The Adelaide Geosyncline of South Australia and its significance in Neoproterozoic continental reconstruction

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by

W.V. Preiss

PRIMARY INDUSTRIES
AND RESOURCES SA

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The Adelaide Geosyncline of South Australia and its significance in Neoproterozoic continental reconstruction

W.V. Preiss

The Adelaide Geosyncline is a deeply subsident Neoproterozoic to Middle Cambrian basin complex in South Australia with a record of at least five major successive rift cycles. Each rift system has its own locus and orientation. Although the rift events led to the breakup of the Neoproterozoic supercontinent Rodinia of which, according to the SWEAT hypothesis, Australia was a part juxtaposed against western Laurentia, the timing of breakup has been controversial. The author favours the interpretation that continental separation commenced soon after the last major Neoproterozoic rift phase associated with the Sturtian glaciation at ~700 Ma.

The stratigraphic record of the Adelaide Geosyncline has been divided into twelve sequence-sets (S-S), each comprising two or more sequences, and separated by breaks in sedimentation. Mafic volcanism and intrusion of northwest-trending dykes at ~827 Ma marked the first onset of rifting after a brief period of deposition in a stable intracratonic basin (S-S Willouran 1). The second phase of rifting (S-S Willouran 2) produced narrow, deeply subsident northwest-trending grabens filled with mixed evaporitic clastic and carbonate sediments, and minor associated mafic volcanism. The third rift phase (S-S Torrensian 1) initiated faulting along the north-south Torrens Hinge Zone and widened the zone of crustal extension; there was minor mafic and local felsic (~777 Ma) volcanism. Terrestrial to shallow marine clastics and minor carbonates overlapped the Willouran grabens onto basement of the Willouran rift shoulders. S-S Torrensian 2 and 3 were deposited in the later stages of this rift phase, with clastic wedges derived from adjacent cratons shedding into the rift basin and interfingering with more distal fine-grained clastic and carbonate sediments. Sedimentation of S-S Torrensian 2 occurred at a time of generally low relative sea level, accompanied by deposition of dolomite and sedimentary magnesite in marginal marine and lagoonal environments and coarse sandy facies in proximal zones. S-S Torrensian 3 records the first major marine inundation of the basin. S-S Sturtian 1 represents renewed basement uplift followed by marine transgression, but this S-S is only partially preserved due to regional erosion at the base of the Sturtian glacials.

S-S Sturtian 2 contains all the Sturtian glacigenic sediments and was accompanied by the fourth major rift episode. Crustal extension at this time produced mainly northwest-trending grabens peripheral to the Curnamona Province and essentially defined the limits of this basement block. S-S Sturtian 3 is marked by the first major marine transgression onto the Gawler Craton and represents a sag phase of sedimentation believed to be associated with the initiation of continental separation. S-S Marinoan 1 continues to record sag-phase deposition but with a prevailing lower sea level at first, followed by a rise. Marinoan glaciation is represented by S-S Marinoan 2, with possibly three sequences recording the waxing, maximum and waning stages of the glaciation, but the Adelaide Geosyncline is likely to have lain just north of the palaeoequator and south of the main continental ice sheet.

S-S Marinoan 3 and 4 are two major post-glacial transgressive-regressive cycles. Local growth faulting in South Australia, and mafic volcanism in western New South Wales, during the latest Neoproterozoic may represent rifting associated with accelerated separation, but it is not yet certain that the NSW volcanics were extruded on the same continental margin as the Adelaide Geosyncline. Similarly, the position of northwestern Tasmania, with its Neoproterozoic basement, remains uncertain despite the presence of probable Marinoan glacials on King Island.

Three sequence sets have previously been recognised in the Early to Middle Cambrian, with deposition in the Arrowie (in the north) and Stansbury (in the south) Basins. In the later Early Cambrian, a renewed phase of crustal extension produced the east to northeast-trending Kanmantoo Trough, which was filled with extremely thick clastic sediments immediately prior to compressive and transpressive deformation in the Delamerian

Orogeny in the latest Early to Late Cambrian, associated with syntectonic I- to marginally S-type granitic magmatism, followed by post-tectonic A-type intrusions. Delamerian plate convergence may have involved collision of a Neoproterozoic micro-continent and/or Cambrian volcanic arcs with the Neoproterozoic Australian southeastern continental margin. The relationship of reported Neoproterozoic orogeny in Tasmania to the eastern rifted margin of Australia remains enigmatic.

Keywords: **Neoproterozoic; Cambrian; South Australia; Stratigraphy; Tectonics; Rodinia**

INTRODUCTION

The purpose of this paper is to highlight advances in the understanding of the stratigraphy and tectonics of the Adelaide Geosyncline since publication of earlier syntheses (Rutland *et al*., 1981; von der Borch, 1980; Preiss, 1987; Preiss, 1990; Jenkins, 1990; Preiss *et al*., 1993; Powell *et al*., 1994; Veevers *et al*., 1997; Walter and Veevers, 1997), to which the reader is referred for background information. The paper specifically excludes critical consideration of palaeomagnetism, and the wealth of new data on isotope stratigraphy which is dealt with in other contributions to this volume.

1.1 HISTORICAL SIGNIFICANCE OF THE ADELAIDE GEOSYNCLINE

Although the existence of a very thick Neoproterozoic to Cambrian sedimentary succession in the Flinders and Mount Lofty Ranges of South Australia was recognised by the State's pioneer geologists, it was Sprigg (1952) who first synthesised the sedimentary and tectonic history of this basin, which he named the Adelaide Geosyncline. In recent years, use of this term has commonly been disparaged as ancient mobile belts are interpreted in the light of plate tectonic theory. However, as originally defined, ‘geosyncline’ is a useful, descriptive, non-genetic term that in no way precludes interpretation of specific tectonic environments. It is that sense in which the historical name continues to be used.

1.2 THE ADELAIDE GEOSYNCLINE AS A RECORD OF THE LATER NEOPROTEROZOIC

Neoproterozoic successions on all continents share a common history as reflected in the presence of characteristic facies, in particular glacigene sediments, often in a similar stratigraphic order. This makes it difficult to use apparent match-ups in geology as a guide to the former juxtaposition of continents. Thus while the Rodinia hypothesis (e.g. Dalziel, 1991; Hoffman, 1991; Moores, 1991) in which Australia-Antarctica was juxtaposed against Laurentia in the Neoproterozoic is supported by a great deal of stratigraphic, tectonic, palaeomagnetic and geochronological data, it is possible to make close lithostratigraphic comparisons of the Neoproterozoic record in Australia with successions on other continents also, e.g. Norway, on the western margin of Baltica (Jenkins *et al*., 1998) or the Dalradian of Scotland, originally on the east margin of Laurentia. Despite their similar lithostratigraphic records, these occurrences seem unlikely to have been juxtaposed against eastern Australia in the Neoproterozoic. Palaeomagnetic data and detailed matching of basement geology and specific structures are required to provide unambiguous reconstruction of formerly adjacent continental margins.

Commonly the most complete stratigraphic record is found in passive continental margin settings, where early rift-phase sediments and later sag-phase deposits attain considerable thicknesses, and the only breaks in sedimentation are those related to tectonic episodes or the most major global falls in sea level. In contrast, platformal regions, where the continental crust has not been attenuated by rifting, or has undergone only broad regional subsidence, stratigraphic sections tend to be thin and incomplete, with numerous breaks in deposition and complete elimination of some sequences by subaerial erosion.

This pattern of sedimentation is well displayed in the Australian Neoproterozoic basins (Fig. 1). The basins of central Australia, i.e. the Officer (including the Savory Sub-basin), Amadeus, Ngalia and Georgina Basins, share a common sedimentary history which led Walter *et al*. (1995) to propose the concept of the Centralian Superbasin. The present-day basins are remnants of this superbasin, separated from each other by intervening areas of Palaeozoic uplift and erosion. The superbasin was largely of cratonic character, although it does contain some depocentres in which there was considerable crustal subsidence, as well as syn-tectonic foreland basins in front of intra-plate thrust belts involving very significant crustal shortening in the latest Neoproterozoic Petermann Range Orogeny and mid-Palaeozoic Alice Springs Orogeny. In shape and scale the Centralian Superbasin is comparable with the Mesozoic Eromanga Basin of Australia.

The Adelaide Geosyncline in contrast is a zone of deep subsidence and extremely thick sediment accumulation. In these respects it is, at least in part, comparable to many present-day passive margins, such as those resulting from the Mesozoic break-up of Gondwana. For example, the Australian Southern Rift System contains up to 11 km of sediments as recorded by seismic data (Krieg *et al*., 1995). Thus the relationship of the Adelaide Geosyncline to the Centralian Superbasin may be compared to the relationship of the Mesozoic-Cainozoic Australian Southern Rift System to the Mesozoic and Tertiary Eromanga and Lake Eyre Basins. Walter and Veevers (1997) highlighted similar comparisons with the Permian to Mesozoic Perth Rift Complex and the Canning Basin.

TECTONIC SETTING

2.1 BASEMENT GEOLOGY

Recent advances in geochronology (summarised by Daly and Fanning, 1993; Parker *et al*., 1993; Flint *et al*., 1993; Daly *et al*., 1998) have allowed a synthesis of the tectonic history that led to the formation of the pre-Neoproterozoic basement of South Australia. There is only limited exposure of the basement beneath the Adelaide Geosyncline, and more is known from the surrounding regions.

Gawler Craton

To the west of the Adelaide Geosyncline lies the Gawler Craton (Figs 1, 2), with a core of late Archaean sedimentary and volcanic precursor rocks deformed and metamorphosed to high grade in the latest Archaean to earliest Palaeoproterozoic Sleafordian Orogeny, to form the Mulgathing and Sleaford Complexes. The Sleaford Complex is locally intruded by ~2400 Ma Dutton Suite granitoids. To the east of these were added mid-Palaeoproterozoic Hutchison Group (<2000 Ma, >1845 Ma) sediments, deposited over the ~2000 Ma Miltalie Gneiss basement, possibly on an eastern continental shelf, that were tectonised in the late Palaeoproterozoic Kimban Orogeny, involving major convergent and strike-slip deformation and medium to high-grade metamorphism and plutonic felsic magmatism of the Donington Granitoid (~1850 Ma) and Moody (~1700 Ma) Suites.

On northeastern Eyre Peninsula, the ~1790 Ma Myola Volcanics are highly deformed and metamorphosed by the Kimban Orogeny, but younger, unmetamorphosed proximal arenaceous siliciclastic and volcaniclastic sediments (Moonabie Formation) are dated at ~1740 Ma on intertonguing felsic volcanics (McGregor Volcanics). Further east, on northern Yorke Peninsula, more distal, fine-grained, deeper water clastic and chemical sediments (Wallaroo Group) contain interbedded felsic and mafic lavas (including the Moonta Porphyry) of similar age. These rocks are variably deformed and metamorphosed to greenschist and amphibolite facies and locally hydrothermally altered, being host to copper mineralisation in the Wallaroo-Moonta region.

Palaeoproterozoic rocks of the Gawler Craton are overlain unconformably by the extensive early Mesoproterozoic Gawler Range Volcanics (~1590 Ma) and associated local, gently folded, clastic sediments, and intruded by comagmatic A-type granites of the Hiltaba Suite. The ~1630 Ma felsic Nuyts Volcanics and granites of the St Peter Suite are less extensive on the southwestern Gawler Craton. The Gawler Range Volcanics are unconformably overlain by fluviatile sandstone, the Pandurra Formation, with Rb-Sr whole rock shale ages of 1424 ±21 Ma (Fanning *et al*., 1983), of the Cariewerloo Basin (Flint *et al*., 1993). A younger plutonic event at ~1510 Ma is recorded in the southeastern Gawler Craton by granites of the Spilsby Suite (Flint *et al*., 1993; Daly *et al*., 1998). The Mesoproterozoic granites are locally deformed by shearing.

Curnamona Province

The Curnamona Province is an aeromagnetically well-defined near-circular area of Proterozoic crust straddling the SA-NSW border (Figs. 1, 2). It is completely surrounded by Palaeozoic mobile belts. Palaeozoic deformation affected the marginal zones of the Province to varying degrees, but the central core is cratonic (the originally named Curnamona Cratonic Nucleus of Thomson, 1970). In the Olary

Domain in the south-west of the Province, and in the Mount Painter and Mount Babbage Inliers in the northwest, the basement rocks were infolded with Neoproterozoic metasedimentary rocks of the Adelaide Geosyncline during the Delamerian Orogeny.

The late Palaeoproterozoic (~1730-1650 Ma) Willyama Supergroup (Willis *et al*., 1983) consists of albitic (formerly ?evaporitic), fine to medium-grained clastic, and minor chemical metasediments and felsic metavolcanics deformed and metamorphosed in the Olarian Orogeny (~1600 Ma) (Robertson *et al*., 1998). The presence of late Archaean to late Palaeoproterozoic zircons in metasediments of the Curnamona Province suggests that the Gawler Craton, and in particular the Kimban Orogen, may have been a source region. Neither the base of the Willyama Supergroup, nor its basement, are preserved. The total thickness of known Willyama Supergroup (probably 3-4 km in the Olary Domain) is not great in relation to known rift basins and passive margin wedges.

In the Mount Lofty Ranges, just east and south of Adelaide, highly sheared and retrogressed originally high-grade metamorphics (the Barossa Complex) occur as thrust sheets and anticlinal cores beneath the Neoproterozoic cover. Limited geochronology suggests that the metamorphism was Olarian; the precursors have some lithological similarities with the Willyama Supergroup.

In the Mount Painter Inlier, an early Mesoproterozoic succession of quartzitic metasediments and felsic volcanics and intrusives possibly overlies an older Palaeoproterozoic core that has been compared to the Willyama Supergroup, in particular in the Broken Hill Domain (Parker *et al*., 1993; Flint *et al*., 1993). However, the stratigraphic and structural relationships are by no means clear, and no rocks from Mount Painter have so far yielded Palaeoproterozoic ages.

The basement beneath the Adelaide Geosyncline is a distinctly younger geological province than most of the Gawler Craton. It is likely that there was a late Palaeoproterozoic precursor basin occupying much the same area as the Neoproterozoic Adelaide Geosyncline, with sedimentation and volcanism between 1.75 and 1.65 Ga, and orogeny at ~1.6 Ga. The presence of shallow water sediments of proximal character on eastern Eyre Peninsula suggests that this area may represent the western margin of an originally very extensive sedimentary basin. The deformation of this belt may be part of a much larger, north-south-trending orogenic belt, referred to by Laing (1996) as the Diamantina Orogen, which includes the Mount Isa-Cloncurry region of northwest Queensland as well as the Curnamona Province.

The SWEAT hypothesis proposes that various continental fragments were amalgamated to form Rodinia during Grenville-age (~1.2 Ga) orogenesis (Dalziel, 1991; Moores, 1991), and the high-grade Musgravian Orogeny in central Australia is of this age (Maboko *et al*., 1991). If the continuity of the ~1.6 Diamantina Orogen belt is established, it would preclude assembly of northern and southern Australia during Grenville-age orogenesis, and would imply that the Musgravian is entirely a within-plate orogeny.

South Australian basement within Rodinia

The Gawler Craton and Curnamona Province form part of the Australian continental landmass. According to the SWEAT hypothesis (Moores, 1991), Australia was part of the supercontinent Rodinia, which split at around 700 Ma to form Gondwana and Laurasia (Powell *et al*., 1994). By the reconstruction of Dalziel (1991), eastern Australia was originally juxtaposed against western Laurentia. While it would be a worthwhile goal to seek extensions of Curnamona Province geology in North America, there are major uncertainties associated with the Neoproterozoic continental separation. In North America, Laramide shortening and foreland basin deposits obscure the critical basement geology. Ross *et al*. (1991) analysed zircon U-Pb ages on Proterozoic basement cores from oil wells in the Alberta Basin, but there is no evidence here of an eastward extension of the Curnamona Province. In Australia, the position of the Neoproterozoic continental margin is highly debatable because it is not known how far east Proterozoic crust extends beneath the Palaeozoic Tasman mobile belt.

Li *et al*. (1995) presented arguments that the Yangtze Block of South China may have been a continental fragment situated between northeastern Australia and Laurentia prior to breakup, based on the evidence of Grenville-age orogenic belts and early Neoproterozoic rift systems in South China. However, the match of basement geology is not strong, and the need for a separate continental fragment at this site ultimately rests upon the assumption that the concave eastern boundary of near-surface Proterozoic rocks in Australia (often referred to as the "Tasman Line") was the actual edge of continental crust in the Neoproterozoic, and that this leaves a space to be filled in continental reconstruction.

2.2 TECTONIC SUBDIVISION OF THE ADELAIDE GEOSYNCLINE AND THE DELAMERIAN OROGEN

The Adelaide Geosyncline developed through several successive episodes of Neoproterozoic rifting. Powell (1998) interpreted these to represent a lower-plate rift geometry. The oldest rifts and bounding structures are not immediately obvious from the outcrop geology, since they are overlapped by the sediments of younger rift and sag cycles, and so have to be inferred from indirect evidence. The present distribution of rock units is very much controlled by Delamerian (~500 Ma) tectonics. The belt of Delamerian deformation is referred to as the Delamerian Orogen; both Neoproterozoic to Cambrian cover and the Palaeo- to Mesoproterozoic basement are affected to varying degrees. The most obvious subdivisions of the Adelaide Geosyncline, defined by Rutland *et al.* (1981), are thus largely based on Delamerian tectonic style (Fig. 2): Torrens Hinge Zone, a meridional belt of gentle folding; Central Flinders Zone, a central zone of broad dome and basin structures, situated between the Gawler Craton and Curnamona Province; North Flinders Zone, an arcuate belt of open to tight linear folds to the north of the Central Flinders Zone; Nackara Arc, an arcuate belt of long, continuous, relatively upright folds south and east of the Central Flinders Zone; Fleurieu Arc, a belt of thrusting and tight folding with northwest-directed tectonic transport in the south. Thin, relatively undeformed Neoproterozoic to Cambrian cratonic platform cover is preserved on the Stuart Shelf and in the centre of the Curnamona Province (Fig. 2).

Neoproterozoic rifts can be delineated by "seeing through" the Delamerian structures. The approach taken involves:

- identification of those Delamerian faults that are a reactivation of earlier extensional faults (Preiss, 1987; Preiss *et al.*, 1993; Flöttmann and James, 1993; Flöttmann *et al.*, 1994)
- identification of those Delamerian faults that are a reactivation of earlier transform faults perpendicular to rifts
- mapping thickness variations in stratigraphic units
- determining onlap relationships of stratigraphic units
- mapping the distribution of diapirs, which are sourced from thick, evaporitic successions of the earliest rifts
- identification of syndepositional tilt resulting in angular unconformities

The succession of interpreted rifts is shown in Figs 3-6.

2.3 RELATIONSHIP TO OTHER NEOPROTEROZOIC TO CAMBRIAN BASINS

Although there is overlap in time between the Adelaide Geosyncline and the Centralian Superbasin, the two depositional systems developed more or less independently, especially during the early Adelaidean active rift phases. The Centralian Superbasin commences with a clastic blanket deposited on a peneplained basement surface and then records transgression to a shallow marine, epeiric basin (Bitter Springs Formation and equivalents) with some lacustrine intercalations (Southgate, 1991). Although this succession shows superficial similarity to parts of the Burra Group, it does not record the successive intervals of active syn-depositional faulting and wedges of arkosic sediment prograding from these faults into the basin that are so characteristic of the Burra Group. Moreover, correlation is not supported biostratigraphically, as the Bitter Springs Formation and Skillogalee Dolomite have no stromatolite taxa in common. A better correlation is of the Bitter Springs Formation with the Callanna Group, given the common presence of mafic volcanics, evaporitic sediments, and the stromatolite *Acaciella australica* (Hill *et al.*, 1999). However, the Centralian Superbasin represents a continental sag, distinct from the active rifts of the Adelaide Geosyncline.

Relatively thin and localised occurrences of Sturtian diamictite, sandstone, siltstone, dolomite and conglomerate are preserved in the main part of the Centralian Superbasin, and are comparable to the glacial shelf sequences of the Adelaide Geosyncline which unconformably overlap the older rift successions. Sturtian glacial sediments, however, attain great thickness in the southwestern Georgina Basin (Walter, 1980), where they occupy northwest-trending graben structures (Fig. 1) comparable to the Sturtian Baratta Trough at the southwest margin of the Curnamona Province.

Complete interconnection between the Adelaide Geosyncline and Centralian Superbasin was probably attained during the Sturtian post-glacial marine transgression recorded by the Tapley Hill Formation and Aralka Formation respectively (Preiss *et al*., 1978). This was the first major inundation of cratonic regions and is herein considered to represent sag-phase sedimentation associated with the separation of Australia-Antarctica from Laurentia. Apart from a less complete sedimentary record in the Centralian Superbasin, the two depositional systems continue to share a common history thereafter until the continuity of the superbasin was interrupted by the massive crustal-scale uplift of the Musgrave Block during the Petermann Range Orogeny toward the end of the Neoproterozoic. Away from the effects of this orogeny, similar depositional styles prevailed in the two basin complexes until the latest Early Cambrian when the Adelaide Geosyncline first came under the influence of plate convergence.

STRATIGRAPHIC RECORD AND AGE CONTROL

3.1 STRATIGRAPHIC SUBDIVISION, AGE CONTROL AND INTRABASINAL CORRELATION

The first subdivision of the Neoproterozoic succession of the Adelaide Geosyncline (the Adelaidean System) by Mawson and Sprigg (1950) and Sprigg (1952) defined the Willouran (oldest), Torrensian, Sturtian and Marinoan (youngest) Series. These were initially used only as local chronostratigraphic units, but in recent years some have appeared in the international literature, where the terms "Sturtian" and "Marinoan" have sometimes been used to refer solely to the Neoproterozoic glacigene deposits. However, this is not a valid usage, any more than it would be correct to use "Permian" only for glacials just because glaciation occurred during the Permian Period.

The succession was subdivided into lithostratigraphic units by Thomson *et al*. (1964) and this classification survives today with numerous refinements and revisions (see Tables 2-5 and summaries in Preiss, 1987; Preiss *et al*.,1993; Preiss *et al*, 1998). Three supergroups have been proposed to encompass all sediments of the Adelaide Geosyncline (Preiss, 1982): the Warrina Supergroup comprises the early rift sequences of the Callanna and Burra Groups; the Heysen Supergroup comprises the glacial, interglacial and post-glacial sediments of the Umberatana and Wilpena Groups; the Moralana Supergroup comprises all Cambrian sediments.

Two competing proposals defining international "Terminal Proterozoic" chronostratigraphic units predate the current IGCP Project in search of a Global Stratotype Section and Point. Jenkins (1981) defined the Ediacaran System to be represented by only the Wonoka Formation and Pound Subgroup of the Wilpena Group, while Cloud and Glaessner (1982) defined the Ediacarian to encompass the entire Wilpena Group. Jenkins' proposal dealt with the Marinoan by claiming a literal interpretation of the original definition of Marinoan (erected before the stratigraphy of the Adelaide region was properly understood); this allowed the Ediacaran to post-date and co-exist with the Marinoan. The other proposal ignored the previous chronostratigraphic terms yet, as defined, the Ediacarian overlaps the late Marinoan in age. In this paper, both these terms are avoided, pending a decision by the Terminal Proterozoic Working Group, and the original chronostratigraphic terms are retained for reference to the Australian stratigraphic record.

3.2 GEOCHRONOLOGICAL CONTROL

Until recently, geochronological control on sedimentation in the Adelaide Geosyncline has been extremely poor. The dearth of volcanic interbeds in the succession means that detailed dating of individual stratigraphic units is even now not possible. Nevertheless, the following section summarises the most recent data bearing on the ages of sedimentation. The data include U-Pb dates on the rare volcanic intercalations and a reconnaissance study of detrital zircons from a few

Adelaide Geosyncline sedimentary units ranging in age from Willouran to Cambrian by Ireland *et al.* (1998), who presented the data in the form of histograms. Although not published, their complete data set is available from the publishers. In this section, the most precise, most concordant detrital zircon ages have been selected from the data set (Table 1) and possible provenances suggested. A few also bear on the ages of sedimentation..

Wooltana Volcanics, Gairdner Dyke Swarm and Beda Volcanics

The Wooltana Volcanics, at the top of the Arkaroola Subgroup of the Callanna Group, near the base of the Adelaidean succession around the Mount Painter Inlier, have long been a target for geochronological studies. However, the pervasive deuteric and locally metamorphic alteration of these mafic lavas have hindered attempts to date this important igneous event. Nevertheless, Compston *et al.* (1966) produced a poorly constrained isochron (age recalculated to ~830 Ma using the constants of Steiger and Jäger, 1977) that was reported to include one sample with primary pyroxene. This result was not widely accepted at the time, when Adelaidean deposition was commonly assumed to date back to ~1400 Ma.

The Gairdner Dyke Swarm of the Stuart Shelf intrudes the Mesoproterozoic arenaceous Pandurra Formation but not the onlapping upper Adelaidean Tapley Hill Formation. The dykes are widely accepted as feeders for the mafic Beda Volcanics (Mason *et al.*, 1978) that intertongue with pebbly sandstone of the Backy Point Formation, basal Adelaidean clastics of the Stuart Shelf. Despite Rb-Sr isochron ages of ~1070 Ma on both lava flows and one of the dykes (Webb and Coats, 1980; Fanning and Webb, 1983), recent Sm-Nd and U-Pb results contradict a Mesoproterozoic age and support the age estimate of Compston *et al.* (1966) for the Wooltana Volcanics. Zhao and McCulloch (1993) and Zhao *et al.* (1984) produced Sm-Nd isochrons of 867 ±47 and 802 ±35 Ma on dolerite from the same dyke as used by Fanning and Webb (1983), and Wingate *et al.* (1998) separated baddeleyite and obtained a SHRIMP U-Pb age of 827 ±6 Ma. The reasons for a Rb-Sr whole rock age considerably older than the magmatic age as determined by Sm-Nd and U-Pb remain unexplained.

Curdimurka Subgroup

The Curdimurka Subgroup is the main rift succession of Willouran age and comprises very thick clastics and carbonates, with a major evaporitic component. It is inferred to overlie the Arkaroola Subgroup, although sedimentary contacts are rarely preserved and much of the Subgroup occurs in a brecciated and disrupted state in diapirs of the Flinders Ranges. Low in the Curdimurka Subgroup is the thin, lenticular Rook Tuff, dated at 802 ±10 Ma (Fanning *et al.*, 1986).

Ireland *et al.* (1998) sampled a fine-grained, silty sandstone with detrital mica from the Spalding Inlier; the present author tentatively correlates this with the Niggly Gap Beds of the Flinders Ranges and Recovery Formation of the Willouran Ranges (Forbes *et al.*, 1981; Preiss, 1985). The best zircon ages suggest sources from the Gawler Craton to the west (Donington Suite granites: ~1850 Ma; Wallaroo Group volcanics: ~1750 Ma; Hiltaba Suite granites and Gawler Range Volcanics: ~1580-1590 Ma) and possibly from the northeast (?Olarian metamorphic, ~1600 Ma).

Boucaut Volcanics

The Boucaut Volcanics are a bimodal suite of amygdaloidal basalt and rhyolitic ignimbrite (Forbes, 1978) occurring in the inner, southeastern portion of the Nackara Arc. Most outcrops are isolated and many are strongly sheared as part of the northeast-trending Anabama Shear Zone. The stratigraphic relationship is established in the core of a tight anticline where the volcanics are overlain by basal clastics of the Burra Group (Rhynie Sandstone). The volcanics have previously been considered to be of Willouran age (Preiss, 1987), however mafic volcanics are now known locally intercalated in the basal clastics of the Burra Group at several localities (Parker *et al.* 1990; Preiss, 1987; Kammermann, 1996; Preiss, 1997) and it is considered likely that the Boucaut Volcanics lie at the base of or within the Rhynie Sandstone.

Both undeformed and sheared rhyolites have U-Pb SHRIMP zircon ages of 777 ±7 Ma (C.M. Fanning, ANU, pers. comm., 1994). It is suggested that the Boucaut Volcanics may record the onset of early Torrensian rifting; the base of the Torrensian can be no older than ~780 Ma.

Rhynie Sandstone

In an attempt to make comparisons with detrital zircons in Palaeozoic-Mesozoic sediments in Alaska, Gehrels *et al*. (1996) analysed detrital zircon grains from the Rhynie Sandstone (Table 1). The likely provenance is on the Gawler Craton with zircons from Donington, Moody, Hiltaba and Spilsby Suite granitoids and the Gawler Range Volcanics being represented.

Belair Subgroup

The arkosic Mitcham Quartzite at the base of the earliest Sturtian Belair Subgroup near Adelaide was sampled by Ireland *et al*. (1998). The presence of coarse, commonly fresh feldspar suggests a rejuvenated clastic source region. Detrital zircons include grains at ~1850 Ma, but these are discordant. The most concordant grains suggest sources in the eastern Gawler Craton (Gawler Range Volcanics: ~1590 Ma and possibly the ~1510 Ma Spilsby Suite granitoids). The latter are considered a more likely source for the coarse feldspars than the approximately coeval, but much more distant, Moolawatana Suite (~1560 Ma) granites of the Mount Babbage Inlier.

More enigmatic is the appearance in the Mitcham Quartzite of much younger zircon grains of approximately Grenvillean age (dates between 975 Ma and 1278 Ma in the unpublished data set of Ireland *et al*., 1998). No Grenville-age source rocks are known in close proximity to the Adelaide Geosyncline, and although there is evidence of a Musgravian (~1200-1100 Ma) overprint on the Curnamona Province (Flint and Webb, 1980), there has been little evidence of plutonic, zircon-crystallising events at this time. The Musgrave Block itself is very distant from the southern Adelaide Geosyncline and is likely to have been completely covered by early Adelaidean sediments of the Centralian Superbasin in the earliest Sturtian when the Mitcham Quartzite was deposited. Another possible provenance is the Albany-Fraser Orogen (Nelson *et al*., 1995), where the Biranup Complex is of similar age (~1280 Ma), or its former extension into Antarctica, but these sources are even more distant.

Tapley Hill Formation

Webb and Coats (1980) recorded a Rb-Sr whole rock isochron of 750 ±50 Ma on siltstone of the Tapley Hill Formation on the Stuart Shelf. These flat-lying sediments are devoid of Delamerian overprint, but are likely to contain a significant proportion of detrital mica and feldspar. The Rb-Sr date should therefore be regarded as a maximum age.

Upalinna Subgroup (Preiss *et al.,* 1998).

A similar but poorly constrained Rb-Sr whole rock isochron of 724 ±40 Ma (Webb and Coats, 1980) on sediments at an uncertain stratigraphic position in the Upalinna Subgroup should also be regarded as a maximum age.

Detrital zircons (Ireland *et al*., 1998) from the Marino Arkose in the upper part of the Upalinna Subgroup mostly indicate a Gawler Craton source (possible Miltalie Gneiss: ~2000 Ma; Donington Suite granite: ~1850 Ma; Hiltaba Suite granite and Gawler Range Volcanics: ~1580-1600 Ma; Spilsby Suite granite ~1510 Ma) but sources in the Curnamona Province are also possible (volcanics in lower Willyama Supergroup: ~1710 Ma; Olarian metamorphism: ~1600 Ma). A number of grains of Grenvillean age (1000-1200 Ma) are, as in the Mitcham Quartzite, of uncertain origin.

Of particular significance is a zircon grain dated at 657 ± 17 Ma, which may record penecontemporaneous volcanism (not necessarily within the Adelaide Geosyncline). Even if not of volcanic origin, the date represents a maximum age for the Marino Arkose and overlying sediments, including the Marinoan glacials.

Yerelina Subgroup

Detrital zircons from a sandstone of the Elatina Formation, also dated by Gehrels *et al*. (1996), yielded ages suggestive of the St Peter Suite, Wallaroo Group volcanics, Donington Granitoid Suite and Sleaford Complex, as well as ages around 1180 Ma, 1680 Ma, 1950 Ma and 3000 Ma of unknown provenance (Table 1).

Sandison Subgroup

The post-Marinoan glacial Sandison Subgroup has an extremely poorly constrained Rb-Sr whole rock isochron of 676 ±200 Ma on the micromicaceous Woomera Shale of the Stuart Shelf (Webb and Coats, 1980), again to be regarded as a maximum age due to the presence of detrital minerals.

Bunyeroo Formation

The Bunyeroo Formation of the upper Wilpena Group has been dated by a Model 3 Rb-Sr whole rock isochron of 588 ±35 Ma on the equivalent Yarloo Shale on the Stuart Shelf (Webb, 1980). Presumably because of their much finer grain size, these shales probably contain a less significant proportion of detrital silicate minerals and hence give a better approximation to the age of deposition. Attempts to date the bolide impact layer in the Bunyeroo Formation (Compston *et al*., 1987) produced only zircon source ages (Gawler Range Volcanics: 1575 ±11 Ma from the Brachina-Bunyeroo area, and detrital zircons of Grenvillean age but uncertain origin from the eastern Flinders Ranges). K/Ar and ^{40}Ar/^{39}Ar analyses of meltrock from the proposed impact site at Lake Acraman gave plateau ages of ~450 Ma and do not bear on the age of the Bunyeroo Formation (Baldwin *et al*., 1991).

Pound Subgroup

The Bonney Sandstone in the lower Pound Subgroup was sampled for detrital zircon by Ireland *et al*. (1998). The Gawler Craton again appears to be the dominant provenance, with possible sources in the Sleaford Complex (~2300 Ma), Miltalie Gneiss (~2000 Ma), Donington Suite granite (~1850 Ma), Myola Volcanics (~1790 Ma), Moody Suite granite (~1700 Ma) and Spilsby Suite granite (~1510 Ma), but there is also a Grenvillean-age assemblage and some grains could reflect a Curnamona Province source (possibly volcanics in lower Willyama Supergroup: ~1700 Ma; Olarian metamorphism: ~1600 Ma; Moolawatana Suite granite: ~1560 Ma).

Of significance is a single grain dated at 556 ±24 Ma, possibly recording penecontemporaneous volcanism. It provides a maximum age for the overlying fossiliferous beds of the Ediacara Member, Rawnsley Quartzite.

Potential for further dating

The scarcity of volcanic layers within the whole Adelaidean stratigraphic column, and the mostly mafic composition of the rare volcanic units, limit the possibilities of close geochronological constraints on sedimentation. The preliminary data on detrital zircons suggest there is potential for much further work which will not only better define provenance regions, but may eventually lead to the dating of distant volcanic events synchronous with sedimentation of various formations in the Adelaide Geosyncline, even if they do not show other evidence of a volcaniclastic contribution.

Further attempts at direct dating of sedimentary materials may be warranted. Rb-Sr dating of totally unmetamorphosed shales on the Stuart Shelf and in the platform cover of the Curnamona Province may produce better results if only the finest diagenetic clays are extracted, and there may be potential for U-Pb dating of unmetamorphosed carbonates. Glauconite has been recorded from the Wonoka Formation in the Flinders Ranges (Haines, 1990), but has not been dated by either K-Ar or Rb-Sr. Given the deep burial of the enclosing sediments and their open folding during the Delamerian Orogeny, such dates may potentially be wholly or partially reset.

3.3 STRATIGRAPHY AND SEDIMENTATION

Neoproterozoic and Cambrian deposition in South Australia has been described in terms of 16 sequence-sets (S-S), 12 for the Adelaidean (Preiss *et al*., 1993) and four in the Cambrian (Gravestock *et al*., 1995). This subdivision is followed here, with some minor refinements, and provides a time framework within which to describe sedimentation. No attempt is made to assign orders to the sequence-sets and their constituent sequences in the absence of time controls by which to establish the duration of individual sedimentary cycles.
Tables 2-5 summarise the content of the sequence sets and interpreted relative sea levels.

WARRINA SUPERGROUP

Callanna Group - Willouran sedimentation

The Callanna Group consists of partially to wholly disrupted sedimentary and minor volcanic rocks preserved in diapirs and anticlinal cores. These beds were originally overlain by the Burra Group, but sedimentary relationships are rarely preserved, contacts commonly being either tectonic or diapirically intrusive.

Sequence-set Willouran 1: Arkaroola Subgroup

The Arkaroola Subgroup comprises basal clastics, a middle carbonate unit and mafic volcanics at the top. The type area is in the northeastern Flinders Ranges, where the subgroup is metamorphosed to lower amphibolite facies, the carbonates being represented by marble and calc-silicate. The basal clastics are mature to supermature quartzites overlying a peneplained basement surface. Commonly, there are no clasts derived from the local granitic/metamorphic basement, except for the thin basal Younghusband Conglomerate of the Peake and Denison Inliers, and the local fault-angle depression-filling Shanahan Conglomerate Member in the northeastern Flinders Ranges. In the Peake and Denison Inliers, and in the Barrier Ranges of western NSW where the equivalent unit is the Poolamacca Group, the carbonates (Coominaree Dolomite and Boco Formation respectively) are stromatolitic (Preiss, 1987). These facies suggest that sedimentation did not commence with rifting, but with gradual subsidence of a peneplained, stable craton.

Mafic lavas are widespread at the top of the Arkaroola Subgroup (and Poolamacca Group) and record the first major phase of Neoproterozoic crustal extension. The extension direction was northeast-southwest, as determined from the orientation of the NW-trending Gairdner Dyke Swarm, a system of feeder dykes cutting the Pandurra Formation and underlying basement of the Gawler Craton (Fig. 3). Powell (1998) interpreted opening around a rotation pole at 126° E, 7° S, which is consistent with the northwestward narrowing and eventual pinch-out of Willouran grabens. The extrusive equivalent of the dykes, the Beda Volcanics, interfinger with and overlie the basal clastic Backy Point Formation; these units are preserved along the eastern margin of the Gawler Craton, but were probably more extensive originally. East of the Torrens Hinge Zone, the basal sequence is downfaulted to great depth; within the Flinders Ranges, the volcanic rocks are observed mainly where they have been rafted to the surface in diapiric intrusions. The Wooltana Volcanics of the northeastern Finders Ranges and Cadlareena Volcanics of the Peake and Denison Inliers occur in continuous successions overlying basement. Probable equivalents of the Coominaree Dolomite and overlying Cadlareena Volcanics were intersected in borehole Manya 5 at the eastern extremity of the Officer Basin, but are not known from any other part of that basin (Preiss *et al.*, 1993).

Sequence-set Willouran 2: Curdimurka Subgroup

The upper part of the Callanna Group is a very thick (up to 6 km), mixed clastic-carbonate-evaporitic unit, the Curdimurka Subgroup. Although no complete sections of the Curdimurka Subgroup are preserved, composite stratigraphic columns have been assembled from the Willouran Ranges (Forbes *et al.*, 1981), Peake and Denison Inliers (Ambrose *et al.*, 1981), the Worumba Anticline (Preiss, 1985) and the Spalding Inlier (Preiss, 1974). The thickest and most complete section of the Curdimurka Subgroup is that in the Willouran Ranges (Table 2). The distribution of diapirs in the Flinders Ranges gives an indication of the shape, size and orientation of the late Willouran rift (Fig. 4). The bounding faults are not directly observable since they have been overlapped and buried by younger Adelaidean sediments, but the western boundary is suggested to lie along the “G2 structural corridor” and the eastern one on a sub-parallel, NNW trend beneath the eastern Nackara Arc. Subdivision into sequences is at present quite uncertain. The top of the Curdimurka Subgroup is almost invariably tectonically disrupted at what appears to be a regional zone of detachment, although an unconformable relationship with the overlying Emeroo Subgroup is preserved at Depot Creek (Preiss and Faulkner, 1984) at the western margin of the Flinders Ranges, while the contact between the ?Curdimurka Subgroup and Emeroo Subgroup and in some drillholes near Port Pirie in the Torrens Hinge Zone may be conformable (Parker *et al.*, 1990).

Altered basalt occurring as small xenoclasts in diapirs (e.g. Blinman, Oraparinna and Worumba Diapirs) probably correlates partly with the Wooltana Volcanics, but some may be volcanics interbedded within the Curdimurka Subgroup (e.g. in the Oraparinna Diapir). The Curdimurka Subgroup possibly represents a second phase of Willouran rifting, the rifts again displaying a general northwesterly trend (Fig. 4).

Dolerite is widespread within diapiric structures in the PARACHILNA 1:250 000 map area (Reid and Preiss, 1999), occurring mostly as plug-like bodies.

These are, however, not intrusive into the diapirs, but form xenoclasts encased in diapiric breccia (e.g. Mount, 1975); rare xenoclasts of Curdimurka Subgroup contain intrusive dolerite, but intrusion predated dismemberment (Preiss, 1985). Both dolerite and basalt have been subjected to deuteric alteration to albite-epidote-actinolite-chlorite assemblages. Since altered dolerites are not seen to intrude strata younger than the Curdimurka Subgroup, either within or outside diapirs, their age is inferred to be latest Willouran.

Burra Group - Torrensian to early Sturtian sedimentation

The Burra Group is the first major sedimentary succession that is widely preserved and exposed in the Adelaide Geosyncline. The area of deposition (Fig. 5) is greater than for the Callanna Group, indicating a widening of the zone of rifting. The western rift margin was at the Torrens Hinge Zone, and it is likely that the thickness of the Burra Group increases eastwards across a series of stepped faults. The Burra Group oversteps the Callanna Group onto basement in the Adelaide and Olary regions, which were on the uplifted shoulders of the Willouran rift. Stratigraphic and structural relationships in the Spalding area can be interpreted in terms of a syndepositional normal fault forming the eastern boundary of the Torrensian Gladstone Trough; the exposed Willouran sediments of the Spalding Inlier to the east of the fault represent the uplifted eastern rift shoulder of that trough, and these were onlapped by a thinner succession of the Burra Group.

The stratigraphy of the Burra Group has been described in some detail (Preiss, 1987, 1990; Belperio, 1990; Uppill, 1979, 1990), and a generalised stratigraphic column is shown in Table 2. Four subgroups have been defined (Emeroo, River Wakefield, Mundallio and Belair) but these have some severe drawbacks. Firstly, the Emeroo and River Wakefield Subgroups interfinger, and their status as separate subgroups results largely from historical precedent. Secondly, the interval between the Mundallio and Belair Subgroups is not currently placed into subgroups. Recent mapping in the Clare-Spalding region has clarified some of the relationships and suggested the presence of sequence boundaries that facilitate subdivision. A revised stratigraphic classification is to be proposed (Preiss and Cowley, in prep.).

Sequence-set Torrensian 1: Emeroo Subgroup

The Emeroo Subgroup is a clastic-dominated sequence at the base of the Burra Group. In the southern Adelaide Geosyncline, the basal units are the Rhynie Sandstone and Arbury Park Sandstone Member of the Aldgate Sandstone (Preiss, 1997). These are dominantly fluvial facies of cross-bedded feldspathic and pebbly sandstone with black heavy mineral laminations (detrital grains of rutile-bearing haematite), with local possibly shallow marine and aeolian variants (W.M. Cowley, PIRSA, pers. comm., 1996). There is local evidence of mostly mafic volcanism: Parker *et al.* (1990) described basalt interbedded within the Emeroo Subgroup in the Torrens Hinge Zone, and recent re-logging of the drillholes has confirmed that the basalt is part of the Rhynie Sandstone; Preiss (1987) described basalt interbedded in the Rhynie Sandstone near Clare and the extent of this complexly folded unit has been mapped by Kammermann (1996); the basaltic flows and rhyolitic ignimbrites of the Boucaut Volcanics (Forbes, 1978), which locally underlie Rhynie Sandstone, are here interpreted as probably of basal Torrensian age; Preiss (1997) interpreted a sheared phyllitic unit within the Aldgate Sandstone near Adelaide as having had a mafic tuff precursor. The upper part of the subgroup is shallow marine feldspathic sandstone and interfingers with more distal facies of the River Wakefield Subgroup.

In the northeastern Flinders Ranges, the Emeroo Subgroup comprises, at the base, pebbly quartzite with halite casts and heavy mineral laminations of the Humanity Seat Formation, interfingering with the Woodnamoka Phyllite west of the Paralana Fault, which was an active rift fault bounding a deeper half-graben. These units are overlain by the arkosic Blue Mine Conglomerate, followed by dolomitic and silty Opaminda Formation and the Wortupa Quartzite. This succession is more of proximal facies, lying adjacent to the Curnamona Province, than equivalents in the Willouran Ranges, where the Emeroo Subgroup is represented by shallow marine siltstone and sandstone.

Sequence-set Torrensian 2: Mundallio Subgroup

The Mundallio Subgroup, comprising the Skillogalee Dolomite and equivalent formations, is a carbonate-dominated sequence characterised by sedimentary magnesite. In the past, the boundary with the Emeroo Subgroup has been considered as gradational and intertonguing (e.g. Uppill, 1979, 1990). However, although there is no major incision at the base, there is at least local minor erosion. In the southwestern part of the Adelaide Geosyncline, adjacent to the uplifted rift shoulder of the eastern Gawler Craton, the Skillogalee Dolomite is of proximal facies, being dominantly arenaceous and feldspathic and hence rendering its distinction from the underlying Emeroo Subgroup difficult, but recent mapping by the author has more clearly defined the boundary. Sandstone in the Mundallio Subgroup is commonly dolomite cemented, and contains occasional dolomite and rare magnesite interbeds.

The major meridional Clare-Spalding Fault (Fig. 4) is interpeted as a Delamerian reactivated, originally extensional fault at the eastern boundary of the Gladstone Trough. East of this fault, there is a radical change of facies in the Skillogalee Dolomite, sandstone giving way to pure dolomite that has been largely recrystallised to marble. The marble facies extends eastwards to the Kingston Fault, which was probably also active during sedimentation. East of this latter fault, the Skillogalee Dolomite consists of a well-defined lower member of pale-coloured dolomite and an upper, organic-rich dark grey dolomite member. There is abundant cryptomicrobial lamination and columnar stromatolites (*Baicalia burra*) occur sporadically; early diagenetic chert is abundant.

In the Flinders Ranges and Willouran Ranges, the facies of the Skillogalee Dolomite are more varied vertically but tend to be very persistent laterally. Detailed descriptions are provided by Forbes, 1960, 1961; Preiss, 1973, 1987; Uppill, 1979, 1990; Belperio, 1990; Preiss *et al*. 1993. Sedimentary magnesite is well developed here, and occurs predominantly as beds of reworked intraclasts. These form part of repetitive small-scale cycles reflecting transgressions and regressions. The long-held analogy with the Coorong lagoons of South Australia (von der Borch and Lock, 1979) is useful in explaining the facies of the Skillogalee Dolomite. The close proximity of such a lagoon to the open ocean means that minor changes in sea level result in near-instantaneous flooding events that rework magnesite muds deposited in lagoons as intraclasts.

The Mundallio Subgroup consists entirely of paralic sediments, varying from lagoonal to very shallow marine. In contrast, Burra Group sediments overlying the Skillogalee Dolomite are of more open marine character, attaining depths below storm wave base at times of maximum transgression.

Sequence-set Torrensian 3

Previously, the Woolshed Flat Shale has been included in the Mundallio Subgroup (Uppill, 1979; Preiss, 1987, Preiss *et al.*, 1993). However, recent mapping has shown that, despite some overlap of rock types such as carbonaceous shale and dolomite between the Skillogalee Dolomite and Woolshed Flat Shale, initially thought to represent intertonguing, there is a sharp, locally slightly erosive boundary at the base of the Woolshed Flat Shale. This is interpreted as a sequence boundary, representing the first onset of fully marine conditions, represented by sequence-set Torrensian 3. The Woolshed Flat Shale commences with transgressive sandstone and siltstone, passing up into laminated siltstone with dark blue-grey, silty dolomite interbeds, recording maximum flooding. The upper part of the Woolshed Flat Shale becomes sandy upward and reflects deltaic progradation, culminating in feldspathic sandstone of the Undalya (and correlative Stonyfell) Quartzite. These arenite units generally represent at least two prograding cycles but the uppermost sections are transgressive into the Saddleworth Formation.

The Saddleworth is commonly thicker than the Woolshed Flat Shale and probably represents an even more significant marine inundation of the basin. Maximum flooding is represented at two major intervals by the Auburn Dolomite Member, a thinly laminated, dark grey, organic-rich and silty carbonate facies lacking shallow water indicators. These two deep-water sequences are separated by the feldspathic Watervale Sandstone Member, another upward-coarsening and then upward-fining clastic wedge. Whereas the Undalya and Stonyfell Quartzites are clearly west-derived, the distribution of the Watervale Sandstone Member suggests at least partial derivation from the Curnamona Province.

Sequence-set Sturtian 1: Belair Subgroup

The uppermost part of the Burra Group is the Belair Subgroup. By definition, this is basal Sturtian (Mawson and Sprigg, 1950), but it predates the

Sturtian glacial succession from which it is separated by a regional unconformity correlative with pre-glacial unconformities elsewhere in Australia and, probably, Laurentia. At the base of the Belair Subgroup near Adelaide, coarse-grained arkose (the Mitcham and Leasingham Quartzites) sharply overlies the Saddleworth Formation with a probable sequence boundary and is transgressive upward to laminated siltstone (Mintaro Shale and equivalents). Contrary to what he has previously stated (Preiss, 1987) and as a result of recent mapping, the author now returns to the formerly held view (Thomson *et al*., 1964) that the Mintaro Shale is part of the Belair Subgroup. The presence of very rare lonestones in the Mintaro Shale allows for the possibility of minor shore ice, but otherwise the facies of the Belair Subgroup are entirely typical of the remainder of the upper Burra Group (Coats, 1967).

HEYSEN SUPERGROUP

Umberatana Group - mid-Sturtian to early Marinoan sedimentation (Table 3).

Sequence-set Sturtian 2: Yudnamutana Subgroup

The base of the Umberatana Group is marked by the onset of major glaciation. In many sections, diamictite overlies an erosional surface in underlying lower Adelaidean and basement rocks, but a number of other facies are intercalated, including well-sorted quartzose sandstone, lithic and feldspathic sandstone, conglomerate and laminated siltstone. The oldest beds, occurring in the Yudnamutana Trough (Fig. 5), an east-west orientated graben in the northeastern Flinders Ranges, are the Fitton Formation and its basal granite conglomerate Hamilton Creek Member (Young and Gostin, 1989). The Fitton Formation is mostly a bedded dropstone-bearing metasiltstone and minor metasandstone and calc-silicate, and passes up into massive diamictite of the Bolla Bollana Tillite recording the main Sturtian glacial maximum. Equivalent diamictite units are the thick Pualco Tillite in the northwest-trending Baratta Trough and thinner shelf successions such as the Appila and Sturt Tillites. The former view that the Bolla Bollana and Pualco Tillites represent an earlier Sturtian glaciation than the Appila and Sturt Tillites (Coats, 1973, 1981, Preiss, 1987) is no longer held, and the term Yudnamutana Subgroup is now used to encompass all the Sturtian glacial units (Preiss *et al*., 1998), as suggested by Murrell *et al*. (1977).

In the Baratta Trough (Fig. 5), the Pualco Tillite passes up into the bedded Benda Siltstone, a unit apparently not represented in the shelf environments. The magnetitic Braemar iron formation facies is characteristic of the Benda Siltstone and Pualco Tillite, and has an equivalent in the haematitic siltstone of the Holowilena Ironstone in the shallower, northwestern part of the trough. Many authors have commented on the similarity of these ferruginous facies with ironstones in the Rapitan glacials of western Laurentia (e.g. Young, 1992) and it is perhaps significant that the greatest thickness and concentration of iron is found in the southeast of the Nackara Arc, closest to the postulated line of Neoproterozoic continental separation (Fig. 1).

The Wilyerpa Formation represents the waning stage of the Sturtian glaciation. In the Baratta Trough, the Wilyerpa is separated from the Benda Siltstone and Pualco Tillite by a disconformity to angular unconformity, and constitutes a separate sequence. However, the Wilyerpa Formation gradationally overlies and partly intertongues with the Appila Tillite in a more condensed stratigraphy of the shelf regions. The unconformity is suggested to be due to a phase of block rotation on active extensional northwest-trending faults in the Baratta Trough.

Sequence-set Sturtian 3: Nepouie Subgroup

The term “Nepouie Subgroup” (sequence-set Sturtian 3) was defined by Preiss *et al*. (1998) to replace the lower part of the former Farina Subgroup to overcome the problem of laterally interfingering subgroups. The Nepouie Subgroup is of late Sturtian age. Laminated, carbonaceous and calcareous siltstone of the Tapley Hill Formation is one of the most persistent facies in the Adelaide Geosyncline and there is strong evidence that it extended into the Centralian Superbasin. This is the first indication of true marine interconnection between this intracratonic basin and the rift complex of the Adelaide Geosyncline. Barovich and Foden (this volume) present evidence from Sm-Nd studies that the Tapley Hill Formation and the equivalent Aralka Formation of the Centralian Superbasin contain a juvenile provenance contribution not found in underlying units. The Brighton Limestone represents the culmination of upward shallowing at the top of the Nepouie Subgroup, and comprises high-energy ooid grainstone with interfingering stromatolitic bioherms (Preiss, 1973; Preiss and Kinsman, 1978).

Sequence-set Marinoan 1: Upalinna Subgroup

The term "Upalinna Subgroup" replaces the former Willochra Subgroup and upper Farina Subgroup which were laterally equivalent facies variants representing relatively shallower and deeper water respectively (Preiss *et al.*, 1998). The Upalinna Subgroup is of earliest Marinoan age and has a sequence boundary first recognised by Dyson (1992a) at its base. In the shallow-water western marginal zone, the basal transgressive unit is a tepee-bearing dolomite, previously considered as the upper member of the Brighton Limestone, that grades upward into rippled and mudcracked red siltstone and sandstone of the Angepena Formation. In the deeper basin to the east, the base is marked by the basal Cox Sandstone Member of the flaser-bedded Tarcowie Siltstone. In the Central Flinders Zone, the sandy, oolitic and stromatolitic limestones of the Etina Formation intertongue with Angepena Formation to the west and Tarcowie siltstone to the southeast. The Etina also gradationally overlies laminated siltstone of the Sunderland Formation, formerly regarded as a member of the Tapley Hill Formation but separated from it by the basal Marinoan sequence boundary. The lower sequence of the Upalinna Subgroup (M1.1) represents a generally lower sea level than the Nepouie Subgroup; the deepest water is represented by the Sunderland Formation in the basin centre, but areas to the east and west were deposited under wave influence. The upper Upalinna Subgroup (sequence M1.2) marks a return to deeper water, with major marine transgression being recorded by the Enormama Shale, Waukaringa Siltstone and Amberoona Formation (Preiss, 1996). The Enorama Shale shallows up into stromatolitic and intraclastic carbonates of the Trezona Formation and then, locally in the Central Flinders Zone, the clastic Yaltipena Formation (Lemon and Reid, 1998).

Sequence-set Marinoan 2: Yerelina Subgroup

The early Marinoan glaciation, represented by sediments of the Yerelina Subgroup (Sequence-set Marinoan 2), has often been suggested to be correlative with the Varanger glaciation of the northern hemisphere, but the Yerelina Subgroup is mostly glaciomarine and unlikely to have been deposited directly from a continental ice-sheet. The preservation of a periglacial regolith, including sand wedge polygons, developed within a pre-Adelaidean silicified weathering surface on the Mesoproterozoic Pandurra Formation on the Stuart Shelf (Williams, 1986a) suggests that this low-lying cratonic region was never overridden by a continental ice sheet. The sandstone-dominated Elatina Formation, now included in the Yerelina Subgroup (Preiss *et al.*, 1998), consists largely of glacial outwash with local lenses of diamictite and evidence of ice-contact deformation (Lemon and Reid, 1998; Lemon and Williams, 1998). In the deeper basin areas of the Nackara Arc and North Flinders Zone, the waxing and waning of the glaciation is recorded by the gradual incoming of dropstones in marine laminated siltstone (Fortress Hill Formation), culminating in sparsely pebbly diamictite (Mount Curtis and Pepuarta Tillites), and a return to dropstone facies in the Ketchowla Siltstone. The sequence-set is possibly divisible into three sequences, the upper two of which commence with sharp-based feldspathic sandstones.

The low palaeolatitude (northern hemisphere) consistently determined for the Elatina Formation of the Flinders Ranges (Schmidt *et al.*, 1991, Schmidt and Williams, 1995; Sohl and Christie-Blick, 1995) suggests that Australia may have lain at the very southern edge of the early Marinoan northern ice sheet. This may be consistent with recent interpretations of late Neoproterozoic ice sheets extending to near equatorial latitudes (the so-called "snowball Earth"). There are excellently preserved Marinoan glacial pavements in a cratonic (low relief) setting in the Kimberley Region, Western Australia, which suggest an extensive continental ice sheet. Given the extreme north-south crustal shortening of central Australia during the later Petermann Ranges and Alice Springs Orogenies, after palinspastic reconstruction, the pavements can reasonably be inferred to have formed significantly further (15 ±5°) from the palaeoequator than the sample locations in the Flinders Ranges. The southern margin of the continental ice sheet may have therefore lain at an intermediate latitude, while cold conditions with local ice persisted to the equator. To test the validity of the "snowball earth" hypothesis versus its chief competitor, the high-obliquity hypothesis of Williams (1975), it will be necessary to find proven high-latitude sediments of exactly the same age as the Marinoan glacials, and determine their palaeoclimate. Whereas the high-obliquity hypothesis predicts that such sediments will contain evidence of extreme seasonality, but not glaciation, a “snowball Earth” would be expected to show evidence of extreme glaciation at high latitudes. To the author’s knowledge, no such data are available at present.

Wilpena Group - mid to late Marinoan sedimentation

The Wilpena Group consists of two major overall upward-shallowing sedimentary cycles, here designated sequence-sets Marinoan 3 and Marinoan 4.

Sequence-set Marinoan 3: Sandison Subgroup

The Sandison Subgroup (sequence-set Marinoan 3) records the major mid-Marinoan post-glacial transgression. The Nuccaleena Formation is the “cap dolomite” generally found at the base, overlying a disconformity to very low angle unconformity. The deepest level of erosion on this sequence boundary is in the northern Flinders Ranges, where any Ketchowla Siltstone that may have been deposited has been completely removed, and the dolomite directly overlies sandstone or diamictite. Dyson (1992b) described incised valleys filled with arenaceous and silty sediments of the Seacliff Sandstone, which interfingers with the Nuccaleena Formation.

The Nuccaleena Formation is considered to be transgressive and to have been deposited in relativley deep water (Dyson, 1992b, Christie-Blick *et al*., 1998). The point of maximum flooding may be represented by a thin, very fine-grained shale commonly found at the top of the formation. The shale grades up into the Brachina Formation, commencing with siltstone with thin event bed sandstones (Moolooloo Siltstone Member) followed by rippled and cross-laminated silts and sands of the Moorillah Siltstone Member. The Bayley Range Siltstone Member records a slight deepening and finally shallowing into the clean sandstones with cross-beds, ripples and mudcracks of the ABC Range Quartzite. The Sandison Subgroup thus records two transgressive-regressive sequences, but without an erosional boundary between them.

The great thickness of the ABC Range Quartzite in the southwestern Flinders Ranges reflects the proximal setting of this zone, and results in part from renewed syndepositional faulting at the Torrens Hinge Zone, and in part from its interfingering with the Moorillah and Bayley Range Members of the Brachina Formation in the southern Flinders Ranges, as first suggested by Plummer (1978).

Sequence-set Marinoan 4

This is the upper of the two major upward shallowing cycles of the Wilpena Group and it is separated from the Sandison Subgroup by a persistent erosional surface. There are also several major erosional surfaces within this sequence-set, and these have been the subject of considerable debate, in particular the kilometre-deep erosional valleys or canyons cut into sediments of the Wonoka Formation. Subdivision of this part of the Wilpena Group into subgroups has not been finalised. The sequence-set includes at its top the Pound Subgroup, a name that is of historical significance referring to the major metazoan-bearing arenite succession at the top of the Adelaidean. However, the base of the Pound Subgroup as originally defined is entirely gradational and probably intertonguing. The remainder of the sequence-set (Bunyeroo and Wonoka Formations) was divided by Dyson (1996) into the Aruhna and Depot Springs Subgroups. However, the present author accepts neither that this grouping is warranted, nor that the constituent units, currently designated as members, should be elevated to formation rank as proposed by Dyson.

The Bunyeroo Formation commences with poorly sorted gritty sandstone of the Wilcolo Sandstone Member of possible fluvial origin. The sandstone rapidly grades up to or is sharply overlain by deep-water red mudstone with minor green and dark grey organic-rich intercalations. An interpreted bolide impact debris layer 80 m above the base has been related to an impact site identified at Lake Acraman on the Gawler Craton (Gostin *et al*., 1986; Williams, 1986b; Wallace *et al*., 1989, Wallace *et al*., 1996).

The Wonoka Formation (as redefined by Gostin and Jenkins, 1983) has been described in detail by Haines (1990); it abruptly but conformably overlies the Bunyeroo Formation. The basal Wearing Dolomite Member may record sediment starvation associated with a maximum flooding event; the member commonly consists of thin micritic dolomite bands interbedded with siltstone and includes intraclast layers possibly due to submarine reworking on hiatal surfaces. The abrupt incoming of storm-deposited sands just above the Wearing indicates a rapid shallowing of the basin, but the persistence of this thin marker bed at a relatively constant distance above the base of the Bunyeroo Formation precludes any significant erosion either above or below the Wearing. A rapid deepening follows the storm beds and marks a return to Bunyeroo-like mudstones, though more calcareous; these grade up through various calcareous silty and sandy facies with evidence of storm deposition that make up the upper units of the Wonoka Formation.

The canyon structures in the Wonoka Formation remain enigmatic. Originally considered mega-slump structures (Coats, 1964), these have more recently been seen as erosional palaeovalleys (Eickhoff *et al*., 1988; Christie-Blick *et al*., 1990), but interpretations vary. An origin by submarine processes akin to Quaternary submarine canyons on continental shelves was favoured by Haines (1987), von der Borch *et al*. (1982) and Preiss (1987) but Eickhoff (1988) and Christie-Blick (1990) preferred a model involving subaerial incision and infilling by initially fluvial and shallow marine sediments, deepening upwards. To explain this pattern, a Messinian-style evaporative draw-down has been invoked. None of these models completely explains all the characteristics of the canyons: Table 4 lists the advantages and disadvantages of each proposal. Whichever model is adopted, the most significant conclusion is that the great depth of the canyons (> 1 km) requires a base level far below the general shelf environment envisaged for sediments of the Adelaide Geosyncline, and strongly indicates a connection with a deep ocean at Wonoka time. This has important implications for the timing of continental break-up; a substantial basin of oceanic depth must have existed to the east and north of the presently exposed Adelaide Geosyncline by ~570-580 Ma.

The Pound Subgroup was defined by Jenkins (1975) to comprise the Bonney Sandstone and Rawnsley Quartzite. The base of the Bonney Sandstone as defined by Forbes (1971) is gradational and involves regional intertonguing of the uppermost carbonate beds of the Wonoka Formation and lowest sandstone bed of the Bonney Sandstone. Reid and Preiss (1999) have redefined the base of the Bonney Sandstone to include the shallow-water carbonates, formerly included in the uppermost Wonoka Formation, as the Patsy Hill Member.

The Bonney Sandstone consists of cyclic, mostly red, fine to medium-grained silty sandstone and siltstone. The Rawnsley Quartzite is largely white, well-washed medium-grained sandstone with abundant cross-bedding and petee structures due to microbial sediment binding (Gehling, 1986). The basal Chace Quartzite Member sharply overlies the Bonney Sandstone and is itself cut by large erosional channels filled with a transgressive-regressive marine sequence, the Ediacara Member, famous for its contained metazoan fossil assemblage.

MORALANA SUPERGROUP – CAMBRIAN SEDIMENTATION

Sedimentation resumed during the Early Cambrian after a basin-wide hiatus and period of erosion at the end of the Proterozoic. Comprehensive summaries of Cambrian sedimentation are given by Gravestock and Hibburt (1991) and Gravestock *et al*. (1995). Sediments in the Flinders Ranges and onlapping the Gawler Craton to the west and Curnamona Province to the east are referred to the Arrowie Basin, and those of the Mount Lofty Ranges and Yorke Peninsula to the Stansbury Basin, but there is likely to have been interconnection and continuity of deposition between these preservational basins. Sequence-set Cambrian 1 comprises the carbonate-dominated Hawker (Arrowie Basin) and Normanville (Stansbury Basin) Groups. In the Arrowie Basin, Sequence-set Cambrian 2 consists of redbeds of the Billy Creek Formation and the marine Wirrealpa Limestone. The overlying Sequence-set 3 marks a return to redbeds of the Lake Frome Group. The Billy Creek Formation contains tuffs dated at 523 ± 2 Ma (Gravestock and Shergold, in press).

In the Mount Lofty Ranges, Early Cambrian sediments of the Stansbury Basin are disconformably overlain by the Kanmantoo Group, consisting mainly of rapidly deposited marine clastics. Although sequence boundaries have been described within the Kanmantoo Group, it is by no means certain how these correlate with sequence boundaries in the Arrowie Basin. Since the Kanmantoo Trough was an active rift basin, disconformities in the succession are likely to relate more to local extension events than to eustatic sea level changes. Correlation of the Kanmantoo

Group with the Billy Creek Formation (Daily, 1976,1990; Gravestock *et al.*, 1995) has been questioned by Jenkins (1990), Jenkins and Sandiford (1992) and Haines and Flöttmann (1998), who prefer to correlate the Kanmantoo Group with the upper part of the Hawker Group. However, the present author prefers the conventional correlation as it best fits the available geochronological constraints (Tables 5,6).

Although the Kanmantoo Group (Belperio *et al.*, 1998; Haines *et al.*, 1996) consists of less well sorted sands than much of the Adelaidean, deposited as event beds interlayered with siltstone and shale, there are clearly recognisable transgressive-regressive cycles not unlike those of the Wilpena Group. However, given the regime of active crustal extension in the formation of the Kanmantoo Trough, it is likely that sequences were generated in response to normal faulting in a relatively deep marine environment. The event beds probably include both turbidites and tempestites, but the Kanmantoo Group also includes shallow-water cross-bedded feldspathic sandstones of the Backstairs Passage Formation and Middleton Sandstone. The Kanmantoo Group was clearly deposited in water of considerably less than oceanic depth. At least in its western occurrences on Fleurieu Peninsula, it overlies Early Cambrian and Adelaidean epicontinental sediments and was not deposited upon oceanic crust. The disconformity between the Backstairs Passage Formation and Talisker Calc-siltstone appears to occur basin-wide (Dyson *et al.*, 1996) and may represent a subaerial erosional surface, again inconsistent with oceanic depths.

The origin and provenance of the Kanmantoo Group has been much debated. Early workers suggested a source in the southeastern part of the Gawler Craton (Thomson, 1969; Daily and Milnes, 1971a,b), however most of the sands are only fine to medium-grained and suggest a more distal setting, despite the thick-bedded nature of some rapidly dumped event beds. Study of current directions gives some conflicting indications; whereas cross-beds in the shallow-water Backstairs Passage Formation northeast of Adelaide yielded easterly-flowing currents (Mills, 1964), sole marks in the Carrickalinga Head and Balquhidder Formations suggest a northerly palaeoslope (Haines and Flöttmann, 1998). Together with detrital zircon data (Ireland *et al.*, 1998) this was used to propose a southerly provenance in Antarctica. A source in Antarctica south of the present Adelaide Geosyncline may explain the presence of very young zircons (550-600 Ma) derived from igneous events associated with the earlier onset of convergent tectonics in the Ross Orogen than in the Delamerian Orogen. However, it does not easily explain the abundance of Grenvillean-age zircons in the Kanmantoo Group (note that, as mentioned above, zircons of this age do occur in lesser abundance in some Adelaidean clastics sediments) as there is no orogen of this age nearby. In addition, it is possible that northerly palaeoslopes could have been generated locally on the sea floor by rotation of extensional fault blocks and thus sole marks need not necessarily indicate regional sediment transport.

An alternative possible source of Grenville-age zircons could be the Albany-Fraser belt of Western Australia, where several plutonic bodies have similar ages (Nelson *et al.*, 1995). Clastic sediments could have been transported into the Kanmantoo Trough by a river system along an incipient Early Cambrian east-west rift, a westerly extension of the Kanmantoo Trough, which is itself east-west-trending on Kangaroo Island. Such a provenance would also be consistent with the general facies trend of sediments within the Kanmantoo Trough, from more proximal on Kangaroo Island to most distal at the northeastern extremity of the trough in the northern Mount Lofty Ranges (Fig. 7). In particular, it would explain the west to east current directions determined by Flint (1979) on probable Middleton Sandstone at the western extremity of Kangaroo Island.

DELAMERIAN OROGENY

4.1 SEQUENCE AND STYLES OF DEFORMATION, METAMORPHISM AND MAGMATISM

The Delamerian Orogeny was an episode of major crustal shortening affecting the Adelaide Geosyncline and its basement during the later part of the Cambrian. Unattenuated continental crust appears to have escaped deformation (e.g. the Gawler Craton and central, cratonic portion of the Curnamona Province), but the very thick rift and sag phase sediments are all affected by folding and contractional faulting of varying intensity. Basement involvement in folding and thrusting is restricted to areas where the evaporitic Curdimurka Subgroup was not deposited, i.e. on the Willouran rift shoulders. Here the basement forms anticlinal cores (e.g. the Mount Painter, Mount Babbage and Willyama Inliers) or thrust sheets (at least some of the basement inliers in the Mount Lofty Ranges). Some basement structures that had been active as extensional faults during the various phases of Neoproterozoic and Cambrian rifting were reactivated as thrusts; others were transform faults perpendicular to rift axes and these suffered strike-slip movement during the Delamerian compression (e.g. Paralana Fault, Anabama Shear Zone). In the remainder of the orogen, basement has been down-faulted to such a great depth that no manifestation of it is visible on aeromagnetic images. Rare samples of metamorphic and plutonic rocks were plucked from the basement and rafted to the surface by diapiric intrusion of brecciated Callanna Group during both Adelaidean to Cambrian sedimentation and the Delamerian Orogeny, attesting to the ensialic nature of the Adelaide Geosyncline.

Delamerian deformation is least intense in the Central Flinders Zone, dominated by open dome-and-basin interference folds, with shortening generally less than 10% (e.g. Paul *et al.*, 1999). The North Flinders Zone and Nackara Arc are arcuate belts of linear, generally upright, more or less concentric folds to the north and south respectively (Fig. 8). The Nackara Arc consists of long, linear synclines, separated by anticlines or, more commonly, strike faults; the folds trend N to NNW in the south near Clare and Burra but swing more or less smoothly into an ENE orientation near Olary. The Nackara Arc is separated from the southeastward-convex Fleurieu Arc in the south by an ill-defined NNW-trending zone of transition, which coincides with the "G2 structural corridor" of O'Driscoll (1983). The Fleurieu Arc is the part of the orogen that has undergone the greatest degree of shortening during the earliest phase of the Delamerian Orogeny, achieved by generally NW-directed thrusting on shallowly SE-dipping shear zones that are rooted in the basement and propagate northwestwards up through the stratigraphy. Within the inner, western portion of the Fleurieu Arc, folds and thrusts verge consistently NW, and basement has been upthrust as sheets and asymmetrical anticlinal cores. Axial plane slaty cleavage in these greenschist-facies metasediments dips shallowly to the east and southeast. However, in the more highly metamorphosed eastern part of the Fleurieu Arc, this earliest cleavage gives way to a pronounced bedding-parallel schistosity which is folded, together with bedding, into a series of relatively upright regional folds that are coaxial with, and probably continuous with, the regional folds of the Nackara Arc to the north. For this reason, the early NW-directed contractional structures in the Fleurieu Arc are designated D_1, while the major N-S trending folds of the Nackara Arc and eastern Fleurieu Arc are referred to D_2. A belt of F_3 folds with NNW-trending axes is largely confined to the area of highest metamorphic grade (see below).

Metamorphism associated with the Delamerian Orogeny is mostly of greenschist grade, the Central Flinders Zone possibly being sub-greenschist. Higher grades are encountered only around the Mount Painter Inlier, in the immediate vicinity of granitic intrusives, and in the NNW-trending zone of amphibolite-facies metamorphism in the eastern Mount Lofty Ranges that transects obliquely the main north-south trend of the eastern Fleurieu Arc. This zone appears to be controlled by the "G2 structural corridor". Within it, migmatite is locally developed, but is restricted to the Kanmantoo Group; the reasons for this are not certain, but may relate to the fact that these were young, rapidly deposited sediments that may not have undergone complete dewatering prior to the onset of metamorphism, the contained fluids facilitating partial melting. Metamorphism to amphibolite facies around the Mount Painter Inlier has been related to radioactive heat production in basement granites; at mid-crustal levels, high geothermal gradients result from deep burial during post-rift thermal subsidence (Sandiford *et al.*, 1998). However, the presence of a pronounced gravity low in the southern part of the Mount Painter Inlier may indicate an unexposed Delamerian granite pluton at depth intruding the basement as an additional heat source.

Igneous activity was closely associated with the Delamerian Orogeny, though mostly confined to a sigmoidal belt along the eastern edge of the exposed Nackara and Fleurieu Arcs. The oldest intrusive, the precursor of the Rathjen Gneiss, was intruded, probably as a pre-tectonic, bedding-concordant sill, into the Backstairs Passage Formation at 514 ±7 Ma (Foden *et al.*, in press) and has undergone all phases of deformation. Syntectonic I-type granites, some with variable admixtures from crustal sources intruded during the Delamerian Orogeny, though the precise timing relationships to phases of deformation have been much debated (Milnes *et al.*, 1977, Mancktelow, 1990; Flöttmann *et al.*, 1996).

4.2 INTERPRETATION OF PLATE CONVERGENCE

As discussed above, the earliest and most strongly contractional deformation is recorded by the NW-directed structures of the Fleurieu Arc, and these are overprinted by meridional folds to the north. This implies that the Fleurieu Arc was the point of first impingement during NW-SE convergence, and that deformation thereafter propagated northward. Although it has been common to view Delamerian deformation of the Nackara Arc in terms of E-W compression (e.g. Clarke and Powell, 1989), it is the author's view that the main direction of plate convergence controlling deformation remained NW-SE, and that after initial contraction in this orientation in the Fleurieu Arc, a sinistral transpressive regime was established along the "G2 structural corridor" (Preiss, 1995). The causes of plate convergence remain obscure, but may involve collision of a microcontinent originating from further south in the Neoproterozoic proto-Pacific Ocean or a Cambrian island arc against a southeastern promontory in the margin of the Australian continent.

4.3 RELATIONSHIP TO THE TASMAN MOBILE BELT OF EASTERN AUSTRALIA.

To a large extent the crucial relationships have been obscured by younger Palaeozoic events along the eastern margin of Australia. It is only recently that the western limit of the Tasman mobile belt has been defined in western Victoria, where strongly folded Cambrian-Ordovician sediments are thrust westwards over Delamerian basement on the Moyston Fault (Cayley, 1995; Cayley and Taylor, 1996). However, the eastward extent of ?Cambrian rocks deformed by the Delamerian Orogeny underneath this thrust remains uncertain. West of the Moyston Fault, ?Silurian sediments of the Grampians Group overlie this Delamerian basement but have also been affected by mid-Palaeozoic thrusting and granite intrusion. Volcanics of the Stavely Belt west of the Grampians have been dated at ~500 Ma (Stuart-Smith and Black, 1994), but their relationship to the approximately coeval Delamerian Orogen remain obscure. The Stavely Belt can be traced in a north-nothwesterly direction on aeromagnetic images toward the S.A.-Victoria border (Moore *et al.*, 1998), but no further west. Just west of the border, a borehole at Peebinga intersected limestone (at top), black shale, and mafic lavas at the bottom. These extrusives are the most easterly occurrence of a set of intra-plate mafic volcanics in the southeast of South Australia (Rankin *et al.*, 1992). The other lithologies at Peebinga are strongly reminiscent of the Normanville Group, but apparently in the reverse stratigraphic order and with sheared contacts. It is suggested here that they are part of an imbricate thrust system in a zone of collision with Cambrian ?arc volcanics of the Stavely Belt, although the vergence of thrusting is not known. The Neoproterozoic to Early Cambrian continental margin can therefore have lain no further west than the present S.A.-Victoria border (Figs 7,8), further east than, and probably of a different orientation to, the continent-ocean boundary shown by Walter and Veevers (1997).

One of the greatest enigmas is the reported occurrence of Neoproterozoic orogeny in Tasmania, including King Island. The tectonic evolution of the Adelaide Geosyncline and Delamerian Orogen cannot be understood without consideration of the Tasmanian evidence. Although conventionally dated at ~700 Ma and affecting Neoproterozoic sediments in northwestern Tasmania, the Penguin Orogeny has recently been reinterpreted by Turner *et al.* (1996) as being of Delamerian age. If all the deformation of Neoproterozoic rocks in Tasmania proved to be of Delamerian age, this would greatly simplify relationships with South Australia. However, granite on King Island has been dated at 760 ±12 Ma and interpreted to post-date the first phase of deformation in the country rock metasediments (Turner *et al.*, 1998) and supports the concept of a Neoproterozoic orogeny, at least on the north and west coasts of the island (the Wickham Orogeny). Similarly, a granitoid intruding metasediments in northwest Tasmania has been dated by these authors at 777 ±7 Ma. Contrary to the conclusions of Turner *et al.* (1998), these events correlate not with early Sturtian tectonism in the Adelaide Geosyncline, but with early Torrensian rifting and sedimentation.

There is now much support for the identification of the Cottons Breccia (Jago, 1974) of southeastern King Island as a Marinoan glacial unit (C.R. Dalgarno, M.R. Walter, P.W. Haines, 1998, pers. comm., and author's personal observations; Calver and Walter, this volume). This conclusion is supported by the unsorted, muddy matrix-supported texture of the diamictite, presence of occasional dropstones in laminated interbeds and rare basement-derived clasts (most clasts are of sedimentary origin, dominantly carbonate), and by the overlying pink, laminated cap dolomite similar to the Nuccaleena Formation, followed by siltstone and mafic volcanics. Though tilted and faulted, these rocks are less deformed than the Proterozoic metasediments of western King Island, but no stratigraphic relationship is known. The dilemma remains that while the diamictite suggests a close relationship to the Adelaide Geosyncline, the reported evidence indicates major orogenic deformation and granite intrusion on King Island and NW Tasmania at a time of rifting and sedimentation of the Burra Group in South Australia. Indeed, such a Neoproterozoic orogen is totally unlike any other Proterozoic basement on mainland Australia.

Although the author has not studied the field relationships in Tasmania, two possible solutions are suggested that require further testing. Either:
(a) the structural relationships of the Tasmanian granitoids have been misinterpreted and the intrusions are actually pre-tectonic and related to an early Torrensian extension event (note that one of the granitoid dates is identical to the age of the Boucaut Volcanics). This would allow northwest Tasmania to lie on a southern extension of the Adelaide Geosyncline, and the granitoids would be of extensional origin. In this scenario, all the orogenic deformation on King Island could be Delamerian, the intensity of deformation and metamorphic grade being higher in the northwest of the island than in the southeast.

or

(b) the structural relationships of the Tasmanian granitoids have been correctly interpreted and indicate Neoproterozoic orogeny. This suggests that northwest Tasmania did not form part of the Australian continental landmass in the ~800-750 Ma interval, but may have been part of a micro-continent that initially lay on a separate plate near but southeast of Australia. This would imply that such a micro-continent had split from Antarctica or Laurentia much earlier, possibly even in pre-Adelaidean times. Proterozoic sediments on this microcontinent would have undergone orogenic deformation in the early Torrensian, been exhumed and unconformably overlain by Sturtian to Marinoan sediments, and been glaciated in the Marinoan glaciation. The microcontinent may then have collided with the Australian continental margin early in the Delamerian Orogeny.

CONCLUSIONS RELATING TO CONTINENTAL RECONSTRUCTION

The geological record in the Adelaide Geosyncline has an important bearing on possible Neoproterozoic continental reconstruction. The recognition of discrete episodes of rifting, each with its own timing, locus and orientation, should allow interpretation of extension directions and possible linkages to the conjugate continental margin, as summarised in diagrams Figs 3-7.

Willouran rifting took place in two phases, the first marked by intrusion of the Gairdner Dyke Swarm and extrusion of the Wooltana and Beda Volcanics, at 827 ±7 Ma (Fig. 3). The second phase, dated approximately by the Rook Tuff at 802 ±10 Ma, involved the formation of a system of deeply subsident NW to NNW-trending grabens. Crustal extension was directed NE-SW during these phases, and appears to have been entirely intracratonic, with a pole of rotation inferred to be in northwest Australia (Fig. 4). There was limited marine interconnection with the rift system, probably from the southeast. Willouran rifting is apparently not recorded in Laurentia.

Torrensian rifting involved a widened zone of crustal extension and the formation of a new, north-south-trending western rift margin at the Torrens Hinge Zone. Normal faulting along this zone, and also at the western margin of the Curnamona Province near Olary, produced a series of half-grabens stepping down into the basin centre. There was extensive marine flooding of the rift system during times of high sea level (S-S Torrensian 3). Assuming that early Torrensian rifting is dated by the Boucaut Volcanics (777 ±7 Ma), this rift event, rather than the Gairdner Dyke event, may coincide with ~780 Ma magmatism in western Laurentia, e.g. the mafic dykes that intrude the Little Dal Group of the Mackenzie Mountains (Jefferson *et al.*, 1989; Park *et al.*, 1995).

Mid-Sturtian rifting, not directly dated but inferred to be ~700 Ma, was marked by an eastward shift of the locus of graben formation and a return to NE-

SW directed extension. A series of northwest-orientated half-grabens defined the southwestern margin of the Curnamona Province and the Yudnamutana Trough of the Northern Flinders Zone trends east-west at the northwest corner of the Curnamona Province. Glaciation and concomitant crustal extension followed a period of subaerial erosion which truncated early extensional faults and some of the earliest diapiric intrusions. The presence of sedimentary ironstones in the Yudnamutana Subgroup, concentrated in the Nackara Arc region, and the close lithostratigraphic matching of the glacials and overlying strata in South Australia with those of the Mackenzie Mountains of western Laurentia has long been considered to favour juxtaposition of these regions during the Neoproterozoic (e.g. Young, 1992). This correlation has received strong support from recent isotope stratigraphic studies (Walter *et al.*, this volume).

The late Sturtian to early Marinoan was a period of mainly sag-phase deposition interpreted as being related to continental separation. The stratigraphic record is thicker and more complete in the Adelaide Geosyncline than in the entirely intracratonic Centralian Superbasin; this may reflect its setting at or adjacent to a passive continental margin. Continental separation at this time is favoured over later break-up at 560 Ma as interpreted by Veevers *et al.* (1997), not only because of the palaeomagnetic evidence presented by Powell *et al.* (1994), but also because of the change in tectonic and sedimentary style above the Sturtian glacials, and because timing at ~700 Ma allows sufficient time (almost 200 million years) for a full cycle of ocean opening and closure.

There was renewed rifting in the mid-Marinoan, especially along the Torrens Hinge Zone, but this did not produce discrete graben structures. Eruption of a thick pile of mafic lavas, possibly dated at ~580 Ma (Crawford and Stevens, 1997) east of the Curnamona Province in the Koonenberry Belt of NSW possibly marked a final phase of late Neoproterozoic extension. However, this belt is separated from the Curnamona Province and its Neoproterozoic cover by the mid-Palaeozoic Bancannia Trough, and its original relationship to the Australian continent is uncertain. This phase of extension apparently post-dated the interpreted separation of Australia from Laurentia, but it is yet not clear which continent this crustal fragment was derived from.

Renewed rifting occurred in the late Early Cambrian in the southern Adelaide Geosyncline to form the Kanmantoo Trough. The main axis of rifting was orientated NE-SW, suggesting NW-SE extension on the Neoproterozoic passive margin, but extends in an east-west direction on Kangaroo Island. The reasons for this rift episode so long after continental separation are uncertain, but the rift clearly cuts across all pre-existing tectonic trends (e.g. the Torrens Hinge Zone). It seems inconceivable that such a deeply subsident trough could terminate abruptly at the western end of Kangaroo Island, and it may be more likely that an incipient intracontinental rift extended westwards in the Early Cambrian. Such a rift could have been a precursor to the Mesozoic rifts that eventually led to separation of Australia and Antarctica; in the Early Cambrian it could have permitted eastward fluvial transport of detritus from the Albany-Fraser Belt of Western Australia. It is even possible that this rifting commenced in the Neoproterozoic, to explain the rare Grenville-age detrital zircons in some Adelaidean sediments. There is in fact evidence of early Adelaidean north-south crustal extension in the Gawler Craton in the east-west-trending Polda Trough containing evaporites and ~800 Ma mafic lavas (Preiss *et al.*, 1993).

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REFERENCES

Ambrose, G.J., Flint, R.B. and Webb, A.W., 1981. Precambrian and Palaeozoic geology of the Peake and Denison Ranges. *South Australia. Geological Survey. Bulletin,* 50.

Baldwin, S.L., McDougall, I. and Williams, G.E., 1991. K/Ar and 40Ar/39Ar analyses of meltrock from the Acraman impact structure, Gawler Ranges, *South Australia. Australian Journal of Earth Sciences,* 38:291-298.

Barovich, K.M. and Foden, J., (this volume). A late Proterozoic continental flood basalt province in southern - central *Australia: geochemical and Nd isotope evidence from Neoproterozoic basin fill. Precambrian Research.*

Belperio, A.P., 1990. Palaeoenvironmental interpretations of the Late Proterozoic Skillogalee Dolomite in the Willouran Ranges, South Australia. In: Jago, J.B. and Moore, P.S. (Eds), The evolution of a late Precambrian-early Palaeozoic rift complex: the Adelaide Geosyncline. Geological Society of Australia. Special Publication, 16:85-104.

Belperio, A.P., Preiss, W.V., Fairclough, M.C., Gatehouse, C.G., Gum, J., Hough, J. and Burtt, A., 1998. Tectonic and metallogenic framework of the Cambrian Stansbury Basin-Kanmantoo Trough, South Australia. *AGSO Journal of Australian Geology and Geophysics,* 17:183-200.

Calver, C.R., 1995. Ediacarian isotope stratigraphy of Australia. *Macquarie University, Sydney, Ph.D. thesis* (unpublished).

Claver, C.R. and Walter, M.R., (this volume). The late Neoproterozoic Grassy Group of King Island, Tasmania: correlation and palaeogeographic significance. Precambrian Research.

Cayley, R.A., 1995. Recent advances in understanding the structural evolution of western Victoria. In: Results of recent GSV work. Programme and abstracts. Geological Survey of Victoria. *Department of Agriculture, Energy and Minerals.*

Cayley, R.A. and Taylor, D.H., 1996. Geological evolution and potential of the Grampians area, Victoria. In: Hughes, M.J., Ho, S.E. and Hughes, C.E. (Eds). *Recent developments in Victorian geology and mineralisation. Australian Institute of Geoscientists, Bulletin,* 20:11-18.

Christie-Blick, N., Kennedy, M. and Sohl, L.E., 1998. Proposed location of a Terminal Proterozoic GSSP: Nuccaleena Formation, Flinders Ranges, South Australia. In: Gehling, J.G. (Compiler). Inaugural Sprigg Symposium: the Ediacaran revolution. Abstracts and Programme. *Geological Society of Australia. Abstracts,* 51:16-17.

Christie-Blick, N., von der Borch, C.C and Di Bona, P.A., 1990. Working hypothesis for the origin of the Wonoka canyons (Neoproterozoic), South Australia. *American Journal of Science,* 290-A:295-332.

Clarke, G.L. and Powell, R., 1989. Basement-cover interaction in the Adelaide Foldbelt, South Australia: the development of an arcuate foldbelt. *Tectonophysics,* 158:209-226.

Cloud, P.E. and Glaessner, M.F., 1982. The Ediacarian Period and System: Metazoa inherit the Earth. *Science, New York,* 217:783-792.

Coats, R.P., 1964. Large scale Precambrian slump structures, Flinders Ranges. South Australia. Geological Survey. *Quarterly Geological Notes,* 11:1-2.

Coats, R.P., 1967. The "Lower Glacial Sequence" - Sturtian type area. South Australia. Geological Survey. *Quarterly Geological Notes,* 23:1-3.

Coats, R.P., 1973. COPLEY, South Australia, sheet SH54-9. South Australia. Geological Survey. 1:250 000 *Series - Explanatory Notes.*

Coats, R.P., 1981. Late Proterozoic (Adelaidean) tillites of the Adelaide Geosyncline. In: Hambrey, M.J. and Harland, W.B. (Eds), Earth's pre-Pleistocene glacial record. International Geological Correlation Programme, Project 38: pre-Pleistocene tillites. *Cambridge University Press, Cambridge,* pp.537-548.

Compston, W., Crawford, A.R. and Bofinger, V.M., 1966. A radiometric estimate of the duration of sedimentation in the Adelaide Geosyncline, South Australia. *Journal of the Geological Society of Australia*, 13:229-276.

Compston, W., Williams, I.S., Jenkins, R.J.F., Gostin, V.A. and Haines, P.W., 1987. Zircon age evidence for the Late Precambrian Acraman ejecta blanket. *Australian Journal of Earth Sciences,* 34:435-445.

Crawford, A.J., Stevens, B.P.J. and Fanning, C.M., 1997. *Geochemistry and tectonic setting of some Neoproterozoic and Early Cambrian volcanics in western New South Wales. Australian Journal of Earth Sciences,* 44:831-852.

Daily, B., 1976. The Cambrian of the Flinders Ranges. In: Thomson, B.P., Daily, B., Coats, R.P. and Forbes, B.G. (Compilers), Late Precambrian and Cambrian geology of the Adelaide 'Geosyncline' and Stuart Shelf, South Australia. 25th International Geological Congress, Sydney, 1976. *Excursion guide,* 33A:15-19.

Daily, B., 1990. Cambrian stratigraphy of Yorke Peninsula. Geological Society of Australia. In: Jago, J.B. and Moore, P.S. (Eds), The evolution of a late Precambrian-early Palaeozoic rift complex: the Adelaide Geosyncline. Geological Society of Australia. *Special Publication,* 16:215-229.

Daily, B. and Milnes, A.R., 1971. Stratigraphic notes on Lower Cambrian fossiliferous metasediments between Campbell Creek and Tunkalilla Beach in the type section of the Kanmantoo Group, Fleurieu Peninsula, South Australia. Royal Society of South Australia. *Transactions,* 95:199-214.

Daily, B. and Milnes, A.R., 1973. Stratigraphy, structure and metamorphism of the Kanmantoo Group (Cambrian) in its type section east of Tunkalilla Beach, South Australia. Royal Society of South Australia. *Transactions,* 97:213-242.

Daly, S.J. and Fanning, C.M., 1993. Archaean. In: Drexel, J.F., Preiss, W.V. and Parker, A.J. (Eds). The Geology of South Australia. Volume 1, The Precambrian. *South Australia. Geological Survey. Bulletin,* 54:32-49.

Daly, S.J., Fanning, C.M. and Fairclough, M.C., 1998. Tectonic evolution and exploration potential of the Gawler Craton, South Australia. *AGSO Journal of Australian Geology and Geophysics*, 17:145-168.

Dalziel, I.W.D., 1991. Pacific margins of Laurentia and East Antarctica-Australia as a conjugate rift pair: evidence and implications for an Eocambrian supercontinent. *Geology,* 19:598-601.

Dyson, I.A., 1992a. Geology of the Upalinna Diapir, central Flinders Ranges. South Australia. Geological Survey. *Quarterly Geological Notes*, 124:2-19.

Dyson, I.A., 1992b. Stratigraphic nomenclature and sequence stratigraphy of the lower Wilpena Group, Adelaide Geosyncline: the Sandison Subgroup. *South Australia. Geological Survey. Quarterly Geological Notes*, 122:2-13.

Dyson, I.A., 1996. Stratigraphy of the Neoproterozoic Aruhna and Depot Springs subgroups, Adelaide Geosyncline. *Transactions of the Royal Society of South Australia,* 120:101-115.

Dyson, I.A., Gatehouse, C.G. and Jago, J.B., 1996. Sequence stratigraphy of the Talisker Calc-siltstone and lateral equivalents in the Cambrian Kanmantoo Group. *South Australia. Geological Survey. Quarterly Geological Notes,* 129:27-41.

Eickhoff, K.H., von der Borch, C.C. and Grady, A.E., 1988. Proterozoic canyons of the Flinders Ranges, South Australia. *Sedimentary Geology,* 58:217-235.

Fanning, C.M., Ludwig, K.R., Forbes, B.G. and Preiss, W.V., 1986. Single and multiple grain U-Pb zircon analyses for the early Adelaidean Rook Tuff, Willouran Ranges, South Australia. In: 8th Australian Geological Convention, Adelaide 1986. *Geological Society of Australia. Abstracts,* 15:71-72.

Fanning, C.M., Flint, R.B. and Preiss, W.V., 1983. Geochronology of the Pandurra Formation. South Australia. Geological Survey. Quarterly Geological Notes, 88:11-16.

Fanning, C.M. and Webb, A.W., 1983. K-Ar and Rb-Sr dating of dolerite samples from Reedy Lagoon 1. Amdel Report GS 498-83. South Australia. *Department of Mines and Energy. Open file Envelope*, 6713 (unpublished).

Flint, D.J., 1978. Deep sea fan sedimentation of the Kanmantoo Group, Kangaroo Island. Royal Society of South Australia. *Transactions,* 102:203-222.

Flint, D.J. and Webb, A.W., 1980. Geochronological investigations of the Willyama Complex, South Australia. *South Australia. Department of Mines and Energy. Report Book,* 79/163 (unpublished).

Flint, R.B., Blissett, A.H., Conor, C.H.H., Cowley, W.M., Cross, K.C., Creaser, R.A., Daly, S.J., Krieg, G.W., Major, R.B., Parker, A.J. and Teale, G.S., 1993. Mesoproterozoic. In: Drexel, J.F., Preiss, W.V. and Parker, A.J. (Eds). The Geology of South Australia. Volume 1, The Precambrian. *South Australia. Geological Survey. Bulletin,* 54(1):106-169.

Flötmann, T. and James, P., 1993. Influence of basin architecture on the style of inversion and fold-thrust belt tectonics-the southern Adelaide Fold-Thrust Belt, South Australia. *Journal of Structural Geology,* 19:1093-1110.

Flötmann, T. James, P., Rogers, J. and Johnson, T., 1994. Early Palaeozoic foreland thrusting and basin reactivation at the Palaeo-Pacific margin of the southeastern Australian Precambrian Craton: a reappraisal of the structural evolution of the Southern Adelaide Fold-Thrust Belt. *Tectonophysics,* 234:95-116.

Flötmann, T., Gum, J. and Haines, P., 1996. Kanmantoo tectonics, sedimentology and metallogeny excursion. Field Guide. Resources '96 Convention, 2nd-3rd December. *South Australia. Department of Mines and Energy. Report book* 96/40.

Foden, J., Sandiford, M., Dougherty-Page, J. and Williams, I. (in press). The geochemistry and geochronology of the Rathjen Gneiss: implications for the early tectonic evolution of the Delamerian Orogen. *Australian Journal of Earth Sciences.*

Forbes, B.G., 1960. Magnesite of the Adelaide System: petrography and descriptive stratigraphy. *Transactions of the Royal Society of South Australia,* 83:1-9.

Forbes, B.G., 1961. Magnesite of the Adelaide System: a discussion of its origin. *Transactions of the Royal Society of South Australia,* 85:217-222.

Forbes, B.G., 1971. Stratigraphic subdivision of the Pound Quartzite (late Precambrian, South Australia). Royal Society of South Australia. Transactions, 95:219-225.

Forbes, B.G., 1978. The Boucaut Volcanics. South Australia. Geological Survey. *Quarterly Geological Notes,* 65:6-10.

Forbes, B.G., Murrell, B. and Preiss, W.V., 1981. Subdivision of lower Adelaidean, Willouran Ranges. *South Australia. Geological Survey. Quarterly Geological Notes,* 79:7-16.

Gehling, J.G., 1986. Algal binding of siliciclastic sediments: a mechanism in the preservation of Ediacaran fossils. *12th International Sedimentological Congress, Canberra, Abstracts,* p.117.

Gehrels, G.E., Butler, R.F. and Bazard, D.R., 1996. Detrital zircon geochronology of the Alexander terrane, southeastern Alaska. *Geological Society of America Bulletin,* 108:722-734.

Gostin, V.A., Haines, P.W., Jenkins, R.J.F., Compston, W. and Williams, I.S., 1986. Impact ejecta horizon within late Precambrian shales, *Adelaide Geosyncline, South Australia. Science,* 233:198-200.

Gostin, V.A. and Jenkins, R.J.F., 1983. Sedimentation of the early Ediacaran, Flinders Ranges, South Australia. In: 6th Australian Geological Convention, Canberra, 1983. *Geological Society of Australia. Abstracts,* 9:196-197.

Gravestock, D.I. and Hibburt, J., 1991. Sequence stratigraphy of the eastern Officer and Arrowie Basins: a framework for Cambrian oil search. *APEA Journal,* 31:177-190.

Gravestock, D.I., Alley, N.F., Benbow, M.C., Cowley, W.M., Farrand, M.G., Flint, R.B., Gatehouse, C.G., Krieg, G.W. and Preiss, W.V., 1995. Early and Middle Palaeozoic. In: Drexel, J.F. and Preiss, W.V. (Eds). The Geology of South Australia. Volume 2, The Phanerozoic. South Australia. Geological Survey. *Bulletin,* 54(2):2-61.

Gravestock, D.I. and Shergold, J.H., (in press). Australian Early and Middle Cambrian sequence biostratigraphy with implications for species diversity and correlation. In: Zhuravlev, A. and Riding, R. (Eds). Ecology of the Cambrian Radiation. *Columbia University Press, New York.*

Haines, P.W., 1987. Carbonate shelf and basin sedimentation, late Proterozoic Wonoka Formation, South Australia. *University of Adelaide, Ph. D. thesis (unpublished).*

Haines, P.W., 1990. A late Proterozoic storm-dominated carbonate shelf sequence: the Wonoka Formation in the central and southern Flinders Ranges, South Australia. In: Jago, J.B. and Moore, P.S. (Eds), The evolution of a late Precambrian-early Palaeozoic rift complex: the Adelaide Geosyncline. *Geological Society of Australia. Special Publication*, 16:177-198.

Haines, P.W. and Flöttmann, T., 1998. Delamerian Orogeny and potential foreland sedimentation: a review of age and stratigraphic constraints. *Australian Journal of Earth Sciences,* 45:559-570.

Haines, P.W., Flöttmann, T., Gum, J.C., Jago, J.B. and Gatehouse, C.G., 1996. Integrated approach to the reinterpretation of the Cambrian Kanmantoo Group type section, South Australia. *Geological Society of Australia. Abstracts,* 41:177.

Hill, A.C., Cotter, K.L., Grey, K. and Zang, W., 1999 (in press). Pre-Sturtian biostratigraphy and isotope stratigraphy of Australia: implications for global correlations. *Precambrian Research (this issue).*

Hoffman, P.F., 1991. Did the breakout of Laurentia turn Gondwanaland inside out? *Science,* 252:1409-1412.

Ireland, T.R., Flöttmann, T., Fanning, C.M., Gibson, G.M. and Preiss, W.V., 1998. Development of the Early Paleozoic Pacific Margin of Gondwana from detrital zircon ages across the Delamerian Orogen. *Geology*, 26:243-246.

Jago, J.B., 1974. The origin of Cottons Breccia, King Island, Tasmania. Royal Society of South Australia. *Transactions,* 98:13-28.

Jefferson, C.W. and Parrish, R.R., 1989. Late Proterozoic stratigraphy, U-Pb zircon ages, and rift tectonics, Mackenzie Mountains, northwestern Canada. *Canadian Journal of Earth Sciences*, 26:1784-1801.

Jenkins, R.J.F., 1975. An environmental study of the rocks containing the Ediacara assemblage in the Flinders Ranges. In: 1st Australian Geological Convention, Adelaide, 1975. Abstracts. *Geological Society of Australia,* pp.21-22.

Jenkins, R.J.F., 1981. The concept of an "Ediacaran Period" and its stratigraphic significance in Australia. *Transactions of the Royal Society of South Australia*, 105:179-194.

Jenkins, R.J.F., 1990. The Adelaide fold belt: tectonic reappraisal. . In: Jago, J.B. and Moore, P.S. (Eds), The evolution of a late Precambrian-early Palaeozoic rift complex: the Adelaide Geosyncline. Geological Society of Australia. *Special Publication*, 16:396-420.

Jenkins, R.J.F. and Sandiford, M., 1992. Observations on the tectonic evolution of the southern Adelaide Fold Belt. *Tectonophysics*, 214:27-36.

Jenkins, R.J.F., McKirdy, D.M. and Nedin, C. (compilers), 1998. The Ediacaran in South Australia: proposal and field guide supporting GSSP Position `C' at Wearing Dolomite, Flinders Ranges, 16th to 22nd June 1998. I.U.G.S. Working Group on the Terminal Proterozoic System. Department of Geology and Geophysics, *The University of Adelaide (unpublished).*

Kammermann, M., 1996. The structure and stratigraphy west of Sevenhill, South Australia. Flinders University (South Australia). *B.Sc. (Hons) thesis (unpublished).*

Krieg, G.W., Alexander, E.M., Alley, N.F., Armstrong, D., Farrand, M.G., Gatehouse, C.G., Gravestock, D.I., Hill, A.J., Kwitko, G., Morton, J.G.G. and Rogers, P.A., 1995. Mesozoic. In: Drexel, J.F. and Preiss, W.V. (Eds). The Geology of South Australia. Volume 2, The Phanerozoic. South Australia. *Geological Survey. Bulletin,* 54:92-149.

Laing, W.P., 1996. The Diamantina orogen linking the Willyama and Cloncurry Terranes, eastern Australia. In: Pongratz, J. and Davidson, G. (Eds). New developments in Broken Hill type deposits. Centre for Ore Deposits Studies, Special Publication, 1:67-72. *University of Tasmania.*

Lemon, N.M. and Reid, P.W. (1998). The Yaltipena Formation of the central Flinders Ranges. *MESA Journal*, 8:37-39.

Lemon, N.M. and Williams, G.E., 1998. Flinders Ranges field trip, 16th-22nd June, 1998, Adjunct field guide. IUGS Working Group on the Terminal Proterozoic System. *The University of Adelaide* (unpublished).

Li, Z-X, Zhang, L-H and Powell, C.McA., 1995. South China in Rodinia: part of the missing link between Australia-East Antarctica and Laurentia? *Geology,* 23:407-410.

Maboko, M.A.H., Williams, I.S. and Compston, W., 1991. Zircon U-Pb chronometry of the pressure and temperature history of granulites in the Musgrave Ranges, central Australia. *Journal of Geology*, 99:675-697.

Mancktelow, N.S., 1990. The structure of the southern Adelaide Fold Belt, South Australia. In: Jago, J.B. and Moore, P.S. (Eds), The evolution of a late Precambrian-early Palaeozoic rift complex: the Adelaide Geosyncline. *Geological Society of Australia. Special Publication,* 16:369-395.

Mason, M.G., Thomson, B.P., and Tonkin, D.G., 1978. Regional stratigraphy of the Beda Volcanics, Backy Point Beds and Pandurra Formation on the southern Stuart Shelf, South Australia. *South Australia. Geological Survey. Quarterly Geological Notes*, 66:2-9.

Mawson, D. and Sprigg, R.C., 1950. Subdivision of the Adelaide System. *Australian Journal of Science,* 13:69-72.

Mills, K.J., 1964. The structural petrology of an area east of Springton, South Australia. *University of Adelaide. Ph.D. thesis (unpublished).*

Milnes, A.R., Compston, W. and Daily, B., 1977. Pre- to syn-tectonic emplacement of Palaeozoic granites in southeastern South Australia. Geological Society of Australia. Journal, 24:87-106.

Moore, D.H., Vandenberg, A.H.M., Willman, C.E. and Magart, A.P.M., 1998. Palaeozoic geology and resources of Victoria. *AGSO Journal of Australian Geology and Geophysics,* 17:107-122.

Moores, E.M., 1991. Southwest U.S. - East Antarctica connection: a hypothesis. *Geology,* 19:425-428.

Mount, T.J., 1975. Diapirs and diapirism in the Adelaide "Geosyncline", South Australia. *University of Adelaide, Ph.D. thesis* (unpublished).

Murrell, B., Link, P.K. and Gostin, V.A., 1977. Evidence for only one Sturtian glacial period in the COPLEY map area. South Australia. *Geological Survey. Quarterly Geological Notes,* 64:16-19.

Nelson, D.R., Myers, J.S. and Nutman, A.P., 1995. Chronology and evolution of the Middle Proterozoic Albany-Fraser Orogen, Western Australia. *Australian Journal of Earth Sciences*, 42:481-495.

O'Driscoll, E.S.T., 1983. Deep tectonic foundations of the Eromanga. Basin. *APEA Journal,* 23:5-17.

Park, J.K., Buchan, K.L. and Harlan, S.S., 1995. A proposed giant radiating dyke swarm fragmented by the separation of Laurentia and Australia based on palaeomagnetism of ca. 780 Ma mafic intrusions in western North America. *Earth and Planetary Science Letters,* 132:129-139.

Parker, A.J., Cowley, W.M. and Thomson, B.P., 1990. The Torrens Hinge Zone and Spencer Shelf with particular reference to early Adelaidean volcanism. In: Jago, J.B. and Moore, P.S. (Eds), The evolution of a late Precambrian-early Palaeozoic rift complex: the Adelaide Geosyncline. *Geological Society of Australia. Special Publication,* 16:129-148.

Parker, A.J., Daly, S.J., Flint, D.J., Flint, R.B., Preiss, W.V. and Teale, G.S., 1993. Palaeoproterozoic. In: Drexel, J.F., Preiss, W.V. and Parker, A.J. (Eds). The Geology of South Australia. Volume 1, The Precambrian. South Australia. *Geological Survey. Bulletin,* 54(1):50-105.

Paul, E., Flöttmann, T and Sandiford, M., 1999 (in press). Structural geometry and controls on basement-involved deformation in the northern Flinders Ranges, Adelaide Fold Belt, South Australia. *Australian Journal of Earth Sciences*.

Plummer, P.S., 1978. Stratigraphy of the lower Wilpena Group (late Precambrian), Flinders Ranges, South Australia. *Transactions of the Royal Society of South Australia,* 102:25-38.

Powell, C.McA., 1998. Assembly and breakup of Rodinia leading to formation of Gondwanaland In: Bird, R.T., (Ed.). The assembly and breakup of Rodinia. Workshop proceedings Perth, 7-8 September. The University of Western Australia. *Geological Society of Australia. Abstracts,* 50:49-53.

Powell, C. McA., Preiss, W.V., Gatehouse, C.G., Krapez, B. and Li, Z.X., 1994. South Australian record of a Rodinian epicontinental basin and its mid-Neoproterozoic breakup (~700 Ma) to form the Palaeo-pacific Ocean. *Tectonophysics,* 237:113-140.

Preiss, W.V., 1973. Palaeoecological interpretations of South Australian Precambrian stromatolites. *Journal of the Geological Society of Australia,* 19:501-532.

Preiss, W.V., 1974. River Broughton Beds - a Willouran sequence in the Spalding Inlier. South Australia. Geological Survey. *Quarterly Geological Notes,* 49:2-8.

Preiss, W.V.. 1982. Supergroup classification in the Adelaide Geosyncline. *Transactions of the Royal Society of South Australia,* 106:81-83.

Preiss, W.V., 1985. Stratigraphy and tectonics of the Worumba Anticline and associated intrusive breccias. *South Australia. Geological Survey. Bulletin,* 52.

Preiss, W.V. (compiler), 1987. The Adelaide Geosyncline - late Proterozoic stratigraphy, sedimentation, palaeontology and tectonics. South Australia. *Geological Survey. Bulletin,* 53.

Preiss, W.V., 1990. A stratigraphic and tectonic overview of the Adelaide Geosyncline, South Australia. In: Jago, J.B. and Moore, P.S. (Eds), The evolution of a late Precambrian-early Palaeozoic rift complex: the Adelaide Geosyncline. *Geological Society of Australia. Special Publication*, 16:1-33.

Preiss, W.V., 1995. Delamerian Orogeny. In: Drexel, J.F. and Preiss, W.V. (Eds). The Geology of South Australia. Volume 2, The Phanerozoic. *South Australia. Geological Survey. Bulletin,* 54(2):45-57.

Preiss, W.V., 1996. New members of the Waukaringa Siltstone - early Marinoan sequence boundaries in the Nackara Arc and their implications for gold mineralisation. *MESA Journal,* 1:40-45.

Preiss, W.V., 1997. Revision of lithostratigraphy and structure, and evidence of volcanism in lower Burra Group type sections, Carey Gully-Basket Range area, Mount lofty Ranges. *MESA Journal*, 7:37-46.

Preiss, W.V., Belperio, A.P., Cowley, W.M. and Rankin, L.R., 1993. Neoproterozoic. In: Drexel, J.F., Preiss, W.V. and Parker, A.J. (Eds). The Geology of South Australia. Volume 1, The Precambrian. *South Australia. Geological Survey. Bulletin,* 54(1):170-203.

Preiss, W.V. and Cowley, W.M. (in prep.). Genetic stratigraphy and revised lithostratigraphic classification of the Burra Group in the Adelaide Geosyncline. *MESA Journal.*

Preiss, W.V., Dyson, I.A., Reid, P.W. and Cowley, W.M., 1998. Revision of lithostratigraphic classification of the Umberatana Group. *MESA Journal*, 9:36-42.

Preiss, W.V. and Faulkner, P., 1984. Geology, geophysics and stratigraphic drilling at Depot Creek, southern Flinders Ranges. South Australia. Geological Survey. *Quarterly Geological Notes*, 89:10-19.

Preiss, W.V. and Kinsman, J.E., 1978. Stratigraphy and palaeoenvironmental interpretation of the Brighton Limestone south of Adelaide and its equivalents in the Orroroo region. South Australia. Geological Survey. *Report of Investigations*, 49.

Preiss, W.V., Walter, M.R., Coats, R.P. and Wells, A.T., 1978. Lithological correlations of Adelaidean glaciogenic rocks in parts of the Amadeus, Ngalia and Georgina Basins. *Bureau of Mineral Resources, Geology and Geophysics, Australia. Journal*, 3:43-53.

Reid, P.W. and Preiss, W.V., 1999. PARACHILNA map sheet (Second edition). South Australia. Geological Survey. Geological Atlas 1:250 000 Series, sheet SH54-13.

Robertson, R.S., Preiss, W.V., Crooks, A.F., Hill, P.W. and Sheard, M.J., 1998. Review of the Proterozoic geology and mineral potential of the Curnamona Province in South Australia. *AGSO Journal of Australian Geology and Geophysics*, 17:169-182.

Rankin, L.R., Clough, B.J. and Farrand, M.G., 1992. *Mines and Energy Review, South Australia*, 158:64-69.

Ross, G.M., Parrish, R.R., Villeneuve, M.E., and S. Bowring, S.A., 1991. Geophysics and geochronology of the crystalline basement of the Alberta Basin, western Canada. *Canadian Journal of Earth Science*, 28:512-522.

Rutland, R.W.R., Parker, A.J., Pitt, G.M., Preiss, W.V. and Murrell, B., 1981. The Precambrian of South Australia. *In: Hunter, D.R. (Ed.), Precambrian of the Southern Hemisphere. Developments in Precambrian Geology Series, 2. Elsevier, Amsterdam*, pp.309-360.

Sandiford, M., Hand, M. and McLaren, S. (1998). High geothermal gradient metamorphism during thermal subsidence. *Earth and Planetary Science Letters*, 163:149-165.

Sandiford, M., Paul, E. and Flötmann, T., (in press). Sedimentary thickness variations and deformation intensity during basin inversion in the Flinders Ranges, South Australia. *Journal of Structural Geology*.

Schmidt, P.W., Williams, G.E. and Embleton, B.J.J., 1991. Low palaeolatitude of late Proterozoic glaciation: early timing of remanence in haematite of the Elatina Formation, South Australia. *Earth and Planetary Science Letters*, 105:355-367.

Schmidt, P.W. and Williams, G.E., 1995. The Neoproterozoic climatic paradox: equatorial palaeolatitude for Marinoan glaciation near sea level in South Australia. *Earth and Planetary Science Letters*, 134:107-124.

Sohl, L.E. and Christie-Blick, N., 1995. Equatorial glaciation in the Neoproterozoic: new evidence from the Marinoan glacial succession of Australia. *Geological Society of America, Abstracts with Programs*, 27(6):A204.

Southgate, P.N., 1991. A sedimentological model for the Loves Creek Member of the Bitter Springs Formation, northern Amadeus Basin. Australia. *Bureau of Mineral Resources, Geology and Geophysics, Bulletin*, 236:113-126.

Sprigg, R.C., 1952. Sedimentation in the Adelaide Geosyncline and the formation of the continental terrace. In: Glaessner, M.F. and Sprigg, R.C. (Eds), Sir Douglas Mawson Anniversary Volume. *University of Adelaide*, pp.153-159.

Steiger, R.H. and Jäger, E., 1977. Subcommission on geochronology: convention on the use of decay constants in geo- and cosmochronology. *Earth and Planetary Science Letters*, 36:359-362.

Stuart-Smith, P.G. and Black, L.P., 1994. The Mount Stavely Volcanic Complex, western Victoria: mainland equivalents of the Tasmanian Cambrian Mount Read Volcanics. *Australian Geological Survey Organisation, Research Newsletter*, 40:275-292.

Thomson, B.P., 1969. Palaeozoic Era. In: Parkin, L.W. (Ed.), Handbook of South Australian geology. *Geological Survey of South Australia,* pp.97-108.

Thomson, B.P., 1970. A review of the Precambrian and lower Palaeozoic tectonics of South Australia. Royal Society of South Australia. *Transactions,* 94:193-221.

Thomson, B.P., Coats, R.P., Mirams, R.C., Forbes, B.G., Dalgarno, C.R. and Johnson, J.E., 1964. Precambrian rock groups in the Adelaide Geosyncline: a new subdivision. South Australia. Geological Survey. *Quarterly Geological Notes*, 9:1-19.

Turner, N.J., Black, L.P. and Kamperman, M., 1994. Pre-Middle Cambrian stratigraphy orogenesis and geochronology in western Tasmania. In: Cooke, D.R. and Kitto, P.A. (Eds). Contentious issues in Tasmanian geology. *Geological Society of Australia Abstracts,* 39; 51-66.

Turner, N.J., Black, L.P. and Kamperman, M., 1998. Dating of Neoproterozoic and Cambrian orogenies in Tasmania. *Australian Journal of Earth Sciences,* 45:789-806.

Uppill, R.K., 1979. Stratigraphy and depositional environments of the Mundallio Subgroup (new name) in the late Precambrian Burra Group of the Mount Lofty and Flinders Ranges. Royal Society of South Australia. Transactions, 103:25-43.

Uppill, R.K., 1990. Sedimentology of a dolomite-magnesite-sandstone sequence in the late Precambrian Mundallio Subgroup, South Australia. . In: Jago, J.B. and Moore, P.S. (Eds), The evolution of a late Precambrian-early Palaeozoic rift complex: the Adelaide Geosyncline. *Geological Society of Australia. Special Publication,* 16:105-128.

Veevers, J.J., Walter, M.R. and Scheibner, E., 1997. Neoproterozoic tectonics of Australia-Antarctica and Laurentia and the 560 Ma birth of the Pacific Ocean reflect the 400 m.y. Pangean Supercycle. *The Journal of Geology,* 105:225-242.

von der Borch, C.C., 1980. Evolution of late Proterozoic to early Palaeozoic Adelaide Foldbelt, Australia: comparisons with post-Permian rifts and passive margins. *Tectonophysics,* 70:115-134.

von der Borch, C.C. and Lock, D., 1979. Geological significance of Coorong dolomites. *Sedimentology,* 26:813-824.

von der Borch, C.C., Smit, R. and Grady, A.E., 1982. Late Proterozoic submarine canyons of the Adelaide Geosyncline, South Australia. *American Association of Petroleum Geologists, Bulletin* 66:332-347.

Wallace, M.W., Gostin, V.A. and Keays, R.R., 1989. Discovery of the Acraman impact ejecta blanket in the Officer Basin and its stratigraphic significance. *Australian Journal of Earth Sciences,* 36:585-587.

Wallace, M.W., Gostin, V.A., and Keays, R.R., 1996. Sedimentology of the Neoproterozoic impact-ejecta horizon, South Australia. AGSO *Journal of Australian Geology and Geophysics,* 16:443-451.

Walter, M.R., 1980. Adelaidean and Early Cambrian stratigraphy of the southwestern Georgina Basin: correlation chart and explanatory notes. *Report Bureau of Mineral Resources, Geology and Geophysics, Australia,* 214.

Walter, M.R., Veevers, J.J., Calver, C.R. and Grey, K., 1995. *Neoproterozoic stratigraphy of the Centralian Superbasin, Australia. Precambrian Research*, 73:173-196.

Walter, M.R and Veevers, J.J., 1997. Australian Neoproterozoic palaeogeography, tectonics, and supercontinental connections. *AGSO Journal of Australian Geology and Geophysics*, 17:73-92.

Walter, M.R., Veevers, J.J., Calver, C.R., Gorjan, P. and Hill, A.C., (this volume). Dating the 840-544 Ma Neoproterozoic interval by isotopes of strontium, carbon, and sulfur in seawater, and some interpretative models. *Precambrian Research.*

Webb, A.W., 1980. Geochronology of stratigraphically significant rocks from South Australia—Amdel progress report 30. *South Australia. Department of Mines and Energy, open file Envelope 1689 (unpublished).*

Webb, A.W. and Coats, R.P., 1980. A reassessment of the age of the Beda Volcanics on the Stuart Shelf, South Australia. *South Australia. Department of Mines and Energy. Report Book,* 80/6 (unpublished).

Williams, G.E., 1975a. Late Precambrian glacial climate and the Earth's obliquity. *Geological Magazine,* 112:441-465.

Williams, G.E., 1986a. Precambrian permafrost horizons as indicators of palaeoclimate. *Precambrian Research,* 32:233-242.

Williams, G.E., 1986b. The Acraman impact structure: source of ejecta in late Precambrian shales, *South Australia. Science, N.Y.*, 233:200-203.

Willis, I.L., Brown, R.E., Stroud, W.J. and Stevens, B.P.J., 1983. The Early Proterozoic Willyama Supergroup: stratigraphic subdivision and interpretation of high to low-grade metamorphic rocks in the Broken Hill Block, NSW. *Geological Society of Australia. Journal,* 30:195-224.

Wingate, M.T.D., Campbell, I.H., Compston, W. and Gibson, G.M., 1998. Ion-probe U-Pb ages for Neoproterozoic basaltic magmatism in south-central Australia and implications for the breakup of Rodinia. *Precambrian Research,* 87:135-159.

Young, G.M., 1992. Late Proterozoic stratigraphy and the Canada-Australia connection. *Geology,* 20:215-218.

Young, G.M and Gostin, V.A., 1989. An exceptionally thick upper Proterozoic (Sturtian) glacial succession in the Mount Painter area, South Australia. *Geological Society of America Bulletin,* 101:834-845.

Zhao, J.-X. and McCulloch, M.T., 1993. Sm-Nd mineral isochron ages of Late Proterozoic dyke swarms in Australia: evidence for two distinct events of mafic magmatism and crustal extension. *Chemical Geology*, 109:341-354.

Zhao, J.-X., McCulloch, M.T. and Korsch, R.J., 1994. Characterization of a plume-related ~800 Ma magmatic event and its implications for basin formation in central-southern Australia. *Earth and Planetary Science Letters,* 121:349-367.

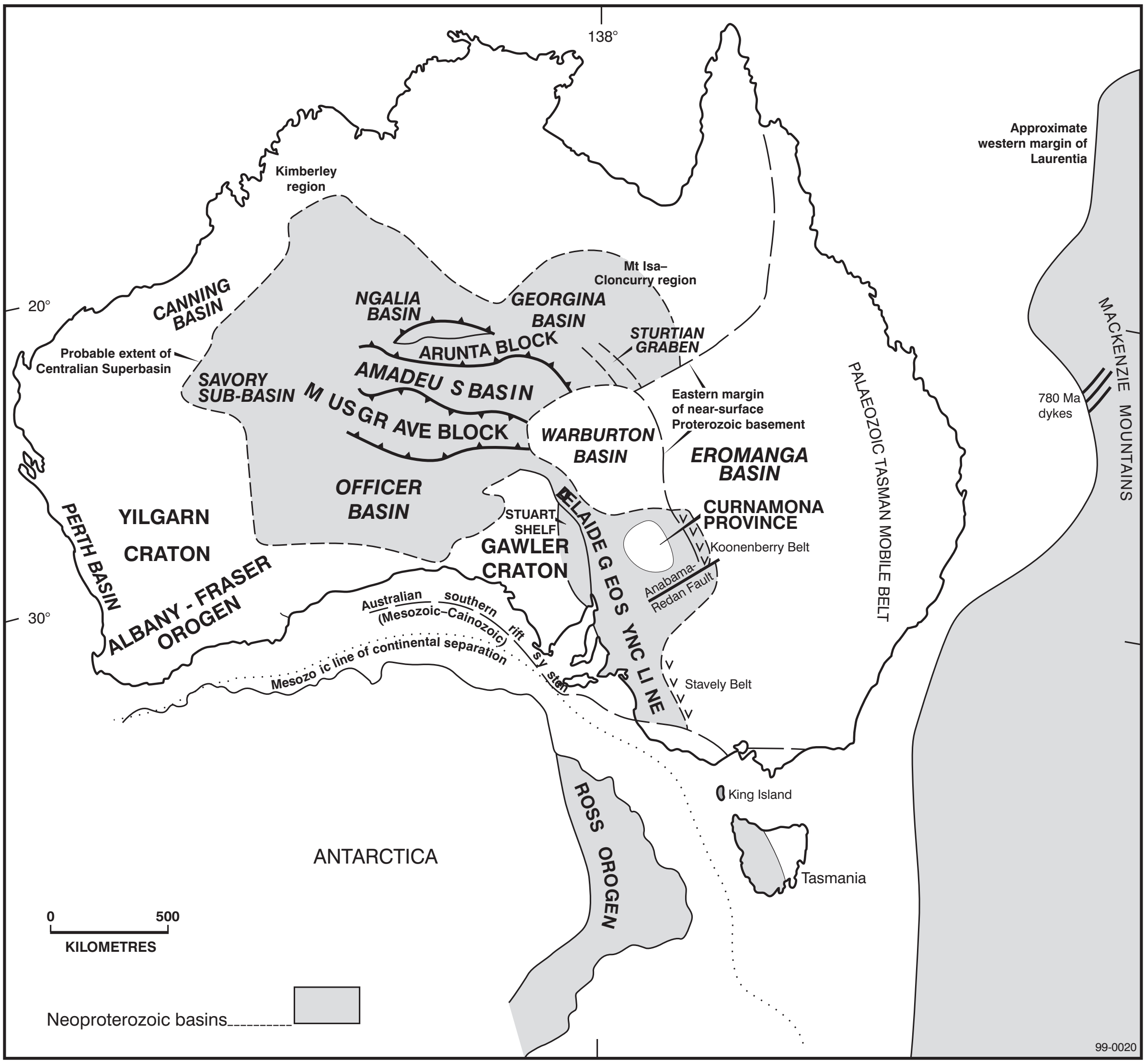

Fig 1 The Adelaide Geosyncline and other Neoproterozoic to Mesozoic basins in relation to western Laurentia and Antarctica.

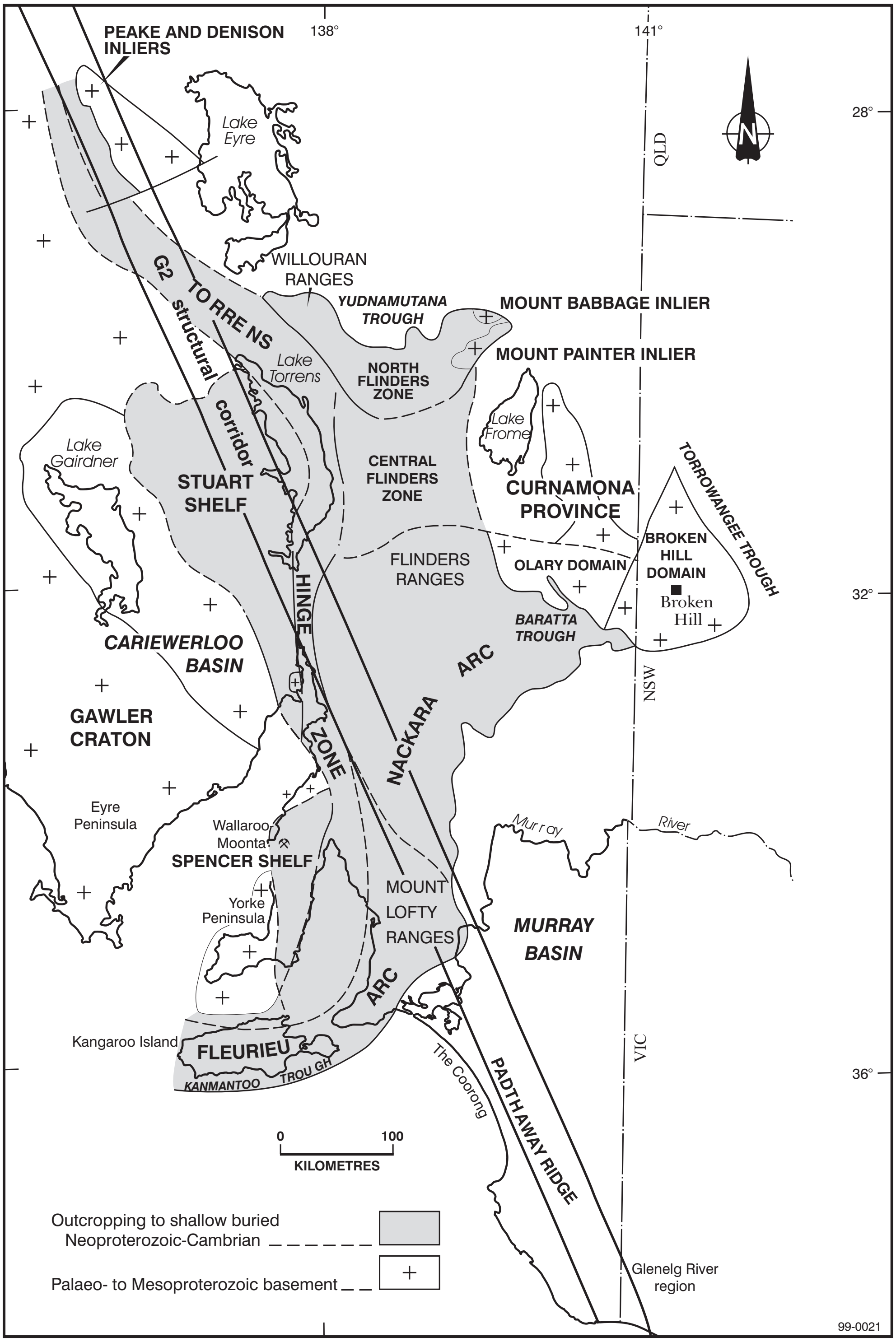

Fig 2 *Tectonic subdivision of the Adelaide Geosyncline and Delamerian Orogen.*

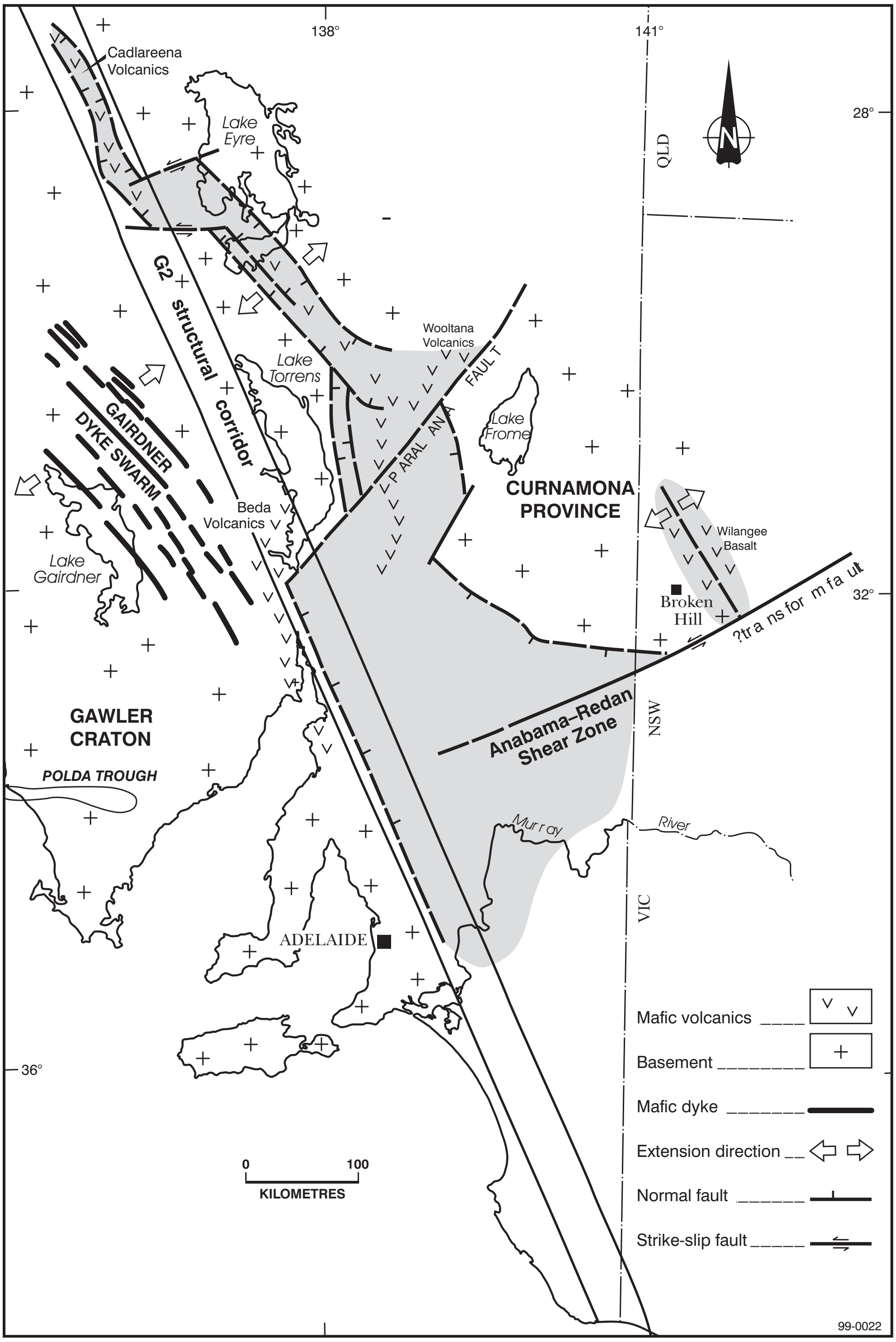

Fig 3 Early Willouran extensional tectonics, Adelaide Geosyncline.

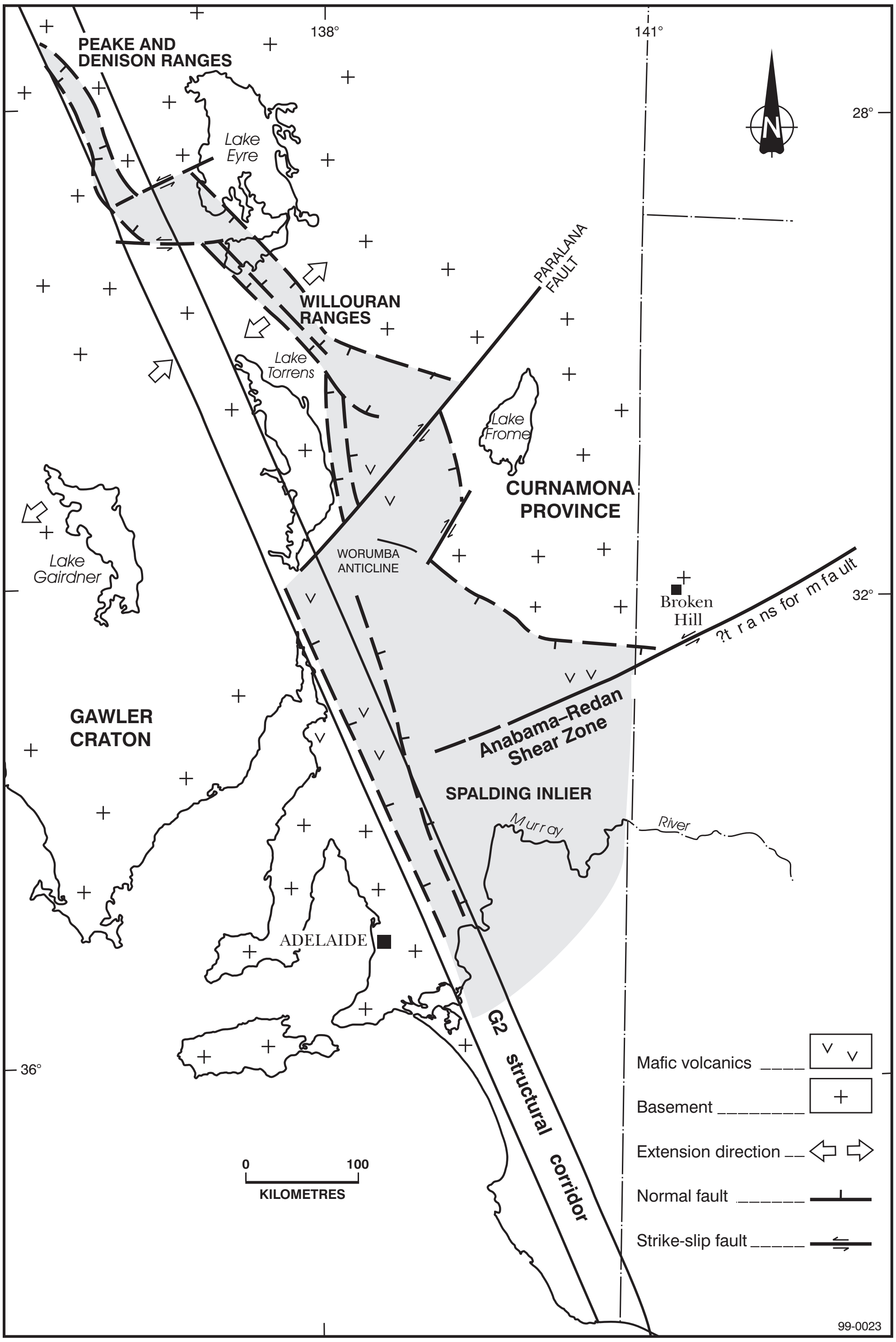

Fig 4 *Late Willouran extensional tectonics, Adelaide Geosyncline.*

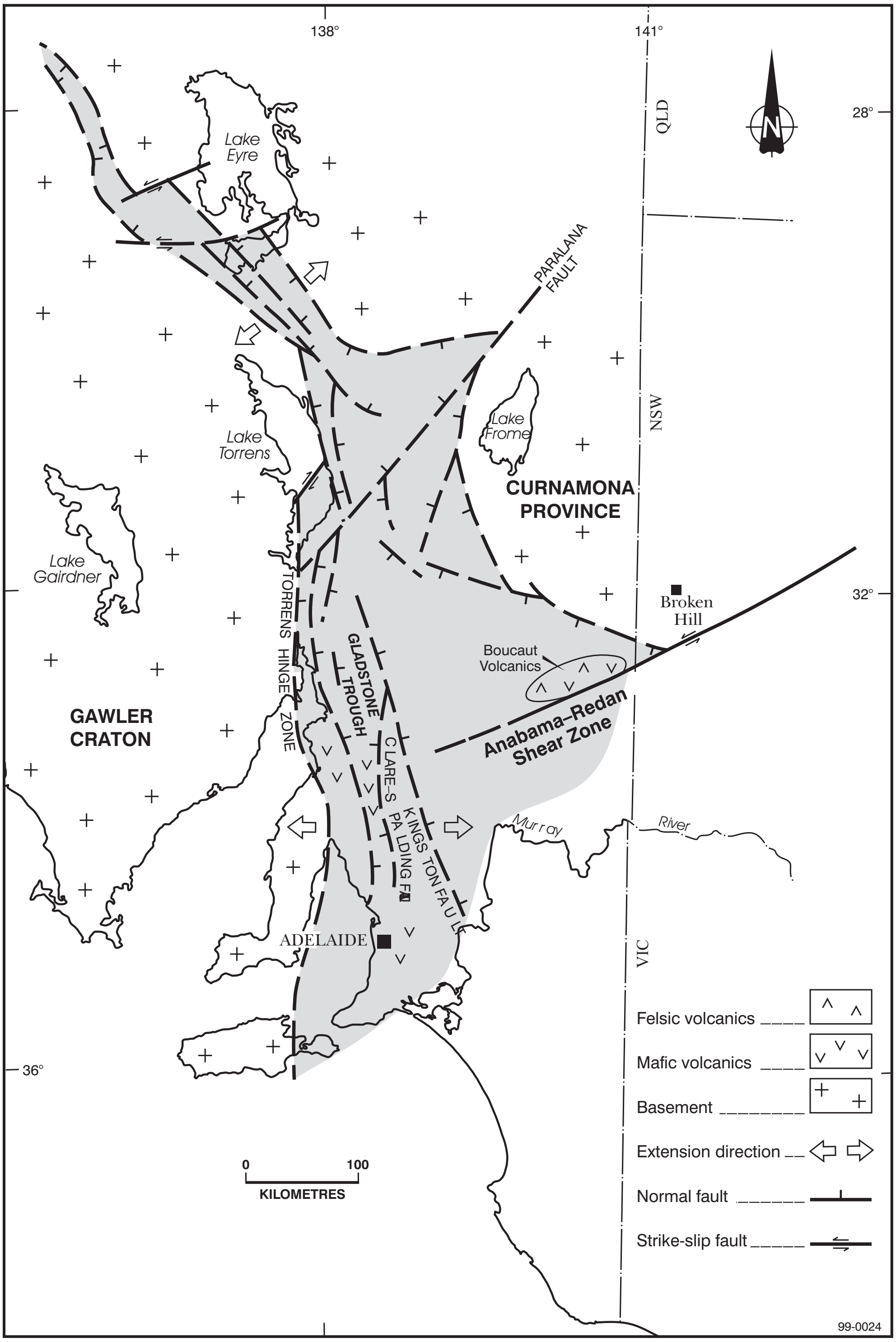

Fig 5 *Torrensian extensional tectonics, Adelaide Geosyncline.*

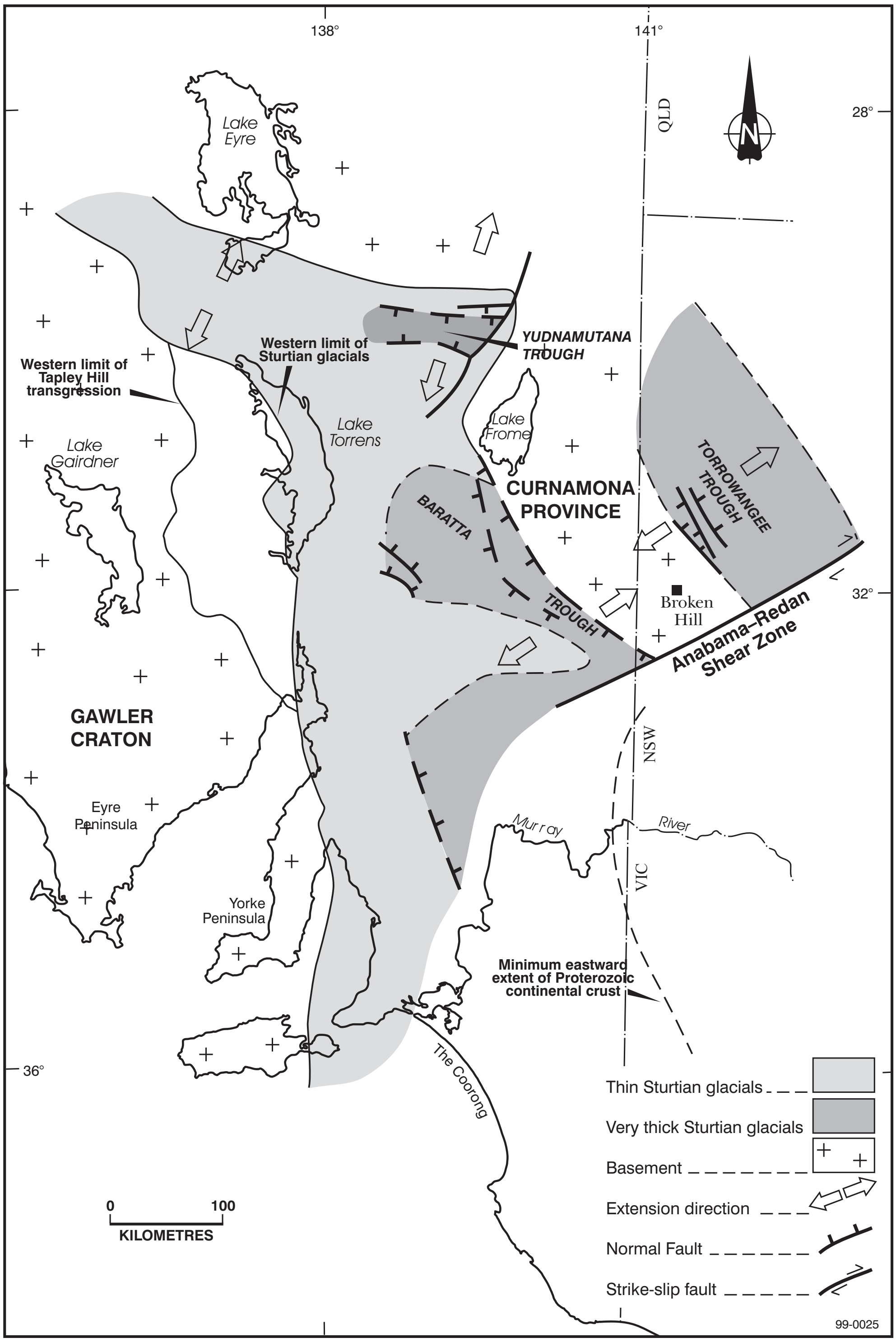

Fig 6 *Sturtian extensional tectonics, Adelaide Geosyncline.*

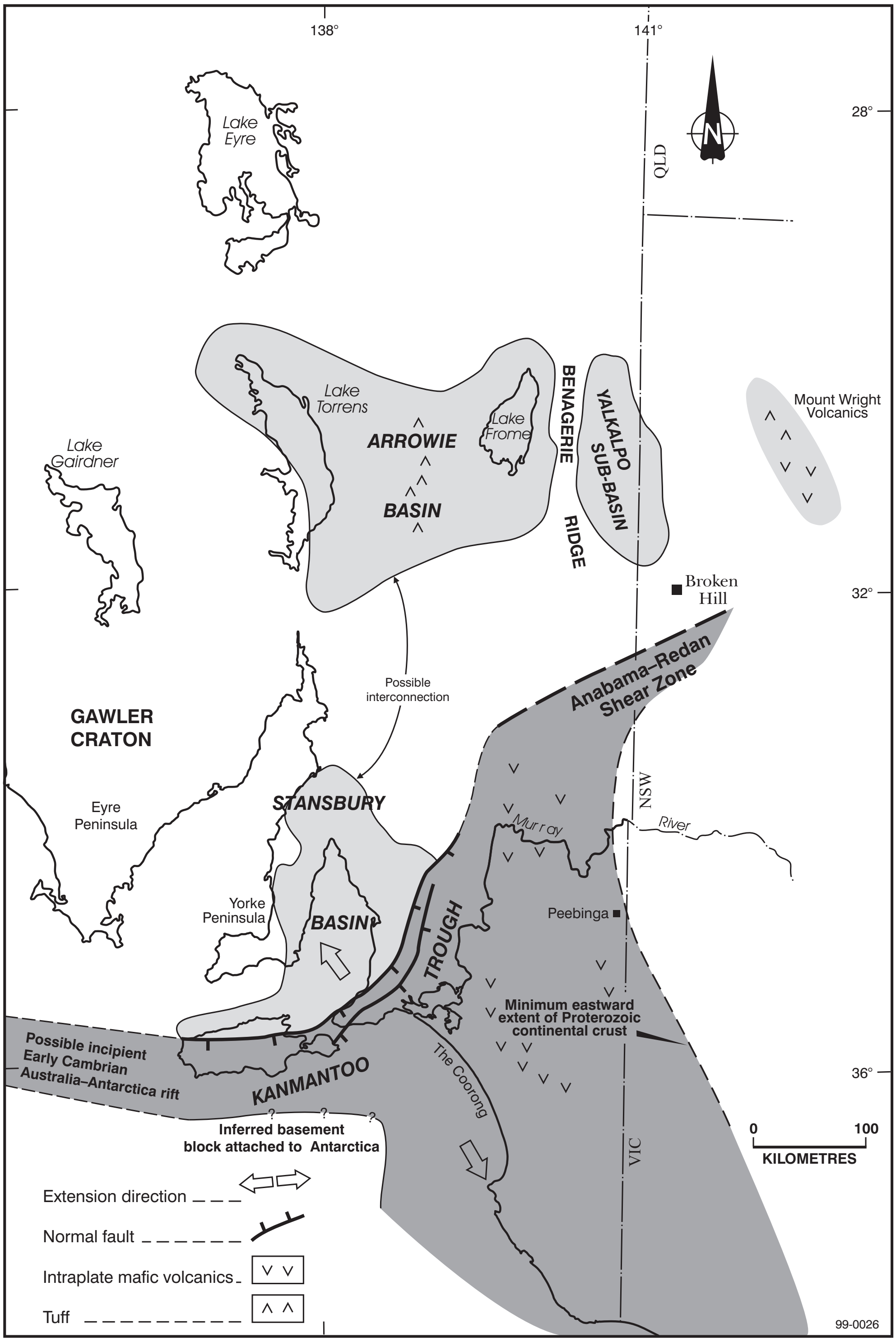

Fig 7 *Early Cambrian extensional tectonics, Adelaide Geosyncline.*
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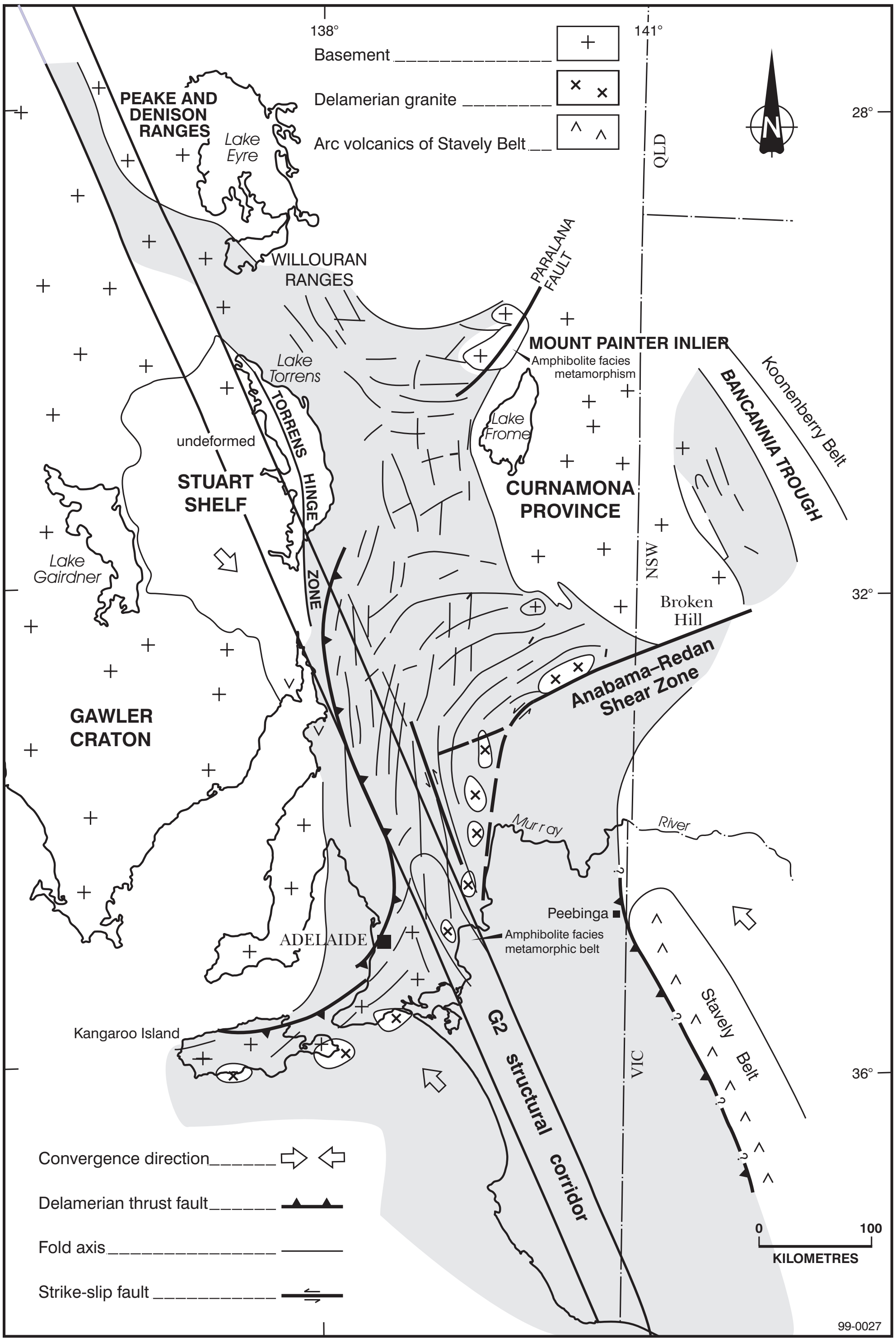


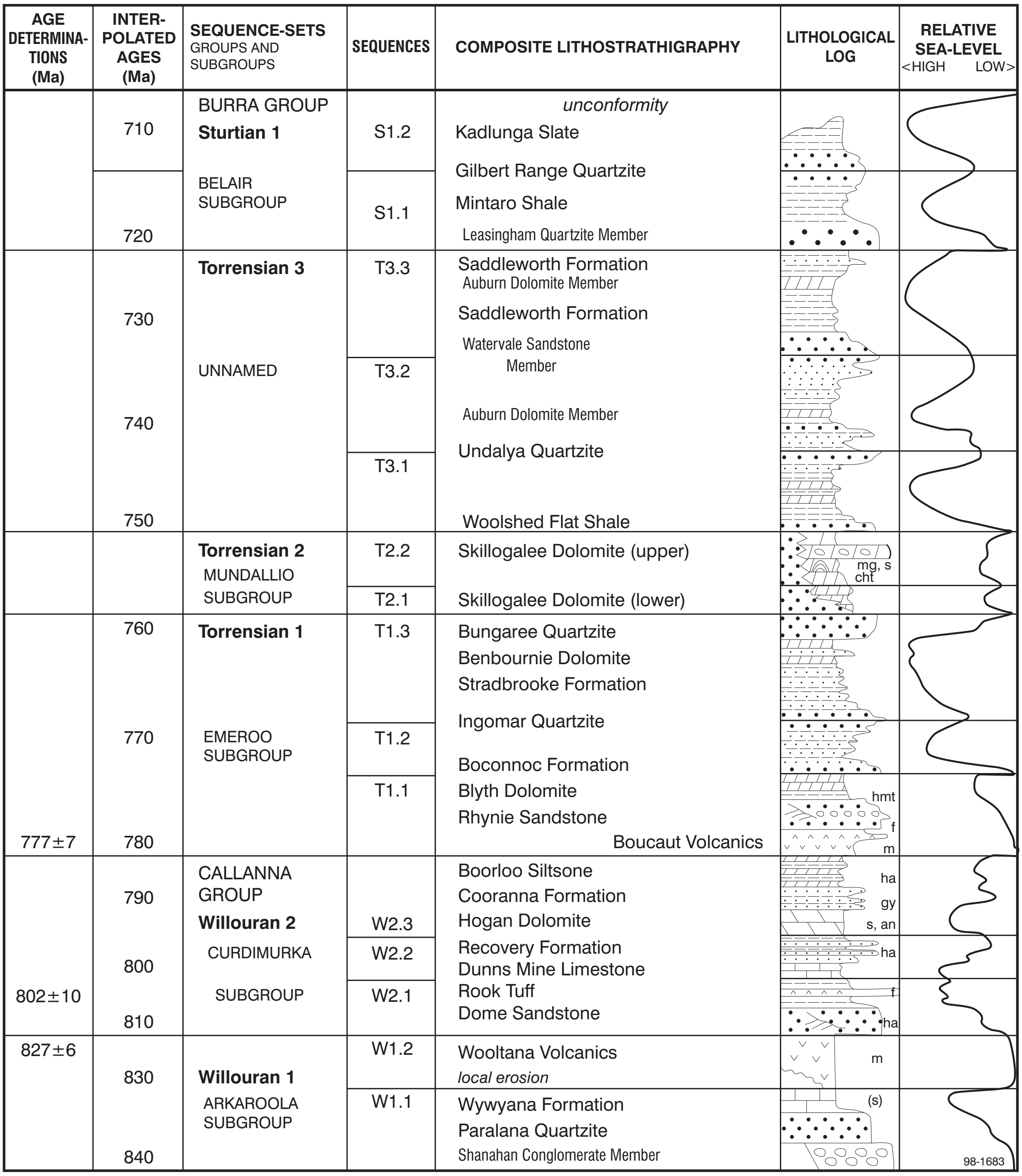
Fig 8 *Delamerian deformation and plate convergence.*

***Table 1** Selection of most concordant detrital zircon U-Pb ages from some Adelaide Geosyncline sedimentary units, and their interpreted possible provenances. Weighted mean ages are for data from Ireland et al. (1997) only, i.e. Niggly Gap Beds, Mitcham Quartzite, Marino Arkose Member, Bonney Sandstone, Mount Terrible Formation, Heatherdale Shale, Carrickalinga Head Formation and Balquhidder Formation; data for Rhynie Sandstone and Elatina Formation from Gehrels et al. (1995) are 207/206 ages for most concordant zircons.*

Stratigraphic unit and age	**Grain No.**	**Weighted Mean Age (Ma)**	**Error ± (Ma)**	**Suggested possible provenance**
Niggly Gap Beds (late Willouran)	23	1580	14	?Hiltaba Suite granites
	41	1584	9	?Hiltaba Suite granites
	22	1594	20	Gawler Range Volcanics
	1	1600	10	?Olarian metamorphic
	30	1601	10	?Olarian metamorphic
	35	1602	17	?Olarian metamorphic
	49	1606	9	?Olarian metamorphic
	5	1613	14	?Olarian metamorphic
	44	1617	12	?Olarian metamorphic
	34	1721	15	?Willyama Supergroup volcanics
	45	1753	11	?Wallaroo Group volcanics
	42	1843	16	Donington Granitoid Suite
	3	1858	15	Donington Granitoid Suite
Rhynie Sandstone (early Torrensian)	–	(1512)	5	Spilsby Suite granitoids
	–	(1549)	29	? Spilsby Suite granitoids
	–	(1552)	9	? Spilsby Suite granitoids
	–	(1576)	4	Hiltaba Suite granitoids
	–	(1579)	3	Hiltaba Suite granitoids
	–	(1580)	3	Hiltaba Suite granitoids
	–	(1589)	2	Gawler Range Volcanics
	–	(1591)	3	Gawler Range Volcanics
	–	(1597)	3	Gawler Range Volcanics
	–	(1646)	19	
	–	(1719)	11	?Moody Suite granitoids
		(1856)	8	Donington Granitoid Suite
Mitcham Quartzite (earliest Sturtian)	39	975	15	
	31	1051	20	
	27	1053	18	
	34	1100	18	
	2	1278	20	?Albany-Fraser Orogen
	14	1555	44	?Spilsby Suite granites
	32	1596	26	Gawler Range Volcanics
	4	1641	22	?Albany-Fraser Orogen
	38	1645	32	?Albany-Fraser Orogen
Marino Arkose Member (early Marinoan)	32	657	17	?Penecontemporaneous volcanism
	9	1004	17	
	20	1076	20	
	7	1096	24	
	2	1156	22	
	47	1158	19	
	26	1169	26	
	25	1194	23	?Albany-Fraser Orogen
	40	1225	20	
	14	1516	23	Spilsby Suite granites
	15	1539	29	?Spilsby Suite granites
	30	1564	29	?Hiltaba Suite granites
	49	1576	33	?Hiltaba Suite granites
	12	1599	39	?Gawler Range Volcanics
	39	1712	20	Moody Suite granites
	28	1823	18	?Donington Granitoid Suite
	3	1905	33	
	5	2009	30	?Miltalie Gneiss

Elatina Formation (early Marinoan)	–	(1182)	5	
	–	(1617)	4	?St Peter Suite granites
	–	(1640)	5	?St Peter Suite granites
	–	(1662)	4	
	–	(1680)	20	
	–	(1684)	2	
	–	(1749)	11	?Wallaroo Group volcanics
	–	(1820)	5	?Donington Granitoid Suite
	–	(1946)	5	
	–	(2398)	4	Sleaford Complex
	–	(2505)	4	Sleaford Complex
	–	(3085)	2	
Bonney Sandstone (late Marinoan)	29	556	24	?Penecontemporaneous volcanism
	38	1021	22	
	31	1033	16	
	16	1081	29	
	10	1098	20	
	48	1153	34	
	6	1191	42	?Albany-Fraser Orogen
	3	1195	21	?Albany-Fraser Orogen
	42	1196	18	?Albany-Fraser Orogen
	15	1251	30	
	22	1508	40	Spilsby Suite granites
	35	1623	43	?St Peter Suite granites
	19	1682	33	?Willyama Supergroup volcanics
	5	1701	31	?Willyama Supergroup volcanics
	14	1767	33	?Wallaroo Group volcanics
	24	1775	34	?Myola Volcanics
	23	1784	41	?Myola Volcanics
	17	1877	65	Donington Granitoid Suite
	33	2003	31	Miltalie Gneiss
	47	2008	18	Miltalie Gneiss
	11	2279	28	?Sleaford Complex
Mount Terrible Formation (Early Cambrian)	13	1789	15	Myola Volcanics
	7	1798	26	Myola Volcanics
	34	1811	22	?Donington Granitoid Suite
	6	1816	13	?Donington Granitoid Suite
	35	1820	14	?Donington Granitoid Suite
	33	1829	18	?Donington Granitoid Suite
	5	1830	21	?Donington Granitoid Suite
	27	1831	17	?Donington Granitoid Suite
	12	1832	26	?Donington Granitoid Suite
	26	2138	17	?Sleaford Complex
Heatherdale Shale (Early Cambrian)	50	645	8	
	37	1028	16	
	42	1056	19	
	49	1082	11	
	40	1102	17	
	36	1109	29	
	43	1122	36	
	8	1135	24	
	17	1149	25	
	34	1860	24	?Donington Granitoid Suite

Carrickalinga Head Formation (Early Cambrian)	56	511	8	?Penecontemporaneous volcanism
	69	513	16	?Penecontemporaneous volcanism
	21	515	7	?Penecontemporaneous volcanism
	85	526	6	Heatherdale Shale tuff
	37	527	11	Heatherdale Shale tuff
	68	532	10	?Heatherdale Shale tuff
	32	570	10	
	48	581	15	
	24	603	11	
	4	612	8	
	15	717	13	
	59	729	10	
	58	850	12	
	52	867	11	
	10	934	30	
	20	934	15	
	23	992	15	
	45	2189	38	?Sleaford Complex
	49	2484	23	Dutton Suite granites
Balquhidder Formation (late Early Cambrian)	83	523	10	Heatherdale Shale tuff
	39	537	10	
	45	539	11	
	78	556	12	
	33	576	13	
	28	580	13	
	3	592	14	
	57	595	16	
	19	613	13	
	98	633	12	
	13	956	19	
	30	985	17	
	79	998	19	
	66	1035	40	
	97	1045	28	
	85	1057	20	
	18	1071	15	
	25	1159	19	
	50	1206	25	?Albany Fraser Orogen
	4	1227	26	?Albany Fraser Orogen
	24	2302	19	?Sleaford Complex



AGE DETERMINA-TIONS (Ma)	INTER-POLATED AGES (Ma)	SEQUENCE-SETS GROUPS AND SUBGROUPS	SEQUENCES	COMPOSITE LITHOSTRATHIGRAPHY	LITHOLOGICAL LOG	RELATIVE SEA-LEVEL <HIGH LOW>
		BURRA GROUP		*unconformity*		
	710	**Sturtian 1**	S1.2	Kadlunga Slate		
				Gilbert Range Quartzite		
		BELAIR SUBGROUP	S1.1	Mintaro Shale		
	720			Leasingham Quartzite Member		
		Torrensian 3	T3.3	Saddleworth Formation		
				Auburn Dolomite Member		
	730			Saddleworth Formation		
				Watervale Sandstone Member		
		UNNAMED	T3.2			
	740			Auburn Dolomite Member		
				Undalya Quartzite		
			T3.1			
	750			Woolshed Flat Shale		
		Torrensian 2	T2.2	Skillogalee Dolomite (upper)	mg, s cht	
		MUNDALLIO SUBGROUP	T2.1	Skillogalee Dolomite (lower)		
	760	**Torrensian 1**	T1.3	Bungaree Quartzite		
				Benbournie Dolomite		
				Stradbrooke Formation		
				Ingomar Quartzite		
	770	EMEROO SUBGROUP	T1.2			
				Boconnoc Formation		
			T1.1	Blyth Dolomite	hmt	
				Rhynie Sandstone	f	
777±7	780			Boucaut Volcanics	m	
		CALLANNA GROUP		Boorloo Siltsone	ha	
	790			Cooranna Formation	gy	
		Willouran 2	W2.3	Hogan Dolomite	s, an	
		CURDIMURKA	W2.2	Recovery Formation	ha	
	800			Dunns Mine Limestone		
802±10		SUBGROUP	W2.1	Rook Tuff	f	
	810			Dome Sandstone	ha	
827±6			W1.2	Wooltana Volcanics	m	
	830	**Willouran 1**		*local erosion*		
		ARKAROOLA SUBGROUP	W1.1	Wywyana Formation	(s)	
				Paralana Quartzite		
	840			Shanahan Conglomerate Member		98-1683

Table 2 *Composite stratigraphy of parts of the Warrina Supergroup.*

AGE DETERMINA-TIONS (Ma)	INTER-POLATED AGES (Ma)	SEQUENCE-SETS GROUPS AND SUBGROUPS	SEQUENCES	COMPOSITE LITHOSTRATHIGRAPHY
	550	WILPENA GROUP	M4.6	*unconformity* Rawnsley Quartzite Ediacara Member
≤556±24	560	POUND	M4.5	Chace Quartzite Member
		SUBGROUP	M4.4	Bonney Sandstone Patsy Hill Member
	570	**Marinoan 4**	M4.3	Wonoka Formation (canyon fill)
	580		M4.2	Wonoka Formation (lower) Wearing Dolomite Member
588±35	600		M4.1	Bunyeroo Formation Wilcolo Sandstone Member
	610	**Marinoan 3** SANDISON SUBGROUP	M3.2	ABC Range Quartzite Brachina Bayley Range Sandstone Mbr
	620		M3.1	Formation Moorillah Siltstone Mbr Moolooloo Siltstone Member Nuccaleena Fm, Seacliff Sandstone
	630	UMBERATANA GROUP	M2.3	Ketchowla Siltstone Grampus Quartzite Elatina
	640	**Marinoan 2** YERELINA SUBGROUP	M2.2	Pepuarta Tillite Formation Gumbowie Arkose
			M2.1	Fortress Hill Formation
≤657±17	650 660	**Marinoan 1** UPALINNA SUBGROUP	M1.2	Yaltipena Formation Trezona Formation Wilmington Formation Enorama Shale Waukaringa Siltstone Marino Arkose Member Wundowie Limestone Member
	670		M1.1	Angepena Formation Tarcowie Etina Formation Siltstone Sutherland Formation Cox Sandstone Member
	680	**Sturtian 3** NEPOUIE SUBGROUP	S3.2	Brighton Limestone
	690		S3.1	Tapley Hill Formation Mount Caernarvon Greywacke Member Tindelpina Shale Member
		Sturtian 2 YUDNAMUTANA	S2.2	Wilyerpa Formation Warcowie Dolomite Member
	700	SUBGROUP	S2.1	Benda Siltstone Appila Tillite Pualco Tillite

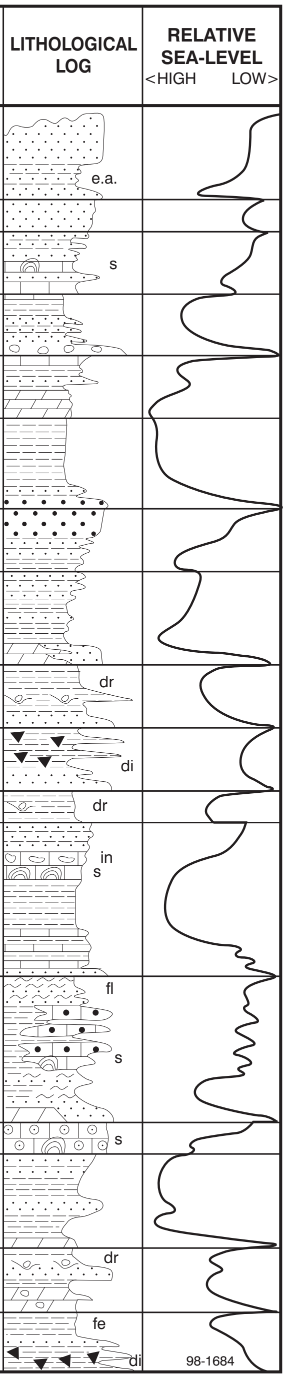
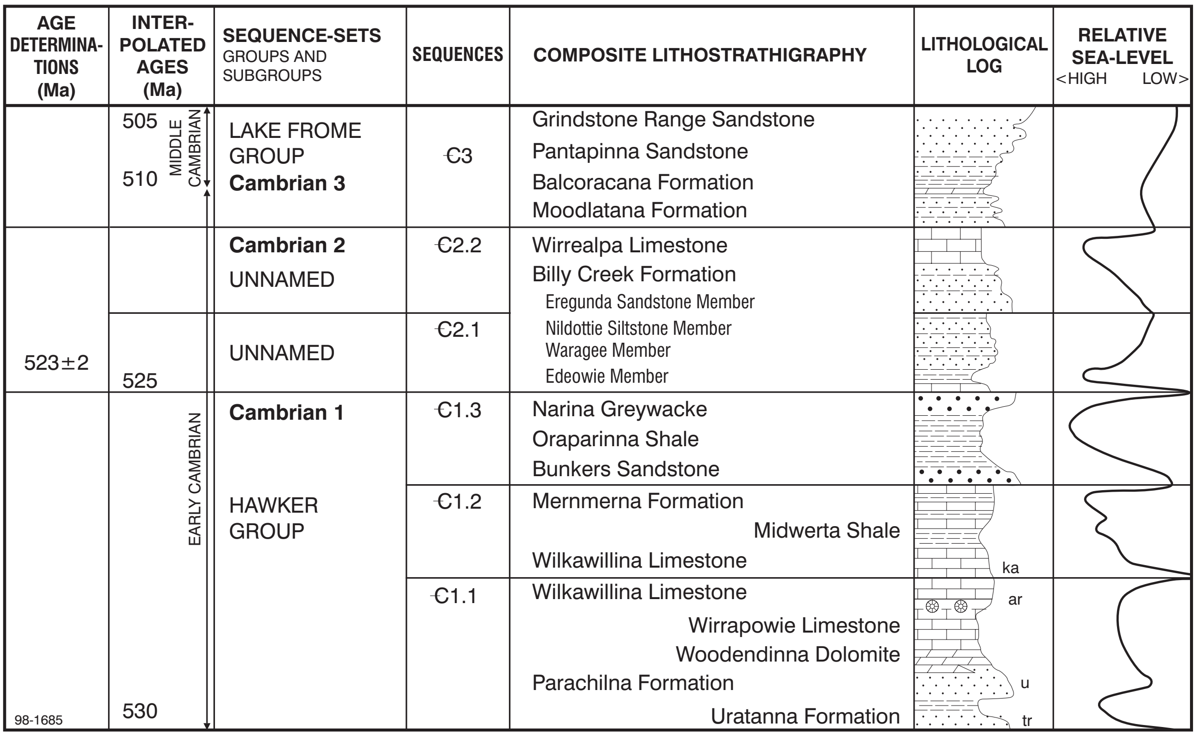


Table 3 *Composite stratigraphy of parts of the Heysen Supergroup.*

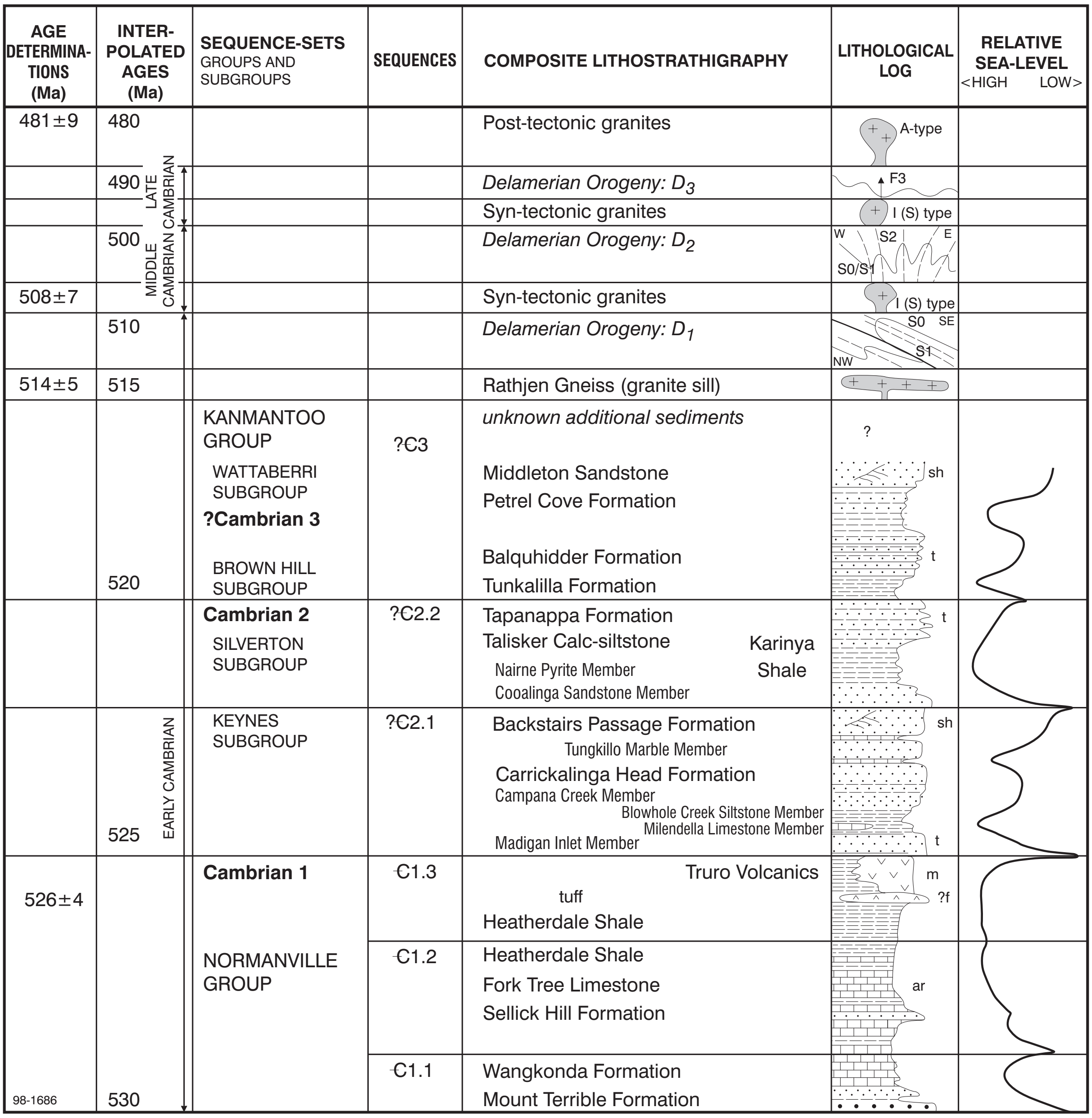
***Table 4**. Comparison of models for the origin of Wonoka Formation canyons.*

Canyon model	**Advantages**	**Disadvantages**
Submarine incision by down-slope currents	Explains incision within canyons while apparently continuous deposition is occurring in intervening areas.	1. Unlikely to produce channels of such great depth. 2. Does not explain upward-deepening but initially shallow-water fill.
Submarine incision by mass wasting	Explains deep incision within canyons while apparently continuous deposition is occurring in intervening areas.	1. Unlikely to produce channels of such great depth. 2. Does not explain upward-deepening but initially shallow-water fill. 3. Difficult to explain meandering form of some channels.
Subaerial incision due to uplift	1. Explains meandering form of some channels. 2. Explains shallow-water facies of lower canyon fill.	1. There is no obvious regional erosional surface away from the canyons. 2. Does not explain upward-deepening facies of canyon fill. 3. The Central Flinders Zone, representing a shelf environment, does not show any regional stripping that would be expected from uplift.
Subaerial incision due to evaporative draw-down.	1. Explains meandering form of some channels. 2. Explains shallow-water facies of lower canyon fill. 3. Explains upward-deepening facies of canyon fill as sea water re-enters the basin.	1. There is no obvious regional erosional surface away from the canyons. 2. There is little evidence of evaporites in the Wonoka Form-ation to record the onset of hyper-salinity, although Calver (1995) reported local gypsum crystals. 3. No mechanism to explain the formation of a barred basin of oceanic depth has been proposed.



AGE DETERMINATIONS (Ma)	INTERPOLATED AGES (Ma)	SEQUENCE-SETS GROUPS AND SUBGROUPS	SEQUENCES	COMPOSITE LITHOSTRATHIGRAPHY	LITHOLOGICAL LOG	RELATIVE SEA-LEVEL <HIGH LOW>
	505 510 MIDDLE CAMBRIAN	LAKE FROME GROUP **Cambrian 3**	Ꞓ3	Grindstone Range Sandstone Pantapinna Sandstone Balcoracana Formation Moodlatana Formation		
		Cambrian 2 UNNAMED	Ꞓ2.2	Wirrealpa Limestone Billy Creek Formation Eregunda Sandstone Member		
523±2	525	UNNAMED	Ꞓ2.1	Nildottie Siltstone Member Waragee Member Edeowie Member		
	EARLY CAMBRIAN	**Cambrian 1**	Ꞓ1.3	Narina Greywacke Oraparinna Shale Bunkers Sandstone		
		HAWKER GROUP	Ꞓ1.2	Mernmerna Formation Midwerta Shale Wilkawillina Limestone	ka	
98-1685	530		Ꞓ1.1	Wilkawillina Limestone Wirrapowie Limestone Woodendinna Dolomite Parachilna Formation Uratanna Formation	ar u tr	

Table 5 *Stratigraphy of the Moralana Supergroup, Arrowie Basin, Flinders Ranges.*



AGE DETERMINA-TIONS (Ma)	INTER-POLATED AGES (Ma)	SEQUENCE-SETS GROUPS AND SUBGROUPS	SEQUENCES	COMPOSITE LITHOSTRATHIGRAPHY	LITHOLOGICAL LOG	RELATIVE SEA-LEVEL <HIGH LOW>
481±9	480			Post-tectonic granites	A-type	
	490 LATE CAMBRIAN			*Delamerian Orogeny: D$_3$*	F3	
				Syn-tectonic granites	I (S) type	
	500 MIDDLE CAMBRIAN			*Delamerian Orogeny: D$_2$*	W S2 E S0/S1	
508±7				Syn-tectonic granites	I (S) type	
	510			*Delamerian Orogeny: D$_1$*	S0 SE S1 NW	
514±5	515			Rathjen Gneiss (granite sill)		
	520	KANMANTOO GROUP WATTABERRI SUBGROUP **?Cambrian 3** BROWN HILL SUBGROUP	?Ꞓ3	*unknown additional sediments* Middleton Sandstone Petrel Cove Formation Balquhidder Formation Tunkalilla Formation	? sh t	
		Cambrian 2 SILVERTON SUBGROUP	?Ꞓ2.2	Tapanappa Formation Talisker Calc-siltstone Karinya Shale Nairne Pyrite Member Cooalinga Sandstone Member	t	
	525 EARLY CAMBRIAN	KEYNES SUBGROUP	?Ꞓ2.1	Backstairs Passage Formation Tungkillo Marble Member Carrickalinga Head Formation Campana Creek Member Blowhole Creek Siltstone Member Milendella Limestone Member Madigan Inlet Member	sh t	
526±4		**Cambrian 1** NORMANVILLE GROUP	Ꞓ1.3	Truro Volcanics tuff Heatherdale Shale	m ?f	
			Ꞓ1.2	Heatherdale Shale Fork Tree Limestone Sellick Hill Formation	ar	
98-1686	530		Ꞓ1.1	Wangkonda Formation Mount Terrible Formation		

Table 6 *Stratigraphy of the Moralana Supergroup, Stansbury Basin and Kanmantoo Trough, and Delamerian Orogeny, Mount Lofty Ranges.*