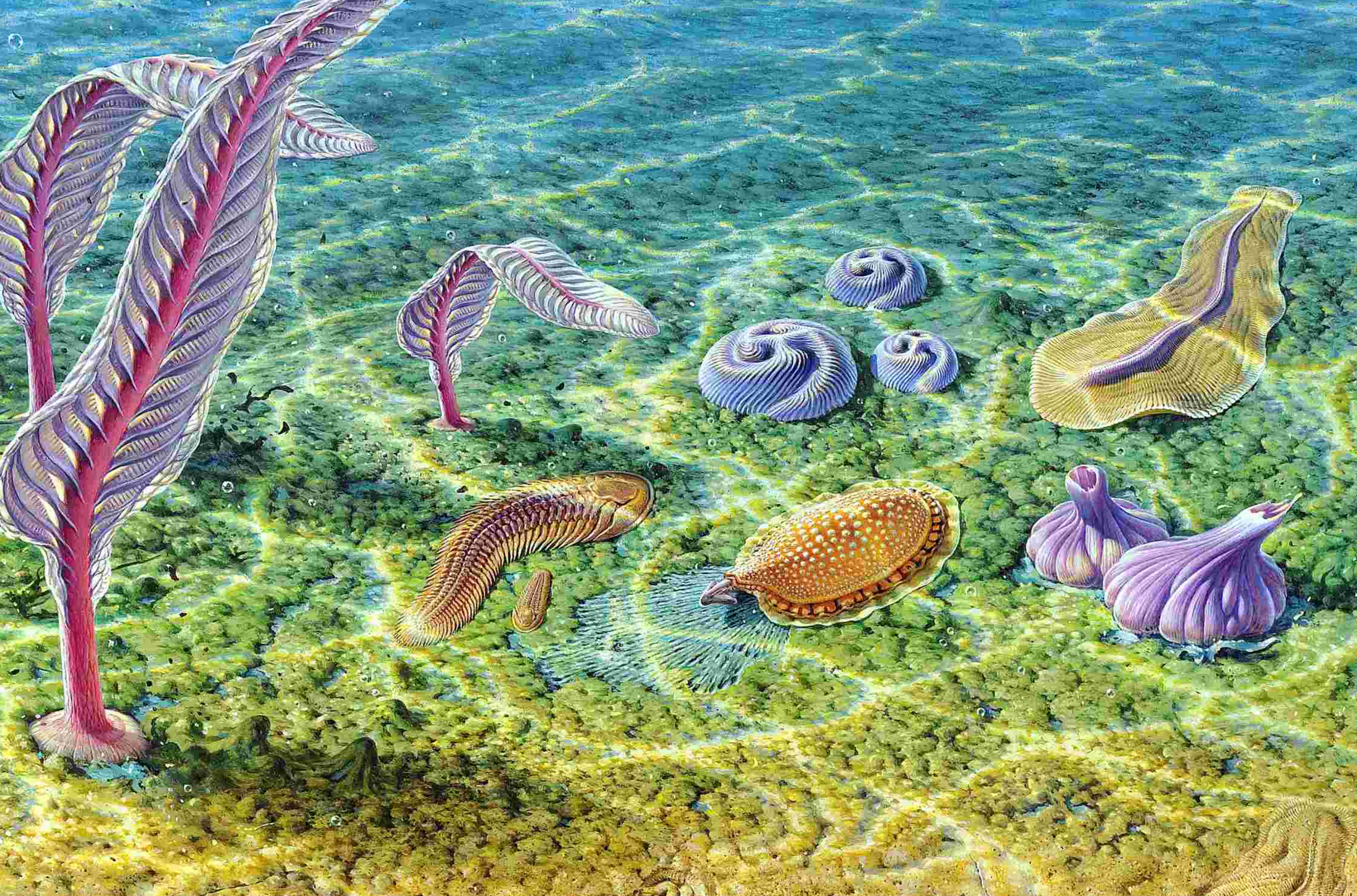

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Neoproterozoic extreme climates and the origin of early metazoan life

Thursday 25 September 2008

Fritz-Loewe Theatre, The University of Melbourne

Editors: Stephen J. Gallagher & Malcolm W. Wallace

The School of Earth Sciences,
The University of Melbourne,
Victoria 3010,
Australia.

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3. Biostratigraphic correlation of Neoproterozoic glacial successions in Australia

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Dr Kath Grey is Chief Palaeontologist at the Geological Survey of Western Australia, where she provides biostratigraphic and palaeoenvironmental data using stromatolites and acritarchs from the Archaean and Proterozoic for incorporation in GSWA maps and publications.

Australia-wide Neoproterozoic correlation and subdivision received a boost when the Ediacaran System and Period was ratified by the definition of a Global Stratotype and Section Point (GSSP) in the Flinders Ranges of South Australia. A revival of interest in hydrocarbon and mineral exploration in the extensive successions found in the Centralian Superbasin (the Officer, Amadeus, and Georgina Basins) and the correlative Adelaide Rift Complex has encouraged attempts to refine stratigraphy and correlation. Although geochronological constraints remain elusive, other methods have proved effective in improving subdivision of the Neoproterozoic and in advancing global correlation. These include lithostratigraphy, carbon and strontium isotope chemostratigraphy, palynology, and stromatolite biostratigraphy. Application of these methods produces internally consistent correlations.

To date, no unequivocal Tonian-aged successions (1000–850 Ma) have been identified in Australia. Part of the Callanna Group in the Adelaide Rift Complex may be Tonian, and the Townsend Quartzite, Pindyan Sandstone, Lefroy and Alinya Formations in the Officer Basin, the Kulail Sandstone, Dean and Heavitree Quartzites in the Amadeus Basin and lateral equivalents in the Georgina Basin could be Tonian if there is a stratigraphic break between these units and the Bitter Springs Formation and its lateral equivalents. Other possible Tonian successions include the Badgeradda, Cardup and Moora Groups around the Yilgarn Craton margins, the Lamil and Throssell Range Groups along the northeastern Pilbara margins, and the Rocky Cape Group in Tasmania.

By contrast, Australia has extensive Cryogenian and Ediacaran successions that can be readily correlated (Fig. 3.1). Pending decisions of the International Subcommission on Neoproterozoic (Cryogenian and Ediacaran) Stratigraphy, Cryogenian is here taken as extending from the chronometrically defined base at 850 Ma, through the currently chronometrically defined top at 650 Ma, to include the overlying interval up to the chronostratigraphically defined base of the Ediacaran System and Period at the base of the Nuccaleena Formation in the Flinders Ranges of South Australia.

Cryogenian-age rocks, including the Sturtian and Elatina glaciations (for discussion of the terms Marinoan and Elatina glaciations see Williams et al., 2008) are present in the Officer, Amadeus, Georgina, Ngalia, Birrindudu, and Wolfe Basins, Adelaide Rift Complex, Tasmania and are widespread in the Kimberley and elsewhere across northern Australia. The Ediacaran succession is more restricted, but is present in the Officer, Amadeus, Georgina, Ngalia and Kimberley areas, and Adelaide Rift Complex, and possibly in Tasmania.

Precise U-Pb zircon and baddellyite dating for the Cryogenian and Ediacaran is limited but provides significant constraints (see Preiss, 2000). Sedimentation post-dates the Warakurna large igneous province and began after intrusion of the Stuart and Kulgera dyke swarms c.1080 Ma.

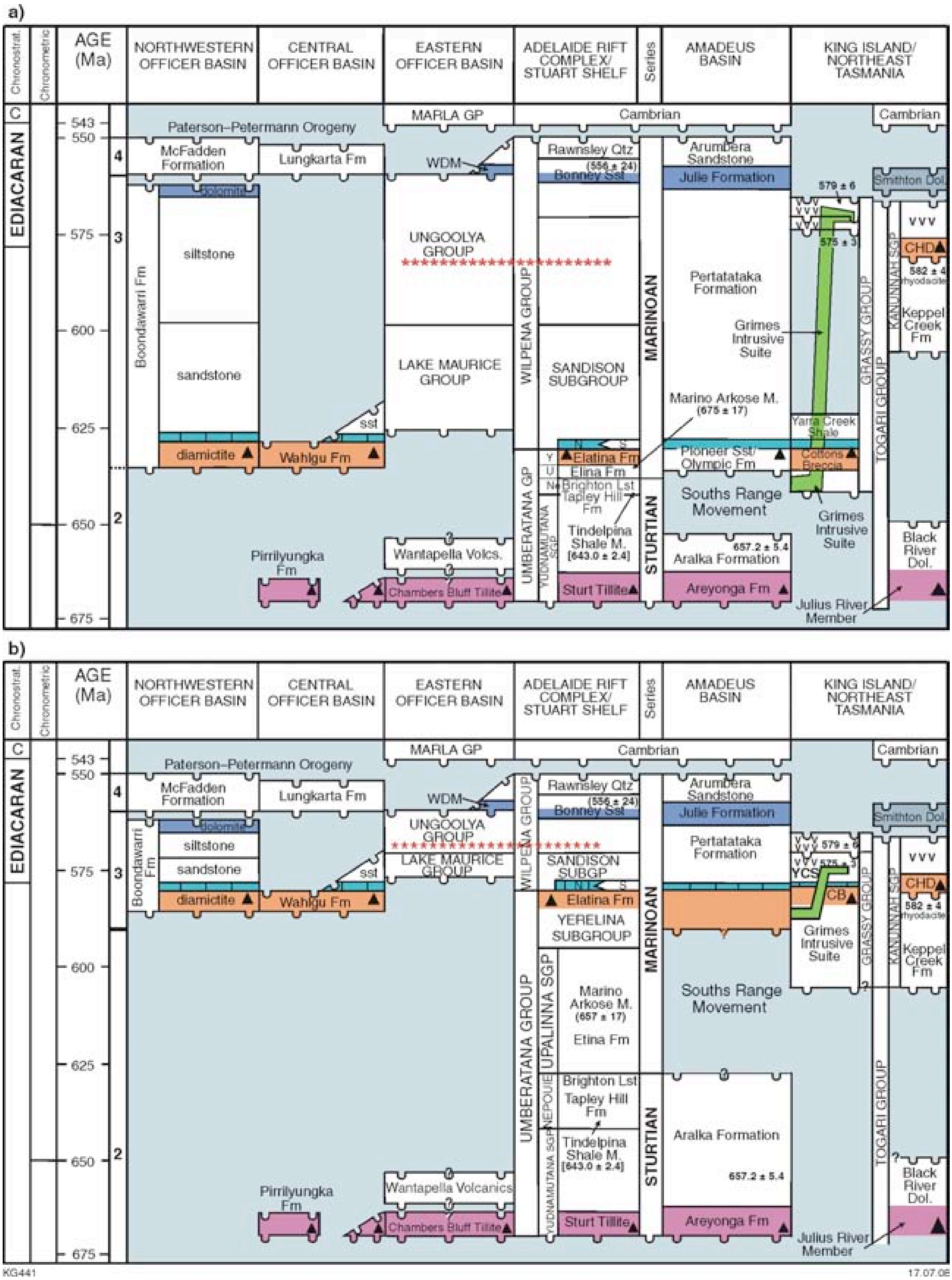

Fig. 3.1. Proposed correlation of selected stratigraphic units in Australia for the Officer and Amadeus Basins, Adelaide Rift Complex, Stuart Shelf, King Island and Tasmania. A) Assuming an age of c. 635 Ma for the Elatina glaciation and equivalents and B) assuming an age of 580 Ma for the Elatina glaciation and equivalents. CB, Cottons Breccia; CHD, Croles Hill Diamictite; Ne, Nepouie Subgroup; N, Nuccaleena Formation; S, Seacliff Sandstone; U, Upalinna Subgroup; WDM, Wilari Dolomite Member; Y, Yerelina Subgroup; YCS, Yarra Creek Shale; Dol., Dolomite; Fm, Formation; GP, Group; SGP, Subgroup; M, Member; Lst, Limestone; Qtz, Quartzite; Volcs, Volcanics; sst, sandstone; VVV, volcanics;

triangle, diamictite; asterisks, Acraman impact ejecta layer.

The younger Gairdner and Amata dyke swarms may slightly post-date the onset of deposition and provide zircon ^{207}Pb–^{206}Pb, U–Pb and baddellyite ages of 824–827 Ma. A Sm–Nd isochron of 802±35 Ma on a Stuart Shelf dyke and concordant U–Pb SHRIMP zircon age of 802±10 Ma on the Rook Tuff constrain the age of the Callanna Group. Rhyolite from the Boucaut Volcanics at the base of the Burra Group has a U–Pb SHRIMP zircon age of 777±7 Ma. A detrital zircon U–Pb SHRIMP age of 725±11 Ma from the upper Kanpa Formation gives a maximum age for Sturtian glaciation in the western Officer Basin (Grey et al., 2005; Haines et al., 2008). Of particular significance is a U–Pb SHRIMP age of 658 Ma on an ash bed within the Merinjina Tillite, a Sturt Tillite equivalent, which provides a definitive age for the Sturtian glaciation in Australia (Fanning and Link, 2006).

There is only limited dating above the Sturtian glaciation (Fig. 3.1). Re–Os ages of 657.2±5.4 Ma from the Aralka Formation in the Amadeus Basin, 643±2.4 Ma on the Tindelpina Shale Member of the Tapley Hill Formation in the Adelaide Rift Complex and 640.7±4.7 Ma from just above the glacial Julius River Member in northwest Tasmania are consistent with a c.658 Ma age for the Sturtian glaciation. Higher in the succession, a sedimentary zircon grain of 657±17 Ma (similar to the Merinjina Tillite age) places a maximum age constraint on the Marino Arkose Member. Other dates in this part of the succession are based on Rb–Sr isochrons from sedimentary rocks and are considered unreliable (Preiss, 2000).

The age of the younger Elatina glaciation remains uncertain, but because the Ediacaran boundary is placed at the base of the Nuccaleena Formation, the underlying diamictite and its lateral equivalents across Australia is here included in the Cryogenian. There is a widely accepted view that the Elatina Formation and overlying Nuccaleena Formation (the 'cap carbonate') correlates with the 635.5±1.2 Ma Ghaub Formation in Namibia and a 635.2±0.6 Ma ash bed within the cap dolostone above the Nantuo Tillite in China (Fig. 3.1). However, dating of glacial successions in King Island and Tasmania (Calver et al., 2004) suggests an alternative correlation (Fig. 9.3 Calver abstract this vol.).

On King Island, the Cottons Breccia, a diamictite containing compelling evidence for glaciation, and an overlying a cap carbonate, the Cumberland Creek Dolostone, bear a strong lithological resemblance to the Elatina and Nuccaleena Formations. The case for correlating these neighbouring glacial units is robust (Calver, 1998; Calver and Walter, 2000; Calver et al., 2004). The King Island glacial succession plus part of the overlying Yarra Creek Shale, is intruded by a 575±4 Ma intermediate sill from the Grimes Intrusive Suite (dated at 575±3 Ma) and overlain by the tholeiitic Bold Head Volcanics with a Sm-Nd age of 579±16. At present there is no maximum constraint on the King Island glacials. However, in northwest Tasmania, the Croles Hill Diamictite, a possible correlative of the Cottons Breccia (Fig. 9.3), overlies a rhyodacite with a SHRIMP U-Pb age of 582±4 Ma (Calver et al., 2004). There is no cap carbonate, but a thin red mudstone marks the top of the unit. If the Cottons Breccia and Croles Hill Diamictite are both correlatives of the Elatina Formation, then the Elatina Formation (and consequently the base of the Ediacaran) is c.580 Ma, about the same age as the Gaskiers Formation in North America, and the Nantuo and Ghaub Formation glaciations represent a glacial episode older than the Elatina glaciation in Australia. A c.580 Ma age for the Elatina Formation and Cottons Breccia is a better fit with the 658 Ma age for the Merinjina Formation because a c.635 Ma age leaves little time (23 m.y. compared to 78 m.y.) to accumulate the thick upper Sturtian Stage and basal Marinoan Stage succession below the Elatina Formation (Fig. 9.1). Disparities in the acritarch record could also be explained if the Elatina Formation does not correlate with the Nantuo Diamictite. If the Elatina Formation does correlate with the Nantuo Diamictite, there has to be a large time gap (60 m.y.) between the glaciation and the Grimes Intrusive Suite, despite evidence for shallow intrusion. If this is the case, the Cottons Breccia and the Elatina Formation would be correlatives and the same age as the Nantuo and Ghaub Formations, but the Cottons Breccia would not be correlative with the Croles Hill Diamictite, but represent a younger glaciation (Fig. 3.1). Currently, there is no firm evidence to support one or the other interpretation.

Constraints on successions above the glaciation are poor. A Rb–Sr whole rock isochron of 588±35 Ma on the postglacial Bunyeroo Formation could be one of the more reliable indicators of depositional age (Preiss, 2000). The Acraman impact event has not been precisely dated but was estimated to be c.580 Ma (Williams and Gostin, 2005). However, if the Elatina Formation glaciation age is 580 Ma, then the best estimate for the age of the Acraman impact is c.570 Ma. Higher in the succession, a sedimentary zircon grain of 657±17 Ma (similar in age to the Merinjina Tillite ash bed) places a maximum age constraint on the Marino Arkose Member. A single detrital zircon grain from the lower part of the Rawnsley Quartzite, many hundreds of metres above the glaciation and below the first bilaterians of the Ediacara fauna, dated at 556±24 Ma, may record penecontemporaneous volcanism (Preiss, 2000), and provides the only constraint on the upper Ediacaran.

Turning to other methods of correlation, the Cryogenian part of the succession can be correlated using lithostratigraphy, stromatolite biostratigraphy and isotope chemostratigraphy, supported by palynology. Correlations between certain drill holes in the Officer Basin can be established through well-log data and seismic interpretation (Gorter et al., 2007). In addition, analyses of fully cored drill holes in the western Officer Basin, especially Empress 1A and Lancer 1, and Wallara 1 in the Amadeus Basin, confirm correlations based on field sections and other drill holes across Australia (Grey et al., 2005).

Carbon and strontium isotope curves for the Cryogenian in the Adelaide Rift Complex and Centralian Superbasin were later extended to Empress 1A and Lancer 1 in the western Officer Basin and preliminary results from biostratigraphy and isotope stratigraphy were integrated in an overview of the Australian Cryogenian succession (Hill and Walter, 2000; Hill et al., 2000; Hill, 2005). The reliability of this integrated approach was further tested by examination of the biostratigraphy Wallara 1 from the Amadeus Basin.

Overlying Ediacaran successions are well correlated using both stable isotope chemostratigraphy and palynology and demonstrate what can be achieved through the application of integrated correlation methods (Grey and Calver, 2007). Biostratigraphic correlation is increasingly significant for Australian Cryogenian and Ediacaran successions and includes the use of chert microfossils, palynology and stromatolite biostratigraphy. Palynology in particular, based to a large extent on continuous core, provides good biostratigraphic control as well as indicating palaeoenvironment and thermal maturity, although much of the data remains unpublished. Cryogenian chert microfossils and palynological assemblages consist predominantly of leiospheres, filaments and mat fragments, mostly of conservative, long-ranging species with simple morphologies, but there are intervals dominated by more elaborate, shorter ranging taxa that are potential biomarkers. Several problems remain, in particular, correlation of assemblages from the Alinya Formation of the eastern Officer Basin remains uncertain. However, where acritarch and microfossil distributions in Australian successions have been studied extensively, they show consistent distribution patterns.

Similar palynological successions are present in Empress 1A and Lancer 1, and are known from several other Officer Basin drill holes. Of particular significance is the distinctive acritarch *Cerebrosphaera buickii*, which consistently first appears about the middle of the Hussar Formation in the western Officer Basin (Hill et al., 2000). In the Adelaide Rift Complex, it is present at about the same level in the Burra Group and has been recorded from an Emeroo Subgroup equivalent in drill hole PP 12 and the Skillogalee Dolomite (in drill hole BLD 4) in the middle of the Burra Group in the Adelaide Rift Complex (Hill et al., 2000a), above the dated (777±7 Ma) Boucaut Volcanics (Preiss, 2000). The same species was recently identified in an informally named unit above the Bitter Springs

Formation in Wallara 1 in the Amadeus Basin.

Vase-shaped microfossils are locally abundant in chert beds in the Black River Dolomite below the Julius River Member in Tasmania (Saito et al., 1988), and are consistent with an age pre-dating the Sturtian glaciation. Although one or two specimens have been recorded elsewhere in Australia, they have not been found in any large numbers and do not appear to be widely distributed in any of the successions examined so far.

Sturtian glacial and post-glacial assemblages are poorly known throughout Australia, but are sometimes characterized by reworked fragments of *Cerebrosphaera buickii*. Above the level of the Elatina glaciation, the Ediacaran acritarch succession is well documented across Australia, apart from the interval immediately above the glaciation, where samples are barren. Only a handful of species survived the two major glacial episodes. Post-glacial benthic mats and leiospheres quickly re-established and flourished as sea level and temperatures rose, but there is no obvious post-glacial species diversification; the limited species present are ones that were present before the Sturtian glaciation and there is no evidence of invasion by non-shelfal species from glacial refugia. Specimen numbers increased rapidly with rising sea level, but no new taxa were identified below the Acraman impact ejecta layer.

In Australia, a major diversification in acritarch species occurs several hundred metres above the glaciation and is associated with the second sea-level rise after the glaciation (Grey, 2005; Grey and Calver, 2007). Correlations based on palynological distributions have been tested against results from isotope chemostratigraphy, seismic interpretation, stromatolite biostratigraphy, and the appearance of the Ediacara fauna, and found to be consistent despite the poor absolute dating. In the eastern Officer Basin, the Amadeus Basin, in the Adelaide Rift Complex (and to a much lesser extent the Georgina Basin) extremely well preserved acritarch assemblages are present and are consistent across Australia (Grey, 2005; Willman et al., 2006; Willman and Moczyd_owska, 2008). The first process-bearing acanthomorphs of the Ediacaran Complex Acanthomorph Palynoflora (ECAP) do not appear until several hundred metres above the Elatina Formation glaciation and its lateral equivalents and the palynoflora seems to have been of relatively short duration, becoming extinct by c.550 Ma or even earlier.

Stromatolite biostratigraphy is based on extensive field collections, together with >70 horizons examined in drill core. Detailed studies of Empress 1 and 1A and Lancer 1 successions demonstrate that the drill holes can be tied to other drillholes (some of which do not have such continuous cores) and to outcrop, by means of lithostratigraphy, seismic and well log data, and isotope chemostratigraphy. In nearly all cases, the ranges shown by acritarchs and stromatolites are consistent across the various basins and correspond to the correlations determined by independent methods. These correlations can be demonstrated to apply to Cryogenian successions elsewhere in Australia (Hill et al., 2000).

The pre-Sturtian-glaciation part of the Cryogenian is characterised by two widespread but apparently time restricted stromatolite assemblages; the *Acaciella australica* Stromatolite Assemblage in the lower part of the succession, and the *Baicalia burra* Stromatolite Assemblage in the upper part of the succession (Hill et al., 2000; Grey et al., 2005; Mory and Haines, 2005). Two other assemblages, the *Inzeria multiplex* Stromatolite Assemblage and the *Linella munyallina* Stromatolite Assemblage can be recognized in the interglacial part of the succession, but so far the taxa are restricted mainly to the Adelaide Rift Complex. In addition to the stromatolites occurring in the main assemblages, several other stromatolites have been recorded at various levels throughout the Neoproterozoic of Australia but are of limited stratigraphic significance. *Anabaria juvensis* (=*Elleria minuta*) may be useful for correlating the cap carbonate, and higher in the succession, *Tungussia julia* allows correlation of the

Julie Formation, the basal Bonney Sandstone and the Egan Formation.

At present, contradictions arise when global correlations are attempted, especially in matching Australian and Chinese Neoproterozoic successions based on acritarchs. Discrepancies between the two successions and the recently reported age of 658 Ma for the Merinjina Tillite raise doubts about the Sturtian glaciation as a synchronous global event and about whether the Nantuo Tillite correlates with the Elatina Formation. Prospects for resolving these issues and for further Neoproterozoic subdivision using biostratigraphy are excellent, provided taxonomic ranges are adequately documented. Continuing improvements in biostratigraphic correlation and its integration with isotope chemostratigraphy and available geochronology, sequence stratigraphy, seismic interpretation and lithostratigraphy should enhance both hydrocarbon and mineral exploration in Neoproterozoic successions, and provide a better framework for model development for hydrocarbon prospectivity in the Officer Basin. It should also increase understanding of the stratigraphic and tectonic setting of the Centralian Superbasin and Adelaide Rift Complex.

Finally, in considering a suitable point for a basal Cryogenian GSSP, it is necessary to pick a boundary that stands a reasonable chance of being identified globally. The older Cryogenian in Australia, although characterized by the *Acaciella australica* assemblage is still too poorly documented elsewhere in the world to be used as a suitable base. In Australia, there are significant gaps in the succession, or the succession is known only in drillholes. Moreover, many researchers investigating the positioning of the GSSP have expressed the view that this should be a geological period characterised by glaciation. Where the c.830–800 Ma interval has been documented, it seems to be dominated by an arid climate, and it is at least another 75 million years (nearly as long an interval as the Cretaceous Period, the longest of the Phanerozoic periods) before glaciation becomes widespread. It would be better to establish the boundary closer to the glaciation, and the near coincidence between the first appearances of *B. burra*, *C. buickii*, and a major carbon isotope excursion may be a much more appropriate position for the boundary.

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