous clasts. The origin of the rock is unclear; it could be either an ignimbrite with very low crystal fragmentation or a coherent dacitic lava.

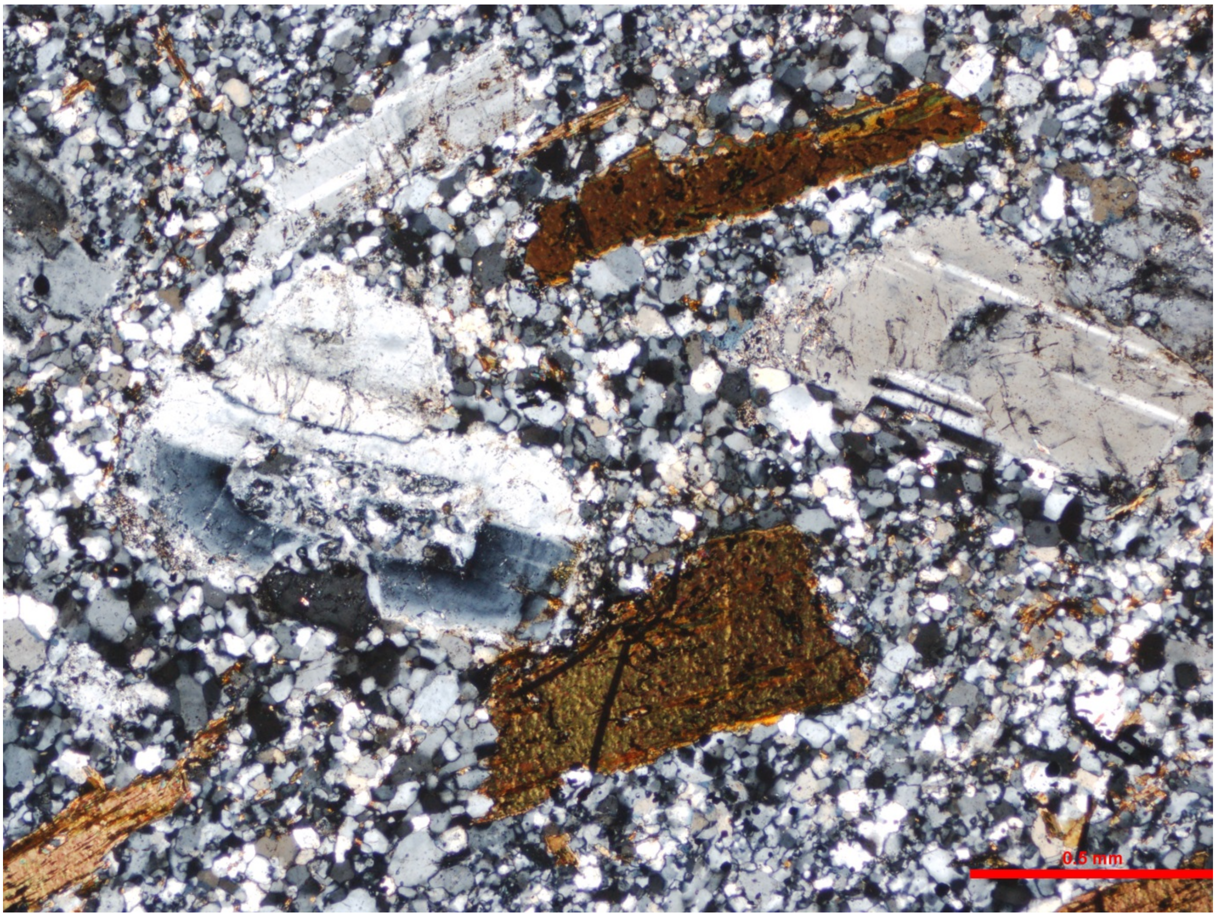


Figure 4.2 Representative photomicrograph of the Wandsworth Volcanic Group 'Attunga Creek volcanics' (GSNSW: BB-10-WVG-07, GA: 2120076) in cross-polarised light. Plagioclase- and biotite-phyric, medium-grained dacite of uncertain origin, which has undergone significant groundmass recrystallisation. Scale bar is 0.5 mm. Image supplied by Geological Survey of NSW.

4.3 Zircon Description

Zircons range from euhedral prismatic grains with well-formed facets and terminations, to round and anhedral grains and fragments (Figure 4.3). Elongate grains are present in the sample. Long axes are 100–400 µm. Grain length to width is variable between 1:1 and 5:1.

In transmitted light (TL) the zircons are predominantly transparent, and colourless to pale amber in colour; translucent grains form approximately 35% of the population. Many grains have variable degrees of non-selective orange staining. Inclusions are present as anhedral and axially-oriented rods and occasional blebs. Core related radial fractures and grain-indiscriminate axial fractures are present (Figure 4.3).

Cathodoluminescence (CL) imaging reveals strong concentric zoning in most grains; in the translucent grains seen in TL, oscillatory zones surround complex central regions with recrystallisation textures and convolute zoning, or as minor concentric rims around central regions with wide and diffuse low contrast zones (Figure 4.3). Transparent prismatic grains show a consistent band of fine-scale oscillatory zoning of low intensity CL emission, around a variety of core structures.

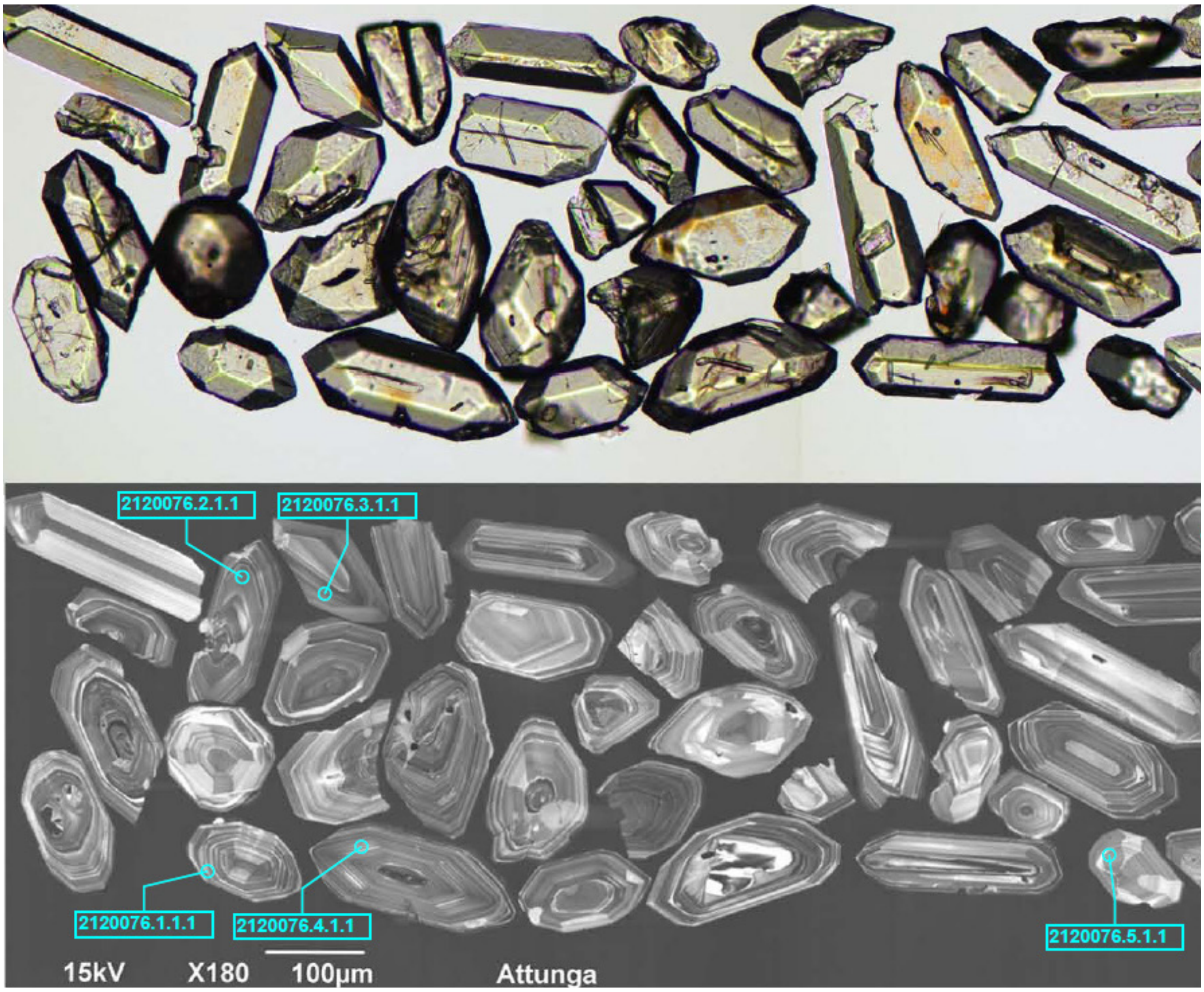


Figure 4.3 Representative zircons from the Wandsworth Volcanic Group 'Attunga Creek volcanics' (GSNSW: BB-10-WVG-07, GA: 2120076). Transmitted light image is shown in the upper half; Cathodoluminescence image is shown in the lower half. SHRIMP analysis sites are indicated, and labelled with sample, grain, spot and replicate number.

4.4 U–Pb Isotopic Results

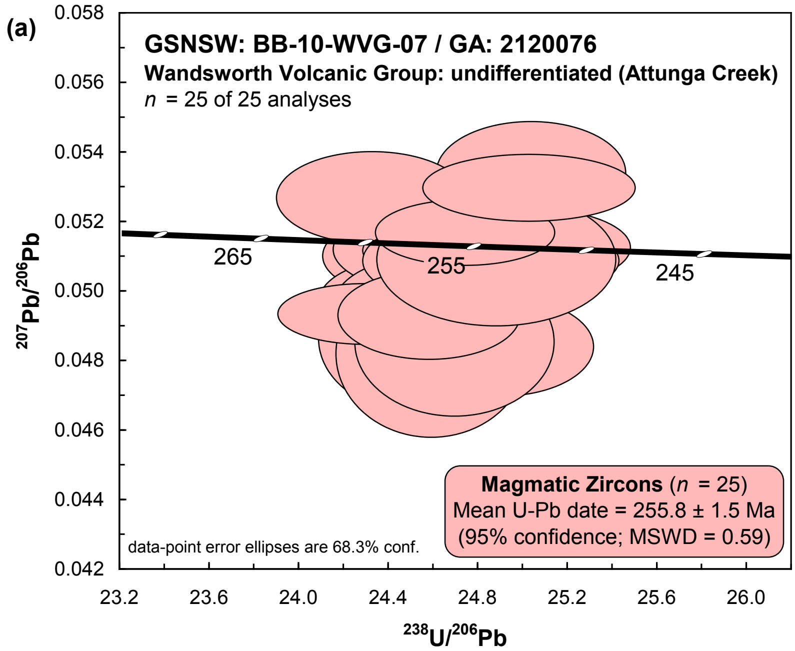
Twenty-five analyses were obtained from 25 individual zircon grains. The results are presented in Table 4.2 and illustrated in Figure 4.4. The analysed zircons are characterised by variable U concentrations (279–1059 ppm, median 559 ppm) with similarly scattered Th/U (0.38–1.00, median 0.61).

The 25 analysed zircons (Figure 4.4, pink fill; Table 4.2, Group 1) have $^{206}Pb_c$ less than 0.38% (median 0.16%) with individual $^{206}Pb/^{238}U$ ages between ~253 Ma and ~260 Ma, which combine to produce a weighted mean $^{206}Pb/^{238}U$ age of 255.8 ± 1.5 Ma (95% confidence, MSWD = 0.59, probability = 0.94).

4.5 Geochronological Interpretation

The weighted mean $^{206}Pb/^{238}U$ age of 255.8 ± 1.5 Ma for the 25 analysed zircons is interpreted to be the magmatic crystallisation age of the Wandsworth Volcanic Group 'Attunga Creek volcanics'.

This new SHRIMP age, along with other new ages from this volume, and pertinent geological relationships are considered in the discussion.



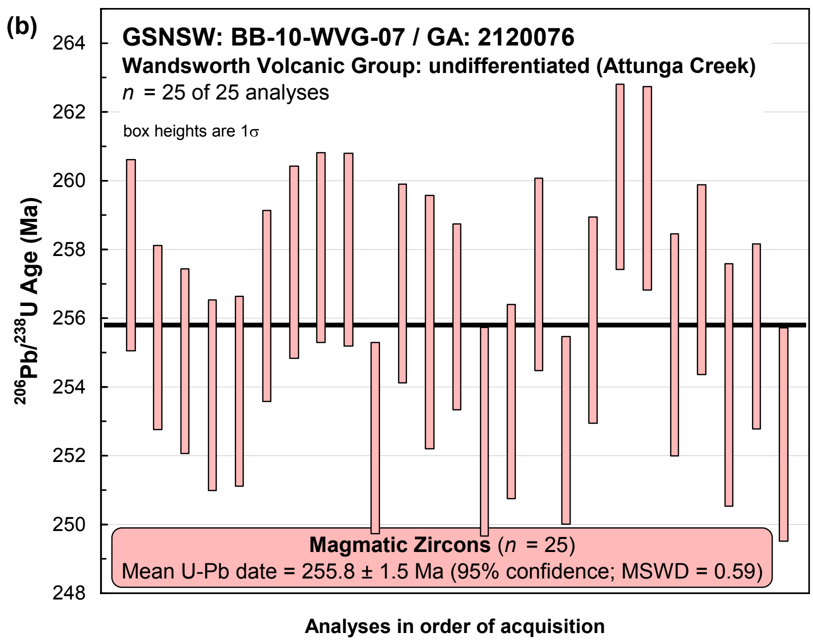


Figure 4.4 SHRIMP U–Pb data for zircons from the Wandsworth Volcanic Group 'Attunga Creek volcanics' (GSNSW: BB-10-WVG-07, GA: 2120076). Pink fill denotes Group 1 (magmatic crystallisation). (a) Tera-Wasserburg concordia diagram; (b) $^{206}Pb/^{238}U$ ages in order of acquisition. Heavy black line denotes the weighted mean $^{206}Pb/^{238}U$ age of the magmatic population.

Table 4.2 SHRIMP U–Pb isotopic data for zircons from the Wandsworth Volcanics at Attunga Creek: 'Attunga Creek volcanics' (GSNSW: BB-10-WVG-07, GA: 2120076). All ages are $^{206}Pb/^{238}U$.

Session No.	Sample. Grain. Spot. Replicate	$^{206}Pb_c$ (%)	U (ppm)	Th (ppm)	$^{232}Th/^{238}U$	$^{238}U/^{206}Pb$	±1σ (%)	$^{207}Pb/^{206}Pb$	±1σ (%)	Age (Ma)	±1σ (Ma)
Group 1: Magmatic zircons (n = 25)											
110005	2120076.19.1.1	0.16	1059	534	0.52	24.287	1.1	0.04937	1.2	260.1	2.7
110005	2120076.20.1.1	-0.04	338	123	0.38	24.318	1.2	0.05271	1.7	259.8	3.0
110005	2120076.8.1.1	0.28	656	403	0.63	24.484	1.1	0.04971	1.7	258.1	2.8
110005	2120076.9.1.1	0.31	523	279	0.55	24.490	1.1	0.04869	2.8	258.0	2.8
110005	2120076.1.1.1	0.18	576	359	0.64	24.505	1.1	0.05104	1.5	257.8	2.8
110005	2120076.7.1.1	0.24	528	405	0.79	24.526	1.1	0.04970	1.8	257.6	2.8
110005	2120076.16.1.1	0.30	528	265	0.52	24.560	1.1	0.04960	1.9	257.3	2.8
110005	2120076.22.1.1	0.27	640	448	0.72	24.575	1.1	0.04934	1.7	257.1	2.8
110005	2120076.11.1.1	0.35	379	172	0.47	24.586	1.1	0.04823	3.3	257.0	2.9
110005	2120076.6.1.1	0.08	559	328	0.61	24.650	1.1	0.05156	1.4	256.4	2.8
110005	2120076.13.1.1	0.06	769	626	0.84	24.680	1.1	0.05119	1.1	256.0	2.7
110005	2120076.18.1.1	0.38	279	138	0.51	24.689	1.2	0.04858	2.9	256.0	3.0
110005	2120076.12.1.1	0.19	487	310	0.66	24.696	1.5	0.05123	1.7	255.9	3.7
110005	2120076.24.1.1	-0.13	868	524	0.62	24.737	1.1	0.05172	1.2	255.5	2.7
110005	2120076.2.1.1	0.22	917	885	1.00	24.741	1.1	0.04988	1.9	255.4	2.7
110005	2120076.21.1.1	0.16	496	317	0.66	24.761	1.3	0.05089	1.6	255.2	3.2
110005	2120076.3.1.1	0.11	781	378	0.50	24.809	1.1	0.05099	1.2	254.7	2.7
110005	2120076.23.1.1	0.12	578	267	0.48	24.877	1.4	0.05094	2.5	254.1	3.5
110005	2120076.5.1.1	0.30	537	348	0.67	24.895	1.1	0.04843	1.9	253.9	2.8
110005	2120076.4.1.1	0.14	495	308	0.64	24.906	1.1	0.05107	1.6	253.8	2.8
110005	2120076.15.1.1	0.19	408	200	0.51	24.925	1.1	0.05102	1.9	253.6	2.8
110005	2120076.17.1.1	0.10	729	383	0.54	25.010	1.1	0.05090	1.3	252.7	2.7
110005	2120076.14.1.1	0.12	599	316	0.55	25.013	1.2	0.05128	1.5	252.7	3.0
110005	2120076.25.1.1	-0.04	668	492	0.76	25.022	1.3	0.05300	1.2	252.6	3.1
110005	2120076.10.1.1	-0.24	467	204	0.45	25.032	1.1	0.05343	1.8	252.5	2.8

5 Wandsworth Volcanic Group: 'Kurrajong Park volcanics'

Table 5.1 Summary of results: Wandsworth Volcanic Group 'Kurrajong Park volcanics', at Honeysuckle Hills (GSNSW: BB-10-WVG-08, GA: 2120077).

GA SampleNo	2120077
GSNSW SiteID	BB-10-WVG-08
Stratigraphic Unit	Wandsworth Volcanic Group (Undifferentiated)
Parent Unit	Wandsworth Volcanic Group
Informal Identifier	'Kurrajong Park volcanics'
Lithology	Dacitic ignimbrite
Province	New England Orogen
1:250 000 Sheet	MANILLA (SH/56-9)
1:100 000 Sheet	BENDEMEER (9136)
Location (GDA94)	30.511789°S, 151.292309°E
Location (MGA94)	Zone 56; 336136 mE, 6623259 mN
Analytical Session No	110005 (see Appendix Table A.1 for parameters derived from concurrent measurements of $^{206}Pb/^{238}U$ and $^{207}Pb/^{206}Pb$ reference zircons)
Interpreted Age	256.3 ± 1.5 Ma (n = 25)
Geological Attribution	Magmatic crystallisation
Isotopic Ratio used	$^{206}Pb/^{238}U$ (^{204}Pb-corrected)

5.1 Sampling Details and Geological Relationships

A sample of the Wandsworth Volcanic Group 'Kurrajong Park volcanics' was taken from private property at the base of Honeysuckle Hills, ~13 km by road west from Yarrowyck. Access to the site is via the private property track to the base of Honeysuckle Hills.

The sample is a dacitic ignimbrite with angular crystals in a fine-grained groundmass (Figure 5.1) hornfelsed by proximal intrusion of the Kurrajong Park Leucogranite. In outcrop the unit displays columnar jointing. The sample was taken from the base of the local volcanic sequence.

The Regional Felsic Dyke Swarm (252.5 ± 1.8 Ma, Cross and Blevin, 2010; 255.0 ± 1.5 Ma, this volume) intrudes igneous and metasedimentary rocks throughout the region.

A SHRIMP U–Pb age for the WVG 'Kurrajong Park volcanics' will determine its relationship with (1) previously dated WVG units (about 254–252 Ma, Cross and Blevin, 2010; 2013); and (2) previously undated WVG units ('Uralla volcanics' and 'Attunga Creek volcanics; this volume). These data will help constrain the timing of commencement of WVG magmatism, the age of the Kurrajong Park Leucogranite, and the locally emplaced RFDS units.

Figure 5.1 Representative photographs of the Wandsworth Volcanic Group 'Kurrajong Park volcanics', at Honeysuckle Hills (GSNSW: BB-10-WVG-08, GA: 2120077) showing outcrop (left) and hand sample (right).

5.2 Petrography

The sample is a medium-grained, moderately crystal-rich, welded dacitic ignimbrite (Figure 5.2). It contains ~15 modal % feldspar, most of which seems to be albitised plagioclase, 7–8% embayed quartz to 5 mm and a few % ferromagnesian and/or biotite laths that have been replaced by aggregates of very fine decussate metamorphic biotite. In some instances, small laths of original biotite are rimmed by very fine-grained biotite but the larger grains could be either biotite or amphibole. Accessory minerals include opaques and zircon crystals to 0.2 mm. The matrix in this sample is finely microcrystalline with rare, very faint swirly textures, probably indicative of dense welding.

Figure 5.2 Representative photomicrograph of the Wandsworth Volcanic Group 'Kurrajong Park volcanics', at Honeysuckle Hills (GSNSW: BB-10-WVG-08, GA: 2120077) in cross-polarised light. Dacitic ignimbrite with phenocrysts of albitised plagioclase, quartz and ferromagnesian minerals/biotite replaced by fine decussate biotite and a finely microcrystalline quartzo-feldspathic matrix. Scale bar is 0.5 mm. Image supplied by Geological Survey of NSW.

5.3 Zircon Description

Zircons are predominantly euhedral prismatic grains with well-formed facets; elongate grains and grain fragments are present in the sample (Figure 5.3). Long axes of grains are variable in size 80–350 µm with length to width aspect ratios variable between 1:1 and 4:1.

In transmitted light the zircons are predominantly transparent and champagne to pale amber in colour with subordinate translucent grains (Figure 5.3). Clarity is variable between poor and reasonable with few cracks present but abundant clear anhedral, axially-oriented rod and core-specific inclusions and minor marginal bleb-like inclusions. Rare euhedral inclusions are noted in the sample as well as epimorphic zircon-zircon grains.

Cathodoluminescence (CL) imaging reveals strong oscillatory zoning with a wide range of textures. Central regions of some grains are complex with convolute and diffuse zoning and occasional resorption textures; CL emission varies from high to low emission intensity and is non-specific to external grain morphology (Figure 5.3). Rims predominantly exhibit concentric oscillatory zoning with moderate CL emission; rare grains have rims with uniform low CL emission.

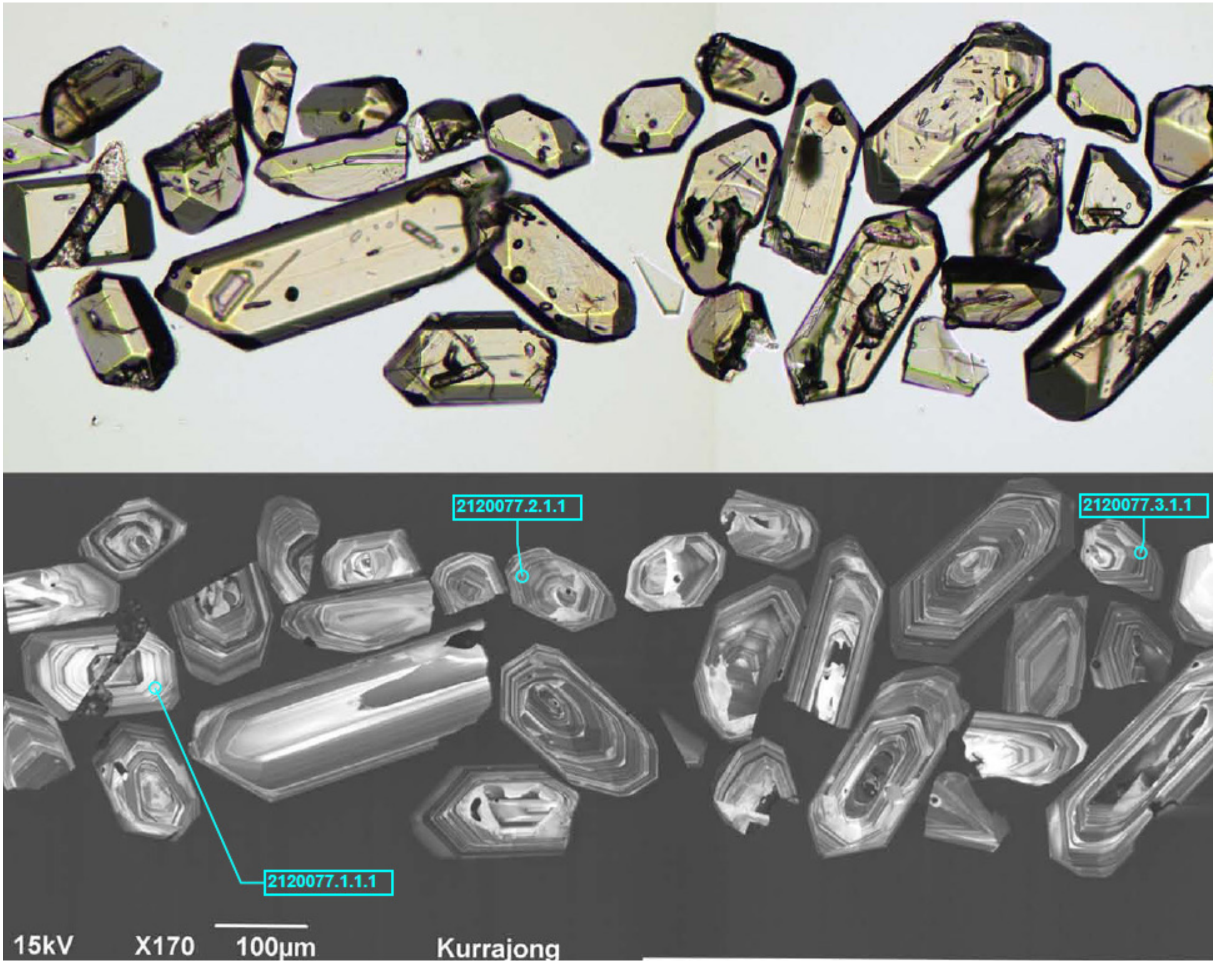


Figure 5.3 Representative zircons from the Wandsworth Volcanic Group 'Kurrajong Park volcanics', at Honeysuckle Hills (GSNSW: BB-10-WVG-08, GA: 2120077). Transmitted light image is shown in the upper half; Cathodoluminescence image is shown in the lower half. SHRIMP analysis sites are indicated, and labelled with sample, grain, spot and replicate number.

5.4 U–Pb Isotopic Results

Twenty-five analyses were obtained from 25 individual zircon grains; the results are presented in Table 5.2 and illustrated in Figure 5.4. The analysed zircons are characterised by low to moderate U concentrations (165–676 ppm, median 340 ppm) and moderate Th/U (0.33–0.96, median 0.49).

The 25 analyses (Figure 5.4, pink fill; Table 5.2, Group 1) have $^{206}Pb_c$ less than 1.06% (median 0.31%) and have individual $^{206}Pb/^{238}U$ ages between ~246 Ma and ~263 Ma, which combine to produce a weighted mean $^{206}Pb/^{238}U$ age of 256.3 ± 1.5 Ma (95% confidence, MSWD = 1.39, probability = 0.10).

5.5 Geochronological Interpretation

The weighted mean $^{206}Pb/^{238}U$ age of 256.3 ± 1.5 Ma is interpreted as the magmatic crystallisation age of the Wandsworth Volcanic Group 'Kurrajong Park volcanics' at Honeysuckle Hills.

This new SHRIMP age, along with other new ages from this volume, and pertinent geological relationships are considered in the discussion.

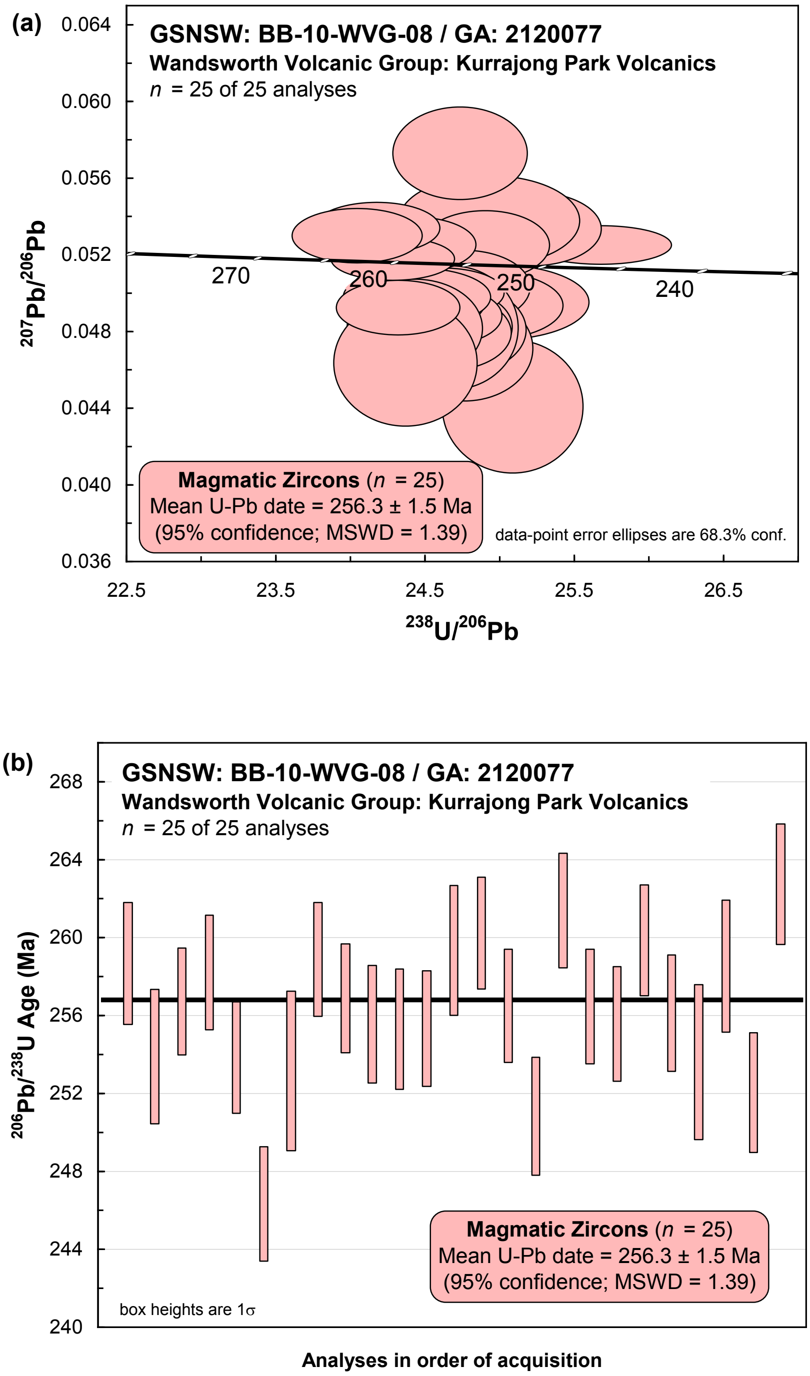


Figure 5.4 SHRIMP U–Pb data for zircons from the Wandsworth Volcanic Group 'Kurrajong Park Volcanics', at Honeysuckle Hills (GSNSW: BB-10-WVG-08, GA: 2120077). Pink fill denotes Group 1 (magmatic crystallisation). (a) Tera-Wasserburg concordia diagram; (b) $^{206}Pb/^{238}U$ ages in order of acquisition. Heavy black line denotes the weighted mean $^{206}Pb/^{238}U$ age of the magmatic population.

Table 5.2 SHRIMP U–Pb isotopic data for zircons from the Wandsworth Volcanic Group 'Kurrajong Park volcanics', at Honeysuckle Hills (GSNSW: BB-10-WVG-08, GA: 2120077). All ages are $^{206}Pb/^{238}U$.

Session No.	Sample. Grain. Spot. Replicate	$^{206}Pb_c$ (%)	U (ppm)	Th (ppm)	$^{232}Th/^{238}U$	$^{238}U/^{206}Pb$	±1σ (%)	$^{207}Pb/^{206}Pb$	±1σ (%)	Age (Ma)	±1σ (Ma)
Group 1: Magmatic zircons (n = 25)											
110005	2120077.25.1.1	0.00	284	122	0.444	24.038	1.2	0.05282	1.8	262.7	3.1
110005	2120077.17.1.1	-0.07	341	176	0.534	24.166	1.2	0.05324	1.6	261.4	2.9
110005	2120077.14.1.1	0.03	450	233	0.535	24.276	1.1	0.05162	1.4	260.2	2.9
110005	2120077.20.1.1	0.23	467	200	0.441	24.311	1.1	0.04909	1.9	259.9	2.9
110005	2120077.13.1.1	0.64	165	65	0.406	24.360	1.3	0.04620	4.7	259.3	3.3
110005	2120077.8.1.1	0.11	350	152	0.448	24.406	1.2	0.05237	1.8	258.9	2.9
110005	2120077.1.1.1	0.51	224	96	0.444	24.424	1.2	0.04799	3.5	258.7	3.1
110005	2120077.23.1.1	0.20	414	220	0.550	24.438	1.3	0.04964	2.0	258.5	3.4
110005	2120077.4.1.1	0.26	349	167	0.495	24.469	1.2	0.04944	2.2	258.2	2.9
110005	2120077.9.1.1	0.39	536	333	0.641	24.598	1.1	0.04865	2.1	256.9	2.8
110005	2120077.3.1.1	0.31	676	629	0.962	24.615	1.1	0.04985	1.7	256.7	2.7
110005	2120077.15.1.1	0.45	340	171	0.521	24.637	1.2	0.04777	2.7	256.5	2.9
110005	2120077.18.1.1	0.44	338	158	0.484	24.638	1.2	0.04807	2.8	256.5	2.9
110005	2120077.21.1.1	0.54	301	158	0.541	24.673	1.2	0.04804	4.4	256.1	3.0
110005	2120077.10.1.1	-0.51	267	112	0.434	24.728	1.2	0.05713	2.8	255.6	3.0
110005	2120077.19.1.1	0.58	330	198	0.619	24.729	1.2	0.04792	3.2	255.6	2.9
110005	2120077.12.1.1	0.28	297	184	0.638	24.751	1.2	0.05013	2.5	255.3	3.0
110005	2120077.11.1.1	0.58	227	115	0.525	24.755	1.2	0.04696	3.9	255.3	3.1
110005	2120077.2.1.1	0.33	381	170	0.461	24.895	1.4	0.04918	2.4	253.9	3.4
110005	2120077.5.1.1	0.32	383	178	0.480	24.899	1.1	0.05234	2.3	253.8	2.9
110005	2120077.22.1.1	-0.20	506	279	0.570	24.924	1.6	0.05361	2.9	253.6	4.0
110005	2120077.7.1.1	0.36	316	119	0.390	24.968	1.6	0.04936	2.6	253.1	4.1
110005	2120077.24.1.1	1.06	229	111	0.500	25.080	1.2	0.04393	5.2	252.0	3.1
110005	2120077.16.1.1	0.13	225	72	0.330	25.203	1.2	0.05319	2.4	250.8	3.0
110005	2120077.6.1.1	0.02	665	302	0.468	25.673	1.2	0.05235	1.2	246.3	2.9

6 Balala Granodiorite

Table 6.1 Summary of results: Balala Granodiorite (GSNSW: PB-10-BL-01, GA: 2121504).

GA SampleNo	2121504
GSNSW SiteID	PB-10-BL-01
Stratigraphic Unit	Balala Granodiorite
Parent Unit	Balala Suite, Uralla Supersuite
Informal Identifier	–
Lithology	Granodiorite
Province	New England Orogen
1:250 000 Sheet	MANILLA (SH/56-9)
1:100 000 Sheet	BENDEMEER (9136)
Location (GDA94)	30.618757°S, 151.350591°E
Location (MGA94)	Zone 56; 341800 mE, 6611300 mN
Analytical Session No	110005 (see Appendix Table A.1 for parameters derived from concurrent measurements of $^{206}Pb/^{238}U$ and $^{207}Pb/^{206}Pb$ reference zircons)
Interpreted Age	295.0 ± 1.7 Ma (n = 25 of 26 analyses)
Geological Attribution	Magmatic crystallisation
Isotopic Ratio used	$^{206}Pb/^{238}U$ (^{204}Pb-corrected)

6.1 Sampling Details and Geological Relationships

A sample of the Balala Granodiorite (Flinter et al., 1972) was collected along the Uralla to Kingstown road. The unit sampled is a medium to coarse-grained biotite- and amphibole-bearing granodiorite (Figure 6.1). The sample comprised 1.3 kg of fresh rock-chips remaining from geochemical analysis, originally collected from outcrop.

The Bundarra Batholith forms a prominent re-entrant against the Balala Granodiorite, seemingly presaging the intrusion of the latter as a non-truncated, ovoid body. The Balala Granodiorite is cut by the Yarrowyck Granodiorite (254.9 ± 1.5 Ma, this volume), the Wongalee Leucogranite of the Uralla Supersuite, and the Regional Felsic Dyke Swarm (252.5 ± 1.8 Ma, Cross and Blevin, 2010; 255.0 ± 1.5 Ma, this volume). Mapping control has been provided by honours, MSc and PhD projects. A previously unpublished Rb–Sr biotite age of 275 Ma, reported by Shaw and Flood (1993), is substantially older than ~250 Ma ages reported by the authors for other I-type granites in the New England Batholith, but younger than ages quoted for the Bundarra Supersuite.

A SHRIMP U–Pb age for the Balala Granodiorite will determine its relationship to: (1) the geochemically indistinguishable Uralla Supersuite (about 255–251 Ma, Cross and Blevin, 2013; this volume); (2) the spatially related Bundarra Supersuite granites (Banalasta Monzogranite:

286.2 ± 2.2 Ma, Black, 2007; and Pringles Monzogranite: ~289 Ma, Cross and Blevin, 2013) to establish intrusive relationships; and (3) with Glenburnie Leucoadamellite (295.2 ± 2.3 Ma, Black, 2007) to establish the extent of "older" I-type magmatism in the southern New England Orogen.

Figure 6.1 Representative photographs of the Balala Granodiorite (GSNSW: PB-10-BL-01, GA: 2121504) showing outcrop (left) and close-up of texture (right). Pencil for scale is 15 cm. Image supplied by Geological Survey of NSW.

6.2 Petrography

The sample represents a massive, very fresh, inequigranular biotite and hornblende-bearing granodiorite that is characterised by scattered large plagioclase crystals (to 6 mm), many of which have spectacular fine concentric zoning (Figure 6.2). Plagioclase (~40 modal % of the rock) occurs as subhedral to almost euhedral crystals and is andesine in composition (An36 to An48). The remainder of the rock is slightly finer grained (< 3 mm) with an estimated modal content of 25% quartz, 20% perthitic alkali feldspar, 10% brown biotite and 5% pale- to mid-green hornblende. The late crystallised phases, quartz and alkali feldspar are coarsely intergrown and with minor development of micrographic texture. Some of the quartz and alkali feldspar is micropoikilitic, containing small inclusions of mainly fine-grained (0.1 mm) biotite. Straw- to chocolate-brown coloured biotite occurs evenly throughout the sample as stumpy laths 0.5–1 mm in length and also as very abundant 0.1–0.2 mm grains. There is minor chlorite replacement of biotite. Hornblende occurs as bladed crystals and in aggregates with plagioclase and some biotite. A single 1 mm fresh allanite with narrow metamict rim was observed as well as smaller completely metamict grains. The granodiorite also contains accessory opaques, rare bladed apatite and zircon.

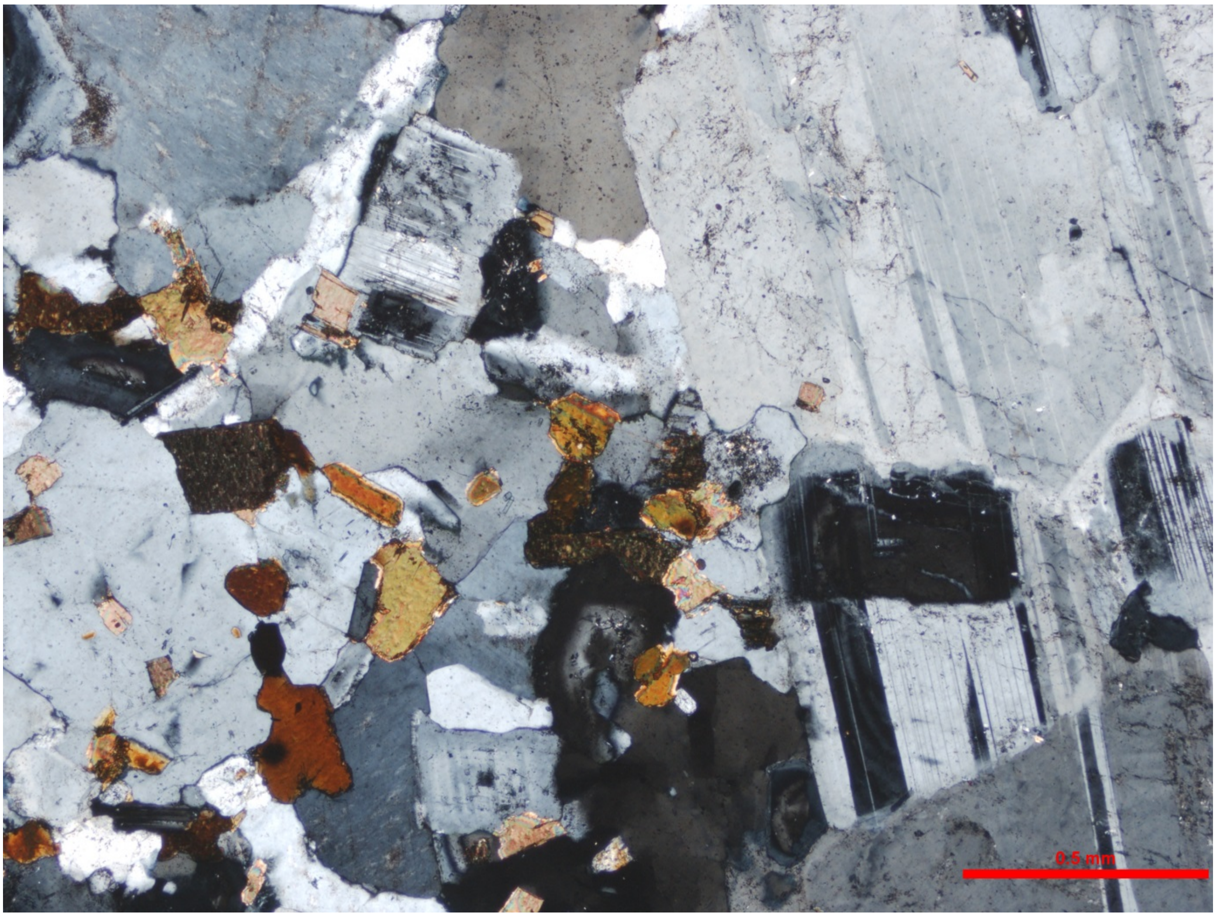


Figure 6.2 Representative photomicrograph of the Balala Granodiorite (GSNSW: PB-10-BL-01, GA: 2121504) in cross-polarised light. Massive, virtually unaltered, inequigranular granodiorite. In this view, a large plagioclase crystal occurs on the right side of the photo. The other minerals are weakly strained quartz (e.g. left margin), perthitic alkali feldspar (top left) and small stumpy biotite grains. Scale bar is 0.5 mm. Image supplied by Geological Survey of NSW.

6.3 Zircon Description

Zircons are strongly euhedral stubby to prismatic grains with well-formed facets (Figure 6.3). Few elongate grains are present in the sample. Long axes are 80–250 µm. Grain length to width is variable from 1.5:1 up to 4:1.

In transmitted light the zircons are predominantly transparent and champagne in colour; inclusions are common as rods and clear blebs, with cavities present in some grains. Translucent grains are pale amber in colour with poor clarity resulting from cracks and ubiquitous inclusions (Figure 6.3).

Cathodoluminescence (CL) images show well-developed concentric oscillatory zoning with moderate CL emission intensity and fine to moderate banding. Cores are variable across the sample with central banding, recrystallisation and local convolute zoning textures present in some grain cores (Figure 6.3).

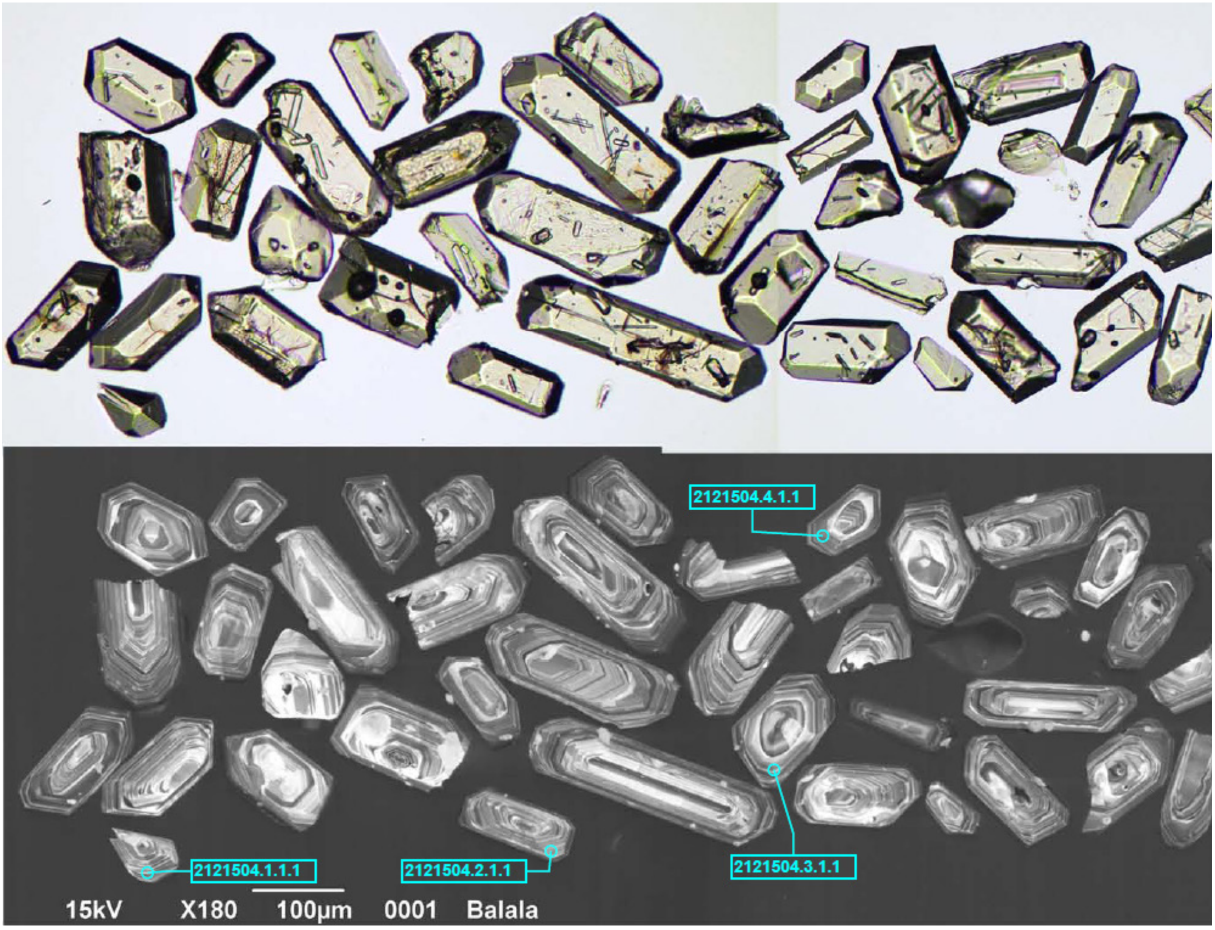


Figure 6.3 Representative zircons from the Balala Granodiorite (GSNSW: PB-10-BL-01, GA: 2121504). Transmitted light image is shown in the upper half; Cathodoluminescence image is shown in the lower half. SHRIMP analysis sites are indicated, and labelled with sample, grain, spot and replicate number.

6.4 U–Pb Isotopic Results

Twenty-six analyses were obtained from 26 individual zircon grains. The results are presented in Table 6.2 and illustrated in Figure 6.4. The analysed zircons are characterised by variable U concentrations (256–1073 ppm, median 412 ppm) with moderate Th/U (0.28–0.61, median 0.35).

Analysis 2121504.20.1.1 (Figure 6.4, white fill) is not considered further due to isotopic mixing resulting from analytical spot overlap onto an inherited core, resulting in an unreliable $^{206}Pb/^{238}U$ age.

The remaining 25 analyses (Figure 6.4, pink fill; Table 6.2, Group 1) have $^{206}Pb_c$ less than 0.66% (median 0.18%) with individual $^{206}Pb/^{238}U$ ages between ~289 Ma and ~301 Ma. These analyses combine to produce a weighted mean $^{206}Pb/^{238}U$ age of 295.0 ± 1.7 Ma (95% confidence, MSWD = 1.28, probability = 0.16).

6.5 Geochronological Interpretation

The weighted mean $^{206}Pb/^{238}U$ age of 295.0 ± 1.7 Ma is interpreted as the magmatic crystallisation age of the Balala Granodiorite.

This new SHRIMP age, along with other new ages from this volume, and pertinent geological relationships are considered in the discussion.

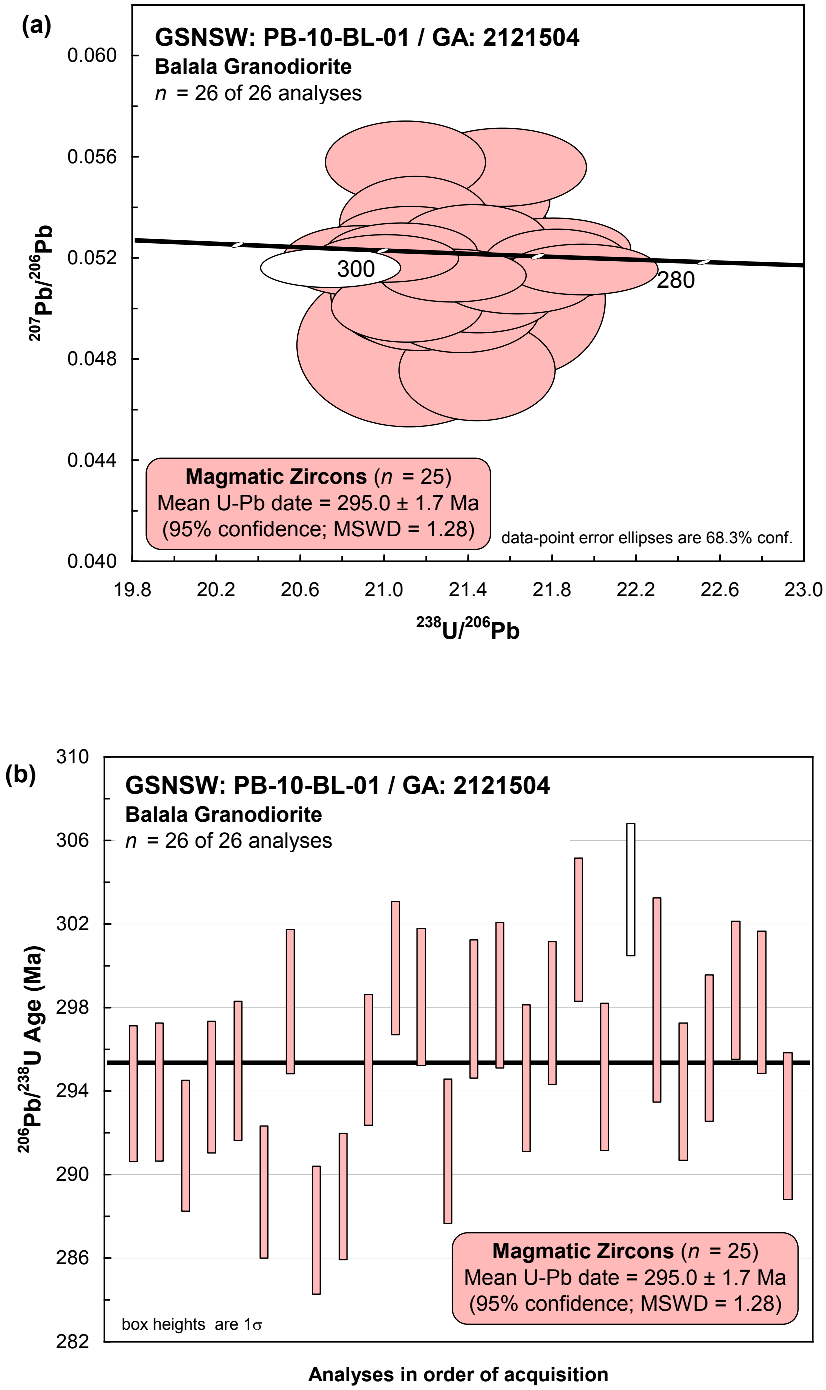


Figure 6.4 SHRIMP U–Pb data for zircons from the Balala Granodiorite (GSNSW: PB-10-BL-01, GA: 2121504). Pink fill denotes Group 1 (magmatic crystallisation), and white fill denotes unreliable analysis affected by isotopic mixing. (a) Tera-Wasserburg concordia diagram; (b) $^{206}Pb/^{238}U$ ages in order of acquisition. Heavy black line denotes the weighted mean $^{206}Pb/^{238}U$ age of the magmatic population.

Table 6.2 SHRIMP U–Pb isotopic data for zircons from the Balala Granodiorite (GSNSW: PB-10-BL-01, GA: 2121504). All ages are $^{206}Pb/^{238}U$.

Session No.	Sample. Grain. Spot. Replicate	$^{206}Pb_c$ (%)	U (ppm)	Th (ppm)	$^{232}Th/^{238}U$	$^{238}U/^{206}Pb$	±1σ (%)	$^{207}Pb/^{206}Pb$	±1σ (%)	Age (Ma)	±1σ (Ma)
Group 1: Magmatic zircons (n = 25)											
110005	2121504.18.1.1	0.10	367	105	0.296	20.848	1.2	0.05276	1.5	301.7	3.4
110005	2121504.11.1.1	0.10	709	203	0.296	20.980	1.1	0.05282	1.0	299.9	3.2
110005	2121504.24.1.1	0.08	485	284	0.606	21.059	1.1	0.05291	1.3	298.8	3.3
110005	2121504.15.1.1	-0.13	316	131	0.428	21.121	1.2	0.05477	1.6	298.6	3.5
110005	2121504.12.1.1	0.28	474	203	0.443	21.042	1.1	0.05236	1.3	298.5	3.3
110005	2121504.21.1.1	0.48	274	92	0.347	21.009	1.7	0.05243	3.4	298.4	4.9
110005	2121504.7.1.1	0.46	313	107	0.352	21.019	1.2	0.05429	1.5	298.3	3.5
110005	2121504.25.1.1	0.07	364	124	0.351	21.103	1.2	0.05331	1.5	298.2	3.4
110005	2121504.14.1.1	-0.05	483	164	0.350	21.153	1.1	0.05295	2.3	297.9	3.3
110005	2121504.17.1.1	0.36	356	132	0.384	21.080	1.2	0.05318	1.5	297.7	3.4
110005	2121504.23.1.1	0.14	291	107	0.379	21.249	1.2	0.05358	1.7	296.1	3.5
110005	2121504.10.1.1	0.18	750	222	0.305	21.281	1.1	0.05281	1.0	295.5	3.1
110005	2121504.5.1.1	0.30	372	102	0.283	21.295	1.2	0.05242	1.4	295.0	3.3
110005	2121504.19.1.1	0.25	256	70	0.284	21.327	1.2	0.05515	1.7	294.7	3.5
110005	2121504.16.1.1	-0.15	262	110	0.435	21.417	1.2	0.05312	1.7	294.6	3.5
110005	2121504.4.1.1	-0.02	610	165	0.280	21.420	1.1	0.05261	1.7	294.2	3.2
110005	2121504.22.1.1	0.66	446	145	0.337	21.292	1.1	0.05291	1.3	294.0	3.3
110005	2121504.2.1.1	0.33	384	122	0.329	21.362	1.1	0.05375	1.4	294.0	3.3
110005	2121504.1.1.1	0.26	439	145	0.340	21.384	1.1	0.05260	1.3	293.9	3.2
110005	2121504.26.1.1	0.00	270	107	0.410	21.557	1.2	0.05562	1.8	292.3	3.5
110005	2121504.3.1.1	0.12	586	276	0.486	21.601	1.1	0.05192	1.1	291.4	3.1
110005	2121504.13.1.1	0.57	287	140	0.502	21.524	1.2	0.05500	2.7	291.1	3.4
110005	2121504.6.1.1	0.10	499	214	0.443	21.774	1.1	0.05325	1.3	289.2	3.2
110005	2121504.9.1.1	0.52	1010	445	0.456	21.701	1.1	0.05595	0.9	288.9	3.0
110005	2121504.8.1.1	0.11	754	249	0.342	21.915	1.1	0.05246	1.1	287.3	3.1
Not considered: Isotopic mixing/Inheritance (n = 1)											
110005	2121504.20.1.1	0.10	1073	542	0.522	20.713	1.1	0.05246	0.8	303.6	3.2

7 Khatoun Tonalite

Table 7.1 Summary of results: Khatoun Tonalite (GSNSW: PB-12-URA-01, GA: 2129544).

GA SampleNo	2129544
GSNSW SiteID	PB-12-URA-01
Stratigraphic Unit	Khatoun Tonalite
Parent Unit	Uralla Suite, Uralla Supersuite
Informal Identifier	–
Lithology	Tonalite
Province	New England Orogen
1:250 000 Sheet	MANILLA (SH/56-9)
1:100 000 Sheet	BENDEMEER (9136)
Location (GDA94)	30.6348433°S, 151.419670°E
Location (MGA94)	Zone 56; 348551 mE, 6609801 mN
Analytical Session No	120062 (see Appendix Table A.1 for parameters derived from concurrent measurements of $^{206}Pb/^{238}U$ and $^{207}Pb/^{206}Pb$ reference zircons)
Interpreted Age	253.3 ± 1.4 Ma (n = 34)
Geological Attribution	Magmatic crystallisation
Isotopic Ratio used	$^{206}Pb/^{238}U$ (^{204}Pb-corrected)

7.1 Sampling Details and Geological Relationships

The Khatoun Tonalite (Chesnut et al., 1973) sample site comprises fresh boulders ripped up by telephone line excavation work on a wide easement ~20 metres off the southern side of the Uralla–Kingstown Road, 6.6 km west of Uralla. Elongate, rounded microgranular mafic enclaves to 10 cm in length are scattered throughout outcrop, but comprise < 1% by volume. There are no aplites or other textural/petrographic variations at outcrop scale.

The Khatoun Tonalite of the Uralla Supersuite intrudes the WVG 'Uralla volcanics' and the Devonian–Carboniferous Sandon Beds. It is cut by the Regional Felsic Dyke Swarm (252.5 ± 1.8 Ma, Cross and Blevin, 2010; 255.0 ± 1.5 Ma, this volume) and appears, on the basis of mapped contacts, to also be cut by the Manuka Farm Porphyritic Microtonalite and Uralla Granodiorite of the Uralla Supersuite.

A SHRIMP U–Pb age for the Khatoun Tonalite will (1) confirm field relationships with the RFDS and the WVG 'Uralla volcanics', and (2) establish age relationships with other Uralla Supersuite members: the Yarrowyck Granodiorite (this volume), Gwydir River Adamellite (252.3 ± 1.5 Ma), Tingha Adamellite (251.3 ± 1.7 Ma), Parlour Mountain Granite (254.7 ± 1.6 Ma) (Cross and Blevin, 2010), and the Mount Duval Monzogranite (253.7 ± 1.4 Ma; Cross and Blevin, 2013).

7.2 Petrography

The sample comprises a medium-grained, inequigranular granodiorite/tonalite with a few outsized plagioclase and a few large micropoikilitic alkali feldspar crystals to 5.5 mm in size within an aggregate with an average grainsize of 2 mm (Figure 7.1). Plagioclase (~50 modal % and andesine; An44–46 on cleavage sections) occurs as stumpy, subhedral laths that are polysynthetic twinned—many are compositionally zoned, some with conspicuous albite. The rock also contains 2–3 modal % relict pyroxene (most, if not all, clinopyroxene) but most is rimmed or completely replaced by mid to pale green hornblende and fibrous actinolite (total 8–10 modal % amphibole). Biotite (up to 10 modal %) is bright orange/brown in colour and occurs as stumpy laths to 2 mm and contains small lamellar of black iron oxides (ilmenite) and rare zircons with haloes. Quartz (~15 modal %) forms highly irregular, interstitial grains that are weakly strained and some are micropoikilitic. Alkali feldspar (~15 modal %), occurs as large, very irregular grains to 4 mm that are micropoikilitic with abundant small inclusions of plagioclase and ferromagnesian minerals. Some of the alkali feldspar is quite coarsely perthitic, containing exsolved finely twinned plagioclase lamellae to 1 mm in size. Zircons are abundant and other accessory minerals include apatite and opaques. Based on the estimated modes in this thin section, particularly the alkali feldspar content, this rock is a granodiorite rather than a tonalite.

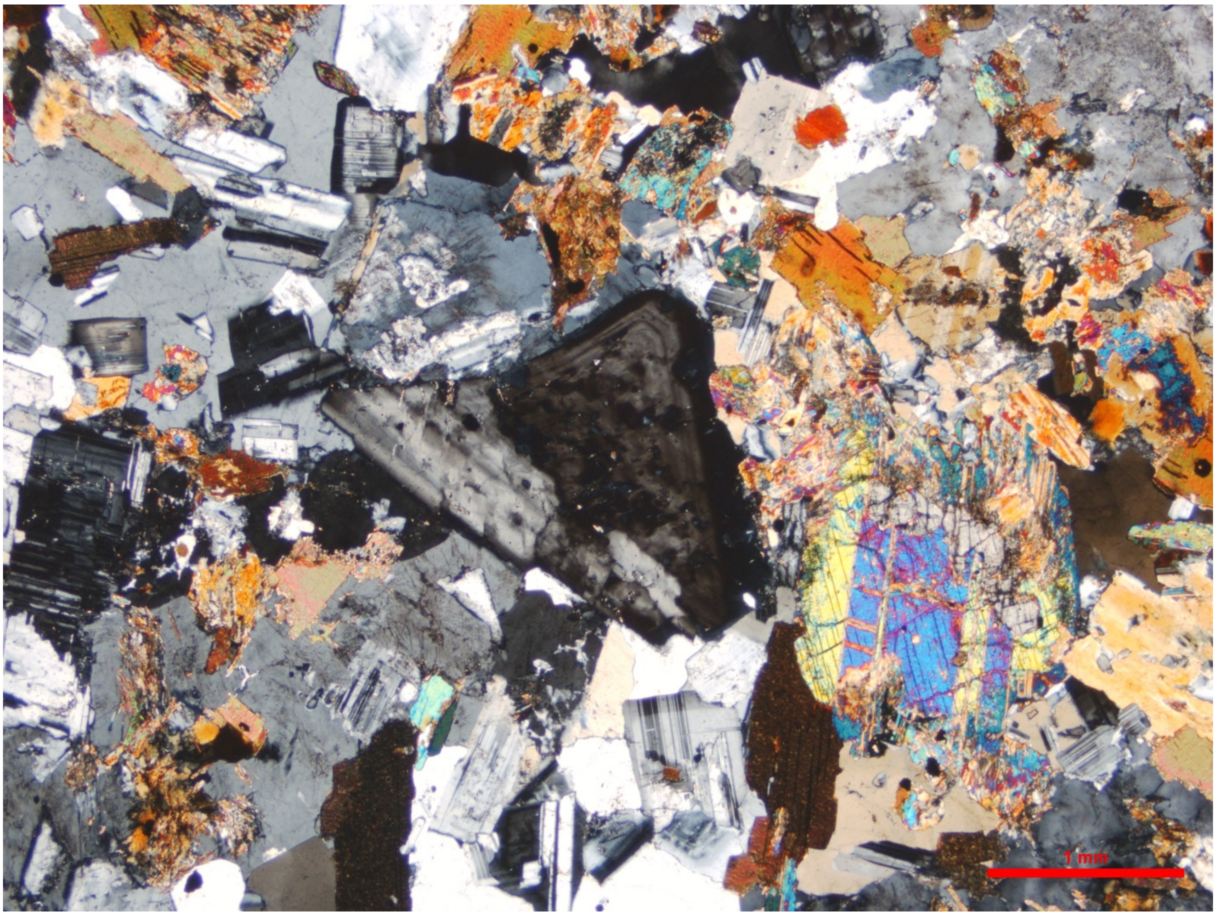


Figure 7.1 Representative photomicrograph of the Khatoun Tonalite (GSNSW: PB-12-URA-01, GA: 2129544) in cross-polarised light. Inequigranular tonalite with relatively well-formed plagioclase crystals (e.g. centre and below), interstitial and micropoikilitic (top left) quartz and alkali feldspar (top right and lower left). Clinopyroxene partly mantled by fibrous amphibole (right of centre) and small hornblende grains on right and upper margins of the photo, along with stumpy biotite laths (mainly orange in this view). Scale bar is 1 mm. Image supplied by Geological Survey of NSW.

7.3 Zircon Description

The zircons consist predominantly of equant to elongate euhedral prismatic grains with well-formed facets. A minor proportion of the sample is fragmented (Figure 7.2). Long axes are 70–400 µm. Grain length to width is variable between 1:1 and 6:1.

In transmitted light the zircons are transparent and colourless. Minor anhedral acicular clear inclusions are present as axially-oriented rods. Cracks in grains are rare and generally present on the long axis of grains (Figure 7.2).

Cathodoluminescence (CL) imaging reveals a high level of consistency in internal structure across the sample; zoning is defined by moderate contrast CL emission and broad diffuse banding relative to grain size and generally parallel to the long axis of the grain and a minority of grains exhibit broad and diffuse oscillatory zoning. Cores are not apparent in the sample (Figure 7.2).

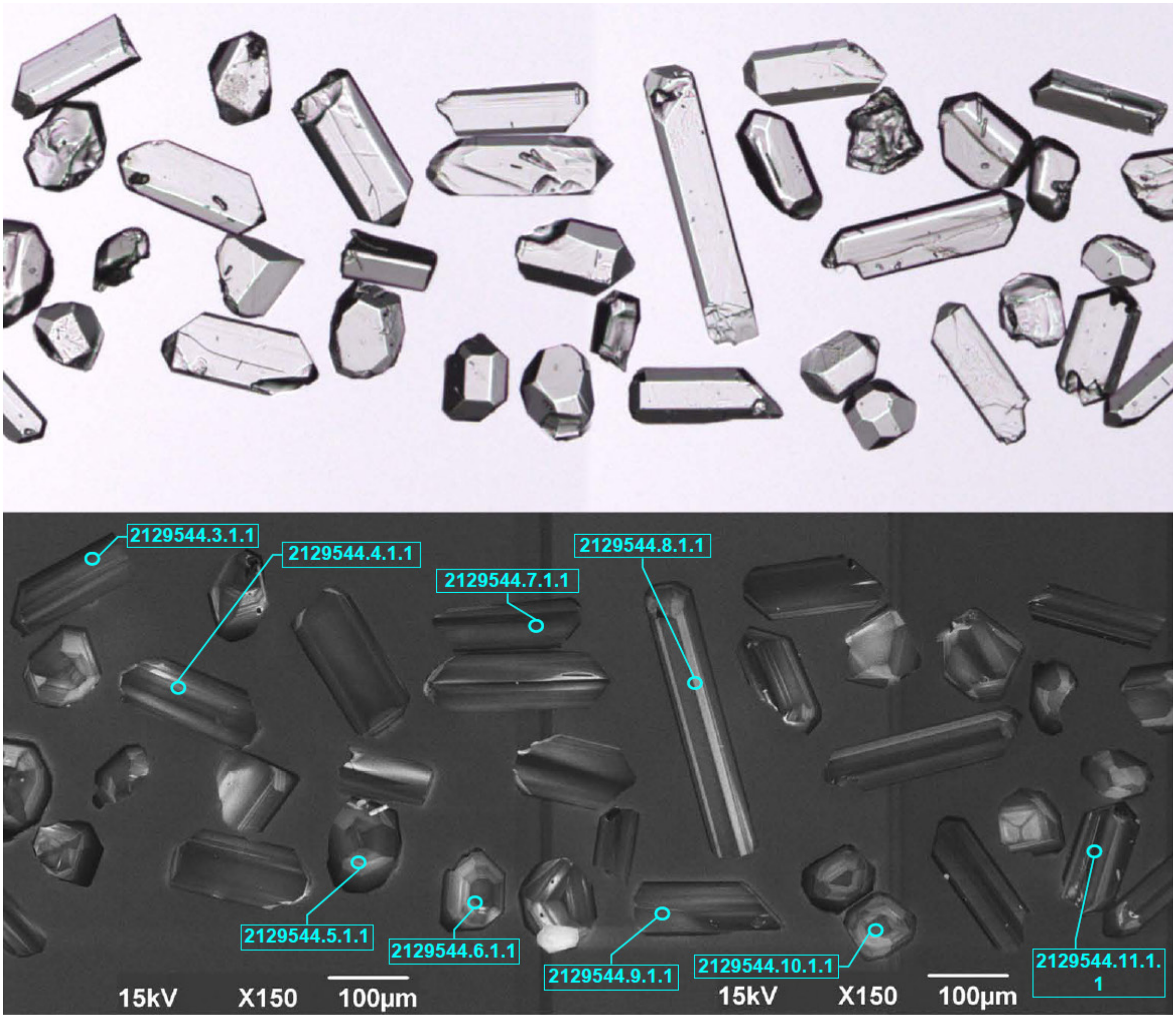


Figure 7.2 Representative zircons from the Khatoun Tonalite (GSNSW: PB-12-URA-01, GA: 2129544). Transmitted light image is shown in the upper half; Cathodoluminescence image is shown in the lower half. SHRIMP analysis sites are indicated, and labelled with sample, grain, spot and replicate number.

7.4 U–Pb Isotopic Results

Thirty-four analyses were obtained from 34 individual zircon grains; the results are presented in Table 7.2 and illustrated in Figure 7.3. Grain labels 19–22 were not used (see Appendix A.4.2).

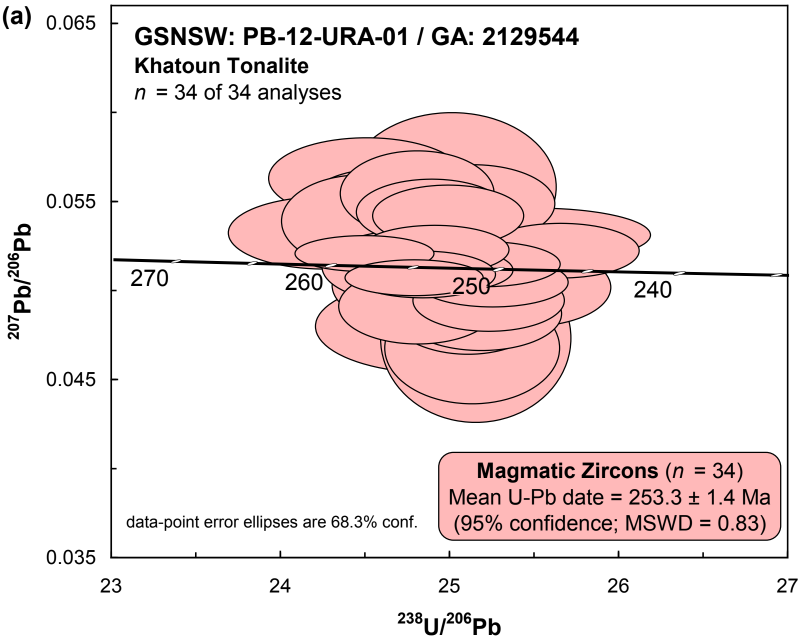
The 34 analyses (Figure 7.3, pink fill; Table 7.2, Group 1) are characterised by low to moderate U concentrations (142–1306 ppm, median 475 ppm), consistent Th/U (0.37–1.12, median 0.71) and have $^{206}Pb_c$ less than 0.89% with individual $^{206}Pb/^{238}U$ ages between ~246 Ma and ~261 Ma, which combine to produce a weighted mean $^{206}Pb/^{238}U$ age of 253.3 ± 1.4 Ma (95% confidence, MSWD = 0.83, probability = 0.74).

7.5 Geochronological Interpretation

The weighted mean $^{206}Pb/^{238}U$ age of 253.3 ± 1.4 Ma is interpreted as the best estimate of the magmatic crystallisation age of the Khatoun Tonalite.

This new SHRIMP age, along with other new ages from this volume, and pertinent geological relationships are considered in the discussion.

(a)



(b)

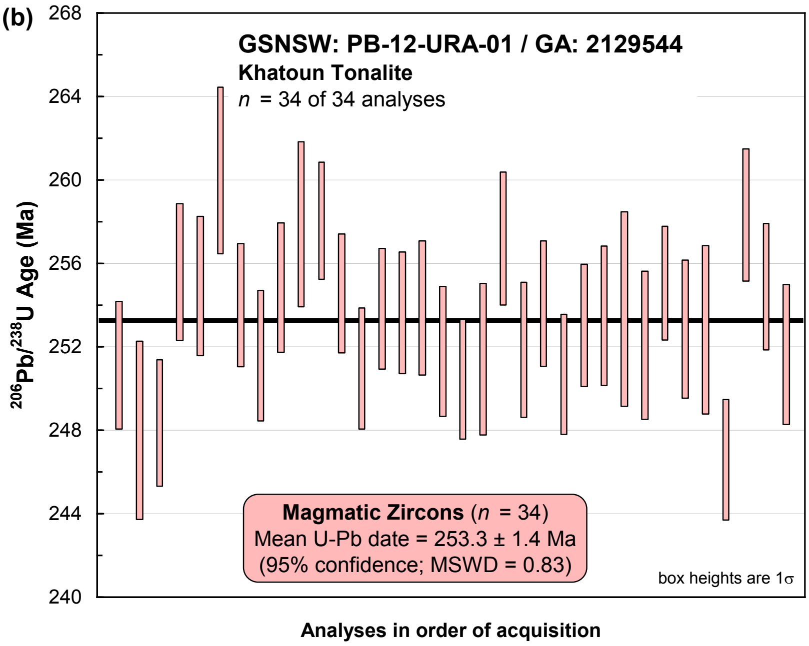


Figure 7.3 SHRIMP U–Pb data for zircons from the Khatoun Tonalite (GSNSW: PB-12-URA-01, GA: 2129544). Pink fill denotes Group 1 (magmatic crystallisation). (a) Tera-Wasserburg concordia diagram; (b) $^{206}Pb/^{238}U$ ages in order of acquisition. Heavy black line denotes the weighted mean $^{206}Pb/^{238}U$ age of the magmatic population.

Table 7.2 SHRIMP U–Pb isotopic data for zircons from the Khatoun Tonalite (GSNSW: PB-12-URA-01, GA: 2129544). All ages are $^{206}Pb/^{238}U$.

Session No.	Sample. Grain. Spot. Replicate	$^{206}Pb_c$ (%)	U (ppm)	Th (ppm)	$^{232}Th/^{238}U$	$^{238}U/^{206}Pb$	±1σ (%)	$^{207}Pb/^{206}Pb$	±1σ (%)	Age (Ma)	±1σ (Ma)
Group 1: Magmatic crystallisation (n = 34)											
120062	2129544.6.1.1	-0.19	446	230	0.53	24.253	1.6	0.05328	2.5	260.5	4.0
120062	2129544.36.1.1	-0.50	407	279	0.71	24.458	1.3	0.05391	3.2	258.3	3.2
120062	2129544.11.1.1	0.02	1020	1012	1.02	24.485	1.1	0.05210	1.3	258.0	2.8
120062	2129544.10.1.1	-0.31	483	341	0.73	24.500	1.6	0.05633	2.7	257.9	4.0
120062	2129544.24.1.1	-0.41	386	265	0.71	24.569	1.3	0.05428	3.1	257.2	3.2
120062	2129544.4.1.1	-0.08	339	228	0.69	24.726	1.3	0.05136	2.6	255.6	3.3
120062	2129544.32.1.1	0.10	1306	1422	1.12	24.779	1.1	0.05074	1.3	255.0	2.7
120062	2129544.5.1.1	-0.18	322	166	0.53	24.793	1.3	0.05029	3.1	254.9	3.3
120062	2129544.37.1.1	-0.52	520	386	0.77	24.796	1.2	0.05548	2.9	254.9	3.0
120062	2129544.9.1.1	0.25	463	327	0.73	24.800	1.2	0.04913	2.9	254.8	3.1
120062	2129544.12.1.1	0.17	1007	954	0.98	24.828	1.1	0.05092	1.7	254.6	2.9
120062	2129544.26.1.1	0.16	503	228	0.47	24.876	1.2	0.05174	2.3	254.1	3.0
120062	2129544.7.1.1	-0.27	642	496	0.80	24.884	1.2	0.05444	2.2	254.0	3.0
120062	2129544.16.1.1	0.08	377	237	0.65	24.897	1.3	0.05170	2.5	253.9	3.2
120062	2129544.14.1.1	-0.08	729	523	0.74	24.901	1.2	0.05232	1.7	253.8	2.9
120062	2129544.30.1.1	0.46	404	198	0.51	24.902	1.9	0.04800	3.6	253.8	4.7
120062	2129544.15.1.1	-0.04	680	484	0.74	24.920	1.2	0.05117	1.7	253.6	2.9
120062	2129544.29.1.1	0.00	679	350	0.53	24.935	1.3	0.05060	1.6	253.5	3.4
120062	2129544.28.1.1	-0.18	583	426	0.76	24.981	1.2	0.05424	2.1	253.0	2.9
120062	2129544.33.1.1	-0.27	296	126	0.44	25.001	1.3	0.05440	3.2	252.8	3.3
120062	2129544.34.1.1	-0.38	142	51	0.37	25.002	1.6	0.05585	5.0	252.8	4.0
120062	2129544.31.1.1	0.05	544	356	0.68	25.078	1.4	0.05118	1.9	252.1	3.5
120062	2129544.25.1.1	0.35	321	156	0.50	25.100	1.3	0.04925	3.8	251.8	3.3
120062	2129544.17.1.1	0.12	466	320	0.71	25.108	1.3	0.05191	2.3	251.8	3.1
120062	2129544.38.1.1	0.47	291	176	0.63	25.123	1.4	0.04678	4.4	251.6	3.3
120062	2129544.8.1.1	-0.21	440	276	0.65	25.129	1.3	0.05491	2.6	251.6	3.1
120062	2129544.23.1.1	0.89	214	93	0.45	25.145	1.5	0.04733	6.6	251.4	3.6
120062	2129544.1.1.1	0.24	447	304	0.70	25.177	1.2	0.04870	2.8	251.1	3.1
120062	2129544.13.1.1	0.00	612	477	0.81	25.193	1.2	0.05149	1.6	250.9	2.9
120062	2129544.27.1.1	0.25	637	461	0.75	25.221	1.2	0.04945	2.3	250.7	2.9

Session No.	Sample. Grain. Spot. Replicate	$^{206}Pb_c$ (%)	U (ppm)	Th (ppm)	$^{232}Th/^{238}U$	$^{238}U/^{206}Pb$	±1σ (%)	$^{207}Pb/^{206}Pb$	±1σ (%)	Age (Ma)	±1σ (Ma)
120062	2129544.18.1.1	0.14	844	690	0.84	25.245	1.2	0.05048	1.8	250.4	2.9
120062	2129544.3.1.1	0.25	456	311	0.70	25.462	1.2	0.05020	2.9	248.3	3.0
120062	2129544.2.1.1	-0.04	648	507	0.81	25.500	1.8	0.05314	1.9	248.0	4.3
120062	2129544.35.1.1	-0.05	551	385	0.72	25.647	1.2	0.05227	1.9	246.6	2.9

8 Regional Felsic Dyke Swarm

Table 8.1 Summary of results: Regional Felsic Dyke Swarm (GSNSW: PB-12-URA-03, GA: 2129546).

GA SampleNo	2129546
GSNSW SiteID	PB-12-URA-03
Stratigraphic Unit	Regional Felsic Dyke Swarm
Parent Unit	–
Informal Identifier	–
Lithology	Porphyritic granodiorite dyke
Province	New England Orogen
1:250 000 Sheet	MANILLA (SH/56-9)
1:100 000 Sheet	BENDEMEER (9136)
Location (GDA94)	30.632081°S, 151.410701°E
Location (MGA94)	Zone 56; 347687 mE, 6610095 mN
Analytical Session No	120062 (see Appendix Table A.1 for parameters derived from concurrent measurements of $^{206}Pb/^{238}U$ and $^{207}Pb/^{206}Pb$ reference zircons)
Interpreted Age	255.0 ± 1.5 Ma (n = 28)
Geological Attribution	Magmatic crystallisation
Isotopic Ratio used	$^{206}Pb/^{238}U$ (^{204}Pb-corrected)

8.1 Sampling Details and Geological Relationships

This sample of the Regional Felsic Dyke Swarm (RFDS) comprises a single 2 kg segment of diamond drill core (Sovereign Gold, drill hole number SGRD007, 42.25–42.75 metres), sampled at the Martins Shaft prospect west of Uralla in the Khatoun area. Weak phyllic alteration associated with gold mineralisation is present in the drill hole, but not in the supplied sample.

Cross and Blevin (2010) obtained an age of 252.5 ± 1.8 Ma for a sample of the RFDS ~39 km to the north of the current sample site. This is consistent with regional field relationships, which indicate that the RFDS (and spatially related gold mineralisation) intrudes the Khatoun Tonalite (253.3 ± 1.4 Ma, this volume), the Sandon Beds, the Yarrowyck Granodiorite (254.9 ± 1.5 Ma, this volume) and the Parlour Mountain Leucoadamellite (254.7 ± 1.6 Ma, SHRIMP, Cross and Blevin, 2010).

The aim of dating an additional RFDS sample was to: (1) constrain the timing of gold mineralisation and local intrusive relationships in the Khatoun area; and (2) add a second date to the regionally extensive RFDS and help constrain the age range of Late Permian magmatism in the southern New England Orogen.

8.2 Petrography

The sample of the RFDS is a comprehensively altered and pyritic presumed igneous rock that contains ~15% very irregular grains of quartz to 1.5 mm in size (Figure 8.1). The quartz is enclosed by a mass of coarsely microcrystalline muscovite/sericite and less abundant and patchy carbonate. Pyrite (2–3% of rock) occurs as mostly perfect crystals to 1.5 mm.

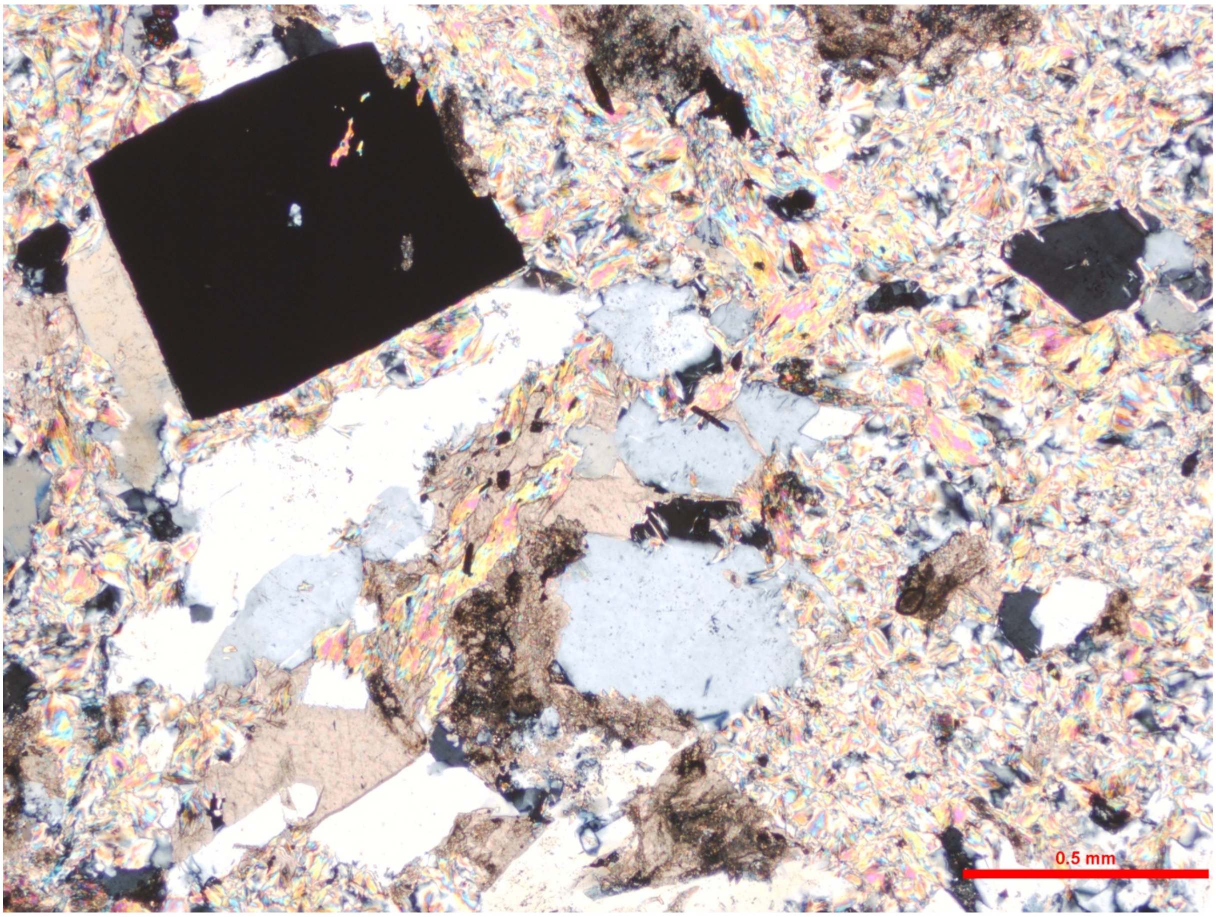


Figure 8.1 Representative photomicrograph of the Regional Felsic Dyke Swarm (GSNSW: PB-12-URA-03, GA: 2129546) in cross-polarised light. Extensively muscovite- and carbonate-altered granitic rock with residual quartz and scattered pyrite cubes. Scale bar is 0.5 mm. Image supplied by Geological Survey of NSW.

8.3 Zircon Description

The zircons are predominantly euhedral to subhedral stubby prismatic grains with occasional subrounded grains; a minor component of the sample is fractured (Figure 8.2). Long axes of grains are 70–300 µm. Grain length to width is variable from 1:1 to predominantly 2:1, up to 5:1.

In transmitted light (TL) the zircons are transparent to translucent and colourless to pale brown. Cracks and crazing are common with few grains completely unaffected (Figure 8.2). Occasional inclusions are present as acicular apatite rods and opportunistic euhedral grains; gas or melt channels are present in a small percentage of grains.

Cathodoluminescence (CL) imaging reveals a high degree of inconsistency in internal textural structure across the sample; zoning textures range from concentric oscillatory zoning with moderate CL emission to grains with extremely low CL emission, diffuse and convolutedly zoned core regions with resorption and cross-cutting textures, to moderate CL emission in some core regions. Grains with the lowest CL emission are seen in TL as the most crazed and cracked—possibly metamict—grains in the sample; occasionally these display moderate CL intensity concentrically zoned rims, verso, some grains with moderate CL cores display low CL rims (Figure 8.2).

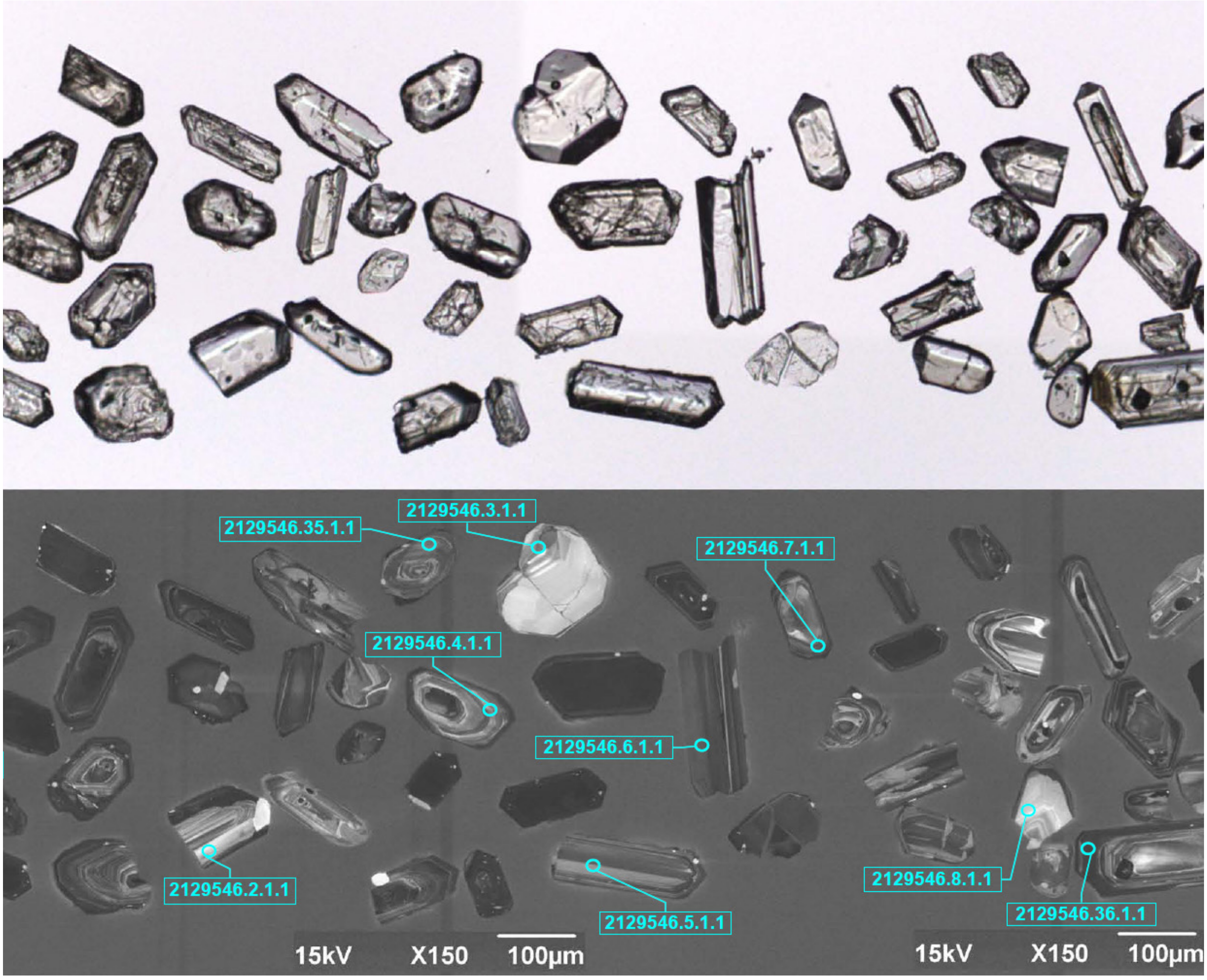


Figure 8.2 Representative zircons from the Regional Felsic Dyke Swarm (GSNSW: PB-12-URA-03, GA: 2129546). Transmitted light image is shown in the upper half; Cathodoluminescence image is shown in the lower half. SHRIMP analysis sites are indicated, and labelled with sample, grain, spot and replicate number.

8.4 U–Pb Isotopic Results

Thirty-nine analyses were obtained from 39 individual zircon grains; the results are presented in Table 8.2 and illustrated in Figure 8.3. Grain labels 20–23 were not used (see Appendix A.4.2).

The 39 analysed zircons are characterised by wide range of U concentrations (113–5119 ppm, median 617 ppm) and Th/U (0.26–3.84, median 0.48), and low $^{206}Pb_c$ (maximum 1.36%, median 0.05%). They can be divided into four groups:

- Group 1: 28 analyses (Figure 8.3, pink fill; Table 8.2) with U concentrations of 324–1919 ppm (median 613 ppm) and individual $^{206}Pb/^{238}U$ ages between ~251 Ma and ~259 Ma which combine to produce a weighted mean $^{206}Pb/^{238}U$ age of 255.0 ± 1.5 Ma (95% confidence, MSWD = 0.58, probability = 0.96).
- Group 2: Five analyses (Figure 8.3, yellow fill; Table 8.2) with U concentrations of 113–399 ppm and individual $^{206}Pb/^{238}U$ ages between ~288 Ma and ~1143 Ma.
- Group 3: Five analyses (Figure 8.3, white fill; Table 8.2) with U > 2100 ppm and individual $^{206}Pb/^{238}U$ ages slightly older than those in Group 1 (between ~259 Ma and ~279 Ma).
- Group 4: One analysis (2129546.36.1.1; Figure 8.3, blue fill; Table 8.2) with U concentration of 1514 ppm yielded a young individual $^{206}Pb/^{238}U$ age of ~239 Ma relative to the rest of the population.

8.5 Geochronological Interpretation

The weighted mean $^{206}Pb/^{238}U$ age of 255.0 ± 1.5 Ma for the 28 analyses in Group 1 is interpreted as the magmatic crystallisation age of the porphyritic granodiorite dyke at the Martins Shaft Prospect of the Regional Felsic Dyke Swarm.

The five analyses represented in Group 2 are interpreted as inheritance of Early Permian to Mesoproterozoic age.

The five analyses in Group 3 are interpreted to be of syn-magmatic zircons, but with individual $^{206}Pb/^{238}U$ ages biased by metamictisation arising from their high U contents (refer to McLaren et al, 1994; Butera et al, 2001).

Group 4 comprises one analysis that yielded an age slightly younger (~239 Ma) than the main magmatic population defined in Group 1. This grain is interpreted as affected by minor post-crystallisation loss of radiogenic Pb possibly facilitated by radiation damage to the crystal lattice arising from its elevated U content.

This new SHRIMP age, along with other new ages from this volume, and pertinent geological relationships are considered in the discussion.

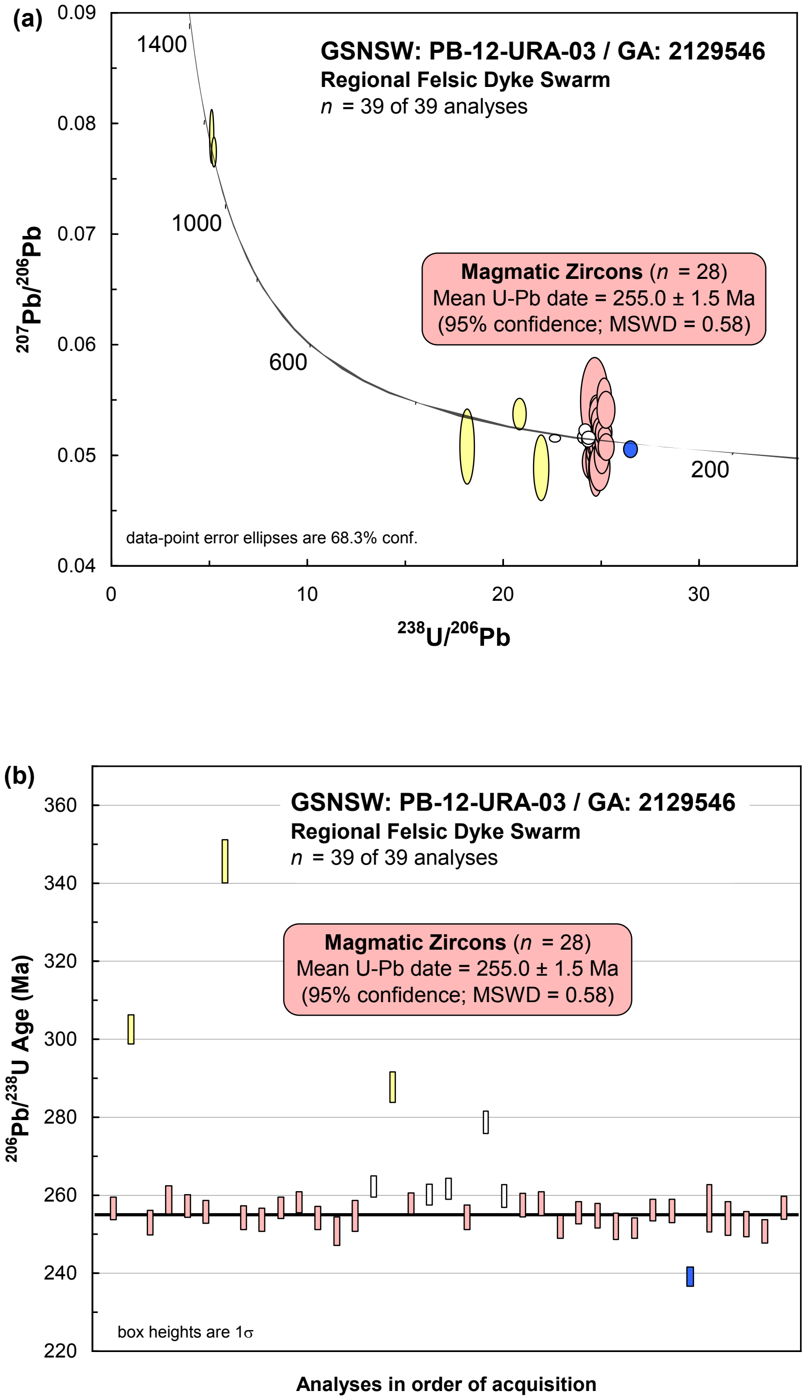


Figure 8.3 SHRIMP U–Pb data for zircons from the Regional Felsic Dyke Swarm (GSNSW: PB-12-URA-03, GA: 2129546). Pink fill denotes Group 1 (magmatic crystallisation), yellow fill denotes Group 2 (inheritance), white fill denotes Group 3 (metamict magmatic zircons), and blue fill denotes Group 4 (loss of radiogenic Pb). (a) Tera-Wasserburg concordia diagram; (b) Post-370 Ma $^{206}Pb/^{238}U$ ages in order of acquisition. Heavy black line denotes the weighted mean $^{206}Pb/^{238}U$ age of the magmatic population.

Table 8.2 SHRIMP U–Pb isotopic data for zircons from the Regional Felsic Dyke Swarm (GSNSW: PB-12-URA-03, GA: 2129546). All ages are $^{206}Pb/^{238}U$.

Session No.	Sample. Grain. Spot. Replicate	$^{206}Pb_c$ (%)	U (ppm)	Th (ppm)	$^{232}Th/^{238}U$	$^{238}U/^{206}Pb$	±1σ (%)	$^{207}Pb/^{206}Pb$	±1σ (%)	Age (Ma)	±1σ (Ma)
Group 1: Magmatic crystallisation (n = 28)											
120062	2129546.5.1.1	0.31	600	327	0.56	24.428	1.4	0.04938	2.6	258.6	3.6
120062	2129546.12.1.1	0.01	1919	1054	0.57	24.481	1.1	0.05083	0.9	258.1	2.7
120062	2129546.17.1.1	0.00	1617	573	0.37	24.513	1.1	0.05217	0.9	257.8	2.7
120062	2129546.28.1.1	-0.05	518	228	0.45	24.516	1.2	0.05160	1.9	257.7	3.0
120062	2129546.27.1.1	0.25	599	272	0.47	24.550	1.2	0.04967	3.8	257.4	3.0
120062	2129546.6.1.1	0.07	771	336	0.45	24.581	1.2	0.05031	1.8	257.1	2.9
120062	2129546.42.1.1	-0.07	682	751	1.14	24.619	1.2	0.05106	1.7	256.7	2.9
120062	2129546.11.1.1	0.08	1363	648	0.49	24.625	1.1	0.05063	1.3	256.6	2.8
120062	2129546.1.1.1	-0.13	830	397	0.49	24.634	1.1	0.05275	1.7	256.5	2.9
120062	2129546.37.1.1	1.36	1141	980	0.89	24.637	2.4	0.05486	5.9	256.5	6.1
120062	2129546.34.1.1	0.19	908	245	0.28	24.679	1.1	0.05165	1.7	256.1	2.8
120062	2129546.35.1.1	0.30	526	133	0.26	24.696	1.2	0.04874	4.1	255.9	3.0
120062	2129546.7.1.1	-0.09	617	269	0.45	24.722	1.2	0.05089	1.9	255.6	3.0
120062	2129546.30.1.1	-0.11	914	346	0.39	24.741	1.1	0.05445	1.5	255.4	2.8
120062	2129546.31.1.1	0.40	395	206	0.54	24.818	1.3	0.04887	3.5	254.7	3.2
120062	2129546.15.1.1	-0.22	514	185	0.37	24.828	1.6	0.05369	2.4	254.6	3.9
120062	2129546.24.1.1	0.00	933	624	0.69	24.860	1.3	0.05283	1.9	254.2	3.2
120062	2129546.9.1.1	-0.09	609	561	0.95	24.870	1.2	0.05312	2.0	254.1	3.1
120062	2129546.13.1.1	0.21	664	209	0.33	24.875	1.2	0.05105	2.2	254.1	3.0
120062	2129546.38.1.1	0.32	324	197	0.63	24.896	1.7	0.04893	3.5	253.9	4.3
120062	2129546.10.1.1	0.00	560	143	0.26	24.916	1.2	0.05228	1.8	253.7	3.0
120062	2129546.4.1.1	0.20	435	191	0.45	25.005	1.3	0.05004	2.8	252.8	3.1
120062	2129546.39.1.1	0.15	344	105	0.32	25.037	1.3	0.05150	2.8	252.5	3.2
120062	2129546.32.1.1	0.18	738	288	0.40	25.094	1.4	0.05204	1.9	251.9	3.4
120062	2129546.29.1.1	-0.37	583	270	0.48	25.109	1.2	0.05535	2.4	251.8	2.9
120062	2129546.33.1.1	0.06	1431	843	0.61	25.145	1.1	0.05175	1.2	251.4	2.7
120062	2129546.14.1.1	-0.24	501	137	0.28	25.219	1.5	0.05410	2.5	250.7	3.7
120062	2129546.41.1.1	0.00	443	209	0.49	25.228	1.2	0.05073	2.0	250.6	3.0
Group 2: Inheritance (n = 5)											
120062	2129546.43.1.1	-0.13	124	84	0.70	5.156	1.7	0.07884	2.5	1142.8	17.7
120062	2129546.40.1.1	0.00	113	420	3.84	5.296	1.7	0.07740	1.4	1115.0	17.7
120062	2129546.8.1.1	0.56	153	96	0.65	18.151	1.6	0.05077	5.4	345.7	5.5

Session No.	Sample. Grain. Spot. Replicate	$^{206}Pb_c$ (%)	U (ppm)	Th (ppm)	$^{232}Th/^{238}U$	$^{238}U/^{206}Pb$	±1σ (%)	$^{207}Pb/^{206}Pb$	±1σ (%)	Age (Ma)	±1σ (Ma)
120062	2129546.3.1.1	-0.11	399	198	0.51	20.817	1.3	0.05369	2.1	302.5	3.7
120062	2129546.2.1.1	0.72	291	125	0.44	21.917	1.4	0.04884	5.0	287.6	3.9
Group 3: high-U metamict syn-magmatic zircons (n = 5)											
120062	2129546.25.1.1	0.05	5119	4306	0.87	22.636	1.0	0.05151	0.6	278.7	2.8
120062	2129546.16.1.1	0.05	2386	817	0.35	24.094	1.1	0.05162	1.0	262.1	2.7
120062	2129546.19.1.1	-0.06	2225	651	0.30	24.148	1.1	0.05224	0.9	261.6	2.7
120062	2129546.18.1.1	0.06	2172	647	0.31	24.298	1.1	0.05134	1.0	260.0	2.7
120062	2129546.26.1.1	0.07	2066	1082	0.54	24.331	1.2	0.05156	1.0	259.6	2.9
Group 4: loss of radiogenic Pb (n = 1)											
120062	2129546.36.1.1	0.12	1541	1135	0.76	26.476	1.1	0.05054	1.2	239.0	2.5

9 ‘Kindee Creek tonalite’

Table 9.1 Summary of results: ‘Kindee Creek tonalite’ (GSNSW: PB-10-BWD-01, GA: 2121505).

GA SampleNo	2121505
GSNSW SiteID	PB-10-BWD-01
Stratigraphic Unit	Undifferentiated porphyry, leuocogranite and granodiorite
Parent Unit	–
Informal Identifier	‘Kindee Creek tonalite’
Lithology	Porphyritic tonalite
Province	New England Orogen
1:250 000 Sheet	HASTINGS (SH/56-14)
1:100 000 Sheet	COWARRAL (9334)
Location (GDA94)	31.346431°S, 152.382191°E
Location (MGA94)	Zone 56; 441234 mE, 6531839 mN
Analytical Session No	110005 (see Appendix Table A.1 for parameters derived from concurrent measurements of $^{206}Pb/^{238}U$ and $^{207}Pb/^{206}Pb$ reference zircons)
Interpreted Age	227.3 ± 1.3 Ma (n = 26)
Geological Attribution	Magmatic crystallisation
Isotopic Ratio used	$^{206}Pb/^{238}U$ (^{204}Pb-corrected)

9.1 Sampling Details and Geological Relationships

The sample for the ‘Kindee Creek tonalite’ was sampled from diamond drillcore (hole B105 drilled by Pickand Mather & Co. International) at the Birdwood Cu-Mo-Au-Sn porphyry prospect, 100 m south-east of Rollands Road at Birdwood. There are no surviving records of the original Pickand Mather’s operation in the area (Daigle, 1993). Granite is fresh at the base of the drillcore and surface outcrop is indicated nearby. The unit sampled is a white feldspar, medium-grained tonalite in which biotite is more abundant than amphibole.

The ‘Kindee Creek tonalite’ intrudes the Carboniferous Nevann Siltstone within the Hastings Block of the New England Orogen. The tonalite is centred on a large diffuse porphyry-like polymetallic system, and is also centred on the Hillview thermal high, identified by biotite isograd conditions (Daigle, 1993). No previous dating or chemistry has been attempted on the ‘Kindee Creek tonalite’ and it has been assumed to be Triassic in age (Daigle, 1993; Roberts et al., 1995).

The objective for SHRIMP U–Pb age dating the ‘Kindee Creek tonalite’ was to obtain a magmatic crystallisation age to compare with the age of other Triassic ~240 Ma to ~210 Ma ‘coastal granitoids’ of the New England Orogen.

9.2 Petrography

This sample is a massive, equigranular, medium-grained biotite tonalite that is composed of approximately 55–60% plagioclase, 35–40% quartz and 5% orange/brown to tan-coloured biotite (Figure 9.1). Accessory minerals include conspicuous small rods of apatite, zircon and very minor opaques, usually associated with secondary chlorite after some of the biotite. Plagioclase occurs as lightly sericitised, subhedral and anhedral tabular crystals to 5 mm in size, a few of which are finely concentrically zoned and have narrow albite rims. Some of the quartz fraction occurs as crudely hexagonal-shaped grains that are 3–5 mm in size but which have anhedral to weakly embayed boundaries and small irregular plagioclase and quartz inclusions. The remainder of the quartz occurs as aggregates of much smaller grains between the larger plagioclase and quartz crystals. No positive alkali feldspar was identified. Biotite occurs as ragged individual subhedral laths to 1.5 mm, some of which are partly chloritised. A couple of the biotites contain inclusions to 0.8 mm in size and with slightly prismatic form. These have been completely replaced by fibrous to fanning aggregates of mainly chlorite.

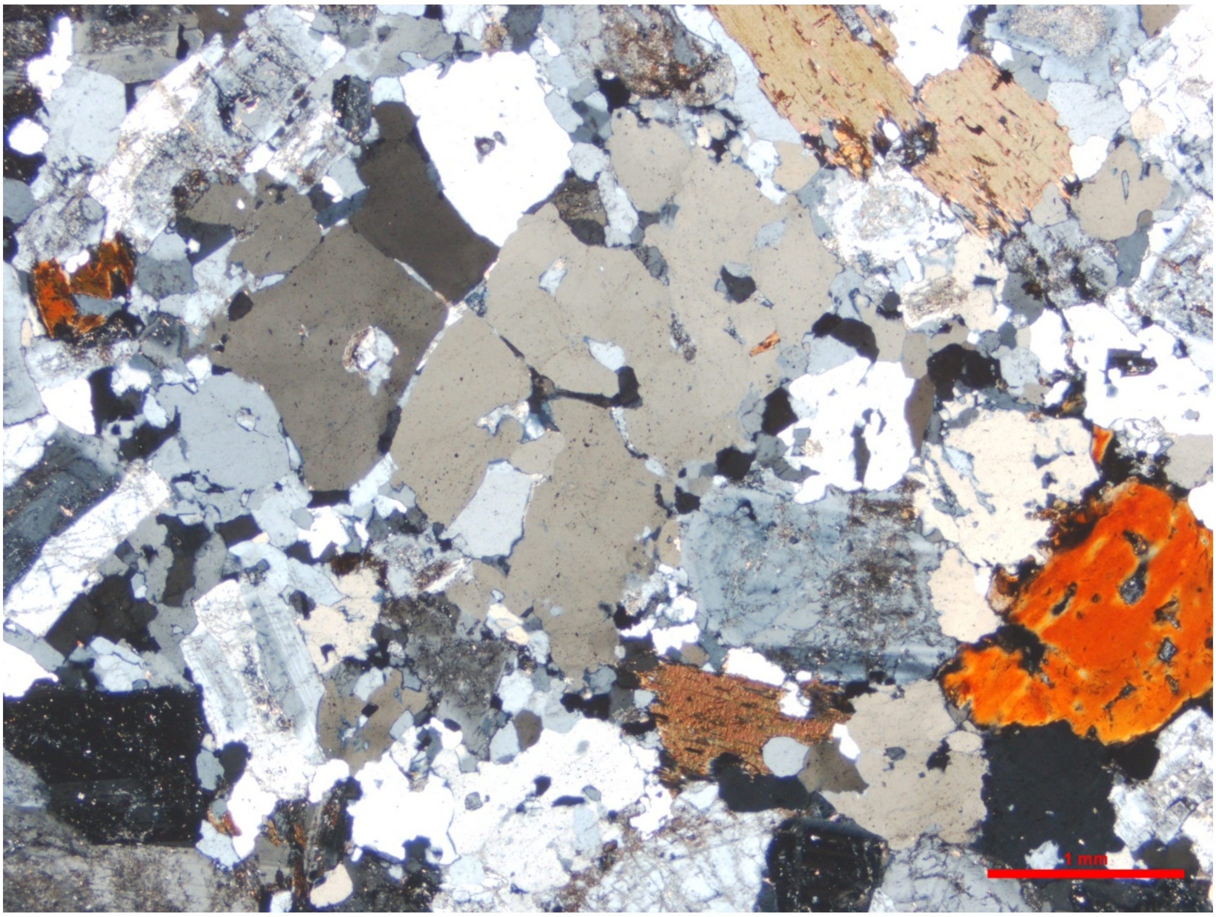


Figure 9.1 Representative photomicrograph of the 'Kindee Creek tonalite' (GSNSW: PB-10-BWD-01, GA: 2121505) in cross-polarised light. Quartz-rich biotite tonalite composed mainly of plagioclase and quartz with subordinate orange/brown biotite. Some quartz occurs as large, roughly hexagonal crystals (left of centre), which are weakly embayed with small plagioclase inclusions. Scale bar is 1 mm. Image supplied by Geological Survey of NSW.

9.3 Zircon Description

The zircons are euhedral to subhedral with some fractured grains and a minor proportion of elongate grains (Figure 9.2). Long axes are between 80–400 μm with grain length to width between 1:1 and 4:1.

In transmitted light the zircons are transparent to translucent and pale amber in colour (Figure 9.2). Clear anhedral and rod-like inclusions are ubiquitous in amber coloured subhedral semi-translucent grains. Few grains are cracked yet cavities are common throughout the sample. Cores are present.

Cathodoluminescence (CL) imaging shows strong concentric oscillatory and occasional sector zoning typical of granodioritic to aplitic zircons; moderate to high contrast CL emission shows some elongate grains have broad and poorly defined banding parallel to the long axis of the grain. Complex diffuse and minor convolutedly zoned cores are present with lesser recrystallisation textures visible in some grains suggesting a minor inherited component (Figure 9.2).

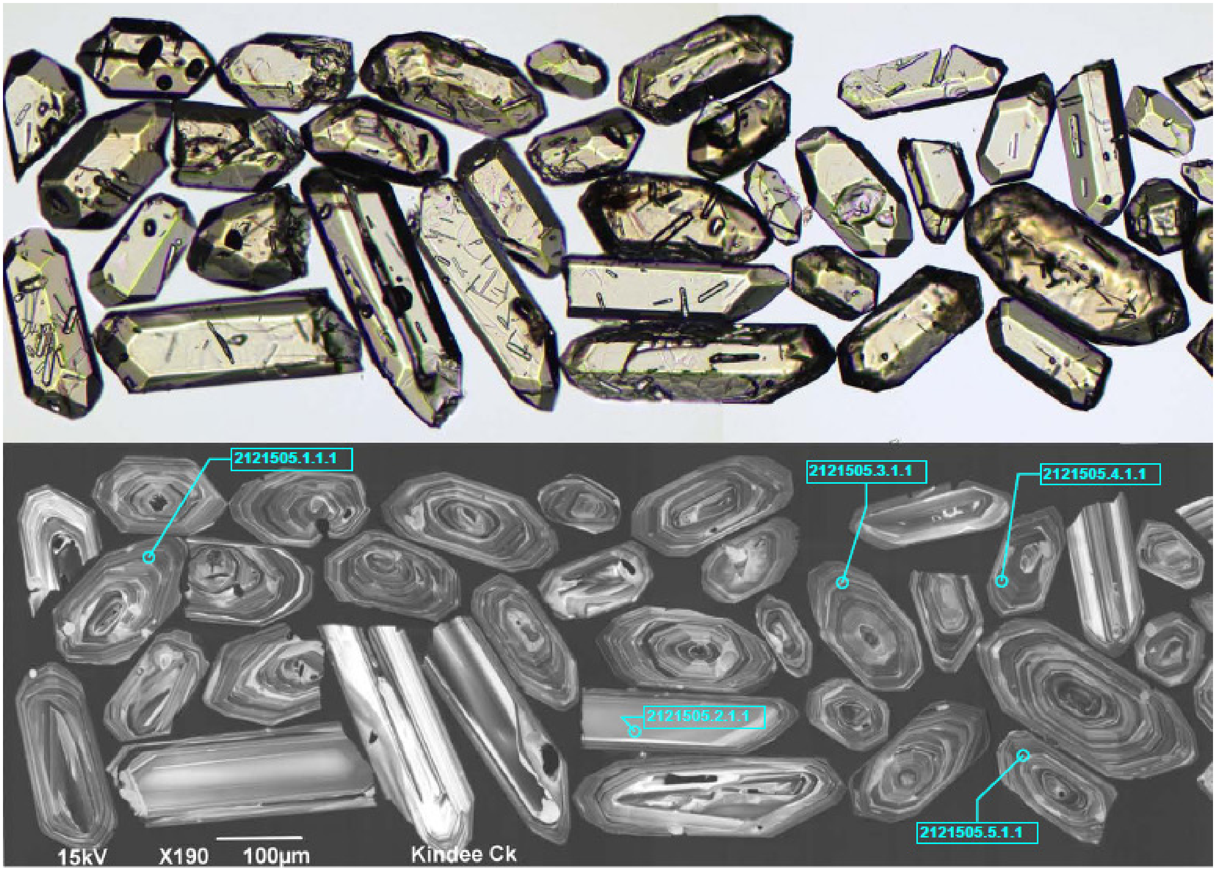


Figure 9.2 Representative zircons from the 'Kindee Creek tonalite' (GSNSW: PB-10-BWD-01, GA: 2121505). Transmitted light image is shown in the upper half; Cathodoluminescence image is shown in the lower half. SHRIMP analysis sites are indicated, and labelled with sample, grain, spot and replicate number.

9.4 U–Pb Isotopic Results

Twenty-six analyses were obtained from 26 individual zircon grains; the results are presented in Table 9.2 and illustrated in Figure 9.3. The analysed zircons are characterised by low to moderate U concentrations (183–720 ppm, median 397 ppm) and consistently moderate Th/U (0.38–0.85, median 0.55).

The 26 analyses (Figure 9.3, pink fill; Table 9.2, Group 1) have $^{206}Pb_c$ less than 2.2% (median 0.22%) with individual $^{206}Pb/^{238}U$ ages between ~223 Ma and ~233 Ma. These analyses combine to produce a weighted mean $^{206}Pb/^{238}U$ age of 227.3 ± 1.3 Ma (95% confidence, MSWD = 1.28, probability = 0.16).

9.5 Geochronological Interpretation

The weighted mean $^{206}Pb/^{238}U$ age of 227.3 ± 1.3 Ma is interpreted as the magmatic crystallisation age of the 'Kindee Creek tonalite'.

This new SHRIMP age and pertinent geological relationships are considered further in the discussion.

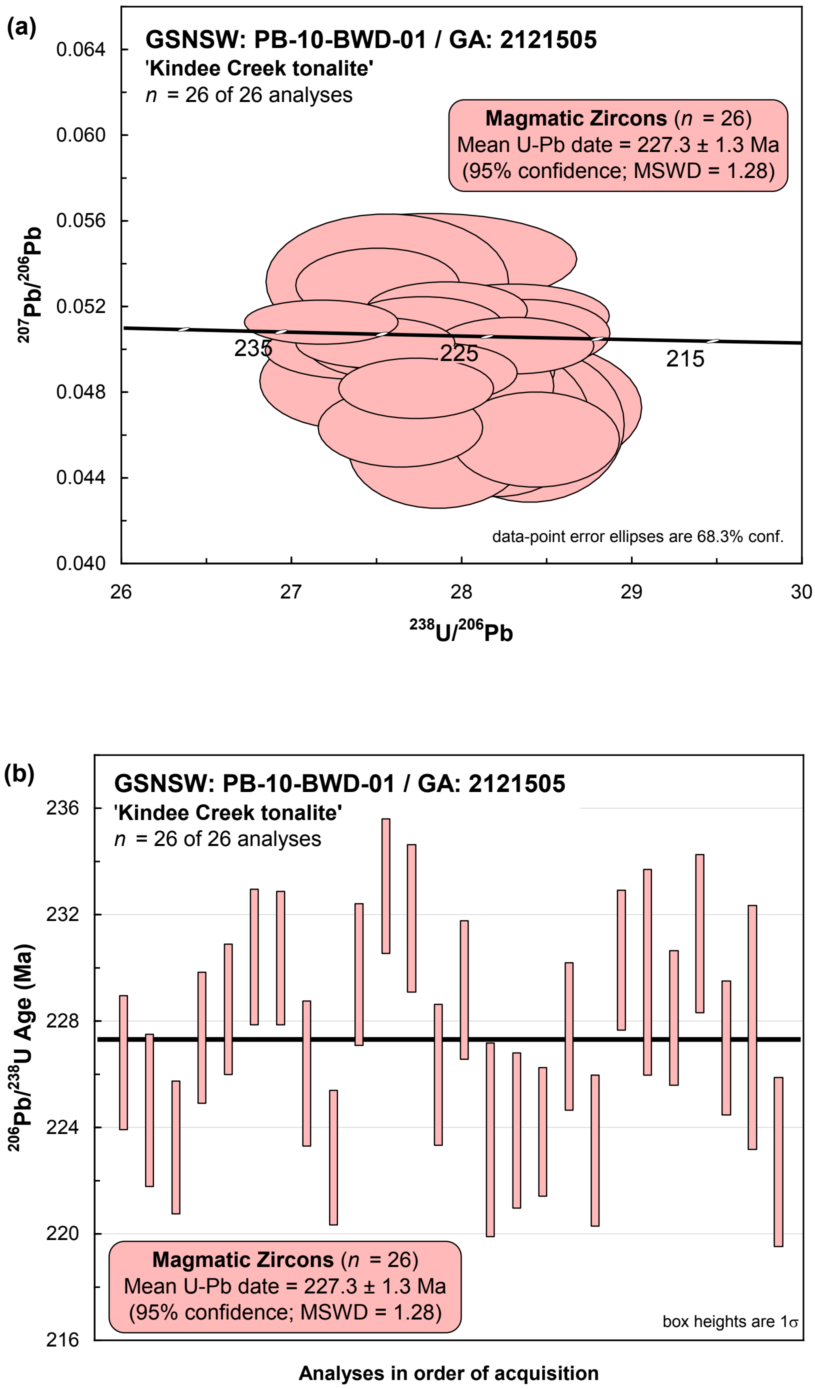


Figure 9.3 SHRIMP U–Pb data for zircons from the 'Kindee Creek tonalite' (GSNSW: PB-10-BWD-01, GA: 2121505). Pink fill denotes Group 1 (magmatic crystallisation). (a) Tera-Wasserburg concordia diagram; (b) $^{206}Pb/^{238}U$ ages in order of acquisition. Heavy black line denotes the weighted mean $^{206}Pb/^{238}U$ age of the magmatic population.

Table 9.2 SHRIMP U–Pb isotopic data for zircons from the 'Kindee Creek tonalite' (GSNSW: PB-10-BWD-01, GA: 2121505). All ages are $^{206}Pb/^{238}U$.

Session No.	Sample. Grain. Spot. Replicate	$^{206}Pb_c$ (%)	U (ppm)	Th (ppm)	$^{232}Th/^{238}U$	$^{238}U/^{206}Pb$	±1σ (%)	$^{207}Pb/^{206}Pb$	±1σ (%)	Age (Ma)	±1σ (Ma)
Group 1: Magmatic crystallisation (n = 26)											
110005	2121505.11.1.1	0.03	582	301	0.53	27.162	1.1	0.05132	1.3	233.1	2.5
110005	2121505.12.1.1	0.30	279	134	0.50	27.308	1.2	0.04859	3.0	231.8	2.8
110005	2121505.23.1.1	0.08	473	217	0.47	27.375	1.3	0.05002	1.8	231.3	3.0
110005	2121505.6.1.1	-0.03	453	279	0.64	27.481	1.1	0.05036	1.6	230.4	2.6
110005	2121505.7.1.1	-0.08	578	320	0.57	27.486	1.1	0.05129	2.8	230.4	2.5
110005	2121505.20.1.1	-0.14	377	154	0.42	27.496	1.2	0.05303	2.2	230.3	2.6
110005	2121505.21.1.1	-0.14	230	108	0.49	27.552	1.7	0.05322	3.9	229.8	3.9
110005	2121505.10.1.1	0.10	309	113	0.38	27.561	1.2	0.05034	2.2	229.7	2.7
110005	2121505.14.1.1	0.32	383	239	0.64	27.633	1.2	0.04641	2.6	229.2	2.6
110005	2121505.5.1.1	0.34	720	400	0.57	27.723	1.1	0.04824	1.9	228.4	2.4
110005	2121505.22.1.1	0.10	508	291	0.59	27.762	1.1	0.05115	1.8	228.1	2.5
110005	2121505.25.1.1	-0.20	266	108	0.42	27.807	2.1	0.05426	2.6	227.8	4.6
110005	2121505.18.1.1	0.41	249	154	0.64	27.850	1.2	0.04536	3.9	227.4	2.8
110005	2121505.4.1.1	0.25	605	278	0.47	27.855	1.1	0.04897	1.9	227.4	2.5
110005	2121505.24.1.1	-0.10	507	334	0.68	27.902	1.1	0.05188	1.7	227.0	2.5
110005	2121505.1.1.1	0.21	433	227	0.54	27.971	1.1	0.05038	2.0	226.4	2.5
110005	2121505.8.1.1	0.45	243	142	0.60	28.023	1.2	0.04928	3.5	226.0	2.7
110005	2121505.13.1.1	0.51	331	172	0.54	28.030	1.2	0.04835	3.3	226.0	2.6
110005	2121505.2.1.1	0.69	183	151	0.85	28.200	1.3	0.04669	5.0	224.6	2.9
110005	2121505.16.1.1	0.12	430	185	0.44	28.295	1.3	0.05163	1.9	223.9	2.9
110005	2121505.17.1.1	0.18	695	448	0.67	28.302	1.1	0.05024	1.7	223.8	2.4
110005	2121505.15.1.1	0.51	195	88	0.46	28.342	1.7	0.04735	4.4	223.5	3.6
110005	2121505.3.1.1	0.24	459	206	0.46	28.380	1.1	0.05081	2.0	223.2	2.5
110005	2121505.19.1.1	0.76	211	134	0.66	28.395	1.3	0.04653	5.1	223.1	2.8
110005	2121505.9.1.1	0.54	411	165	0.41	28.429	1.2	0.04585	3.2	222.9	2.5
110005	2121505.26.1.1	2.18	152	110	0.74	28.450	1.5	0.03145	14.1	222.7	3.2

10 Nerong Volcanics

Table 10.1 Summary of results: Nerong Volcanics (GSNSW: PB-12-PTS-01, GA: 2129547).

GA SampleNo	2129547
GSNSW SiteID	PB-12-PTS-01
Stratigraphic Unit	Nerong Volcanics
Parent Unit	–
Informal Identifier	–
Lithology	Rhyodacitic ignimbrite
Province	New England Orogen
1:250 000 Sheet	NEWCASTLE (SH/56-2)
1:100 000 Sheet	PORT STEPHENS (9332)
Location (GDA94)	32.788293°S, 152.1062355°E
Location (MGA94)	Zone 56; 416308 mE, 6371829 mN
Analytical Session No	120062 (see Appendix Table A.1 for parameters derived from concurrent measurements of $^{206}Pb/^{238}U$ and $^{207}Pb/^{206}Pb$ reference zircons)
Interpreted Age	340.5 ± 2.0 Ma (n = 31)
Geological Attribution	Magmatic crystallisation
Isotopic Ratio used	$^{206}Pb/^{238}U$ (^{204}Pb-corrected)

10.1 Sampling Details and Geological Relationships

The sample of the Nerong Volcanics (Engel, 1962) was taken from large boulders left over from the construction of the water pumping station between Kingsley Drive and the beach at Boat Harbour, near Morna Point, Port Stephens (Figure 10.1). The volcanics in this area represent the southern-most exposure of the New England Orogen (Rose et al., 1966).

The Nerong Volcanics at Port Stephens are massive in outcrop and probably comprise a single thick sheet of ignimbrite. Rare quenched fine-grained enclaves (to 10 cm) represent earlier/more rapidly crystallised material subsequently entrained in the ignimbrite. Elsewhere at this location, voids in the ignimbrite are suggestive of degassing; zones and veins of hematisation are also apparent. Outcrops have magnetic susceptibilities between $1x10^{-3}$ and $3x10^{-3}$ SI, indicative of the presence of magnetite.

Port Stephens has previously been interpreted as the central focus of the Nerong Volcanics (Roberts et al., 1995). Carboniferous *Rhacopteris* flora were recovered from sedimentary rocks interbedded with the ignimbrites at Soldiers Point (White, 1994), 10 km northwest of the sample site. A low-level sample of the Nerong Volcanics (338.6 ± 3.8 Ma, Roberts et al., 1995) was obtained from the type section, where the volcanic rocks conformably overlie marine to continental sedimentary rocks of the

Conger Formation, and are disconformably overlain by the Booti Booti Sandstone and Karuah Formation.

The aim of SHRIMP U–Pb age dating of the Nerong Volcanics was to obtain a magmatic crystallisation age from the base of the volcanic pile at Port Stephens, thereby constraining the onset of volcanic eruption in the region.

Figure 10.1 Representative photograph of the Nerong Volcanics (GSNSW: PB-12-PTS-01, GA: 2129547) at Boat Harbour, near Morna Point, Port Stephens, NSW. Image supplied by Geological Survey of NSW.

10.2 Petrography

This sample is a medium-grained (average phenocryst size of 2 mm), rhyolitic welded ignimbrite that is crystal-rich, containing ~40 modal % phenocrysts and crystal fragments (Figure 10.2). The crystal fraction comprises quartz (~12 modal %), many of which have hexagonal shapes but are intricately embayed, lightly sericitised plagioclase (~15 modal %; An32), dusty altered alkali feldspar (10 modal %) and 3 modal % biotite laths that have been completely replaced by clays and iron oxide. Although many of the phenocrysts are complete, a fairly low degree of crystal fragmentation is indicated by plagioclase fragments truncated across zoning. The ignimbrite contains a single 2 mm lithic fragment of fine-grained plagioclase-phyric intermediate lava and there is also a irregular-shaped microgranite aggregate that may be a cognate inclusion. There is also a star shaped lithophysae in-filled by similar microgranite. The brownish coloured, clay-altered matrix contains abundant, well-preserved cuspate to elongate shard shapes, which are only strongly plastically deformed around crystal margins and which indicate that overall the rock is only moderately welded.

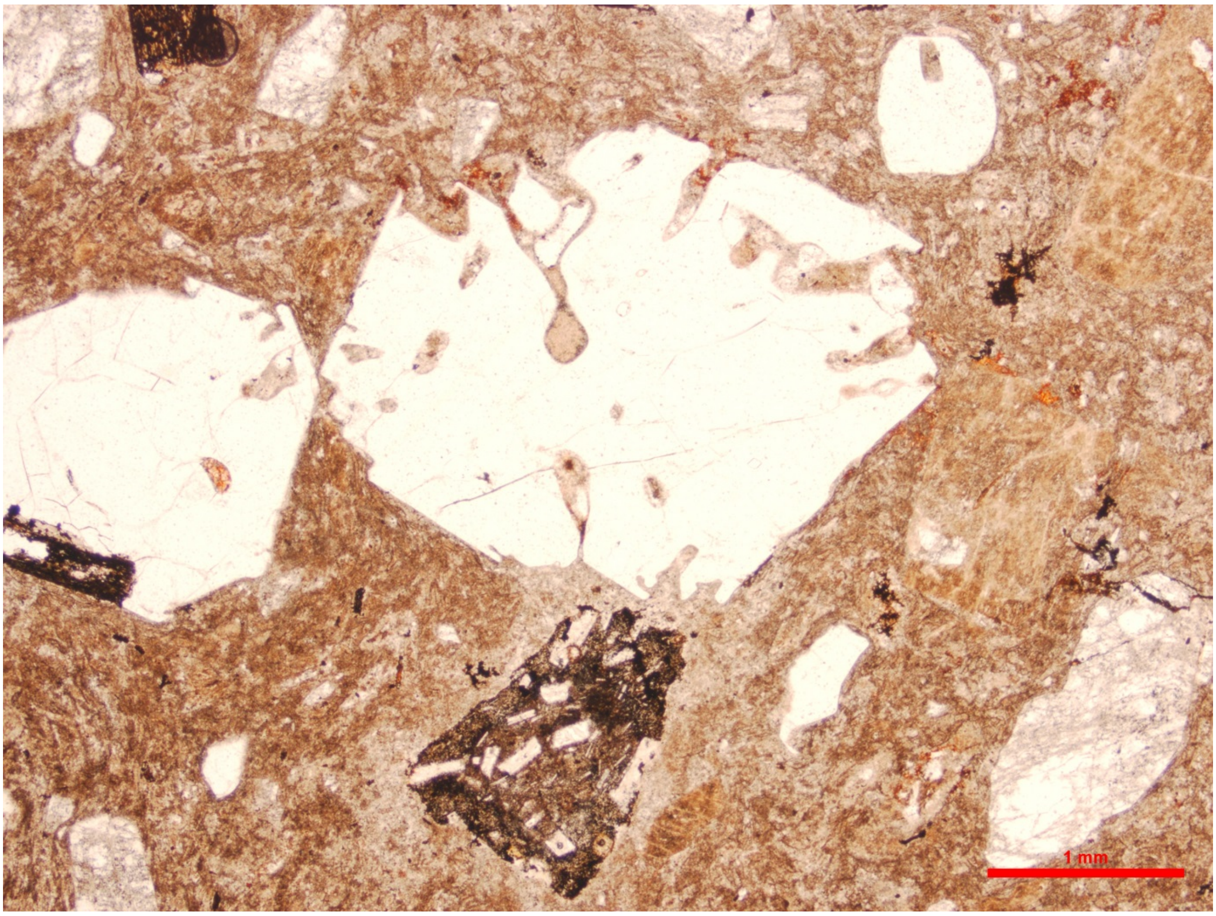


Figure 10.2 Representative photomicrograph of the Nerong Volcanics (GSNSW: PB-12-PTS-01, GA: 2129547) in cross-polarised light. Crystal-rich moderately welded ignimbrite. This view includes embayed quartz, faint clay-altered alkali feldspar (two on right side), several small plagioclase (around photo margins), altered biotite (two on left side) and a lithic clast of intermediate volcanic origin (lower centre). Scale bar is 1 mm. Image supplied by Geological Survey of NSW.

10.3 Zircon Description

The zircons are predominantly subhedral and stubby hemimorphic grains, up to euhedral elongate prismatic grains (Figure 10.3). Long axes are 50–200 µm, with the majority of grains between 80 and 100 µm. Grain length to width is between 1:1 and 3:1.

In transmitted light, the zircons are transparent to very mildly translucent and colourless. Occasional gas or melt channels are present, with few clear anhedral rod-like apatite inclusions. Few grains are cracked (Figure 10.3).

Cathodoluminescence (CL) imaging reveals the majority of grains have oscillatory zoning with moderate CL emission; there is little discrimination between stubby and elongate grains with the majority of grains represented by this concentric texture. Some rounded subhedral stubby grains are represented by oscillatory zoned rims and convolutedly zoned cores. Other zircons have high–moderate CL emission cores surrounded by a moderate CL emission rim; both are concentrically zoned and continuous with no cross-cutting textures or disconformities (Figure 10.3).

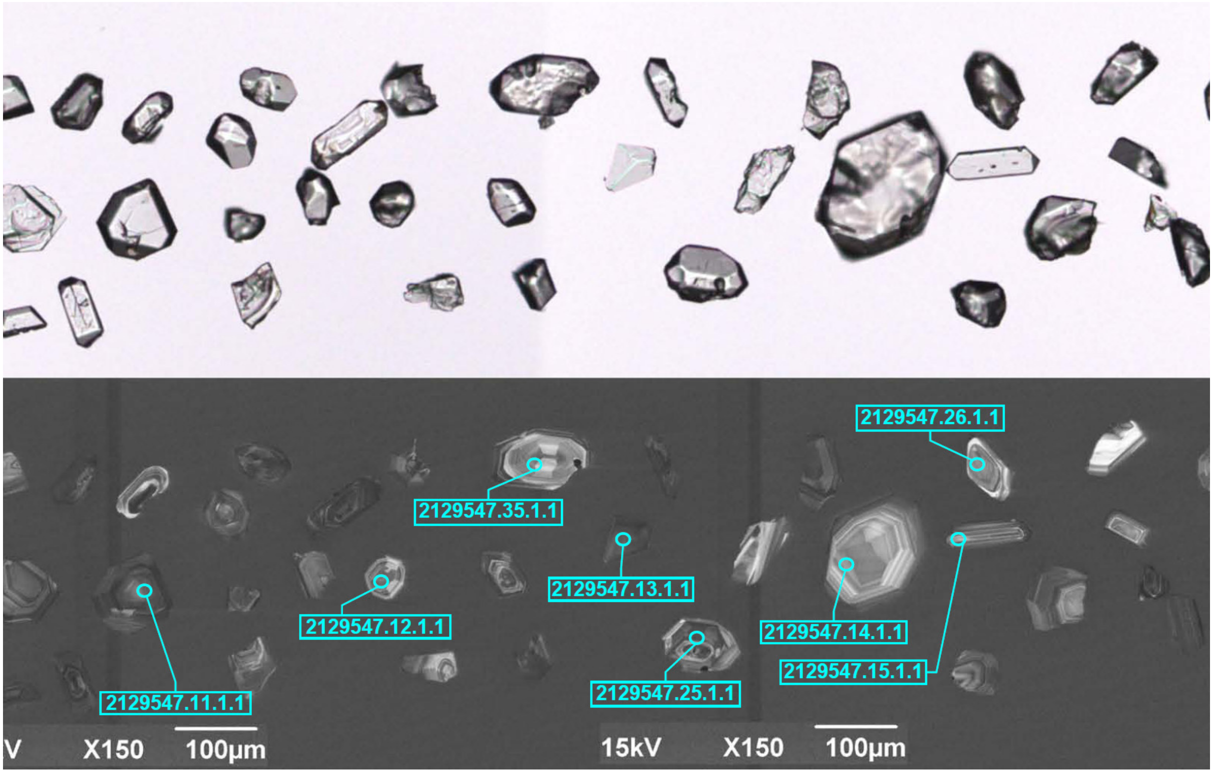


Figure 10.3 Representative zircons from the Nerong Volcanics (GSNSW: PB-12-PTS-01, GA: 2129547). Transmitted light image is shown in the upper half; Cathodoluminescence image is shown in the lower half. SHRIMP analysis sites are indicated, and labelled with sample, grain, spot and replicate number.

10.4 U–Pb Isotopic Results

Thirty-four analyses were obtained from 34 individual zircon grains; the results are presented in Table 10.2 and illustrated in Figure 10.4. Grain labels 18–21 were not used (see Appendix A.4.2).

One analysis (2129547.12.1.1) was adversely affected by heterogeneous U and Pb with depth, and another (2129547.4.1.1) yielded a large negative $^{206}Pb_c$ value (-1.5%), indicating inaccurate common Pb correction. These two analyses (Figure 10.4, white fill; Table 10.2) are unreliable, and are not considered further.

The remaining 32 analyses are characterised by low to moderate U concentrations (57–861 ppm, median 355 ppm), consistent Th/U (0.34–1.25, median 0.67), and $^{206}Pb_c$ less than 0.92% (median 0.10%). They can be divided into two groups:

- Group 1: 31 analyses (Figure 10.4, pink fill; Table 10.2) with individual $^{206}Pb/^{238}U$ ages between ~331 Ma and ~352 Ma, which combine to produce a weighted mean $^{206}Pb/^{238}U$ age of 340.5 ± 2.0 Ma (95% confidence, MSWD = 0.95, probability = 0.55).
- Group 2: one analysis (Figure 10.4, blue fill; Table 10.2) yielded an unreliably young age of ~273 Ma.

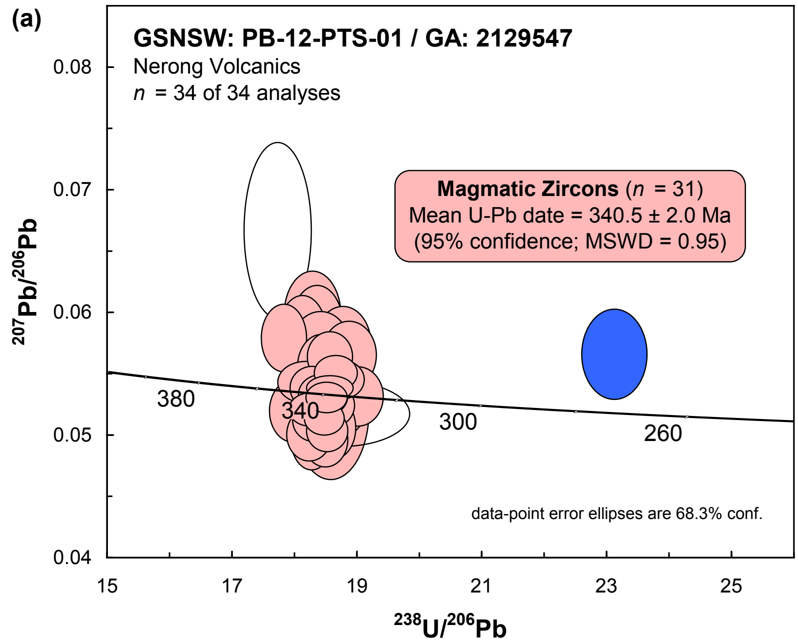
10.5 Geochronological Interpretation

The weighted mean $^{206}Pb/^{238}U$ age of 340.5 ± 2.0 Ma is interpreted as the best estimate of the magmatic crystallisation age for the zircons of the Nerong Volcanics, and consequently, the age of eruption onset for the Nerong Volcanics pile.

The single analysis in Group 2 is interpreted to have undergone a degree of post-crystallisation radiogenic Pb loss.

Carboniferous *Rhacopteris* flora recovered from sedimentary rocks interbedded with the Nerong Volcanics previously extended to ~325 Ma (White, 1994); the age range of this fossil can be extended at least as far back as ~340 Ma.

This new SHRIMP age and pertinent geological relationships are considered further in the discussion.



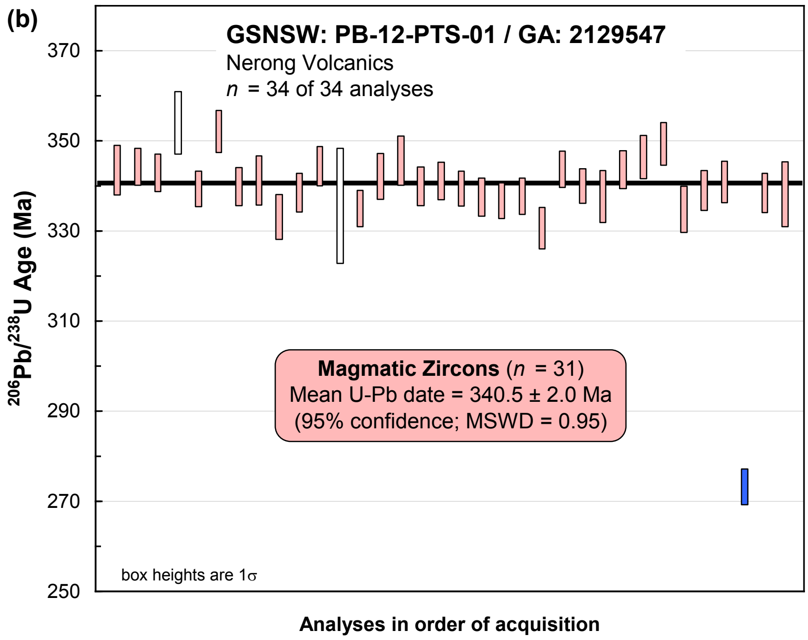


Figure 10.4 SHRIMP U–Pb data for zircons from the Nerong Volcanics (GSNSW: PB-12-PTS-01, GA: 2129547). Pink fill denotes Group 1 (magmatic crystallisation), blue fill denotes Group 2 (radiogenic Pb loss), and white fill denotes analyses not considered. (a) Tera-Wasserburg concordia diagram; (b) $^{206}Pb/^{238}U$ ages in order of acquisition. Heavy black line denotes the weighted mean $^{206}Pb/^{238}U$ age of the magmatic population.

Table 10.2 SHRIMP U–Pb isotopic data for zircons from the Nerong Volcanics (GSNSW: PB-12-PTS-01, GA: 2129547). All ages are $^{206}Pb/^{238}U$.

Session No.	Sample. Grain. Spot. Replicate	$^{206}Pb_c$ (%)	U (ppm)	Th (ppm)	$^{232}Th/^{238}U$	$^{238}U/^{206}Pb$	±1σ (%)	$^{207}Pb/^{206}Pb$	±1σ (%)	Age (Ma)	±1σ (Ma)
Group 1: Magmatic crystallisation (n = 31)											
120062	2129547.6.1.1	-0.53	299	175	0.60	17.813	1.4	0.05789	3.2	352.1	4.7
120062	2129547.32.1.1	0.31	249	187	0.77	17.957	1.4	0.05192	3.3	349.4	4.7
120062	2129547.31.1.1	-0.61	225	121	0.56	18.112	1.4	0.05808	3.8	346.4	4.8
120062	2129547.15.1.1	-0.15	436	452	1.07	18.156	1.6	0.05427	2.1	345.6	5.4
120062	2129547.11.1.1	0.28	348	270	0.80	18.219	1.3	0.05000	2.8	344.5	4.4
120062	2129547.2.1.1	0.04	458	409	0.92	18.227	1.2	0.05204	1.8	344.3	4.1
120062	2129547.27.1.1	0.92	510	486	0.98	18.259	1.2	0.04973	3.5	343.7	4.1
120062	2129547.30.1.1	0.15	381	160	0.43	18.265	1.3	0.05380	2.2	343.6	4.2
120062	2129547.1.1.1	-0.30	141	100	0.73	18.271	1.7	0.05977	3.9	343.5	5.5
120062	2129547.3.1.1	0.18	441	254	0.60	18.301	1.2	0.05115	2.2	342.9	4.2
120062	2129547.14.1.1	-0.53	198	131	0.69	18.345	1.5	0.05869	3.9	342.2	5.1
120062	2129547.8.1.1	0.00	157	52	0.34	18.395	1.6	0.05735	3.1	341.2	5.4
120062	2129547.17.1.1	0.10	417	383	0.95	18.403	1.3	0.05323	2.1	341.1	4.2
120062	2129547.35.1.1	-0.38	257	162	0.65	18.413	1.4	0.05550	3.2	340.9	4.6
120062	2129547.28.1.1	0.25	782	948	1.25	18.465	1.1	0.05133	1.8	340.0	3.8
120062	2129547.16.1.1	0.06	361	367	1.05	18.471	1.3	0.05317	2.0	339.9	4.3
120062	2129547.7.1.1	0.40	424	255	0.62	18.475	1.3	0.04959	3.0	339.8	4.2
120062	2129547.22.1.1	-0.09	656	407	0.64	18.496	1.2	0.05306	1.5	339.4	3.9
120062	2129547.5.1.1	0.31	612	287	0.48	18.503	1.2	0.05031	2.2	339.3	3.9
120062	2129547.34.1.1	0.33	301	164	0.56	18.517	1.3	0.05133	4.6	339.1	4.4
120062	2129547.10.1.1	-0.22	375	162	0.45	18.548	1.3	0.05637	2.4	338.5	4.3
120062	2129547.37.1.1	-0.04	861	467	0.56	18.550	1.3	0.05381	1.2	338.5	4.3
120062	2129547.38.1.1	0.34	57	43	0.77	18.564	2.2	0.05195	7.2	338.2	7.2
120062	2129547.29.1.1	0.33	407	191	0.48	18.592	1.8	0.05169	2.6	337.7	5.8
120062	2129547.25.1.1	0.25	456	326	0.74	18.594	1.2	0.05238	2.2	337.7	4.0
120062	2129547.23.1.1	0.54	343	375	1.13	18.602	1.3	0.05052	3.3	337.6	4.3
120062	2129547.24.1.1	-0.08	470	293	0.64	18.646	1.2	0.05504	1.7	336.8	4.0
120062	2129547.13.1.1	-0.09	447	349	0.81	18.747	1.2	0.05449	1.9	335.0	4.1
120062	2129547.33.1.1	-0.25	143	128	0.92	18.759	1.6	0.05740	3.5	334.8	5.2
120062	2129547.9.1.1	0.13	175	84	0.49	18.856	1.6	0.05651	3.2	333.1	5.0

Session No.	Sample. Grain. Spot. Replicate	$^{206}Pb_c$ (%)	U (ppm)	Th (ppm)	$^{232}Th/^{238}U$	$^{238}U/^{206}Pb$	±1σ (%)	$^{207}Pb/^{206}Pb$	±1σ (%)	Age (Ma)	±1σ (Ma)
120062	2129547.26.1.1	0.18	218	121	0.57	19.000	1.4	0.05309	3.0	330.7	4.6
Group 2: Loss of radiogenic Pb (n = 1)											
120062	2129547.36.1.1	0.47	174	135	0.80	23.112	1.5	0.05656	4.3	273.1	4.0
Not considered: Inaccurate common Pb correction (n = 1)											
120062	2129547.4.1.1	-1.45	98	56	0.59	17.714	2.0	0.06669	7.1	354.0	7.0
Not considered: Heterogeneous U and Pb with depth (n = 1)											
120062	2129547.12.1.1	0.37	270	234	0.90	18.714	3.9	0.05169	3.4	335.6	12.8

Discussion

This discussion specifically refers to the statistical distinguishability of samples within this Record with selective regional age comparisons; it does not consider all of the relevant and available geological and geochronological information, nor does it provide an exhaustive regional assessment. The comprehensive geological interpretations stemming from this data will be documented elsewhere.

Carboniferous

Port Stephens, in the southern-most reaches of the New England Orogen (NEO) was interpreted by Roberts et al. (1995) as the central focus and basal component of the Nerong Volcanics.

The sample dated herein is interpreted as part of the lowermost Nerong Volcanics, yielding an age of 340.5 ± 2.0 Ma that accords with the previous low-level age of 338.6 ± 3.8 Ma (Roberts et al., 1995) obtained from the type section (Crane and Hunt, 1979; Roberts et al., 1991), approximately 20 km north of the central focus and west of Bulahdelah. Biostratigraphic constraints from the sedimentary rocks above and below the Nerong Volcanics indicate that accumulation of the volcanic pile took at least 6 million years (Crane and Hunt, 1980; Roberts et al., 1995).

Carboniferous *Rhacopteris* flora, previously known up to ~325 Ma, have been recovered from sedimentary rocks interbedded with the ignimbrites at Soldiers Point, 10 km north-west of the current sample site (White, 1994), and our new result extends the age of *Rhacopteris* back at least as far as ~340 Ma.

Early Permian

The position of the Balala Granodiorite in the regional chronology of the southern NEO has been uncertain; on one hand, it appears to predate emplacement of the Bundarra Supersuite—which has previously yielded SHRIMP data at 286.2 ± 2.2 Ma (Banalasta Monzogranite, Black, 2007) and 288.7 ± 1.6 Ma (Pringles Monzogranite, Cross and Blevin, 2013)—yet on the other hand, it is geochemically and petrographically indistinguishable from the ~255 Ma I-type Uralla Supersuite, although a Rb–Sr biotite age of ~275 Ma (Shaw and Flood, 1993) is significantly older.

The Rb–Sr data is supported by the mapped relationships, which indicate that the Balala Granodiorite is cut by the Yarrowyck Granodiorite (254.9 ± 1.5 Ma, this volume) and the Wongalee Leucogranite of the Uralla Supersuite, and the Regional Felsic Dyke Swarm (252.5 ± 1.8 Ma, Cross and Blevin, 2010; 255.0 ± 1.5 Ma, this volume).

The new SHRIMP U–Pb age of 295.0 ± 1.7 Ma for the Balala Granodiorite is nevertheless older than expected (although indistinguishable from the 295.2 ± 2.3 Ma Glenburnie Adamellite) and confirms I-type plutonism in the southern NEO during the earliest Permian, prior to emplacement of the Bundarra Supersuite.

Late Permian

The Wandsworth Volcanic Group (WVG) is traditionally regarded as having the Drake Volcanics at its base. However, Cross and Blevin (2010) dated the Drake Volcanics at 264.4 ± 2.5 Ma, noted that its chemical composition is distinct from the rest of the WVG, and recommended that the unit be seceded from the WVG.

With the Drake Volcanics excluded, this Record presents three new dates from near the base of the redefined WVG to ascertain the extent of regional age variation, determine the age of the base of the extensive volcanic pile and to compare with local intrusive units.

The three informally-named units yielded identical magmatic crystallisation ages: 256.0 ± 1.5 Ma for the 'Uralla volcanics', 255.8 ± 1.5 Ma for the 'Attunga Creek volcanics' and 256.3 ± 1.5 Ma for the 'Kurrajong Park volcanics'. All three dates are completely consistent with existing age data for the units higher in the WVG succession: 254.1 ± 2.2 Ma for the Dundee Rhyodacite (Brownlow and Cross, 2010; and 254.34 ± 0.34 Ma, TIMS) and 252.3 ± 2.0 Ma for the Emmaville Volcanics (Cross and Blevin, 2013). These three new ages extend the known timeframe of WVG magmatic activity in the region to a minimum of 4 million years.

The 256.0 ± 1.5 Ma WVG 'Uralla volcanics' was sampled adjacent to the contact with the 253.3 ± 1.4 Ma intrusive Khatoun Tonalite. The volcanics are also intruded by the Uralla Granodiorite and Wilhelmshohe Tonalite, which are interpreted to have ages in the range 252–255 Ma based on association with similar granites immediately to the northwest, Rb–Sr ages of 251–246 Ma obtained by Shaw et al. (1994) from the Uralla Granodiorite, and SHRIMP ages of 255–251 Ma on other Uralla Supersuite granites (Cross and Blevin, 2010; 2013).

The 255.8 ± 1.3 Ma 'Attunga Creek volcanics' represent the southwestern-most occurrence of the WVG (Vickery et al., 2010), and are intruded and metamorphosed by the Attunga Creek Monzogranite of the Moonbi Supersuite. Bywater (1991) demonstrated a geochemical affinity between the Attunga Creek Monzogranite and the overlying volcanics, concluding they are comagmatic and the volcanics collapsed onto the monzogranite during subsidence and cooling.

The intrusive Attunga Creek Monzogranite has an Rb–Sr age of 249 Ma (Shaw et al., 1994), similar to Rb–Sr ages on Moonbi Supersuite granites (243–250 Ma, Shaw et al., 1994), most of which have since yielded U–Pb SHRIMP ages within the range 254–252 Ma. These previously SHRIMP-dated Moonbi Supersuite units include the Inlet Monzonite (252.6 ± 1.9 Ma: Black, 2007; 251.3 ± 2.6 Ma, Jeon, 2012), Walcha Road Monzogranite (253.8 ± 1.8 Ma, Black, 2006; 251.8 ± 3.0 Ma, Jeon, 2012), Red Range Leucoadamellite (253.2 ± 1.5 Ma, Cross and Blevin, 2013), Oban River Leucoadamellite (252.1 ± 1.4 Ma, Cross and Blevin, 2013) and the Bendemeer Monzogranite (247.5 ± 1.6 Ma, Jeon, 2012).

Based on geochemical conclusions in Bywater (1991), the magmatic crystallisation age of 255.8 ± 1.5 Ma for the 'Attunga Creek volcanics' can be extrapolated to infer the Attunga Creek Monzogranite is similar in age to other Moonbi Supersuite granites, supporting theories that the 'Attunga Creek volcanics' and the Attunga Creek Monzogranite are comagmatic and subsidence onto a still-cooling pluton resulted in local contact metamorphism of the volcanic unit. Additionally, the subsidence of the volcanics onto the pluton indicates minimal loss of initial volcanic pile material to erosion, suggesting that the unit may be close to the base of the volcanic pile.

The sample of the WVG ‘Kurrajong Park volcanics’ was taken from the base of the local volcanic sequence and was hornfelsed during subsequent emplacement of the Kurrajong Park Leucogranite.

Dating of the Yarrowyck Granodiorite and the Khatoun Tonalite was undertaken to confirm intrusive field relationships and establish age relationships with other Uralla Supersuite members. The Yarrowyck Granodiorite cuts the Balala Granodiorite (295.0 ± 1.7 Ma) immediately to the south of the sample area and is cut by the Regional Felsic Dyke Swarm (RFDS). The magmatic crystallisation age for the Yarrowyck Granodiorite of 254.9 ± 1.5 Ma is indistinguishable from the new RFDS magmatic crystallisation age of 255.0 ± 1.5 Ma, despite cross-cutting relationships between the granodiorite and member units of the RFDS. Phillips et al. (2011) obtained a U–Pb zircon LA-ICPMS age of 249 ± 3 Ma on the Yarrowyck Granodiorite that is inconsistent with the age reported herein and mapped geological relationships. The new magmatic crystallisation age is consistent with mapped relationships.

The new RFDS age, compared with a previous SHRIMP age on the RFDS (252.5 ± 1.8 Ma, Cross and Blevin, 2010), reveals an expanded chronology for emplacement of the RFDS and indicates the new date is from an earlier flush of intrusive activity in the region. Further, this new age disentangles complex relationships between units involving the RFDS, for example, the where the RFDS cuts the Yarrowyck Granodiorite, but both are truncated by the Gwydir River Adamellite (252.3 ± 1.5 Ma, Cross and Blevin, 2010).

The Khatoun Tonalite intrudes the WVG ‘Uralla volcanics’ and is intruded by the Uralla Granodiorite and the Manuka Farm Porphyritic Microtonalite (both undated by SHRIMP), and the RFDS. The magmatic crystallisation age of 253.3 ± 1.4 Ma obtained for the Khatoun Tonalite is very slightly younger than the new RFDS age (255.0 ± 1.5 Ma), but is within error of the younger RFDS age (252.5 ± 1.8 Ma, Cross and Blevin, 2010). The new RFDS age does not concur with the geological relationships that indicate the Khatoun Tonalite is cut by the RFDS, however, the expanded age range of the RFDS and the initial age obtained by Cross and Blevin (2010) indicate the newly dated RFDS sample is from an older phase of the swarm.

Other SHRIMP dated Uralla Supersuite members include the Gwydir River Adamellite at 252.3 ± 1.5 Ma, Tingha Adamellite at 251.3 ± 1.7 Ma and Parlour Mountain Granite at 254.7 ± 1.6 Ma (Cross and Blevin, 2010), and the Mount Duval Monzogranite at ~253.7 ± 1.4 Ma (Cross and Blevin, 2013).

Late Triassic

Coastal granitoid magmatism in the New England Ororgen occurred episodically between ~240 Ma and ~210 Ma (Cross and Blevin, 2013). A Late Triassic magmatic crystallisation age of 227.3 ± 1.3 Ma for the ‘Kindee Creek tonalite’ corresponds to the 228.4 ± 1.7 Ma age obtained for the Yarrahappini Adamellite by Cross and Blevin (2013), and with the Valla Granite at 230.7 ± 1.6 Ma, contributes to the ~230 Ma flush of magmatism in the region. Other SHRIMP dated Triassic plutons in the region are the Round Mountain Leucoadamellite at 238.0 ± 1.7 Ma, Glen Esk Adamellite at 221.2 ± 1.5 Ma and the Smokey Cape Adamellite at 218.4 ± 1.6 Ma (Cross and Blevin, 2013).

Acknowledgements

At Geoscience Australia we are fortunate to have a highly skilled and dedicated team in the Mineral Separation Laboratory. We thank Chris Foudoulis (ret.), David DiBugnara, Ben Linehan and Simon Webber for the production of high quality zircon separates mounts and images used in this report. Patrick Burke was responsible for maintaining the SHRIMP instrument; assistance with tuning and troubleshooting is greatly appreciated. We also acknowledge Simon Bodorkos and Andrew Cross for advice, technical assistance and discussions on various aspects of data collection, processing and interpretation. Bob Brown, formerly of the GSNSW (ret.) is thanked for sample collection of the Wandsworth Volcanic Group. Simon Bodorkos and Natalie Kositcin are thanked for providing formal reviews of this record.

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Appendix A Analytical Procedures

A.1 Summary

All isotopic analyses reported in this record were undertaken using the SHRIMP-IIe at Geoscience Australia in Canberra. A summary of key parameters from individual analytical sessions is shown in Appendix Table A.1. The analytical procedures adopted (outlined in sections A.3–A.4) for zircon follow those published by Compston et al. (1984), Claoué-Long et al. (1995), Nelson (1997), Williams and Claesson (1987), and Williams (1998). Procedures and parameters relevant to the GSNSW–GA Geochronology Project are detailed in previous Records (e.g. Bodorkos et al., 2010; 2013), and parameters specific to this Record are updated below.

A.2 Sample Preparation

A.2.1 Sample Acquisition

The locations of field sites refer to the Geocentric Datum of Australia 1994 (GDA94). Coordinates are reported as decimal latitude and longitude, and as Map Grid of Australia eastings and northings (MGA94; Zone 56). Site locations are labelled using relevant identifiers in corporate databases: SITES SiteID for GSNSW, FIELDSITES SampleNo for GA.

Three of the nine samples in this report (Wandsworth Volcanic Group) comprised whole rock material collected in the field by Emma Chisholm and Bob Brown in October 2010. The Nerong Volcanics, Khatoun Tonalite and Yarrowyck Granodiorite samples comprised whole rock material collected in the field by Phil Blevin. The Regional Felsic Dyke Swarm and the 'Kindee Creek tonalite' were provided as drill core material sourced from mining operations and the Balala Granodiorite was provided as rock-chip material remaining from geochemical analysis, provided by Phil Blevin.

A.2.2 Mineral Separation

In the Mineral Separation Laboratory at GA, whole rock samples were split into 4–6 cm blocks using a pre-cleaned Rocklabs hydraulic splitter, washed in an ultrasonic bath and dried in a Labec oven. Samples were then crushed to ~1 cm chips; approximately 50 gm of sample was removed at this stage and set aside for geochemical analysis for whole rock samples only; the remaining sample was milled with a target grain size between 50 µm and 200 µm.

Mineral-density separation commenced with gravity separation on a Wilfley Table with multiple iterations resulting in sample reduction to ~1% of total sample weight. After drying the sample in a clean oven, a ferrous and a rare-earth magnet were used respectively to remove the paramagnetic grains from the heavy mineral fraction remaining from the Wilfley separation. The lesser-magnetic remnant then underwent a series of magnetic separations on a Frantz Isodynamic Separator (Frantz), with up to 12 separations in total. The magnetic current was sequentially increased, consecutively removing the more paramagnetic grains. The sample underwent density separation using diiodomethane (specific gravity 3.3) before being returned to the Frantz; sequential adjustments made to the horizontal tilt of the chute consecutively removed paramagnetic fractions. Zircon grains were then handpicked in a Petri dish in a solution of 99.95% ethanol. Selection of grains for all samples was biased towards the least magnetic and clearest grains to aid determination of a magmatic crystallisation age. External morphologies were not biased against.

Appendix Table A.1 Summary of session-specific metadata; parameters obtained from analyses of $^{206}Pb/^{238}U$ and $^{207}Pb/^{206}Pb$ reference zircons and samples analysed.

	Session 110005	Session 120062
MountID	GA6152	GA6201
Session dates	12–16 January 2011	20–23 August 2012
Calibration batch number	1 of 1	1 of 1
206Pb/238U reference zircon	TEMORA2: 416.8 ± 1.3 Ma (Black et al., 2004)	TEMORA2: 416.8 ± 1.3 Ma (Black et al., 2004)
Analyses used	35 of 36	53 of 53
206Pb/238U session-to-session error (2σ)	0.34%	0.36%
206Pb/238U spot-to-spot error (2σ)	1.14% increased to 2.00%	0.00% increased to 2.00%
Slope of ln(206Pb+/238U+) / ln(254UO+/238U+) [Calibration exponent C used, eqn (3)]	1.63 +0.37/-0.31 [2.00]	1.55 +0.28/-0.63 [2.00]
Mean 207Pb/206Pb age (Ma, 95% confidence)	372 ± 33 Ma	451 ± 55 Ma
Mean 204Pb overcounts/second from 207Pb (95% confidence)	+0.022 ± 0.019 (no correction)	-0.007 ± 0.010 (no correction)
207Pb/206Pb reference zircon	OG1: 3465.8 ± 0.6 Ma (Stern et al., 2009)	OG1: 3465.8 ± 0.6 Ma (Stern et al., 2009)
Analyses used	26 of 26	15 of 15
Mean 207Pb/206Pb age (Ma, 95% confidence)	3463.2 ± 1.9 Ma	3468.1 ± 2.5 Ma
Mass fractionation correction applied	No	No
Number of samples analysed	5	4
GSNSW SiteID (GA SampleNo)	BB-10-WVG-05 (2120074)	PB-12-URA-01 (2129544)
GSNSW SiteID (GA SampleNo)	BB-10-WVG-07 (2120076)	PB-12-URA-02 (2129545)
GSNSW SiteID (GA SampleNo)	BB-10-WVG-08 (2120077)	PB-12-URA-03 (2129546)
GSNSW SiteID (GA SampleNo)	PB-10-BL-01 (2121504)	PB-12-PTS-01 (2129547)
GSNSW SiteID (GA SampleNo)	PB-10-BWD -01 (2121505)	—

A.2.3 Mount Preparation

Where available, up to 200 handpicked grains for each of the nine samples were mounted in a 25 mm epoxy-resin disc (GA6152, GA6201) together with ~100 grains of the $^{206}Pb/^{238}U$ zircon reference TEMORA2 (416.8 ± 0.3 Ma, Black et al., 2004), ~80 grains of the $^{207}Pb/^{206}Pb$ zircon reference OG1 (3465.4 ± 0.6 Ma; Stern et al., 2009) and a fragment of the uranium concentration standard M257 (840 ppm U; Nasdala et al., 2008). After cooling, epoxy discs were placed in an oven at 60°C for 24 hours to assist epoxy curing. Following curing, mounts were polished on a Struers polisher to expose an equatorial cross-section through the mounted zircon grains, photographed in reflected and transmitted light using a Leica DM6000 and a Leica DFC310 FX 1.3 Mp camera, cleaned with ethanol and Milli-Q water and coated with a 2 nm thickness of gold prior to Cathodoluminescence imaging in a JEOL JSM-6490LV Scanning Electron Microscope housed at Geoscience Australia. The thin gold coat was then removed using 99.95% ethanol and mounts cleaned ultrasonically using first RB32 detergent, then petroleum spirit, followed by 99.95% ethanol and finally triple rinsed in Milli-Q water. Mounts were dried in a 30°C oven prior to being coated with 15 nm of 99.999% gold.

Each mount was loaded into the high-vacuum SHRIMP sample lock chamber 48 hours prior to analysis to enable complete out-gassing of the newly-cured epoxy and lowered into the SHRIMP source chamber immediately prior to analysis.

A.3 Zircon data acquisition and processing

A.3.1 Data Acquisition

Sensitive High Resolution Ion Micro Probe (SHRIMP) U–Pb zircon analyses were obtained on the SHRIMP-IIe instrument housed at Geoscience Australia in the SHRIMP Laboratory.

A 100 µm Kohler aperture was used to achieve a 25 µm diameter primary beam of O^{2-} ions at 10 keV (selected by means of a Wein filter) with total ion count at the mount surface between 1.8 nA and 2.5 nA to cause atoms on the crystal surface to sputter and ionise. Approximately 3 ng of sample is sputtered, forming a flat-bottom pit 0.5–2 µm deep. Sputtered secondary ions are extracted from the sample surface and are focussed and steered through an electrostatic analyser and magnet into a collector through a series of electrostatic lenses and steering plates.

Prior to each analysis the surface of the analysis site was cleaned by rastering the beam for three minutes to reduce the amount of surface common lead. Data acquisition involved six magnet cycles through a ten mass-station run-table with the following counting times in seconds (s): $^{196}Zr_2O$ (2 s), background 204.1 (20 s), ^{204}Pb (20 s), ^{206}Pb (15 s), ^{207}Pb (40 s), ^{208}Pb (5 s), ^{238}U (5 s), ^{248}ThO (2 s), ^{254}UO (2 s) and $^{270}UO_2$ (2 s). A full analysis (6 scans of the run-table) was set for 25 minutes with these conditions.

Once the instrument was tuned the analytical session commenced with an analysis of M257 zircon for calibration of the uranium concentration measurement (840 ppm U; Nasdala et al., 2008) and data program inputs for SHRIMP software. This is followed by reference zircon analyses for an early indication of machine performance: $^{206}Pb/^{238}U$ ratios were calibrated using the TEMORA2 reference zircon ($^{206}Pb/^{238}U$ = 416.8 Ma, Black et al., 2004), and $^{207}Pb/^{206}Pb$ ratios monitored using the OG1 reference zircon ($^{207}Pb/^{206}Pb$ = 3465.4 Ma, Stern et al., 2009). The usage of decay constants followed Steiger and Jäger (1977).

Standard procedures in the GA Geochronology Laboratory for analysis site labels are used herein and take the form: SampleNumber.GrainNumber.SpotNumber.ReplicateNumber; where grains are numbered in sequence of analysis, spots are numbered in sequence of analysis within a grain, and replicates are numbered in sequence of analysis within a single spot location (e.g. 2129547.10.1.1).

Analyses were collected in a 'round-robin' sequence of one measurement from each sample on the mount in turn with one measurement of TEMORA2 reference zircon made after every third to fourth sample analysis, and a minimum of one OG1 reference zircon measured after every second TEMORA2 measurement. During each session run, periodic data reduction was undertaken to monitor machine performance and assess the $^{206}Pb/^{238}U$ calibration and $^{207}Pb/^{206}Pb$ ratios.

A.3.2 Data Processing

Data from the SHRIMP was processed, calculated and portrayed using Microsoft Excel® 2003, and the add-ins SQUID 2.50.09.08.06 (Ludwig, 2009) and Isoplot v3.71.09.05.23 (Ludwig, 2008) downloaded from Sourceforge (http://sourceforge.net/). Squid processes standard and spot data for evaluation, calculates element concentrations and isotopic ratios required for age calculation, and propagates the uncertainties associated with the $^{206}Pb/^{238}U$ ages. The decay constants used are those of Jaffey et al., (1971), together with present-day $^{238}U/^{235}U$ = 137.88, following the recommendations of Steiger and Jäger (1977).

Common-Pb corrections for unknowns were based on measured ^{204}Pb, and a Pb isotopic composition calculated using the single-stage Pb isotopic evolution model of Stacey and Kramers (1975) at a date corresponding to the individually estimated age of each unknown analysis. The result of this calculation is expressed for each analysis in each of the analytical data-tables, in terms of common ^{206}Pb as a percentage of total measured ^{206}Pb ($^{206}Pb_c$). All isotopic ratios and dates cited in this Record are corrected for common Pb.

Dates derived from the pooling of multiple individual analyses are error-weighted means unless otherwise specified, and their uncertainties are quoted at the 95% confidence level unless otherwise indicated. Each error-weighted mean has an associated Mean Square of Weighted Deviates (MSWD) value, which is a measure of the degree of scatter of the constituent analyses relative to the assigned uncertainties (Ludwig, 2003), and a 'probability of equivalence' (P_{equiv}) value, which is the probability that all of the constituent analyses are equivalent within their uncertainties. By convention, scatter beyond the assigned uncertainties is assumed to be present when P_{equiv} is less than 0.05. In cases where P_{equiv} is equal to or greater than 0.05, but the MSWD value exceeds 1, the implied dispersion of the data-points beyond their analytical uncertainties is acknowledged by expanding the 95% confidence interval of the mean, via multiplication of its 1σ error firstly by Student's t for n - 1 degrees of freedom (where n is the number of constituent analyses), and secondly by the square root of the MSWD value (Ludwig, 2003).

A.3.3 Calibration Procedures

Elemental U concentrations in the unknown zircons were calibrated using the M257 reference zircon (840 ppm U; Nasdala et al., 2008), and the power-law relationship of Claoué-Long et al., (1995):

$$\left[{}^{196}Zr_2O^+/{}^{238}U^+\right] = A \times \left[{}^{254}UO^+/{}^{238}U^+\right]^{0.66} \tag{1}$$

where A is a session-dependent constant determined from measurements on M257. All U concentration data tabulated for unknowns have uncertainties of the order of 15–20%, based on the extent of known variations in U abundance in M257.

The values of $^{232}Th/^{238}U$ in the unknown zircons were calculated using the relationship proposed by Williams et al. (1996):

$$^{232}\mathrm{Th}/^{238}\mathrm{U} = \left[^{248}\mathrm{ThO}^{+}/^{254}\mathrm{UO}^{+}\right] \times \left\{\left(0.03446 \times \left[^{254}\mathrm{UO}^{+}/^{238}\mathrm{U}^{+}\right]\right) + 0.868\right\} \quad (2)$$

The values of $^{238}U/^{206}Pb$ in the unknowns were calibrated using the TEMORA2 reference zircon ($^{206}Pb/^{238}U$ = 0.0668, corresponding to an age of 416.8 Ma; Black et al., 2004), and a power-law relationship (Claoué-Long et al., 1995) of the form:

$$\left[^{206}\mathrm{Pb}^{+}/^{238}\mathrm{U}^{+}\right] = \mathrm{B} \times \left[^{254}\mathrm{UO}^{+}/^{238}\mathrm{U}^{+}\right]^{\mathrm{C}} \quad (3)$$

where B and C are session-dependent constants determined from measurements on TEMORA2. The canonical value of C is 2.00 (Claoué-Long et al., 1995; Williams, 1998), but its session-specific apparent value was determined independently (via calculation of the slope of the robust regression of $\ln[^{206}Pb^{+}/^{238}U^{+}]$ against $\ln[^{254}UO^{+}/^{238}U^{+}]$) in order to inform the decision regarding the most applicable value for each session. In general, the 95% confidence interval of the independently determined value encompassed 2.00, so the canonical value was used.

The values of $^{207}Pb/^{206}Pb$ in the unknowns were monitored using the OG1 reference zircon ($^{207}Pb/^{206}Pb$ = 0.29907 ± 0.00011, corresponding to an age of 3465.4 ± 0.6 Ma; Stern et al., 2009). For each session, the error-weighted mean $^{207}Pb/^{206}Pb$ age for OG1 (denoted $[^{207}Pb/^{206}Pb]_{OG1}$) was calculated (Appendix Table A.1), and the procedure of Stern et al. (2009) was used to determine an instrumental mass fractionation (IMF) factor (α):

$$\alpha = \left[^{207}\mathrm{Pb}/^{206}\mathrm{Pb}\right]_{\mathrm{OG1}} / 0.29907 \quad (4)$$

The session-specific α values are summarised in Appendix Table A.1. In some geological scenarios (e.g. when comparing highly precise weighted mean $^{207}Pb/^{206}Pb$ dates from Archean and Paleoproterozoic rocks), it is desirable to perform session-specific standardisation of $^{207}Pb/^{206}Pb$ and propagate inter-session calibration uncertainties, as described in detail by Bodorkos et al. (in press). However, in the samples documented in this Record, zircons of pre-Neoproterozoic age were rarely encountered, and the calculation of weighted mean $^{207}Pb/^{206}Pb$ dates was unnecessary. Uncertainties on individual $^{207}Pb/^{206}Pb$ analyses are governed by (relatively poor) counting statistics, and are almost always large enough that both the instrumental mass fractionation correction and its associated uncertainty are rendered insignificant. Consequently, the tabulated values of $^{207}Pb/^{206}Pb$ for each sample have not been corrected for instrumental mass fractionation.

A.3.4 Propagation of Uncertainties

In each session, a 'calibration constant' value is determined for each individual analysis of the $^{238}U/^{206}Pb$ reference zircon TEMORA2 (i.e. $b_i = [^{206}Pb^{+}/^{238}U^{+}]_i/([^{254}UO^{+}/^{238}U^{+}]_i^{C})$. Uncertainties associated with each of these individual 'calibration constants' (i.e. ± b_i) are governed primarily by the counting statistics associated with the constituent isotopic ratio(s). The value of the session 'calibration constant' (B; see equation (3)) is calculated as the error-weighted mean of the session-specific population of individual calibration constants. However, these populations commonly display significant excess scatter, manifested as an MSWD value for B that far exceeds unity, despite the fact that most reference zircons are (by definition) characterised by $^{238}U/^{206}Pb$ homogeneity at a range of scales. This indicates that the values of ± b_i are usually underestimated in going from analysis to analysis. Consequently, for each session, SQUID calculates the constant additional uncertainty per spot (expressed as a percentage) that needs to be added in quadrature to each ± b_i value, in order to produce MSWD ~1 for the population of b_i values used to calculate B (Ludwig, 2009). This constant additional uncertainty is termed the 'spot-to-spot error' (or 'reproducibility'), and its session-specific 2σ values are presented in Appendix Table A.1. The 1σ spot-to-spot error is added in quadrature to the other sources of error (principally related to counting statistics and the common Pb correction) for each value of $^{238}U/^{206}Pb$ in the unknowns, and thus is incorporated in the uncertainties for all individual $^{238}U/^{206}Pb$ values presented in the analytical data-tables.

For each session, SQUID also calculates an uncertainty for the session-specific calibration constant (i.e. ± B). This uncertainty is termed the 'session-to-session error' (or 'calibration uncertainty'), and its session-specific 2σ values are presented in Appendix Table A.1. The session-to-session error is not included in the uncertainties for individual $^{206}Pb/^{238}U$ values presented in the analytical data-tables, and should be neglected when comparing error-weighted mean $^{206}Pb/^{238}U$ dates for unknowns co-analysed in a single analytical session. However, it must be accounted for when seeking to compare $^{206}Pb/^{238}U$ datasets more widely (e.g. between different analytical sessions), especially when calculating error-weighted mean $^{206}Pb/^{238}U$ dates for unknowns, because the session-to-session error can be of comparable magnitude to the 95% confidence interval arising from population statistics.

For example, calculating the magmatic crystallisation age of the Khatoun Tonalite (GSNSW PB-12-URA-01, GA 2129544) using the 34 $^{238}U/^{206}Pb$ dates in Group 1 (Table 7.2) yields a weighted mean age of 253.3 ± 1.1 Ma (i.e. an uncertainty of 0.36% at the 95% confidence level) based solely on the tabulated data. This uncertainty is appropriate for the purpose of direct comparison with the co-analysed Regional Felsic Dyke Swarm 'porphyritic granodiorite dyke' (GSNSW PB-12-URA-03, GA 2129546), for which the analogous calculation yields a weighted mean $^{206}Pb/^{238}U$ date of 255.0 ± 1.2 Ma for the 29 analyses in Group 1 (Table 8.2), because the two samples were co-analysed and thus share a common calibration. However, when seeking to compare the magmatic crystallisation age of the Khatoun Tonalite with any SHRIMP result beyond this session, it is necessary to include (via quadratic addition) the session-to-session error for the relevant session (0.36% (2σ) for session 120062; Appendix Table A.1), and the expanded uncertainty is given by $\text{sqrt}[(0.36\%)^2 + (0.36\%)^2] = 0.51\%$, which represents an absolute uncertainty of 1.4 Ma relative to a weighted mean of 253.3 Ma. Consequently, the magmatic crystallisation age of the Khatoun Tonalite is reported as 253.3 ± 1.4 Ma (and likewise the Regional Felsic Dyke Swarm 'porphyritic granodiorite dyke as 255.0 ± 1.5 Ma) throughout this Record, in order to maximise its comparability with existing (and future) geochronological determinations.

A.4 Session-specific calibrations and data processing

The data reported herein was obtained over the course of two analytical sessions. Session-specific calibrations and data processing are summarised in **Error! Reference source not found.** and detailed session-specific information is below.

A.4.1 Session 110005: Mount GA6152, 12–16 January 2011

This session comprised the analysis of five samples:

- BB-10-WVG-05 (GA 2120074): Wandsworth Volcanic Group: 'Uralla volcanics'
- BB-10-WVG-07 (GA 2120076): Wandsworth Volcanic Group: 'Attunga Creek volcanics'
- BB-10-WVG-08 (GA 2120077): Wandsworth Volcanic Group: 'Kurrajong Park volcanics'
- PB-10-BL-01 (GA 2122504): Balala Granodiorite
- PB-10-BWD-01 (GA 2122505): 'Kindee Creek tonalite'

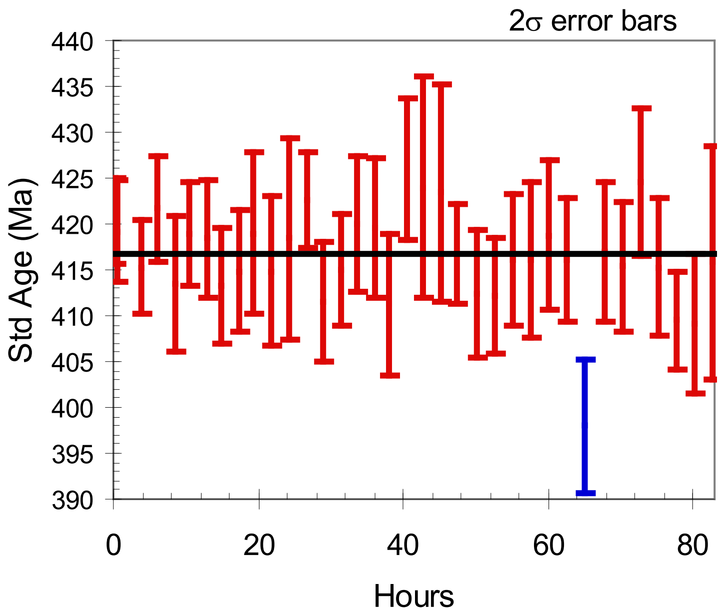
A total of 36 analyses of the TEMORA2 zircon standard were obtained during session 110005. One of these was removed from consideration prior to data processing due to an anomalously young age. Appendix Figure A.1 shows a well-defined calibration, with a 2σ session-to-session error of 0.34%, and a 2σ spot-to-spot error of 1.14%. The session-to-session error is included, in quadrature, in the uncertainty of each weighted mean $^{206}Pb/^{238}U$ age calculated for this session. The spot-to-spot error, however, is significantly lower than that typically determined for TEMORA2 on the GA SHRIMP IIe (e.g. Appendix A.3.5 of Bodorkos et al., 2013), which raises the possibility that the value determined for session 110005 is underestimated. Consequently, the spot-to-spot error for session 110005 was increased to a nominal 2σ value of 2.00% prior to its incorporation in quadrature into the uncertainties of individual $^{206}Pb/^{238}U$ analyses in the unknowns, based on (i) the recommendations of Stern and Amelin (2003) regarding the unaccounted variation in $^{206}Pb/^{238}U$ measurements via SHRIMP in general, modified by (ii) the consistent behaviour of TEMORA2 when analysed by the Geoscience Australia SHRIMP IIe (Bodorkos et al., 2013).

Due to little dispersion in Ln [$(^{238}U^{16}O)^+/^{238}U^+$] for the 35 analyses, the slope is not well defined at 1.68 +0.37/-0.31, and is not significantly different from 2.0, therefore equation [1] was used with a value of 2.0 to define the calibration exponent B.

Overcounts on mass ^{204}Pb were monitored through reference to the robust mean of the $^{207}Pb/^{206}Pb$ ages determined for TEMORA2 (372 ± 33 Ma). This result is slightly younger than the reference value (416.8 ± 0.38; Black et al., 2004) at the 95% confidence level indicating that ^{204}Pb was potentially incorrectly counted. Estimated ^{204}Pb overcounts on measured ^{207}Pb ($^+$0.022 ± 0.02) is supported by those on measured ^{208}Pb (-0.037 ± 0.02); however, the overcount correction was not applied to the concurrently analysed unknowns because the effect is marginal (weighted means increase by 0.2 Ma and 0.4 Ma) as listed below:

- 2120074 = +0.4 Ma
- 2120076 = +0.2 Ma
- 2120077 = +0.3 Ma
- 2121504 = +0.2 Ma
- 2121505 = +0.3 Ma

A total of 26 analyses of the $^{207}Pb/^{206}Pb$ reference zircon OG1 were obtained over the SHRIMP session with a weighted mean of 3463.2 ± 1.9 Ma (MSWD = 0.90). As this result is indistinguishable from the OG1 reference value of 3465.4 ± 0.6 Ma (Stern et al., 2009), no correction for instrumental fractionation of $^{207}Pb/^{206}Pb$ was applied to the session.



Appendix Figure A.1 SHRIMP $^{206}Pb/^{238}U$ ages on TEMORA2 zircon during SHRIMP Session 110005 in order of acquisition. Red bars are analyses used in the determination of the $^{206}Pb/^{238}U$ uncertainty and reproducibility. Heavy black line is the reference age of 416.8 Ma. Error bars are 2σ, n = 36.

A.4.2 Session 120062: Mount GA6201, 20–23 August 2012

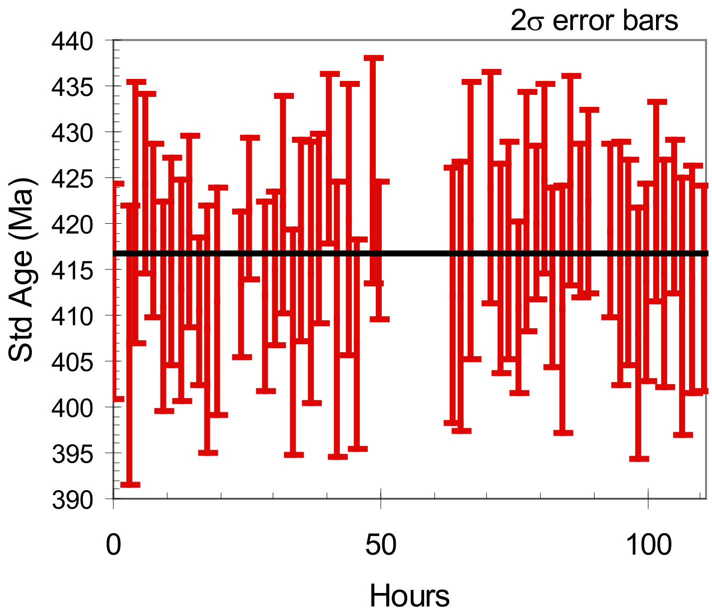
This session comprised the analysis of four samples:

- PB-12-URA-01 (GA 2129544): Khatoun Tonalite
- PB-12-URA-02 (GA 2129545): Yarrowyck Granodiorite
- PB-12-URA-03 (GA 2129546): Regional Felsic Dyke Swarm
- PB-12-PTS-01 (GA 2129547): Nerong Volcanics

Session 120062 was beset by a transient 14-hour period of instrumental instability. All analyses from this period, including the standards, were removed prior to final processing of the data file. After this, a total of 53 analyses of the TEMORA2 zircon standard were used from SHRIMP session 120062 at Geoscience Australia to define the calibration (Appendix Figure A.2), with a 2σ internal uncertainty on the weighted mean of 0.36% and assigned $^{206}Pb/^{238}U$ reproducibility at 2σ of 2.00%. The former value is included in the weighted mean uncertainty for each $^{206}Pb/^{238}U$ age calculated for this session. The latter value is the uncertainty associated with $^{206}Pb/^{238}U$ for individual analyses in this session at the 1σ level (0.60%). Due to little dispersion in Ln $[(^{238}U^{16}O)^+/^{238}U^+]$ for the 33 analyses, the slope is defined at 1.55 +0.28/-0.26, and is significantly different from 2.0. Processing data with defined slopes did not alter the results, therefore equation [1] was used with a value of 2.0 to define the calibration exponent B.

Overcounts on mass ^{204}Pb were monitored through reference to the robust mean of the $^{207}Pb/^{206}Pb$ ages determined for TEMORA2 (451 ± 55 MA). This result is within error of the reference value (416.8 ± 0.38 Ma; Black et al., 2004) at the 95% confidence level indicating that there were no irregularities with ^{204}Pb counts, therefore no correction was required.

A total of 25 analyses of the $^{207}Pb/^{206}Pb$ reference zircon OG1 were obtained over the SHRIMP session with a weighted mean of 3468.5 ± 2.5 Ma (MSWD = 0.93). As this result is indistinguishable from the OG1 reference value of 3465.4 ± 0.6 Ma (Stern et al., 2009), no correction for instrumental fractionation of $^{207}Pb/^{206}Pb$ was applied to the session.



Appendix Figure A.2 SHRIMP $^{206}Pb/^{238}U$ ages on TEMORA2 zircon during SHRIMP Session 120062 in order of acquisition. Red bars are analyses used in the determination of the $^{206}Pb/^{238}U$ uncertainty and reproducibility. Heavy black line is the reference age of 416.8 Ma. Error bars are 2σ, n = 53. Central gap between hours 52 and 63 is a result of transient instrument instability where all data was deleted.