

Fossil protists (algae and testate protozoans) in the marine Phanerozoic of Western Australia: a review through latitudinal change, climate extremes, and breakup of a supercontinent

DAVID W HAIG^{1*}, CLINTON B FOSTER², RICHARD W HOWE¹, DANIEL MANTLE³, JOHN BACKHOUSE¹, DANIEL PEYROT¹, JESSE VITACCA¹

¹ School of Earth Sciences, The University of Western Australia, 35 Stirling Highway, Perth WA 6009, Australia

² Research School of Earth Sciences, The Australian National University, Building 142, Mills Road, Canberra ACT 2601, Australia

³ MGPalaeo Geological and Stratigraphical Consultants, Unit 1, 5 Arvida St., Malaga WA 6090, Australia

* Corresponding author: ✉ david.haig@uwa.edu.au

Abstract

Algae and testate protozoans in Western Australian Cambrian–Neogene marine deposits are reviewed in terms of their broad occurrence. Known groups include: organic-walled unicellular phytoplankton, mostly algae (acritarchs and dinoflagellates); calcareous unicellular algal phytoplankton (calcareous nannoplankton and calcareous dinoflagellate cysts); benthic calcareous macroalgae as well as the enigmatic *Tubiphytes*; testate protozoans, including Foraminifera and Radiolaria; and groups of uncertain affinity including calcareous tests of *Calcitarcha*, tuberitids, *Draffania*, and possible Charophyta. A record of calpionellids from the uppermost Jurassic of the Canning Basin is discounted. In addition to the groups listed above, stromatolites and calcareous and organic-walled cyanobacteria are considered and chitinozoans are included in this discussion although their biological group affinities are uncertain. The stratigraphic and geographic distribution of these fossil groups depended mainly on: (1) major evolutionary events; (2) latitudinal position from warm low latitudes in the Northern Hemisphere during the Early Paleozoic, to cold high latitudes in the Southern Hemisphere during the Pennsylvanian and earliest Permian, and later to warmer mid southern latitudes; and (3) the nature of the sedimentary basins and the seas that inundated these regions during phases of breakup of the Gondwana supercontinent. The basins developed within the interior of East Gondwana during the Paleozoic to middle Mesozoic and then along a continental margin newly formed by the progressive north–south opening of the Indian Ocean from the Middle Jurassic to Early Cretaceous. These changes in ocean configuration led to a significant diversification of dinoflagellates, calcareous nannoplankton, and Foraminifera: all of which are important stratigraphic guide fossils in the Jurassic to Cretaceous strata.

Keywords: Paleozoic, Mesozoic, Cenozoic, Acritarchs, Dinoflagellates, Calcareous nannofossils, Macroalgae, Foraminifera, Radiolaria, Western Australia

Manuscript received 8 August 2018; accepted 19 December 2018

INTRODUCTION

Marine deposits of each Phanerozoic system from the Cambrian to the Quaternary are present in sedimentary basins on mainland Western Australia and on the adjacent continental shelf and contiguous deep-water marginal plateaus (Geological Survey of Western Australia 1990). The Paleozoic and early Mesozoic marine record is from basins that were positioned in the interior of East Gondwana (Fig. 1A, C). These shallow-marine basins are confined mainly to the north of the State with a marine influence extending as far south as the central Perth Basin (Jurien area) during some periods. Broad-scale climate variation in interior East Gondwana ranged from equatorial warm and dry conditions during the early and middle Paleozoic to high-latitude continental ice cover during part of the Pennsylvanian (Late Carboniferous) followed by alternating cool and warm intervals during the Permian and a warm wet phase

during the Mesozoic (Tables 1–5). The late Mesozoic and Cenozoic marine basins developed on the newly formed margin of the Australian continent (Fig. 1B). Breakup of Gondwana that led to the formation of the Indian Ocean took place progressively from the late Middle Jurassic (ca. 165 Ma) in the Timor Sea region, to Late Jurassic (ca. 155 Ma) in the Argo Abyssal Plain north of Exmouth Plateau, to Early Cretaceous (ca. 136 Ma) in the Perth Abyssal Plain (Metcalf 2011; Haig & Bandini 2013; Heine & Müller 2005; Gibbons *et al.* 2013). The Southern Ocean started to open along the southern margin of Western Australia during the Late Cretaceous (ca. 83.5 Ma; Williams *et al.* 2011).

A great diversity of fossil protists, including algae and testate protozoans, is known from the marine deposits (Tables 1–5). The published record of algae comprises: (a) organic-walled unicellular phytoplankton including acritarchs, of uncertain affinity but some probably algae, from the Ordovician to Cretaceous (Fig. 2A–C), and algal dinoflagellates from the Triassic to Cenozoic (Fig.

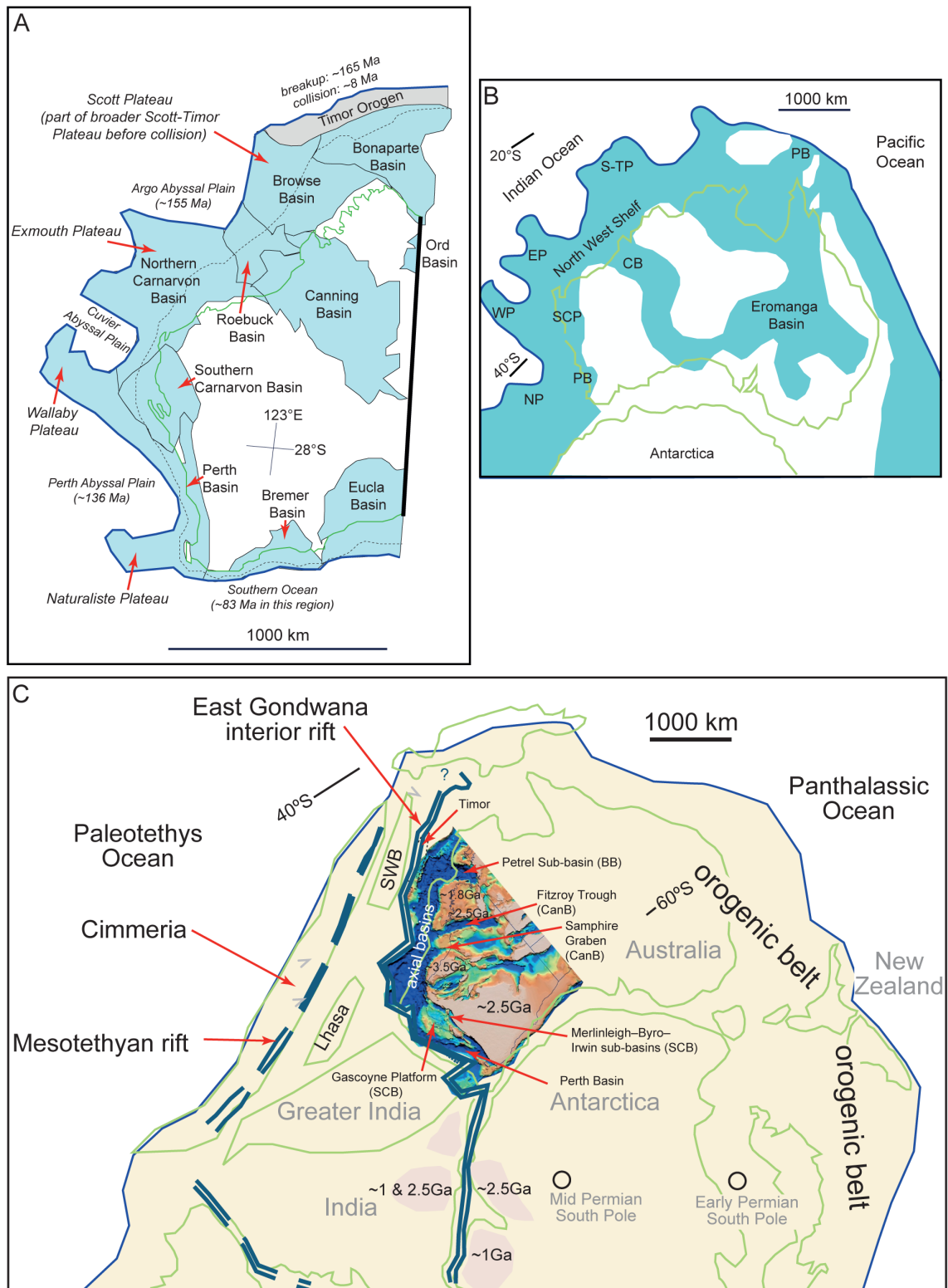


Figure 1. Western Australian Phanerozoic sedimentary basins containing marine strata and examples of past continent configurations. A, Present-day position of basins, shoreline (green line) and the ocean–continent boundary (blue line). The approximate ages of opening of the Indian Ocean and of collision in the Timor region are given in “Ma” units (millions of years before present; see text for references). B, Australian–Antarctic continent reconstruction at about 100 Ma (late Early Cretaceous) and the extent of shallow marine flooding across the continent (blue area; after Henderson *et al.* 2000). C, Reconstruction of East Gondwana at about 290 Ma (Early Permian, Sakmarian), with Western Australia shown by a basement terrane map (compiled by FROGTECH, www.frogtech.com.au) with dark blue areas outlining late Paleozoic depocentres (modified from Haig *et al.* 2017).

2G–I); (b) calcareous unicellular algal phytoplankton (calcareous nannoplankton from the Late Triassic to Cenozoic; and calcareous dinoflagellate cysts from the Early Cretaceous); and (c) benthic calcareous macroalgae from the Devonian, Carboniferous, Triassic, and Cenozoic and the enigmatic *Tubiphytes* from the Permian (Fig. 3). The testate protozoans include Foraminifera (Devonian to Cenozoic, Fig. 4) and Radiolaria (Devonian, Cretaceous, Cenozoic). Remane (1971, 1985) disputed Brunnenschweiler's (1951, 1960) record of calpionellids from the uppermost Jurassic of the Canning Basin. These small test-like structures require detailed re-examination to establish their true affinities and are not discussed further. In addition to the groups listed above, stromatolites and calcareous and organic-walled cyanobacteria reported from the Phanerozoic of Western Australia are also considered as well as microfossil groups of uncertain affinities from the Devonian and Carboniferous (calcareous tests of Calcitarcha, tuberitnids, *Draffania*, and possible Charophyta). Because of their small size, simple flask-like morphology and organic-walled test, chitinozoans that are known from the Ordovician and Silurian, are also included in this discussion although their biological group affinities are uncertain.

Different methods are used for the extraction from rock and preparation for study of the algae and testate protozoans (Kummel & Raup 1965). Most of these fossils are minute and large assemblages with many thousands of specimens can be recovered from small rock samples, including core and cuttings from boreholes. Palynomorphs, including the organic-walled cyanobacteria, acritarchs, dinoflagellates and chitinozoans, are usually extracted from mudstone, muddy sandstone, or muddy limestone by digestion in acid, including hydrofluoric acid under highly controlled conditions. The residues are routinely viewed on strew slides under a transmitted-light microscope. Calcareous fossils preserved in limestone including stromatolites, calcareous cyanobacteria, calcareous macroalgae, some of the problematic calcareous algal microfossil groups and calcareous testate protozoans (e.g. many Foraminifera) are studied in thin sections of the rock or in acetate peels, including serial peels, of slabbed limestone surfaces. These are viewed using transmitted-light microscopy. Free specimens of protists with mineralized tests (particularly Foraminifera) are extracted from friable mudstone by disaggregation of the rock and wet sieving, with specimens picked from washed residues using a fine 000 sable-haired brush and mounted onto gridded cardboard microfossil slides. These are routinely viewed under reflected light using a stereomicroscope. Siliceous testate protozoans (radiolarians and organic-cemented siliceous agglutinated Foraminifera) may be extracted from calcareous rocks by digestion of the rock in dilute hydrochloric acid, or from siliceous rocks by digestion, under highly controlled conditions, using dilute hydrofluoric acid. Recently new imaging techniques have become available that are enhancing the description and illustration of the microfossils. These include rendering of multifocal images of three-dimensional microfossils taken under reflected light to produce composite images in sharp focus; micro-CT scanning; and Focused Ion Beam (FIB) imaging.

Stratigraphic ranges of particular species of acritarchs (Ordovician to Triassic) chitinozoans (Ordovician), dinoflagellates (Triassic to Cenozoic), Foraminifera (Late Devonian to Cenozoic) and calcareous nannofossils (Late Triassic to Cenozoic) have great significance in resource exploration in the Western Australian sedimentary basins, particularly for petroleum, water, and geothermal energy exploration. Zonations based on stratigraphic ranges of species are used to define stratigraphic level and age, and for correlation of rock successions within basins, between basins and globally. The distribution patterns of species are compared to modern analogues and used in modelling sedimentary environments in order to build detailed palaeogeographic maps that are used as predictive tools in resource exploration.

This review has three major aims focussed on Western Australian basins. (1) Document the published fossil record of marine algae and testate protozoans from the Cambrian to Neogene. The Quaternary biota is not covered as it is very similar to the modern flora and fauna. (2) Review the significance of selected groups that are particularly important in evolutionary, ecological, or biogeographic studies. (3) Note gaps in the record that may be filled by future study.

SUMMARY OF PUBLISHED RECORD

General background

The presence of marine fossil groups in Western Australian basins is influenced by inter-related factors including: (1) major global geological events; (2) changes in palaeolatitude; (3) changes in climate; (4) changes in local palaeogeography; and (5) marine depositional cycles involving variation in local sea-level caused by tectonic subsidence or uplift and by eustatic (global) sea-level change (Tables 1–5). During Phanerozoic time, Western Australia has been subject to continual change in these factors and this has led to the evolution of our modern fauna and flora.

Knowledge of the fossil groups also depends on the availability of outcrop or of samples from subsurface sections. Much information on groups used for resource exploration remains unpublished either in company proprietary archives or in open-access archives that are now available via the on-line Western Australian Petroleum and Geothermal Information Management System (WAPIMS) of the Geological Survey of Western Australia or the National Offshore Petroleum Information Management System (NOPIMS) of Geoscience Australia. This information is not reviewed here. The published record of algae and testate protozoans is discussed below for five intervals, each summarized on a different table (Tables 1–5).

Early Paleozoic interior seas (20°N–20°S)

Limited successions of marine Cambrian to Silurian strata are available for study in Western Australia (Playford *et al.* 1975; Mory 2017; Table 1). Stromatolites are described only from the Cambrian and organic-walled cyanobacteria, acritarchs, and chitinozoans are known only from subsurface sections of the Ordovician and Silurian. As more borehole sections are cored

Table 1. Summary chart listing key references for protists from Cambrian to Silurian marine strata in Western Australia. Time scale follows Cohen *et al.* (2017); global events follow Gradstein *et al.* (2012); latitudinal range follows Li & Powell (2001); palaeogeography and climate follows Li & Powell (2001) and Mory (2017). Depositional cycles are modified from Trendall & Cockbain (1990). Asterisk after reference indicates species listed but not illustrated.

AGE (Ma)	PERIOD	GLOBAL EVENTS	LATITUDE	CLIMATE	PALAEOGEOGRAPHY	MARINE DEPOSITIONAL CYCLES	BIOTA (KEY REFERENCES)
419	SILURIAN					s	
444		Mass extinction at end of Ordovician; Late Ordovician widespread glaciation; Middle Ordovician cooling	20°N–20°S	tropical dry	Interior East Gondwana, shallow seas flooding from North and probably West; marine influence known as far south as Kalbarri region; highly saline seas during some intervals suggesting arid hinterland during these times	regional hiatus	Stromatolites Cam 2: Etheridge 1917 Cam 1: Grey 1985
	ORDOVICIAN					O	Organic-walled cyanobacteria S: Gorter <i>et al.</i> 1994* O: Foster & Wicander 2016; Spaak <i>et al.</i> 2017
485							Organic-walled unicellular phytoplankton of uncertain affinity (some probably algal): Acritarchs S: Edgell 1963a*; Gorter <i>et al.</i> 1994* O: Combaz & Peniguel 1972; Playford & Martin 1984; Quintavalle & Playford 2006a, 2008; Spaak <i>et al.</i> 2017
	CAMBRIAN			tropical	Interior East Gondwana: shallow sea flooding from North, confined to northern-most basin (Bonaparte Basin)	Cam 2	Incertae sedis: Chitinozoans S: Edgell 1963a* O: Combaz & Peniguel 1972; Winchester-Seeto <i>et al.</i> 2000a, b; Quintavalle & Playford 2006b; Spaak <i>et al.</i> 2017
541		Spectacular diversification of burrowing metazoans and metazoans with mineralized skeletons during earliest Cambrian				Cam1	

Table 2. Summary chart listing key references for protists from Devonian to Carboniferous marine strata in Western Australia. Time scale follows Cohen *et al.* (2017); global events follow Gradstein *et al.* (2012); latitudinal range follows Li & Powell (2001); palaeogeography and climate follows Li & Powell (2001) and Mory (2017). Depositional cycles are modified from Trendall & Cockbain (1990). Asterisk after reference indicates species listed but not illustrated.

AGE (Ma)	PERIOD and EPOCH	GLOBAL EVENTS	LATITUDE	CLIMATE	PALAEOGEOGRAPHY	MARINE DEPOSITIONAL CYCLES	BIOTA (KEY REFERENCES)
299	CARB. (PENNSYLVANIAN)	Global warm spike in latest Pennsylvanian	0° (Devonian) to 40°S (late Pennsylvanian)	Rapid warming leading to melting of ice sheet at ~ 300 Ma	Interior East Gondwana: major hiatus in sedimentation in most basins because of ice-sheet cover; marine deposition continued in northern areas of East Gondwana interior rift system; major rifting during this time led to changes in interior basin configuration		Stromatolites D2: Fenton 1943; Playford & Cockbain 1969; Playford <i>et al.</i> 1976; Grey 1982 Benthic calcareous cyanobacteria C1–D2: Mamet & Roux 1983 D2: Wray 1967 Organic-walled unicellular phytoplankton of uncertain affinity (some probably algae) Acritarchs D–C, D2: Playford 1976, 1981; Playford & Dring 1981
323		Rapid cooling giving rise to continental ice sheet over much of East Gondwana		Rapid cooling leading to continental ice sheet after ~ 315 Ma		C1	Calcareous microalgae (?) of uncertain affinities and life mode Calcitarcha C1: Veevers 1970; Mamet & Roux 1983; Vachard <i>et al.</i> 2014 D–C, D2: Wray 1967; Veevers 1970; Mamet & Roux 1983 Tuberitinids C1: Vachard <i>et al.</i> 2014 Incertae sedis <i>Draffania</i> D2: Belford 1967
359	DEVONIAN	Mass extinction at Frasnian–Famennian boundary (~372 Ma)	0° (Devonian) to 40°S (late Pennsylvanian)	tropical dry	Interior East Gondwana: shallow seas flooding East Gondwana interior rift system from North and possibly West; marine influence known as far south as near Kalbarri; during Mississippian progressively higher salinity conditions were prevalent in very shallow sea in southern region (Southern Carnarvon Basin)	D–C	Benthic calcareous macroalgae (Solenoporaceans, codiaceans, ?dasycladaleans, Bryopsidales; "incertae sedis algae Algospongia" of Vachard <i>et al.</i> 2014) C1: Veevers 1970; Mamet & Roux 1983; Vachard <i>et al.</i> 2014 D–C, D2: Wray 1967; Veevers 1970; Riding & Jansa 1976; Mamet & Roux 1983 ? Charophyta C1: Vachard <i>et al.</i> 2014 D–C, D2: Edgell 2003
419						D2	Benthic testate protozoans Foraminifera C1: Vachard <i>et al.</i> 2014 C1, D–C: Mamet & Belford 1968*; Belford 1970 D–C: Edgell 2004 D2: Crespin 1961; Conkin & Conkin 1968; Belford 1970 Radiolaria D2: Nazarov <i>et al.</i> 1982; Nazarov & Ormiston 1983; Aitchison, 1993; Won, 1997a, 1997b

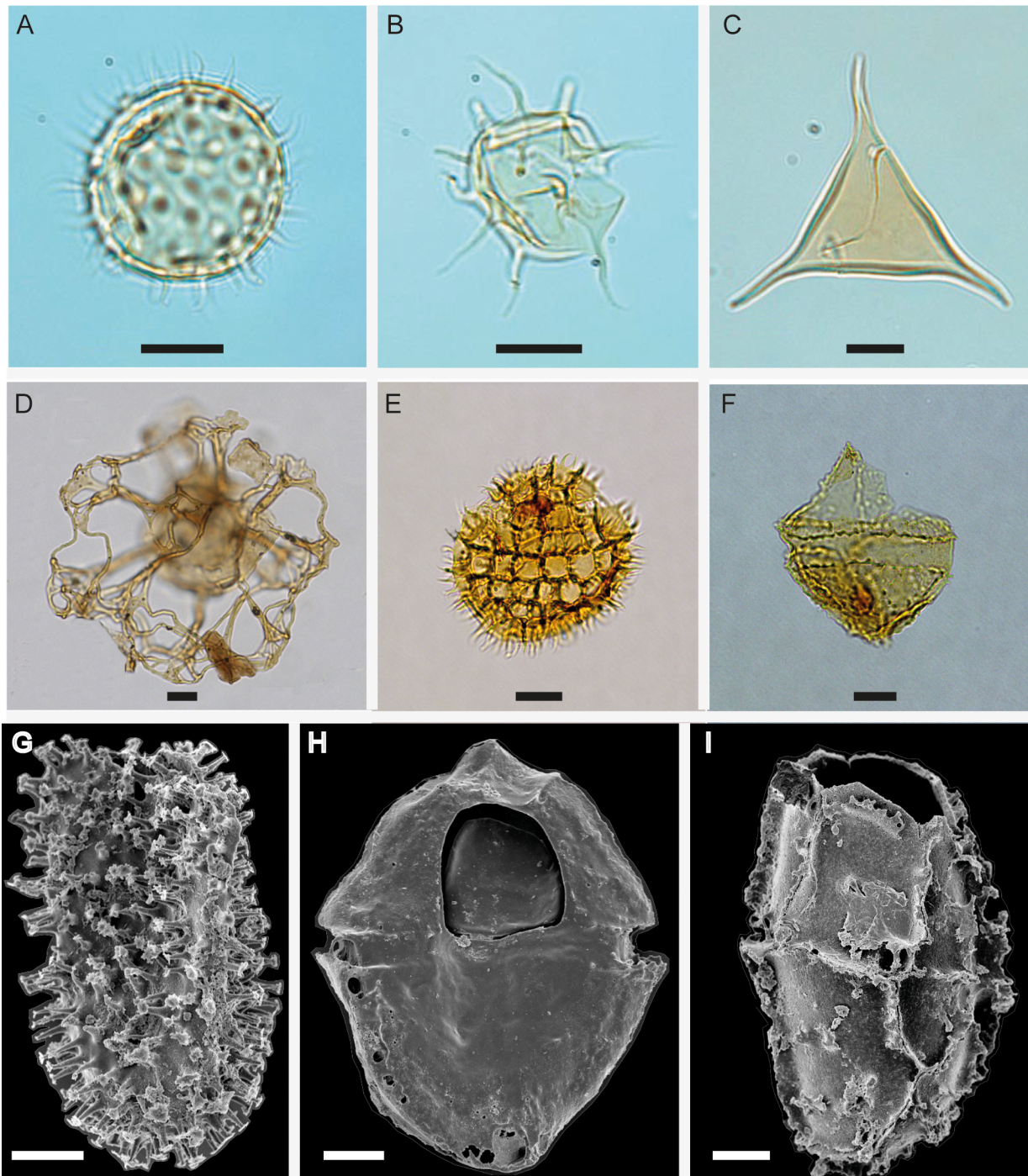


Figure 2. Selected acritarchs and dinoflagellate cysts from Western Australian Basins; A–F, transmitted-light images; G–I, SEM images; bar scales = 10 µm. A–C, acritarchs from the Kockatea Shale, northern Perth Basin, Early Triassic, where they are present in “flood” abundance after the end-of-Permian mass extinction; A, B, *Michrhystridium* spp.; C, *Veryhachium* sp. D–I, dinoflagellate cysts important for biostratigraphic zonation of the Late Triassic and Jurassic; D, *Rigaudella aemula* (Deflandre) Below from the Frigate Formation, Bonaparte Basin (Late Jurassic; Oxfordian); E, *Wanneria listeri* (Stover & Helby) Below from the Brigadier Formation, Northern Carnarvon Basin (Late Triassic; Rhaetian); F, *Rhaetogonyaulax wigginsii* (Stover & Helby) Lentin & Williams from the Mungaroo Formation, Northern Carnarvon Basin (Late Triassic; Carnian–Norian); G, *Prolixosphaeridium capitatum* (Cookson & Eisenack) Singh from the Dingo Claystone, Northern Carnarvon Basin (Late Jurassic; Oxfordian); H, *Scrinodinium crystallinum* (Deflandre) Klement from the Dingo Claystone, Northern Carnarvon Basin (Late Jurassic; Oxfordian); I, *Egmontodinium* sp. from the Dingo Claystone, Northern Carnarvon Basin (Late Jurassic; Oxfordian).

through this interval, a greater diversity of algae and testate protozoans may become known. These will add to a significant Australian-wide biogeographic record as East Gondwana drifted from the Northern to Southern Hemisphere. The Western Australian Ordovician acritarch and chitinozoan records are globally important for taxonomic and biogeographic evaluation.

Middle Paleozoic interior seas (0–40°S)

The Canning Basin has an outstanding Middle to Late Devonian carbonate reef-facies succession and similar facies are also present in the Bonaparte Basin (Playford *et al.* 2009). Limestone sequences extend into the Mississippian (Early Carboniferous) in both basins (Playford *et al.* 1975; Mory 2017). More environmentally restricted, including hypersaline, carbonate facies of the same age are known in outcrop and in the subsurface in the Southern Carnarvon Basin (Hocking *et al.* 1987; Mory & Haig 2011). Devonian and Mississippian deposition took place under warm conditions as indicated by the presence of diverse calcareous macroalgae (e.g. Fig. 3A–C), colonial corals, and Foraminifera of the Class Fusulinata (e.g. Fig. 4A–F). During the Pennsylvanian, rapid cooling led to Antarctic-scale continental ice cover across much of Western Australia and adjacent parts of East Gondwana. This is represented by a major regional stratigraphic hiatus overlain by glacially influenced deposits of the latest Pennsylvanian and earliest Permian.

Diverse stromatolites, calcareous cyanobacteria, organic-walled acritarchs, calcareous microalgae (calcitarchs and tuberitnids), calcareous macroalgae, possible charophytes, Foraminifera, and radiolarians are present in the Devonian and Mississippian deposits (Table 2). For global biogeographic comparisons these provide a critical Southern Hemisphere record.

Late Paleozoic East Gondwana interior rift (40–60°S)

An almost complete record of Permian marine deposition is present in Western Australian basins (Hocking *et al.* 1987; Haig *et al.* 2014; Haig *et al.* 2017; Mory 2017) with the biota of the Cisuralian (Early Permian) better known than that of the Guadalupian (Middle Permian) and Lopingian (Late Permian) as indicated on Table 3. In comparison to assemblages known from Permian open continental margins, the Western Australia fossil record is significantly influenced by basin position within a rift system in the interior of a continent, variable climate, and cyclic changes in marine inundation. Because of the different environmental settings, it is difficult to evaluate biogeographic affinities between the Western Australian biota and that from the open peri-Gondwana continental shelf.

The Western Australian basins formed along the axis of the East Gondwana interior rift. This became the site of continental breakup much later during the late Middle Jurassic to the earliest Cretaceous. Marginal rift basins, such as the Petrel Sub-basin (Bonaparte Basin), Fitzroy Trough and Samphire Graben (Canning Basin), and Merlinleigh to Irwin sub-basins (Southern Carnarvon and northern Perth basins) splayed from the axial rift system (Fig. 1A, C). The marginal basins are mudstone dominated, with limestone present only during some of the warm-temperate phases. Within these basins

the rate of deposition almost kept pace with the rate of subsidence and/or eustatic sea-level change. Because of this, low-gradient seafloors and shallow-water depths characterized the inland seas. Depositional cyclicity on various scales is particularly evident in the marginal rift basins where shoaling-upwards shale to sandstone or shale to limestone parasequences form broader scale parasequence sets and sequences. Maximum marine flooding for the entire Permian took place during the late Early Permian (close to the Artinskian–Kungurian boundary). The mudstone-dominated marine successions indicate a humid wet climate in the hinterland as also confirmed by the presence of coal deposits in interbedded fluvial formations. During the earliest Permian, melting of the continental ice sheet led to phases of diamicite (glacial till) deposition. The only other interval of cold-water deposition was during the middle part of the Early Permian (late Artinskian) when sea-ice formed in the southern marginal rift basins, as evidenced by the presence of dropstones in marine mudstone units (Haig *et al.* 2017). For the remainder of the Permian the climate was temperate with warm-temperate phases during the late Sakmarian (Early Permian), close to the Artinskian–Kungurian boundary in the late Early Permian, late Wordian–Capitanian (Middle Permian), and Wuchiapingian (Late Permian).

The marine Permian of the North West Shelf is related to the Permian of Timor where it occurs in structurally dislocated outcrops (Charlton *et al.* 2002) that are regarded as Gondwanan in origin, and were deposited in the East Gondwana interior rift system contiguous with Western Australian basins (Haig *et al.* 2014, 2017). The warm-temperate phases recognized in the Western Australia basins have equivalent but warmer-water carbonate depositional intervals in Timor. Similar warm-water carbonate deposits are likely to occur in subsurface in the under-explored Permian succession of the northern North West Shelf.

In the Western Australian basins, acritarchs and Foraminifera are generally abundant in marine mudstone facies (Table 3). The Foraminifera are “smaller” benthic types (belonging mainly to organic-cemented agglutinated groups and the calcareous Nodosariata and Miliolata, e.g. Fig. 4G, J, K) whose assemblages change with water depth (Haig 2003). Larger benthic fusulinids are known from limestones in Timor as well as from the Bird’s Head region of New Guinea, another area contiguous with the present Australian continent (Haig *et al.* 2017). The supposed fusulinids reported from the Canning Basin Permian by Chapman & Parr (1937) are not Foraminifera but possibly echinoid spines. Although larger fusulinids are absent, smaller representatives of the Class Fusulinata (e.g. tetrataxids, abadehellids, endothyrids and lasiodiscids; e.g. *Abadehella* sp., Fig. 4H, I) are present in warm-phase limestones in marginal-rift and axial-rift basins in Western Australia. *Tubiphytes* encrustations, of probable algal affinity, are found on skeletal debris in limestones of the late Sakmarian and latest Artinskian–earliest Kungurian warm phases in the marginal rift basins (e.g. Fig. 3D, E).

Mesozoic East Gondwana interior rift (50–30°S)

Triassic to earliest Cretaceous marine sediments deposited before continental breakup in the East

Table 3. Summary chart listing key references for protists from Permian marine strata in Western Australia. Time scale follows Cohen *et al.* (2017); global events follow Gradstein *et al.* (2012); latitudinal range follows Li & Powell (2001); palaeogeography follows Li & Powell (2001) and Mory (2017). Depositional cycles and climate are modified from Haig & Mory (2016), Haig *et al.* (2017) and unpublished work by Haig and co-authors. Asterisk after reference indicates species listed but not illustrated.

AGE (Ma)	PERIOD and EPOCH	GLOBAL EVENTS	LATITUDE	CLIMATE	PALAEOGEOGRAPHY	MARINE DEPOSITIONAL CYCLES	BIOTA (KEY REFERENCES)
252	LATE PERMIAN (LOPINGIAN)	Most severe mass extinction (> 90% of species) at end of Permian	40–60°S	Temperate humid/wet	Interior East Gondwana: shallow seas flooding East Gondwana interior rift system from North to as far south as central Perth Basin (around Jurien area). Very shallow seas extending into marginal rifts splaying from the axial rift (e.g. Petrel Sub-basin of Bonaparte Basin; Fitzroy Trough and Samphire Graben of Canning Basin; Merlinleigh to Irwin Sub-basins of Southern Carnarvon and northern-most Perth basins). Marginal seas are mainly brackish with normal-marine phases during marine flooding episodes. Maximum marine flooding occurred at ~ 284 Ma (within Pm3)	Pm5	Organic-walled cyanobacteria ?Pm5–2: Segroves 1967 Pm2: Foster <i>et al.</i> 1985 Pm2–Pm1: Foster & Waterhouse 1998*
259				Warm spike during early Pm5; humid/wet			Organic-walled phytoplankton of uncertain affinity (some probably algae) Acritarchs ?Pm5–2: Segroves 1967 Pm4–1: Backhouse 1991 ?Pm5–?4: Balme & Segroves 1966 Pm2: Foster <i>et al.</i> 1985 Pm2–Pm1: Foster & Waterhouse 1998*
273	MIDDLE PERMIAN (GUADALUPIAN)	Progressive opening of Mesotethyan Ocean along the northern margin of Gondwana (separating the Cimmerian block from the rest of East Gondwana)		Warm spike during mid to late Pm4; humid/wet		Pm4	Benthic calcareous macroalgae (? affinities) <i>Tubiphytes</i> Pm3: Haig <i>et al.</i> 2017 Pm2: Haig <i>et al.</i> 2014
	Temperate humid/wet			Pm3		Benthic testate protozoans Foraminifera Pm5, 3–1: Crespin 1958; Palmieri 1993 Pm3: Parr 1942; Crespin & Belford 1957; Belford 1962, 1968; Haig 2003, 2004, 2018; Haig <i>et al.</i> 2017; Haig & Mory 2016 Pm2: Howchin 1895; Foster <i>et al.</i> 1985; Dixon & Haig 2004; Haig <i>et al.</i> 2014; Taboada <i>et al.</i> 2015*	
	Warm spike at ~284 Ma; humid/Wet					Pm2	
299	EARLY PERMIAN (CISURALIAN)	Melting of Gondwana ice sheets		Cold; waning of ice-sheets		Pm1 – Glacigene	

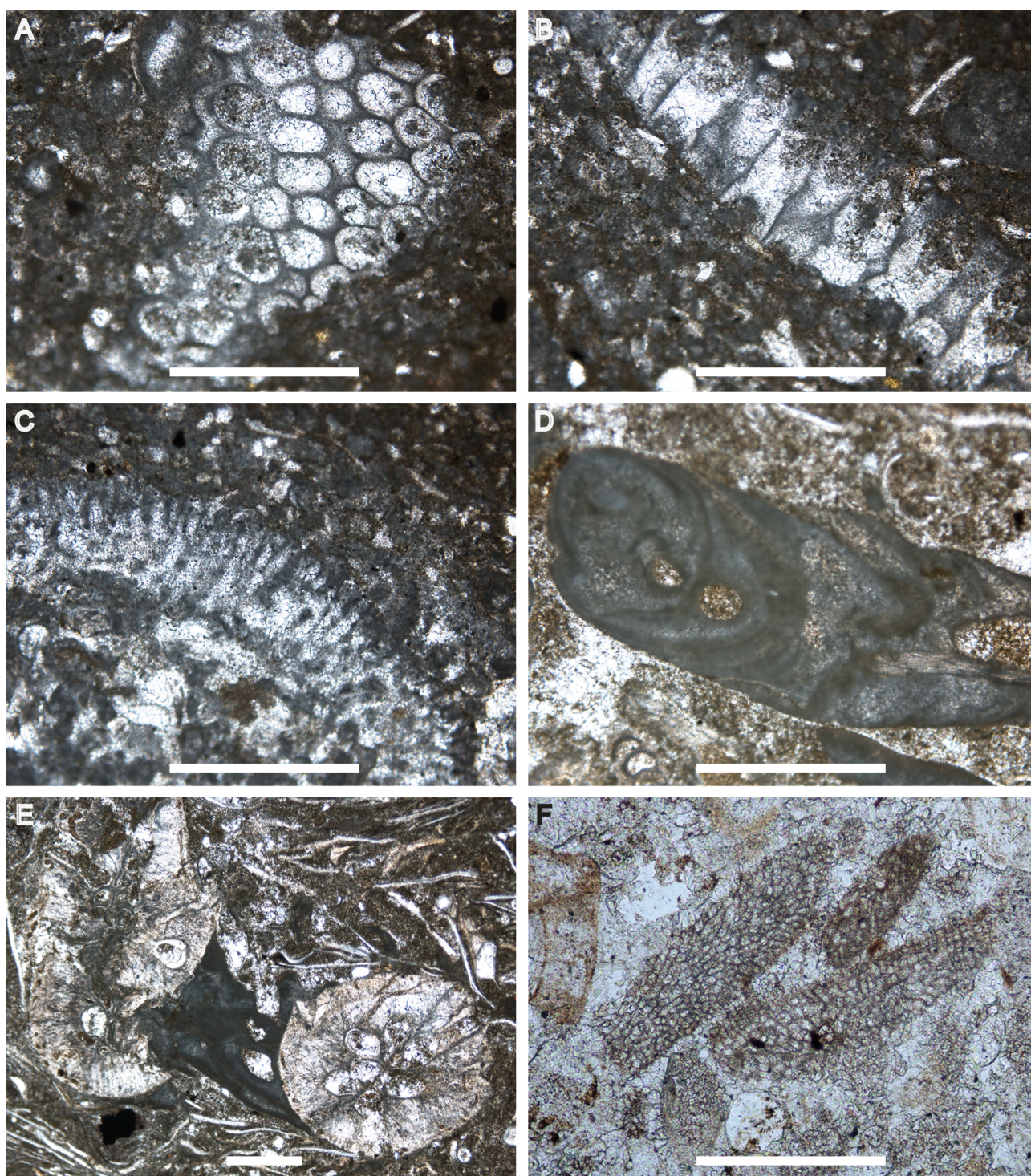


Figure 3. Selected macroalgae and related groups from Western Australian basins; images taken from thin sections viewed in transmitted light (bar scale = 0.5 mm). A, B fragments of probable dasycladalean *Koninckopora tenuiramosa* Wood from the Yindagindy Formation, Southern Carnarvon Basin: A, oblique tangential section across thallus, B, transverse section through portion of thallus; this species is important for confirming the middle Visean (Early Carboniferous) age for this formation. C fragment viewed in slightly oblique transverse section of thallus of the scribroporellacean algae (Order Bryopsidales) *Orthriosiphon?* sp., associated with *K. tenuiramosa* in the Yindagindy Formation. D, fragment of *Tubiphytes* from the lower Callytharra Formation, late Sakmarian (Early Permian) of the Southern Carnarvon Basin, indicative of warm-temperate or warm conditions. E, *Tubiphytes* (central dark area) encrusting two bryozoan skeletons, lower Callytharra Formation of Southern Carnarvon Basin. F, fragments of coralline algae from the Jubilee Member of the Cardabia Calcarene, Southern Carnarvon Basin, early Eocene; oldest indicators of warm-water conditions in the Western Australian Cenozoic.

Gondwana interior rift system are known mainly in the subsurface of the North West Shelf where an almost continuous marine succession is present. Facies range from very shallow marine to upper bathyal water depths in subsiding rifts. Dinoflagellates (e.g. Fig. 2D–I), acritarchs (Fig. 2A–C), calcareous nannofossils and Foraminifera have been intensely studied in industry exploration work but much of this information is unpublished. The published record is listed on Table 4. Shallow-marine macroalgae and Foraminifera have been described from subsurface cores of Late Triassic limestone indicative of warm-water carbonate platforms. Contiguous Triassic to Early Jurassic sections are exposed in the Timor orogenic belt (Charlton *et al.* 2009; Haig & McCartain, 2010, 2012).

Post-breakup Mesozoic and Cenozoic shelf seas (50–15°S)

The Western Australian continental shelf facing the Indian Ocean developed progressively from north to south during the late Middle Jurassic to earliest Cretaceous. Sandstone and mudstone were deposited in restricted shallow seas on the newly formed shelf, where the outer shelf margin was initially elevated, or in large prograding deltas with high influx of freshwater and sediment. In the ~30 million years following breakup the shelf-margin crust progressively cooled and the margin subsided allowing open-marine shallow-water facies to accumulate. During the Late Cretaceous and Cenozoic chalk or shallow-marine skeletal limestone was deposited over much of the shelf. A few million years after initial breakup large areas of marginal continental crust subsided to lower bathyal water depths (1500–2500 m) forming submarine plateaus contiguous with the continent. These include from north to south (Fig. 1A, B): Scott-Timor Plateau that at about 8 Ma started to collide with the Banda Arc, eventually forming the island of Timor; Exmouth Plateau; Wallaby Plateau; and Naturaliste Plateau.

The Early Cretaceous (Barremian–Albian) seas transgressing across the western continental shelf formed part of a broader marine transgression that covered over 60% of the present Australian mainland (Fig. 1B; Henderson *et al.* 2000). On the Southern Carnarvon Platform, a broad part of the onshore Southern Carnarvon Basin, the deposits of the marginal sea outcrop well and because of this have been the focus of many of the published studies of the testate protozoans of this age.

There is an extensive published record of algal phytoplankton and testate protozoans from outcrop and borehole sections (Table 5). Late Jurassic and Early Cretaceous dinoflagellates (Fig. 2D, G–I) and calcareous nannoplankton are best represented among the algal groups, whereas Cretaceous and Cenozoic benthic and planktonic Foraminifera (Fig. 4L–U) are the best-known testate protozoans. During the transgressive phase of the Aptian–Albian (late Early Cretaceous) marine inundation across the Australian continent (Fig. 1B), radiolarians (siliceous plankton) were preserved in abundance in mudstones of the shelf and interior seas (Haig & Barnbaum 1978; Ellis 1993; Haig 2005). In the Western Australian basins, the microfossil groups record changing water depths and temperatures as continental

crust adjacent the new continental margin cooled and subsided, and the continent slowly drifted north. Benthic foraminiferal assemblages (e.g. Fig. 4L–R) changed from having an estuarine-like interior-sea character during the Barremian–Albian (Early Cretaceous) to more diverse open-marine faunas during the Late Cretaceous (Dixon *et al.* 2003a,b; Haig *et al.* 2004). Near the Paleocene–Eocene boundary (ca. 56 Ma) a significant change occurs in the Southern Carnarvon Basin from middle–outer neritic chalk facies, that characterized sea-floor sediment over much of the Southern Carnarvon Platform from the Turonian (Late Cretaceous) to end Paleocene, to middle neritic and shallower limestone facies containing larger benthic Foraminifera (primitive discocyclinids, Fig. 4T; Haig, unpublished observations on the type section of the Jubilee Calcarenite) and coralline macroalgae (Fig. 3F).

SIGNIFICANT PARTS OF RECORD

Organic-walled phytoplankton: cyanobacteria, acritarchs, dinoflagellates

Microscopic, organic-walled phytoplankton groups are present in both marine and freshwater environments. Phytoplankton respond dramatically to external stimuli, especially increased nutrients and temperature (climate change), to form ‘algal blooms’; where a litre of water may contain up to a million cells (Davies *et al.* 2016), and the blooms extend over hundreds of kilometres. The fossil record includes globally recognisable bloom events of algae (prasinophytes and dinoflagellates), cyanobacteria and acritarch as described below.

Cyanobacteria

‘Blooms’ of *Gloeocapsomorpha prisca*, originally described from Middle Ordovician (Darrawillian) and Upper Ordovician organic-rich rocks in Estonia, occur in the Darrawillian upper Goldwyer Formation of the Canning Basin (Spaak *et al.* 2017), and in coeval sediments in Canada: all localities lie within $\pm 10^\circ$ N or S of the palaeo-equator (Foster *et al.* 1986) and the records reflect growth in optimal shallow warm marine conditions.

Acritarchs

Acritarchs range in size from 5 to ~100 μm and, by definition, are of unknown affinities although may include ‘cryptic’ dinoflagellates (see *Dinoflagellates*, below). They are common in palynological assemblages recovered from Early Paleozoic rocks, and may show a high diversity of different morphologies, which are attributed to form species. In late Mesozoic acritarch records are rare, and morphologic diversity is low (Playford 2003).

In Western Australia the oldest Phanerozoic acritarchs are known from the Lower Ordovician (late Tremadocian to Floian) Nambeet Formation of the Canning Basin (Combaz & Peniguel 1972; Foster & Wicander 2016). Middle Ordovician acritarch assemblages have been described from the Goldwyer Formation by G. Playford and co-workers (see Table 1 for references). Morphologically, the Nambeet palynoflora is moderately diverse, with shared species known elsewhere from Australia, China, and Canada (Alberta): all localities occur within $\pm 15^\circ$ S or N of the Early–Middle Ordovician

equator (see Foster & Wicander 2016, fig.5), and the assemblage reflects a warm-water marine environment. The Ordovician records illustrate the application of fossil phytoplankton in age determination, and paleo-environmental/ecological studies. Acritarch assemblages from fully marine conditions show the greatest species (i.e. morphologic) diversity.

Diverse assemblages of acritarchs are documented through the Devonian, particularly the Late Devonian Gneudna Formation of the Carnarvon Basin (Playford 1981; Playford & Dring 1981), and the approximately coeval reef complex at Limestone Billy Hills in the Canning Basin (Colbath 1990). Acritarchs show a marked decline, both quantitatively and qualitatively, in the latest Devonian of the Canning Basin (Playford 1976). As noted above, acritarchs are useful indicators of palaeoenvironmental conditions, often reflecting transgressive and regressive cycles in the sedimentary record (e.g. Wicander & Wood 1997). Molyneaux *et al.* (2013) noted “a high degree of similarity” between acritarch assemblages from the Euramerican region and Australia and China.

Phytoplankton occur in vast numbers, dominating latest Permian–Early Triassic palynofloras from many parts of the world (see Balme 1970). In Western Australia there is an explosion of the acritarch genera *Veryhachium* and *Michrhystridium* in assemblages from the basal Kockatea Formation of the Perth Basin (Fig. 2A–C; Haig *et al.* 2015). The prolific numbers result from a global marine transgressive event which expanded the epicontinental shelf, covering nutrient-rich former exposed land surfaces. *Veryhachium* first appears in the Lower Ordovician (Tremadocian; Servais *et al.* 2007) and is recorded through to the Neogene (see Fensome *et al.* 1990), but there are few periods that show such prolific blooms of this acritarch as the Early Triassic. Following the Early Triassic, acritarchs are much less abundant in younger Mesozoic palynofacies from the Western Australian basins.

Dinoflagellates

Dinoflagellates are single-celled, typically marine, flagellate eukaryotes that are best known in modern environments for creating ‘red tides’ or algal blooms and their associated shellfish-poisoning events. Many dinoflagellates have both a motile phase and a resting stage where a hypnozygote or thick-walled cyst is formed. These dinoflagellate cysts (typically 15–100 µm in length) are composed of highly resistant organic polymers (such as dinosporin) and are thus readily preserved, often in large volumes, in fine-grained sedimentary rocks.

Biogeochemical evidence, including the isolation of dinosteranes (steroidal alkanes abundant in extant dinoflagellates) from ancient rocks, and molecular clocks both suggest dinoflagellates originated in the earliest Cambrian or more likely the Neoproterozoic (Moldowan & Talyzina 1998; Fensome *et al.* 1999). However, the oldest unequivocal dinoflagellate cyst (*Sahulidinium ottii*) is not recorded until the Middle Triassic from shallow marine successions in the Bonaparte and Carnarvon basins of northern and north-western Australia (Stover & Helby 1987a). It is also likely that many Paleozoic and Proterozoic acritarchs are ‘cryptic’ dinoflagellates,

as supported by the strong correlation of dinosteroid abundance and acritarch diversity in pre-Triassic rocks (Moldowan *et al.* 1996). However, the major Late Triassic radiation of dinoflagellates as they ‘switched on’ their ability to form fossilized cysts is still considered likely to reflect a real radiative event, rather than just a change in preservation bias (Fensome *et al.* 1996). This major evolutionary event is well represented in the Carnarvon, Browse and Bonaparte basins as cyst-forming dinoflagellates likely arose to fill the available marine niches left over from the end Permian mass extinction and abundant new opportunities for rapidly evolving single-celled organisms. The major oil and gas reservoirs hosted in Upper Triassic successions of the Northern Carnarvon Basin have provided ready access to large volumes of samples, thus this first radiation of cyst-forming dinoflagellates is particularly well-studied in the Carnian–Norian marine incursions that are identified throughout the deltaic Mungaroo Formation (Helby *et al.* 1987; Stover & Helby 1987a; Backhouse & Balme 2002; and numerous unpublished industry reports). Although the species may vary (eg. *Hebecysta balmei*, *Rhaetogonyaulax wigginsii*, Fig. 2F, and *Wanneria listeri*, Fig. 2G, are prominent in Western Australian assemblages), there is notable consistency in the emergence of the key dinoflagellate groups (suessoids and rhaetogonyaulacoids) between the Northern and Southern hemispheres across these stages. For example, the increase in *Sverdrupiella* in the mid-Norian, best represented in the more open marine conditions of the Bonaparte Basin or outboard Northern Carnarvon Basin, closely mirrors the acmes of this group in the Alaskan and northern Canadian assemblages (Bujak & Fisher 1976). These Arctic dinoflagellate cysts are the only other documented Triassic assemblages of comparable diversity to the western and northern Australian palynofloras. The Rhaetian saw the development of more open marine conditions, and associated carbonate deposition. This is the first interval with an almost complete stratigraphic record of dinoflagellate cysts across the North West Shelf and the often conspicuous presence of *Rhaetogonyaulax rhaetica* – the first cosmopolitan dinocyst species.

The end-Triassic mass extinction wiped out most dinoflagellate cyst genera with only *Dapcodinium* and *Beaumontella* surviving into the Early Jurassic on the North West Shelf. The recovery period was also particularly prolonged, globally, for cyst-forming dinoflagellates compared to other protists. Modest dinoflagellate cyst assemblages do not re-occur until the late Pliensbachian–early Toarcian (late Early Jurassic) *Luehndea* Assemblage of the Northern Carnarvon and Perth basins. In turn, these are followed by the significant acme of *Dissilodinium caddaense* in the earliest Bajocian (early Middle Jurassic); a feature that was first noted in the Cadda Formation of the Perth Basin (Filatoff 1975) and subsequently tracked across most offshore western and northern Australia basins. This event heralded the next major phase of dinoflagellate evolution and morphological diversification through the Bajocian and Bathonian, co-incident with the opening of the Indian Ocean in the northern sector of the Western Australian continental margin. Many of the subsequently dominant dinoflagellate cyst forms first evolved in this period, and the Gonyaulacaceae rose to particular prominence. Various precingular and epicystal archaeopyle types were

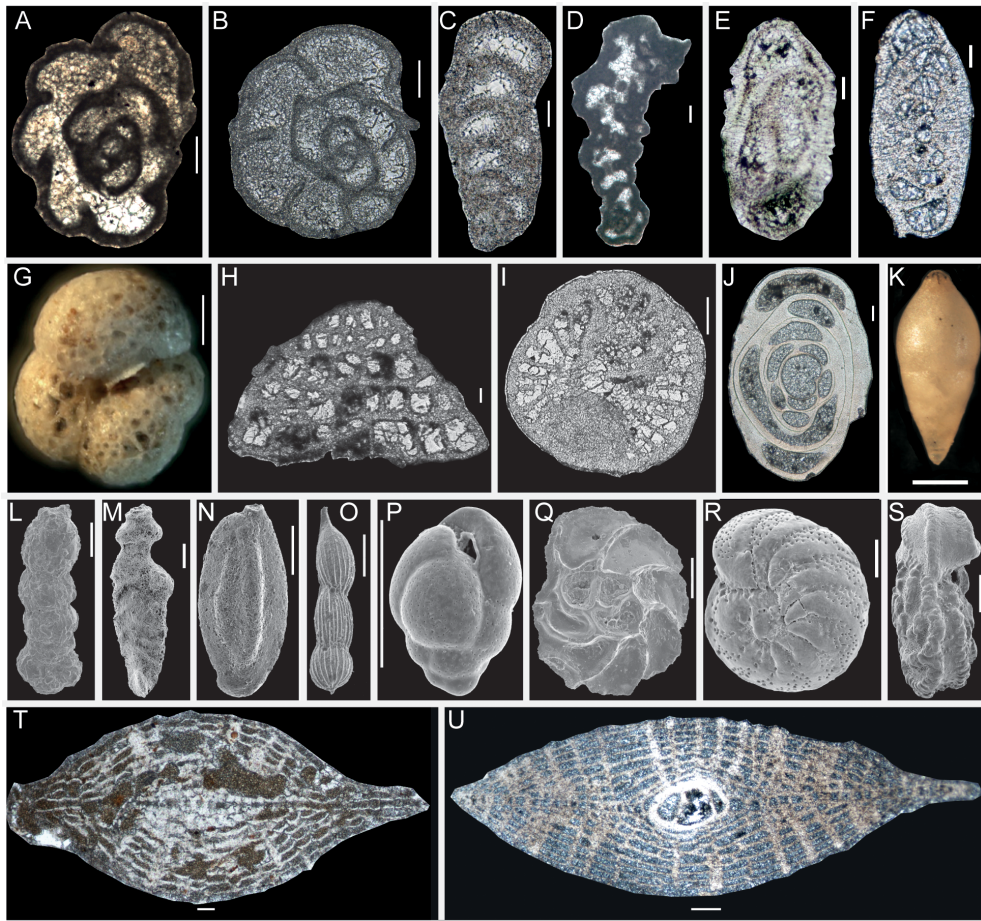


Figure 4. Selected Foraminifera from Western Australian basins; B, C, E, F, H–J, T, U, images of sections through foraminifera observed in acetate peels in transmitted light; A, D, images of sections through foraminifera observed in thin sections in transmitted light; G, K, free specimens of foraminifera taken under reflected light; L–S, free specimens of foraminifera taken in SEM. Bar scales = 100 µm. A–F, foraminifera from the Class Fusulinata that evolved in the first major radiation of calcareous species during the Late Devonian and Early Carboniferous (Mississippian). A, *Laxoendothyra* sp. from lower Fairfield Group, Canning Basin, Upper Devonian (Famennian). B, *Endothyra* ex. gr. *bowmani* Phillips from Utting Calcarenite, Bonaparte Basin, Mississippian (middle Viséan). C, *Plectinopsis michelsenii* Vachard, Haig and Mory from Yindagindy Formation, Southern Carnarvon Basin, Mississippian (Viséan). D, *Rectopravina multifida* Vachard, Haig and Mory from Yindagindy Formation, Southern Carnarvon Basin, Mississippian (Viséan). E, *Archaeodiscus* sp. from Utting Calcarenite, Bonaparte Basin, Mississippian (middle Viséan). F, *Archaeodiscus* sp. from Burvill Formation, Bonaparte Basin, Mississippian (late Viséan). G–K, representatives of the main groups of Foraminifera present in the Western Australian Permian. G, organic-cemented siliceous agglutinated *Trochammina* sp. that is similar to modern *T. inflata* that inhabits estuarine environments. H, I, off-centered longitudinal and transverse sections through *Abadehella* sp. (Fusulinata, Abadehellidae), indicative of warm-water conditions, Beekeeper Formation, northern Perth Basin (Guadalupian, Capitanian). J, axial section through porcelaneous *Hemigordipsis* sp. from Holmwood Shale, Irwin Sub-basin of northern Perth Basin, Early Permian (Cisuralian, Sakmarian). K, lateral view of *Pseudonodosaria serocoldensis* (Crespin), one of the earliest known Nodosariata with a radiate aperture (visible at top of image), from Noonkanbah Formation, Canning Basin, Early Permian (Cisuralian, close to Artinskian–Kungurian boundary). L–S, representatives of each major foraminiferal group in the Western Australian Cretaceous; L–R are benthic types; S is a planktonic species. L, organic-cemented siliceous agglutinated *Ammobaculites humei* Nauss from Muderong Shale, Southern Carnarvon Basin, Early Cretaceous (Barremian). M, carbonate-cemented agglutinated *Spiroplectinata annectens* (Parker & Jones) from upper Gearle Siltstone, Southern Carnarvon Basin, Early Cretaceous (Cenomanian). N, porcelaneous *Pseudosigmolina* sp. (Miliolida) from Haycock Marl, Southern Carnarvon Basin, Late Cretaceous (Turonian). O, nodosariid *Dentalina delicatula* Cushman from Haycock Marl, Southern Carnarvon Basin, Late Cretaceous (Turonian). P, buliminid *Turrilina* sp. cf. *T. evexa* (Loeblich & Tappan) from upper Gearle Siltstone, Southern Carnarvon Basin, Late Cretaceous (Cenomanian). Q, *Epistomina spinulifera* (Reuss) from Gearle Siltstone, Southern Carnarvon Basin, Early Cretaceous (Albian). R, *Stensioeina?* sp. of Howe *et al.* (2000), Haycock Marl, Southern Carnarvon Basin, Late Cretaceous (Turonian). S, *Globotruncana linneiana* (d’Orbigny), Toolonga Calcilitite, Southern Carnarvon Basin, Late Cretaceous (Santonian). T, U, Cenozoic larger benthic Foraminifera (Rotaliida) with complex chamber arrangements viewed in axial sections. T, *Discocyclina* sp. from the Jubilee Member of the Cardabia Calcarenite, Southern Carnarvon Basin, early Eocene; oldest complex species indicative of warm-water conditions in the Western Australian Cenozoic. U, *Lepidocyclina* (*Nephrolepidina*) sp. from the Tulki Limestone, Northern Carnarvon Basin, early Miocene. *Discocyclina* and *Lepidocyclina* have similar disc-shaped tests with an equatorial layer overlain on either side by layers of lateral chamberlets. The chamber arrangements in the equatorial layer cannot be seen in the axial sections but differ in these genera.

Table 4. Summary chart listing key references for protists from Mesozoic pre-continental-breakup marine strata in Western Australia. Time scale follows Cohen *et al.* (2017); global events follow Gradstein *et al.* (2012); latitudinal range follows Li & Powell (2001); palaeogeography follows Li & Powell (2001). Depositional cycles are from Marshall & Lang (2013). Asterisk after reference indicates species listed but not illustrated.

AGE (Ma)	PERIOD	GLOBAL EVENTS	LATITUDE	PALAEOGEOGRAPHY	CLIMATE	MARINE DEPOSITIONAL CYCLES	BIOTA (KEY REFERENCES)
132	CRETACEOUS (earliest part)	Progressive sea-level rise through Jurassic until major fall during latest Jurassic	30–50°S	Final breakup of Australian western margin to form Indian Ocean in Perth area at ~136 Ma	Warm humid/wet	K10	Stromatolites TR10: Lipps & Culver 2002; Chen <i>et al.</i> 2014
145	LATE JURASSIC			Continental breakup to form Indian Ocean in Argo Abyssal Plain area north of Exmouth Plateau at ~155 Ma		J50	Organic-walled algal phytoplankton Dinoflagellates (TR20 and above) ± Acritarchs K10–TR20: Helby <i>et al.</i> 1987; Burger 1996 J50–TR20: Riding <i>et al.</i> 2010 J20: Filatoff 1975; Stover & Helby 1987a; Helby & Stover 1987a; Mantle & Riding 2012 TR30–20: Bint & Helby 1988; Brenner 1992a; Brenner & Foster 1994; Backhouse & Balme 2002; Backhouse <i>et al.</i> 2002 TR20: Helby 1987a TR20–10: Stover & Helby 1987a TR10: Medd 1966; Sappal 1978; Haig <i>et al.</i> 2015
164	MIDDLE JURASSIC			Continental breakup to form Indian Ocean in Timor area at ~165 Ma		J30	Calcareous algal phytoplankton Calcareous nannofossils J50–10: Howe 2000 J20: Shafik 1994 TR30–20: Bralower <i>et al.</i> 1992
174	EARLY JURASSIC			Interior East Gondwana: shallow seas flooded East Gondwana interior rift system from North to as far south as central Perth Basin (around Jurien area). Carbonate-platforms including reefs developed on topographic highs in northern parts of axial rift system. Large deltas formed at basin margins and fluvial conditions were present in the southern axial basins. Only during the Early Triassic did very shallow seas flood the marginal rifts splaying from the axial rift system		J20	Benthic calcareous macroalgae (codiaceans; dasycladaceans; udoteaceans.) TR30–20: Von Rad <i>et al.</i> 1990; Röhl <i>et al.</i> 1991
201	LATE TRIASSIC	Severe mass extinction at end of Triassic	30–50°S	Interior East Gondwana: shallow seas flooded East Gondwana interior rift system from North to as far south as central Perth Basin (around Jurien area). Carbonate-platforms including reefs developed on topographic highs in northern parts of axial rift system. Large deltas formed at basin margins and fluvial conditions were present in the southern axial basins. Only during the Early Triassic did very shallow seas flood the marginal rifts splaying from the axial rift system	Warm humid/wet	J10	Benthic testate protozoans Foraminifera Late Jurassic: Quilty 2011 J20: Bartenstein & Malz 2001 J20–10: Apthorpe 1994*; Quilty 1981a; TR30–20: Quilty 1990; Von Rad <i>et al.</i> 1990; Röhl <i>et al.</i> 1991; Zaninetti <i>et al.</i> 1992; Kristan-Tollmann & Gramann 1992 TR10: Heath & Apthorpe 1986; Apthorpe 2003; Haig <i>et al.</i> 2015
237	MIDDLE TRIASSIC					TR30	
247	E. TR.					TR20	
252						TR10	

Table 5. Summary chart listing key references for protists from late Mesozoic and Cenozoic post-continental-breakup marine strata in Western Australia. Time scale follows Cohen *et al.* (2017); global events follow Gradstein *et al.* (2012); latitudinal range follows Li & Powell (2001); palaeogeography follows Li & Powell (2001). Depositional cycles for the Jurassic and earliest Cretaceous are from Marshall & Lang (2013). SCP numbers indicate marine depositional cycles recognized in the onshore Southern Carnarvon Basin (Haig & Mory 2003; Haig *et al.* 2004; Haig 2005 and unpublished data). Publications on the Southern Carnarvon and northern Perth basins are listed under SCP cycles. Away from these basins, publications are listed under broad age categories (abbreviations: Cen = Cenozoic; Neo = Neogene; Pal = Paleogene; L Cret = Late Cretaceous; E Cret = Early Cretaceous). Asterisk after reference indicates species listed but not illustrated.

AGE (Ma)	PERIOD or EPOCH	GLOBAL EVENTS	LATITUDE	CLIMATE	PALAEOGEOGRAPHY	MARINE DEPOSITIONAL CYCLES	BIOTA (KEY REFERENCES)
2.58	PLIO	Polar ice sheets from latest Miocene; Cooling from Early to mid-Miocene climatic optimum.	15–35°S	Warm	Shallow warm seas flooded Southern Carnarvon Platform and basins along southern continental margin at ~ 17 Ma	SCP12	Organic-walled algal plankton Dinoflagellates (\pm acritarchs) [cysts] Cen–J30: Cookson & Eisenack 1974, 1982 Pal: Cookson & Eisenack 1961, 1962b Cret: Cookson & Eisenack 1970 Cret–J50: Cookson & Eisenack 1958 Cret–J30: Helby <i>et al.</i> 1987; Stover & Helby 1987a; Riding & Helby 2001a–h
23	NEOGENE MIOCENE			dry			SCP8–3: Haig <i>et al.</i> 2004* SCP7–4: Cookson & Eisenack 1960a, 1962, 1968 SCP7–2: Dixon <i>et al.</i> 2003a*, b* E Cret: Eisenack & Cookson 1960; Brenner 1992b SCP4: Deflandre & Cookson 1955; Cookson 1956; Cookson & Eisenack 1962a, b, 1969, 1971; Backhouse 2006 SCP4–SCP1: Backhouse 1987, 1988 SCP2: McLoughlin <i>et al.</i> 1995 SCP1–J50: Cookson & Eisenack 1960b K10: Helby & Stover 1987b; Stevens 1987; Stevens & Helby 1987; May <i>et al.</i> 1987 K10–J50: Helby 1987b J50: Stover & Helby 1987b; Bint & Marshall 1994 J30–20: Mantle 2009a, b J30: Mantle 2005
	OLIGOCENE	Major global cooling during Oligocene		? wet	Formation of extensive laterite, silicrete, and calcrete in soils on land		
	PALEOGENE Eocene	Complete opening of Southern Ocean by ~45 Ma		Warm	Shallow warm seas flooded Southern Carnarvon Platform and basins along southern continental margin at ~ 41 Ma	SCP11	
	PALEOC.	Paleocene-Eocene Thermal Maximum at ~ 56 Ma		dry			
66	LATE CRETACEOUS	Severe mass extinction at end of Cretaceous Max. sea-levels (>250 higher than present) Global ocean bottom-water anoxia at ~93 Ma		Temperate dry in southern areas	Post-rift thermal subsidence and global sea-level rise, led to extensive areas of open-marine chalk deposition on parts of shelf	SCP10 SCP9 SCP8 SCP7 SCP6 SCP5	Calcareous algal plankton Calcareous dinoflagellate cysts E. Cret.: Keupp 1992 Calcareous nannofossils Neo: Siesser <i>et al.</i> 1992b Neo–Pal: Siesser & Bralower 1992 Neo–L. Cret: Shafik 1991 Pal.: Siesser <i>et al.</i> 1992a Pal–L. Cret: Pospichal & Bralower 1992 L. Cret: Howe <i>et al.</i> 2003; Campbell <i>et al.</i> 2004 Cret: Bralower & Siesser 1992; Shafik 1994 SCP8–3: Shafik 1990; Haig <i>et al.</i> 2004* SCP7–2: Dixon <i>et al.</i> 2003a*, b* SCP6–5: Howe <i>et al.</i> 2000 SCP4: Haig <i>et al.</i> 1996 J50–J30: Howe 2000 Calcareous macroalgae Pal: Cockbain 1969
100	EARLY CRETACEOUS			Cool temperate humid/wet	Until ~95 Ma, the new shelf in the Carnarvon and Perth Basins was flooded by restricted seas with muddy substrates, probably caused by an elevated shelf edge on ocean side. Marine flooding across Australia was out of step with global sea-level.	SCP4 SCP3 SCP2 SCP1	Testate protozoans Foraminifera (benthic and/or planktonic) Neo: Crespin 1955* Neo–Pal: Quilty 1974 Neo–L. Cret: Quilty 1978 SCP12–3: Edgell 1952* Pal: Quilty 1969, 1975, 1981b; McGowran & Lindsay 1969; McGowran 1977*, 1989* SCP11: Chapman & Crespin 1935; Cockbain 1967, 1968, 1974, 1978, 1981; Haig <i>et al.</i> 1997; Haig & Mory 2003 SCP10: Parr 1938; Coleman 1950*; McGowran 1964; Haig <i>et al.</i> 1993 L. Cret: Edgell 1964*, McGowran 1977*; Howe <i>et al.</i> 2003; Campbell <i>et al.</i> 2004; Petrizzo 2000; Petrizzo & Premoli Silva 2000; Petrizzo 2003 L–E Cret.(Alb): Haig 1992; Wonders 1992 SCP8: Belford 1961 SCP8–5: Belford 1958* SCP8–3: Edgell 1957; Haig <i>et al.</i> 2004* SCP7: Howchin 1907; Chapman 1917; Belford 1960, 1983 SCP7–2: Dixon <i>et al.</i> 2003a*, b* SCP6–5: Howe <i>et al.</i> 2000 E Cret.: Crespin 1963; Jones & Wonders 1992; Haig 1992; Stillwell <i>et al.</i> 2012 SCP4: Edgell 1963a, 1963b; Haig <i>et al.</i> 1996 SCP3: Haig 2005 SCP2: Taylor & Haig 2001
145	LATE JURASSIC	Major changes in ocean circulation with breakup of Gondwana and opening of Indian and Atlantic oceans	30–50°S		Continental shelf formed as Indian Ocean opened progressively from North to South (~165 Ma in Timor region; ~155 Ma off the Pilbara; ~136 Ma off Perth. Initial marine deposits on shelf were deltaic sands	K10 J50 J40 J30	Radiolaria (planktonic) Pal: Blome 1992 SPC3: Ellis 1993
164	MIDDLE JUR.						
174							

notably prevalent, as evidenced by the prominence of *Ctenodinium*, *Dissiliodinium*, *Durotrigia* and *Wanaea* types in the *D. caddaense* to *W. indotata* zones of the North West Shelf (Helby *et al.* 1987; Riding *et al.* 2010; Mantle and Riding 2012).

As the opening of the Indian Ocean progressed southward to the Exmouth Plateau region, the Late Jurassic saw a further major period of dinoflagellate cyst diversification, within the now established key tabulation patterns. The abundant experimentation and appearance of short-lived new taxa (Deflandre & Cookson 1955; Cookson & Eisenack 1958; Cookson & Eisenack 1960b; Stover & Helby 1987b) during this epoch has allowed an extremely fine-scale stratigraphic subdivision of the Oxfordian *Wanaea spectabilis* Zone to Tithonian *P. iehiense* Zone (part of), equating to subzones of average duration of less than 500,000 years across the North West Shelf basins.

As the break-up of Gondwana progressed to the Perth Basin margin of Australia, and India rifted off in the Early Cretaceous, progressively more marine conditions developed in the Southern Carnarvon and Perth basins. Backhouse (1987, 1988) neatly documented this succession from the Late Jurassic spore and pollen sequences (*Retitriteles watheroensis* and *Aequitriradites acus* zones) to the marginal and restricted marine, low dinoflagellate diversity assemblages in the Berriasian and most of the Valanginian (*Fusiformacysta tumida* and *Gagiella mutabilis* zones) prior to the development of diverse, fully marine assemblages in the latest Valanginian (*Kaiwaradinium scrutillinum* Zone) and younger stages. These abundant and diverse dinoflagellate cyst assemblages also dominated most North West Shelf assemblages during the Early Cretaceous (Cookson & Eisenack 1958; Stevens 1987; Stevens & Helby 1987; Stover & Helby 1987a, c, d) after moderately restricted dinocyst abundances and diversities in the early Berriasian. The first Australian ceratioids appeared in the latest Tithonian (*Pseudoceratium australiense* and *P. iehiense*), whilst the more iconic ceratioid genera, *Phoberocysta* and *Muderongia*, arose to prominence in the Hauterivian to Aptian on the North West Shelf (Helby 1987b) and represent some of the most important Early Cretaceous zonal markers.

Dinoflagellate diversity continued to be high in the Valanginian to Cenomanian marine sequences in the post-breakup basins on the west coast as sea-floor spreading progressed and fully marine deposition developed. By the Barremian marine microplankton are also present in parts of the Eucla and Officer basins (Cookson & Eisenack 1970, 1971; Kemp 1976) along the southern margin of Western Australia. A peak of abundance and diversity is reached in the extensive post-breakup Muderong Shale and upper Leederville Formation of the Carnarvon and Perth basins respectively, in the extensively documented *Muderongia australis* Zone, where several new species, including the first *Ovoidinium* species, appear.

The diverse Late Aptian palynofloras have been little studied with only a small number of dinoflagellates formally described from this age (Eisenack & Cookson 1960; Riding & Helby 2001h). By comparison, Albian

and Cenomanian dinoflagellate floras are rich and relatively well documented in the Perth and Carnarvon basins (Deflandre & Cookson 1955; Cookson & Eisenack 1958, 1962b, 1969; Eisenack & Cookson 1960) and are dominated by *Diconodinium* and *Spiniferites* lineages (Backhouse 2006).

As a result of a dinoflagellate species turnover near the end of the Cenomanian, few Albian–Cenomanian dinoflagellate species extend into the Turonian and younger strata. *Diconodinium* type cysts disappear, but *Spiniferites* spp. continue to be common and cavate cysts become prominent at many levels (as outlined in an unpublished 1984 University of Western Australia PhD Thesis by N. Marshall). Although well preserved, diverse and abundant, an absence of commercial imperative has resulted in few studies of Late Cretaceous dinoflagellates in Western Australia.

Cenozoic dinoflagellates are known from several formations along the west coast, including the Paleocene–Eocene (Cookson & Eisenack 1961) and the Pliocene–Pleistocene. At species level there is some similarity to south-eastern Australian assemblages and at generic level they are comparable to northern hemisphere dinoflagellates but have not been studied in detail.

Benthic calcareous macroalgae

Shallow-water limestone successions of the warm intervals (viz. Late Devonian–Mississippian, Middle to Late Triassic, Eocene and Early to Middle Miocene) contain diverse calcareous macroalgal assemblages important for evaluation of global biogeography in tropical–subtropical carbonate-platform facies. However, these have been only partly documented and, as shown by the work of Vachard *et al.* (2014), many recorded taxa require revision. Microfacies have been poorly described and the facies associations are incompletely known. The Mississippian assemblages from the Bonaparte Basin described by Mamet & Roux (1983) lived under normal-marine salinity as indicated by the accompanying diverse invertebrate assemblages including corals (Playford *et al.* 1975) whereas those from the Southern Carnarvon Basin recorded by Vachard *et al.* (2014) are associated with a low diversity invertebrate fauna and lived mainly under metahaline conditions.

The recognition of *Tubiphytes* (Fig. 3D, E) by Haig *et al.* (2014) in the lower part of the Callytharra Formation (upper Sakmarian) in the Southern Carnarvon Basin, was significant in changing views of Early Permian climate in Western Australia. The Callytharra Formation represents a southern area of carbonate deposition in the East Gondwana interior rift system that about 2000 km to the north included the type Maubisse Limestone of Timor, also containing *Tubiphytes* (Haig *et al.* 2014). *Tubiphytes* is also present in rare thin limestone beds in the latest Artinskian–earliest Kungurian part of the Noonkanbah Formation of the Canning Basin (Haig *et al.* 2017).

Calcareous nannoplankton

The earliest true calcareous nannoplankton (i.e. those that form heterococcoliths) first appear at the base of the Rhaetian and have an excellent record in the offshore Northern Carnarvon Basin (undocumented, but recorded in unpublished data from exploration wells), and on the

Exmouth and Wombat Plateaus (Bralower *et al.* 1991, 1992). The offshore marine Brigadier Formation has abundant and well preserved nannofossils (*Eoconusphaera*, *Crucirhabdus* and *Archaeozygodiscus*), nannoliths (*Prinsiosphaera*) and calcispheres (*Obliquipithonella*, *Orthopithonella* and *Thoracosphaera*). Thick Early Jurassic marine successions in the sub-basins of the Northern Carnarvon Basin contain abundant nannofossils and calcispheres (Howe 2000; Shafik 1993). The nannofossil zonation in this interval has much greater resolution than the spore/pollen zones commonly used in exploration.

Middle Jurassic nannofossils are recorded in the offshore Northern Carnarvon Basin by Howe (2000) and Shafik (1993, 1994). Further south, calcareous nannofossils of this age are known only from the Bajocian assemblages recorded by Shafik (1994) in the Newmarracarra Limestone near Geraldton. Only poor nannofossil assemblages are known from the marine Late Jurassic (Howe 2000), which is puzzling as environments in this interval are mainly offshore marine over the North West Shelf. It is likely related to somewhat restricted surface-water circulation before and immediately after continental breakup in the region.

Throughout most of the Lower Cretaceous, nannofossils are consistently present, but not common. After final continental breakup in the Perth Basin region during the Valanginian, with widespread marine flooding across the Perth and Carnarvon basins, nannofossil abundance and diversity increases markedly from the latest Aptian into the transition from siliciclastic to calcareous sediments in the Turonian–Coniacian. Rich and well-preserved nannofossil assemblages from the Albion–Turonian shales and marls, and the Coniacian–Maastrichtian marls and calcilutites of the western Australian margin were described by Pospichal & Bralower (1992), Moran (1992), Bralower & Siesser (1992), Shafik (1978b, 1990, 1991, 1994), Haig *et al.* (1996, 2004), Howe *et al.* (2000, 2003), Campbell *et al.* (2004), Howe (2005) and Thibault *et al.* (2012).

There has been little published work on the nannofossil assemblages of the Cenozoic, largely due to the focus of the hydrocarbon exploration industry on the Mesozoic. Shafik (1985, 1978a, c, 1991), Moran (1992), Siesser & Bralower (1992) and Siesser *et al.* (1992a, b) describe Cenozoic nannofossils from Western Australia and relate the assemblages to cosmopolitan stratigraphic zonations.

Foraminifera

During the Late Devonian and Early Carboniferous (Mississippian) there was substantial diversification among Foraminifera world-wide with calcareous Fusulinata rapidly evolving and including a wide variety of chamber shapes, coiling modes, and wall microstructures, particularly during the Mississippian (e.g. Fig. 4A–F). The Western Australian shallow-water limestone formations in the northern basins record this evolution and are significant because they contain the only documented Australian Southern Hemisphere faunas that allow comparison to better known Asian, European and North American assemblages. Fusulinata families that have been described include parathuramminids, pseudoammodiscids,

palaeospiroplectamminids, haplophragminids, koktjabinids, nodosinellids, tournayellids, endothyrids and ozawainellids (Belford 1970; Edgell 2004; Vachard *et al.* 2014). Some of these provide an important link to the evolution of carbonate-cemented agglutinated Foraminifera, an important benthic foraminiferal group in modern open-shelf seas. Because of the rapid cooling and depositional hiatus during the Pennsylvanian, the foraminiferal succession in Western Australia does not include the evolution of complex fusulinids. The discovery in Timor toward the northern end of the East Gondwana interior rift of a late Gzhelian (latest Pennsylvanian) coral-*Tubiphytes* reef containing a diverse fusulinid assemblage allowed recognition of a global warm spike, of uncertain cause, that was responsible for the melting of the continental ice sheet covering much of Western Australia (Davydov *et al.* 2013, 2014).

The importance of the Permian record lies in the evolution of very conservative groups of Foraminifera in the shallow-marine marginal-rift basins that were inundated by restricted seas with estuarine water quality (Haig 2004). The Western Australian basins provide some of the best Permian records of these groups. The organic-cemented siliceous agglutinated Foraminifera resemble assemblages from similar facies in the Carboniferous mid-continental basin of North America (Crespin 1958; Haig 2003, 2018; Haig & Mory 2016). A major change in the Nodosariata took place during the late Artinskian (Early Permian) with the appearance of different genera with radiate apertures including the first appearances of *Nodosaria*, *Pyramidulina*, *Pseudonodosaria* and *Dentalina* that persist to the present-day (Crespin 1958; Haig *et al.* 2017).

In the warm-temperate Permian intervals when carbonate deposits accumulated in the shallow seas, Foraminifera of Tethyan (warm-water) affinities were present as far south as the Perth Basin. These include lasiodiscids recognized in the Late Sakmarian and late Wordian–Capitanian intervals; endothyrids from the Late Sakmarian and late Wordian–Capitanian; tetrataxids from the Late Sakmarian; abadehellids from the late Wordian–Capitanian (e.g. Fig. 4H, I); and robuloidids from the Wuchiapingian (Crespin 1958; Dixon & Haig 2004; Haig *et al.* 2014; and unpublished data).

Although the Triassic and Jurassic foraminiferal faunas from mudstone facies are poorly documented, the excellent preservation of assemblages recorded by Heath & Apthorpe (1986, Triassic), Apthorpe (2003, Triassic) and Bartenstein & Malz (2001, Middle Jurassic) indicate that when the faunas are better known they will provide significant information particularly about the evolution of the Triassic duostominids and the aragonitic Jurassic ceratobuliminids and epistominids.

The shelf basins of the Cretaceous contain an almost complete Cretaceous marine section. The succession on the Southern Carnarvon Platform with mudstone facies ranging from the Barremian to Cenomanian followed by chalk facies from the Turonian to Maastrichtian provides a standard outcrop reference section for placing the Australian Cretaceous in a global context. Continuous stratigraphic cores in selected boreholes complement the outcrop sections and enable benthic and planktonic foraminiferal successions to be related to zones based

on calcareous nannoplankton, dinoflagellates and other palynomorphs (Dixon *et al.* 2003a,b; Haig *et al.* 2004). The Lower Cretaceous mudstone succession includes foraminiferal assemblages of estuarine aspect similar to those found in the marginal rift basins of the Western Australian Permian (Haig 2004). The Late Cretaceous planktonic foraminiferal succession from chalk facies, described from subsurface cored sections on Exmouth Plateau and the North West Shelf, forms the basis of an Indian Ocean mid-latitude zonation and provides important oceanographic indicators in the juvenile Indian Ocean (Petrizzo 2000, 2003; Petrizzo & Premoli Silva 2000; Howe *et al.* 2003; Campbell *et al.* 2004).

Western Australian Cenozoic foraminiferal faunas have been incompletely documented (see references listed on Table 5). The Paleocene–Eocene and Lower to Middle Miocene carbonate successions, outcropping in the Giralda and Cape Range Anticlines between Carnarvon and Exmouth may provide a standard mid-latitude faunal record for the Indian Ocean region when the faunas are better known.

Radiolaria

Fossil radiolarian assemblages are generally found in radiolarian ooze deposited on the deep ocean floor. The ooze is often preserved in orogenic outcrop belts as radiolarian chert or siliceous argillite; see, for example, the Middle Jurassic siliceous argillite with a diverse radiolarian assemblage described from Timor by Haig & Bandini (2013) and used as evidence for continental breakup and the opening of the Indian Ocean in the Timor region during the late Bathonian–early Callovian.

In contrast to radiolarians from deep-sea chert, in Western Australia diverse radiolarian assemblages have been described from Late Devonian shallow-water interior-sea mudstone facies of the Canning Basin (Nazarov *et al.* 1982; Nazarov & Ormiston 1983; Aitchison 1993; Won 1997a, 1997b) and Early Cretaceous restricted marginal shelf mudstone deposits of the Southern Carnarvon Platform (Ellis 1993). These are therefore of considerable interest because of the facies contrast with the deep-ocean deposits. Haig (2005) showed that the Windalia Radiolarite, from the Aptian (Early Cretaceous) of the Southern Carnarvon Platform, was a radiolarian-rich mudstone deposited in the mid-neritic zone, and that radiolarians formed part of the plankton in the epicontinental seas at shallower water depths than preferred by planktonic foraminifera. This view is supported by the coeval radiolarian assemblages known from the Surat Basin of Queensland, part of the area flooded in the interior of Australia during the Barremian to Albian (Haig & Barnbaum 1978).

FOCUS FOR FUTURE STUDIES

In publications, only a small fraction of species of most of the groups discussed in this paper have been systematically described and evaluated using modern observational methods and up-to-date taxonomy. Because of this, consistent recognition by different workers of the biostratigraphic ranges of the species is difficult to establish, as is integration of biozonations based on the different groups. If this could be achieved, finer-scale

correlation and environmental interpretations may be possible within the sedimentary basins, and a clearer pattern of evolution and/or migration of species could be established.

Among the organic-walled phytoplankton a major gap appears in published records of acritarchs from the Silurian of Western Australia. This is clearly an area for further investigation and is best explored in the subsurface Silurian strata of the Southern Carnarvon Basin where acritarchs have been reported in petroleum industry reports. Among dinoflagellates, more detailed documentation of species assemblages and the environmental controls on these is required throughout the Mesozoic and also in the very poorly understood Cenozoic record.

The Late Triassic, Paleogene (Middle Eocene) and Neogene (Early to Middle Miocene) contain diverse macroalgal assemblages that have not been described. The systematic evaluation of these assemblages will be important in biogeographic comparisons particularly with coeval assemblages in exotic terranes emplaced during the tectonic collisions on the northern and north-western margins of the continent.

Among the calcareous nannoplankton, the Late Triassic, Jurassic and Early Cretaceous assemblages have not been fully documented. Systematic documentation of these assemblages will assist greatly in calibrating the ages of the dinoflagellate and spore/pollen zonations that are so important for hydrocarbon exploration. Because of the focus of the hydrocarbon exploration industry on the Mesozoic, Cenozoic nannofossils from Western Australia have received little attention. Further study of this interval should yield improvements in biostratigraphic resolution and also provide greater palaeo-oceanographic information concerning the eastern Indian Ocean during the Paleogene and Neogene.

Large gaps in the published fossil record of Western Australian Foraminifera are present in the Mississippian shale successions of the Bonaparte Basin, the marine Triassic–Jurassic successions of the North West Shelf, and the Cretaceous–Paleogene strata of the continental shelf basins, including those along the southern margin. Better knowledge of these microfaunas may lead to a greater understanding of foraminiferal evolution and migration both within interior basins and on a continental shelf transgressing latitudes and climatic belts through time.

The Early Cretaceous (late Aptian) radiolarian fauna from the Windalia Radiolarite has only been described from the type outcrop section of this formation. Equivalent Early Cretaceous radiolarian-rich mudstone successions are widespread in Western Australian basins and are known in Cretaceous basins across Australia. The distribution of radiolarians species within these rocks may lead to a better understanding of water-quality conditions associated with the major Early Cretaceous marine transgression across the continent.

CONCLUSIONS

(1) Algae and testate protozoans form an important component of the Western Australian Phanerozoic fossil record. Representatives of these groups, particularly

the acritarchs, dinoflagellates, calcareous nannofossils and foraminifera are important stratigraphic guides in petroleum and groundwater exploration and much unpublished industry work has been done on these microfossils.

(2) Changes in continental configuration, palaeolatitudes, climate and marine inundations that affected Western Australian basins during the Phanerozoic are reflected in the stratigraphic record of algae and testate protozoans.

(3) The Paleozoic and early to mid-Mesozoic fossil assemblages are from shallow interior seas of East Gondwana that varied from a warm Northern Hemisphere position during the Ordovician to high latitudes during the Pennsylvanian when the region was covered by a continental ice sheet, followed by variable humid climatic conditions during the Permian and generally warm to temperate humid conditions during the Triassic and Jurassic.

(4) Open continental shelves and marginal continental plateaus facing the Indian Ocean developed first in northern Western Australia during the Middle Jurassic, with continental breakup and ocean formation progressively taking place in segments toward the South (Late Jurassic in the Argo Abyssal Plain, north of Exmouth Plateau; Early Cretaceous in the Perth Abyssal Plain). The opening of the Indian Ocean and the almost concomitant opening of the Atlantic Ocean led to major changes in ocean-circulation patterns. These changes probably allowed a marked diversification of dinoflagellates and foraminifera (particularly planktonic types) during the Late Jurassic and Cretaceous, and resulted in assemblages that even by the latest Cretaceous began to resemble the modern biota of the Western Australian continental margin.

ACKNOWLEDGMENTS

Geoffrey Playford, Brian McGowan and Tony Cockbain are thanked for reviewing the manuscript and providing useful suggestions for its improvement.

REFERENCES

- AITCHISON J C 1993. Devonian (Frasnian) radiolarians from the Gogo Formation, Canning Basin, Western Australia. *Palaeontographica A* **228**, 105–128.
- APTHORPE M 1994. Towards an Early to Middle Jurassic palaeogeography for the North West Shelf: a marine perspective. Pages 201–210 in Purcell P G & Purcell R R, editors, *The Sedimentary Basins of Western Australia: Proceedings of the Petroleum Exploration Society Australia Symposium, Perth, 1994*. Petroleum Exploration of Australia, Perth.
- APTHORPE M 2003. Early to lowermost Middle Triassic Foraminifera from the Locker Shale of Hampton-1 well, Western Australia. *Journal of Micropalaeontology* **22**, 1–27.
- BACKHOUSE J 1970. Foraminifera from the Plantagenet Group east of Esperance, Western Australia. *Geological Survey of Western Australia, Annual Report* **1969**, 40–42.
- BACKHOUSE J 1987. Microplankton zonation of the Lower Cretaceous Warnbro Group, Perth Basin, Western Australia. *Memoir of the Association of Australasian Palaeontologists* **4**, 205–226.
- BACKHOUSE J 1988. Late Jurassic and Early Cretaceous palynology of the Perth Basin, Western Australia. *Geological Survey of Western Australia, Bulletin* **135**, 1–237.
- BACKHOUSE J 1991. Permian palynostratigraphy of the Collie Basin, Western Australia. *Review of Palaeobotany and Palynology* **67**, 237–314.
- BACKHOUSE J 2006. Albian (Lower Cretaceous) dinoflagellate cyst biostratigraphy of the Lower Gearle Siltstone, Southern Carnarvon Basin, Western Australia. *Palynology* **30**, 43–68.
- BACKHOUSE J & BALME B E 2002. Late Triassic palynology of the Northern Carnarvon Basin. *Minerals and Energy Research Institute of Western Australia (MERIWA) Report* **226**, 1–168.
- BACKHOUSE J, BALME B E, HELBY R, MARSHALL N G & MORGAN R 2002. Palynological zonation and correlation of the latest Triassic, Northern Carnarvon Basin. Pages 179–201 in Keep M & Moss S J, editors, *The Sedimentary Basins of Western Australia 3: Proceedings of the Petroleum Exploration Society of Australia Symposium, Perth, WA, 2002*. Petroleum Exploration Society of Australia, Perth.
- BALME B E 1970. Palynology of Permian and Triassic strata in the Salt Range and Surghar Range, West Pakistan. *Stratigraphic Boundary Problems: Permian and Triassic of West Pakistan* **4**, 306–453.
- BALME B E & SEGROVES K L 1966. *Peltacystia* gen. nov.: a microfossil of uncertain affinities from the Permian of Western Australia. *Journal of the Royal Society of Western Australia* **49**, 26–31.
- BARTENSTEIN H & MALZ H 2001. Foraminifera aus dem Newmarracarra Limestone (Unter-Bajocium; W-Australien). *Senckenbergiana Lethaea* **81**, 25–57.
- BELFORD D J 1958. Stratigraphy and micropalaeontology of the Upper Cretaceous of Western Australia. *Sonderdruck aus der Geologischen Rundschau* **47**, 629–646.
- BELFORD D J 1960. Upper Cretaceous Foraminifera from the Toolonga Calcilutite and Gindin Chalk, Western Australia. *Australia Bureau of Mineral Resources, Geology and Geophysics, Bulletin* **57**, 1–198.
- BELFORD D J 1961. *Spirotecta pellicula* n. gen. n. sp., from the Upper Cretaceous and *Giraliarella triloba* n. sp., from the Permian of Western Australia. *Contributions from the Cushman Foundation for Foraminiferal Research* **12**, 81–83.
- BELFORD D J 1962. Appendix, Foraminifera from bores BMR 6 and 7, Muderong, Western Australia. *Australia Bureau of Mineral Resources, Geology and Geophysics, Report* **81**, 17–22.
- BELFORD D J 1967. Occurrence of the genus *Draffania* Cummings in Western Australia. *Australia Bureau of Mineral Resources, Geology and Geophysics, Bulletin* **92**, 49–55.
- BELFORD D J 1968. Permian Foraminifera from BMR Bores 6, 7, 8, and 9, Western Australia. *Australia Bureau of Mineral Resources, Geology and Geophysics, Bulletin* **80**, 1–13.
- BELFORD D J 1970. Upper Devonian and Carboniferous Foraminifera, Bonaparte Gulf Basin, Northwestern Australia. *Australia, Bureau of Mineral Resources, Geology and Geophysics, Bulletin* **108**, 1–38.
- BELFORD D J 1983. Note on costellate planktonic foraminifera, and the generic designation of Late Cretaceous forms from Western Australia. *Australia Bureau of Mineral Resources, Geology and Geophysics, Bulletin* **217**, 1–9.
- BINT A N & HELBY R 1988. Upper Triassic palynofacies and environmental interpretations for the Rankin Trend, Carnarvon Basin, W.A. Pages 591–598 in Purcell P G & Purcell R R, editors, *The North West Shelf, Australia: Proceedings of the Petroleum Exploration Society Australia Symposium, Perth, 1988*. Petroleum Exploration Society of Australia, Perth.
- BINT A N & MARSHALL N G 1994. High resolution palynostratigraphy of the Tithonian Angle Formation in the Wanaea and Cossack Oil Fields, Dampier Sub-Basin. Pages 543–554 in Purcell P G & Purcell R R, editors, *The Sedimentary Basins of Western Australia: Proceedings of the Petroleum Exploration Society Australia Symposium, Perth, 1994*. Petroleum Exploration Society of Australia, Perth.
- BLOME C D 1992. Radiolarians from Leg 122, Exmouth and Wombat Plateaus, Indian Ocean. *Proceedings of the Ocean Drilling Program, Scientific Results*, **122** 633–652.

- BRALOWER T J, BOWN P R & SIESSER W G 1991. Significance of Upper Triassic nannofossils from the Southern Hemisphere (ODP Leg 122, Wombat Plateau, N.W. Australia). *Marine Micropaleontology*, **17**, 119–154.
- BRALOWER T J, BOWN P R & SIESSER W G 1992. Upper Triassic calcareous nannoplankton biostratigraphy, Wombat Plateau, northwest Australia. *Proceedings of the Ocean Drilling Program, Scientific Results*, **122**, 437–451.
- BRALOWER T J & SIESSER W G 1992. Cretaceous calcareous nannofossil biostratigraphy of sites 761, 762, and 763, Exmouth and Wombat Plateaus, northwest Australia. *Proceedings of the Ocean Drilling Program, Scientific Results* **122**, 529–556.
- BRENNER W 1992a. First results of Late Triassic palynology of the Wombat Plateau, northwestern Australia. *Proceedings of the Ocean Drilling Program, Scientific Results* **122**, 413–426.
- BRENNER W 1992b. Dinoflagellate cyst stratigraphy of the Lower Cretaceous sequence at sites 762 and 763, Exmouth Plateau, northwest Australia. *Proceedings of the Ocean Drilling Program, Scientific Results* **122**, 511–528.
- BRENNER W & FOSTER C B 1994. Chlorophycean algae from the Triassic of Australia. *Review of Palaeobotany and Palynology* **80**, 209–234.
- BRUNNSCHWEILER R O 1951. Discovery of the Late Jurassic genus *Calpionella* Lorenz (Oligotric Infusoria) in Australia. *Australian Journal of Science* **14**, 3.
- BRUNNSCHWEILER R O 1960. Marine fossils from the Upper Jurassic and the Lower Cretaceous of Dampier Peninsula, Western Australia. *Australia Bureau of Mineral Resources, Geology and Geophysics, Bulletin* **59**, 1–53.
- BUJAK J P & FISHER M J 1996. Dinoflagellate cysts from the Upper Triassic of Arctic Canada. *Micropaleontology* **22**, 44–70.
- BURGER D 1996. Mesozoic palynomorphs from the North West Shelf, offshore Western Australia. *Palynology* **20**, 49–103.
- CAMPBELL R J, HOWE R W, REXILIUS J P, 2004. Middle Campanian–lowermost Maastrichtian nannofossil and foraminiferal biostratigraphy of the northwestern Australian margin. *Cretaceous Research* **25**, 827–864.
- CHAPMAN F 1917. Monograph of the Foraminifera and Ostracoda of the Gingin Chalk. *Geological Survey of Western Australia, Bulletin* **72**, 9–87.
- CHAPMAN F & CRESPIAN I 1935. Foraminiferal limestones of Eocene age from Northwest Division, Western Australia. *Proceedings of the Royal Society of Victoria* **48**, 55–62.
- CHAPMAN F & PARR W 1937. On the discovery of fusulinid Foraminifera in the upper Palaeozoic of North-West Australia: with a note on a new bivalve. *The Victorian Naturalist* **53**, 175–179.
- CHARLTON T R, BARBER A J, HARRIS R A, BARKHAM S T, BIRD P R, ARCHBOLD N W, MORRIS N J, NICOLL R S, OWEN H G, OWENS R M, SOURAU F J E, TAYLOR P D, WEBSTER G D & WHITTAKER J E 2002. The Permian of Timor: stratigraphy, palaeontology and palaeogeography. *Journal of Asian Earth Sciences* **20**, 719–774.
- CHARLTON T R, BARBER A J, MCGOWRAN A J, NICOLL R S, RONIEWICZ E, COOK S E, BARKHAM S T & BIRD P R 2009. The Triassic of Timor: Lithostratigraphy, chronostratigraphy and palaeogeography. *Journal of Asian Earth Science* **36**, 341–363.
- CHEN Z-Q, WANG Y, KERSHAW S, LUO M, YANG H, ZHAO L, FENG Y, CHEN J, YANG J & ZHANG L, 2014. Early Triassic stromatolites in a siliciclastic nearshore setting in northern Perth Basin, Western Australia: Geobiologic features and implications for post-extinction microbial proliferation. *Global and Planetary Change* **121**, 89–100.
- COCKBAIN A E 1967. *Asterocyclina* from the Plantagenet Beds near Esperance, W.A. *Australian Journal of Science* **30**, 68.
- COCKBAIN, A.E., 1968. Eocene Foraminifera from the Norseman Limestone of Lake Cowan, Western Australia. *Geological Survey of Western Australia, Annual Report* **1967**, 59–60.
- COCKBAIN, A.E., 1969. Dasycladacean algae from the Werillup Formation, Esperance. *Geological Survey of Western Australia, Annual Report* **1968**, 52–53.
- COCKBAIN, A.E., 1974. The foraminifer *Cyclammina* from the Plantagenet Group. *Geological Survey of Western Australia, Annual Report* **1973**, 107–109.
- COCKBAIN A E 1978. Discocyclinid Foraminifera from Western Australia. *Geological Survey of Western Australia, Annual Report* **1977**, 68–70.
- COCKBAIN A E 1981. On the age of the Merlinleigh Sandstone, Carnarvon Basin. *Geological Survey of Western Australia, Annual Report* **1980**, 44–46.
- COHEN K M, FINNEY S C, GIBBARD P L & FAN J-X 2017. The ICS International Chronostratigraphic Chart v 2017/02. <https://www.stratigraphy.org/> (accessed 7.6.2018)
- COLBATH G K 1990. Devonian (Givetian–Frasnian) organic-walled phytoplankton from the Limestone Billy Hills reef complex, Canning Basin, Western Australia. *Palaeontographica Abteilung B* **217**, 87–145.
- COLEMAN, P.J., 1950. Foraminifera investigations in the Perth Basin, Western Australia. *Journal of the Royal Society of Western Australia* **36**, 31–43.
- COMBAZ A & PENIGUEL G 1972. Étude palynostratigraphique de l'Ordovicien dans quelques sondages du Bassin de Canning (Australie Occidentale). *Bulletin Centre de Recherches de Pau (Societe Nationale des Petroles d'Aquitaine)* **6**, 121–167.
- CONKIN J E & CONKIN B M 1968. A revision of some Upper Devonian Foraminifera from Western Australia. *Palaeontology* **11**, 601–609.
- COOKSON I 1956. Additional microplankton from Australian Late Mesozoic and Tertiary sediments. *Australian Journal of Marine and Freshwater Research* **7**, 183–191.
- COOKSON I & EISENACK A 1958. Microplankton from Australia and New Guinea upper Mesozoic sediments. *Proceedings of the Royal Society of Victoria* **70**, 19–79.
- COOKSON I C & EISENACK A 1960a. Microplankton from Australian Cretaceous sediments. *Micropaleontology* **6**, 1–18.
- COOKSON I C & EISENACK A 1960b. Upper Mesozoic microplankton from Australia and New Guinea. *Palaeontology* **2**, 243–261.
- COOKSON I C & EISENACK A 1961. Tertiary microplankton from the Rottnest Island Bore, Western Australia. *Journal of the Royal Society of Western Australia* **44**, 39–47.
- COOKSON I C & EISENACK A 1962a. Additional microplankton from Australian Cretaceous sediments. *Micropaleontology* **8**, 485–507.
- COOKSON I C & EISENACK A 1962b. Some Cretaceous and Tertiary microfossils from Western Australia. *Proceedings of the Royal Society of Victoria* **75**, 269–274.
- COOKSON I C & EISENACK A 1968. Microplankton from two samples from Gingin Brook No. 4 borehole, Western Australia. *Journal of the Royal Society of Western Australia* **51**, 110–122.
- COOKSON I C & EISENACK A 1969. Microplankton from two bores at Balcatta, Western Australia. *Journal of the Royal Society of Western Australia* **52**, 3–8.
- COOKSON I C & EISENACK A 1970. Cretaceous microplankton from the Eucla Basin, Western Australia. *Proceedings of the Royal Society of Victoria* **83**, 137–157.
- COOKSON I C & EISENACK A 1971. Cretaceous microplankton from Eyre No. 1 Bore Core 20, Western Australia. *Proceedings of the Royal Society of Victoria* **84**, 217–226.
- COOKSON I C & EISENACK A 1974. Mikroplankton aus australischen mesozoischen und tertiären Sedimenten. *Palaeontographica B* **148**, 44–93.
- COOKSON I C & EISENACK A 1982. Mikroplankton aus australischen mesozoischen und tertiären Sedimenten. Zweiter Teil. *Palaeontographica B* **184**, 23–63.
- CRESPIAN I 1955. The Cape Range Structure, Western Australia, Part II Micropalaeontology. *Australia Bureau of Mineral Resources, Geology and Geophysics, Bulletin* **21**, 49–82.

- CRESPIAN I 1958. Permian Foraminifera of Australia. *Australia Bureau of Mineral Resources, Geology and Geophysics, Bulletin* **48**, 5–207.
- CRESPIAN I 1961. Upper Devonian Foraminifera from Western Australia. *Palaeontology* **3**, 397–409.
- CRESPIAN I 1963. Lower Cretaceous arenaceous Foraminifera of Australia. *Australia Bureau of Mineral Resources, Geology and Geophysics, Bulletin* **66**, 1–110.
- CRESPIAN I & BELFORD D J 1957. New genera and species of Foraminifera from the Lower Permian of Western Australia. *Contributions from the Cushman Foundation for Foraminiferal Research* **8**, 73–76.
- DAVIES C H, and 51 co-authors 2016. A database of marine phytoplankton abundance, biomass and species composition in Australian waters. *Scientific Data* **3**, article number 160043.
- DAVYDOV V I, HAIG D W & MCCARTAIN E 2013. A latest Carboniferous warming spike recorded by a fusulinid-rich bioherm in Timor Leste: Implications for East Gondwana deglaciation. *Palaeogeography, Palaeoclimatology, Palaeoecology* **376**, 22–38.
- DAVYDOV V I, HAIG D W & MCCARTAIN E 2014. Latest Carboniferous (Late Gzhelian) fusulinids from Timor Leste and their paleobiogeographic affinities. *Journal of Paleontology* **88**, 588–605.
- DEFLANDRE G & COOKSON I C 1955. Fossil microplankton from Australian Late Mesozoic and Tertiary sediments. *Australian Journal of Marine and Freshwater Research* **6**, 243–313.
- DIXON M & HAIG D W 2004. Foraminifera and their habitats within a cool-water carbonate succession following glaciation, Early Permian (Sakmarian), Western Australia. *Journal of Foraminiferal Research* **34**, 308–324.
- DIXON M, HAIG D W, MORY A J, BACKHOUSE J, GHORI K A R & MORRIS P A 2003a. GSWA Yinni 1 well completion report (interpretive), Gascoyne Platform, Southern Carnarvon Basin, Western Australia. *Geological Survey of Western Australia, Record* **2003/7**, 1–44.
- DIXON M, HAIG D W, MORY A J, BACKHOUSE J, GHORI K A R, HOWE R & MORRIS P A 2003b. GSWA Edaggee 1 well completion report (interpretive), Gascoyne Platform, Southern Carnarvon Basin, Western Australia. *Geological Survey of Western Australia, Record* **2003/8**, 1–80.
- EDGEHILL H S 1952. The micropalaeontology of the Giralia Anticline, N.W. Australia. *Australia Bureau of Mineral Resources, Geology and Geophysics, Record* **1952/75**, 1–12.
- EDGEHILL H S 1957. The genus *Globotruncana* in north-west Australia. *Micropalaeontology* **3**, 101–126.
- EDGEHILL H S 1963a. Micropalaeontology and stratigraphy of Marrilla No. 1 Bore, Carnarvon Basin, W.A. *Geological Survey of Western Australia, Record* **1963/21**, 1–21.
- EDGEHILL H S 1963b. Micropalaeontology and stratigraphy of Minderoo No. 1 Bore, Carnarvon Basin, W.A. *Geological Survey of Western Australia, Record* **1963/23**, 1–18.
- EDGEHILL H S 1964. The occurrence of Upper Cretaceous marine strata of Campanian age at Lancelin, Perth Basin. *Geological Survey of Western Australia, Annual Report* **1963**, 57–60.
- EDGEHILL H S 2003. Upper Devonian Charophyta of Western Australia. *Micropalaeontology* **49**, 359–374.
- EDGEHILL H S 2004. Upper Devonian and Lower Carboniferous Foraminifera from the Canning Basin, Western Australia. *Micropalaeontology* **50**, 1–26.
- EISENACK A & COOKSON I C 1960. Microplankton from Australian Lower Cretaceous sediments. *Proceedings of the Royal Society of Victoria* **72**, 1–11.
- ELLIS G 1993. Late Aptian–Early Albian Radiolaria of the Windalia Radiolarite (type section), Carnarvon Basin, Western Australia. *Eclogae Geologicae Helvetiae* **86**, 943–995.
- ETHERIDGE R 1917. *Girvanella* in the Cambrian rocks of north-west Australia. *Geological Survey of Western Australia, Bulletin* **72**, 88–90.
- FENTON C L 1943. A new Devonian Alga from Western Australia. *The American Midland Naturalist* **30**, 112.
- FENSOME R A, MACRAE R A, MOLDOWAN J M, TAYLOR F J R & WILLIAMS G L 1996. The early Mesozoic radiation of dinoflagellates. *Paleobiology* **22**, 329–338.
- FENSOME R A, SILDARRIAGA J F & TAYLOR M F J R, 1999. Dinoflagellate phylogeny revisited: reconciling morphological and molecular based phylogenies. *Grana* **38**, 66–80.
- FENSOME R A, WILLIAMS G L, BARSS M S, FREEMAN J M & HILL J M 1990. Acritarchs and fossil prasinophytes: an index to genera, species and infraspecific taxa. *American Association of Stratigraphic Palynologists Contribution Series* **25**, 1–771.
- FILATOFF J 1975. Jurassic palynology of the Perth Basin, Western Australia. *Palaeontographica B* **154**, 1–113.
- FOSTER C B, PALMIERI V & FLEMING P J G 1985. Plant microfossils, Foraminiferida, and Ostracoda, from the Fossil Cliff Formation (Early Permian, Sakmarian), Perth Basin, Western Australia. *South Australian Department of Mines and Energy, Special Publication* **5**, 61–105.
- FOSTER C B & WATERHOUSE J B 1998. The *Granulatisporites confluens* Opeel-zone and Early Permian marine faunas from the Grant Formation on the Barrow Terrace, Canning Basin, Western Australia. *Australian Journal of Earth Sciences* **35**, 135–157.
- FOSTER C & WICANDER R 2016. An Early Ordovician organic-walled microphytoplankton assemblage from the Nambeet Formation, Canning Basin, Australia: biostratigraphic and paleogeographic significance. *Palynology* **40**, 379–409 (published online 2015).
- FOSTER C B, WINCHESTER-SEETO T & O'LEARY T 1986. Hydrocarbon source potential of the Goldwyer Formation, Barrow Terrace, Canning Basin, Western Australia. *The Australian Petroleum Exploration Association Journal* **26**, 142–155.
- GEOLOGICAL SURVEY OF WESTERN AUSTRALIA 1990. Geology and mineral resources of Western Australia. *Geological Survey of Western Australia Memoir* **3**, 1–827.
- GIBBONS A D, WHITTAKER J M & MÜLLER R D 2013. The breakup of East Gondwana: Assimilating constraints from Cretaceous ocean basins around India into a best-fit tectonic model. *Journal of Geophysical Research, Solid Earth*, **118**, 808–822.
- GORTER J D, NICOLL R S & FOSTER C B 1994. Palaeozoic facies in the Carnarvon Basin, Western Australia: stratigraphy and hydrocarbon prospectivity. Pages 373–396 in Purcell P G & Purcell R R, editors, *The sedimentary basins of Western Australia: Proceedings of Petroleum Exploration Society of Australia Symposium, Perth, 1994*. Petroleum Exploration Society of Australia, Perth.
- GRADSTEIN F M, OGG J G, SCHMITZ M, OGG G 2012. *The Geologic Time Scale* 2012. Elsevier.
- GREY K 1982. Devonian and Carboniferous stromatolites from the Bonaparte Gulf Basin. *Geological Survey of Western Australia, Palaeontology Report* **27/1982**, 1–7.
- GREY K 1985. Stromatolites from the ?Cambrian Antrim Plateau Volcanics, Lissadell and Gordon Downs 1:250,000 sheet areas, W.A. *Geological Survey of Western Australia, Palaeontology Report* **15/1985**, 1–9.
- HAIG D W 1992. Aptian–Albian Foraminifera from site 766, Cuvier Abyssal Plain, and comparison with coeval faunas from the Australian region. *Proceedings of the Ocean Drilling Program, Scientific Results* **123**, 271–297.
- HAIG D W 2003. Palaeobathymetric zonation of Foraminifera from lower Permian shale deposits of a high-latitude southern interior sea. *Marine Micropalaeontology* **49**, 317–334.
- HAIG D W 2004. Comparisons of foraminifera and habitats from Australian Permian and Cretaceous interior seas. *Memoirs of the Association of Australasian Palaeontologists* **29**, 31–46.
- HAIG D W 2005. Foraminiferal evidence for inner neritic deposition of Lower Cretaceous (Upper Aptian) radiolarian-

- rich black shales on the Western Australian margin. *Journal of Micropalaeontology* **24**, 55–75.
- HAIG D W 2018. Permian (Kungurian) Foraminifera from Western Australia described by Walter Parr in 1942: reassessment and additions. *Alcheringa* **42**, 37–66.
- HAIG D W & BANDINI A N 2013. Middle Jurassic Radiolaria from a siliceous argillite block in a structural melange zone near Viqueque, Timor Leste: paleogeographic implications. *Journal of Asian Earth Sciences* **75**, 71–81.
- HAIG D W & BARNBAUM D 1978. Early Cretaceous microfossils from the type Wallumbilla Formation, Surat Basin, Queensland. *Alcheringa* **2**, 159–178.
- HAIG D W, GRIFFIN B J & UJETZ B F 1993. Redescription of type specimens of *Globorotalia chapmani* Parr from the Upper Paleocene, Western Australia. *Journal of Foraminiferal Research* **23**, 275–280.
- HAIG D W, MARTIN S K, MORY A, McLOUGHLIN S, BACKHOUSE J, BERRELL R, KEAR B P, HALL R, FOSTER C B, CHI G R & BEVAN J 2015. Early Triassic (early Olenekian) life in the interior of East Gondwana: mixed marine–terrestrial biota from the Kockatea Shale, Western Australia. *Palaeogeography, Palaeoclimatology, Palaeoecology* **417**, 511–533.
- HAIG D W & McCARTAIN E 2010. Triassic organic-cemented siliceous agglutinated foraminifera from Timor Leste: conservative development in shallow-marine environments. *Journal of Foraminiferal Research* **40**, 366–392.
- HAIG D W & McCARTAIN E 2012. Intraspecific variation in Triassic ophthalmitid Foraminifera from Timor. *Revue de Micropaléontologie* **55**, 39–52.
- HAIG D W, McCARTAIN E, MORY A J, BORGES G, DAVYDOV V I, DIXON M, ERNST A, GROFLIN S, HÅKANSSON E, KEEP M, SANTOS Z dos, SHI G R & SOARES J 2014. Postglacial Early Permian (late Sakmarian–early Artinskian) shallow-marine carbonate deposition along a 2000 km transect from Timor to west Australia. *Palaeogeography, Palaeoclimatology, Palaeoecology* **409**, 180–204.
- HAIG D W & MORY A J 2003. New record of siliceous, marine, later Eocene from Kalbarri, Western Australia. *Journal of the Royal Society of Western Australia* **86**, 107–113.
- HAIG D W & MORY A J 2016. Middle Permian (Roadian) Foraminifera from mudstone facies of the type Baker Formation, Southern Carnarvon Basin, Western Australia. *Journal of the Royal Society of Western Australia* **99**, 61–75.
- HAIG D W, MORY A J, DIXON M, BACKHOUSE J, CAMPBELL R J, GHORI K A R, HOWE R & MORRIS P A 2004. GSWA Booloogooro 1 well completion report (interpretive) Southern Carnarvon Basin Western Australia. *Geological Survey of Western Australia, Record* **2004/4**, 1–106.
- HAIG D W, MORY A J, McCARTAIN E, BACKHOUSE J, HÅKANSSON E, ERNST A, NICOLL R S, SHI G R, BEVAN J, DAVYDOV V I, HUNTER A W, KEEP M, MARTIN S K, PEYROT D, KOSSAVAYA O & SANTOS Z dos 2017. Late Artinskian–Early Kungurian (Early Permian) warming and maximum marine flooding in the East Gondwana interior rift, Timor and Western Australia, and comparisons across East Gondwana. *Palaeogeography, Palaeoclimatology, Palaeoecology* **468**, 88–121.
- HAIG D W, SMITH M & APHORPE M C 1997. Middle Eocene Foraminifera from the type Giralia Calcareenite, Gascoyne Platform, Southern Carnarvon Basin, Western Australia. *Alcheringa* **21**, 229–245.
- HAIG D W, WATKINS D K & ELLIS G 1996. Mid-Cretaceous calcareous and siliceous microfossils from the basal Gearle Siltstone, Giralia Anticline, Southern Carnarvon Basin. *Alcheringa* **20**, 41–68.
- HEATH R S & APHORPE M C 1986. Middle and Early(?) Triassic Foraminifera from the Northwest Shelf, Western Australia. *Journal of Foraminiferal Research* **16**, 313–333.
- HEINE C & MÜLLER R D 2005. Late Jurassic rifting along the Australian North West Shelf: margin geometry and spreading ridge configuration. *Australian Journal of Earth Sciences* **52**, 27–39.
- HELBY R 1987a. Three Late Triassic palynomorphs from northwestern Australia. *Memoir of the Association of Australasian Palaeontologists* **4**, 95–100.
- HELBY R 1987b. *Muderongia* and related dinoflagellates of the latest Jurassic to Early Cretaceous of Australasia. *Memoir of the Association of Australasian Palaeontologists* **4**, 297–336.
- HELBY R, MORGAN R & PARTRIDGE A D 1987. A palynological zonation of the Australian Mesozoic. *Memoir of the Association of Australasian Palaeontologists* **4**, 1–94.
- HELBY R & STOVER L E 1987a. *Ternia balmey* gen. et sp. nov., a Jurassic dinoflagellate with possible dinophysalian affinity. *Memoir of the Association of Australasian Palaeontologists* **4**, 135–141.
- HELBY R & STOVER L E 1987b. Paratabulation of the Early Cretaceous dinoflagellate *Dolldinium sinuosum* (Cookson & Eisenack) comb. nov. *Memoir of the Association of Australasian Palaeontologists* **4**, 159–164.
- HENDERSON R A, CRAMPTON J S, DETTMANN M E, DOUGLAS J G, HAIG D, SHAFIK S, STILWELL J D & THULBORN R A 2000. Biogeographical observations on the Cretaceous biota of Australasia. *Memoir of the Association of Australasian Palaeontologists* **23**, 355–404.
- HOCKING R M, MOORS H T & VAN DE GRAAFF W J E 1987. Geology of the Carnarvon Basin Western Australia. *Geological Survey of Western Australia, Bulletin* **13**, 1–289.
- HOWCHIN W 1895. Carboniferous Foraminifera of Western Australia, with descriptions of new species. *Transactions of the Royal Society of South Australia* **19**, 194–198.
- HOWCHIN W 1907. Foraminifera from a calcareous marlstone, Gingin. *Geological Survey of Western Australia, Bulletin* **27**, 38–43.
- HOWE R W 2000. Jurassic calcareous nannofossil biostratigraphy of the North West Shelf and Timor Sea areas. *Minerals and Energy Research Institute of Western Australia (MERIWA) Report M319*, 1–24.
- HOWE R W, HAIG D W & APHORPE M C 2000. Cenomanian–Coniacian transition from siliciclastic to carbonate marine deposition, Giralia Anticline, Southern Carnarvon Platform, Western Australia. *Cretaceous Research* **21**, 517–551.
- HOWE R W 2005. Results of calcareous nannofossil analyses. Appendix G in Blevin J E, editor. Geological framework of the Bremer and Denmark sub-basins, southwest Australia, R/V Southern Surveyor Survey SS03/2004, Geoscience Australia Survey 265, post-survey report and GIS. *Geoscience Australia Record* **2005/05**.
- HOWE R W, CAMPBELL R J, REXILIUS J P 2003. Integrated uppermost Campanian–Maastrichtian calcareous nannofossil and foraminiferal biostratigraphic zonation of the northwestern margin of Australia. *Journal of Micropalaeontology* **22**, 29–62.
- JONES R W & WONDERS A A H 1992. Benthic Foraminifera and paleobathymetry of Barrow Group (Berriasian–Valanginian) deltaic sequences, sites 762 and 763, Northwest Shelf, Australia. *Proceedings of the Ocean Drilling Program, Scientific Results* **122**, 557–568.
- KEMP E M 1976. Palynological observations in the Officer Basin, Western Australia. *Australia Bureau of Mineral Resources, Geology and Geophysics, Bulletin* **160**, 23–39.
- KEUPP H 1992. Calcareous dinoflagellate cysts from the Lower Cretaceous of Hole 761C, Wombat Plateau, Eastern Indian Ocean. *Proceedings of the Ocean Drilling Program, Scientific Results* **122**, 497–509.
- KRISTAN-TOLLMANN E & GRAMANN F 1992. Paleontological evidence for the Triassic age of rocks dredged from the northern Exmouth Plateau (Tethyan Foraminifera, echinoderms, and ostracodes). *Proceedings of the Ocean Drilling Program, Scientific Results* **122**, 463–474.
- KUMMEL B & RAUP D 1965. *Handbook of Paleontological Techniques*. W.H. Freeman and Co., San Francisco and London.
- LI Z & POWELL C McA 2001. An outline of the palaeogeographic

- evolution of the Australasian region since the beginning of the Neoproterozoic. *Earth-Science Reviews* **53**, 237–277.
- LIPPS J H & CULVER S J 2002. The trophic role of marine microorganisms through time. *Paleontological Society Papers* **8**, 69–92.
- MAMET B L & BELFORD D J 1968. Carboniferous foraminifera, Bonaparte Gulf Basin, northwestern Australia. *Micropaleontology* **14**, 339–347.
- MAMET B & PLAYFORD P E 1968. Sur la presence de Quasiendothyriinae (Foraminifères) en Australie occidentale (Canning Basin). *Compte-Rendu Sommaire des Séances de la Société Géologique de France* **7**, 229–230.
- MAMET B & ROUX A 1983. Algues Dévono-Carbonifères de l'Australie. *Revue de Micropaléontologie* **26**, 63–131.
- MANTLE D J 2005. New dinoflagellate cyst species from the upper Callovian–lower Oxfordian *Rigaudella aemula* Zone, Timor Sea, northwestern Australia. *Review of Palaeobotany and Palynology* **135**, 245–264.
- MANTLE D J 2009a. Palynology, sequence stratigraphy, and palaeoenvironments of Middle to Upper Jurassic strata, Bayu-Undan Field, Timor Sea region, Part One. *Palaeontographica B* **280**, 1–86.
- MANTLE D J 2009b. Palynology, sequence stratigraphy, and palaeoenvironments of Middle to Upper Jurassic strata, Bayu-Undan Field, Timor Sea region, Part Two. *Palaeontographica B* **280**, 87–212.
- MANTLE D J & RIDING J B 2012. Palynology of the Middle Jurassic (Bajocian–Bathonian) *Wanaea verrucosa* dinoflagellate cyst zone of the North West Shelf of Australia. *Review of Palaeobotany and Palynology* **180**, 41–78.
- MARSHALL N G & LANG S C 2013. A new sequence stratigraphic framework for the North West Shelf, Australia. *West Australian Basins Symposium* **2013**, 1–32.
- MAY F E, STEVENS J, PARTRIDGE A D 1987. The Early Cretaceous dinoflagellate, *Dissimulidinium lobispinosum* gen. et sp. nov. from Western Australia. *Memoir of the Association of Australasian Palaeontologists* **4**, 199–204.
- MCGOWRAN B 1964. Foraminiferal evidence for the Paleocene age of the King's Park Shale (Perth Basin, Western Australia). *Journal of the Royal Society of Western Australia* **47**, 81–86.
- MCGOWRAN B 1977. Maastrichtian to Eocene foraminiferal assemblages in the northern and eastern Indian Ocean region: correlations and historical patterns. *Indian Ocean Geology and Biostratigraphy* **9**, 417–458.
- MCGOWRAN B 1989. The later Eocene transgressions in southern Australia. *Alcheringa* **13**, 45–68.
- MCGOWRAN B & LINDSAY J M 1969. A Middle Eocene planktonic foraminiferal assemblage from the Eucla Basin. *Quarterly Geological Notes Geological Survey of South Australia* **30**, 2–10.
- McLOUGHLIN S, HAIG D W, BACKHOUSE J, HOLMES M A, ELLIS G, LONG J A & McNAMARA K J 1995. Oldest Cretaceous sequence, Giralia Anticline, Carnarvon Basin, Western Australia: late Hauterivian–Barremian. *AGSO Journal of Australian Geology & Geophysics* **15**, 445–468.
- MEDD A W 1966. The fine structure of some Lower Triassic acritarchs. *Palaeontology*, **9**, 351–354.
- METCALFE I 2011. Tectonic framework and Phanerozoic evolution of Sundaland. *Gondwana Research* **19**, 3–21.
- MOLDOWAN J M, DAHL J, JACOBSON, SR, HUIZINGA BJ, FAGO, FJ, SHETTY R, WATT, DS & PETERS KE 1996. Chemostratigraphic reconstruction of biofacies: Molecular evidence linking cyst-forming dinoflagellates with pre-Triassic ancestors. *Geology* **24**, 159–162.
- MOLDOWAN J M & TALYZINA N M 1998. Biogeochemical evidence for dinoflagellate ancestors in the Early Cambrian. *Science* **281**, 1168–1170.
- MOLYNEAUX S G, DELABROYE A, WICANDER R & SERVAIS T 2013. Biogeography of early to mid Palaeozoic (Cambrian–Devonian) marine phytoplankton. *Memoirs of the Geological Society of London* **38**, 365–397.
- MORAN M J 1992. Biostratigraphy of Upper Cretaceous and Paleocene calcareous nannofossils from Leg 123, northeastern Indian Ocean. *Proceedings of the Ocean Drilling Program, Scientific Results*, **123**, 381–405.
- MORY A J 2017. *A Paleozoic perspective of Western Australia*. Geological Survey of Western Australia, Perth, 58 p.
- MORY A J & HAIG D W 2011. Permian–Carboniferous geology of the northern Perth and Southern Carnarvon basins, Western Australia — a field guide. *Geological Survey of Western Australia, Record* **2011/14**, 1–65.
- NAZAROV B B, COCKBAIN A E & PLAYFORD P E 1982. Late Devonian Radiolaria from the Gogo Formation, Canning Basin, Western Australia. *Alcheringa* **6**, 161–173.
- NAZAROV B B & ORMISTON A R 1983. Upper Devonian (Frasnian) radiolarian fauna from the Gogo Formation, Western Australia. *Micropaleontology* **29**, 454–466.
- PALMIERI V 1993. Foraminifera. *Geological Survey of Western Australia, Bulletin* **136**, 30–32 (and Appendix A1–A90).
- PARR W J 1938. Upper Eocene Foraminifera from deep borings in King's Park, Perth, Western Australia. *Journal of the Royal Society of Western Australia* **24**, 69–101.
- PARR W J 1942. Foraminifera and a tubicolous worm from the Permian of the North-West Division of Western Australia. *Journal of the Royal Society of Western Australia* **27**, 97–115.
- PETRIZZO M R 2000. Upper Turonian–lower Campanian planktonic foraminifera from southern mid-high latitudes (Exmouth Plateau, NW Australia): biostratigraphy and taxonomic notes. *Cretaceous Research* **21**, 479–505.
- PETRIZZO M R 2003. Late Cretaceous planktonic foraminiferal bioevents in the Tethys and in the Southern Ocean record: an overview. *Journal of Foraminiferal Research* **33**, 330–337.
- PETRIZZO M R & PREMOLI SILVA I 2000. Upper Cretaceous meridionally costellate hedbergellids: the genus *Meridionella* El-Nakhal, 1982 vs. the genus *Costellagerina* Petters, El-Nakhal and Cifelli, 1983. *Journal of Foraminiferal Research* **30**, 306–309.
- PLAYFORD G 1976. Plant microfossils from the Upper Devonian and Lower Carboniferous of the Canning Basin, Western Australia. *Palaeontographica B* **158**, 1–71.
- PLAYFORD G 1981. Late Devonian acritarchs from the Gneudna Formation in the western Carnarvon Basin, Western Australia. *Geobios* **14**, 145–171.
- PLAYFORD G 2003. *Acritarchs and Prasinophyte Phycomata: A Short Course*. American Association of Stratigraphic Palynologists Foundation.
- PLAYFORD G & DRING R S 1981. Late Devonian acritarchs from the Carnarvon Basin, Western Australia. *Special Papers in Palaeontology* **27**, 1–78.
- PLAYFORD G & MARTIN F 1984. Ordovician acritarchs from the Canning Basin, Western Australia. *Alcheringa* **8**, 187–223.
- PLAYFORD P E & COCKBAIN A E 1969. Algal stromatolites: deepwater forms in the Devonian of Western Australia. *Science, New Series* **165**, 1008–1010.
- PLAYFORD P E, COCKBAIN AE, DRUCE E C, WRAY J L 1976. Devonian stromatolites from the Canning Basin, Western Australia. Pages 543–564 in Walter M R, editor, *Stromatolites*. Elsevier Science, Amsterdam.
- PLAYFORD P E, COPE R N, COCKBAIN A E, LOW G H & LOWRY D C 1975. Phanerozoic. *Geological Survey of Western Australia, Memoir* **2**, 223–433.
- PLAYFORD P E, HOCKING R M & COCKBAIN A E 2009. Devonian reef complexes of the Canning Basin, Western Australia. *Geological Survey of Western Australia, Bulletin* **145**, 1–444.
- POSPICHAL J J & BRALOWER T J 1992. Calcareous nannofossils across the Cretaceous/Tertiary boundary, site 761, northwest Australian margin. *Proceedings of the Ocean Drilling Program, Scientific Results* **122**, 735–751.
- QUILTY P G 1969. Upper Eocene planktonic Foraminifera from Albany, Western Australia. *Journal of the Royal Society of Western Australia* **52**, 41–58.

- QUILTY P G 1974. Tertiary stratigraphy of Western Australia. *Journal of the Geological Society of Australia* **21**, 301–318.
- QUILTY P G 1975. A new species of *Schackoinella* from the Eocene of Western Australia with comments on the Glabratellidae. *Journal of Foraminiferal Research* **5**, 326–333.
- QUILTY P G 1978. The Late Cretaceous–Tertiary section in Challenger No 1 (Perth Basin) – details and implications. *Australia Bureau of Mineral Resources, Geology and Geophysics, Bulletin* **192**, 109–124.
- QUILTY P G 1981a. Early Jurassic Foraminifera from the Exmouth Plateau, Western Australia. *Journal of Paleontology* **55**, 985–995.
- QUILTY P G 1981b. Late Eocene benthic Foraminiferida, south coast, Western Australia. *Journal of the Royal Society of Western Australia* **64**, 79–100.
- QUILTY P G 1990. Triassic and Jurassic foraminiferid faunas, northern Exmouth Plateau, Eastern Indian Ocean. *Journal of Foraminiferal Research* **20**, 349–367.
- QUILTY P G 2011. Late Jurassic Foraminifera, Wallaby Plateau, offshore Western Australia. *Journal of Foraminiferal Research* **41**, 182–195.
- QUINTAVALLE M & PLAYFORD G 2006a. Palynostratigraphy of Ordovician strata, Canning Basin, Western Australia. Part one: acritarchs and prasinophytes. *Palaeontographica B* **275**, 1–88.
- QUINTAVALLE M & PLAYFORD G 2006b. Palynostratigraphy of Ordovician strata, Canning Basin, Western Australia. Part two: chitinozoans and biostratigraphy. *Palaeontographica B* **275**, 89–131.
- QUINTAVALLE M & PLAYFORD G 2008. Stratigraphic distribution of selected acritarchs in the Ordovician subsurface, Canning Basin, Western Australia. *Revue de micropaléontologie* **51**, 23–37.
- REMANE J 1971. Les calpionelles, protozoaires planctoniques des mers mésogénées de l'époque secondaire. *Annales Guebhard* **47**, 1–25.
- REMANE J 1985. 12, Calpionellids. Pages 555–572 in Bolli H M, Saunders J B & Perch-Nielsen, K., editors, *Plankton Stratigraphy*. Cambridge University Press, Cambridge.
- RIDING J B & HELBY R 2001a. Early Jurassic (Toarcian) dinoflagellate cysts from Timor Sea, Australia. *Memoir of the Association of Australasian Palaeontologists* **24**, 1–32.
- RIDING J B & HELBY R 2001b. A selective reappraisal of *Wanaea* Cookson & Eisenack 1958 (Dinophyceae). *Memoir of the Association of Australasian Palaeontologists* **24**, 33–58.
- RIDING J B & HELBY R 2001c. *Phallocysta granosa* sp. nov., a Mid Jurassic (Bathonian) dinoflagellate cyst from the Timor Sea, Australia. *Memoir of the Association of Australasian Palaeontologists* **24**, 59–63.
- RIDING J B & HELBY R 2001d. Microplankton from the Mid Jurassic (late Callovian) *Rigaudella aemula* Zone in the Timor Sea, north-western Australia. *Memoir of the Association of Australasian Palaeontologists* **24**, 65–110.
- RIDING J B & HELBY R 2001e. Dinoflagellate cysts from the Late Jurassic (Oxfordian) *Wanaea spectabilis* Zone in the Timor Sea region. *Memoir of the Association of Australasian Palaeontologists* **24**, 111–140.
- RIDING J B & HELBY R 2001f. Dinoflagellate cysts from the Late Jurassic (Kimmeridgian) *Dingodinium swanense* Zone in the North-West Shelf and Timor Sea, Australia. *Memoir of the Association of Australasian Palaeontologists* **24**, 141–176.
- RIDING J B & HELBY R 2001g. Marine microplankton from the Late Jurassic (Tithonian) of the north-west Australian region. *Memoir of the Association of Australasian Palaeontologists* **24**, 177–220.
- RIDING J B & HELBY R 2001h. Some stratigraphically significant dinoflagellate cysts from the Early Cretaceous (Aptian and Albian) of Australia. *Memoir of the Association of Australasian Palaeontologists* **24**, 225–235.
- RIDING J B, MANTLE D J & BACKHOUSE J 2010. A review of the chronostratigraphical ages of Middle Triassic to Late Jurassic dinoflagellate cyst biozones of the North West Shelf of Australia. *Review of Palaeobotany and Palynology* **162**, 543–575.
- RIDING J B, WESTERMANN G E G & DARBYSHIRE D P F 2010. New evidence for the age of the Athol Formation (Middle Jurassic; Bajocian) in the Tusk-1 and Tusk-2 wells, offshore Carnarvon Basin, Western Australia. *Alcheringa* **34**, 21–35.
- RIDING R & JANS A L F 1976. Devonian occurrence of *Uraloporella* (? Foraminifera) in the Canning Basin, Western Australia. *Journal of Paleontology* **50**, 805–807.
- RÖHL U, DUMONT T, VON RAD U, MARTINI R & ZANINETTI L 1991. Upper Triassic Tethyan carbonates off northwest Australia (Wombat Plateau, ODP Leg 122). *Facies* **25**, 211–252.
- SAPPAL K K 1978. Triassic acritarchs from Western Australia and their stratigraphic significance. *Proceedings of the Third Regional Conference on Geology, Mineral and Energy Resources of Southeast Asia (GEOSEA)* **3**, 91–97.
- SEGROVES K L 1967. Cutinized microfossils of probable nonvascular origin from the Permian of Western Australia. *Micropaleontology* **13**, 289–305.
- SERVAIS T, VECOLI M, LI J, MOLYNEUX S G, RAEVSKAYA E G, RUBINSTEIN C V 2007. The acritarch genus *Veryhachium* Deunff 1954: Taxonomic evaluation and first appearance. *Palynology* **31**, 191–203.
- SHAFIK S 1978a. Paleocene and Eocene nannofossils from the Kings Park Formation, Perth Basin, Western Australia. *Australia Bureau of Mineral Resources, Geology and Geophysics, Bulletin* **192**, 165–171.
- SHAFIK S 1978b. A new nannofossil zone based on the Santonian Gingin Chalk, Perth Basin, Western Australia. *BMR Journal of Australian Geology & Geophysics* **3**, 211–226.
- SHAFIK S 1978c. The near-surface sediments of the Scott Plateau and Java Trench: nannofossil assessment and implications. *BMR Journal of Australian Geology & Geophysics* **3**, 341–345.
- SHAFIK S 1985. Cretaceous coccoliths in the middle Eocene of the western and southern margins of Australia: evidence of a significant reworking episode. *BMR Journal of Australian Geology & Geophysics* **9**, 353–359.
- SHAFIK S 1990. Late Cretaceous nannofossil biostratigraphy and biogeography of the Australian western margin. *Australia Bureau of Mineral Resources, Geology and Geophysics, Report* **295**, 1–164.
- SHAFIK S 1991. Upper Cretaceous and Tertiary stratigraphy of the Fremantle Canyon, South Perth Basin: a nannofossil assessment. *BMR Journal of Australian Geology & Geophysics* **12**, 65–91.
- SHAFIK, S., 1993. First Australian record of Jurassic calcareous nannofossil-bearing sediments: offshore Canning Basin, NW Australia. *Association of Australasian Palaeontologists, K.S.W. Campbell Symposium, Australian National University, Canberra, 8–10 February, 1993, Abstracts*, 23.
- SHAFIK S 1994. Significance of calcareous nannofossil-bearing Jurassic and Cretaceous sediments on the Rowley Terrace, offshore northwest Australia. *AGSO Journal of Australian Geology & Geophysics* **15**, 71–88.
- SIESSER W G, BRALOWER T J & DE CARLO E H 1992a. Mid-Tertiary *Braarudosphaera*-rich sediments on the Exmouth Plateau. *Proceedings of the Ocean Drilling Program, Scientific Results* **122**, 653–663.
- SIESSER W G, BRALOWER T J, TANG C & GALBRUN B 1992b. Late Miocene–Quaternary calcareous nannofossil biomagnetochronology on the Exmouth Plateau, northwest Australia. *Proceedings of the Ocean Drilling Program, Scientific Results* **122**, 677–681.
- SIESSER W G & BRALOWER T J 1992. Cenozoic calcareous nannofossil biostratigraphy on the Exmouth Plateau, eastern Indian Ocean. *Proceedings of the Ocean Drilling Program, Scientific Results* **122**, 601–631.
- SPAACK G, EDWARDS D S, FOSTER C B, PAGÉS A, SUMMONS R E, SHERWOOD N & GRICE K 2017. Environmental conditions and microbial community structure during the Great Ordovician

- Biodiversification Event; a multi-disciplinary study from the Canning Basin, Western Australia. *Global and Planetary Change* **159**, 93–112.
- STEVENS J 1987. Some Early Cretaceous dinoflagellates from the *Cassiculosphaeridia delicata* Zone on the Exmouth Plateau, Western Australia. *Memoir Association of Australasian Palaeontologists* **4**, 185–197.
- STEVENS J & HELBY R 1987. Some Early Cretaceous dinoflagellates encountered in the Australian *Kalypte wisemanianae* Zone. *Memoir Association of Australasian Palaeontologists* **4**, 165–184.
- STILLWELL J D, QUILTY P G & MANTLE D J 2012. Paleontology of Early Cretaceous deep-water samples dredged from the Wallaby Plateau: new perspectives of Gondwana break-up along the Western Australian margin. *Australian Journal of Earth Sciences* **59**, 29–49.
- STOVER L E & HELBY R 1987a. Some Australian Mesozoic microplankton index species. *Memoir of the Association of Australasian Palaeontologists* **4**, 101–134.
- STOVER L E & HELBY R 1987b. The Jurassic dinoflagellate *Omatia* and allied genera. *Memoir of the Association of Australasian Palaeontologists* **4**, 143–158.
- STOVER L E & HELBY R 1987c. Early Cretaceous dinoflagellates from the Vinck-1 well, offshore Western Australia. *Memoir of the Association of Australasian Palaeontologists* **4**, 227–260.
- STOVER L E & HELBY R 1987d. Some Early Cretaceous dinoflagellates from the Houtman-1 well, Western Australia. *Memoir of the Association of Australasian Palaeontologists* **4**, 261–295.
- TABOADA A C, MORY A J, SHI G-R, HAIG D W & PINILLA M K 2015. An Early Permian brachiopod–gastropod fauna from the Calytrix Formation, Barbwire Terrace, Canning Basin, Western Australia. *Alcheringa* **39**, 207–223.
- TAYLOR B A & HAIG D W 2001. Barremian foraminifera from the Muderong Shale, oldest marine sequence in the Cretaceous of the Southern Carnarvon Basin, Western Australia. *Micropaleontology* **47**, 125–143.
- THIBAUT N, HUSSON D, HARLOU R, GARDIN S, GALBRUN B, HURET E & MINOLETTI F 2012. Astronomical calibration of upper Campanian–Maastrichtian carbon isotope events and calcareous plankton biostratigraphy in the Indian Ocean (ODP Hole 762C): Implication for the age of the Campanian–Maastrichtian boundary. *Palaeogeography, Palaeoclimatology, Palaeoecology* **337–338**, 52–71.
- TRENDALL A F & COCKBAIN A E 1990. Basins: Introduction. *Geological Survey of Western Australia Memoir* **3**, 291–293.
- VACHARD D, HAIG D W, MORY A J 2014. Lower Carboniferous (middle Viséan) Foraminifera and algae from an interior sea, Southern Carnarvon Basin, Australia. *Geobios* **47**, 57–74.
- VEEVERS J J 1970. Upper Devonian and Lower Carboniferous calcareous algae from the Bonaparte Gulf Basin, northwestern Australia. *Australia, Bureau of Mineral Resources, Geology and Geophysics, Bulletin* **116**, 173–188.
- VON RAD U, SCHOTT M, EXON N F, MUTTERLOSE J, QUILTY P & THUROW J W 1990. Mesozoic sedimentary and volcanic rocks dredged from the northern Exmouth Plateau: petrography and microfacies. *BMR Journal of Australian Geology & Geophysics* **11**, 449–472.
- WICANDER R & WOOD G D 1997. The use of microphytoplankton and chitonozans for interpreting transgressive/regressive cycles in the Rapid Member of the Cedar Valley Formation (Middle Devonian), Iowa. *Review of Palaeobotany and Palynology* **98**, 125–152.
- WILLIAMS S E, WHITTAKER J M & MÜLLER R D 2011. Full-fit, palinspastic reconstruction of the conjugate Australian–Antarctic margins. *Tectonics* **30**, TC6012, doi:10.1029/2011TC002912.
- WINCHESTER-SEETO T, FOSTER C & O’LEARY T 2000a. The environmental response of Middle Ordovician large organic walled microfossils from the Goldwyer and Nita Formations, Canning Basin, Western Australia. *Review of Palaeobotany and Palynology* **113**, 197–132.
- WINCHESTER-SEETO T, FOSTER C & O’LEARY T 2000b. Chitinozoans from the Middle Ordovician (Darriwilian) Goldwyer and Nita formations, Canning Basin (Western Australia). *Acta Palaeontologica Polonica* **45**, 271–300.
- WON M-Z 1997a. Review of Family Entactiniidae (Radiolaria) and taxonomy and morphology of Entactiniidae in the Late Devonian (Frasnian) Gogo Formation, Australia. *Micropaleontology* **43**, 333–369.
- WON M-Z 1997b. The proposed new radiolarian Subfamily Retentactiniinae (Entactiniidae) from the Late Devonian (Frasnian) Gogo Formation, Australia. *Micropaleontology* **43**, 371–418.
- WONDERS A A H 1992. Cretaceous planktonic foraminiferal biostratigraphy, Leg 122, Exmouth Plateau, Australia. *Proceedings of the Ocean Drilling Program, Scientific Results* **122**, 587–599.
- WRAY J L 1967. Upper Devonian calcareous algae from the Canning Basin, Western Australia. *Professional Contributions of the Colorado School of Mines* **3**, 1–76.
- ZANINETTI L, MARTINI R & DUMONT T 1992. Triassic Foraminifera from Sites 761 and 764, Wombat Plateau, northwest Australia. *Proceedings of the Ocean Drilling Program, Scientific Results* **122**, 427–436.