Development of the early Paleozoic Pacific margin of Gondwana from detrital-zircon ages across the Delamerian orogen

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ABSTRACT
Detrital-zircon age spectra have been determined for sedimentary rocks from the Delamerian orogen, southern Australia. In Neoproterozoic sedimentary rocks, patterns progressively change from Mesoproterozoic- to Neoproterozoic-dominated detritus and there are few zircons that are close to the depositional age. The base of the Cambrian Kanmantoo Group marks an abrupt change in provenance to detrital patterns dominated by Ross and Delamerian (600–500 Ma) and Grenvillian ages (1200–1000 Ma). These patterns are strikingly similar to those obtained from Lachlan fold belt sedimentary rocks, indicating that the sedimentation recorded in the Kanmantoo Group marks a change from deposition of sediments derived from the Australian cratons to those representative of the early Paleozoic Gondwana mudpile. If sedimentary rocks with zircon-provenance characteristics such as those of the Kanmantoo rocks extend under elements of the Lachlan fold belt, they would provide suitable protoliths for the S-type granites of southeastern Australia.

INTRODUCTION
Plate reorganization at continental margins is generally accompanied by substantial erosion and consequent deposition of significant volumes of monotonous clastic sediments, with often elusive provenance. However, key information on the crustal elements in the sediment provenance is commonly held in the age spectra of detrital zircons. These spectra can provide a powerful tool in understanding geologic links and possible plate movements in ancient orogenic systems where the record of former plate-tectonic configurations has been destroyed (Ireland, 1992; Gehrels et al., 1996).

Gondwana’s Paleozoic plate margin constitutes one of the most extensive orogenic belts in Earth history. The margin was initiated during Neoproterozoic rifting followed by early Paleozoic convergent tectonism that appears related to subduction of oceanic crust beneath the eastern Gondwana craton (Flöttmann et al., 1993). Subsequent accretion of arc-trench systems formed a series of eastward-migrating orogenic belts, the oldest of which are the formerly continuous Neoproterozoic-Ordovician Ross and Cambrian-Ordovician Delamerian orogens (Stump et al., 1986; Flöttmann et al., 1993). Remnants of this orogenic belt are preserved in the formerly contiguous Gondwana fragments of southeastern Australia, Antarctica, and New Zealand (Gibson and Ireland, 1996). All outboard terranes are characterized by vast volumes of monotonous early Paleozoic sandstone and mudstone sequences. A key question in understanding the tectonic evolution at the paleo-Pacific margin of Gondwana remains the provenance of this uniform and massive “mud-pile” (Coney et al., 1990).

The southeast Australian margin of Gondwana exhibits the most complete rock record from the craton in the west to the eastern (outboard) Paleozoic orogenic zones. The Archean-Mesoproterozoic Gawler craton contains rocks with at least five distinct episodes of zircon growth (Daly and Fanning, 1993; Parker, 1993): (1) Sleafordian orogeny and post-orogenic granites (2600–2400 Ma); (2) 2000 Ma gneiss basement below the Paleoproterozoic Hutchinson Range Volcanics that yield ages between 1584 Ma and 1592 Ma, similar to those of their intrusive equivalents in the Hiltaba suite. East of the Gawler craton, Neoproterozoic to Lower Cambrian sedimentary rocks of >10 km thickness were deposited during repeated rift-and-sag phases between 830 Ma and ca. 520 Ma (Preiss, 1993). Neoproterozoic rocks are overlain by the platform-deposited Lower Cambrian Normanville Group. East and south of the exposed Neoproterozoic rocks, renewed crustal attenuation led to deposition of the Lower Cambrian Kanmantoo Group, a rapidly deposited elastic wedge consisting of >8 km of turbidites. The Neoproterozoic and Cambrian sedimentary units were deformed during the Early to Late Cambrian Delamerian orogeny (Coney et al., 1990; Preiss 1995; Haines and Flöttmann, 1998) (Fig. 1).

Farther east, the Lachlan fold belt encompasses Ordovician-Silurian turbidites, pelagic pelites, and cherts that, in their present deformed state, crop out over an area of 800 by 600 km. The palinspastically restored expanse of these rocks has been likened to the depositional realm of the modern-day Bengal Fan (Fergusson and Coney, 1992). The turbidites are interspersed...
Zircons were analyzed on SHRIMP I following standard operating procedures (Ireland, 1992; Ireland and Gibson, 1998). The age for an individual zircon is derived from the weighted mean of the 206Pb/238U and 207Pb/206Pb ages. As such, the 206Pb/238U age is the main determinant for younger zircons and the 207Pb/206Pb age is better determined in older grains. In general, the analytical precision of an individual 206Pb/238U age determination is better than ~2%, with better precision for older grains whose 207Pb/206Pb age is well determined. In some cases, poor counting statistics of low U grains or large variations in the isotope count rates produce larger errors. The 207Pb/206Pb age was used for discordant analyses of older grains. In younger zircon populations, discordia trajectories are close to concordia and constraining Pb loss is not analytically possible. In the context of detrital zircon age spectra, the effect of Pb loss is to broaden the peaks with tailing to younger ages. However, the clustering of individual ages in the peaks, and the reproducibility of the Kanmantoo patterns despite indications for Pb loss, suggests that the source age-characteristics are largely being retained. Our conclusions would not be affected if solely 207Pb/206Pb or 206Pb/238U ages were used.

Fifty zircons were analyzed from each of the Adelaidean sedimentary rocks. The Niggly Gap Beds of the Callanna Group is the oldest of the Adelaidean units examined and stratigraphically overlies the 802 Ma Rook Tuff (Preiss, 1993). The detrital-zircon age spectrum (Fig. 2A) shows that most zircons are 1550–1900 Ma with three main peaks at ca. 1600, 1680, and 1840 Ma. A significant Paleoproterozoic and late Archean (2100–2700 Ma) component is present. Even though the depositional age of this unit cannot be older than 802 Ma, there are no zircons from any source younger than 1550 Ma.

The age spectrum of the Mitcham Quartzite is similar to that of the Niggly Gap Beds with main peaks at 1560, 1640, and 1820 Ma. Only two early Paleoproterozoic–late Archean grains were identified (both just younger than 2500 Ma). The Mitcham Quartzite has a contribution of Mesoproterozoic zircons with peaks at 980, 1050, and 1100 Ma and with a minor contribution at 1300 Ma.

The Marino Arkose of the Umberatana Group has a dominant peak in the zircon age spectrum (Fig. 2C) at 1140 Ma with a strong contribution from Mesoproterozoic to Paleoproterozoic ages (1500–2000 Ma; peaks at ca. 1550 and 1830 Ma). Only three zircons older than 2000 Ma were analyzed. The coincidence of the three youngest zircons at ca. 650 Ma may place an upper limit on the depositional age.

The Bonney Sandstone of the Wilpena Group (Fig. 2D) shows a dominant Grenvillean provenance (ca. 1100 and 1180 Ma peaks) with only

RESULTS

U-Pb SHRIMP (sensitive high resolution ion microprobe) ages from nine samples are presented here.1 Samples were selected to cover the stratigraphic ages represented across the Adelaide fold belt with particular emphasis on the nature of the transition from the Neoproterozoic Adelaidean succession to the Early Cambrian Kanmantoo Group.

The Neoproterozoic rocks are divided into four lithostratigraphic units, which are from oldest to youngest, the Callanna, Burra, Umberatana, and Wilpena Groups (Fig. 1). Determining a detailed chronology has proved difficult. The only well-constrained age is for the Rook Tuff in the Callanna Group at 802 ± 10 Ma (Fanning et al., 1986). The Neoproterozoic sequence is unconformably overlain by the Lower Cambrian Normanville Group, Cooper et al. (1992) obtained an age of 526 ± 4 Ma from a tuff contained in the Heatherdale Shale of the upper Normanville Group. The Kanmantoo Group rests unconformably on the Normanville Group.

1GS Data Repository item 9828, U-Pb analyses of Adelaide fold belt and Kanmantoo Group detrital zircons, is available on request from Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301. E-mail: editing@geosociety.org.
a minor contribution from Proterozoic and Archean grains. Grains younger than the main peak range in age from 950 Ma down to 400 Ma. Since the depositional age must be Precambrian, it is clear that the 400 Ma grain at least has experienced Pb loss. The next four youngest zircons give ages of 600–700 Ma which are close to the likely depositional age.

The Lower Cambrian Mount Terrible Formation of the Normanville Group rests disconformably upon the Wilpena Group. Its age spectrum (Fig. 2E) shows a dominant peak at ca. 1830 Ma with only minor contributions from 2000–2800 Ma and a single younger zircon at 1200 Ma.

In contrast to the simple spectrum of the Mount Terrible Formation, the Heatherdale Shale of the upper Normanville Group shows a wide range of ages. Both Grenvillean and older Proterozoic components are well represented with peaks at 1030, 1100, and 1190 Ma and at 1700 and 1810 Ma, respectively. Four grains have ages between 2000 and 2500 Ma. While the youngest zircons (younger than 500 Ma) must have experienced Pb loss, it is not clear whether the few ages between 800 and 500 Ma are discordant Grenvillean peaks or represent contributions from a Neoproterozoic-Cambrian source.

The Kanmantoo Group rests disconformably upon the Normanville Group and is marked by a dramatic change in detrital zircon ages. Three units of the Kanmantoo Group were sampled: the Carrickalina Head Formation, the lowermost unit of the Kanmantoo Group (Fig. 2G); a shear zone from the Fleurieu Peninsula (Fig. 2H); and the Balquhidder Formation, one of the higher units (Fig. 2I). Age spectra for these three samples (100 grains each) show similar patterns: a main peak at 500–700 Ma, a subordinate peak at 900–1200 Ma, and scattered ages of older zircons from 1500 to 3500 Ma. Zircon ages substantially younger than ca. 500 Ma, particularly in the shear zone, must be due to Pb loss.

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The Adelaidean sedimentary rocks show a general progression of zircon ages consistent with depositional age, i.e., older sediments have older zircon components (Fig. 2). However, these components are all much older than the depositional age, which is not well represented in any of the spectra. Possible ages of deposition are given by only a few zircons which makes it difficult to discount Pb loss from older zircons as the source. Gehrels et al. (1996) have presented detrital zircon ages from two rocks from the Adelaide sequence: the Rhyolite Sandstone of the Burra Group, and the Elatina Formation of the Umbertana Group. Their results are entirely consistent with that reported here: dominant Mesoproterozoic populations and small amounts of older (Paleoproterozoic and Archean) as well as younger Grenvillean components. The Adelaidean rocks require a provenance not dissimilar to rocks exposed in the Gawler craton today.

The abrupt change in the zircon-age patterns and the disconformity between the Kanmantoo and Normanville Groups suggests that this section of the Australian paleo-Pacific Gondwana margin is not necessarily complete. Other paleo-margins, such as in North Victoria Land of the once contiguous Antarctic section, may prove more complete in elucidating the transition from locally derived detritus to that characteristic of the Ross-Delamerian orogen. The tectonic disruption on the Australian margin may have resulted in fragments once linked to Australia being found in Alaska (Gehrels et al., 1996) or China (Li et al., 1995). Gehrels et al. (1996) make a strong case for common detrital-zircon source characteristics of the Alexander terrane, Alaska, and Adelaidean rocks. The case for the Chinese connection has not been made through detrital zircon geochronology as yet.

Although the Kanmantoo Group contains age components similar to those in the Adelaidean...
rocks in the broadest sense, the proportions of these components are very different. This finding precludes simple reworking of the Adelaidean units to form the Kanmantoo rocks. The dominant population in the Kanmantoo rocks is 500–600 Ma, which is only a minor component in any of the Adelaidean rocks. The Kanmantoo pattern could be derived by mixing zircons from Bonney Sandstone or Marino Arkose with Delanian zircons; however, in the other Adelaidean samples, the early Mesoproterozoic peak is dominant over the Grenvillian peak, the opposite of that found in the Kanmantoo. The Kanmantoo is apparently derived largely from rocks not available at the time the Adelaidean was being deposited.

The Kanmantoo Group patterns are strikingly similar to detrital patterns from the Lachlan fold belt (Fig. 21; Ireland and Gibson, 1998). This similarity must be more than coincidence and a common provenance for the Kanmantoo Group and the Lachlan fold belt is suggested. Although the Kanmantoo Group and Adelaide fold belt are now juxtaposed (Preiss, 1987), the former apparently did not receive craton-derived Adelaidean detritus. Rather, it reflects the onset of sedimentation associated with the development of the regional Tasman orogen of Australia, which is itself only a fraction of the Paleozoic Gondwana mud pile.

The Kanmantoo (and Lachlan fold belt) sedimentary deposits require a major component of 500–650 Ma detrital zircons that were contributed from an active paleo-Pacific margin. The Kanmantoo Group thus marks the onset of sedimentation of these rocks (Wyborn and Chappell, 1983; Chappell, 1984).

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