

A Middle Triassic age for felsic intrusions and associated mineralisation in the Doradilla prospect area, New South Wales

ABSTRACT

The Doradilla prospect area, containing a skarn-type deposit, lies 45 km south-east of Bourke in western New South Wales. Tin and other base metal mineralisation is genetically associated with the highly fractionated I-type Midway granite. In this study, the SHRIMP zircon U–Pb dating technique has been used to determine that the Midway granite and comagmatic quartz–feldspar porphyry dykes are of Middle Triassic age. Hence, it is concluded that the mineralisation is also Middle Triassic in age. No other granites of this age are known in the Bourke region. However, highly fractionated, weakly oxidised to reduced granites of Early to Middle Triassic ages with associated tin, gold and base metal mineralisation occur approximately 500 km to the east-northeast within the New England Orogen. This suggests that the Early to Middle Triassic pulse of magmatism that occurred in northern New South Wales is of greater extent than previously suspected and suggests that similar fertile granites may occur beneath cover within the Bourke–Brewarrina–Byrock region.

KEYWORDS: *Doradilla, tin, granite, quartz–feldspar porphyry, skarn, zircon, Middle Triassic, SHRIMP dating*

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INTRODUCTION

The Doradilla prospect area is 45 km south-east of Bourke in western New South Wales (Figure 1). Copper mineralisation was discovered in 1901, with 150–200 t of oxidised ore extracted at 8–25% Cu to 1920 (McClatchie 1969). Tin mineralisation was discovered in 1972 by North Broken Hill Limited (Forwood 1981), but to date it remains sub-economic, principally due to metallurgical difficulties. The prospect area has been extensively explored since the late 1960s, with numerous exploration holes having been drilled and numerous geophysical and geochemical surveys carried out.

The Doradilla mineralisation is skarn-hosted, occurring within a linear calc-silicate unit that has been contact metamorphosed and altered by the adjacent Midway granite and associated dyke swarm. Carr et al. (1995) reported a model lead age of 295 Ma for sulphides sampled from drill core from the Doradilla Prospect and suggested a late Carboniferous to early Permian thermal event was responsible for the intrusions and associated mineralisation. That result implied that the Doradilla system is significantly younger than other recognised granites in the region, some of which had been previously dated as Devonian using the K–Ar technique (e.g. Evernden & Richards 1962). Recent zircon U–Pb dating of granites in the area has returned Silurian and Early Devonian ages (Black unpublished data; Burton et al. in press).

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Given the anomalous model lead age for the Doradilla mineralisation, it was considered that a potentially more reliable dating method should be employed. This study represents the first attempt to definitively date intrusive rocks associated with mineralisation at the Doradilla Prospect using the zircon U–Pb method with the Sensitive High-Resolution Ion Microprobe (SHRIMP).

GEOLOGICAL SETTING OF THE DORADILLA PROSPECT AREA

Figure 2 is a geological map of the Doradilla prospect area. Exposure of bedrock in the area is poor and that which crops out is commonly deeply weathered. The depth of weathering extends to 100 m (Young 1982).

The Doradilla prospect area consists of a linear calc-silicate unit which extends for 16.8 km in a north-easterly direction (Poxon 1981). It is between 40 m and 110m wide (Plimer 1984) and extends to at least 330 m in depth (Freytag & Thompson 1981), dipping between 75° and 80° to the south-east (Young 1982). Known tin mineralisation occurs in three main areas — Doradilla (south of the Doradilla copper mine), Midway–East Midway and 3KEL (Figure 2) leading to the calc-silicate horizon being referred to by previous workers as the DMK line.

In the Doradilla area, tin mineralisation occurs in steeply plunging shoots with an estimated resource of 3 Mt at 1% Sn in the footwall of the calc-silicate unit (Freytag & Thompson 1981; Young 1982). Tin mineralisation is in the form of cassiterite and occurs with massive pyrite, pyrrhotite, galena, sphalerite, chalcopyrite, arsenopyrite, bismuth and bismuthinite (Freytag & Thompson 1981; Young 1982). The calc-silicate rock in that area consists of andradite and diopside with minor tremolite, wollastonite, calcium carbonate, vesuvianite, fluorite, phlogopite, actinolite, chlorite and magnetite (Kwak 1982; Young 1982).

In the Midway–East Midway and 3KEL areas tin occurs mainly as malayaite (a tin-rich titanite mineral — CaSnSiO_3) with very little cassiterite (Poxon 1981) along with sulphides, including bornite, chalcopyrite, sphalerite, galena, arsenopyrite, pyrrhotite and stannite with biotite, chlorite, titanite, magnetite, fluorite, calcite and quartz (Plimer 1984). Tin also occurs within pyroxene, garnet and magnetite (Joyce & Young 1981). Tungsten (as scheelite) is minor (Forwood 1981) and minor silver has been noted (Metals Exploration Limited 1984). The primary mineralisation resource for these three areas was estimated to be 0.36 Mt at 1.0% Sn (Forwood 1981) whereas the secondary (oxidised and supergene) mineralisation resource was estimated to amount to 600 000 t at 1.1% Sn (McGain 1990). High-grade occurrences of varlamoffite (a tin hydroxide) are present in deeply weathered fault and fracture zones, although extraction would be a problem (Kwak 1987).

Plimer (1984) described the calc-silicate rock in the Midway–East Midway–3KEL area as grading, both along and across

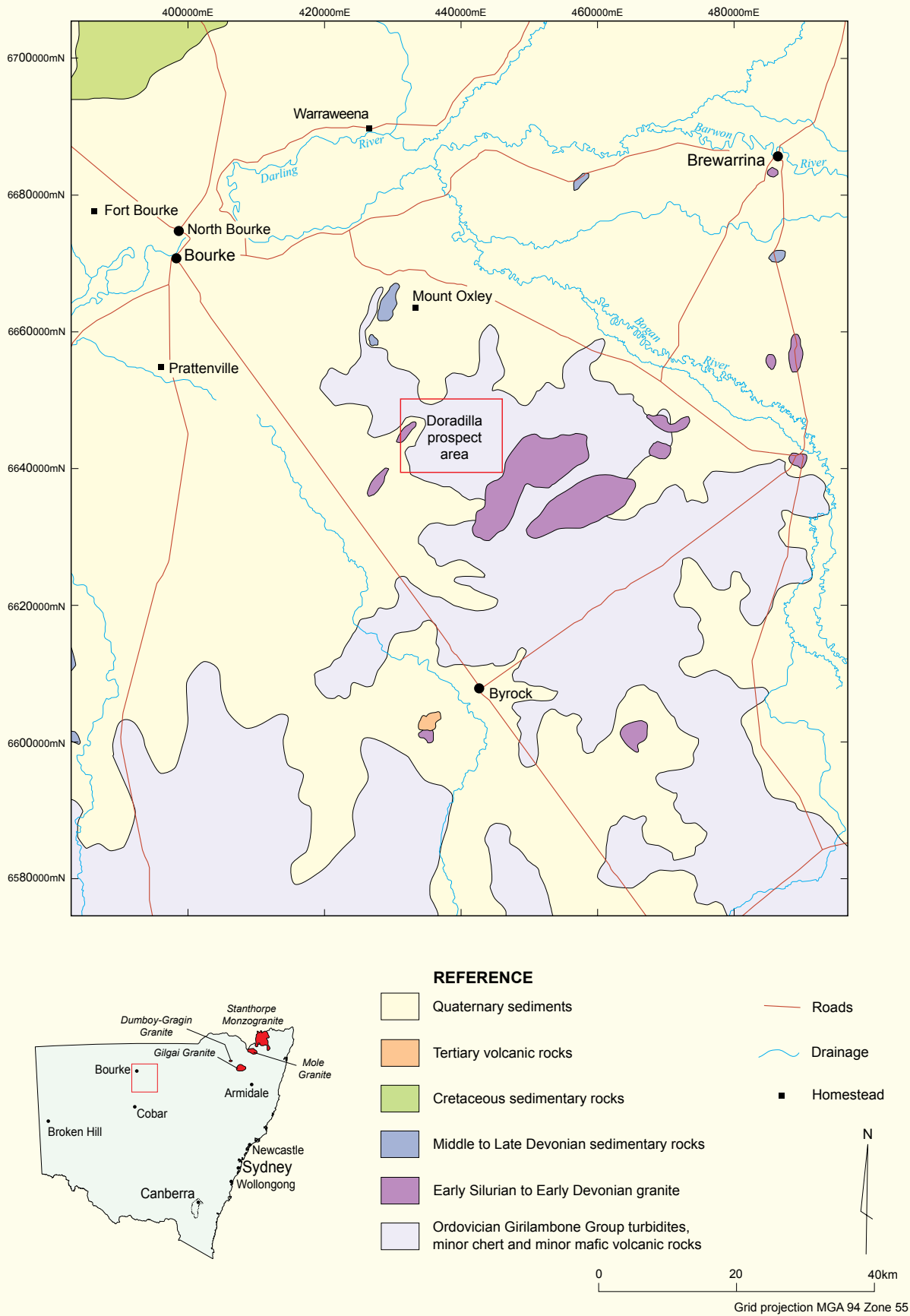


Figure 1 Location of the Doradilla prospect area. Geological linework is from Byrnes et al. (1993) and Fitzpatrick et al. (1965). Locations of granites of the New England area discussed in text are also shown.

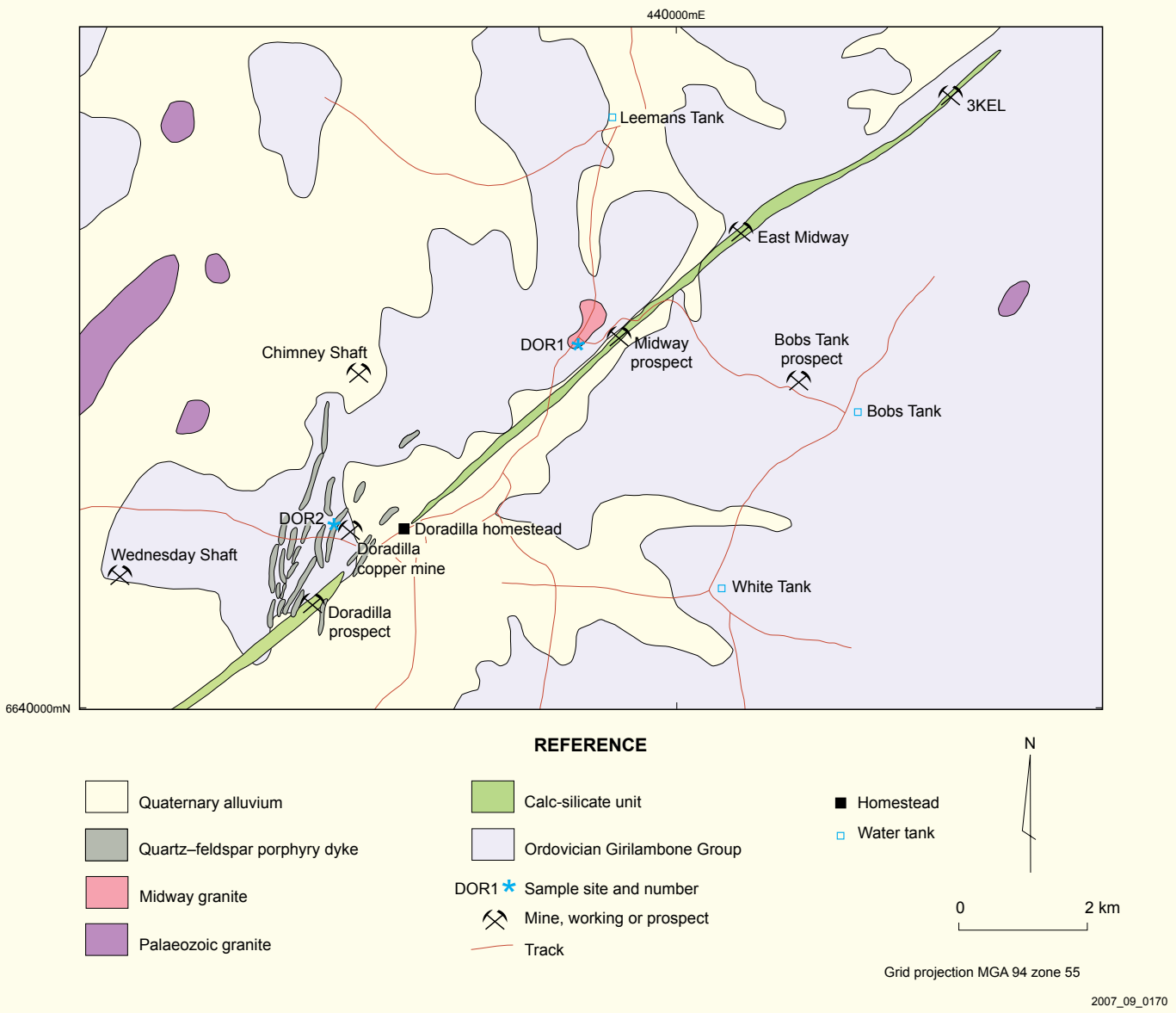


Figure 2 Geological map of the Doradilla prospect area, modified from Metals Exploration Limited (1981) and Byrnes et al. (1993).

strike, from granoblastic marble adjacent to the Midway granite, which he referred to as 'leucoadamellite', to complex skarn, consisting of grossular-andradite garnet, clinopyroxene, wollastonite and rare vesuvianite, away from the granite, and thence into well-laminated calc-silicate rock consisting of andradite, diopside, plagioclase, wollastonite, K-feldspar, quartz, titanite and cross-cutting quartz veinlets. Further out, Plimer (1984) described an outer zone of interlaminated calc-silicate rock (consisting of plagioclase and minor diopside replacing pelitic hornfels along laminae) and pelitic hornfels (consisting of laminated quartz-biotite±K-feldspar±sericite ±chlorite rock) with an external calc-silicate-dolomite rock. Metals Exploration Limited (1984) described massive, fracture-controlled andradite-hedenbergite skarn closer to the intrusion in the Midway area, whereas diopside-wollastonite skarn occurs further away and dominates the 3KEL region.

The most intense fracturing and highest grade of metamorphism within the calc-silicate unit occurs in the vicinity of the Midway granite (Metals Exploration Limited 1984). Wrigglite, a contorted, rhythmically mineralogically layered skarn containing, in particular, fluorite, tin and an iron phase (Kwak & Askins 1981), occurs in the Midway area, implying a higher temperature of formation (Metals Exploration Limited 1984). The mineralogical and textural zoning of the calc-silicate unit strongly suggests that the Midway granite has been the source of the contact metamorphism and associated mineralisation.

The calc-silicate unit is contained within metasediments which all previous workers have correlated with the Girilambone Group. Field inspection of the area, and a comparison with rocks mapped as Girilambone Group 20 km to the south-southwest (Burton et al. in prep.) supports this interpretation. The metasediments have been described as a sequence of sericite schists, quartzites and metasiltstones (Young 1982) and pelitic metasediments consisting of quartz, biotite, chlorite and sericite (Metals Exploration Limited 1984). Thin calc-silicate units flank the DMK line (Young 1982). Intermediate and mafic volcanic rocks have been described as interbedded with the Girilambone Group metasediments (Heydon 1980; Chance 1982; Proksch 1982) and gabbros have been noted (e.g. Metals Exploration Limited 1984).

The Midway granite crops out close to the centre of the calc-silicate rock band and Byrnes (1993) noted the presence of a gravity low centred on the Doradilla homestead (Figure 2) — suggesting that the granite is more substantial at depth. Quartz-feldspar porphyry dykes several metres wide (e.g. Freytag & Thompson 1981 describe 5.5 m and 2.4 m wide dykes intersected in drill core) intrude the calc-silicate rocks and surrounding metasediments in the vicinity of the Doradilla copper mine and mostly trend in a north-south direction (Young 1982). Kwak (1982) noted that the highest

tin grades in the skarn unit occur where it is cross-cut by the highest density of quartz-feldspar porphyry dykes, suggesting that the dykes are genetically related to the mineralisation. Kwak (1982) also noted that the porphyry dykes contain elevated tin values.

The depositional age of the calc-silicate unit is not known. Marble was sampled from drill core (this study) and dissolved in acid in an attempt to recover conodonts. However, no conodonts were recovered from the residue (I. Percival, pers. comm. 2006). Having such a strong linear geometry, it is most probable that the calc-silicate unit occupies a fault or shear zone. Previous workers (e.g. Plimer 1984) have considered that the layering within the calc-silicate rock is bedding but Byrnes (1993) interpreted it as a mylonitic fabric. Petrological examination of samples from drill core (this study) favours the latter interpretation. Previous workers (e.g. Metals Exploration Limited 1984) have concluded that the calc-silicate rock post-dates the Girilambone Group. That interpretation was based on structural differences between the calc-silicate rock and the enclosing Girilambone Group rocks — that is, folding within the calc-silicate unit has been attributed to a single, tight to isoclinal fold (inclined) which contrasts with the multiply deformed Girilambone Group rocks. The calc-silicate unit has been correlated with the Siluro-Devonian Cobar Supergroup by some workers (Byrnes 1993). Mapping by Burton et al. (in prep.) in the Byrock 1:100 000 map sheet area to the south of the Doradilla area has identified linear, mylonitic quartzite bodies within fault/shear zones cross-cutting the Girilambone Group. Within some of these zones the mylonitic quartzites exhibit upright, steeply plunging, isoclinal, intrafolial folds, indicative of high strain (e.g. the Three Sisters area, 38 km south-southwest of Doradilla). The quartzites are correlated with Cobar Supergroup rocks. Those deformed quartzites are considered here to be structurally analogous with, and of similar age to, the Doradilla calc-silicate unit.

DATING OF INTRUSIVE ROCKS

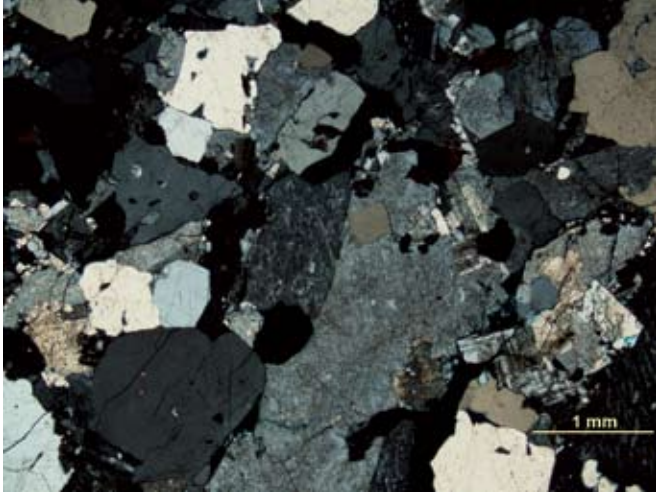
Sampling strategy

Two samples were collected from the Doradilla prospect area for zircon U-Pb dating. Sample DOR1 (GA sample number 2005844032) was taken from the Midway granite (GR 438360 mE, 6645730 mN) (Figure 2) whereas sample DOR2 (GA sample number 2005844033) was taken from a quartz-feldspar porphyry intrusion (GR 434310 mE, 6642800 mN), immediately north of the Doradilla copper mine. The analysis of two separate samples of different but probably comagmatic rock types separated by several kilometres was expected to provide some internal control on the confidence of the ages determined.

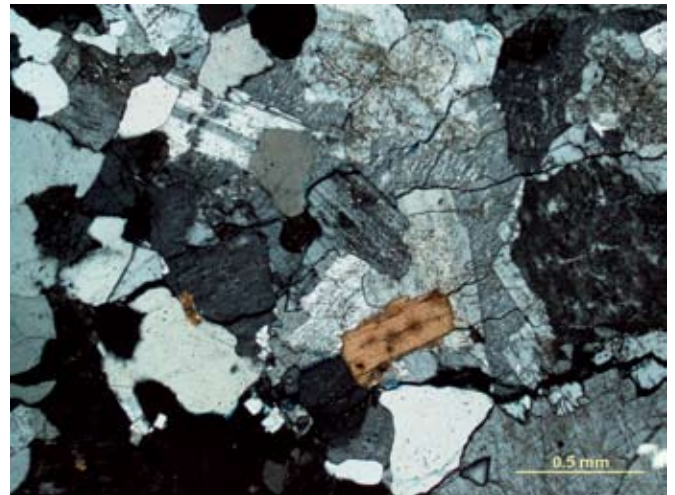
Petrology of the collected samples

The granite sample (DOR1) consists of a homogeneous mixture of quartz, pale pink alkali feldspar, plagioclase and biotite (photographs 1, 2). Quartz grains range from 1 mm to 4 mm and make up about 45% of the rock. Alkali feldspar grains (about 39% of the rock) exhibit perthitic texture (Photograph 3), and generally average 2 mm in length but are commonly

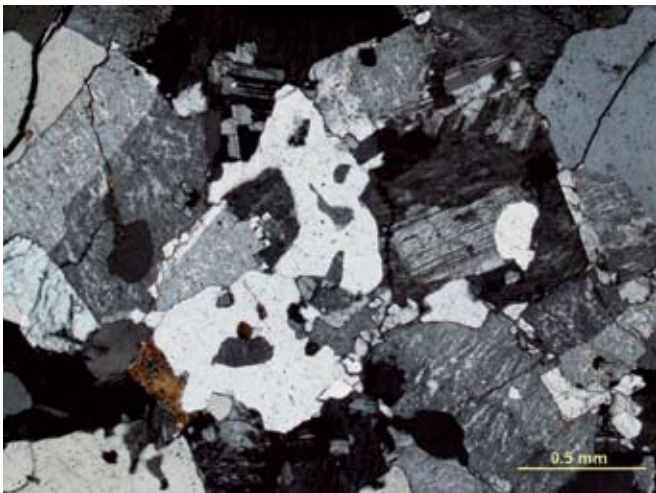
irregular to subhedral (though some are up to 6 mm long and form euhedral phenocrysts). Swapped rims and “manhattan texture” (oriented laths of multiply twinned albite) are well developed between adjoining feldspar grains, a texture typical of tin-bearing granites (P. Blevin pers. comm. 2007). Plagioclase (about 15% of the rock) forms subhedral to irregular grains which average about 1 mm but some are up to 2 mm long. Biotite (chocolate brown to light straw) constitutes about 1% of the rock and forms ragged tabular grains which average about 0.5 mm but some extend to 1.5 mm long. Pleochroic haloes are common. Minor sericite alteration occurs within feldspar grains. Tourmaline (blue to pale brown), zircon, fluorite and xenotime form very fine-grained accessory phases. Rare acicular rutile(?) occurs in quartz adjacent to altered biotite.



Photograph 1 General view of potassic, leucocratic granite containing abundant perthitic alkali feldspar, quartz, less abundant plagioclase and minor biotite. The inequigranular texture (weakly porphyritic in perthitic alkali feldspar – see centre of field of view) and the rapidly cooled texture are suggestive of high-level emplacement (e.g. intergrown quartz and alkali feldspar above centre). Thin section T76707, transmitted light, crossed polars, x2 lens. (Petrographer and photographer: C.J. Simpson)



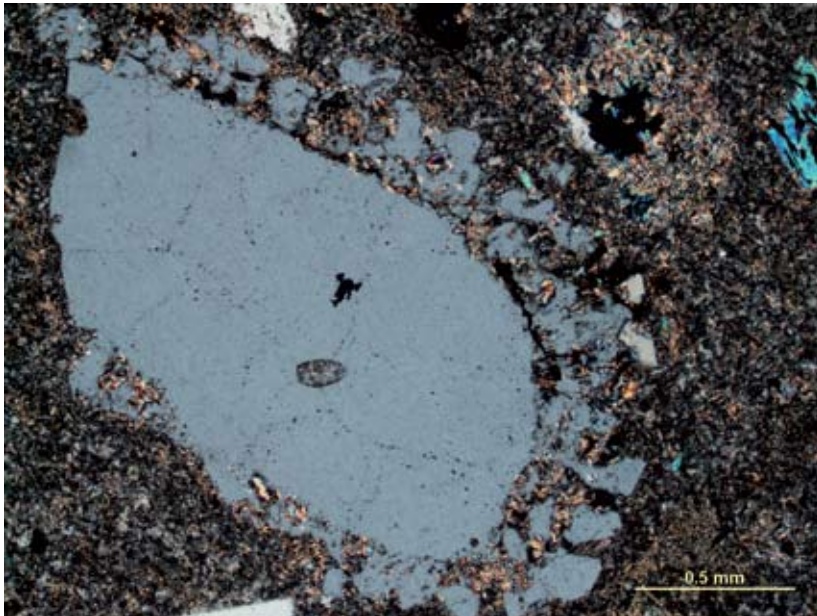
Photograph 3 The granite displays abundant perthitic alkali feldspar (right side and lower left of field of view) and coarsely intergrown alkali feldspar and quartz. Small plagioclase crystals occur in the centre and upper left of the field of view, and biotite can be seen in the lower centre. Thin section T76707, transmitted light, crossed polars, x4 lens. (Petrographer and photographer: C.J. Simpson)



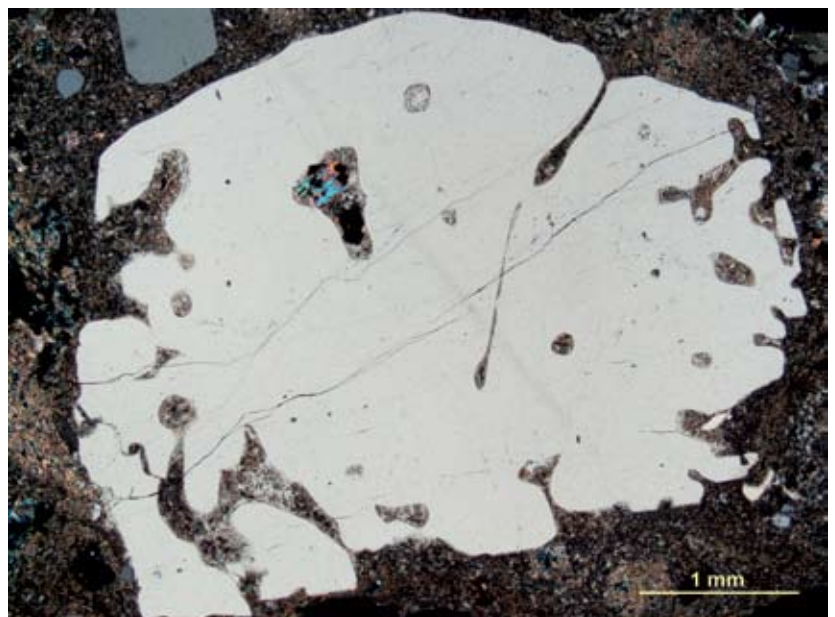
Photograph 2 Quenched cooling texture of intergrown alkali feldspar and quartz in the granite. Thin section T76707, transmitted light, crossed polars, x4 lens. (Petrographer and photographer: C.J. Simpson)

The quartz–feldspar porphyry sample (DOR2) consists of a very fine-grained greenish (altered) groundmass consisting of extremely fine-grained sericite (probably after feldspar) and quartz (Photograph 4). The groundmass constitutes about 70% of the rock. Phenocrysts make up about 30% of the rock, of which about 60% are quartz, 35% are feldspar and 5% are muscovite. Quartz crystals are broken and partially resorbed (Photograph 5), ranging from 0.1 mm to about 5 mm in length. They contain blebs and embayments of sericitised matrix. Arrowhead shaped terminations indicate

quench crystallisation driven by strong undercooling. Rare quartz grains contain tiny tourmaline inclusions. Feldspar phenocrysts are tabular to sub-tabular and are up to about 2 mm long. They are strongly sericitised and iron oxide-corroded and are probably after alkali feldspar (rather than plagioclase). Muscovite (after biotite) forms iron oxide-corroded platy grains to about 1 mm. Clasts of country rock up to at least 4 cm long occur within the porphyry and consist of crenulated quartz–mica schist typical of Girilambone Group metasedimentary rocks.



Photograph 4 The quartz–feldspar porphyry, showing a quartz phenocryst that has been resorbed around its margins. A small sericite-replaced probable feldspar phenocryst in the top right of the field of view lies adjacent to a bluish muscovite- and iron oxide-replaced probable biotite phenocryst. The microcrystalline, quartzo-feldspathic groundmass is strongly sericite-altered. Thin section T76682, transmitted light, crossed polars, x4 lens. (Petrographer and photographer: C.J. Simpson)



Photograph 5 A large, embayed quartz phenocryst in the quartz–feldspar porphyry. Thin section T76682, transmitted light, crossed polars, x2 lens. (Petrographer and photographer: C.J. Simpson)

Chemistry of the collected samples

Whole-rock geochemical analyses for samples DOR1 and DOR2 are shown in Table 1. The two rocks are chemically very similar, with notably high values of F and Rb, and low Sr values. The petrographically observed alteration in DOR2 is mirrored chemically by low Na and Ca (i.e. loss of plagioclase); elevated S, As and Pb (i.e. presence of sulphides); and elevated LOI (presence of secondary sericite). Potassium from alkali feldspar breakdown in DOR2 has been partially retained in secondary sericite.

Blevin (2005), based on his own whole-rock geochemical analyses, described the Midway granite as being extremely fractionated (Rb/Sr >20), moderately reduced and compositionally evolved (K/Rb <100). He noted that it has very high values of Nb, Ta, Th, U, Y-REE, Sn and W indicating that it is the end product of extended fractionation processes (Blevin 2005). The low P, and high Th and HREE character of the granite and dykes indicate a metaluminous fractionation history consistent with an I-type origin.

Table 1. Geochemical analyses of the Midway granite and quartz–feldspar porphyry

	Midway granite (DOR1)	Quartz–feldspar porphyry (DOR2)		Midway granite (DOR1)	Quartz–feldspar porphyry (DOR2)
Major elements (%)			Trace elements (ppm)		
SiO ₂	76.62	75.18	As	3	56
TiO ₂	0.07	0.21	Ba	70	185
Al ₂ O ₃	12.73	12.54	Ce	73	70
Fe ₂ O ₃	1.04	5.33	Co	58	36
FeO	0.08	0.08	Cr	-2	6
MnO	0.03	0.04	Cs	75	-8
MgO	0.06	0.33	Cu	-1	3
CaO	0.19	0.01	F	2623	3318
Na ₂ O	3.89	0.07	La	24	29
K ₂ O	4.75	3.98	Mo	-1	7
P ₂ O ₅	0.02	0.08	Nb	49	44
SO ₃	0.01	0.07	Nd	23	18
LOI	0.40	1.97	Ni	9	8
Total	99.89	99.89	Pb	25	774
			Rb	815	469
			Sc	7	-2
			Sr	11	20
			Th	42	51
			U	8	11
			V	3	10
			Y	69	21
			Zn	24	18
			Zr	109	172

Negative values = below indicated level of detection. Analyses were carried out by Bill Pappas, Liz Webber and John Pyke at the geochemistry laboratory of Geoscience Australia. Major and trace elements were measured by XRF (except FeO, which was measured by titration). The XRF machine used was a Philips PW2404 4 kW sequential spectrometer using an Rh tube.

SHRIMP zircon U–Pb dating method and results

Zircons from the samples DOR1 and DOR2 were dated in the same analytical session on SHRIMP A at Curtin University in December 2005. The 416.8 Ma Temora 2 zircon standard (Black et al. 2004) was used for U–Pb calibration. The data have been processed with SQUID software (Ludwig 2002).

Zircons from sample DOR1 from the Midway granite are mostly euhedral, with simple prismatic and pyramidal faces. Although oscillatory prismatic zoning is common at the exteriors of grains, many interiors consist of a broad, concordant zone with consistent cathodoluminescent response. Most grains are relatively squat, with aspect ratios generally 2:1 or less, and an average length of about 160 μm . Discordant cores are rare. Four rounded cores gave a spread of ages from about 460 Ma to 480 Ma and one discordant core has a 900 Ma age. Many of the zircons are flawed by imperfections, such as cracks, irregular oxide and silicate inclusions and metamict areas, but only one such grain was analysed — which produced the youngest of the ages shown in Figure 3. Fortunately, sufficiently unflawed zircon grains were present to enable determination of the crystallisation age of the granite. No observable Pb loss has been recorded in those analyses. Comagmatic zircon grains have 215–1740 ppm U, with an average U value of 650 ppm.

Thirty-one individual analyses yielded a weighted mean age for the granite of 235.1 ± 1.4 Ma (MSWD = 1.37; probability of equivalence = 0.08) (Figure 3).

The zircon grains in quartz–feldspar porphyry sample DOR2 commonly display the same simple euhedral facets as those in the Midway granite. Euhedral zonation is not as easily recognisable, due to the reduced cathodoluminescence (CL) response of these grains, resulting from their still higher U contents (average of the grains considered suitable for analysis is 735 ppm, and no attempt was made to analyse those grains with even darker CL images).

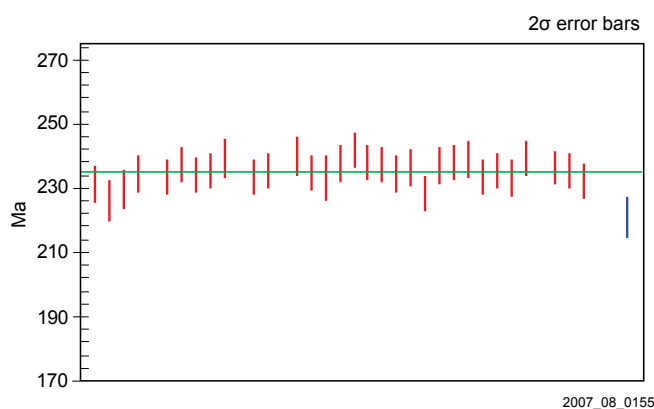


Figure 3 Diagram showing the ages (represented as ± 2 sigma uncertainty bars) of individual zircon grains derived from sample DOR1 from the Midway granite. Data represented by the blue bar lies outside the limits of the main (red) population. Five ages lie above the limits of the graph (see text).

Although many of the zircon grains in the sample are similar in their shape, aspect ratio and size to those in the Midway granite, there is a larger proportion of rounded grains (which were not analysed) in the quartz–feldspar porphyry. Attention was focused on those parts of euhedral grains that were free of cracks, inclusions (oxides in most grains) and metamict, high-U zones.

Figure 4 shows the ages of individual zircon grains obtained from the quartz–feldspar porphyry sample DOR2. The one older age represents a 250 Ma rounded core. Its Th/U is comparable to values obtained for inherited zircon in the Midway granite but in the case of the porphyry the Th/U of the inherited zircon is similar to values determined for comagmatic zircon (which range to lower values than occur in the zircons from the granite). The three younger ages are considered to be due to lead loss from metamict grains. The remaining 34 individual ages produce a weighted mean age of 230.7 ± 1.4 Ma (MSWD = 1.39; probability of equivalence = 0.07) (Figure 4) for the crystallisation of the porphyry, which is considered to be slightly younger than the Midway granite (the probability that the two ages are equivalent is 0.000).

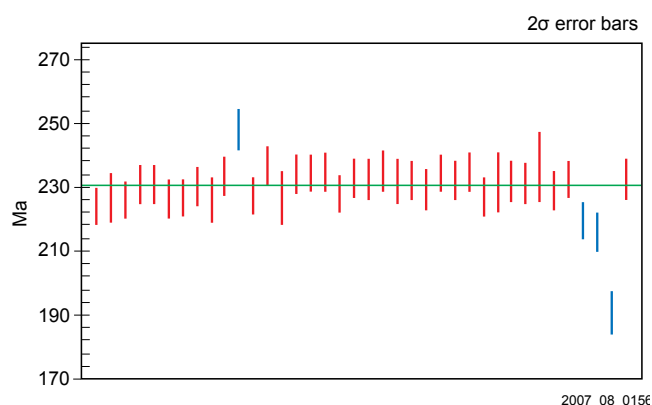


Figure 4 Diagram showing the ages (represented as ± 2 sigma uncertainty bars) of individual zircon grains derived from sample DOR2 from the quartz–feldspar porphyry. Data represented by the blue bars lie outside the limits of the main (red) population.

DISCUSSION AND CONCLUSION

The SHRIMP age data indicate that the Midway granite and the quartz–feldspar porphyry dyke are of Middle Triassic age (using the time scale of Gradstein et al. 2004). While the derived age of the quartz–feldspar porphyry is slightly younger than that of the granite, the difference is only about 4 Ma. The two rock types can be considered as effectively comagmatic, possibly with the porphyry being a later-stage magmatic phase of the granite. As the Doradilla mineralisation is associated with the Midway granite, it is concluded that it too is of Middle Triassic age. This age is substantially younger than the 295 Ma model lead age suggested by Carr et al. (1995) and no other granite or mineral system in the region is known to have such a relatively young age. Granite which crops out at the town of Gongolgon, approximately 55 km east of Doradilla,

has been described by Blevin (2005) as a highly evolved, fractionated I-type with a significant potential for associated Sn–W mineralisation, similar to the Midway granite. However, zircon U–Pb dating of that granite (Black unpublished data) returned a crystallisation age of 410.9 ± 2.5 Ma (Early Devonian).

The nearest recognised granites of similar age and chemistry to the Doradilla intrusions, which also have associated Sn \pm base metal \pm Au mineralisation, are those within the New England region, approximately 500 km to the east-northeast, such as the Mole, Dumboy–Gragin, Gilgai and Stanthorpe granites (Brown et al. 1992; Brown & Stroud 1997; Vickery et al. 1997; Henley et al. 2001) (Figure 1). Those granites range in age from Early to Middle Triassic (Shaw & Flood 1993; Kleeman et al. 1997; Vickery et al. 1997). Like the Midway granite, those granites are highly fractionated I-types, those associated with tin mineralisation being reduced (Blevin & Chappell 1993). The Mole Granite, Dumboy–Gragin Granite and Gilgai Granite, in particular, are very similar geochemically to the Midway granite with, for example, elevated Rb, Y and F and low Sr (Geological Survey of New South Wales whole-rock geochemical database, derived from various sources; AMIRA New England granite geochemical database). Other Sn-mineralised I-type granites in eastern Australia also occur in the Herberton–Chillagoe region of northern Queensland (Carboniferous) and western Tasmania (Devonian).

The results of this study indicate that the Early to Middle Triassic magmatic and mineralising pulse in northern New South Wales extended beyond the area of the New England Orogen. It is therefore possible that other such granites (of similar ages) may be present in the Bourke–Brewarrina–Byrock region below cover and may be hosts to tin \pm base metal \pm Au mineralisation.

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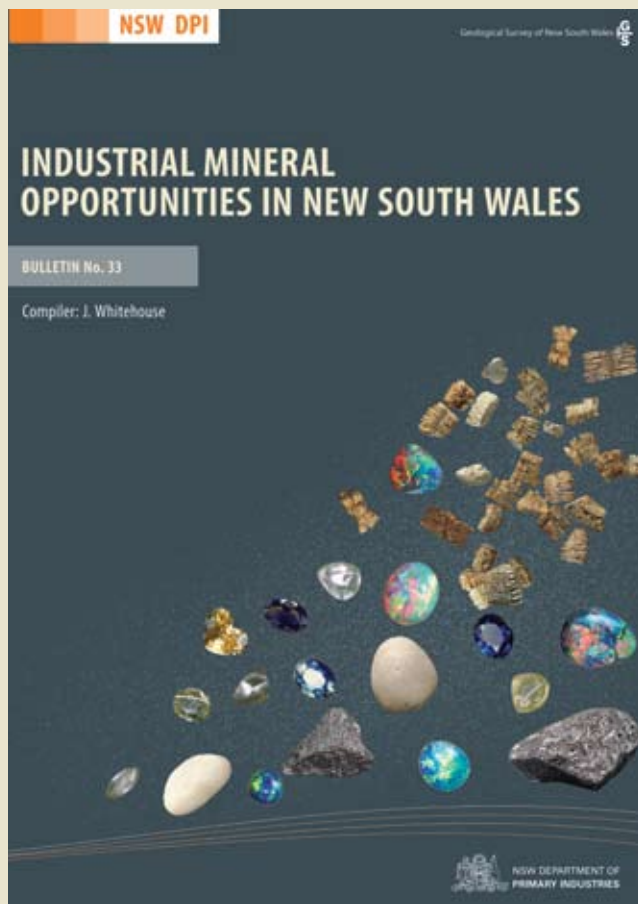
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