Provenance of Mesozoic sediments in the southern Eromanga Basin, NSW: implications for the source of placer gold of the Tibooburra goldfields

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Introduction

Mesozoic sediments of the Eromanga Basin are a widespread component of the sedimentary cover that extends across Proterozoic bedrock in central Australia, including northern South Australia and northwestern New South Wales (Fig. 1). Explorers searching for bedrock-hosted mineralisation have considered these sediments an impediment, with geochemical characteristics unlikely to be related to underlying bedrock targets. However, these sediments have the potential to assist mineral exploration by hosting enlarged geochemical footprints of otherwise buried mineral systems. Potentially, such geochemical footprints may even provide direction information that can be considered in follow up exploration (Forbes et al. 2015). An important component to utilising sedimentary cover sequences in mineral exploration programs is understanding the paleogeographical context for the sedimentary systems, including the provenance of the sediments. Obtaining this information becomes even more compelling when cover sediments not only contain geochemical footprints of buried mineral systems, but host mineralisation in their own right (e.g. placer and sediment-hosted mineralisation).

Basal Mesozoic sediments in the Tibooburra area in northwestern New South Wales host placer gold mineralisation. The sediments were the focus of the Tibooburra–Milparinka (Albert Goldfields) gold rush of the 1880s; however, no source of primary mineralisation has been found in the Tibooburra Inlier. Nevertheless, in the Warratta Inlier to the south, primary gold mineralisation is present in the form of orogenic gold-style auriferous quartz vein networks (Thalhammer 1992; Greenfield and Reid 2006a). This primary bedrock gold has been eroded and reworked by fluvial processes to be later deposited and concentrated within Jurassic gravels, and into recent and contemporary drainage (e.g. Hill et al. 2008).

There have been several interpretations of the stratigraphy and provenance of the Mesozoic sediments surrounding Tibooburra (Kenny 1934; Morton 1982; Stevens and Etheridge 1989; Chamberlain 2001; Hill 2005; Greenfield, Gilmore and Mills 2010), as well as the nature of gold deposits and sources of mineralisation (Kenny 1934; Thalhammer 1992; Thalhammer et al. 1998; Brown, Vickery and Greenfield 2006; Greenfield and Reid 2006b). However, no zircon U–Pb data has been available with which to assess the validity of these interpretations.

In this article we report detrital zircon U–Pb data from the Mesozoic sediments near Tibooburra to investigate if there is a local bedrock signature in the Mesozoic sediments that could have provided a source for the placer gold mineralisation. This study is part of a memorandum of understanding between the Geological Survey of New South Wales and the Geological Survey of South Australia to promote cross-border geological understanding. These Mesozoic sedimentary rocks are also present in South Australia and the data obtained in this study contributes towards characterising the sedimentary cover in regions of eastern South Australia.

Geological background

Neoproterozoic to Ordovician

The Tibooburra Inlier is part of the Koonenberry Belt of the southwestern Thomson Orogen, western New South Wales. The Koonenberry Belt comprises a basal Neoproterozoic volcano-sedimentary succession, the Grey Range Group, which contains the c. 585 Ma Mount Arrowsmith Volcanics and shallow marine shelf sediments of mudstone and sandstone (Crawford, Stevens and Fanning

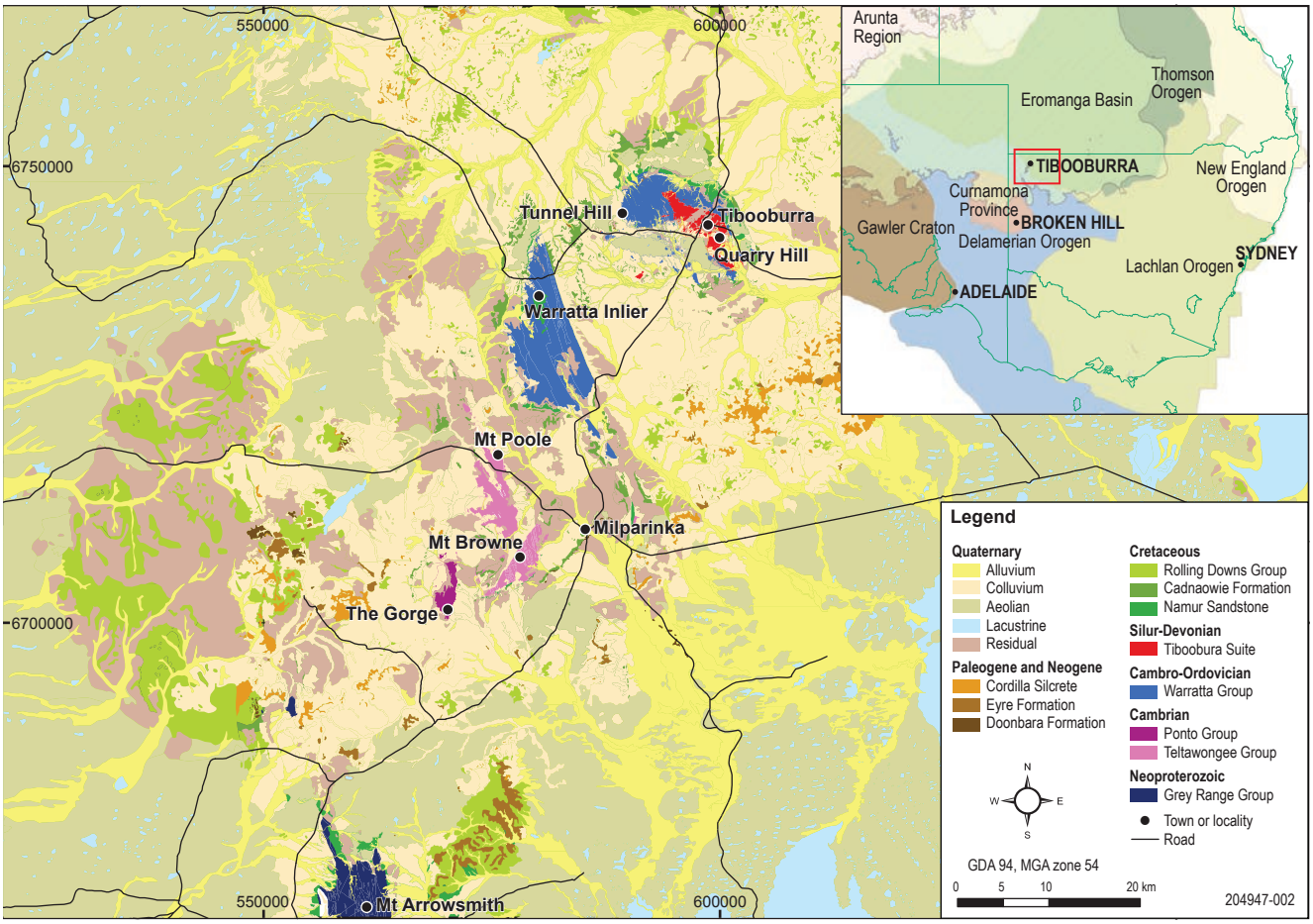


Figure 1 *Geological map of the Tibooburra–Milparinka area. Inset shows the location of the area in the context of the geological elements of eastern Australia. Australian crustal elements map courtesy Geoscience Australia data.*

1997). These units are stratigraphically overlain by c. 510 Ma volcanics of the Mount Wright Arc and related sedimentary units of the Teltawongee Group and Ponto Group (Greenfield et al. 2011). These units were subjected to deformation and metamorphism during the Delamerian Orogeny at c. 500 Ma, which produced folds and thrusts in the greenschist facies (Brown, Vickery and Greenfield 2006; Greenfield, Gilmore and Mills 2010).

A second cycle of marine deposition and associated volcanism occurred post-Delamerian, and manifests as Cambrian – Early Ordovician metasedimentary rocks of the Warratta Group, which includes units such as the Easter Monday Formation and Jeffreys Flat Formation (Greenfield, Gilmore and Mills 2010; Percival, Quinn and Glen 2011). Felsic volcanic units within the Easter Monday Formation of the Koonenberry Belt erupted at c. 497 Ma, while some metasedimentary units within the Warratta Group have maximum depositional ages c. 465 Ma indicating clastic sedimentation continued into the Ordovician (Greenfield, Gilmore and Mills 2010).

Deformation and metamorphism of these volcanic and sedimentary units occurred between c. 441–424 Ma and produced tight folds and thrusts associated with a penetrative, largely west-dipping cleavage (Greenfield, Gilmore and Mills 2010). The sequence was intruded by post-D1 monzodioritic sills and dykes between c. 423 and 416 Ma, and by the 420.6 ± 3.3 Ma geochemically related I-type Tibooburra Granodiorite, part of the Tibooburra Suite (Greenfield, Gilmore and Mills 2010). Primary gold mineralisation formed during this tectono-magmatic event, hosted by Warratta Group rocks and associated with syn-D1, S1-parallel, replacement quartz veins (Greenfield and Reid 2006b).

Mesozoic

Several Paleozoic bedrock inliers occur near the township of Tibooburra and surrounding region including the Tibooburra and Warratta inliers, which are exposed through the predominantly Mesozoic to Holocene sedimentary cover (Fig. 1). Other Paleozoic bedrock inliers are located to the southwest of the study area (e.g. Mount Poole, Mount Browne and the Gorge inliers; Fig. 1). The Tibooburra Inlier is a topographic high that forms the southern extent of the larger Grey Range. This high represents an area of uplift, which is a regional drainage divide (Hill 2005).



2(a) Profile showing sample locations and lithology. (Photo 415908)



2(b) Detail showing cross-bedding within interpreted Namur Sandstone. (Photo 415909)



2(c) Silicified conglomerate layers, upper Quarry Hill profile. (Photo 415910)



2(d) Interpreted Cadna-owie Formation, upper portion of Quarry Hill profile. (Photo 415912)

Figure 2 Quarry Hill site.

The bedrock inliers of the Tibooburra region are surrounded by Mesozoic–Cenozoic sedimentary cover. The Mesozoic sediments of interest are part of the southeastern margin of the Eromanga Basin (Fig. 1). The sediments of the basin have been given various classifications, with different frameworks proposed for South Australia, New South Wales and Queensland (Exon and Senior 1976; Morton 1982). As the study area is located within New South Wales, the New South Wales nomenclature will be used and the South Australian equivalents will be mentioned. The basal Mesozoic unconformity can be distinguished in the landscape today as bare surface scattered with rounded quartz and unconsolidated material (Hill et al. 2008).

The oldest sedimentary package within the Eromanga Basin is the Namur Sandstone. Plant fossils from Quarry Hill suggested a Jurassic age to Kenny (1934), although more recent work suggests a Cretaceous age (Exon and Senior 1976; Hill et al. 2008). The Namur Sandstone is a lateral equivalent of the Early Cretaceous Algebuckina Sandstone that crops out across South Australia (Alley et al. 2006). The Cadna-owie Formation overlies the Namur Sandstone and has been interpreted as Early Cretaceous and more specifically Valanginian in age (Greenfield, Gilmore and Mills 2010). It contains terrestrial to marine transition sediments (Exon and Senior 1976). Overlying the Cadna-owie Formation is the uppermost group of the Eromanga Basin, the Rolling Downs Group, which comprises alternating sandstone, mudstone and calcareous units and represents sedimentation from Early to Late Cretaceous before marine regression and closure of the Eromanga Basin (Exon and Senior 1976; Greenfield, Gilmore and Mills 2010).

Overlying the Mesozoic succession are Cenozoic sediments that make up part of the Lake Eyre Basin. They do not outcrop in the immediate vicinity of the Tibooburra Inlier, but cover expanses to the west, east and far north.

Mesozoic sediments of Tibooburra region: Quarry Hill and Tunnel Hill sites and detrital zircon sample descriptions

Three samples of sandstone were collected for detrital zircon U–Pb dating from Quarry Hill, 2.5 km southeast of Tibooburra. The samples were collected at approximate intervals 185 m, 191 m and 198 m along the exposed stratigraphic profile (samples 2116187, 2116188, 2116189; Table 1; Figs 2a, 3). The lower 10–11 m of logged sediment is interpreted as equivalent to the Namur Sandstone from the Late Jurassic – Early Cretaceous (Hill et al. 2008). It consists of a basal 1–2 m of sandy, grey, medium-grained, layered sandstone with minor ferruginous banding and conglomerate layers. The next 3 m is a more homogenous medium-grained sandstone with trough-crossbedding structures. The next 7 m, the main part of the profile, shows large tabular-crossbedding structures within medium-grained, pale sandstone. The profile fines upward in a sequence of interbedded fine-grained sandstone–claystone layers and gravelly medium-grained sandstone. Most layers have crossbedding structures (Fig. 2b). There are three upper layers of conglomerate comprising coarse, subangular quartzose pebbles within a gravelly clay cement. Upper conglomerate sandstone layers show silicification between the layers (Fig. 2c). The upper 4 m of the Quarry Hill section is interpreted as Cadna-owie Formation where the well-sorted, massively bedded sandstone is highly weathered, ferruginous and oxidised on the outside (Fig. 2d). The Quarry Hill section represents a marine transgression from a fluvial environment through to beach forefront and shallow marine.

A fourth sample of sandstone for detrital zircon dating was taken from Tunnel Hill, ~8 km west of Tibooburra along the Cameron Corner Road and then 2–3 km north of the main road (sample 2116190; Table 1; Fig. 4). The sedimentary rocks at Tunnel Hill have been mapped as Mesozoic and are similar to sediments at Quarry Hill, albeit being a coarser grained, more gravelly equivalent to the Namur Sandstone. Tunnel Hill and adjacent Nuggety Gully have hosted alluvial gold, collected by prospectors who dug the tunnel through the basal 60 cm of Tunnel Hill sediment. Kenny (1934) reported assays of 11 g/t Au over 4.6 m within this basal layer. The Tunnel Hill exposure of Namur Sandstone overlies exposed Easter Monday Formation metasediments.

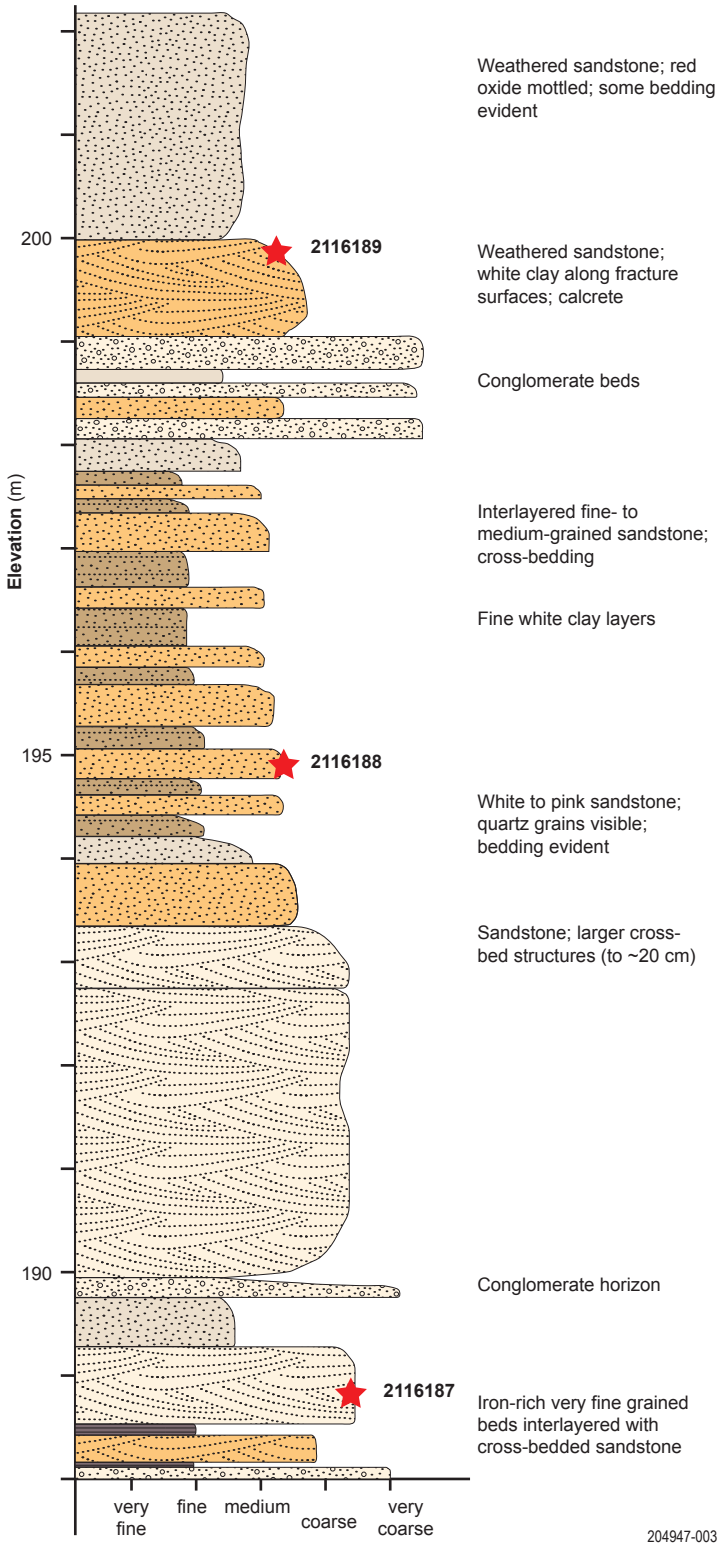


Figure 3 *Lithological log of exposed profile on southern side of Quarry Hill.*

Table 1 *Summary of samples analysed in this study*

SA Geodata sample number	Location	Lithology	Stratigraphic unit	Easting (m)	Northing (m)	Zone
2116187	Quarry Hill	Sandstone	Namur Sandstone	599414	6742354	54
2116188	Quarry Hill	Sandstone	Namur Sandstone	599420	6742355	54
2116189	Quarry Hill	Sandstone	Cadna-owie Formation	599426	6742354	54
2116190	Tunnel Hill	Sandstone	Namur Sandstone	589437	6744822	54



Figure 4 *Tunnel Hill sample location, interpreted as Namur Sandstone. (Photo 415912)*

Table 2 *Summary of ages obtained from zircon reference material analysed during this study*

Standard	n	$^{207}Pb/^{206}Pb$ (Ma)	1σ	$^{206}Pb/^{238}U$ (Ma)	1σ
Plešovice					
This study	18*			340.6	1.4
Sláma et al. 2008				337.13	
QGNG					
This study	20	1851	4.3	1866	16
Black et al. 2003		1851.6	0.6		

* Two analyses produced ages not within statistical uncertainty of the main population and are not included in this weighted mean age.

Analytical methods

Zircons were analysed by laser ablation-inductively coupled plasma mass spectrometry (LA-ICPMS) at Adelaide Microscopy, University of Adelaide. The samples analysed in this study were processed at a commercial mineral separation facility, Geotrack, in Victoria. Zircon concentrates were made using standard rock crushing, density and magnetic techniques. Concentrates were then hand-picked using a binocular microscope before being mounted in epoxy resin and polished to expose the grains. Zircon grains were imaged using plane-polarised light optical microscopy and cathodoluminescence (CL).

LA-ICPMS analysis utilised a 213 nm New Wave Research LA unit coupled with an Agilent 7300 quadrupole ICPMS. Time-resolved signals of $^{204, 206, 207, 208}Pb$, ^{232}Th and ^{238}U were acquired with a 30 µm spot size and a 5 Hz repetition rate. This data was processed using the software GLITTER (Jackson et al. 2004) with U and Th decay constants (Jaffey et al. 1971), as recommended by Steiger and Jäger (1977). The GJ standard zircon was used to calibrate Pb/U fractionation, and data quality was monitored by analysis of the Plešovice (Sláma et al. 2008) and QGNG (Black et al. 2003) reference zircons (Table 2). The LA-ICPMS technique cannot account for non-radiogenic Pb due to interference on ^{204}Pb by ^{204}Hg present in trace amounts in the carrier gas. Nevertheless, ^{204}Pb was monitored during the analyses to give an indication of zircons that have very elevated non-radiogenic Pb. In most cases ^{204}Pb remained at background values, and no correction for non-radiogenic Pb has been applied to the data. Zircon ages are reported relative to an assigned 1% uncertainty on the age of the standard for sample age error calculations.

Where the $^{207}Pb/^{206}Pb$ age was <1000 Ma, the $^{206}Pb/^{238}U$ age was used as the preferred crystallisation age. For each sample, weighted mean ages were calculated using Isoplot v3 (Ludwig 2003) to describe the major age peaks by selecting those analyses that conform to a single statistically meaningful population as indicated by a mean square of weighted deviates (MSWD) approximating 1 and a probability statistic >0.05. A weighted mean age was calculated only when the number of analyses that describe the population is greater than five. This somewhat arbitrary limit was imposed to indicate a more significant contribution to the provenance signal. A discordance filter was applied to the data such that any analysis with $^{207}Pb/^{206}Pb$ age >1000 Ma with discordance >± 10% was omitted from the calculation of statistical age populations. U–Pb data is presented in full in the Appendix.

Results

Zircons from the samples show a range of morphologies from elongate grains to equant grains with low length to width ratios; however, many of the grains show euhedral to subhedral crystal morphology, suggesting relatively small degrees of transport (Fig. 5). Detrital zircon samples 2116187, 2116188, 2116189 and 2116190 all show broadly similar age populations (Fig. 6; Table 3). The major age peaks and populations within all samples are dominantly Neoproterozoic to Carboniferous in age, c. 700 to 300 Ma. All Quarry Hill samples (2116187, 2116188 and 2116189) preserve major peaks at c. 575, c. 510, 480 ± 12 and 430 ± 6 Ma (Table 3). The youngest zircons, for samples collected at Quarry Hill, decrease in age as elevation within the stratigraphic profile increases (Table 3). The youngest zircon in sample 2116190 from Tunnel Hill produced a youngest age population at 434 ± 3 Ma (Table 3). All samples display small Proterozoic zircon populations, ranging from c. 2020 to 900 Ma. Samples from Quarry Hill have a minor Archean population, ranging from c. 3330 to 2555 Ma.

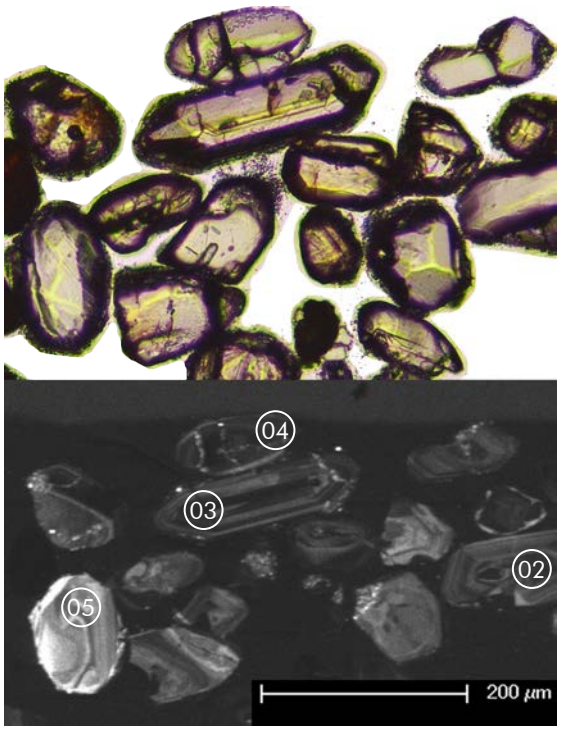


Figure 5 *Representative zircons from sample 2116187 shown under plane-polarised light (top) and CL (bottom). Circles indicate analytical sites and corresponding analysis numbers.*

Discussion

Zircon provenance

Detrital zircons from each of the localities and stratigraphic units yield a predominance of Neoproterozoic to Carboniferous ages, between c. 600 and c. 316 Ma, with a subordinate population of Mesoproterozoic, c. 1300–250 Ma grains (Table 3; Fig. 6).

There are substantial Early Cambrian detrital zircon populations with peaks similar to those of the Jeffreys Flat Formation, which has populations at c. 575, 505 and 484 Ma (Greenfield, Gilmore and Mills 2010; Glen 2013). Other possible regional sources for c. 515–510 Ma zircon include units of the Mount Wright Arc such as the Teltawongee Group, Ponto Group, the c. 510 Ma Cymbric Vale Formation (EA Jagodzinski, Geological Survey of South Australia, pers. comm. 2017), and also intrusive rocks such as the c. 515 Ma Williams Peak Granite and related intrusions (Greenfield, Gilmore and Mills 2010). The detrital zircon populations in the Mesozoic sandstones support a local derivation from these units.

In addition, there are several potential local sources for Neoproterozoic zircons, including the Grey Range Group and the c. 585 Ma Mount Arrowsmith Volcanics, which crop out southwest of Tibooburra, and were also likely reworked themselves into the Cambrian and Ordovician sedimentary succession of the Warratta Group.

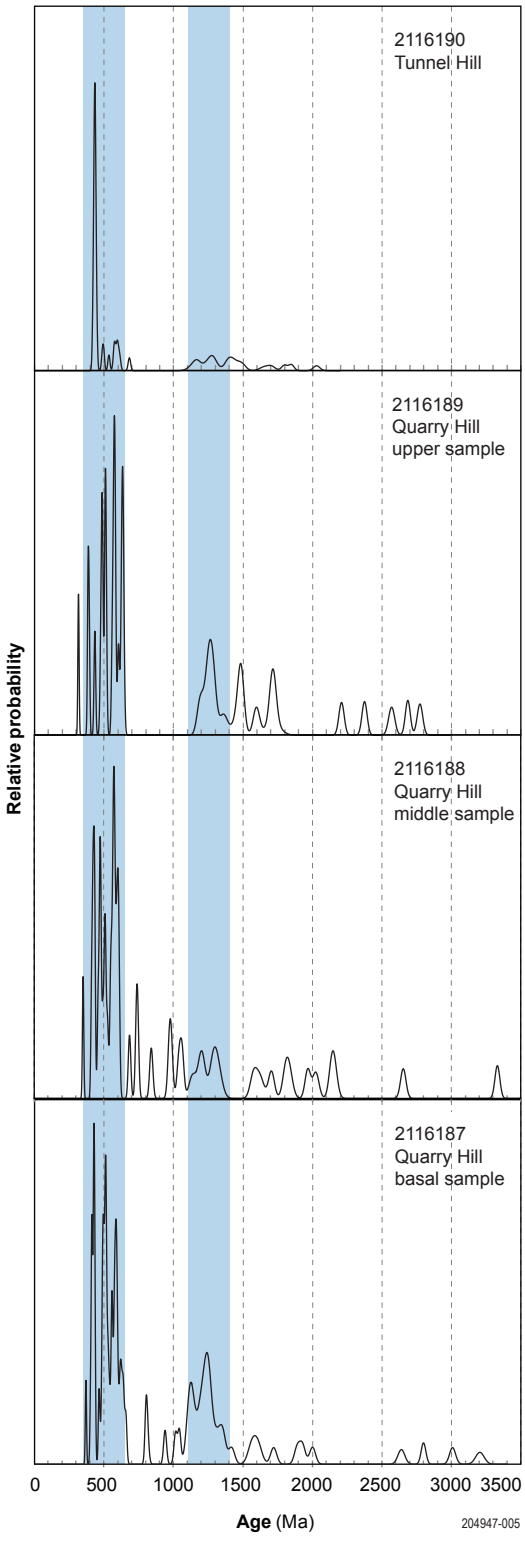


Figure 6 *Detrital zircon probability density distribution for all samples analysed in this study. All data plotted for each sample.*

Table 3 Summary of the statistical age peaks obtained from each sample

SA Geodata sample number	Total data	Analyses not in WM age	% analyses not in WM age	Youngest zircon	WM age (Ma)	n	WM age (Ma)	n	WM age (Ma)	n	WM age (Ma)	n	WM age (Ma)	n	WM age (Ma)	n	WM age (Ma)	n
2116187	80	38	48	369 ± 4	411 ± 5	4	428 ± 4	6	493 ± 5	6	514 ± 5	6	553 ± 13	4	583 ± 5	7	1246 ± 15	9
2116188	50	30	60	351 ± 5			429 ± 6	4	475 ± 7	3			571 ± 9	6	601 ± 8	4	1302 ± 31	3
2116189	40	17	43	316 ± 4					485 ± 7	3	510 ± 8	3	572 ± 9	5	633 ± 8	4	1263 ± 20	5	1714 ± 29	3
2116190	60	31	52	n/a			434 ± 3	22					586 ± 19	4			1288 ± 27	3

Note: Each weighted mean (WM) age has a MSWD <1.5.

Mesoproterozoic detrital zircons in the Mesozoic sandstone samples are likely derived originally from the Musgrave Province, specifically the Pitjantjatjara Supersuite (e.g. Wade et al. 2008; Jagodzinski and Dutch 2013). Zircons with ages c. 1300–1100 Ma are present in Neoproterozoic sedimentary rocks of the Adelaide Rift Complex (Ireland et al. 1998) and are likely to have been reworked along with the Neoproterozoic zircons of the Warratta Group into the Mesozoic sandstones.

The Devonian–Carboniferous age zircons could have been sourced from the Georgetown Inlier to the northeast, the New England Orogen to the east or the Lachlan Fold Belt to the east-southeast, possibly being reworked into continental-scale east–west sediment transport systems during the Mesozoic (e.g. Bodorkos et al. 2010; MacDonald et al. 2013). These younger zircons are subordinate to the main Cambrian and Ordovician zircon populations, suggesting a strong local source to the overall provenance of these Mesozoic sandstones.

Quarry Hill and Tunnel Hill sites compared

The detrital zircon age spectra suggest that Mesozoic sandstones from Quarry Hill and Tunnel Hill had different sources (Fig. 6). The Quarry Hill samples display a greater range of ages. This may suggest that paleorivers that formed this section of the Mesozoic sampled a greater variety of source material. In contrast, the Tunnel Hill sample shows a dominant peak at c. 434 Ma with only minor input of other age populations and few older (e.g. Mesoproterozoic or Archean) zircons (Fig. 6). This age peak is close to the crystallisation age of the Tibooburra Granodiorite, and the ages for the Tibooburra Suite more broadly (427.7 to 420.2 Ma; Greenfield, Gilmore and Mills 2010), and could be derived from magmatic rocks of this suite. We note that 434 ± 3 Ma lies slightly outside the uncertainty given for Tibooburra Suite intrusions, and there remains a possibility that the detrital zircon data indicate that the Tibooburra Suite may contain some slightly older intrusive phases, or they may derive from a slightly older, unrelated source.

Placer gold was historically found in Mesozoic sandstone at the Tunnel Hill locality (Kenny 1934). As the source region for the zircon at Tunnel Hill appears to be somewhat different to that in the Quarry Hill locality, this may indicate the possible source region for the alluvial gold. Sedimentary flow directions for Mesozoic units in this area indicate derivation from a source region to the west of the Tibooburra Inlier (Hill et al. 2008). Therefore, it is possible that a now buried portion of the Koonenberry Belt to the west of the Tibooburra Inlier contains a predominance of c. 434 Ma magmatic rocks. We note that there is no necessity to correlate magmatic rocks (and their zircon proxies) with the primary orogenic gold of the type found in the Warratta Inlier, since the orogenic gold does not appear to be associated with magmatism. However, coincidence between an apparently dominant zircon source and placer gold raises the question of whether the primary gold source could be associated with either the younger portions of the Warratta Group, or an unknown magmatic suite, possibly to the west of Tibooburra Inlier.

Conclusion

Mesozoic sandstones from two localities in the Tibooburra region have been analysed for their zircon age provenance. Samples from Quarry Hill have age populations of c. 575, c. 510, 480 ± 12 and 430 ± 6 Ma, with a minor Mesoproterozoic and Archean detrital component. In contrast, a sample from Tunnel Hill, which is a site of historical placer gold workings, is dominated by zircons with an age of c. 434 Ma, and less input from Ordovician or older source regions. The majority of these zircon ages can be sourced from local volcano-sedimentary units of the Koonenberry Belt, or in the case of the few

Carboniferous zircons present in each sample, sourced from more distal regions such as the New England Orogen. It is possible that the c. 434 Ma age peak is an indicator of the age of the rocks that host the primary source region for the gold present at Tunnel Hill, deposited within the gravelly Mesozoic sediments. The location of the primary gold remains unclear; it may be associated with the upper units of the Warratta Formation, such as the Easter Monday Formation, or possibly with c. 427–420 Ma Tibooburra Suite intrusions, or an as yet unknown c. 434 Ma magmatic suite in the region.

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Appendix (electronic): LA-ICPMS U–Pb zircon geochronology data

A summary of LA-ICPMS U–Pb zircon geochronology data obtained in this study is attached to the PDF of this article.

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FURTHER INFORMATION

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