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Australian Neoproterozoic palaeogeography, tectonics, and supercontinental connections

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Increasingly precise stratigraphic resolution by biostratigraphy, isotope stratigraphy, and sequence analysis in the Neoproterozoic allows more convincing palaeogeographic reconstructions than hitherto possible, so that the original connections amongst structural basins can be demonstrated. The Neoproterozoic stratigraphy of Australia can now be analysed in terms of four supersequences, with finer subdivision possible in the Ediacarian or 'Terminal Proterozoic'. The palaeogeography of Australia during eight time intervals within the Neoproterozoic is assessed, with varying degrees of confidence.

Our interpretation follows previous models of the Adelaide Rift Complex as a Neoproterozoic intracratonic rift between the Gawler and Curnamona cratons. The rift is at a high angle to the associated east–west elongated epicratonic sag of the Centralian Superbasin. In the earliest Cambrian the Flinders zone of the Adelaide Rift Complex was transformed to a failed arm or aulacogen by continental breakup along its southern part. Sedimentation ceased before the Late Cambrian–Early Ordovician (500 Ma) Delamerian Orogeny. The Rift Complex underwent two phases of onlap (= extension) accompanied by the deposition of (Sturtian and Marinoan) glacials. A third phase of onlap represented by the Billy Springs Formation occurred during right-lateral shearing (Petermann Ranges orogeny) that caused thrusting and the emergence of the east–west oriented Musgrave Block in the middle of the Superbasin. The Superbasin was finally dismembered by the rise of the southern Arunta Block between the Amadeus and Ngalia structural basins during the mid-Carboniferous Alice Springs Orogeny.

According to the SWEAT hypothesis, Australia was joined in the Neoproterozoic with India, Antarctica, and Laurentia, so that the Tasman Line faced the Canadian-Wyoming cordilleran line. The configuration of the north–south trending Adelaide Rift Complex and the east–west trending Centralian Superbasin was mirrored by the basins in Laurentia to form a T, which split at the end of the Neoproterozoic by growth of a precursor of the Pacific Ocean.

Introduction

Currently a global effort is extending to the latest Proterozoic the insights that detailed stratigraphy has provided in the Phanerozoic, and at the same time focusing on the tectonic, climatic and biological changes that mark the transition from the Proterozoic to the Phanerozoic (Knoll & Walter 1992).

Stratigraphic resolution within the Neoproterozoic is generally poor, though great strides have been taken in the 'Terminal Proterozoic' (Ediacarian). Conventional lithostratigraphic analyses have in the past been supplemented by stromatolite biostratigraphy and to some extent magnetostratigraphy. In recent years new finds of metazoan trace and body fossils have offered promise of stratigraphic utility (Jenkins 1995, Narbonne & Aitken 1995). Sequence stratigraphy is sharpening intrabasinal analysis (Christie-Blick et al. 1995). Where zircon-bearing tuffs have been found, substantial improvements in resolution have resulted from precise dating (e.g. Compston et al. 1987, Grotzinger et al. 1995). Big advances of recent years have resulted from the application of isotope chemostratigraphy (e.g. Knoll et al. 1986, Kaufman & Knoll 1995, Knoll et al. 1995) and acritarch biostratigraphy (e.g. Vidal & Knoll 1983, Zang & Walter 1992). In combination, all these approaches now allow a degree of precision in the analysis of Neoproterozoic history previously beyond our reach.

The Australian continent is a large segment of the Earth's crust and on it Neoproterozoic rocks are particularly abundant, making this a good place to elucidate the history of the eon. There is a long history of such studies, with notable early work including Chewings (1914) and Mawson (1925) on stromatolites, Mawson on tillites (1949) and Sprigg (1947) and Glaessner (1984) on the Ediacara Fauna of early metazoans (amongst many other studies). Our approach has been to focus on isotope chemostratigraphy and acritarch biostratigraphy, within a framework of sequence stratigraphy, lithostratigraphy and tectonic analysis; projects by K. Grey (acritarchs) and C.R. Calver (isotopes and sedimentology) on the Ediacarian interval have recently been completed, and others by S.W. Grant (acritarchs and isotopes on the interglacial succession), K. Cotter (palaeobiology of the early Neoproterozoic), A. Hill (isotope geochemistry of the early Neoproterozoic), and P. Gorjan (sulphur isotope geochemistry) are continuing. Field work in the Savory and Amadeus Basins and the Adelaide Rift Complex and the study of cores from the Georgina, Amadeus and Officer Basins, the Stuart Shelf and the Adelaide Rift Complex, with a compilation of existing data, have lead to the recognition and describing of the Centralian Superbasin (Fig. 1) (Walter & Gorter 1994, Walter et al. 1995). It has proven possible to analyse the Neoproterozoic stratigraphy of the Superbasin in terms of four supersequences (Fig. 2), and to produce isopach maps for these (Walter et al. 1995). The stratigraphic interpretations in those papers form the basis for what follows here, and we have added new information from the Paterson Orogen and from the Kimberley region and other areas of northern Australia. We have not included Tasmania because it was probably isolated from the rest of the continent at that time.

In this paper we combine our work with that of Preiss (1987, 1993), Zang (1995), Christie-Blick et al. (1995) and many others (e.g. in Jenkins et al. 1993) to make a preliminary attempt to portray the palaeogeography of the Australian continent during the Neoproterozoic. We have selected eight time intervals to portray on palaeogeographic maps. Some represent 'moments' in geological history, others are poorly resolved. Specifically, stratigraphic resolution within the early Neoproterozoic Supersequence 1 (Fig. 2) is extremely poor, that in the overlying Supersequence 2 is moderately good, and that in the Ediacarian-aged Supersequences 3 and 4 is, in a Proterozoic context, very good. The stratigraphic framework is taken from Preiss (1987, 1993), Walter & Gorter (1994) and Walter et al. (1994, 1995), and the reader is referred to those publications for detailed discussions. Preiss (1987, 1993) has attempted a much more detailed analysis of the palaeogeography of the Adelaide Rift Complex and we have adopted his interpretations. Some aspects of the hydrocarbon prospectivity that follow from this analysis are discussed in Walter & Gorter (1994) and Bradshaw et al. (1994).

Our palaeogeographic maps follow in Figure 3, after an outline of our correlation scheme and its radiometric calibration. A synthesis of Neoproterozoic palaeogeography and tectonics of Australia-Antarctica and Laurentia is presented by Veevers et al. (1997).

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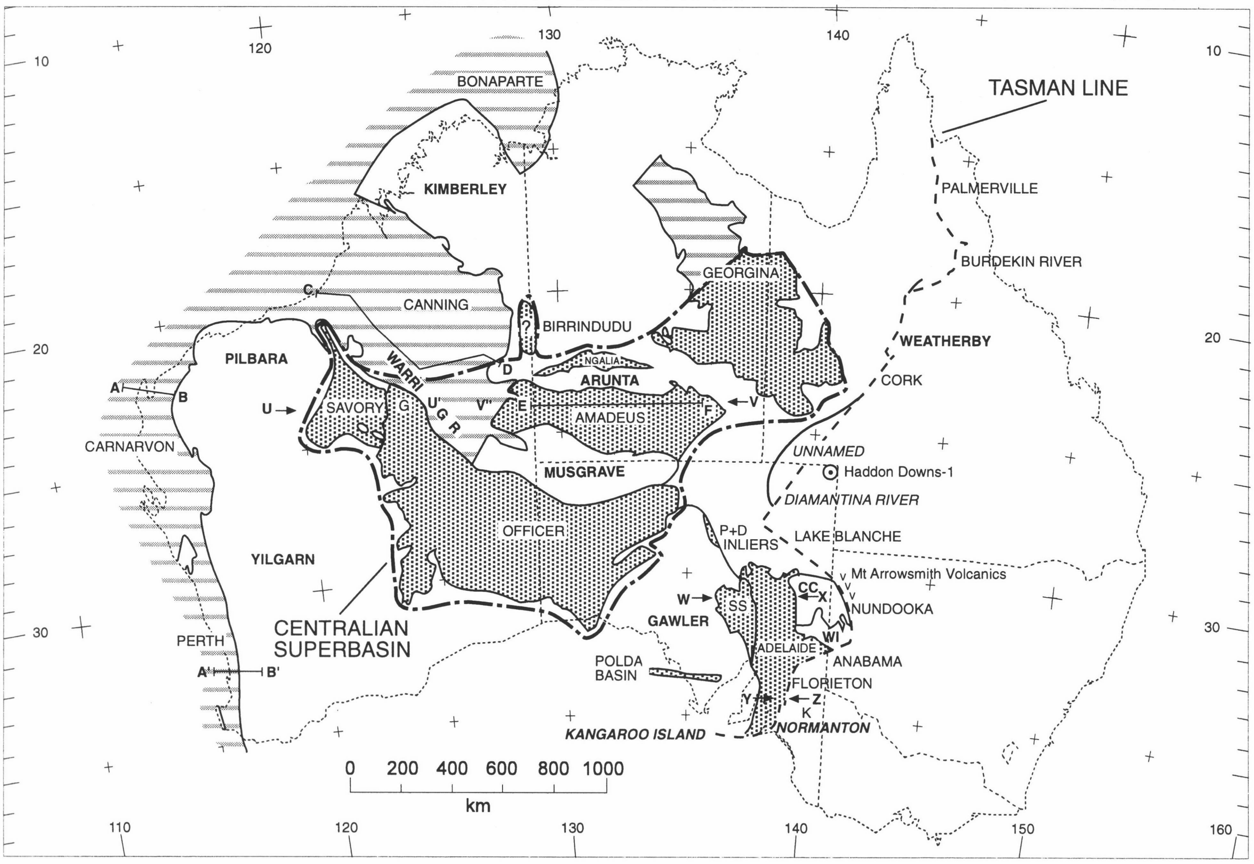


Figure 1. Centralian Superbasin (dot-and-dashed outline) and constituent structural basins (stippled) (amended from Walter et al. 1995) (see below). Stuart Shelf (SS), Adelaide Rift Complex and adjacent structures: CC = Curnamona Craton; WI = Willyama Inliers; K = Kanmantoo Fold Belt (Scheibner 1993). Proterozoic is delimited by the Tasman Line (Murray et al. 1989), with components labelled as faults (e.g. PALMERVILLE), an undifferentiated structure (WEATHERBY), a lineament (*DIAMANTINA RIVER*) and a shear zone (*NORMANTON*). Phanerozoic basins on west shown by ruled pattern. A–B, C–D, E–F locate the 500–45 Ma time-space diagrams (Fig. 4) and cross sections (Fig. 5); and U–V, W–X, Y–Z locate the 900–445 Ma time-space diagrams (Fig. 4) and cross sections (Fig. 5). The Centralian Superbasin is modified from Walter et al. (1995, fig. 1) in these ways: (a) the Savory Basin is expanded to the north and northwest by including the Tarcunyah Group, correlated with Supersequence 1 (Bagas et al. 1996); (b) to the east, the northern limit of the Superbasin passes about 22°S towards the Ngalia Basin, north of the Gibson (G) Sub-basin (with Supersequence 1 seen in diapirs) (Wells 1980) across the Warri Gravity Ridge (GR) into an area of >8 km deep basement beneath the thin Phanerozoic Canning Basin (Walter & Gorter 1994, fig. 2). Basement <2 km deep in this area could be a continuation of the Petermann Ranges uplift of the Musgrave Block; c) the southeastern outline of the Officer Basin is modified from Preiss et al. (1993, fig. 6.1). The Polda Basin and the Peake & Denison (P+D) Inliers are added from Preiss et al. (1993, fig. 6.2).

Correlation and calibration (Figs 2, 4). There is a 200 m.y. gap between latest Mesoproterozoic orogeny and the next recorded events, mafic volcanism (Volcanic Interval I–V/I) of the Amata mafic suite (AMS), Gairdner dyke swarm (GDS), and Willouran volcanic province in the Callanna Group, including the Rook Tuff (Preiss, 1987), all dated ca 800 Ma (Zhao & McCulloch 1993, Zhao et al. 1994). This was at least partly coeval with the deposition of Supersequence 1, including consanguineous lavas in the Bitter Springs Formation and sills in the Jillyili and Coondra Formations. Time-slices A and B are arbitrarily assigned dates younger than these 800 Ma events. Formations within Supersequence 1 are correlated by means of lithostratigraphy and stromatolite and preliminary acritarch biostratigraphy (Walter et al. 1995, Zang 1995; K. Grey, Geological Survey of Western Australia, pers. comm. 1996).

A gap of unknown duration is followed by Supersequence 2, conventionally assigned a date of ca 700 Ma, with Volcanic Interval II (V/II) represented by possible tuff and agglomerate in the Appila Tillite of the Adelaide Rift Complex (Preiss 1987, p. 364) and possibly the Wantapella Volcanics (option '**a**', Preiss 1987, 1993). The evidence for volcanism is weak, as the volcanics in the Appila Tillite could be re-worked from an older unit (Preiss, Geological Survey of South Australia, pers. comm. 1996) and the Wantapella Volcanics are more likely to be younger (see below); we have included them here to draw attention to the possibility of volcanism at this time. We agree with many authors that the Tapley Hill Formation and correlatives constitute a post-glacial stratigraphic marker. In the Adelaide Rift Complex, the Umberatana Group includes the Marinoan glacials, correlated with the Varanger glaciation, which is considered to be 590–610 Ma (Knoll & Walter 1992). Within this interval, the Ediacara fauna is about 560–570 Ma, apparently about the same age (564 ± 40 Ma by the Rb/Sr method, but with many uncertainties) as the Table Hill Volcanics (Compston 1974), and probably the Antrim Plateau Volcanics; with the probably somewhat older Wantapella Volcanics (the more likely option '**b**') this comprises Volcanic Interval III (V/III).

Supersequence 1

We attempt to portray the palaeogeography at two intervals during the deposition of Supersequence 1. Time-slice 1A (Fig. 3) is during the deposition of the basal sand sheet, and time-slice 1B, the overlying succession of carbonate, evaporite and fine-grained siliciclastics. Without an objective time correlation of these rocks and in the absence of sequence

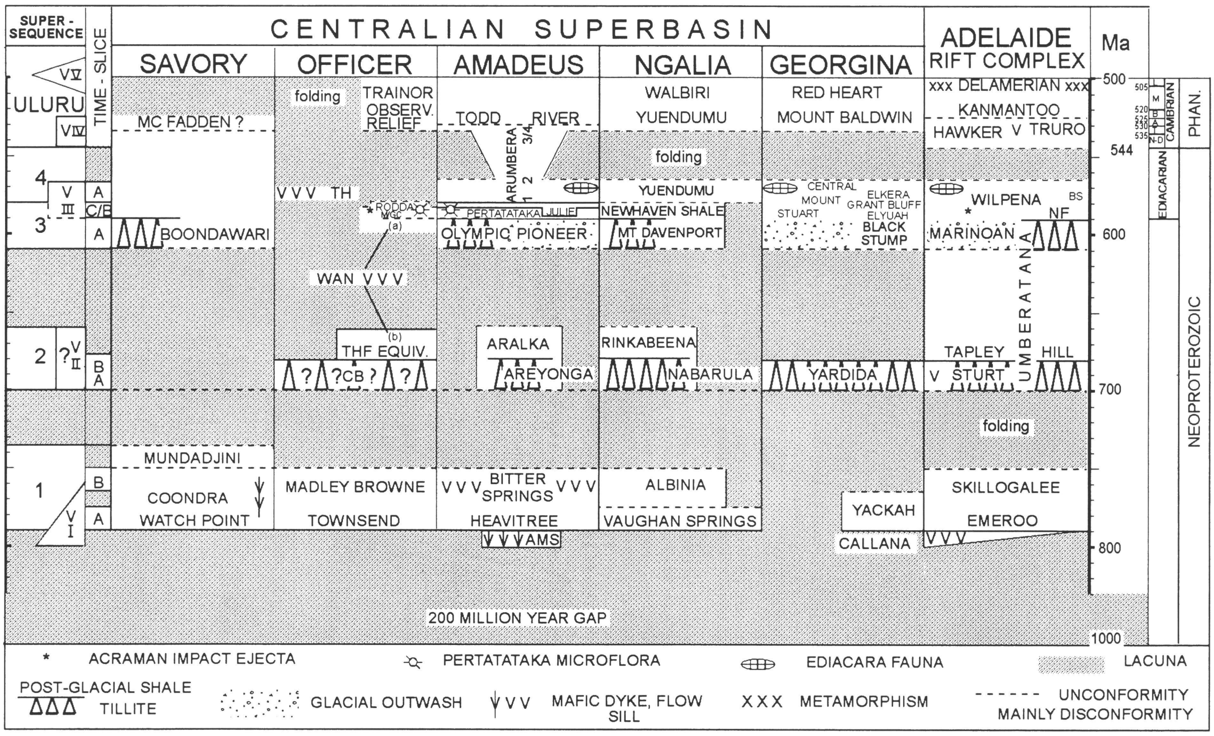


Figure 2. Correlation chart of the Centralian Superbasin and Adelaide Rift Complex, with ages calibrated in Ma. AMS = Amata mafic suite. BS = Billy Springs Formation. CB = Chambers Bluff Tillite. M/GC = Murnaroo Formation/Giles Creek Mudstone. NF = Nuccaleena Formation. TH = Table Hill volcanics. THF equiv. = Tapley Hill Formation equivalent ? V = times of volcanism. WAN = Wantapella Volcanics. After Walter et al. (1995), which should be seen for detailed discussion.

analyses in most structural basins we rely on lithostratigraphy and stromatolite and preliminary acritarch biostratigraphy.

Time-slice 1A

No geological record of the interval after the 1.1 Ga Musgrave Ranges and other orogenies and slightly younger dyke swarms is known until the 800 Ma start of Volcanic Interval I (V/I in Fig. 2).

We have assumed that the basal sand sheet of the Centralian Superbasin is at least roughly the same age everywhere, and that it correlates with the lower part of the Emeroo Sub-group of the Adelaide Rift Complex (time intervals T-1 and T-2 of Preiss 1987). Preiss (1987) interpreted T-2 as a time of relative high sea level, consistent with our assumption of widespread marine sedimentation in the adjacent Centralian Superbasin. No correlatives of the underlying Callanna Group of the Adelaide Rift Complex are known with any confidence from elsewhere in Australia, although Preiss (1987) and Zang (1995) recognise a possible correlative in the eastern Officer Basin. Correlations of the Callanna Group and the overlying Burra Group in the Adelaide Rift Complex with units in the Centralian Superbasin are still uncertain and controversial. An alternative interpretation to that presented here is that the Callanna Group belongs to Supersequence 1 and the Burra Group is younger (Bagas et al. 1996).

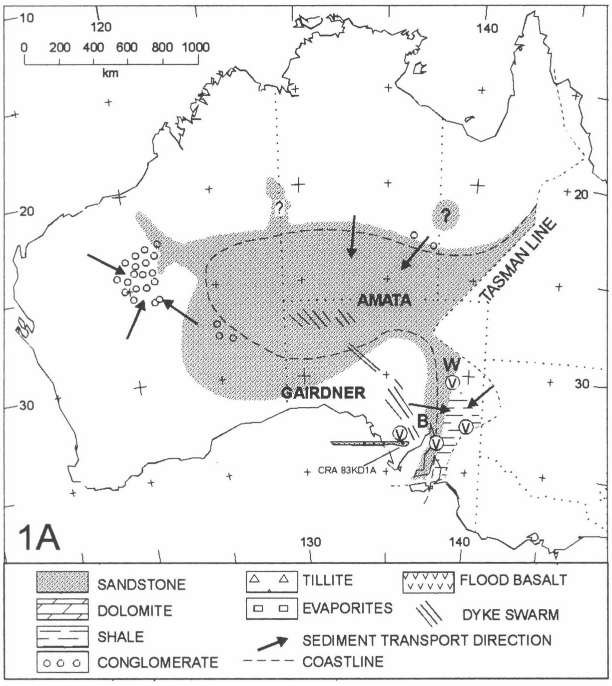
In the southern Georgina Basin, the sand sheet wedges out against several internal basement highs and against granitic basement (Walter 1980). At the locations of such wedge-outs carbonates are interbedded with the sands, and so the sands and carbonates of this supersequence are partly coeval.

As yet there are no detailed sedimentological studies of the sand sheet in the Centralian Superbasin, but most observers consider that it is a mixed fluvial and shallow marine succession. In the Heavitree Quartzite of the Amadeus Basin, palaeocurrent directions and isopachs suggest a provenance from the northeast to north-northeast. This is consistent with the observation that the correlative unit in the Georgina Basin, the basal Yackah beds, thins to the north and wedges out against granitic basement. Fluvial facies predominated, but parts were intertidal to very shallow marine (Clarke 1976). Lindsay (1991) recognised cycles which begin with a deeply channelled erosion surface, on which were deposited conglomerate and sandstone from braided streams, or laminated shale deposited in lakes. The basal beds are overlain by laminated and cross-bedded sandstone of mixed fluvial and dune origin, and pass upwards into well-stratified, cross-bedded, tidal sandstones. The cycle terminates with well-laminated or parallel-bedded, fluvial sandstone, indicating a sheet-flood event. The Vaughan Springs Quartzite of the Ngalia Basin has been interpreted as the deposits of alluvial fans overlain by fluvial, tidal flat and marine sandstone and conglomerate (Clarke 1976). The Townsend Quartzite of the Officer Basin was interpreted by Jackson & van de Graaff (1981) as shallow marine to deltaic.

In the Savory Basin the Jilyili Formation formed a westerly and northwesterly prograding delta, fed by the fluvial system of the Brassey Range Formation, and emptying into the shallow-marine depocentre of the Glass Spring Formation (Williams 1992). The possibly correlative Watch Point and Coondra Formations were sourced from the northwest and southwest, and include beds of conglomerate. The Watch Point Formation is interpreted as a rapidly prograding, coarse-grained delta (Williams 1992). The sandstone of the Googhenama Formation of the Tarcunyah Group occurs on the northern margin of the Savory Basin (Bagas et al. 1996).

The Redcliff Pound Group and possible equivalents, all in the Birrindudu Basin northwest of the Ngalia Basin, consist of poorly outcropping and poorly known siliciclastics and minor carbonates which have been suggested to correlate with Supersequence 1 (Blake et al. 1979, K. Grey in GSWA 1990). This correlation is based only on the common presence of siliciclastics and carbonates in the Redcliff Pound Group and Supersequence 1. The Redcliff Pound Group is overlain by a thin outlier of the Antrim Plateau volcanics.

In the Adelaide Rift Complex 'deposition probably took



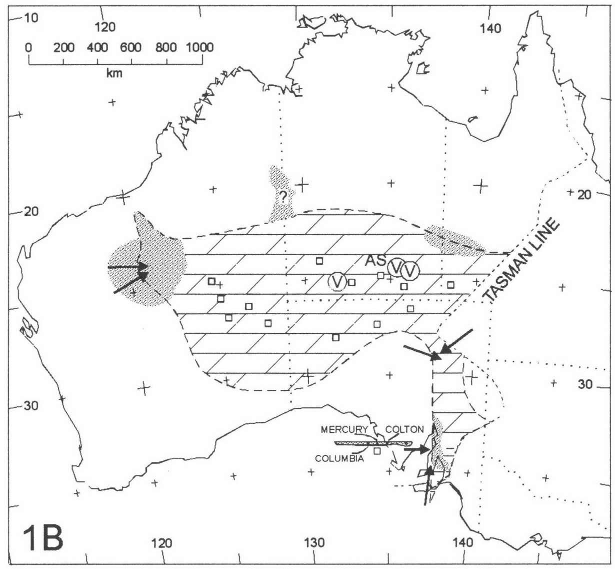


Figure 3. Palaeogeographic maps. Time-slice 1A, lower Supersequence 1. Also shown are the underlying Amata and Gairdner dykes and the underlying Beda (B) and Willouran (W) volcanics of the Callanna Group. In the Polda Trough, sediment of this age is associated with basalt in CRA 83KD1A drill-hole (Flint et al. 1988). Time-slice 1B, upper Supersequence 1. Drill-holes in the Polda Trough penetrate sediment of this age (Flint et al. 1988). AS = Alice Springs. Time-slice 2A, lower Supersequence 2. Time-slice 2B, upper Supersequence 2. Time-slice 3A, lower Supersequence 3. Time-slice 3B, middle Supersequence 3. Time-slice 3C, upper Supersequence 3. Time-slice 4A, lower Supersequence 4. Short arrows indicate presence of Table Hill Volcanics in seismic sections, solid black is outcrop, encircled Vs indicate inferred extent (Cook 1988).

place in proximal alluvial fans … grading basinward to braided streams and perhaps meandering streams' (Preiss 1987, p. 332). Subsequent marine transgression resulted in the deposition offshore of fine sand, silt and mud. Transgression from the southeast, inferred by Preiss (1987), cannot be observed because of lack of outcrop.

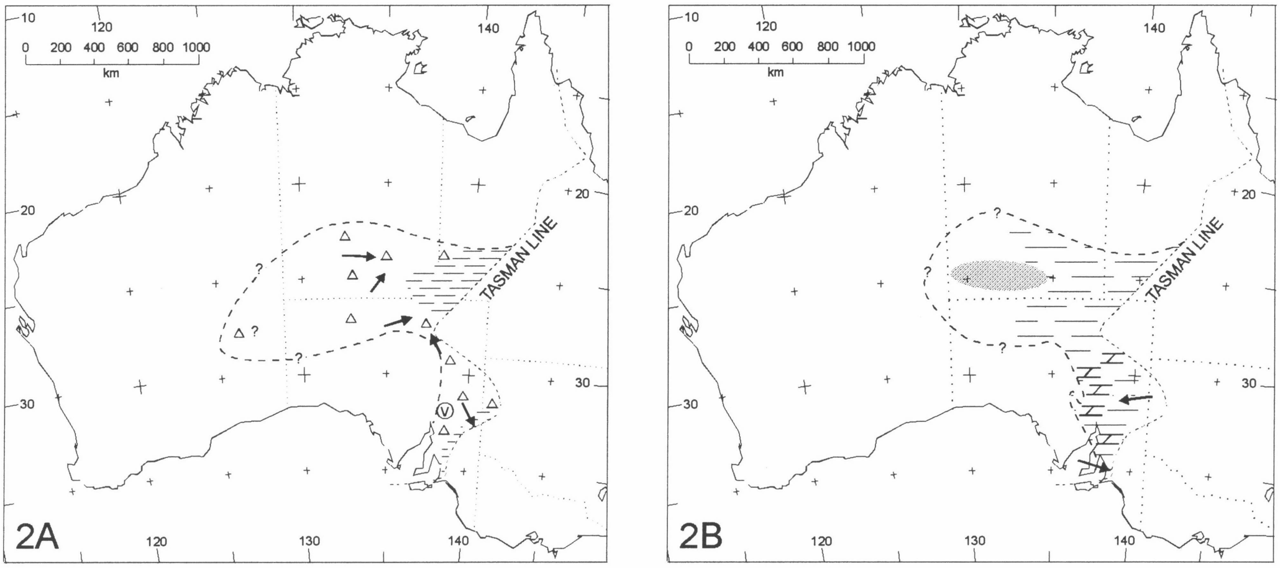
Time-slice 1B

The upper part of Supersequence 1 is characterised by interbedded stromatolitic carbonates and evaporites including halite and anhydrite (Fig. 3, 1B). The lithostratigraphic correlations within the Centralian Superbasin are convincing because of the presence of distinctive lithologies, continuity in outcrop or in seismic records, and the presence of a distinctive assemblage of columnar stromatolites (Walter et al. 1995). Correlation to the Adelaide Rift Complex, based on lithological similarities and the common presence of the stromatolite *Baicalia burra* (Walter et al. 1995), is contentious.

In the Amadeus Basin, the lower (Gillen) member of the Bitter Springs Formation contains thick units of halite and anhydrite as well as dolostone and fine siliciclastics. Stewart (1979) suggested that the evaporites formed in a marine barred basin, but Lindsay (1987a) favoured deposition in two major, poorly circulated anoxic sub-basins of the saline giant type, with carbonates and sulphates developed around basin margins, and halite and possibly potassium salts deposited in the sub-basin centres. A significant period of erosion occurred after deposition of the Gillen Member (Southgate 1989, 1991). The environment of the upper (Loves Creek) member began with deeper water, quiet marine conditions and then shallowed upwards to an emergent lacustrine setting (Southgate 1989, 1991). The central stromatolite-dominated unit represents an initial transgressive stage, with domical stromatolites alternately buried and exposed by the movement of ooid grainstones. Following the transgression, water conditions were deeper and quieter. There was then an abrupt reversal in stromatolite growth patterns and conditions became cyclic and upward shallowing, with evidence of emergence at the top of each cycle. The uppermost part of the Loves Creek Member is interpreted as an environment of shallow metahaline to hypersaline lakes in a flood plain (Southgate 1986, 1991). The stromatolite development indicates gradual shallowing culminating in emergence, indicated by desiccation cracks, indurated surfaces, karst deposits, and halite pseudomorphs and other evidence of brine concentration in ponded areas. Cyanobacterial communities inhabited the shallow metahaline to hypersaline lakes and were preserved by saline groundwaters and silica precipitation. Mafic lavas in the Loves Creek Member (Wells et al. 1967, Shaw & Wells 1983) are consanguineous with the Amata and Gairdner dyke swarms and volcanics in the Callanna Group (Zhao et al. 1994) and mark the end of Volcanic Interval I. A long period of exposure resulted in the weathering and erosion of the top of the carbonate units.

The Albinia Formation of the Ngalia Basin and the Yackah beds of the Georgina Basin are both siltstone and shale interbedded with stromatolitic cherty dolostone. Little is known about either because of very poor outcrop. Correlative units in the Officer Basin are known by many different names, including the Alinya, Browne, Madley, Kanpa, Hussar and Steptoe Formations (Walter et al. 1995, Zang 1995). These comprise stromatolitic dolostone, anhydrite, and halite, with interbedded sandstone, siltstone and shale. Seismic interpretation suggests that at least 4000 m are present in the Yowalga Sub-basin (Townson 1985). There are columnar stromatolites and chert microfossils closely comparable with those in the Bitter Springs Formation; the rock types are also very similar, and a similar set of palaeoenvironments can be envisaged, although there have been no detailed studies.

In the southeast Savory Basin the Skates Hills Formation consists of stromatolitic dolostone, sandstone, siltstone, shale, local thick conglomerate, and minor chert (Williams 1992). Evaporitic conditions are indicated by the presence of cauliflower chert and crystal voids after gypsum. Both the rock types and the contained stromatolites are closely comparable with those of the Bitter Springs Formation (Grey 1995). The Mundadjini Formation is considered by Williams (1992) to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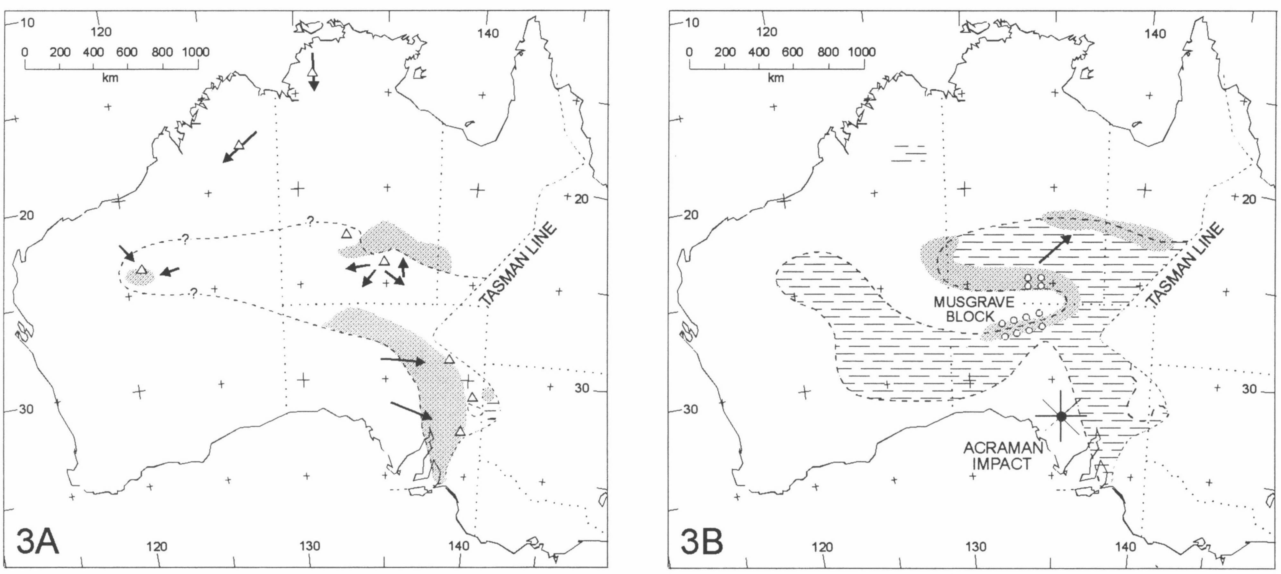
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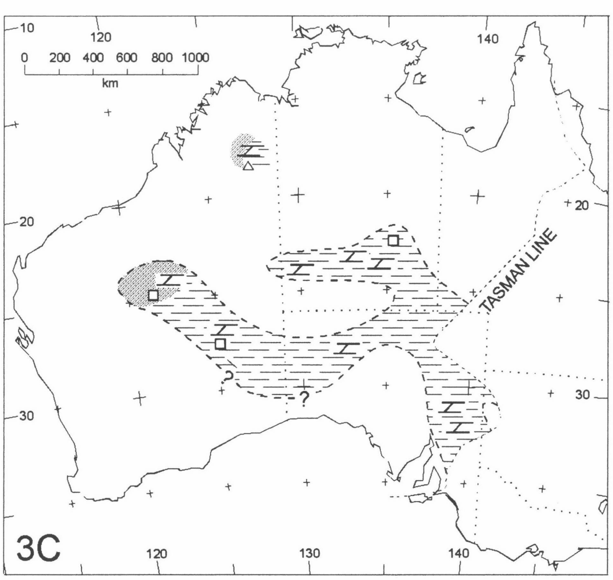
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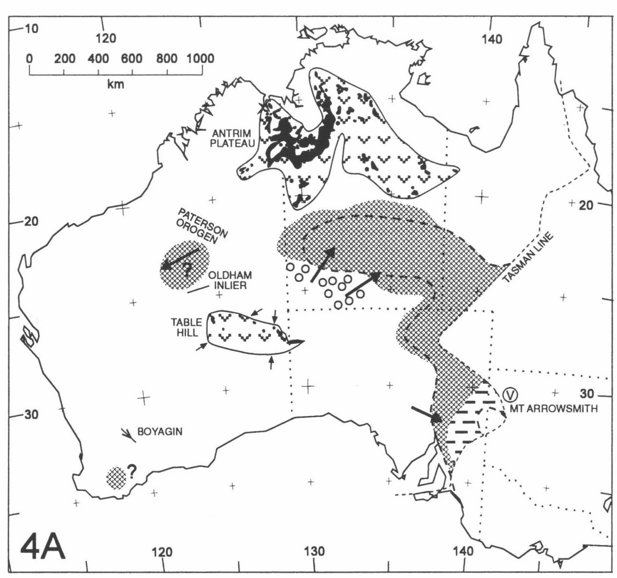
4A
ANTRIM PLATEAU
PATERSON OROGEN
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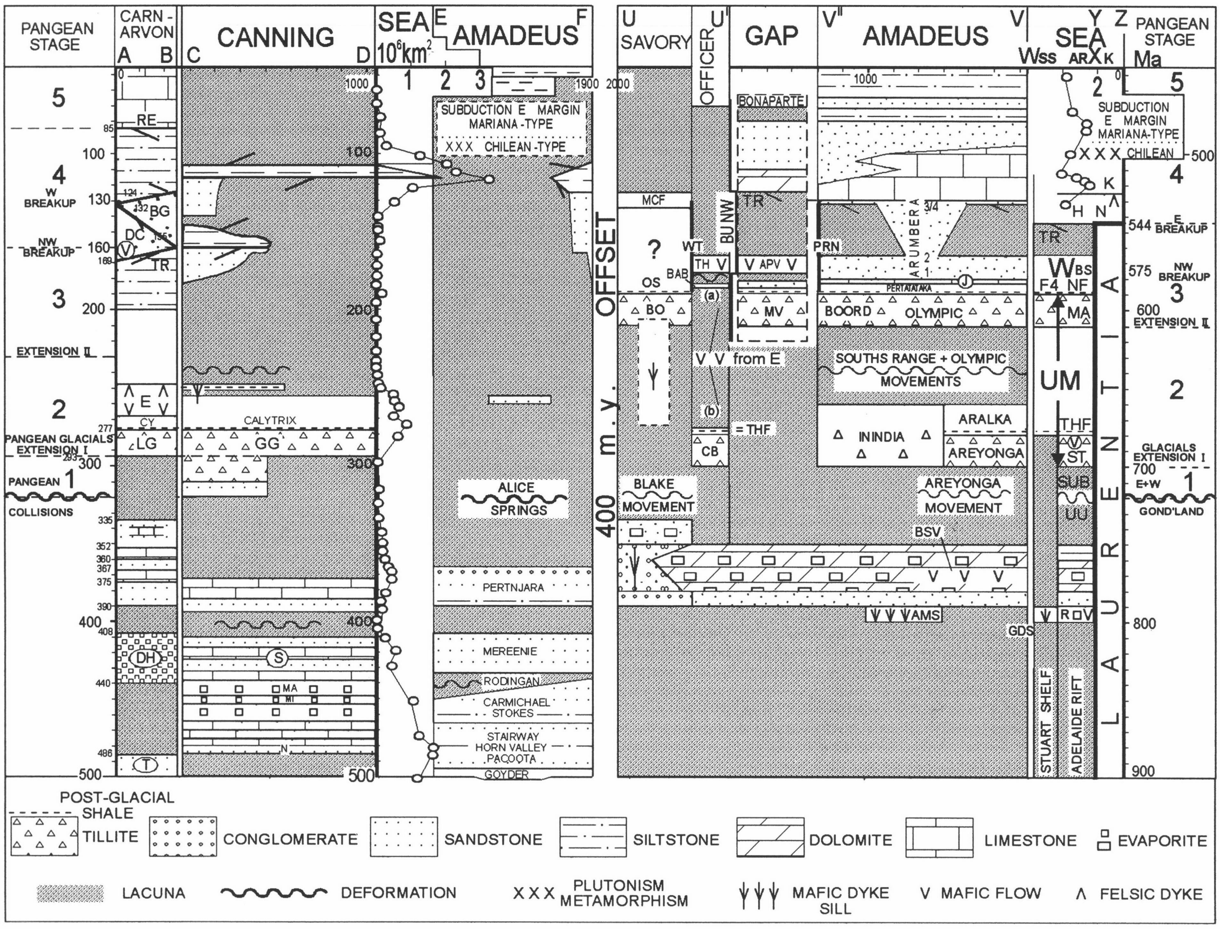

Figure 4. Time-space diagrams from 500 to 45 Ma along the 1900 km long line of A–B, C–D, E–F, and from 900–445 Ma along the 2000 km long line of U–V, W–X, Y–Z, both located in Fig. 1.

***500–45 Ma* AB–CD–EF (left side of diagram).**

***Pangean stages* from Veevers (1990); BU = breakup. Pangea-forming events at the start of stage 1 (ca 320 Ma) are the collision of Laurussia and Gondwanaland, marked by the Sudetic (330–320 Ma) phase of the Variscan orogeny of Europe-Africa (Ziegler 1990, Veevers et al. 1994), the collision of Siberia with Baltica (Sengor et al. 1993) on one side, and possibly with Greater Australia on the other, as suggested by palaeomagnetism (Klootwijk 1995).**

***AB: Carnarvon Basin* (Barber 1988, Gorter et al. 1994). BG = Barrow Group; CY = post-glacial Carrandibby Formation succeeding the LG = Lyons Group glacial sediment; DC = Dingo Claystone; DH = Dirk Hartog Group; E = Edell volcanics (Veevers & Tewari 1995); RE = regression; T = Tumblagooda Group; TR = transgression. The encircled V at 160 Ma denotes the Wandagee Province (WP) of picritic diatremes dated by U-Pb of zircon as 16010 Ma, coincident with the age of breakup on the northwest (GSWA 1990, pp. 566, 587).**

***CD: Canning Basin* (Kennard et al. 1994, Gorter et al. 1994). Details of post-glacial Calytrix Formation on diamictite of the Grant Group (GG) from Redfern & Millward (1994) and Foster & Waterhouse (1988). The mafic sills at ca 250 Ma are from Veevers & Tewari (1995). MA = Mallowa Salt; MI = Minjoo Salt; N = Nambeet Formation; S = Sahara Formation.**

***Sea*: area of Australian platform flooded by the sea (Veevers 1995).**

***EF: Amadeus* (BMR Palaeogeographic Group 1990, Gorter et al. 1994). The region was inverted at the 320 Ma Alice Springs orogeny, dotted with nonmarine sediment in the Late Permian (255 Ma) and intermittently in the Cenozoic on either side of an Oligocene lacuna (Senior et al. 1995), and encroached by the sea at the peak of the Aptian (115 Ma) transgression (Veevers 1995). Rodingan Movement from Oaks et al. (1991, p. 84). In box near top: Subduction eastern margin, change from Chilean- to Marianas-type subduction in Cenomanian (95–90 Ma)(Veevers 1984, 1991).**

***900–445 Ma*: UV–WX–YZ (right side of diagram).**

***UV (i) Savory Basin* (Walter et al. 1994). MCF = McFadden Formation. BO = Boondawari Formation diamictite and OS = overlying siltstone (Walter et al. 1995, p. 186); mafic sills are 'vesicular and amygdaloidal fine-grained basalt ... near the contact of the Watch Point and Coondra Formations ... emplaced at a shallow depth early in the history of the basin' (Walter et al. 1994, p. 535), possibly at the same time as the eruption of the Bitter Springs volcanics in the Amadeus Basin. 'A preliminary Rb-Sr isochron date of c.640 Ma for a coarse-grained dolerite that intrudes the glacial Boondawari Formation' (Williams 1994, p. 843) plots below the ca 600 Ma presumed age of the glacials but possibly falls within the (unstated) range of error. The Blake Movement took place soon after the deposition of the Coondra Formation, and involved inversion of the basin along its northwest margin in the Blake Fault and Fold Belt (Williams 1994, p. 847).**

***(ii) Officer Basin* (Walter et al. 1994). 'VV from E' = Wantapella Volcanics, projected from the east, overlie the Chambers Bluff Tillite (CB), which is overlain by a thin laminated dolomite and siltstone, possibly equivalent to the Tapley Hill Formation (THF) (Preiss 1987, p. 201–203). Preiss (1993) groups the Wantapella Volcanics with the overlying strata, option (a), but they could be much older, option (b).The Babbagoola Formation (BAB) was deformed by thrusting and stripped before being overlain by the Table Hill Volcanics (TH). On the northern and eastern edge of the Officer Basin, the Musgrave Block was uplifted at 590 Ma during movement along the Woodroffe Thrust (WT) in the south and the Petermann Range Nappe (PRN) in the north, as indicated by a widespread sheet of sand on the south, west, and north (ABC Quartzite, Murnaroo Formation, Cyclops Member, Grant Bluff Formation) to 550–530 Ma, the age of syntectonic muscovite in the Musgrave Block (Maboko et al. 1992).**

***(iii) Gap* in information of 445–750 Ma rocks occupied by column of Bonaparte Basin and East Kimberley projected from the north. Data from Cook (1988), Shergold (1995), BMR Palaeogeographic**

be the western lateral equivalent of the Skates Hill Formation, although it is predominantly siliciclastic. Evaporite pseudomorphs are abundant. Its presence on the tectonically active western margin of the superbasin is consistent with the interpretation of a facies change westwards from carbonates to sandstones (Fig. 3, 1B). On the northern margin of the Savory Basin the Waroongunyah and Waltha Woora Formations of the Tarcunyah Group consist of stromatolitic carbonates, red beds and evaporites (Bagas et al. 1996).

The Burra Group is considered to be the correlative in the Adelaide Rift Complex; this correlation is tenuous and is based on lithological similarities and the possible common presence of a distinctive stromatolite (Walter et al. 1995). During times T-5 to T-12 of Preiss (1987) there was widespread carbonate deposition in the shallower areas, giving way to black muds in the southeast. Oolitic, stromatolitic and intraclastic facies suggest deposition in marginal marine environments. Magnesite was deposited in lagoons. Sandy deltas spread from marginal areas so that towards the end of this period siliciclastic deposition was dominant. Late in these times organic-rich muds accumulated in relatively deep offshore environments, below wave-base.

Supersequence 2

Supersequence 2 followed after a substantial lacuna, spanning at least 50 Ma.

Time-slice 2A

We assume that all the glacial sediments that mark the base of this supersequence are approximately coeval. They are known from every basin in the Centralian Superbasin except the Savory Basin, but are patchy in their distribution and frequently thin. The patchy distribution and rapid lateral thickness changes result, at least in part, from syndepositional faulting. In the Kimberley region, the Landrigan Tillite, deposited on a pavement striated from the east, may be of this age (Coats & Preiss 1980), although recent work suggests that it is Marinoan (Plumb 1996, Corkeron et al. 1996). The thickest accumulations are in the Adelaide Rift Complex.

In the Amadeus Basin, the Areyonga Formation is preserved as erosional remnants on the Bitter Springs unconformity (Areyonga Movement, Fig. 4). Small steep-sided valleys are cut into the main erosional surface. The valleys are filled with large, randomly oriented blocks. Elsewhere the formation consists of diamictite, conglomerate and sandstone with rare dropstones and minor shale. Clasts are very varied and have both intrabasinal and extrabasinal sources. The lower, probably marine, part of the succession passes upwards into a fluvial succession. The overlying diamictites are thinner and probably represent subglacial and ice-margin deposits. The final phase of sedimentation consisted of shallow-marine ice-proximal deposits indicated by poorly bedded diamictites and sandstone bodies with abundant soft-sediment deformation (Lindsay 1989).

The Inindia beds of the southern Amadeus Basin are probably lateral equivalents of the Areyonga Formation. They comprise massive sandstone with siltstone interbeds, with a diamictite at several localities (Wells et al. 1966).

Group (1990), and Walter et al. (1994). MV = Moonlight Valley Tillite and overlying 15 m thick dark-red shale with sparse pebbles (Coats & Preiss 1980, p. 185; Preiss 1987, photo on p. 206). APV = Antrim Plateau Volcanics; BU NW indicates breakup of a continental sliver off northwest Australia (Veevers 1988).

***(iv) Amadeus*. Phanerozoic from Wells et al. (1970) and Gorter et al. (1994), showing facies change from Cambrian sandstone in the west to carbonate in the east; Early Cambrian Arumbera 3/4 and underlying Neoproterozoic rocks from Walter et al. (1995), including post-glacial shale on tillite at 680 Ma (Aralka/Areyonga [AREY]) and 590 Ma (Pertatataka/Olympic). The Areyonga Movement produced uplift in the region, as indicated by clasts of the Bitter Springs Formation, the Heavitree Quartzite, and older rocks of the Arunta Block in the Areyonga Formation of the Amadeus Basin, and resulted in a radical change in the palaeogeography; the Souths Range Movement (Wells et al. 1970, p. 129) and the Olympic Movement (Oaks et al. 1991, p. 81) also produced uplift. The basin was disrupted in the south by uplift of the Musgrave Block at 590 Ma during movement along the Woodroffe Thrust (WT) and the Petermann Range Nappe (PRN), as described above for the Officer Basin. Dykes of the Amata mafic suite (AMS) ca 800 Ma from Sm-Nd mineral isochron dates of 790 ± 40 Ma and 797 ± 49 Ma (Zhao & McCulloch 1993; Zhao et al. 1994); and mafic lavas in the middle of the Bitter Springs Formation (Bitter Springs Volcanics, BSV) have a comparable isotopic signature (Zhao et al., 1994) but, by superposition, are younger. J = Julie Formation.**

***WX: (i) Sea* (top, Phanerozoic, only), area of sea on Australian platform (Veevers 1995), continued down to 534 Ma from Sea column on left.**

***(ii) Stuart Shelf (SS) and Adelaide Rift Complex (AR)* at 31°S across the Central Flinders Zone. Information from Preiss (1987, 1990, 1993). Sequences of post-glacial shale on tillite at 680 Ma are Sturtian/Tapley Hill Formation (THF) and at 590 Ma facies 4 = shale and carbonate of the Nuccaleena Formation (F4 NF)/Marinoan glacials (MA). The dykes of the Gairdner Dyke Swarm (GDS) underlie the Tapley Hill Formation (THF), and are dated by Zhao & McCulloch (1993) as ca 800 Ma from Sm-Nd mineral isochron dates of 802 ± 35 Ma and 867 ± 47 Ma. The Rook Tuff (R) in the northern Flinders area contains a lenticular porphyritic dacite, and zircons from the dacite are dated by the SHRIMP U-Pb method as 802 ± 10 Ma. Zircon-bearing rock of this age possibly extended 350 km southwest to the Acraman area of the Gawler Block whence it was ejected during a bolide impact and deposited in the Bunyeroo Formation. A zircon (grain 18) from the ejecta layer has an indistinguishable, possibly original, date of 804 ± 9 Ma by the SHRIMP U-Pb method (Compston et al. 1987, p. 444). The underlying Willouran volcanic province (WVP), including the Wooltana Volcanics, is grouped in the same ca 800 Ma range of ages from the common trace-element composition that suggests it belonged to a plume-related magmatic event (Zhao et al. 1994). Another ca 800 Ma date comes from zircon in a mafic granulite xenolith in a kimberlite pipe at the Calcutteroo locality, about 230 km north of Adelaide, that intrudes the folded Burra and Umberatana Groups. Chen et al. (1994) found by the SHRIMP method a date of ca 780 Ma, which they interpret as registering mantle-lower crustal magmatism shortly before 780 Ma. The regional unconformity beneath the Umberatana Group (UM)(SUB-UU) is 'more intense in the Central Flinders Zone, where several diapirs became active and the Burra Group was stripped from many areas. Angular unconformities ... suggest tilting of fault blocks and perhaps minor compressive deformation. ... Locally the Burra Group was folded relatively tightly adjacent to the Bungarider Fault in the Willouran Ranges' (Preiss 1987, p. 265). BS = Billy Springs Formation; GDS = Gairdner Dyke Swarm; H = Hawker Group; R = Rook Tuff; UM = Umberatana Group; W = Wilpena Group.**

***YZ: The Kanmantoo Fold Belt (K)* (Scheibner 1993), as seen in the Kanmantoo Trough about 35°S, comprises an Early Cambrian succession of basal sandstone and carbonate and mixed carbonate/clastics of the Normanville Group (N) and presumably equivalent basalt, porphyritic andesite, and flow-banded trachyte of the Truro Volcanics (encircled V) (Preiss 1987, p. 268), overlain by the Early–Middle Cambrian Kanmantoo Group including turbidite fans that prograded towards the east or southeast (Jenkins 1989). All were intensely deformed and overthrusted, and injected with granite during the Delamerian orogeny about 500 Ma (crosses). 'Subduction eastern margin, change from Chilean- to Marianas-type', latest Cambrian (ca 500 Ma) (Powell 1984). Continent-backed lithosphere, probably Laurentia, was adjacent to Australia along the Tasman Line until breakup about 544 Ma (von der Borch 1980). K = Kanmantoo Group; N = Normanville Group; encircled V = Truro Volcanics.**

***Interpreted 700–544 Ma Pangean stages*, modified from Veevers (1990). The deformation at the start of stage 1 (ca 720 Ma) is that reported from East Africa, interpreted as the collision of East and West Gondwanaland (E+W G) (Maboko et al. 1985, Stern 1994).**

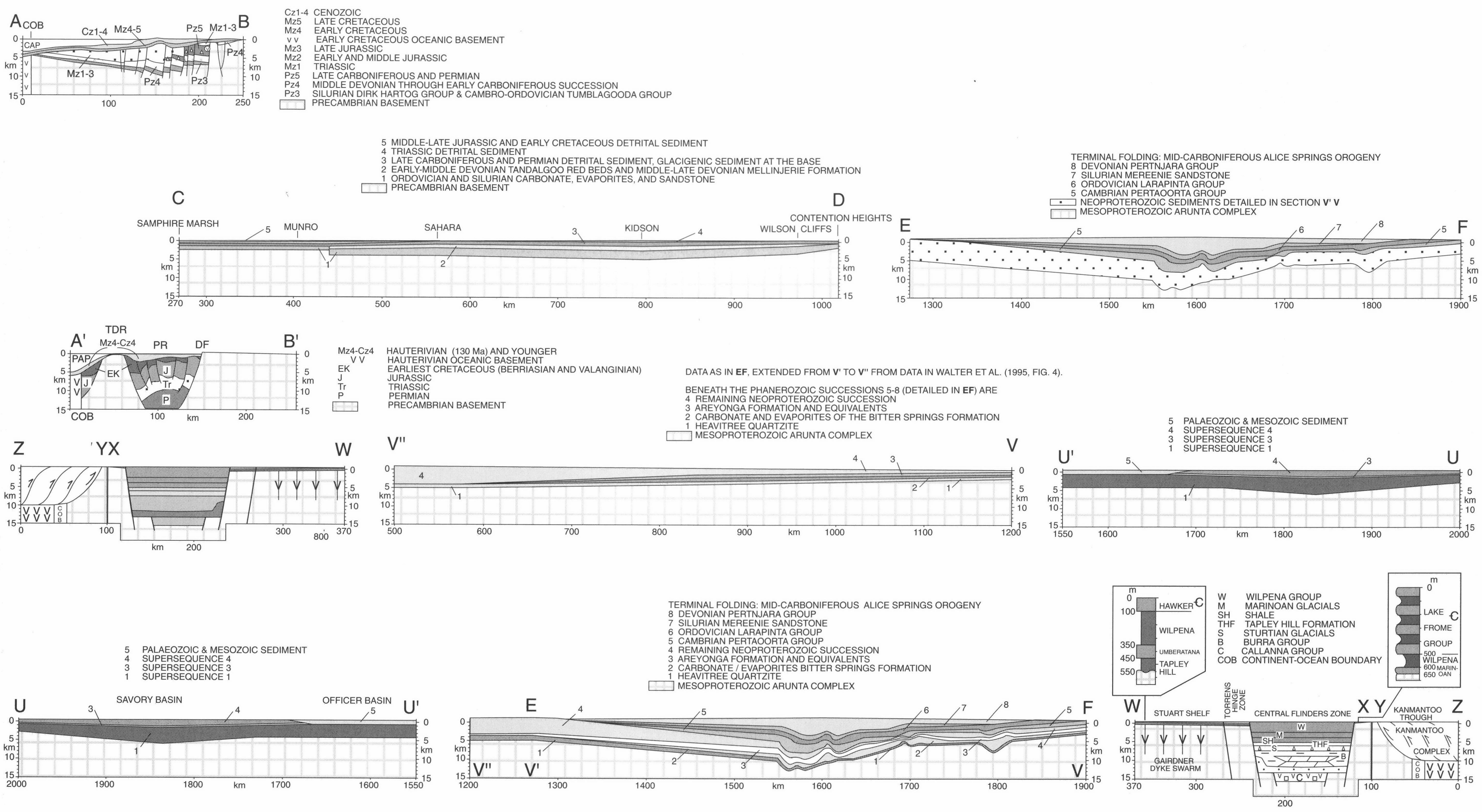

Figure 5. Cross sections, located in Fig. 1, along the 1900 km long line of A–B, C–D, E–F from 500 to 45 Ma, and along the 2000 km long line of U–V,W–X, Y–Z from 900–445 Ma. V:H = 4.

The Naburula Formation of the Ngalia Basin consists of a basal diamictite, shale and 'cap dolomite'. At the type section the diamictite is only about 2 m thick (Wells & Moss 1983). The Yardida Tillite of the Georgina Basin consists of light to dark green-grey diamictite and laminated siltstone with infrequent fine to very coarse-grained sandstone and arkose. The equivalent Mount Cornish Formation consists of blue-green diamictite with clasts, up to 12 m in diameter, of gneiss, pegmatite, granite, dolerite, sandstone, and dolostone, with interbeds of green varve-like siltstone (Walter 1980).

In the eastern Officer Basin, the Chambers Bluff Tillite consists of pebbly, silty diamictite and calcareous diamictite, a middle unit of silty diamictite containing abundant clasts, and an upper thin unit of sandstone and minor limestone. At the base of the succession are graded sandy siltstones that may be glacial varves. Clasts comprise a wide variety of igneous, sedimentary and metamorphic rocks. There is no internal evidence for the age of the Chambers Bluff Tillite, but it is suggested by Preiss (1993) that the grey dolomite and silty shale and the overlying sandstone near the top of the succession may be correlatives of the Sturtian Tapley Hill Formation and Marinoan glacial sandstones of the Adelaide Rift Complex, respectively. So a Sturtian age for the tillite is most likely (see Preiss 1987 and 1993 for discussion). The diamictite is probably of marine-glacial origin (Preiss 1987). The environment may have been initially lacustrine in the Chambers Bluff area, and the succession may have transgressed westward on to basement. Deeper marine, iron-rich, sediments were deposited in the east.

All the glaciogenic sediment described above is assumed here to correlate with the most extensive of the Sturtian glacial units of the Adelaide Rift Complex, at time S-5 of Preiss (1987). Such a correlation is consistent with the correlation of the superjacent 'lower marker cap dolomite', which occurs in all basins except the Kimberley region. In the Adelaide Rift Complex, glaciogenic sediment seems to have been derived from the west (Gawler Craton) and the northeast (Curnamona Cratonic Nucleus and Muloorina Ridge). Highlands in these areas collected ice which fed glaciers in the major valleys, and these coalesced in the lowlands to form a continuous thick ice-sheet over the shelf regions (Preiss 1987). Agglomerate and tuff are reported from the Appila Tillite (Preiss 1987), but these may be reworked from older volcanics (Preiss pers. comm. 1996).

Time-slice 2B

Widespread deposition in a shallow epeiric sea of a thick succession of silt and mud is interpreted as reflecting a major post-glacial eustatic rise in sea level. The succession shallows up and in places there are peritidal carbonates and sands.

The Aralka Formation of the Amadeus Basin consists of evenly bedded green siltstone and shale with subordinate sandstone. Near the base, the siltstone and shale are dark grey and contain dolostone concretions (the 'lower marker cap dolomite'), as elsewhere. In the northeastern part of the basin, the Ringwood Member consists of stromatolitic dolostone, limestone and siltstone, and the Limbla Member consists of siltstone, shale, sandy calcarenite and festoon cross-laminated sandstone. Little work has been carried out on the environmental interpretation of the Aralka Formation. The dominant rock types, laminated siltstone and shale with some ripple marks, were presumably deposited in relatively deep water, but still

Figure 5 (details). TOP ROW

***AB*. Northern Carnarvon Basin, at about 22°S. From west to east, the section crosses the easternmost Cuvier Abyssal Plain (CAP) and the continent-ocean boundary (COB) (from Veevers & Cotterill, 1978), the main part of the Carnarvon Basin to the Darling Fault System, and finally the thin cover over the Precambrian basement (from GSWA 1990, p. 459). The breakup unconformity in the west (W in Fig. 4) is marked by the base of Mz4. Breakup in the northwest (outer columns of Fig. 4) is reflected by the encircled V at 160 Ma (Fig. 4) that denotes the Wandagee Province of picritic diatremes dated by U-Pb of zircon as 160 ± 10 Ma (GSWA 1990, pp. 566, 587). Poorly dated mafic flows along the northwest margin, penetrated in wells at Ashmore Reef, Scott Reef, and near Yampi, are believed to be the same age (Veevers 1984, pp. 187, 188).**

***A′B′*. Section through Perth Rift Complex System at latitude of Perth, from eastern edge of Perth Abyssal Plain (PAP) across the continent-ocean boundary (COB), a presumed outer rift, the Turtle Dove Ridge (TDR), the inner, Perth Rift Complex (PR), the Darling Fault (DF) and the Yilgarn Block. From Veevers & Hansen (1981, fig. 7).**

***CD*. Onshore Canning Basin, from Forman & Wales (1981, plate 3), ages modified from Kennard et al. (1994) and Gorter et al. (1994).**

***EF*. Amadeus Basin, at about 24°S. AA[1] of Lindsay (1987a, fig. 7), subdivided and extended to east and west from information in Wells et al. (1970). Above the Mesoproterozoic Arunta Complex are the <800 Ma (1) Heavitree Quartzite and (2) carbonate and evaporites of the Bitter Springs Formation; Lindsay (1987a) detailed the growth of salt cores beneath the major structures; (3) Areyonga Formation and equivalents; (4) the rest of the Neoproterozoic sediments; (5) the Cambrian Pertaoorta Group; (6) the Ordovician Larapinta Group; (7) the Silurian Mereenie Sandstone; and (8) the Devonian Pertnjara Group, all terminally folded during the mid-Carboniferous Alice Springs orogeny.**

BOTTOM ROW

***UU′*. Neoproterozoic Savory Basin and, additionally, Phanerozoic Officer Basin. Data from Walter et al. (1995, fig. 4).**

***V″V′V (EF)*. Amadeus Basin, at about 24°S. AA[1] of Lindsay (1987, fig. 7), subdivided and extended to east and west from information in Wells et al. (1970). Above the Mesoproterozoic Arunta Complex are the <800 Ma (1) Heavitree Quartzite and (2) carbonate and evaporites of the Bitter Springs Formation; Lindsay (1987) detailed the growth of salt cores beneath the major structures; (3) Areyonga Formation and equivalents; (4) the rest of the Neoproterozoic sediments; (5) the Cambrian Pertaoorta Group; (6) the Ordovician Larapinta Group; (7) the Silurian Mereenie Sandstone; and (8) the Devonian Pertnjara Group, all terminally folded during the mid-Carboniferous Alice Springs orogeny.**

***WX*. Stuart Shelf, Central Flinders Zone, Curnamona Craton at about 32°S. Compiled from crustal cross-section (Preiss 1987, fig. 93, p. 260), with columns of the Stuart Shelf and Curnamona Craton (Preiss 1986). Thicknesses in the section of the Central (and projected North) Flinders Zone (Preiss 1987):**

UNIT	***km***
Wilpena Group	**3**
Marinoan glacials	**1**
shale	**1.5**
Tapley Hill Formation	**1**
Sturtian glacials	**1**
Burra Group	**6**
Callanna Group	**2.7**
Total	**16.2**

***YZ*. Kanmantoo Trough. From Jenkins' (1989) interpretive section of the Mount Lofty Ranges as a set of imbricate thrusts, with our interpretation of the continent-ocean boundary (COB) and Early Cambrian oceanic basement.**

MIDDLE ROW

Sections ZW and U′U are mirror images of WZ and UU′ in the bottom row. VV″ is derived from V″V by removing Phanerozoic strata 5–8 to simulate the end-Neoproterozoic state, and then orienting it (as also ZW and U′U) so that east is on the left, to afford direct comparison with AB-CD-EF above.

above storm wave-base. The abundant ooids, intraclasts and stromatolites of the Ringwood Member indicate a littoral environment. The top of the Naburula Formation of the Ngalia Basin comprises dark grey to black siltstone like that of the Aralka Formation (Wells & Moss 1983). Locally at the top of the Yardida Tillite of the Georgina Basin there is dark grey, laminated, dolomitic shale with, in its lower half, abundant lenses of dolostone (Walter 1980).

These formations are closely comparable with their presumed correlative in the Adelaide Rift Complex, the Tapley Hill Formation, of time interval S-6, interpreted by Preiss (1987) as marine and deposited mostly below wave base. A substantial amount of the pyrite in the formation is extremely depleted in ^{32}S ($\delta^{34}S$ up to +50, Lambert et al. 1984, Hayes et al. 1992), possibly indicating that access to the open ocean was restricted. The Tapley Hill Formation is the first unit to transgress westward from the Adelaide Rift Complex across the Stuart Shelf (Fig. 5, column above section WX).

Supersequence 3

Sequence analysis, chemostratigraphy and biostratigraphy all provide a basis for precise correlation within this supersequence, and offer the promise of narrow temporal resolution (Christie-Blick et al. 1995, Jenkins 1995, Walter et al. 1995). Because most of the detailed studies of chemostratigraphy and biostratigraphy have not yet been published, we analyse only three broadly defined time-slices.

Time-slice 3A

Glacial units lie at the base of the supersequence, and were deposited in environments of the same kind as Supersequence 2 (Fig. 3, 3A). Again, we have assumed that the glacial sediments are approximately coeval. Diamictites are not known from the Georgina Basin, nor with certainty from the Officer Basin, and elsewhere are patchy in their distribution. Arkose, conglomerate and arkosic sand are more widespread, and are interpreted as glacial outwash deposits.

In the eastern part of the Amadeus Basin, the Olympic Formation contains a distinctive reddish diamictite, considered to be tillitic in part, and containing striated and faceted clasts and dropstones. For the most part, the formation consists of red and green mudstone and siltstone, with intercalated sandstone, conglomerate and dolostone (Field 1991; Preiss et al. 1978, table 1). Rare lonestones occur in siltstone beds above mass-flow conglomerates. Most clasts are carbonate, others are quartz, quartzose sandstone, granite, and gneiss. Field (1991) interpreted the formation as indicative of a periglacial environment rather than a continental ice sheet. He regarded it as partly nonmarine and partly lacustrine or marine, with shoreface and foreshore deposits marginal to an ice-sheet of fringing glaciers, perhaps a trough between two areas of glacial activity.

The Pioneer Sandstone has been traced from the north-central Amadeus Basin east into the Olympic Formation (R.J.F. Jenkins, University of Adelaide, pers. comm.). It consists of cross-bedded feldspathic sandstone (Field 1991), except in the east, where much of the unit is conglomerate (Preiss et al. 1978). The upper part of the Pioneer Sandstone consists of two intertidal deposits: a cross-bedded unit with centimetre-amplitude, bimodal, tabular foresets; and an overlying unit of tidal channel-fill sands (Field 1991). The formation is interpreted as glacial outwash from the tillitic Olympic Formation (Preiss et al. 1978, Shaw & Wells 1983). Field (1991) interpreted the conglomerate as mainly a mass-flow deposit, and the lonestones as dropstones. He recognised non-marine, paralic and shallow-marine to basinal settings. A shoreface environment is inferred for the lower part of the formation, and a fluvial to paralic environment for the upper part.

In the Georgina Basin the Black Stump and Oorabra Arkoses form deposits up to 1000 m thick in half-grabens, and consist of arkose, pebbly arkose, conglomerate, siltstone and shale (Walter 1980). They are proximal deposits in a regime of rapid erosion and mass-transport, interpreted as glacial outwash deposits (Walter 1980).

The Mount Davenport Member, the lower part of the Mount Doreen Formation of the Ngalia Basin, comprises poorly sorted boulder, cobble and pebble conglomerate, diamictite and arkose. Clasts are subrounded, striated, and faceted, up to 4 m in diameter, and include igneous and metamorphic rocks, sandstone, and dolostone (Preiss et al. 1978, Wells & Moss 1983).

The Moonlight Valley Tillite and equivalents of northern Australia (Dow & Gemuts 1969, Edgoose 1986; Fig. 3, 3A) rest on glaciated pavements and are overlain by 'cap dolomites' very similar to those above the Marinoan glacials in the Adelaide Rift Complex. Recent work by Plumb (1996) and Corkeron et al. (1996) supports this correlation and disputes the alternative proposed by Coats & Preiss (1980).

The lower part of the Boondawari Formation of the Savory Basin consists of diamictite, rhythmite, sandstone, pebbly sandstone and conglomerate (Williams 1992, Walter et al. 1994). Clasts are angular, subrounded or wedge-shaped pebbles, cobbles, and boulders. They are polished, striated, and faceted, and include metamorphic, igneous and a wide variety of sedimentary rocks, resembling those of the Nabberu Basin to the southwest. The middle Boondawari Formation consists mainly of sandstone. Williams (1992) interpreted the diamictites as glaciogenic, indicating a glacial shallow-marine environment, distant from the ice-source. Clasts were derived from a wide variety of sources from outside the Savory Basin, particularly from the west (Williams 1992). The presence of glauconite suggests a marine environment. The middle part of the formation has been interpreted as a high energy, sandy shelf environment that was glacially influenced (Williams 1992). No correlative units are recognised with confidence in the Officer Basin, though a thin sandstone in the eastern part of the basin could date from this time interval (Preiss 1993), as could the diamictites of the Lupton and Turkey Hill Formations in the western part of the basin (Jackson & van de Graaff 1981).

The Marinoan glaciation of the Adelaide Rift Complex encompasses time intervals M6–M8 of Preiss (1987). On the Stuart Shelf to the west periglacial conditions produced patterned ground (Williams & Tonkin 1985) and dunefields. In the Adelaide Rift Complex, paralic sandstone of the Elatina Formation is inferred to tongue out laterally to the east and northeast into diamictites of the Mount Curtis and Pepuarta Tillites. On the basis of observed gradients in the concentrations of boulders, Preiss (1987) inferred that there were only local sources of ice rather than an extensive ice sheet. Rhythmite in the Elatina Formation has been interpreted as the distal deposits of glacial lakes (Williams 1983, Preiss 1987). Siltstone in the southeast is considered by Preiss (1987) to mark an opening to a fully marine basin in that direction. Palaeomagnetic studies of the Elatina Formation indicate deposition in near-equatorial latitudes, at 2.7° ± 3.7°N (Embleton & Williams 1986, Schmidt & Williams 1995). Evidence for grounded ice at low altitudes, in the form of glaciated pavements, is known only from the Moonlight Valley Tillite and equivalents of northern Australia (Dow & Gemuts 1969, Coats & Preiss 1980, Edgoose 1986; Figs 3, 3A), currently some 15° of latitude north of the Elatina Formation site.

Time-slice 3B

As for the earlier glaciation, a major eustatic rise in sea level followed deglaciation, resulting in the deposition of a thick succession of silt and shale in a shallow epeiric sea. The Musgrave Block emerged and shed coarse sediment to the north and south (Fig. 3).

The potential for fine subdivision of this time interval is illustrated particularly by the work of Preiss (1987), Jenkins

(1995), and Christie-Blick et al. (1995) in the Adelaide Rift Complex. We have decided not to work at this fine scale until the detailed chemostratigraphic and biostratigraphic studies of C. Calver and K. Grey, which allow comparable fine-scale subdivision of the Ediacarian successions in the Centralian Superbasin, have been published. In time-slice 3B we have generalised the palaeogeography of times equivalent to the lower and middle Wilpena Group of the Adelaide Rift Complex (M10–14 of Preiss 1987). If the implied correlations in Fig. 2 are correct, our map (Fig. 3, time 3B) can be taken to indicate the palaeogeography at time M14 of the Acraman meteorite impact on the Gawler Craton, west of the Adelaide Rift Complex, which spread an ejecta blanket north into the Officer Basin (Rodda beds) and east into the Adelaide Rift Complex (Bunyeroo Formation of the Wilpena Group). Fairly precise correlation to the Amadeus Basin with acritarch biostratigraphy and isotope chemostratigraphy indicates that the Acraman impact occurred soon after the deposition of the sands of the Cyclops Member in the middle of the Pertatataka Formation.

The Pertatataka Formation, including sandstones of the Cyclops and Waldo Pedlar Members, is present throughout the northeastern part of the Amadeus Basin. The formation consists of grey-green and purple-brown, laminated, micaceous siltstone and shale with thin interbeds of sandstone and rare limestone. In places it contains glauconite and clay pellets. Korsch (in Kennard et al. 1986) described one area of outcrop as shale with about 30% distal sandstone turbidite beds. Palaeocurrents are north to northeast directed. Wave-rippled tops suggest deposition within storm wave-base. In seismic sections the formation is distinguished by weak discontinuous parallel reflectors with, in places, large north-prograding clinoforms (e.g. Kennard & Lindsay 1991).

With a diverse assemblage of acritarchs, presumably marine plankton (Zang & Walter 1989, 1992; Grey 1993), the Pertatataka Formation is considered to be predominantly marine, and part of a single major upward-shallowing sequence which includes the carbonate of the overlying Julie Formation. Pertatataka deposition started during a sudden deepening of the basin so that the water depth of the basin was at its maximum. Pelagic muds and turbidites were deposited from turbidity currents travelling northward in an outer submarine fan to a basin plain that rose to a strandline in the northeast (Kennard et al. 1986).

The Winnall beds in the southwest of the Amadeus Basin consist of siltstone, sandstone, pebbly sandstone, dolostone and limestone (Wells et al. 1970). Conglomerate indicates uplift to the south with erosion of the Bitter Springs Formation and metamorphic and igneous rocks. Shallow marine conditions, indicated by glauconite and phosphate, in a subsiding depression then predominated.

The equivalent units in the Georgina Basin are the Elyuah and Grant Bluff Formations, and parts of the Elkera and Central Mount Stuart Formations (Walter 1980). The Elyuah Formation consists mainly of laminated, grey, green or red, fissile shale. The Grant Bluff Formation is mainly undulose laminated to thin-bedded, fine-grained quartz arenite. The lower Elkera Formation consists of interbedded siltstone, sandstone and shale. The sandstone locally contains anhydrite and pseudomorphs of anhydrite nodules and gypsum. The trace fossil *Planolites ballandus* occurs rarely. There are no detailed sedimentological studies, but trace fossils, stromatolites, ripple marks and sulphate evaporites suggest a shallow marine environment. Further west these units grade into the Central Mount Stuart Formation, which has a higher proportion of sandstone.

In the Ngalia Basin the Newhaven Shale Member of the Mount Doreen Formation consists of a uniform succession of red shale (Wells & Moss 1983). In the lower part of the Boondawari Formation of the Savory Basin, diamictite is overlain by a rhythmite (OS in Fig. 2). Above the rhythmite the dominant lithology is coarse to fine-grained sandstone containing scattered pebbles, cobbles and occasional boulders. Planar and trough cross-bedding are common. Polymict conglomerate fills penecontemporaneous scour-channels in sandstone (Williams 1992, Walter et al. 1994).

In the Kimberley region, the glacial units and the succeeding 'cap dolomites' are overlain by a succession of shale, siltstone, greywacke and sandstone (Coats & Preiss 1980 and earlier references therein).

In the eastern Officer Basin an unnamed siltstone is overlain by the Murnaroo Sandstone (M) and by the Rodda beds, which contain ejecta from the Acraman impact near the base (Wallace et al. 1989). The Murnaroo Formation is widespread in the eastern Officer Basin and consists of sandstone, which is fine to coarse-grained and rarely conglomeratic. The Rodda beds consist of grey-green siltstone, which is frequently calcareous and dolomitic. They include grey and minor pink, brown and purple limestone and dolostone beds, feldspathic and calcareous sandstone, and pebble–cobble conglomerate beds. The upper part of the succession consists of grey-green siltstone with thin beds of very fine sandstone. Sukanta et al. (1991) recognised five sequences in the Rodda beds; a canyon-forming event cuts down into the underlying Murnaroo Sandstone. Well-preserved acritarchs in the Rodda beds (Jenkins et al. 1992, K. Grey pers. comm.) are closely comparable with those in the upper Pertatataka Formation of the Amadeus Basin. The Rodda beds were deposited in a deep-water slope-and-basin environment by mass flow, turbidity currents and hemipelagic processes (Brewer et al. 1987).

The Babbagoola Formation of the western Officer Basin consists of shale, siltstone, sandstone, anhydrite, gypsum and conglomerate. In Hussar-1, conglomerate is overlain by interbedded sandstone, claystone and siltstone (Phillips et al. 1985). Jackson & van de Graaff (1981) and Jackson & Muir (1981) divided the succession into three units: a lower unit of fissile grey to green laminated siltstone and claystone about 100 m thick, a middle unit of dolostone or dolomitic sandstone (less than 10 m thick), and an upper unit of reddish-brown poorly sorted sandstone and siltstone. Recent work indicates that some of what has been called Babbagoola Formation is part of Supersequence 1 (K. Grey, Geological Survey of Western Australia, pers. comm. 1996).

In the Adelaide Rift Complex, mud and silt of the Bunyeroo Formation, including the Acraman impact ejecta layer (Compston et al. 1987), were being deposited in what Preiss (1987) interpreted as a moderately deep marine environment. Several diapirs formed small islands.

Time-slice 3C

In each region the post-glacial siliciclastic successions shallow upward to become rich in carbonate, locally with evaporites, ooid grainstones, and stromatolites (Fig. 3). The Julie Formation of the Amadeus Basin is a succession of dolostone, limestone and siltstone with lenses of sandstone. The dolostone is frequently oolitic, and locally contains stromatolites. The Julie Formation is the upper part of a single major upward-shallowing sequence which began with rapid deepening to form the Pertatataka Formation. Lithologies indicate a shallow marine environment with ooid shoals. The upper part of the Boord Formation in the western Amadeus Basin consists of oolitic, stromatolitic calcilutite and calcarenite, which are interbedded with siltstone and shale. No equivalent units are known from the Ngalia Basin.

The Elkera Formation of the Georgina basin consists of interbedded siltstone, stromatolitic dolostone, sandstone, and shale. The sandstone locally contains anhydrite and pseudomorphs of anhydrite nodules and gypsum. Some argillaceous beds contain halite pseudomorphs. Trace fossils, stromatolites, ripple marks, and sulphate evaporites suggest a shallow marine environment. The formation apparently grades west into sandstone of the Central Mount Stuart Formation, interpreted as deltaic (Shaw & Warren 1975, Walter 1980).

Recent reinterpretations of the stratigraphy of the Neoproterozoic succession in the Kimberley region suggest that the glacial diamictites of the Egan Formation represent a third, younger, glaciation not recognised in other basins in Australia (Plumb 1996, Corkeron et al. 1996). On the basis of the occurrence of the stromatolite *Tungussia julia* the Egan Formation has been correlated by these authors with the Julie Formation, and the included diamictites are suggested to result from a local mountain glaciation. Also included in the formation are dolomite, limestone, and fine to coarse-grained siliciclastics. Overlying this is the Yurabi Formation of dolomitic sandstone.

The upper Boondawari Formation of the Savory Basin is an argillaceous-carbonate association of upward-coarsening shale and siltstone to fine and coarse-grained sandstone. Halite casts occur in sandstone. Some sandstone and siltstone horizons have graded bedding, occasional mud-cracks, and load and flute casts. The dolostone locally is oolitic, pisolitic and stromatolitic.

In the Officer Basin, the middle Rodda beds include limestone and dolostone, as well as laminated siltstone and shale, and feldspathic and calcareous sandstone, and are correlated with the Julie Formation. As mentioned above, the Rodda beds were deposited in a deep-water slope and basin environment by mass flow, turbidity currents and hemipelagic processes (Brewer et al. 1987).

In the Adelaide Rift Complex at time M-15 of Preiss (1987), lime mud and fine calcareous sand and silt of the Wonoka Formation were deposited in a deep shelf to slope environment. Divergent carbon-isotopic compositions of kerogen and carbonate imply a restricted basinal environment (C. Calver, Macquarie University, pers. comm. 1995). Canyons up to 1 km deep were eroded into the shelf, implying a water

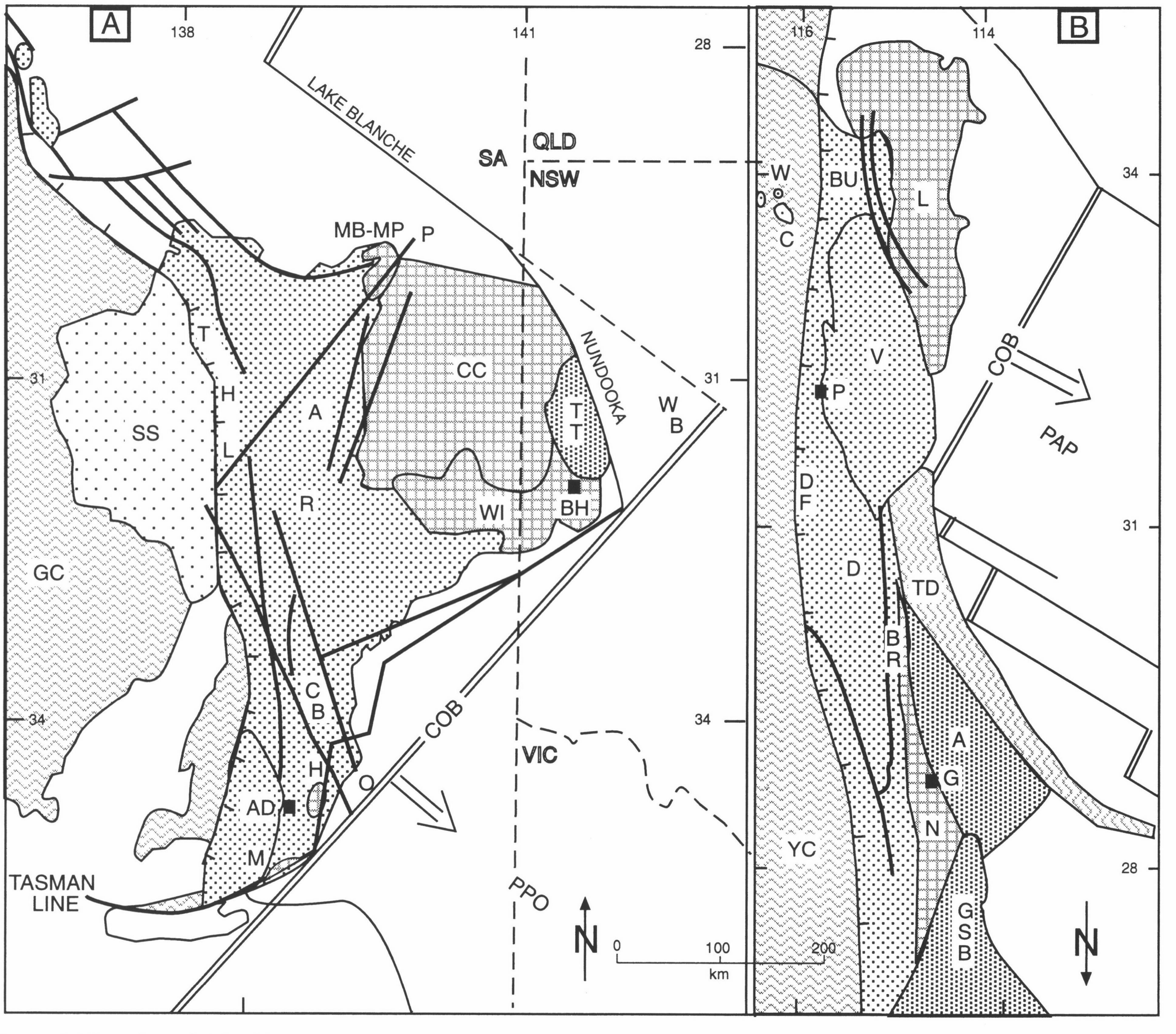

Figure 6. Plan view of Adelaide and Perth Rift Complexes at same scale, oriented such that the passive continental margin is on the right. (Documented below). Adelaide: AD = Adelaide BH = Broken Hill CB = Crystal Brook lineament CC = Curnamona Craton GC = Gawler Craton H = Houghton Inlier O = Ororoo Fault P = Paralana Fault PPO = Paleo-Pacific Ocean SS = Stuart Shelf THL = Torrens Hinge Line TT = Torrowangee Trough WB = Wonaminta Block WI = Willyama Inliers. Perth A = Abrolhos Sub-Basin BR = Beagle Ridge BU = Bunbury Trough C= Collie Basin D = Dandaragan Trough G = Geraldton GSB = Gascoyne Sub-Basin L = Leeuwin Complex N = Northampton Complex P = Perth PAP = Perth Abyssal Plain TD = Turtle Dove Ridge V = Vlaming SubBasin W = Wilga Basin YC = Yilgarn Craton.

***A: Adelaide Rift Complex.* From Preiss (1987). Palinspastic view in the Cambrian, shortly after breakup, oriented with north up. Broad arrow indicates presumed direction of seafloor spreading and progradation of the Kanmantoo submarine fans; continent-ocean boundary (COB) (Tasman Line) restored to straight-line segments by eliminating the foldbelt arc.**

***B: Perth Rift Complex.* From Harris et al. (1994).**

depth of at least that much; controversy continues as to whether the canyons were cut in a subaerial or a subaqueous environment (Christie-Blick et al. 1995). For the first time, the basin deepened to the north as well as to the south from a shallow zone in the central Flinders Ranges (Preiss 1987).

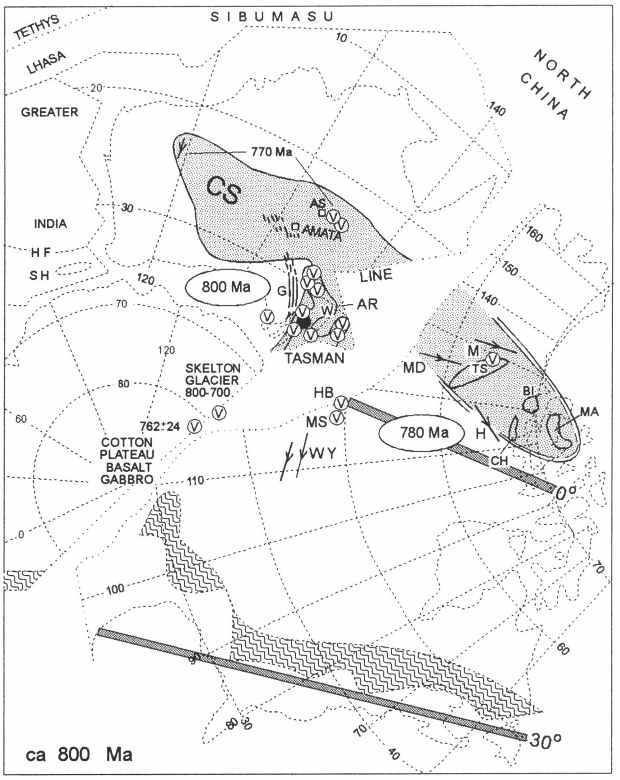

Figure 7. Australia–Antarctica and Laurentia reconstruction at 800 Ma. HF = Himalayan Front, SH = Shillong Hills.

Base as in the cartoons of Moores (1991), Borg & De Paulo (1994) and Park et al. (1995), but from the quantitative reconstruction, on a Mercator projection, by Powell et al. (1993). Greater India, Lhasa, Sibumasu from data in Veevers & Tewari (1995); North China from McKerrow et al. (1992, fig. 1). Dotted (Tasman) line on eastern and northern margins of Australia (present coordinates) marks limit of known Precambrian rocks; the light dotted line on the western side of Laurentia marks the limit of Proterozoic strata in the cordillera (Hoffman 1989).

Laurentia*: average trend of 780 Ma mafic dykes of the Outer Fold Belt of the Mackenzie Mountains (M) and the Wyoming Province (WY), and of the 780 Ma Hottah sheets (H), from Park et al. (1995, fig. 4). Outline (heavy broken line) of Mackenzie Mountains Supergroup in Mackenzie Mountains (M), and equivalents in the Brock Inlier (BI), Coppermine Homocline (CH), and Minto Arch (MA), from Narbonne and Aitken (1995, p. 104). Note mirror-image symmetry of the E–W trend of the Centralian Superbasin along the Amadeus Transverse Zone coming off the re-entrant of the Tasman Line and the SW–NE trend of the basins with the Mackenzie Mountains Supergroup, outlined by the double line, at a right-angle to the subsequent cordillera. The comparable 700 Ma outline (broken line) also contains the SW–NE trend. This is the zero-thickness line of Neoproterozoic and Early Cambrian (Stewart 1972), extended around Victoria Island (Kaufman & Knoll *1995, p. 42).

***Australia*: the ca 800 Ma Amata and Gairdner (G) mafic dyke swarms (Zhao et al. 1994, fig. 1), mafic volcanics, mainly flows, of the Adelaide Rift Complex, including the Wooltana Volcanics (W) (Preiss 1987, fig. W-3, p. 373), and shoreline of the overlying Supersequence 1A and B, which includes the Bitter Springs volcanics, east of Alice Springs (AS). According to Zhao et al. (1994, fig. 5), a postulated plume head (large black dot) could have resulted in domal uplift and subsidence (and presumably minor volcanism) of an area with radius of 4000 km, and Park et al. (1995) postulate that the Laurentian dykes and sheets (and the Amata and Gairdner dykes) may represent subswarms of a giant radiating dyke swarm centred on the Adelaide Rift Complex.**

Supersequence 4

Time-slice 4A

Most of the southern part of the Superbasin, including much of the Officer Basin and the central Amadeus Basin, may have been emergent (Fig. 3, time 4A). In the northern part of the Superbasin, time-slice 4A began with a deepening, during which possibly turbiditic sands were deposited locally in a basin fringed by fluvial and shallow marine deltaic complexes. Coarse sediment was again shed from the Musgrave Block. An extensive flood of basalt covered the western Officer Basin (Table Hill Volcanics) and northern Australia (Antrim Plateau Volcanics), and also the Mount Arrowsmith block (Scheibner 1993). However, the ages of both the Table Hill Volcanics and the Antrim Plateau Volcanics are very poorly known.

In the Amadeus Basin, the Arumbera Sandstone consists of red-brown and white sandstone and minor siltstone, shale, conglomerate and carbonate. The lower Arumbera Sandstone (units 1 and 2) contains *Charniodiscus* and other metazoan body fossils of the latest Proterozoic Ediacara fauna, but no definite trace fossils have been found (Walter et al. 1989). The formation was deposited in a shallow marine and deltaic or coastal plain setting (Lindsay 1987b), with sediment supply from the southwest carried by braided streams. The Amadeus Basin was modified as a result of the Petermann Ranges orogeny to form a shallow, east–west trending basin along the northern margin, separated from a shallower southern shelf area by a broad central ridge. Subsequent sedimentation was controlled by varying rates of subsidence in each tectonic subdivision. Deposition was largely progradational, as major deltaic complexes developed on the southern and southwestern margins of the sub-basins. The Mount Currie Conglomerate in the southern part of the basin is a presumed proximal correlative of the Arumbera Sandstone, though whether of the lower, Neoproterozoic part, or of the upper, Cambrian part, or both, is unknown. The same applies to the Sir Frederick Conglomerate and its correlative the Ellis Sandstone, in the western part of the basin (Wells et al. 1964).

The red-brown and green-grey sandstone and siltstone of the upper part of the Central Mount Stuart Formation of the Georgina Basin include soft-bodied metazoan fossils and trace fossils of the Ediacara fauna (Walter 1980), which indicate a marine environment. To the east, the sandstones of the uppermost Elkera Formation and to the west the predominantly fine- to coarse-grained, red-brown sandstone of the Yuendumu Sandstone of the Ngalia Basin may be this age.

The siltstone, sandstone and conglomerate of the upper Louisa Downs Group of the Kimberley region probably correlate with Supersequence 4, but there is no definitive evidence as yet. Preliminary searches for fossils have not been successful.

In northern Australia the Antrim Plateau Volcanics extend over an area of 425 000 km^2, and comprise several hundred metres of tholeiitic flows with interbeds of nonmarine sandstone, chert, and limestone (Bultitude 1976, Cook 1988). They are conventionally regarded as being of Early Cambrian age, but the only direct evidence, stromatolites in interbedded cherts, indicates a latest Neoproterozoic age (Walter 1972, p. 49). The Table Hill Volcanics cover an area of 90 000 km^2 in the Officer Basin southwest of the Musgrave Block (Jackson & van de Graaff 1981, Cook 1988, GSWA 1990 p. 377). They are tenuously dated by Rb/Sr at 563 ± 40 Ma (recalculated from Compston 1974) or latest Neoproterozoic, probably the same age as the Antrim Plateau Volcanics.

The McFadden Formation of the Savory Basin, also possibly of this age, consists of fine to coarse-grained sandstone, feldspathic sandstone, minor pebble and granule conglomerate, and siltstone. Conglomerate occurs as thin interbeds or penecontemporaneous channel fills. Large cross-bed sets, up to 10 m thick, are typically flaggy and show grading. They may be point-bar deposits formed in large meandering channels in delta build-up areas, delta fronts, and migrating ridges or giant channel ripples (Williams 1992). Current lineation, ripple mark, and dewatering structures are also present. Grain-size coarsens northwards towards the basin margin. Palaeocurrent directions show a strong west-southwesterly directed flow. Sediment is immature and coarse-grained, suggesting that the source was probably local, most probably from the Paterson Orogen, with local input from the Oldham Inlier (Fig. 3, time 4A).

In the Adelaide Rift Complex the base of Supersequence 4 is likely to be at or near sequence boundary 10 of Christie-Blick et al. (1995), in the upper Wonoka Formation. The overlying Bonney Sandstone was deposited 'as a prograding coastal sandflat or tidal delta' and above this the Rawnsley Quartzite as a 'prograding shoreface, barrier and tidal channel facies complex' at times M-16 and M-17 (Preiss 1987). The Ediacara fauna of soft-bodied metazoans is preserved (in the Rawnsley Quartzite) in muddy sands, perhaps the deposits of submarine channels. There appear to be deeper basinal sands to the southeast and northeast, the latter being in part the Billy Springs Formation. We interpret this deepening as a third phase of onlap.

What seems to have been a eustatic fall in sea level occurred near the time of the Proterozoic–Cambrian boundary, exposing the continent (except that part of the Amadeus Basin with continuous deposition of the Arumbera Sandstone) to subaerial conditions. Fluvial and shallow marine deposition resumed in the Early Cambrian (Fig. 4) (Cook 1982, 1988).

Tectonics

The part of the Adelaide Rift Complex north of 32°S that outcrops in the Flinders Ranges is confined between the internal Gawler Craton on the west and the external Curnamona Craton on the east (Fig. 1). Preiss (1990, fig. 3) compared this part of the Adelaide Rift Complex with the failed arm of the Mesozoic–Cenozoic Bass Basin of southeastern Australia, confined by the internal mainland craton and the external Tasmanian craton; the Fleurieu-Nackara (Delamerian) arc on the southeast is matched by the passive margin ('successful arms') of offshore western Victoria and western Tasmania.

Our interpretation follows von der Borch's (1980) model of the Adelaide Rift Complex as a Neoproterozoic (800–544 Ma) intracratonic rift between the Gawler and Curnamona cratons transformed in the earliest Cambrian (544 Ma) to a failed arm (Flinders zone) by continental breakup along its southern part. Analysis of the subsidence history of the Neoproterozoic and Cambrian basins supports this interpretation (Lindsay et al. 1987). Sedimentation ceased before the Late Cambrian–Ordovician (500 Ma) Delamerian orogeny.

Powell et al. (1994, fig. 8) also view the Adelaide Rift Complex as an intracratonic rift basin but for a much shorter time interval, from 800 to 720 Ma, and thereafter as a passive continental margin. The need for an earlier breakup came from Powell et al.'s (1993) postulate from palaeomagnetic data that Laurentia and Australia began to separate after 720 Ma during the rapid growth of the Pacific Ocean such that East Gondwanaland and Laurentia were about 8000 km apart by 580 Ma. Accordingly, Powell et al. (1994) interpreted the onlap of the post-Sturtian glacial Tapley Hill Formation as reflecting breakup at 700 Ma, and the Adelaide Rift Complex as a passive continental margin from about 700 Ma to the 500 Ma Delamerian Orogeny. Continental separation was dated by the rapid divergence of the apparent polar wander paths of Australia and Laurentia from 720 Ma. But another interpretation of the palaeomagnetic evidence suggests the radically different possibility of Laurentia remaining fixed alongside Australia–Antarctica at least to 600 Ma, entailing a 100 m.y. later birth of the Pacific Ocean (Meert & van der Voo 1994, fig. 7). Birth of the Pacific Ocean towards the end of the Neoproterozoic would be consistent with there being no known oceanic facies older than Phanerozoic.

Furthermore, breakup in eastern Australia is indicated by the change in sediment provenance and the southeastward shift in the depocentre represented by the Cambrian Kanmantoo Group (von der Borch 1980, Flottmann et al. 1996, Foden 1996), and the appearance of Early Cambrian (525 Ma) mafic lava and felsic tuff (Shergold 1995) along the newly formed margin and of 530 Ma ophiolite in the palaeo-Pacific ocean floor (Aitchison et al. 1992). Breakup no older than latest Neoproterozoic is consistent with the geochemical evidence outlined above for restricted water circulation in the Adelaide Rift Complex during the deposition of the Tapley Hill Formation (about 700 Ma) and the lower and middle Wonoka Formation (about 570–580 Ma). It is notable that Preiss (1987) indicated a substantial change in palaeogeography in the Adelaide Rift Complex at the time of deposition of the Wonoka Formation. As noted above, the subsidence history of the Neoproterozoic and Cambrian basins also suggests breakup near the base of the Cambrian (Lindsay et al. 1987).

A comparative stratigraphic-tectonic study of Phanerozoic basins also bears on the age of continental breakup. We compare the Neoproterozoic Adelaide Rift Complex and Centralian Superbasin with the Palaeozoic–Mesozoic Perth Rift Complex and Canning and Amadeus Basins. The Canning and Amadeus Basins and much of the Centralian Superbasin occupy the Amadeus Transverse Zone (ATZ). The comparison is made in plan (Fig. 1), in time-space (Fig. 4), in section (Fig. 5), and, in detailed plan (Fig. 6) between the Adelaide Rift Complex and Perth Rift Complex. The ages of these structures are 400 m.y. apart, which is the period of the Pangean cycle (Veevers 1990).

Time-space

Notable comparisons (Fig. 4) are:

(a) supercontinental collisions of Gondwanaland and Laurussia at 320 Ma and of East and West Gondwanaland at 720 Ma;

(b) post-collision lacunas at 320–300 Ma and 720–700 Ma (assumed age);

(c) Extension I generating new basins for glaciogenic sediment at 293 Ma and 700 Ma (assumed age), followed by

(d) Extension II making new (coal) basins at 230 Ma, and new (glaciogenic) basins at 610 Ma (assumed age);

(e) continental breakup of northwest and west Australia at an observed 160 Ma and 130 Ma (west of Perth Rift Complex), and a postulated breakup at 575 Ma of northwest Australia and 544 Ma on the east (east of Adelaide Rift Complex), all accompanied by mafic volcanics. Major marine transgressions follow continental breakup, with a peak in the Aptian (115 Ma) and peaks in the Early Cambrian (520 Ma) and Early Ordovician (480 Ma); likewise, the subduction on the eastern margin changed from Chilean type to Mariana type at 90 Ma and 490 Ma.

Cross-section

In cross section (Fig. 5), the Adelaide Rift Complex mimics the salient features of the Perth Rift Complex (Fig. 5, ZY–XW and A'B') as do the contemporary basins occupying the Amadeus Transverse Zone. The only significant difference is the thick infilling of the Amadeus Basin by the Devonian Pertnjara Group, which arose from compression associated with the Alice Springs Orogeny, itself a distant effect of the Variscan collision of Gondwanaland and Laurussia.

Plan

The Neoproterozoic Adelaide Rift Complex was compared by

Preiss (1987, fig. 3) with aulacogens and geosynclines in Laurussia and with the Mesozoic continental margin and failed arm of the Bass Basin of southeastern Australia; by von der Borch (1980) with the southern margin of Australia; and by Eyles (1993) with the Gulf Coast of the USA. We believe a more cogent comparison is with the Permian and Mesozoic Perth Rift Complex (Fig. 6), also shown in time-space (Fig. 4) and in section (Fig. 5). Essential features, in bands of similar size and shape from craton to ocean, are as follows (see Appendix for explanation of abbreviations):

Adelaide	*Perth*	*Feature*
GC	YC	Archaean craton
SS	C, W	epicratonic sediment
THL	DF	hinge-line
AR	BU, V, D	inner basins of thick epicratonic sediment including glacials
CC, WI	L, BR, N	inner ridge of pre-basinal rocks
TT	A, GSB	outer basins
?WB	TD	outer ridge

Supercontinental connections

According to the SWEAT hypothesis (Moores 1991, Dalziel 1991), Neoproterozoic Australia (with India and Antarctica) was joined to Laurentia so that the Tasman Line faced the Canadian–Wyoming cordillera, and the Grenville Orogen of Laurentia continued into Antarctica.

Events common to Australia and Laurentia include:

a) ***ca 800 Ma*** (Fig. 7). According to Zhao et al. (1994, fig. 5), a postulated plume head (black dot in Fig. 7) could have resulted in domal uplift and subsidence (and presumably minor volcanism) of an area with radius of 4000 km, and Park et al. (1995) postulated that the Laurentian dykes and sheets, together with the Amata and Gairdner dykes, represent subswarms of a giant radiating dyke swarm centred on the Adelaide Rift Complex. The tholeiitic magma intruded pre-Neoproterozoic rocks except the early Neoproterozoic Mackenzie Mountains Supergroup and equivalents, which occupied a SW–NE-trending depocentre. Following the magmatism in Laurentia, sediment continued to accumulate in a narrower SW–NE-trending depression and newly accumulated along the cordilleran area. In Australia, sediment initially accumulated with the igneous rock in the Adelaide Rift Complex and then succeeded it, as sediment in the Centralian Superbasin rested over the Amata dyke swarm and was interlayered with the Bitter Springs volcanics. The configuration of S–N-trending Adelaide Rift Complex and E–W-trending Centralian Superbasin is a mirror image of the basins in Laurentia, such that the combined system forms a T.

b) ***ca 700 Ma.*** The 723 Ma Franklin igneous events in northern Canada and the emplacement of the 725 ± 35 Ma Cooee Dolerite in Tasmania denote extension of the continental crust soon after the ca 720 Ma collision of East and West Gondwanaland by the closing of the Mozambique ocean, possibly reflected in Tasmania by the 730 Ma Penguin Orogeny. Further extension trapped the copious glaciogenic deposits produced during the early Pangean icehouse. In Laurentia, glacial deposits stretched from 30°N to 65°N, and in Australia from the Adelaide Rift Complex to the Centralian Superbasin. This succession of events constitutes the first stage of a Pangean cycle, involving crustal extension driven by the first release of heat from the supercontinental insulator to provide accommodation space for the glaciogenic sediment produced by the icehouse climate (Veevers, 1990). This anticipates by some 400 m.y. the train of events starting with the 320 Ma collision of Gondwanaland and Laurussia, followed by 300 Ma extension and fill of Gondwanan glaciogenic sediment. Powell et al. (1994) and Young (1995) interpreted the extension that produced the rifts with glacial sediments as reflecting supercontinental breakup; instead, we believe it reflects supercontinental crustal extension. Incidentally, Eyles (1993) also interpreted the Sturtian glaciogenic strata as resulting from the break-out of Laurentia from the Neoproterozoic supercontinent, as well as deposits preserved within mobile belts along compressional plate margins.

c) ***ca 600 Ma.*** A second extensional event (cf. 230 Ma Pangean extension by rifting) provided accommodation space for a second set of glaciogenic sediments, the Marinoan Elatina Formation and Pepuarta Tillite in Australia and Ice Brook and Mount Vreeland formations in Laurentia. The Marinoan saw the sea cross the Curnamona Craton, as shown in Fig. 5, column at east end of WX (Preiss 1987, p. 393–399). The corresponding facies in what had become the Mesozoic greenhouse climate was coal measures.

d) ***600–565 Ma.*** Mafic volcanism in Australia, including the voluminous Antrim Plateau (tholeiitic) Volcanics of the north and the Table Hill Volcanics of the centre and dykes in the southwest and Tasmania, accompanied the right-lateral shearing (Petermann Ranges Orogeny) that was transformed to seafloor spreading at the end of the Neoproterozoic. A 580 Ma trachyte in Utah (Christie-Blick & Levy 1989) is the only known possible equivalent in Laurentia.

e) ***ca 544 Ma = Neoproterozoic–Cambrian boundary.*** Breakup of Laurentia from Australia–Antarctica is interpreted in the cordilleran area of Laurentia from the pattern of subsidence (Bond et al. 1984, Kominz 1995) and in the Mackenzie Mountains from a spectacular regional angular unconformity in the latest Neoproterozoic (Narbonne & Aitken 1995). In Mexico, latest Neoproterozoic basalt in an otherwise non-igneous succession (Stewart et al. 1984, McMenamin & McMenamin 1990) may indicate breakup. The evidence of breakup in Australia is given above.

Conclusions

Palaeogeography

After a hiatus of some 200 million years, the Australian Neoproterozoic record started with ca 800 Ma mafic magmatism from a plume-head near Adelaide, which produced mafic volcanics interbedded with carbonates and evaporites in the Callanna Group of the Adelaide Rift Complex and dyke swarms to the northwest in the Gairdner and Amata areas. Correlatives of these rocks are not known elsewhere in Australia. This rift-volcanic event was followed by widespread subsidence and accumulation of Supersequence 1. The first sediments, mixed fluvial and shallow marine, were followed by interbedded stromatolitic carbonates and evaporites, including halite and anhydrite, deposited in peritidal to very shallow marine settings, and locally accompanied by mafic volcanism.

At about 700 Ma, Supersequence 2 started with the Sturtian glaciation, followed by thick widespread post-glacial silt and mud in an epeiric sea that shallowed up to peritidal carbonate and sand. Supersequence 3 started at about 610 Ma with the second (Marinoan) glaciation, with environments as for Supersequence 2. Diamictites were replaced by arkose, conglomerate, and arkosic sand, interpreted as glacial outwash deposits. A major eustatic rise in sea level at about 590 Ma followed deglaciation, with deposition of thick silt and shale in an epeiric sea. The Musgrave Block emerged from the middle of the Centralian Superbasin and shed coarse sediment to the north and south. The supersequence shallows up to peritidal carbonates, including extensive ooid and intraclast shoals, and evaporites in the southern Georgina Basin.

Supersequence 4 (about 580–544 Ma) began with a flooding event, during which turbiditic sands were deposited locally and coarse sediment was again shed from the Musgrave Block, bypassing the emergent southern part of the Superbasin and the central Amadeus Basin to form fluvial and shallow marine deltaic complexes in the north. Extensive tholeiitic lava covered the western Officer Basin and northern Australia (though the ages of these units are poorly known). What seems to have been a eustatic fall in sea level near the Proterozoic–Cambrian boundary exposed most of the Superbasin to subaerial conditions until fluvial and shallow marine deltaic conditions were re-established in the Early Cambrian.

Tectonics

The Adelaide Rift Complex is a Neoproterozoic intracratonic rift between the Gawler and Curnamona cratons, and the Centralian Superbasin an associated epicratonic sag elongated east–west at a high angle to the rift. The combined structures compare closely with the Palaeozoic–Mesozoic Perth Rift Complex and Canning and Amadeus Basins. During the Ediacarian, right-lateral shearing (Petermann Ranges Orogeny) caused thrusting and the emergence of the Musgrave Block, oriented east–west through the middle of the Superbasin.

Continental breakup in the northwest is indicated by the eruption of flood basalt during the Ediacarian, and at the Proterozoic–Cambrian transition in the southeast by a shift in provenance of the sediments, and volcanism on the newly formed margin. At this latter time the Flinders zone of the Adelaide Rift Complex was transformed to a failed arm. Sedimentation ceased before the Late Cambrian–Ordovician (500 Ma) Delamerian Orogeny.

According to the SWEAT hypothesis, Neoproterozoic Australia (with India and Antarctica) was joined to Laurentia, so that the Tasman Line faced the Canadian–Wyoming cordillera. The configuration of the north–south-trending Adelaide Rift Complex and the east–west-trending Centralian Superbasin is mirrored in the basins in Laurentia to form a T, which split at about 544 Ma.

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