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Key Points:
- A provenance study is conducted to determine the origin of the Gympie terrane
- This terrane contains substantial detrital zircons from the Australian continent
- The Gympie terrane is likely an autochthonous tectonic unit in eastern Australia

Supporting Information:
- Supporting Information S1
- Table S1
- Figure S1
- Figure S2

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Australian-derived detrital zircons in the Permian-Triassic Gympie terrane (eastern Australia): Evidence for an autochthonous origin

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Abstract The Tasmanides in eastern Australia record accretionary processes along the eastern Gondwana margin during the Phanerozoic. The Gympie terrane is the easternmost segment of the Tasmanides, but whether its origin was autochthonous or allochthonous is a matter of debate. We present U-Pb ages of detrital zircons from Permian and Triassic sedimentary rocks of the Gympie terrane with the aim of tracing the source of the sediments and constraining their tectonic relationships with the Tasmanides. Our results show that the Permian stratigraphic units from the Gympie terrane mainly contain Carboniferous and Permian detrital zircons with dominant age peaks at ~263 Ma, ~300 Ma, ~310 Ma, and ~330 Ma. The provenance ages of the Triassic sedimentary units are similar (~256 Ma, ~295 Ma, and ~328 Ma) with an additional younger age peak of ~240 Ma. This pattern of provenance ages from the Gympie terrane is correlative to episodes of magmatism in the adjacent component of the Tasmanides (New England Orogen), indicating that the detrital zircons were dominantly derived from the Australian continent. Given the widespread input of detrital zircons from the Tasmanides, we think that the sedimentary sequence of the Gympie terrane was deposited along the margin of the eastern Australian continent, possibly in association with a Permo-Triassic continental arc system. Our results do not show evidence for an exotic origin of the Gympie terrane, indicating that similarly to the vast majority of the Tasmanides, the Gympie terrane was genetically linked to the Australian continent.

1. Introduction

Since the 1980s, the accretion of allochthonous ("exotic") terranes has been considered as an important factor in the origin of Circum-Pacific subduction-related orogens [*Coney et al.*, 1980; *Ben-Avraham et al.*, 1981; *Nur and Ben-Avraham*, 1982; *Jones et al.*, 1983]. In the North American Cordillera, for example, it has been assumed that fault-bounded terranes, which had originated as oceanic plateaus or isolated continental fragments, were subsequently accreted onto the margin of Laurentia [*Coney et al.*, 1980; *Silberling et al.*, 1992]. The ability to test the exotic nature of accreted terranes has improved substantially in the last 20 years due to technological advances in detrital zircon geochronology [*Gehrels*, 2014]. Accordingly, some terranes that have previously been considered to be exotic relative to each other have recently been shown to have a common provenance [*Colpron et al.*, 2007; *Israel et al.*, 2014].

In the SW Pacific region, subduction processes along the margin of eastern Gondwana during the Phanerozoic have been responsible for orogenesis in the Tasmanides of eastern Australia and its correlative displaced fragments in the southwest Pacific (Figure 1a) [*Day et al.*, 1978; *Glen*, 2005; *Mortimer et al.*, 2008; *Matthews et al.*, 2015]. The evolution of this orogenic system has possibly involved episodic trench retreat and advance [*Collins*, 2002a] accompanied by oroclinal bending [*Cawood et al.*, 2011b; *Rosenbaum et al.*, 2012; *Moresi et al.*, 2014], accretion of allochthonous terranes [*Cayley*, 2011; *Aitchison and Buckman*, 2012], and continental fragmentation [*Schellart et al.*, 2006]. One of the characteristics of the Tasmanides is its vast width (>1500 km), which is partly explained by a long (~300 Ma) history of subduction and accretion [*Collins*, 2002b; *Cawood et al.*, 2009; *Aitchison and Buckman*, 2012]. Nevertheless, there is relatively little evidence for accretion of exotic terranes, and whether some of the terranes in the Tasmanides are allochthonous or autochthonous is still a matter of debate. One way to address this issue is by tracing the provenance of detrital zircons and to determine whether they were sourced from the Australian continent or unrelated exotic terranes.

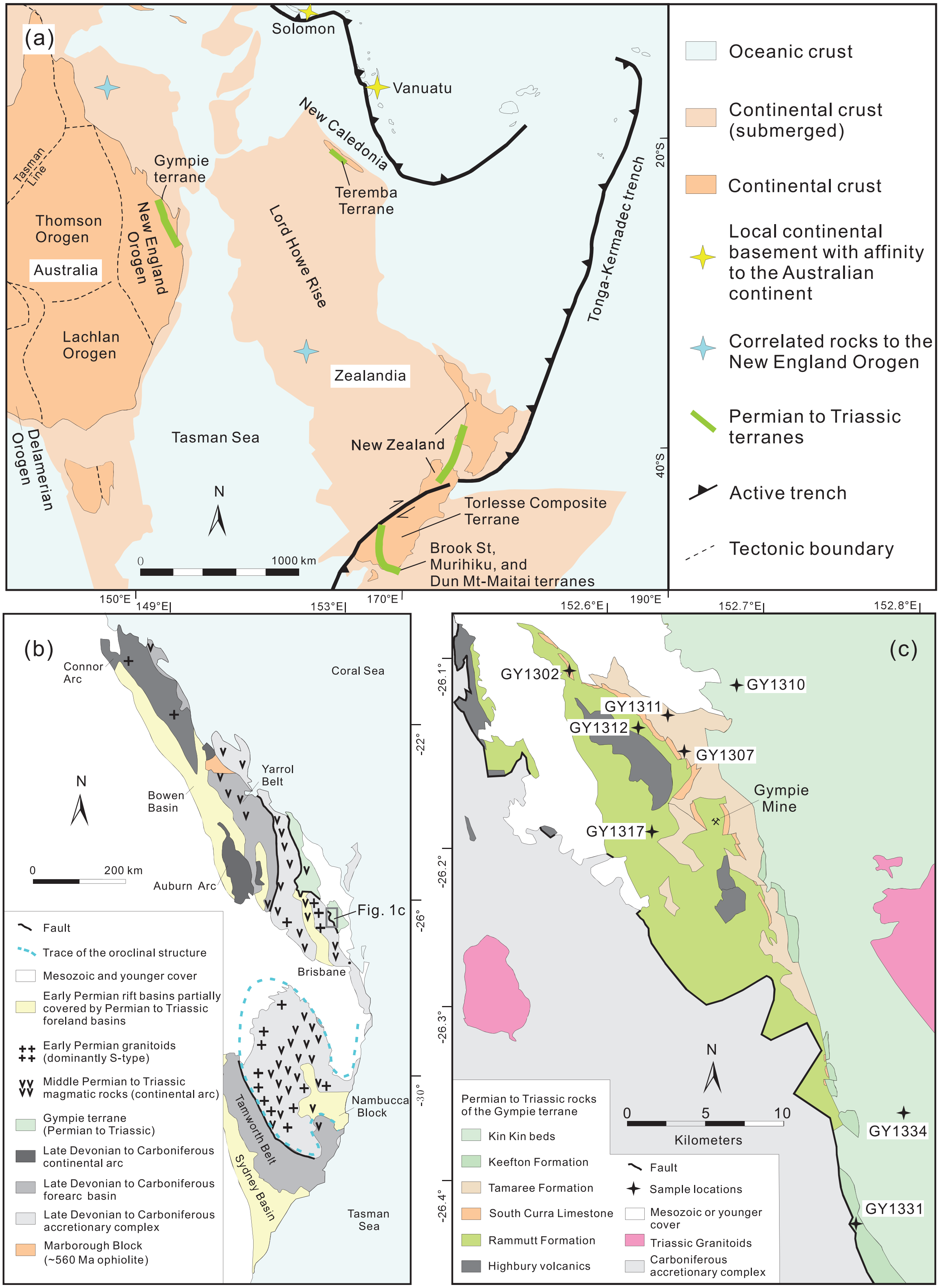
(a)
Solomon
Vanuatu
New Caledonia
Teremba Terrane
Gympie terrane
Tasman Line
Thomson Orogen
New England Orogen
Australia
Lachlan Orogen
Lord Howe Rise
Zealandia
Tonga-Kermadec trench
Tasman Sea
New Zealand
Delamerian Orogen
Torlesse Composite Terrane
Brook St, Murihiku, and Dun Mt-Maitai terranes
1000 km
Oceanic crust
Continental crust (submerged)
Continental crust
Local continental basement with affinity to the Australian continent
Correlated rocks to the New England Orogen
Permian to Triassic terranes
Active trench
Tectonic boundary
(b)
Connor Arc
Coral Sea
Yarrol Belt
Bowen Basin
Auburn Arc
Fig. 1c
Brisbane
Nambucca Block
Tamworth Belt
Sydney Basin
Tasman Sea
200 km
Fault
Trace of the oroclinal structure
Mesozoic and younger cover
Early Permian rift basins partially covered by Permian to Triassic foreland basins
Early Permian granitoids (dominantly S-type)
Middle Permian to Triassic magmatic rocks (continental arc)
Gympie terrane (Permian to Triassic)
Late Devonian to Carboniferous continental arc
Late Devonian to Carboniferous forearc basin
Late Devonian to Carboniferous accretionary complex
Marborough Block (~560 Ma ophiolite)
(c)
GY1302
GY1310
GY1311
GY1312
GY1307
Gympie Mine
GY1317
GY1334
GY1331
Kilometers
Permian to Triassic rocks of the Gympie terrane
Kin Kin beds
Keefton Formation
Tamaree Formation
South Curra Limestone
Rammutt Formation
Highbury volcanics
Fault
Sample locations
Mesozoic or younger cover
Triassic Granitoids
Carboniferous accretionary complex

Figure 1

Here we concentrate on the Gympie terrane, which is the easternmost tectonic unit of the Tasmanides (Figure 1b). It contains Permian to Triassic volcanic and sedimentary rocks, which appear to be separated from the adjacent New England Orogen (NEO) by a fault [*Cranfield et al*., 1997]. Based on the geochemical signature of basalts from the basal unit of the Gympie terrane (Highbury Volcanics, Figure 1c), *Sivell and Waterhouse* [1988] have proposed that the origin of these rocks was associated with an early Permian island arc. Accordingly, these authors suggested that the succession of Permian to Triassic volcanic/sedimentary rocks of the Gympie terrane represents an allochthonous island arc system that was subsequently accreted to the Australian continent. Alternatively, other authors have considered that the Gympie terrane originated in a continental arc system that was developed during the early Permian in response to a retreating subduction system [*Little et al*., 1992; *Holcombe et al*., 1997a]. On a larger scale, the Gympie terrane has been proposed to correlate with Permian to Triassic volcano-sedimentary rocks in New Zealand (Brook Street, Murihiku, and Dun Mountain-Maitai terranes, Figure 1a) and New Caledonia (Teremba Terrane, Figure 1a) [*Waterhouse and Sivell*, 1987; *Harrington*, 2008], but whether these terranes share a similar sedimentary provenance is still uncertain.

Geochronological data from the Gympie terrane is relatively limited. *Korsch et al*. [2009a] obtained ages of 40 detrital zircons from a sandstone sample near the base of the sedimentary sequence of the Gympie terrane (Rammutt Formation, Figure 1c). These zircons yielded a dominant Permian age peak (~276 Ma) and two Carboniferous ages of 318 Ma and 330 Ma [*Korsch et al*., 2009a]. Given the limited input of pre-Permian detrital zircons, *Korsch et al*. [2009a] considered that the Gympie terrane was isolated from the Australian continent during the Permian and therefore did not received much detritus from the Australian continent. *Korsch et al*. [2009a] had also dated 39 detrital zircons from a Triassic sample of the Gympie terrane (Keefton Formation), which contained 36% Carboniferous detrital zircons. The source of these detrital zircons was interpreted to be associated with the NEO, meaning that the deposition of the Keefton Formation must have occurred after the accretion of the Gympie terrane onto the Australian margin [*Korsch et al*., 2009a].

This paper aims at constraining the timing of deposition, the sedimentary provenance, and the tectonic origin of the Gympie terrane. We present U-Pb ages of magmatic zircons from volcanic layers and detrital zircons from each sedimentary unit in the Gympie terrane. Our results show that all sedimentary units from this terrane contain Australian-sourced detrital zircons, thus indicating a non exotic origin of the Gympie terrane and a close tectonic affinity with the Australian continent.

2. Geological Setting

The Tasmanides comprise a series of orogenic belts that developed along the eastern margin of the Australian continent during the Phanerozoic [*Glen*, 2005]. The NEO and Gympie terrane are the easternmost components of the Tasmanides (Figures 1a and 1b). Development of the NEO mainly occurred during the Devonian to Triassic along the convergent plate boundary of the proto-Pacific plate [*Day et al*., 1978; *Holcombe et al*., 1997a]. The orogenic belt is characterized by a Late Devonian to Carboniferous continental arc system that was generated above a west dipping subduction zone [*Leitch*, 1975; *Murray et al*., 1987]. The Late Devonian to Carboniferous volcanic arc is exposed in the northern NEO (Connors-Auburn Arc, Figure 1b) but is mostly absent in the southern part, where it is thought to be thrust under fore-arc basin rocks or overlain by younger sedimentary sequences [*Glen and Roberts*, 2012]. The Devonian-Carboniferous fore-arc basin rocks and accretionary complex are exposed in both the northern and southern segments of the NEO and are represented by shallow marine shelf to fluvial sedimentary

Figure 1. (a) A simplified basement map of eastern Australia and SW Pacific (based on *Harrington* [2008], *Mortimer* [2008], and *Collot et al*. [2012]). The map highlights Permian to Triassic lithostratigraphic units in Australia (Gympie terrane), New Caledonia (Teremba Terrane), and New Zealand (Brook Street, Murihiku, and Dun Mountain-Maitai terranes). Star indicates the locations of possible Australian-derived continental fragments [*Mortimer et al*., 2008; *Buys et al*., 2014; *Tapster et al*., 2014]. (b) Simplified geological map of the New England Orogen and the Gympie terrane [after *Glen and Roberts*, 2012]. The spatial distribution of Permian to Triassic magmatic rocks is based on *Gust et al*. [1993], *Murray* [2003], *Rosenbaum et al*. [2012], and *Li et al*. [2012b]. The trace of the oroclinal structure is after *Rosenbaum* [2012], *Li et al*. [2012a], and *Li and Rosenbaum* [2014]. (c) Geological map of the southern Gympie terrane and sample locations. The map is modified from the Gympie 1:100,000 geological map. Stratigraphy of the Gympie terrane is described in Table 1.

rocks, and deep marine turbidites interlayered with ribbon chert and pillow basalt, respectively [*Korsch*, 1977; *Roberts and Engel*, 1987; *Holcombe et al*., 1997a].

In the early Permian, the NEO was subjected to widespread extension as indicated by the formation of rift-related sedimentary basins [*Leitch*, 1988; *Korsch et al*., 2009b] and the development of a metamorphic core complex [*Little et al*., 1992, 1993]. Extension was accompanied by high-temperature metamorphism [*Craven et al*., 2012] and the emplacement of S-type granitoids [*Shaw and Flood*, 1981], indicating a hot environment typical of subduction zone back arcs [*Hyndman et al*., 2005]. An early Permian back-arc setting, which was likely generated by eastward trench retreat [*Holcombe et al*., 1997a; *Jenkins et al*., 2002; *Shaanan et al*., 2015], is supported by the pattern of detrital zircon populations from the rift basin of the Nambucca Block (Figure 1b) [*Shaanan et al*., 2015]. In the late Permian to Triassic, the orogen was affected by a continental arc system associated with west dipping subduction, as indicated by widespread occurrence of calc-alkaline igneous rocks [*Shaw and Flood*, 1981; *Gust et al*., 1993; *Bryant et al*., 1997; *Murray*, 2003]. Arc magmatism was accompanied by ~E-W contraction, commonly referred to as the Hunter-Bowen Orogeny [*Carey and Browne*, 1938; *Fergusson*, 1991; *Holcombe et al*., 1997b; *Korsch et al*., 2009c; *Li et al*., 2012b] that may have been triggered by an episode of trench advance [*Jenkins et al*., 2002].

The Gympie terrane lies to the east of the exposed NEO accretionary complex and is separated from it by a fault contact (Figure 1b) [*Cranfield et al*., 1997]. It is characterized by Permian volcanic rocks and Permian to Triassic shallow marine and fluviatile sedimentary rocks [*Day et al*., 1978]. The formalized rock units in the Gympie terrane, from the base up, are the Highbury Volcanics, Rammutt Formation, South Curra Limestone, Tamaree Formation, Keefton Formation, and Kin Kin beds (Figure 1c). The lithological characteristics and subdivisions of each unit are summarized in Table 1. The boundary between the basal Highbury Volcanics with the overlying Rammutt Formation has been described as disconformable or unconformable [*Cranfield et al*., 1997]. Numerous intraformational unconformities have been recognized within the Rammutt Formation, which is conformably overlain by the middle to late Permian South Curra Limestone and Tamaree Formation [*Cranfield et al*., 1997; *Sivell and Mcculloch*, 2001]. The Triassic Keefton Formation unconformably overlies the Permian rocks [*Runnegar and Ferguson*, 1969] and has a fault contact with the Kin Kin beds [*Cranfield et al*., 1997].

The stratigraphic sequence across each unit of the Gympie terrane is not well constrained due to relatively poor exposure and a deformation overprint. Limited structural data show evidence for multiple episodes of deformation, forming widespread folds and foliations in each unit and involving multiple stages of fault movement [*Cranfield et al*., 1997; *Sivell and Mcculloch*, 2001; *Crawford*, 2003]. A macroscopic recumbent fold was recognized within the South Curra Limestone, indicating partial overturning of the sedimentary sequence [*Runnegar and Ferguson*, 1969]. A penetrative slaty cleavage occurs throughout the top unit of the Gympie terrane (the Kin Kin beds), strongly obliterating the stratigraphic sequence [*Runnegar and Ferguson*, 1969; *Day et al*., 1978; *Cranfield et al*., 1997].

3. U-Pb Geochronology and Hf Isotopic Analysis

3.1. Sample Description

Eight samples from five separate formations were analyzed in order to constrain the timing of deposition and the provenance of the Gympie terrane (Figures 1c and S1 in the supporting information and Table 1). Five samples were taken from Permian stratigraphic units. Sample GY1312 is a very fine grained poorly sorted feldspathic greywacke from the Rammutt Formation, containing subrounded to subangular quartz and feldspar clasts, as well as minor mica flakes in a clay-rich matrix. A slaty cleavage is defined by seams of insoluble minerals. Sample GY1317 is a tuffaceous sandstone (lithic greywacke), also from the Rammutt Formation. The rock is fine to medium grained and comprises angular quartz, altered feldspar, chlorite, volcanic lithic clasts, and opaque minerals. Sample GY1302 was collected from an interstratified tuff layer within the South Curra Limestone. The tuff sample shows a prominent cleavage defined by stylolitic dissolution seams and is composed mainly of quartz, sericitized feldspar, clay, and volcanic glass. Two samples (GY1307 and GY1311) were taken from the Tamaree Formation. Sample GY1307 is a fine-grained feldspathic arenite with subangular quartz and feldspar, as well as minor mica flakes, whereas sample GY1311 is a fine to medium grained poorly sorted lithic arenite, containing subangular quartz, feldspar, and sedimentary/volcanic lithic fragments and minor mica flakes.

Table 1. Stratigraphic Units and Lithological Description of the Gympie Terrane

	Stratigraphic Units[a]				
	Runnegar and Ferguson [1969]	*Arnold* [1996]	Lithological Description	Sample Number/Location (WGS84)	Phanerozoic Age Peaks (Ma)
Early to Middle Triassic	Kin Kin beds		A relatively homogenous sequence of phyllites and slate (marine)	GY1310 (26°6′52.54″S; 152°40′33.09″E); GY1334 (26°21′28.38″S; 152°47′45.09″E)	240, 256, 296, 318, and 394
	Keefton Formation		Pebble conglomerate, sandstone, siltstone, limestone, and mudstone (fluvial terrestrial)	GY1331 (26°25′28.01″S; 152°45′31.09″E)	251, 268, 295, 328, 378, and 424
Late Permian	Tamaree Formation		Rhythmically bedded sandstone, siltstone, and mudstone (distal to shoreline turbidites)	GY1307 (26°9′5.66″S; 152°38′54.60″E); GY1311 (26°7′56.90″S; 152°38′23.24″E)	255, 299, 312, and 333
Middle to late Permian	South Curra Limestone		Impure bioclastic limestone, calcarenite, and minor volcanic rocks (shallow marine to lagoonal)	GY1302 (26°6′22.02″S; 152°34′28.53″E)	258
Early to middle Permian	Rammutt Formation	Top Conglomerate	Clast-supported conglomerate (estuarine/fluvial)		
		Pengelly Siltstone	Carbonaceous and calcareous shale (protected anoxic, shallow marine)		
		Upper Nash Clastics	Conglomerate, arenite, siltstone, and shale (shallow marine to alluvial fan)		
		Calton Clastics	Arenite, siltstone, conglomerate, and tuff (shallow marine to emergent)	GY1317 (26°12′1.89″S; 152°37′52.98″E)	265 and 312
		Calton Volcanics	Feldspar-phyric andesitic and dacitic lavas, tuffs, and hyaloclastites		
		Lower Nash Clastics	Volcanogenic conglomerate, arenite, and siltstone (shallow marine to alluvial fan)		
		Mary Volcanics	Clinopyroxene and plagioclase-phyric basaltic lavas and tuff breccias; hematite rich (shallow marine to emergent)		
		Hall Clastics	Conglomerate, arenite, and siltstone; no hematite (shallow marine)		
		Tozer Volcanics	Basaltic lavas and tuff breccias; no hematite (marine)		
		Alma Formation	Pale green, massive or laminated mudstone and siltstone interbedded with fine-grained tuffaceous rocks and hyaloclastites (deepwater marine)	GY1312 (26°8′21.58″S; 152°37′10.98″E)	302, 345, 384, 427, and 505
Early Permian	Highbury Volcanics		Basaltic tuff breccias, agglomerate, and mafic volcanic lavas (submarine)		

[a]In the paper, we use the term “Rammutt Formation” for all rocks above the Highbury Volcanics and below the South Curra Limestone (i.e., using the definition of *Runnegar and Ferguson* [1969]). We refer to the informal stratigraphic division by *Arnold* [1996] only in section 4.1, when discussing the relative stratigraphic levels of our samples.

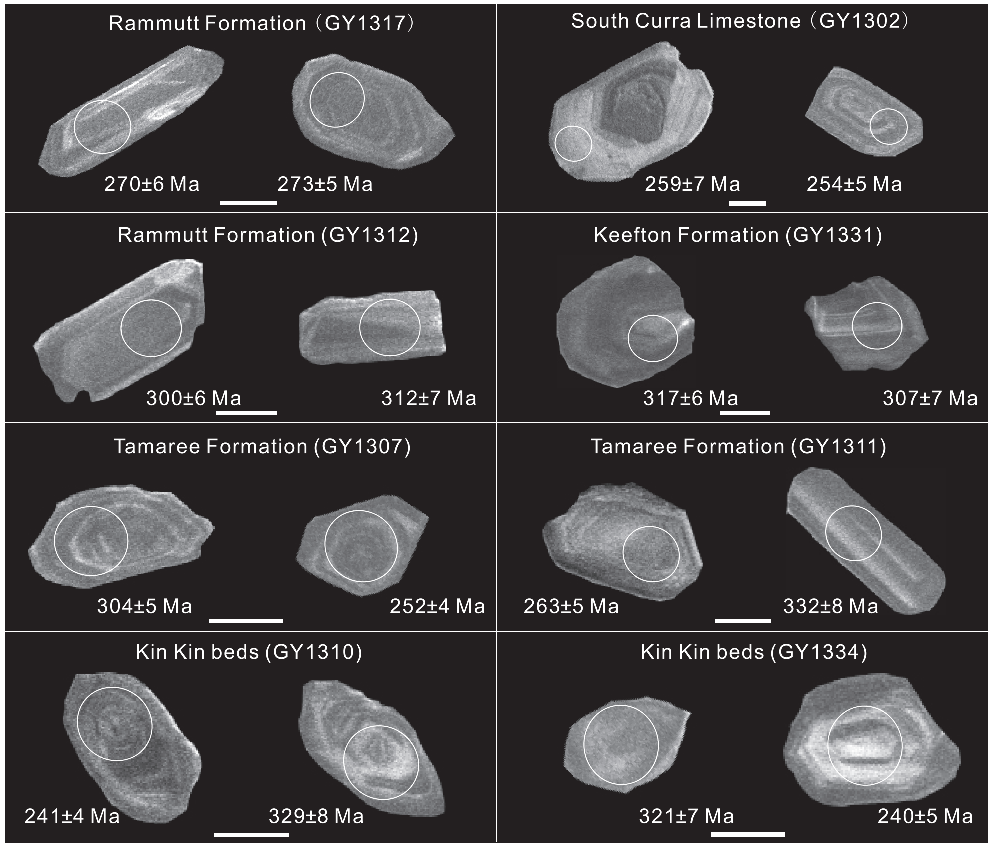

Figure 2. Cathodoluminescence images (CL) of selected zircon crystals. Circles indicate locations of U-Pb analyses, and white line represents a scale of 32 μm.

Three samples were collected from Triassic stratigraphic units. Sample GY1331 is a conglomerate from the Keefton Formation. The conglomerate is matrix supported and contains rounded to subangular quartz and sedimentary lithic clasts, as well as minor volcanic/plutonic fragments with a size range of ~0.2–2 cm. Two phyllite samples were collected from the Kin Kin beds (GY1310 and GY1334). They mainly consist of fine-grained quartz, altered feldspar, muscovite, and clay minerals. Both samples are characterized by a penetrative slaty cleavage defined by the preferred alignment of micas and lenticular clasts.

3.2. Methods

Zircon grains were separated with conventional crushing, heavy liquid, and magnetic techniques. The grains were mounted in epoxy resin and polished to expose a near equatorial section. Cathodoluminescence (CL) images were taken using a CAMECA SX-50 microprobe at the Institute of Geology and Geophysics, Chinese Academy of Sciences in Beijing, to characterize the internal structures of zircons and to target potential spots for U-Pb dating and Hf isotope analyses.

Zircons were analyzed for U, Th, and Pb using Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) at the Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing. Instrumental conditions and data acquisition follow the procedure documented in *Yuan et al*. [2004] and *Xie et al*. [2008]. Zircon 91500 was used as the primary standard, and NIST 610 silicate glass was used to optimize the instrument. U, Th, and Pb concentrations were calibrated using ^{29}Si as an internal standard and NIST 610 as reference materials. The data processing was done with the Glitter program [*Jackson et al*., 2004], and the weighted mean age calculation and concordia plots were done using the ISOPLOT program [*Ludwig*, 2003].

Analysis of zircon Hf isotopes were conducted using a Neptune Plus multiple collector ICP-MS in combination with a Geolas 2005 excimer ArF laser ablation system at the State Key Laboratory of Geological Processes and

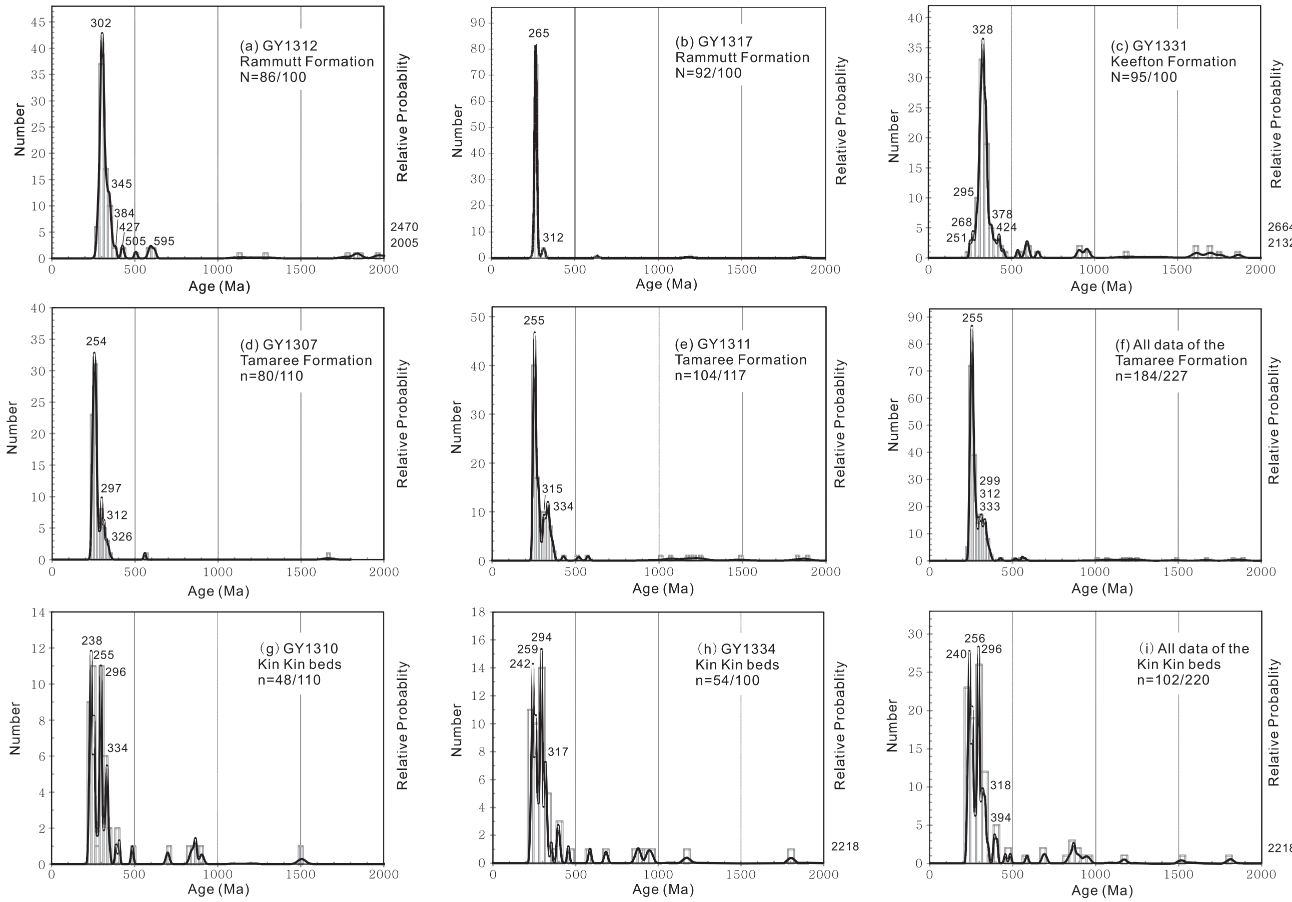

Figure 3. (a–i) Age probability diagrams of detrital zircons from each sedimentary unit in the Gympie terrane.

Mineral Resources, China University of Geosciences, Wuhan. The analytical procedure follows the description by *Hu et al*. [2012]. The data processing was conducted using the ICPMSDataCal software [*Liu et al*., 2010]. The chondritic values of ^{176}Lu/^{177}Hf = 0.0332 and ^{176}Hf/^{177}Hf = 0.282772 [*Blichert-Toft and Albarède*, 1997] were used for the calculation of εHf(t) values. The depleted mantle line is defined by present-day ^{176}Hf/^{177}Hf = 0.28325 and ^{176}Lu/^{177}Hf = 0.0384 [*Griffin et al*., 2000]. We calculated two-stage crustal model Hf ages (T_{DM2}) using the mean ^{176}Lu/^{177}Hf ratio of 0.015 for the average continental crust [*Griffin et al*., 2002].

3.3. Results

Representative CL images of analyzed zircons are shown in Figure 2, and U-Pb and Hf isotope analytical results are presented in Figures 3, 4, and S2 and Table S1. Concordant ages (<10% discordance, Table S1) are presented in histogram/probability density plots for sedimentary rocks. Zircons that are younger than 1000 Ma are reported as ^{206}Pb/^{238}U ages, whereas ^{206}Pb/^{207}Pb ages are used for older ages. In the tuff sample (GY1302), a single cluster is identified and the weighted mean of this cluster is interpreted as the age of the eruption. The reported weighted mean ^{206}Pb/^{238}U ages of samples GY1302 and GY1317, which typically have a 0.4%–0.7% error (95% confidence level), are forced to 1% to account for external errors. In this study, we targeted analytical spots for Hf isotopes nearby the previously dated sites, which is within the same zircon growth zone as constrained by CL images. The zircon Hf isotope analysis was only done on Carboniferous and Permian detrital zircons from samples GY1311, GY1312, and GY1317.

3.3.1. Permian Samples

Zircon grains from a sedimentary rock within the Rammutt Formation (sample GY1312, Figure 1c) are commonly euhedral to subeuhedral (Figure 2). Most zircon grains have oscillatory zoning and moderate to high Th/U ratios (0.1–1.6), indicating a magmatic origin. Zircons from this sample define one main age peak of ~302 Ma and one minor peak of ~345 Ma (Figure 3a). Some of the zircons yielded older age

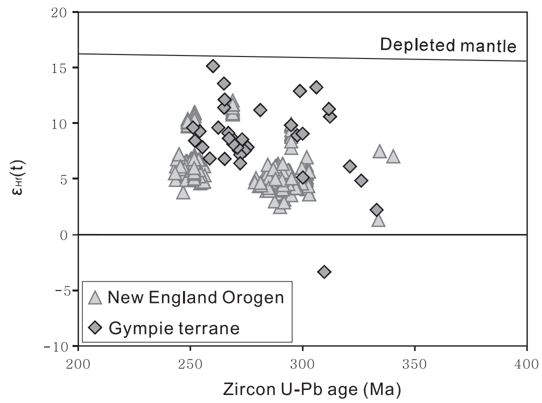

Figure 4. Diagram of εHf(*t*) values versus crystallizing ages for detrital zircons from the Gympie terrane and granitoids of the NEO. Data from the NEO are taken from *Kemp et al*. [2009] and *Jeon et al*. [2014].

clusters of ~384 Ma, ~427 Ma, and ~505 Ma, and 11 analyses yielded Proterozoic ages of 592–2470 Ma. The εHf(*t*) values of both Carboniferous and Permian zircons show a similar range. Nine zircon grains with ages of 295 to 321 Ma gives εHf(*t*) values from 5.1 to 13.2, and yielded T_{DM2} model ages are 475 to 987 Ma (Figure 4).

Zircons from sample GY1317 (tuffaceous sandstone, Figure 1c) are euhedral, commonly with oscillatory zoning (Figure 2), which together with moderate to high Th/U ratios (0.4–1.38), suggest an igneous origin. The 84 zircons from this sample cluster at a major age peak of ~265 Ma (Figure 3b) and give a weighted mean age of 265.7 ± 2.7 Ma (mean square weighted deviate (MSWD) = 1.19). A minor age peak of ~312 Ma and three Precambrian zircons of 634 Ma, 1180 Ma, and 1861 Ma were also found in this sample (Figure 3b). The εHf(*t*) values of 17 zircons with ages at ~265 Ma range from 6.4 to 15.1, corresponding to T_{DM2} model ages from 317 to 884 Ma (Figure 4).

Zircons from sample GY1302 (tuff, South Curra Limestone, Figure 1c) are euhedral and show oscillatory zoning, which together with moderate to high Th/U ratios (0.4–1.1), suggest an igneous origin. Zircon analyses for this sample yielded an age range of ~268–242 Ma, and 40 zircons gave a weighted mean age of 258.3 ± 2.6 Ma (MSWD = 0.66, Figure S2c) after excluding 10 zircons with >10% discordance between the $^{206}Pb/^{238}U$ and $^{207}Pb/^{235}U$ ratios.

Two samples from the Tamaree Formation (Figure 1c) were analyzed. Zircons from these samples show a similar crystal habit as the sample from the Rammutt Formation and are characterized by euhedral to subeuhedral shape and oscillatory zoning (Figure 2). Most zircons show moderate to high Th/U ratios that range from 0.19 to 1.2 for sample GY1307 and from 0.19 to 1.46 for sample GY1311 except of a single zircon grain with a low Th/U ratio of 0.07, indicating a predominant magmatic origin. Zircon ages from both samples are characterized by a main age peak of 254 Ma (GY1307) and 255 Ma (GY1311), respectively (Figures 3d and 3e). Three minor age peaks of ~297, ~312, and ~326 Ma cluster in sample GY1307 (Figure 3d), whereas two minor age peaks of ~315 and ~334 Ma are defined in sample GY1311 (Figure 3e). In addition, two older zircons of 428 and 519 Ma were found in sample GY1311 (Figure 3e). A total of 12 zircon grains from the two samples yielded Proterozoic ages of 558–1882 Ma (Figure 3f). The combined 184 analyses from both samples of the Tamaree Formation define a major peak of ~255 Ma and three minor peaks of 299 Ma, 312 Ma, and 333 Ma (Figure 3f). The Hf isotope analysis was restricted to sample GY1311. Seven Permian zircons yielded εHf(*t*) values of 7.8 to 11.2 (corresponding T_{DM2} model ages from 585 to 795 Ma), and three Carboniferous zircons gave εHf(*t*) values of −3.3, 2.2, and 4.9 (corresponding to T_{DM2} model ages of 1531, 1196, and 1024 Ma) (Figure 4).

3.3.2. Triassic Samples

The conglomerate sample from the Keefton Formation (GY1331) contains zircons with euhedral to subeuhedral shape and typically oscillatory zoning (Figure 2) as well as predominantly moderate to high Th/U ratio of 0.2–1.2, indicating an igneous origin. Zircon ages from this sample are characterized by a major age peak of 328 Ma and a few minor age peaks of 251 Ma, 268 Ma, 295 Ma, 378 Ma, and 424 Ma (Figure 3c). Two zircons from this sample yielded slightly older ages of 450 Ma and 537 Ma. Fifteen zircon grains yielded a Proterozoic age range of 586–2132 Ma, and one zircon grain gave an Archean age of 2664 Ma.

The two samples from the Kin Kin beds, from the uppermost unit of the Gympie terrane, contain zircons with subeuhedral to rounded shape and oscillatory zoning (Figure 2). Most zircon grains of sample GY1310 and sample GY1334 are <100 μm with moderate to high Th/U ratios of 0.15–1.5 and 0.1–1.3, indicating a predominantly igneous origin that is supported by the zircon crystal habit. Sample GY1310 is characterized by four main age peaks of 238 Ma, 255 Ma, 296 Ma, and 334 Ma (Figure 3g). Three zircons yielded older ages of 388 Ma, 407 Ma, and 485 Ma, and six zircons yielded Proterozoic zircon ages of 699–1506 Ma. Zircons from sample GY1334 cluster at four main age peaks of 242 Ma, 259 Ma, 294 Ma, and 317 Ma (Figure 3h). Five zircon grains yielded older ages of 353 Ma, 388 Ma, 396 Ma, 403 Ma, and 456 Ma, and nine zircons grains yielded a Proterozoic age range of 586–2218 Ma. Combining the two samples from the Kin Kin beds, five well-defined age peaks of 240 Ma, 256 Ma, 296 Ma, 318 Ma, and 394 Ma are observed (Figure 3i).

4. Discussion

4.1. Timing of Deposition

The timing of deposition of dated sedimentary rocks must be later than the formation of detrital zircons. Therefore, the youngest age peak can be used to constrain the maximum deposition age of the dated samples [*Nelson*, 2001; *Fedo et al*., 2003]. The age of each unit of the Gympie terrane, as constrained by our new zircon ages, is compatible with fossil ages as stated below.

The age of the Highbury Volcanics at the bottom of the Gympie terrane is poorly constrained. *Runnegar and Ferguson* [1969] proposed that the age of these volcanic rocks is early Permian based on the stratigraphic position below the Rammutt Formation. Our results for a sandstone (GY1312) from the Rammutt Formation show the youngest provenance age peak at ~302 Ma (Figure 3a), thus indicating that deposition must be younger than this age. The tuffaceous sandstone from the Rammutt Formation (GY1317) is characterized by a youngest age peak of ~265 Ma, constraining the timing of deposition to be middle Permian or later. Combining our data with information on the occurrence of Artinskian fossils (*Anidanthus springsurensis*, *Cancrinella farleyensis*, *Megadesmus nobilissimus*, *Pyramus concentricus*, and *Deltopecten limaeformis*; 290.1–283.5 Ma) in the Rammutt Formation [*Runnegar and Ferguson*, 1969], we consider that this formation was deposited from the early to middle Permian (~290–265 Ma). These age constraints indicate that the stratigraphic level of sample GY1317 is in the upper Rammutt Formation, which is possibly equivalent to the tuff-rich unit of the Calton Volcanics/Calton Clastics using the stratigraphic division of *Arnold* [1996] (Table 1). In contrast, sample GY1312, which does not contain middle Permian detrital zircons, is assumed to be associated with a lower stratigraphic level, possibly correlated to the Alma Formation [*Arnold*, 1996] (Table 1). This is supported by the fact that this sample was taken from a succession dominated by pale green thinly interbedded siltstones that are stratigraphically below the distinctly shallower marine facies sedimentary and tuffaceous rocks that characterize the upper Rammutt Formation.

The South Curra Limestone conformably overlies the Rammutt Formation [*Runnegar and Ferguson*, 1969; *Cranfield et al*., 1997]. We have obtained an age of 258.3 ± 2.6 Ma from an interstratified tuff layer from the upper part of this unit. At a lower stratigraphic level within the South Curra Limestone, the ammonite *Neocrimites meridionalis* has been documented [*Runnegar and Ferguson*, 1969], indicating a slightly older age between 272 ± 3 Ma and 264 ± 2 Ma (based on sensitive high-resolution ion microprobe (SHRIMP) zircon ages from tuffaceous sandstones above and below a similar fossiliferous horizon in the Sydney Basin [*Roberts et al*., 1996]). Combining these data with the ~265 Ma age peak of detrital zircons from the underlying Rammutt Formation, we consider that the deposition of the South Curra Limestone occurred in the middle Permian and probably continued to 258.3 ± 2.6 Ma.

The South Curra Limestone is conformably overlain by the Tamaree Formation [*Runnegar and Ferguson*, 1969; *Cranfield et al*., 1997], in which the youngest age peak of ~255 Ma (Figure 3f) gives a maximum age constraint for the dated samples. The presence of *Nuculana*, *Platyteichum*, and *Cladochonus* within the Tamaree Formation and the occurrence of 258.3 ± 2.6 Ma tuff in the overlying South Curra Limestone limits the deposition of the Tamaree Formation to the late Permian [*Runnegar and Ferguson*, 1969].

The contact between the Permian and Triassic rocks in the Gympie terrane was originally thought to be an angular unconformity [*Runnegar and Ferguson*, 1969], but *Cranfield et al*. [1997] reinterpreted it to be a conformable contact and proposed a regression to explain terrestrial deposits of the Keefton Formation. We consider that this boundary is likely to be an unconformity that represents the abrupt change in the sedimentary environment during a regression. Samples from the Keefton Formation yielded a youngest age peak of

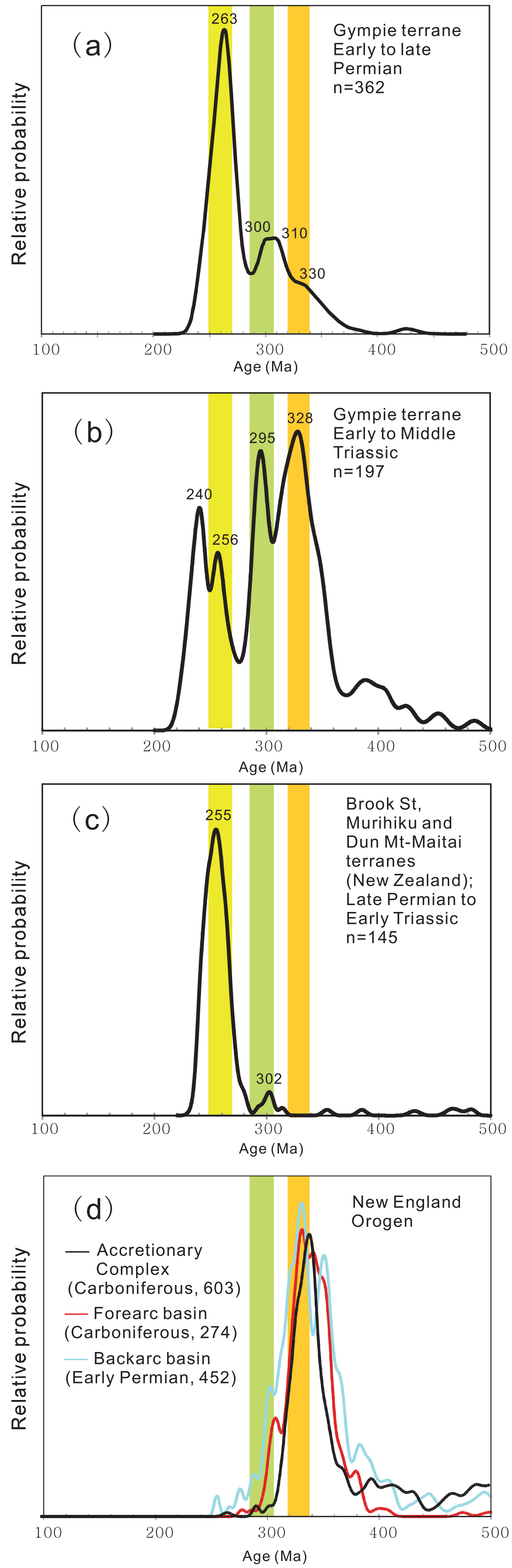

Figure 5. (a–d) Comparison of the age population of detrital zircons from the middle Permian to Triassic sedimentary rocks of the Gympie terrane with the Carboniferous to Permian rocks of the NEO, and the late Permian to early Triassic sedimentary rocks of the Brook Street, Murihiku, and Dun Mountain-Maitai terranes in New Zealand (see the location in Figure 1a). Detrital zircon ages in New Zealand are adapted from *Adams et al.* [2007], while data from the NEO are taken from *Korsch et al.* [2009a], *Hoy et al.* [2014], and *Shaanan et al.* [2015]. The plotted detrital zircon ages of the accretionary complex in Figures 5d and 6 just refer to LA-ICP-MS data of *Korsch et al.* [2009a], which were conducted with an aim at tracing the provenance.

~251 Ma (Figure 3c), thus providing a maximum depositional age for this formation. This age roughly matches the previously suggested Induan age (252.17–251.2 Ma [*Cohen et al.*, 2013]) for this formation based on plant fossils [*Runnegar and Ferguson*, 1969].

The contact between the Kin Kin beds and the underlying Keefton Formation is partly faulted [*Cranfield et al.*, 1997]. Detrital zircons from the Kin Kin beds yielded a youngest age peak of ~240 Ma (Figure 3i). This age is younger than the Early Triassic ammonoid fauna within the Kin Kin beds [*Runnegar and Ferguson*, 1969], so we consider that the deposition of the Kin Kin beds continued at least as late as ~240 Ma.

4.2. Provenance of the Gympie Terrane

Detrital zircons of Permian sedimentary rocks in the Gympie terrane mainly cluster within an age range of the Carboniferous to Permian, with main age peaks of 263 Ma, 300 Ma, 310 Ma, and 330 Ma (Figure 5a). Triassic rocks yielded similar age peaks of 256 Ma, 295 Ma, and 328 Ma and an additional younger age peak of 240 Ma (Figure 5b).

The late Permian to Triassic age peaks of 240 Ma and 263–256 Ma in the Gympie terrane overlap with the age of calc-alkaline volcanic and plutonic rocks that belong to a continental arc system in the NEO at ~264–240 Ma [*Gust et al.*, 1993; *Bryant et al.*, 1997; *Stewart*, 2001; *Murray*, 2003; *Li et al.*, 2012b]. Therefore, we think that detrital zircons defining late Permian to Triassic age peaks in the Gympie terrane were most likely sourced from the middle Permian to Triassic continental arc system to the west, which was built on the former accretionary complex of the NEO (Figure 1b) [*Gust et al.*, 1993;

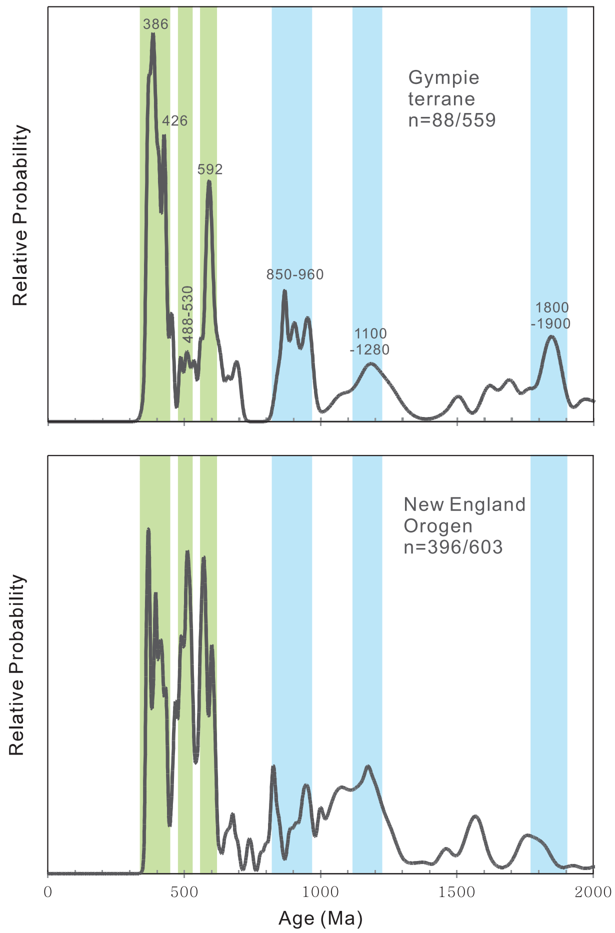

Figure 6. Comparison of age peaks of pre-Carboniferous detrital zircons from the Gympie terrane with the accretionary complex of the NEO in eastern Australia. Data from the NEO are taken from *Korsch et al.* [2009a].

Bryant et al., 1997; *Holcombe et al.*, 1997b; *Li et al.*, 2012b].

The 300–296 Ma age peak of detrital zircons in the Gympie terrane is compatible with the ~297–293 Ma zircon peaks of sedimentary rocks in the early Permian rift basin of the Nambucca Block in the NEO (Figure 5d) [*Adams et al.*, 2013; *Shaanan et al.*, 2015]. This time interval overlaps with the widespread occurrence of early Permian bimodal volcanic rocks and S-type granitoids in response to eastward trench retreat [*Shaw and Flood*, 1981; *Murray*, 2003; *Cawood et al.*, 2011a; *Rosenbaum et al.*, 2012]. Therefore, we consider that detrital zircons defining the 300–296 Ma age peak in the Gympie terrane are dominantly sourced from latest Carboniferous to early Permian magmatic rocks of the NEO. Although probably of an early Permian age, the basal Highbury Volcanics of the Gympie terrane cannot be the main source of this group of zircons, because they are dominated by basaltic rocks that are zircon undersaturated [*Runnegar and Ferguson*, 1969; *Sivell and Waterhouse*, 1988; *Cranfield et al.*, 1997]. In addition, volcanic rocks within the early to middle Permian Rammutt Formation cannot significantly contribute to the source of this group of zircons (~300–296 Ma) due to the obvious age discrepancy.

The 310 Ma and 330 Ma age peaks of detrital zircons in the Gympie terrane correspond to provenance data from the accretionary complex and fore-arc basin of the NEO (Figure 5d), in which Carboniferous detrital zircons were considered to derive from the Late Devonian to Carboniferous continental arc [*Korsch et al.*, 2009a; *Hoy et al.*, 2014]. This is supported by previous geochronological studies, which provided age constraints at ~359–305 Ma for the volcanism associated with the Late Devonian to Carboniferous continental arc system [*Claoue-Long et al.*, 1992; *Roberts et al.*, 1995; *Roberts et al.*, 2006; *Cawood et al.*, 2011a; *Jeon et al.*, 2012]. We therefore think that detrital zircons defining the 330 Ma and 310 Ma age peaks originated from the Carboniferous magmatic arc of the NEO and were either eroded directly from the magmatic arc or recycled through the Carboniferous fore-arc and accretionary complex rocks.

Cambrian to Devonian detrital zircons from the early Permian to Triassic sedimentary rocks of the Gympie terrane compose up to 6% of total detrital zircons and define two major age peaks at ~386 Ma and ~426 Ma, and three minor age peaks within an age range of 488–530 Ma (Figure 6). Detrital zircons with these age peaks (~386 Ma, ~426 Ma, and 488–530 Ma) roughly overlap with detrital zircon ages from the NEO (Figure 6), where recycled Cambrian to Devonian detrital zircons likely originated from the Tabberabberan (~382–397 Ma), Benambran (~430–450 Ma), and Delamerian (~490–516 Ma) orogenies [*Korsch et al.*, 2009a]. Similarly, the Cambrian to Devonian detrital zircons from the Gympie terrane may have originated from igneous rocks associated with these Paleozoic orogenic phases and were later recycled through the NEO (Figure 6). We note, however, that there are only few detrital zircons with Delamerian ages in the Gympie terrane (Figure 6).

Precambrian detrital zircons are recognized in all of the analyzed sedimentary samples, with ages of ~592 Ma, 850–960 Ma, 1100–1280 Ma, and 1800–1900 Ma, which takes up 10% of total detrital zircons. These age peaks roughly coincide the age range of Precambrian detrital zircons from the accretionary complex of the NEO (Figure 6), interpreted to be derived from the Australian continental interior [*Korsch et al*., 2009a]. Given the similar age peaks of Precambrian detrital zircons and close spatial proximity between the Gympie terrane and the NEO, we think that this group of detrital zircons in the Gympie terrane was mostly recycled from the NEO.

Overall, our results show that detrital zircons in the Gympie terrane are predominantly sourced from the Australian continent. In samples GY1317, GY1307, GY1311, GY1310, and GY1334, the youngest age peak, which is close to the deposition age, represents the major zircon population of each sample (Figure 3), indicating a major contribution of a coeval volcanic-derived detritus. In contrast, sample GY1331 (Keefton Formation) has a major detrital zircon peak at ~328 Ma, which is significantly older than the youngest peak (~251 Ma) that overlaps with the deposition age. This pattern is interpreted to represent a larger input of NEO-sourced detritus for the Keefton Formation, which is also reflected in the widespread occurrence of sedimentary lithic clasts in sample GY1331. The youngest zircon age peak in sample GY1312 (Rammutt Formation) is ~302 Ma, which is slightly older than the stratigraphic age (~290–265 Ma), thus indicating a major contribution of latest Carboniferous to earliest Permian zircons during deposition. In addition, all stratigraphic units contain Devonian to Cambrian detrital zircons, which together with Precambrian zircon population take up 16% of the total analyzed zircons in the Gympie terrane. These detrital zircons are significantly older than stratigraphic ages and are likely recycled through the NEO.

4.3. Implications for the Origin of the Gympie Terrane

Our results indicate that the sedimentary rocks of the Gympie terrane received a major input of detrital zircons from the Australian continent. This conclusion does not support previous interpretations that considered the Gympie terrane as allochthonous based on the island arc-related geochemical affinity of the basal Highbury Volcanics [*Waterhouse and Sivell*, 1987; *Sivell and Waterhouse*, 1988]. The previous geochronological study of *Korsch et al*. [2009a] involved a relatively limited number of zircon data from two samples. One of the samples was a volcaniclastic sandstone from the Rammutt Formation, in which 40 zircon grains yielded a Permian age peak (~276 Ma) and two older Carboniferous ages of 318 Ma and 330 Ma. The detrital zircons from the Triassic Keefton Formation yielded Carboniferous age peaks with an inferred NEO source [*Korsch et al*., 2009a]. Based on these results, *Korsch et al*. [2009a] proposed that the early Permian Gympie terrane was a Japan-type island arc in the Permian [*Xiao et al*., 2010] and was accreted to the Australian continent prior to the Triassic. In contrast, our new detrital zircon data indicate that both Permian and Triassic sedimentary units of the Gympie terrane received a large number of detrital zircons with an Australian continent affinity. Given the widespread contribution of NEO-sourced detrital zircons for the sedimentary sequence in the Gympie terrane, we think that these sedimentary rocks were deposited along the eastern margin of the Australian continent. Indeed, the early Permian rocks at the Gympie terrane do share some of the characteristics of the early Permian extensional rifts of the NEO [*Holcombe et al*., 1997a], and the early Permian faunal assemblage in the Rammutt Formation overlaps with Fauna II, which is one of the key assemblages used for correlation across the early Permian Bowen Basin [*Dickins et al*., 1964; *Runnegar and Ferguson*, 1969]. In addition, Hf compositions of Permian detrital zircons in the Gympie terrane yielded high εHf values of +6.4 to +15.1, indicating a predominant juvenile origin, which is compatible with high zircon εHf values of middle to late Permian granitoids of the NEO (Figure 4) [*Kemp et al*., 2009; *Phillips et al*., 2011; *Jeon et al*., 2014] and thus supports the occurrence of detrital zircons in the same arc system as the NEO granitoids.

Our data show a relatively uniform pattern of detrital zircon ages from the late Permian to Triassic units (Figure 3), but a more variable provenance from the early to middle Permian Rammutt Formation (Figures 3a and 3b). Sample GY1317 from the upper Rammutt Formation shows a dominant zircon age peaks of ~265 Ma, which corresponds to the initiation of widespread felsic magmatism in the NEO in the middle Permian (Figure 1b) [*Holcombe et al*., 1997b; *Li et al*., 2012b]. The absence of middle Permian zircon grains in sample GY1312 (the lower Rammutt Formation) indicates that the early stage of deposition of the Rammutt Formation likely took place prior to the development of the middle Permian to Triassic continental arc system, probably in an extensional environment as expressed by the development of rift

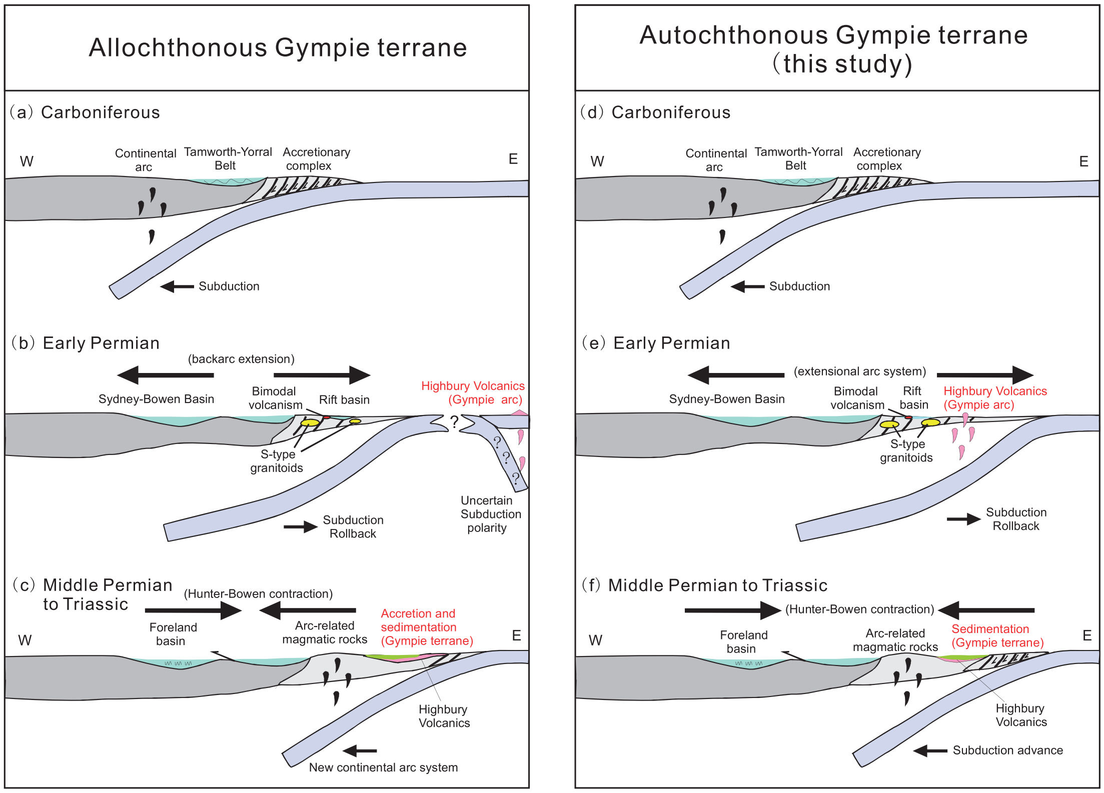

Figure 7. Two alternative models for the tectonic evolution of the Gympie terrane. (a–c) In this scenario the basal Highbury Volcanics of the Gympie terrane is interpreted as an intraoceanic island arc in the early Permian (based on *Sivell and Waterhouse* [1988] and *Buckman et al*. [2015]), and accreted to the Australian continent prior to the Middle Permian. (d–f) In this scenario the basal Highbury Volcanics of the Gympie terrane is assumed to be an early Permian extensional arc in response to eastward trench (based on *Holcombe et al*. [1997a]). In the middle to late Permian, a contractional phase of continental arc system occurred, possibly related to subduction advance.

basins, a metamorphic core complex, and bimodal volcanism in the NEO [*Little et al*., 1992; *Korsch et al*., 2009b; *Cawood et al*., 2011a]. Therefore, we think that the deposition of the Rammutt Formation may record the tectonic transition from an early Permian extensional arc system to the middle Permian establishment of a contractional phase of continental arc system [e.g., *Li et al*., 2014], which is supported by the observed unconformity within the Rammutt Formation [*Cranfield et al*., 1997]. The top part of the Rammutt Formation is conformably overlain by the South Curra Limestone and the Tamaree Formation, which together with a large number of middle to late Permian detrital zircons with a juvenile origin in these units, indicates continuous sedimentation with a source from the middle Permian to Triassic continental arc system to the west. Given the spatial occurrence of middle Permian to Triassic sedimentary rocks of the Gympie terrane to the east of the coeval continental arc, we consider that the Gympie terrane was most likely in a fore-arc basin environment in the middle to late Permian.

The tectonic origin of the basal unit of the Gympie terrane, Highbury Volcanics, remains enigmatic. *Sivell and Waterhouse* [1988] suggested that the geochemical affinity of these rocks is characteristic of an intraoceanic island arc (Mariana-type [*Xiao et al*., 2010]), with low Mg numbers, Ni, Cr, REE, and HFSE as well as low Zr/Y, Ti/Y, and Nb/Zr ratios. Accordingly, these rocks were interpreted as a remnant of an early Permian exotic island arc (e.g., Figures 7a–7c) [*Sivell and Waterhouse*, 1988; *Buckman et al*., 2015]. An alternative interpretation was provided by *Sivell and McCulloch* [2001], who suggested that the Highbury Volcanics may represent a marginal island arc (Japan-type [*Xiao et al*., 2010]) that was built on the rifted accretionary complex of the NEO in response to an eastward trench retreat. According to these authors, the Highbury Volcanics and the andesites in the overlying Rammutt Formation may represent evolved magmatism of the same arc system. Our data show that at least the upper part of this arc system (i.e., Rammutt Formation) has received older zircons from the NEO. Both of the Highbury Volcanics and the andesites in the Rammutt Formation are characterized by depleted asthenospheric mantle sources that were metasomatized by hydrous fluids from the subducted slab as shown by high Nd-isotope ratios, Zr/Nb, Sr/Nd, and La/Nb

[*Sivell and Mcculloch*, 2001]. However, the andesites from the Rammutt Formation with high Al_2O_3, Zr, and SiO_2 show higher Zr/Y, Nb/Y, Ti/V, La/Y, P/Nd, and K/P in comparison to isotopically similar basaltic rocks of the Highbury Volcanics. These geochemical features suggest that the andesites may represent basaltic magma that assimilated ~40% isotopically primitive (young) terrigenous sediments affiliated to the Carboniferous accretionary complex of the NEO [*Sivell and Mcculloch*, 2001]. This interpretation can be reconciled with the proposal that the Highbury Volcanics represents an early Permian continental arc that developed during eastward trench retreat (Figures 7d–7f) [*Little et al*., 1992; *Holcombe et al*., 1997a]. The formation of the Highbury Volcanics was likely coeval with extensional tectonics in the early Permian, as expressed by the development of rift basins, bimodal volcanism, and a metamorphic core complex [*Little et al*., 1992; *Korsch et al*., 2009b; *Cawood et al*., 2011a; *Shaanan et al*., 2015], which have been suggested to represent overriding plate back-arc extension in response to eastward trench retreat [*Jenkins et al*., 2002; *Cawood et al*., 2011a; *Rosenbaum et al*., 2012]. Exposed igneous rocks associated with the early Permian retreating subduction system in the NEO are predominantly S-type granitoids and bimodal volcanic rocks [*Shaw and Flood*, 1981; *Cawood et al*., 2011a]. The early Permian arc, which is not exposed elsewhere in the NEO, is likely represented by the early Permian Highbury Volcanics and possibly also by the volcanic rocks of the lower Rammutt Formation. The "island arc" geochemical affinity of the Highbury Volcanics may reflect limited assimilation of continental materials during arc magmatism, given that the overlying plate of the Carboniferous accretionary complex was rich in oceanic materials [*Holcombe et al*., 1997a] and had been thinned due to widespread early Permian extension. Indeed, continental fragments in the overriding plate do not necessarily modify the geochemical signature of arc magmatism. This has been demonstrated, for example, in the Solomon Island and Vanuatu (Figure 1a), where Precambrian and Paleozoic inherited zircons within arc magmatic rocks are indicative of the existence of continental basements, but the geochemistry of these rocks is characteristic of a Mariana-type island arc with a negligible contribution of continental materials [*Buys et al*., 2014; *Tapster et al*., 2014].

Overall, based on the available geological, geochemical, and geochronological data from the Gympie terrane, we consider that the Highbury Volcanics were most likely formed as an extensional continental arc in the earliest Permian (Figures 7d–7f), which evolved to be more felsic as represented by the andesites of the early to middle Permian Rammutt Formation [*Sivell and Mcculloch*, 2001]. Alternatively, the Highbury Volcanics could possibly represent an exotic rock association that was accreted to the NEO prior to the deposition of the Rammutt Formation (i.e., before ~290–265 Ma; section 4.1). This interpretation is not preferred given the evidence for extensional tectonics in eastern Australia in the earliest Permian [*Little et al*., 1995; *Holcombe et al*., 1997a; *Korsch et al*., 2009b], which is incompatible with the type of tectonism associated with terrane accretion.

On a larger scale, Permian to Triassic rocks in New Zealand (Brook Street, Murihiku, and Dun Mountain-Maitai terranes, Figure 1a) and New Caledonia (Teremba Terrane, Figure 1a), similarly to the Gympie terrane, are characterized by arc-related rocks overlain by the middle/late Permian to Triassic sedimentary sequence [*Waterhouse and Sivell*, 1987; *Harrington*, 2008]. Our detrital zircon data from the middle Permian to Triassic rocks of the Gympie terrane show similar age peaks as the coeval sedimentary sequence in New Zealand (Figure 5) [*Adams et al*., 2007], and rocks in both areas contain detrital zircons from eastern Gondwana (Australia and Antarctica), indicating a genetic link with the continents. Combining with the widespread arc-related magmatism in the NEO, we think that a continental arc system existed along the eastern Gondwana margin in the middle Permian to Triassic. The earliest accretionary complex of the Torlesse Composite Terrane (Figure 1a) was deposited in the late Permian and contains Gondwana-sourced detrital zircons [*Adams et al*., 2007], which supports the development of a continental arc along the eastern Gondwana margin since the late Permian.

5. Conclusions

Detrital zircons of Permian sedimentary rocks in the Gympie terrane yielded age peaks of 263 Ma, 300 Ma, 310 Ma, and 330 Ma, which are similar to the main age peaks of 256 Ma, 295 Ma, and 328 Ma for Triassic sedimentary rocks except for an additional younger age peak of 240 Ma. These zircon age peaks overlap with the age range of magmatism in the NEO and also match with available detrital zircon ages from the NEO. This indicates that sedimentary rocks in the Gympie terrane were at least partly sourced from the

Australian continent. Therefore, we interpret that sedimentary rocks of the Gympie terrane were deposited along the eastern Australian margin rather than within an island arc environment far from the Australian continent. Combined with the available geological, geochemical, and geochronological data, we consider that the Gympie terrane most likely represents an autochthonous tectonic unit in eastern Australia rather than an allochthonous terrane. Our results support the conclusion by *Colpron et al*. [2007] that some terranes in accretionary orogens, which were previously considered to be exotic, are, in fact, genetically linked to the adjacent continents.

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