Devonian Great Barrier Reef of the Canning Basin, Western Australia: the evolution of our understanding

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Devonian reef complexes are spectacularly exposed along the northern margin of the Canning Basin in Western Australia, and have become renowned as 'The Devonian Great Barrier Reef'. The geological literature on these rocks dates back to 1884 and the first studies of the biostratigraphy were conducted during the 1940s. Geologists of the Commonwealth Bureau of Mineral Resources were the first to systematically map the Devonian rocks, during the late 1940s and early 1950s, and since then studies by many individuals and organisations have progressively increased knowledge of the stratigraphy and paleontology of these reef complexes. The Geological Survey of Western Australia's research culminated in 2009 with the publication of a comprehensive bulletin on the geology of the reef complexes.

KEYWORDS: allochthonous block, atoll, barrier reef, bioherm, Canning Basin, cyclicity, depositional dip, Devonian, facies, mass extinction, mineralisation, paleontology, pinnacle reef, reef complexes, sequence stratigraphy, stromatolite, stylolitisation.

INTRODUCTION

Middle and Upper Devonian reef complexes form a series of spectacular limestone ranges that extend for some 350 km along the northern margin of the Canning Basin (Figures 1, 2). They are acknowledged to constitute the best example in the world of an ancient barrier reef system, and have become widely known as 'The Devonian Great Barrier Reef'.

Publications and unpublished reports considered to be turning points in the understanding of these reef complexes are summarised below. There are many more publications than those referenced here — for a comprehensive bibliography readers can refer to Playford *et al*. (2009).

FIRST DISCOVERY

The first geologist to examine these rocks was the Government Geologist E T Hardman, as a member of John Forrest's expedition exploring the area in 1883 (Hardman 1884). He examined the Napier Range at Windjana Gorge ('Devil's Pass': Figure 3), Geikie Gorge, Mt Pierre and adjoining areas (Playford & Ruddock 1985). Hardman did not recognise these rocks as reef deposits, and concluded that they were Carboniferous in age. However, examination of his fossil collections soon showed them to be Devonian (Nicholson 1890; Hinde 1890; Foord 1890).

RECOGNITION OF REEFS

Arthur Wade, while working for the Freney Kimberley Oil Company, was the first geologist to recognise that these limestones constitute reef deposits (Wade 1924), and he later described them as being remnants of an 'ancient barrier reef' (Wade 1936).

PIONEERING PALEONTOLOGY AND BIOSTRATIGRAPHY

Curt Teichert, then with the University of Western Australia, worked on the Devonian reefs in association with geologists of Caltex (Australia) Oil Development Pty Ltd, who were assessing the oil prospects of the Canning Basin. Teichert examined the Devonian paleontology and biostratigraphy, publishing a series of papers on what he termed the 'Great Devonian Barrier Reef' (Teichert 1939, 1941, 1943, 1947, 1949). He was the first to recognise the facies equivalence of various parts of the complexes and their associated conglomerates (Figure 4: Teichert 1949). Although he was able to spend relatively little time in the field, Teichert laid firm foundations for subsequent studies of the reef complexes. Indeed, he was ahead of his time — he understood these rocks better than some geologists who studied them subsequently.

MAPPING BY THE COMMONWEALTH BUREAU OF MINERAL RESOURCES

From 1948 to 1952 the Commonwealth Bureau of Mineral Resources (BMR, now Geoscience Australia) mapped the full extent of the Devonian reef complexes for the first time, as part of a regional geological survey of the northern Canning Basin (then known as the 'Fitzroy Basin'). In 1953 the manuscript of a bulletin on the geology of this area was destroyed in a fire at the Bureau's offices in Canberra, but it was subsequently re-written by the same authors, all but one of whom were by then employed by WAPET (West Australian Petroleum Pty Ltd). Guppy *et al.* (1958) defined many rock units in the reef complexes, and realised that the

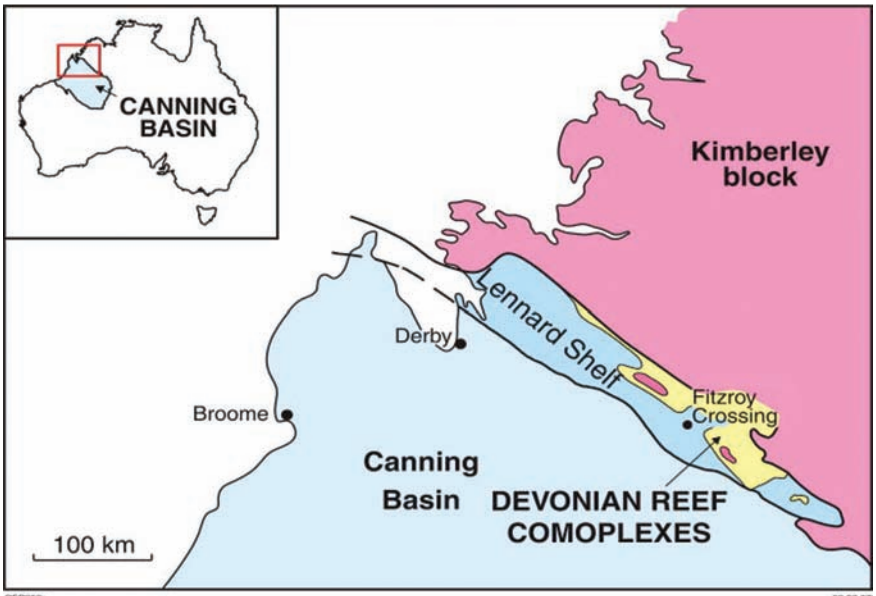

Figure 1 Locality map, Devonian reef complexes of the Canning Basin.

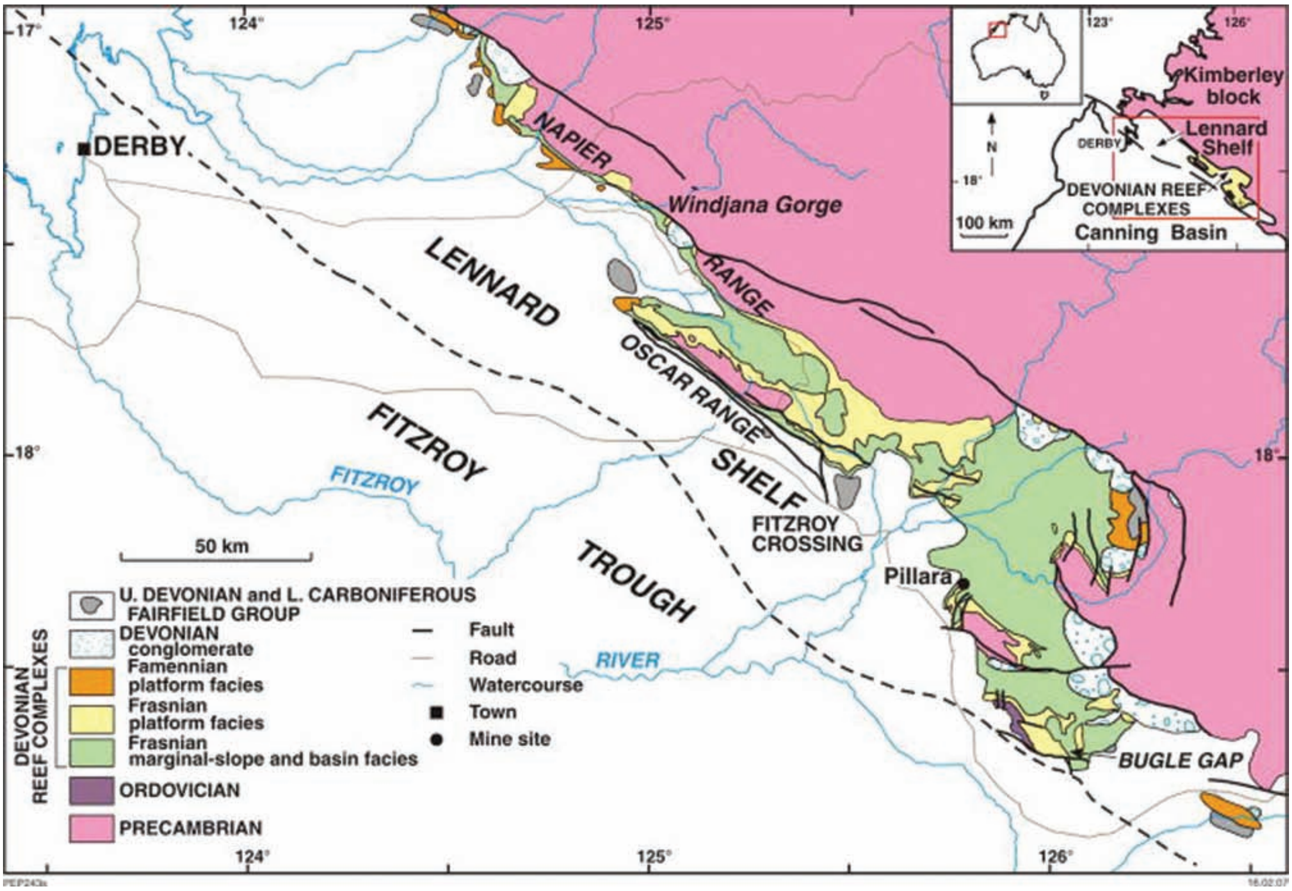

Figure 2 Generalised geological map, Devonian reef complexes of the Canning Basin.

steep dips in some of the limestones were largely depositional, but they did not recognise the equivalence of the various facies. They mistakenly concluded that the Pillara Limestone is entirely Middle Devonian (Givetian) in age and that it is overlain unconformably by Upper Devonian strata (Figure 5).

OSCAR RANGE STUDY

WAPET recognised that if these Devonian reef complexes extend into the subsurface, they would have a high potential for petroleum, because similar Devonian reefs in Alberta were known to contain large oil reserves. The

Figure 3 Sketch by E T Hardman of the southern entrance to Windjana Gorge ('Devil's Pass').

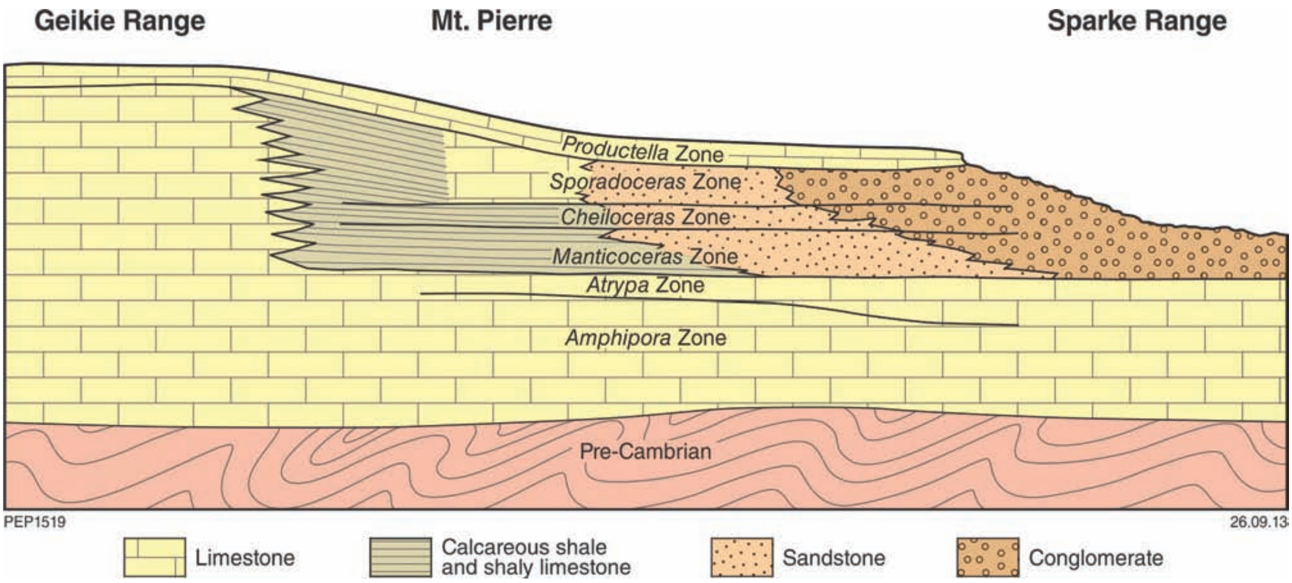

Figure 4 Diagrammatic cross-section illustrating the facies and paleontological zones of Devonian reef complexes between Geikie Range and Sparke Range, as interpreted by Teichert (1949 plate 6).

company concluded that there was a need for a better understanding of these reef complexes, and consequently a detailed study of the Oscar Range reef complex was undertaken in 1956 (Smith *et al*. 1957).

In this study Smith and Williams were responsible for the mapping, while Playford made periodic visits to the field and studied the petrology of the rocks, while becoming familiar with the literature on ancient reef complexes. One of the publications that he studied was that of King (1942) on the Permian reef complex of West Texas and southeastern New Mexico, in which he showed that distinct facies could be recognised in the reef complex. Playford concluded that comparable facies might be present in the Oscar Range reef complex, and as a result that was proved to be the case: three basic facies — reef, back reef, and fore reef — were recognised there (Smith *et al*. 1957) (Figure 5). It was also confirmed that the steep dips in fore-reef deposits are largely depositional.

Another important outcome of this work was recognition of the major role played by microbes in constructing the reefs. Those microbes, first seen in thin-sections, were termed 'ghost algae', and were later recognised as the microbe *Renalcis* (Playford & Lowry 1966; Wray 1967; Playford 1967). That microbe would later be found to also occur in the Canadian reef complexes.

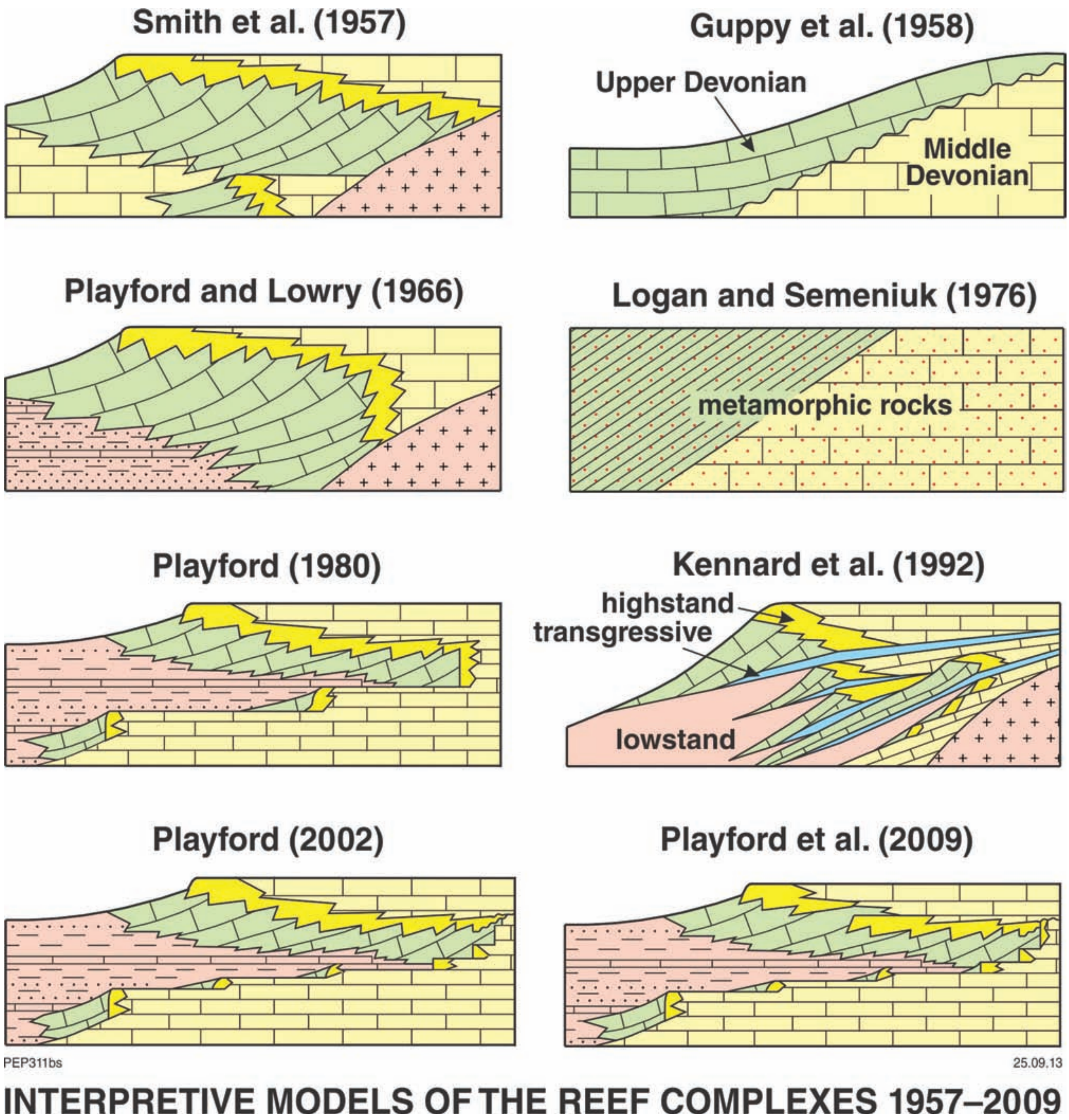

Figure 5 Diagram illustrating some changing concepts since 1957 in interpretation of the Devonian reef complexes.

WINDJANA GORGE

A study of the Upper Devonian reef complex at Windjana Gorge in the Napier Range was undertaken for WAPET in 1958 (Playford & Johnstone 1959; Playford 1961) (Figure 6). A notable outcome of that work was recognition of the spectacular exposure in the gorge that would later become known as 'The Classic Face' (Figure 7).

MAPPING AND ASSOCIATED RESEARCH BY THE GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

Systematic mapping and interpretation of the reef complexes was conducted during 1962 and 1963 for the Geological Survey of Western Australia (GSWA), the results being published in Bulletin 118 (Playford & Lowry 1966). Among the outcomes of that study were recognition

Figure 6 Aerial view of the Napier Range at Windjana Gorge looking northwest. The sinuous front of the range is essentially the late Famennian reef scarp.

Figure 7 Panoramic view of the Classic Face at Windjana Gorge, showing flat-bedded back-reef and reef-flat limestones on the right, passing into massive reef-margin in the centre and steeply dipping marginal-slope deposits on the left.

of atolls and pinnacle reefs in the eastern part of the outcrop area (Figures 8, 9) and of the importance of contemporary tectonism in controlling development of the reef complexes. Fracturing of early-cemented limestones, resulting from that tectonism, formed networks of neptunian dykes (Figure 10) and gave rise to megabreccia debris flows and isolated allochthonous blocks on marginal slopes in front of the reefal platforms (Figures 11, 12). Large masses of reef limestone in fore-reef deposits, previously considered to be bioherms, were now recognised as allochthonous reef blocks, in some cases capped by deep-water microbial limestone (Figure 12).

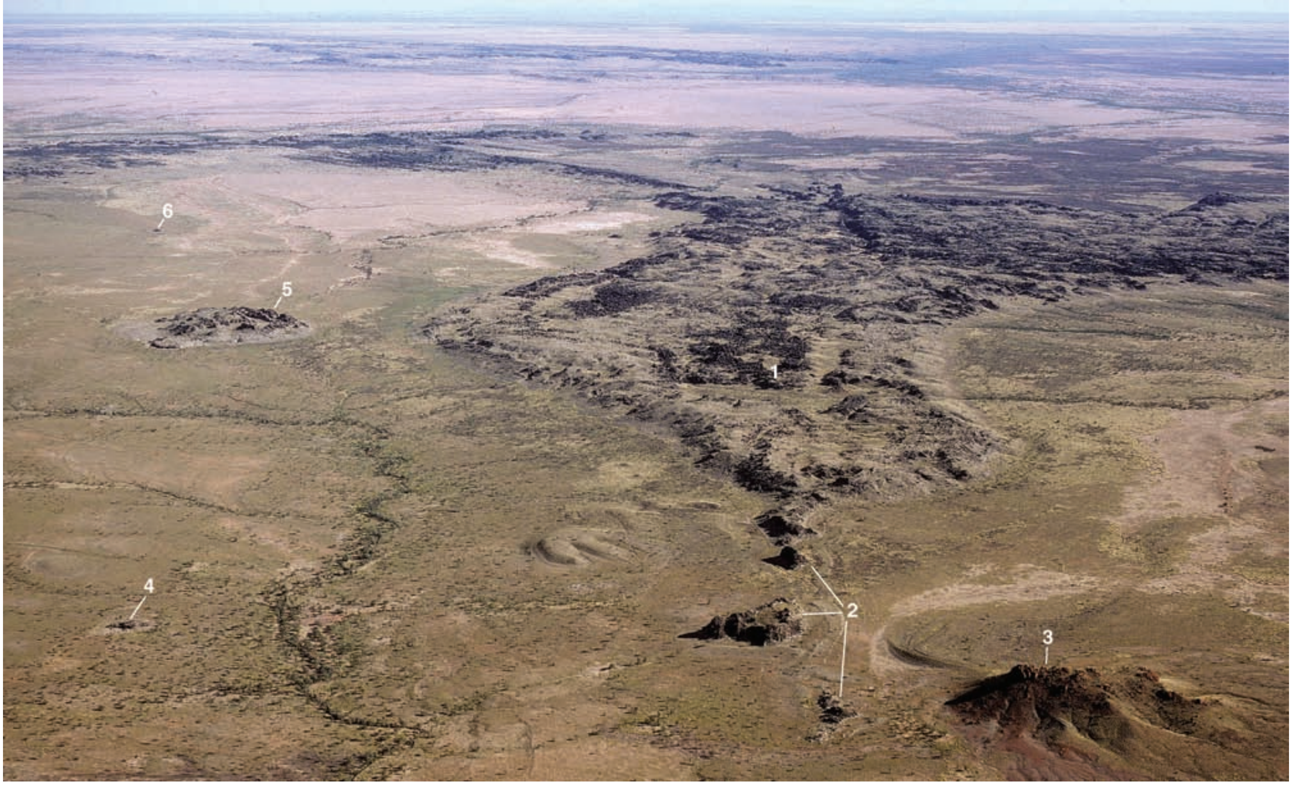

Figure 8 Aerial view looking north over the Laidlaw Range reef complex, showing (1) the Laidlaw Range atoll; (2) the 'tail' of Glenister Knolls patch reefs; (3) Ross Hill (Lower Permian sandstone); (4) Smith Knoll pinnacle reef; (5) Lloyd Hill atoll; and (6) Wade Knoll pinnacle reef.

Figure 9 Aerial view of Wade Knoll pinnacle reef looking south, showing concentric marginal-slope deposits and cyclic basin strata surrounding the reef pinnacle.

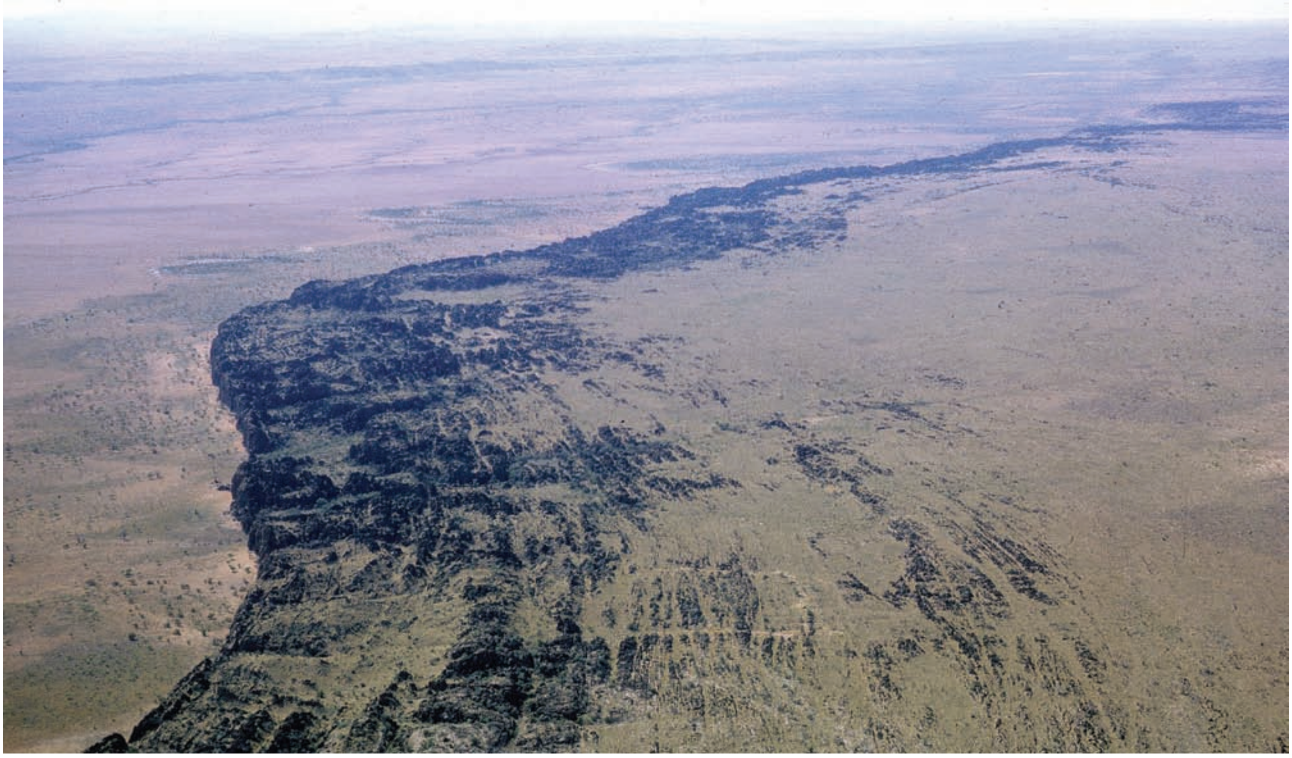

Figure 10 Aerial view looking east over the northeast side of the Oscar Range. Morown Cliff, at the front of the range, is essentially the exhumed late Famennian reef scarp. Note linear corridors following neptunian dykes, parallel to the reef front, with a subsidiary fracture system at right angles to those dykes.

Figure 11 Typical debris-flow megabreccia in fore-reef subfacies (Napier Formation), at Dingo Gap in the Napier Range. The megabreccia is composed of blocks of reef and reefal-slope limestones in a matrix of calcareous sandstone.

Figure 12 Allochthonous block of reef limestone in fore-reef subfacies (Napier Formation) 0.5 km south of McSherrys Gap, Napier Range. A thin (~15 cm thick) layer of deep-water stromatolites, at the foot of the person in the photograph, grew on top of the block after it came to rest.

Figure 13 Oncolites and capped oncolites in Sadler Limestone in the karst corridor on the west side of McWhae Ridge. The oncolites were built by *Girvanella*, and caps on the oncolites in the last layer were built by *Sphaerocodium*.

Figure 14 Receptaculitid in marginal-slope Sadler Limestone in the karst corridor on the west flank of McWhae Ridge, showing a geopetal infilling that marks the approximate horizontal at the time of deposition, compared with the depositional dip of the overlying marginal-slope limestones.

Figure 15 Early Famennian columnar stromatolites that grew vertically on a marginal slope in the Virgin Hills Formation at Ngumban Cliff.

BUGLE GAP AND DEEP-WATER STROMATOLITES

The GSWA, in association with the BMR, conducted detailed studies of reef complexes in the Bugle Gap area during 1968. One outcome of that work was the use of geopetal structures to quantify depositional dips and deduce paleobathymetry (Figures 13–15). It was shown that some stromatolites must have grown on marginal slopes in water depths of at least 35 m, and probably more than 100 m (Playford & Cockbain 1969). That conclusion was contrary to the belief, commonly held at that time, that stromatolites are solely intertidal phenomena (Logan 1961).

RECOGNITION OF CYCLICITY

Reid (1973a, b) was the first to recognise cyclicity in back-reef limestones. The shallowing-upward cycles in that facies are deduced to be eustatic in origin, and are known as Milankovitch cycles (Figure 16). Subsequently it was shown that cyclicity can also be recognised in other facies of the reef complexes (Playford *et al*. 2009).

DEEP-WATER BIOHERMS

Playford *et al*. (1976) described the presence in the northeastern Oscar Range of major Late Devonian deep-water microbial and receptaculitid bioherms (Figure 17).

Figure 16 Low-level aerial view looking north, immediately north the eastern part of Windjana Gorge, showing strong cyclicity in Pillara Limestone, back-reef subfacies. Prominent white limestone is at the base of each cycle and is overlain by recessive-weathering calcareous sandstone.

Figure 17 Aerial view looking north over the southwest culmination of Elimberrie no. 2 bioherm. The width of the field of view in the centre of the photo is about 150 m.

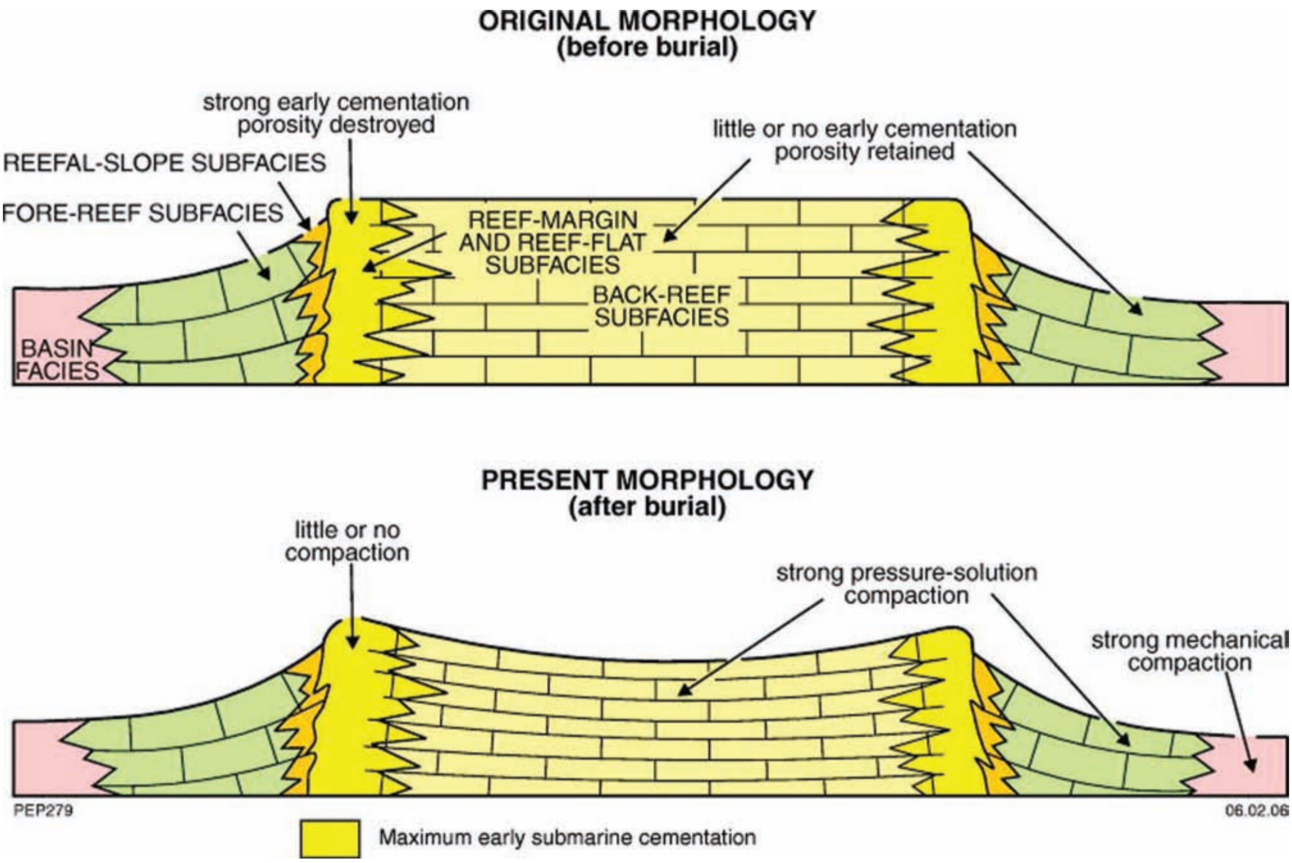

Figure 18 Diagram to illustrate changes in the morphology of the Devonian limestone platforms, resulting from pressure-solution compaction after burial.

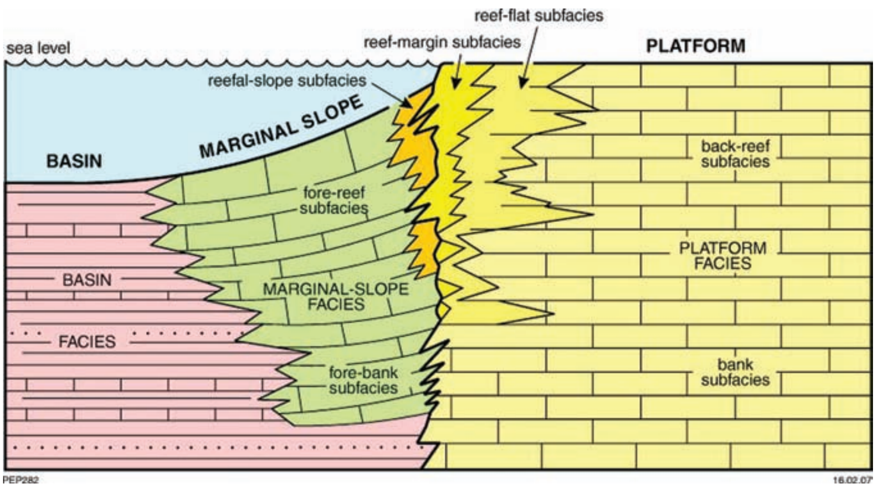

Figure 19 Diagrammatic cross-section illustrating the morphology and facies relationships of the reef complexes.

These remarkable bioherms grew over drowned Late Devonian pinnacle reefs, and are thought to be unique in the world.

‘DYNAMIC METAMORPHISM’

A special publication of the Geological Society of Australia described the Devonian limestones as being products of dynamic metamorphism (Logan & Semeniuk 1976) (Figure 5). Those authors asserted that the limestones do not form reef complexes, but are instead the products of dynamic metamorphism, associated with intensive shear faulting, and with metamorphic grades as high as greenschist facies. Similar claims were put forward by Logan (1984) and Logan *et al*. (1994). However, those conclusions were not accepted by other authors, all of whom have recognised that the limestones represent unmetamorphosed reef complexes, and the supposed shear faults do not exist.

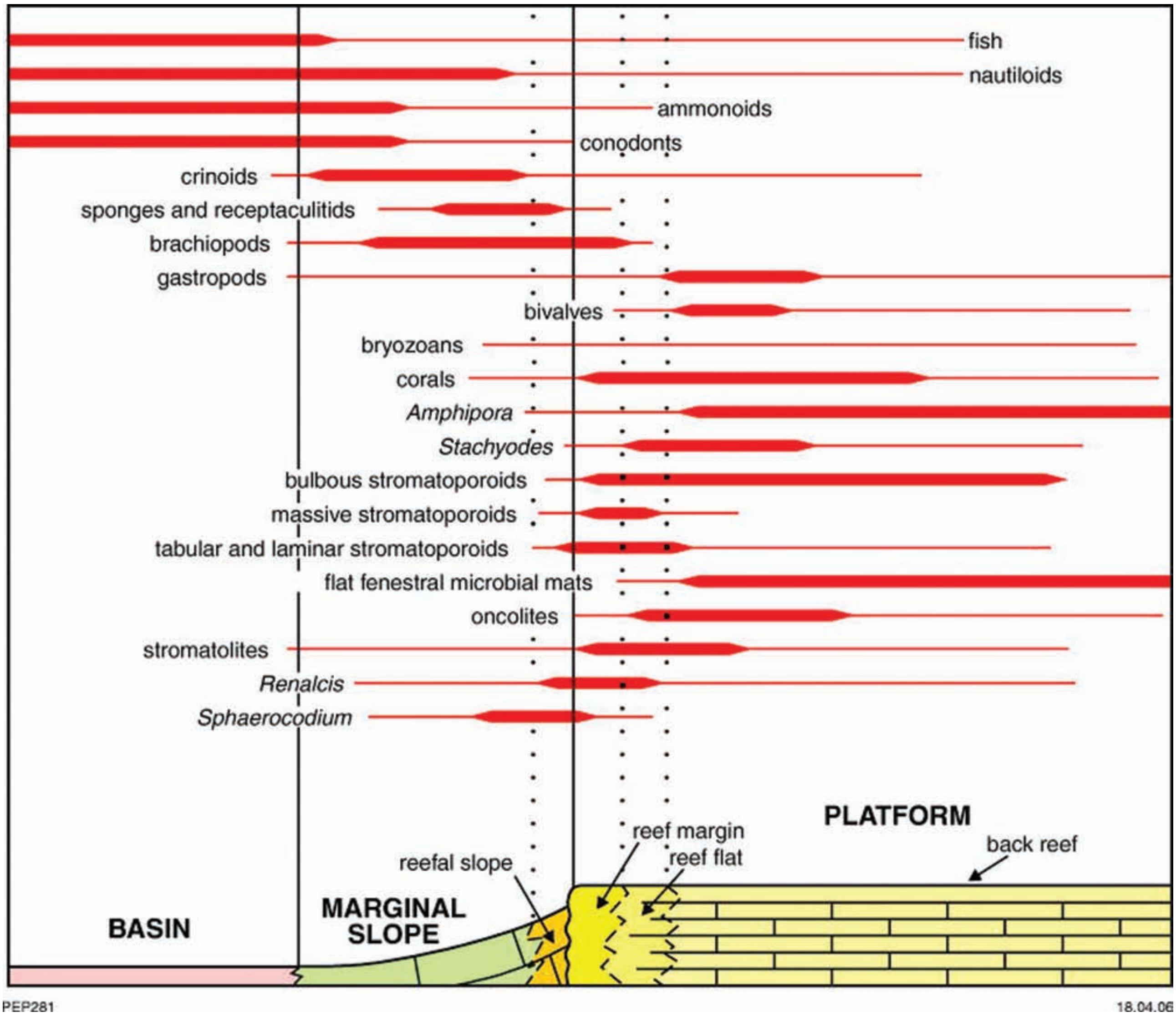

Figure 20 Diagram illustrating the biotic distribution of principal organisms in the Frasnian reef complexes.

GIVETIAN–FRASNIAN RETREATING AND BACKSTEPPING PLATFORMS, FAMENNIAN ADVANCING PLATFORMS, AND DIFFERENTIAL STYLOLITISATION

Playford (1980) published a paper entitled 'Devonian Great Barrier Reef of the Canning Basin, Western Australia', following a tour of the United States and Canada in 1978 as a Distinguished Lecturer of the American Association of Petroleum Geologists. A feature of that paper was the recognition of Givetian–Frasnian retreating and backstepping reefal platforms, followed during the Famennian by advancing platforms (Figure 5). It was also shown that differential compaction of the limestones has been controlled by variations in the degree of pressure-solution stylolitisation. Strong stylolitisation, and resulting compaction, has occurred in the back-reef subfacies, with little or no stylolitisation or compaction in reef-margin and reef-flat subfacies. This differential compaction has resulted in the characteristic 'dished' shape of many platforms (Figure 18).

FACIES NOMENCLATURE AND THE FRASNIAN/FAMENNIANMASS EXTINCTION

In a publication for a PESA (Petroleum Exploration Society of Australia) Canning Basin Symposium, Playford (1984) presented an updated facies nomenclature for the reef complexes (Figure 19), and also discussed the mass extinction at the Frasnian/Famennian (F/F) boundary (Figures 20–23). That mass extinction resulted in the loss of many marine species, so that the reef-building stromatoporoids, corals and microbes of the Frasnian were replaced by microbes, almost alone, during the Famennian. Marked changes also occurred in conodont and ammonoid faunas in basin and marginal-slope deposits at that boundary. The F/F boundary was shown to be unconformable in reef, reefal-slope, and back-reef facies, and conformable in basin facies and deeper fore-reef facies (Figures 22, 23).

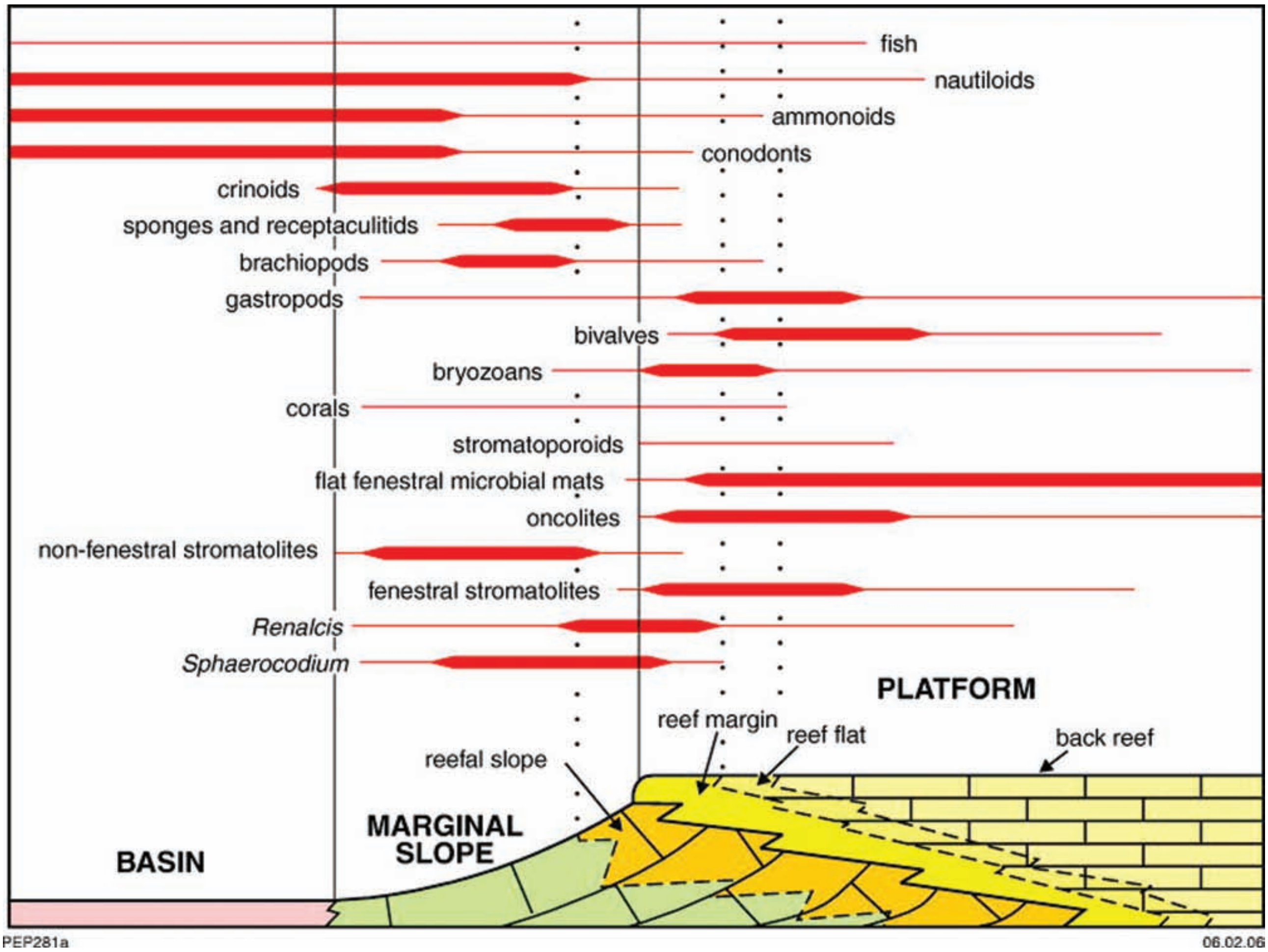

Figure 21 Diagram illustrating the biotic distribution of the principal organisms in the Famennian reef complexes.

PETROGRAPHY OF THE REEF COMPLEXES

Kerans (1985) made the first detailed studies of the petrology of the reef complexes, emphasising the importance of marine cementation in early diagenesis, and confirming earlier observations of Playford (1980, 1984). The strongest early cementation, with concomitant destruction of porosity, occurred in reef-margin, reef-flat, and reefal-slope deposits (Figures 24–26).

SEQUENCE STRATIGRAPHY

Kennard *et al*. (1992) were the first to apply the concept of sequence stratigraphy to the reef complexes. They adopted what has become known as the 'Exxon paradigm', whereby eustatic fluctuations in sea level are said to drive reciprocal sedimentation of highstand, transgressive and lowstand system tracts. They claimed that this gave rise to deposition of terrigenous conglomerates as lowstand deposits, and reefal platforms as highstand deposits, with thin intervening transgressive deposits (Figure 5). However, field studies by Playford *et al*. (2009) showed that most conglomerates in the area are highstand deposits that interfinger with platform, marginal-slope, and basin facies.

DEEP-WATER STROMATOLITE MOUNDS AND SULFIDE MINERALISATION

Deep-water stromatolite mounds, associated with barite mineralisation, and cut by iron-sulfide veins, were formed as exhalative deposits over cool-water seepages on the basin floors (Playford & Wallace 2001) (Figure 27). These deposits resulted from compaction-driven fluids, expelled from anoxic muds of the basin facies. In addition to nourishing stromatolites, the fluids gave rise to the associated barite and sulfide mineralisation (Figure 27). It had previously been known that a wide variety of other stromatolites grew on shallow reefal platforms and adjoining marginal slopes in the reef complexes, where they were associated with open-marine benthic faunas, whereas the exhalative stromatolites grew on and below the muddy floors of deep-water basins, without any associated benthic faunas (Figure 28).

EFFECTS OF THE PERMIAN GLACIATION

In a West Australian Basins Symposium (WABS), Playford (2002) discussed the role of the Permian glaciation in planing down the reef complexes below thick ice caps that flowed from south to north (Figure 29). Subglacial water below those ice caps resulted in

Figure 22 The Frasnian–Famennian unconformity near Limestone Spring in the northwestern Napier Range, showing well-bedded Nullara Limestone (Famennian back-reef subfacies) unconformably overlying crudely bedded Napier Formation (late Frasnian reefal-slope subfacies). The dip in the Napier Formation is largely depositional.

extensive networks of Nye channels and sub-glacial karst (Figures 30, 31).

PALEONTOLOGY

The Devonian paleontology of the Canning Basin is renowned worldwide, and a review of work on the various groups is beyond the scope of this paper. The most recent publications on important groups have been by Wray (1967) on microbes; Cockbain (1984) on stromatoporoids; Won (1997) on radiolarians; Jell & Jell (1999) on echinoderms; Klapper (2009) on conodonts; Becker & House (2009) on ammonoids; G. Playford (2009) on palynomorphs; Long & Trinajstic (2010) on fish; and Feist & McNamara (2013) on trilobites.

SYNTHESIS OF MORE THAN 50 YEARS OF RESEARCH

A detailed synthesis of more than 50 years of research on the Devonian Great Barrier reef by GSWA and its many collaborators was published by Playford *et al*. (2009) as Bulletin 145 of the Geological Survey. This major publication was based largely on remapping and detailed stratigraphic studies of the reef complexes, with associated paleontological research. It refines earlier understandings of the facies and stratigraphy, and presents an event-based sequence stratigraphy of the reef complexes. Siliciclastic conglomerates were shown to be tectonically driven and synchronous with the reef complexes, and tectonic versus eustatic controls on the cyclicity and development of the various facies were discussed.

The bulletin includes a guide to the most significant field localities and includes more than 530 colour photos and diagrams. The diagrams include a model illustrating the various facies recognised in the reef complexes (Figure 32), and another showing the lithostratigraphy, sequence stratigraphy and events responsible for backstepping and partial drowning of reefal platforms (Figure 33).

Accompanying the bulletin are a series of maps at scales of 1:500 000, 1:250 000, and 1:100 000 of the entire reef belt, and 1:50 000 and 1:25 000 of key areas. Also included are appendices on important elements of the

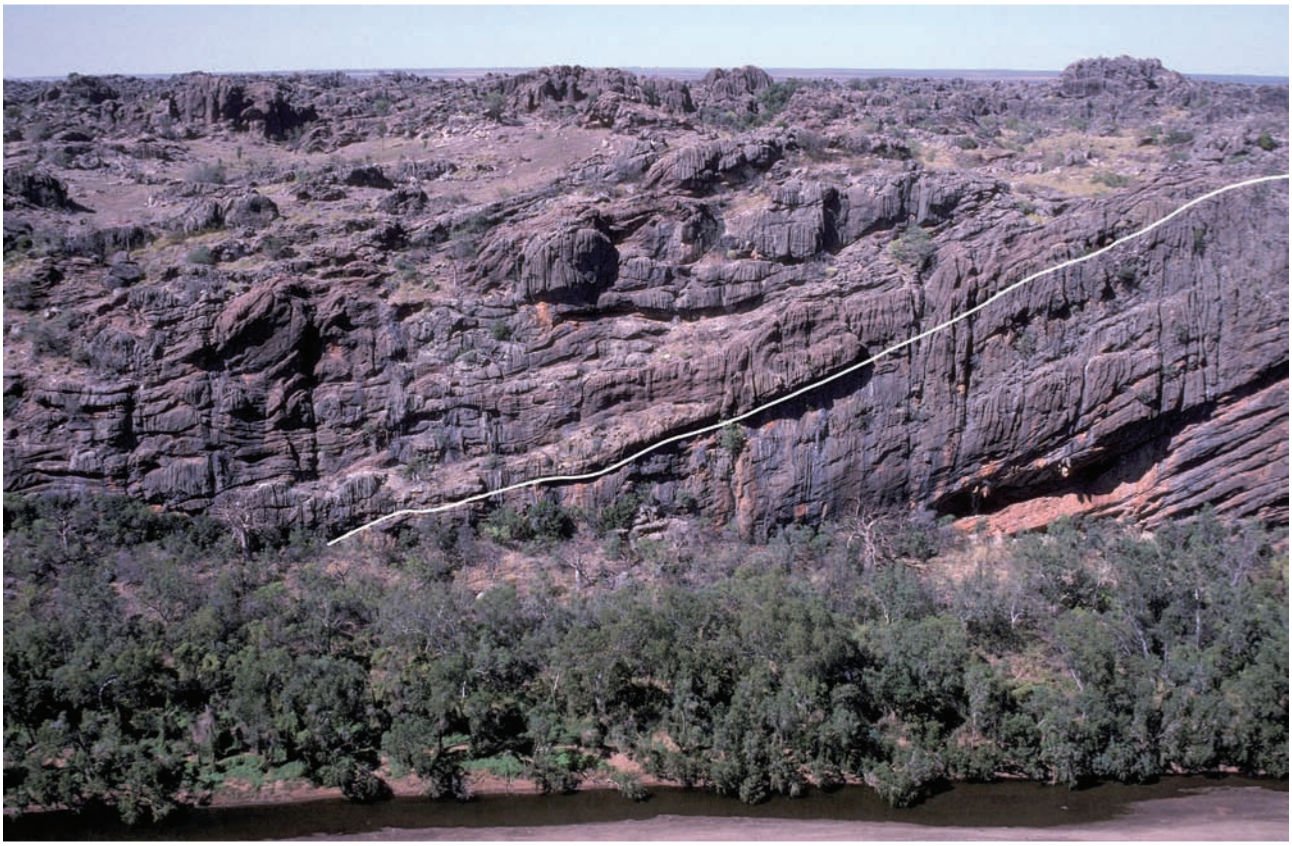

Figure 23 The Frasnian–Famennian boundary, marked by a white line, in marginal-slope deposits (Napier Formation) in the eastern part of Windjana Gorge, on its south side. The Frasnian deposits on the right are generally well bedded, whereas the Famennian deposits on the left are poorly bedded and marked by many allochthonous blocks of reef limestone. Note the undulating bedding, probably stromatolitic, above the boundary.

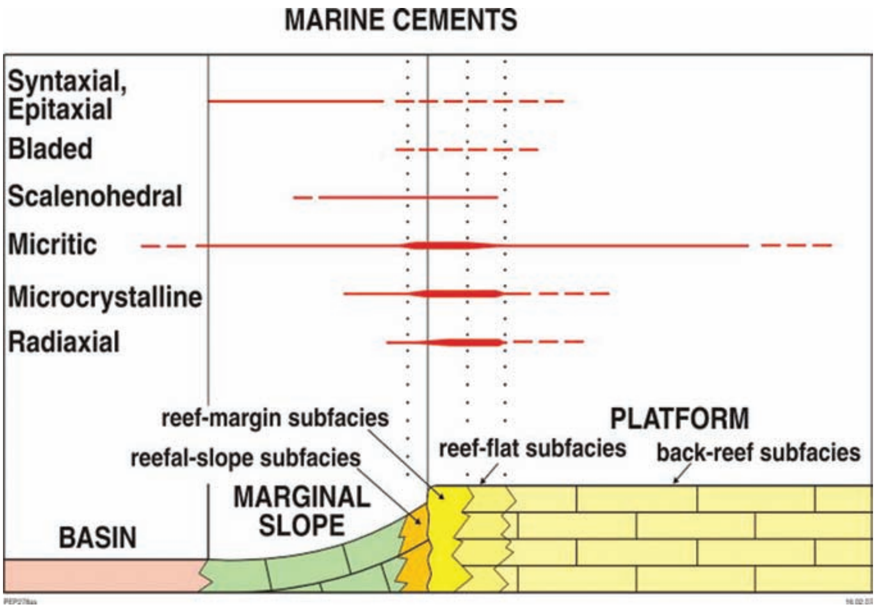

Figure 24 Diagram illustrating the distribution of various types of early marine cements in the reef complexes.

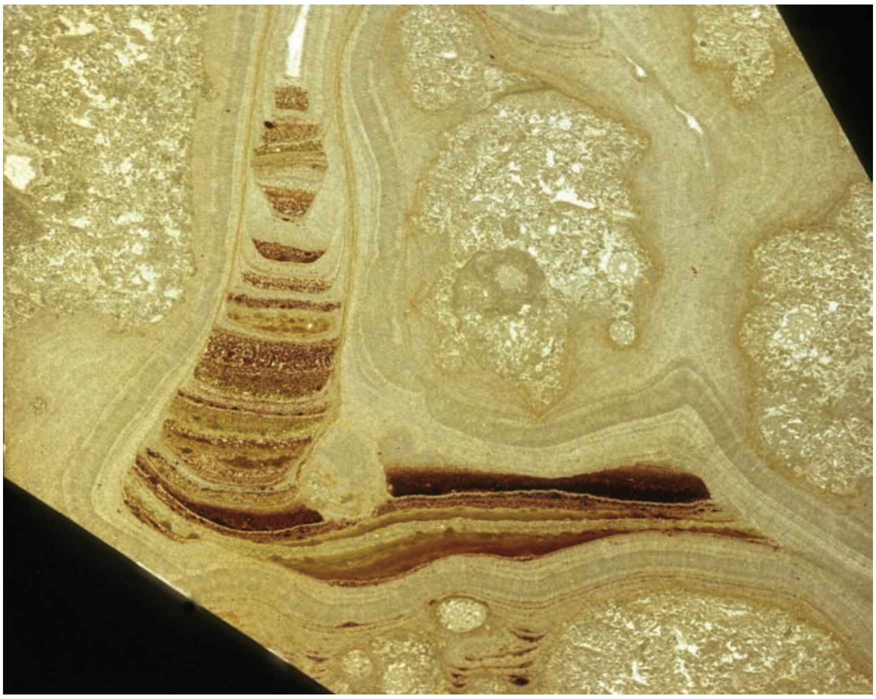

Figure 25 Thin-section of microbial stromatoporoid reef limestone (Pillara Limestone) showing a former large cavity, now filled with interlaminated fibrous sparry calcite and red cavity peloids, from an allochthonous block at McIntyre Knolls.

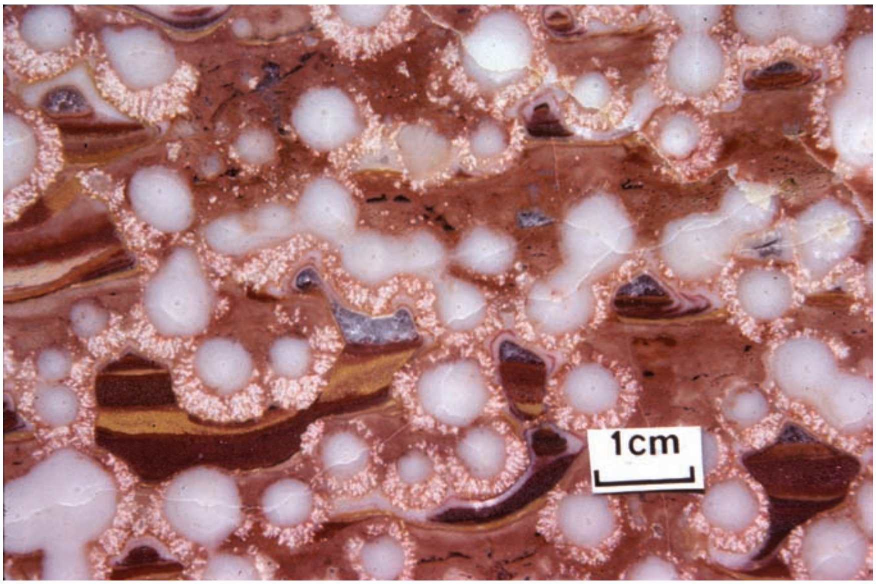

Figure 26 Polished slab of reef limestone (Pillara Limestone) from an allochthonous block in marginal-slope deposits at McIntyre Knolls, showing a colony of *Stachyodes* that fell over before being encrusted by *Renalcis*. The rest of the cavity system was then filled successively with red laminated peloidal limestone and clear sparry calcite.

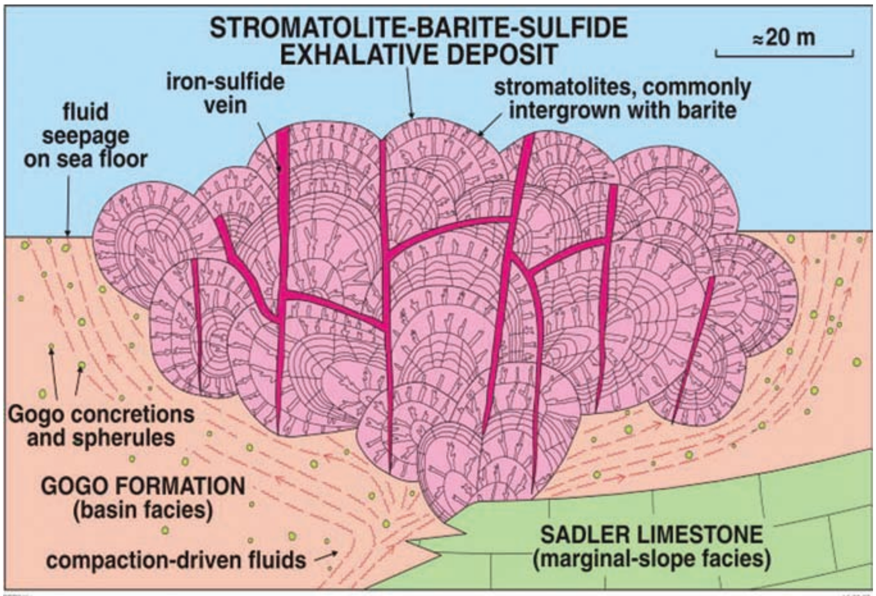

Figure 27 Diagrammatic cross-section through a Frasnian exhalative deposit, showing bulbous stromatolites, intergrown with barite and cut by iron-sulfide veins. The deposit was generated in deep water by compaction-driven fluids above the contact between Gogo Formation (basin facies) and Sadler Limestone (marginal-slope facies).

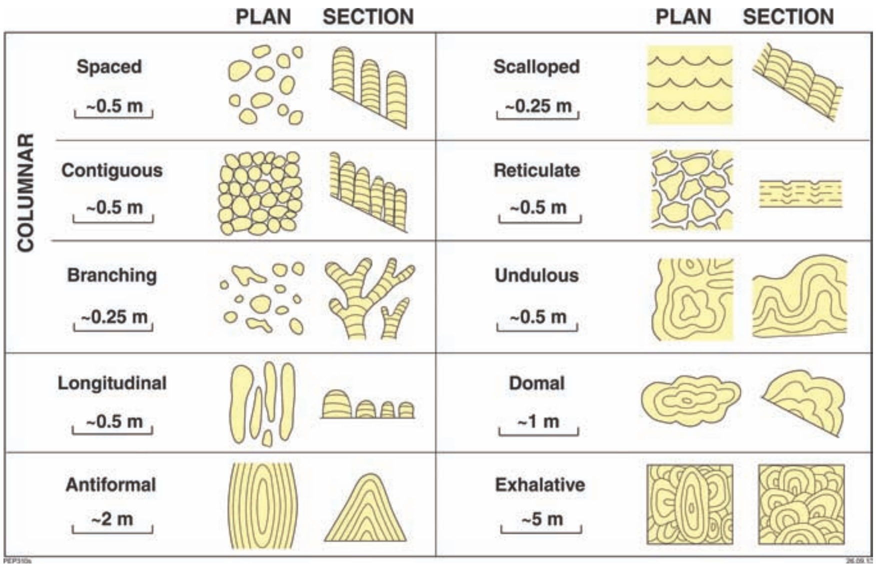

Figure 28 Diagram illustrating the different types of stromatolites recognised in the reef complexes.

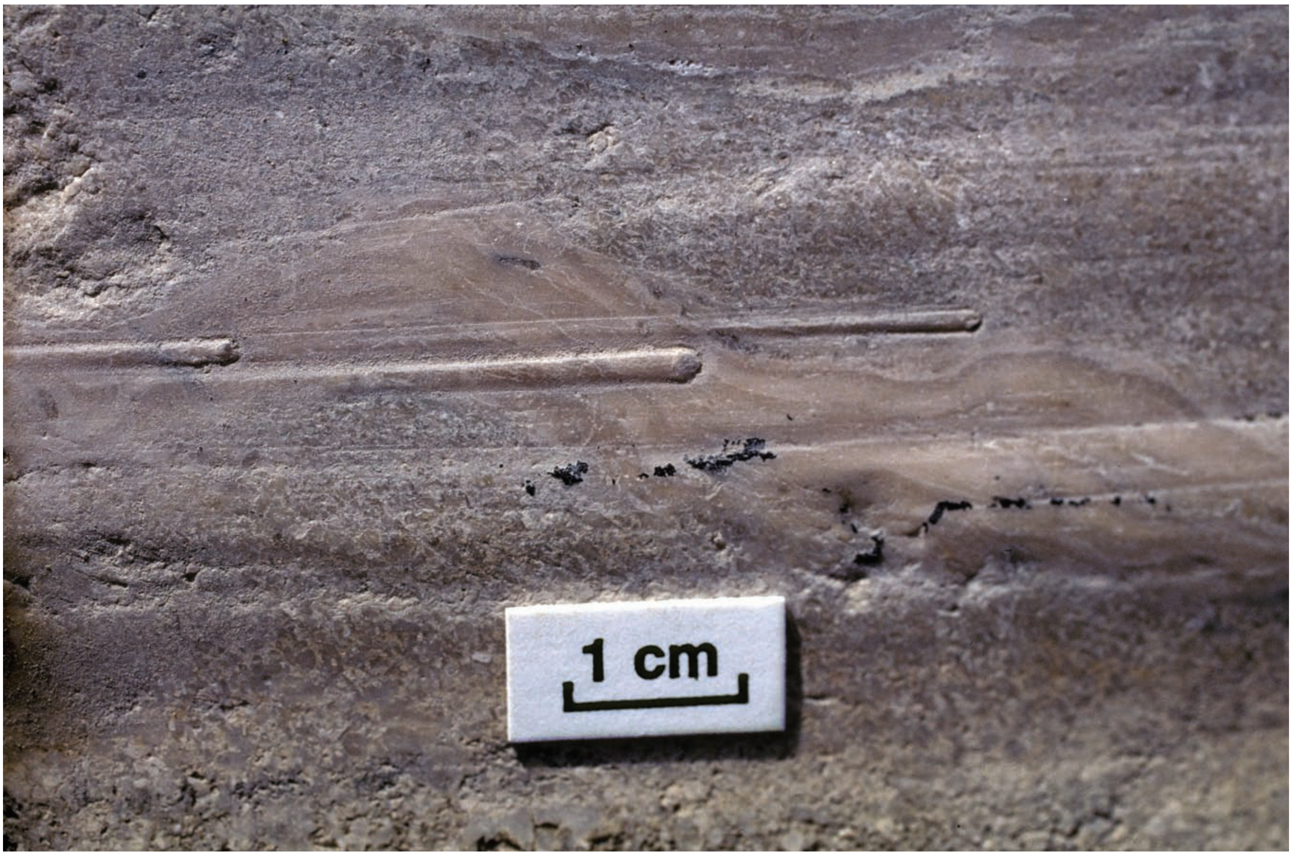

Figure 29 Striated and polished glacial pavement in reef limestone exposed in the Goongewa box-cut, showing small-scale crag-and-tail structures. Ice movement was from right to left on the photo (south to north).

fossil biota (Klapper 2009; Becker & House 2009; G Playford 2009).

CONCLUSION

A great deal of research has been documented on this Devonian Great Barrier Reef since the first of Teichert's papers was published in 1939, but the potential remains for more research on various aspects of these remarkable reef complexes. One of the most pressing needs is to devise the means to achieve precise correlation between back-reef, reef, and marginal-slope deposits, and collaborative work, by several research workers, is now seeking to resolve that issue.

Figure 30 Aerial view of Kimberley Rover solution doline in the northern Laidlaw Range, looking northwest, showing outcrops of Lower Permian silicified sandstone within the doline, surrounded by karstified Pillara Limestone. Karst corridors follow joints in the limestone, and a large cave system (Kimberley Rover Cave) underlies the dark rugged limestone on the upper right.

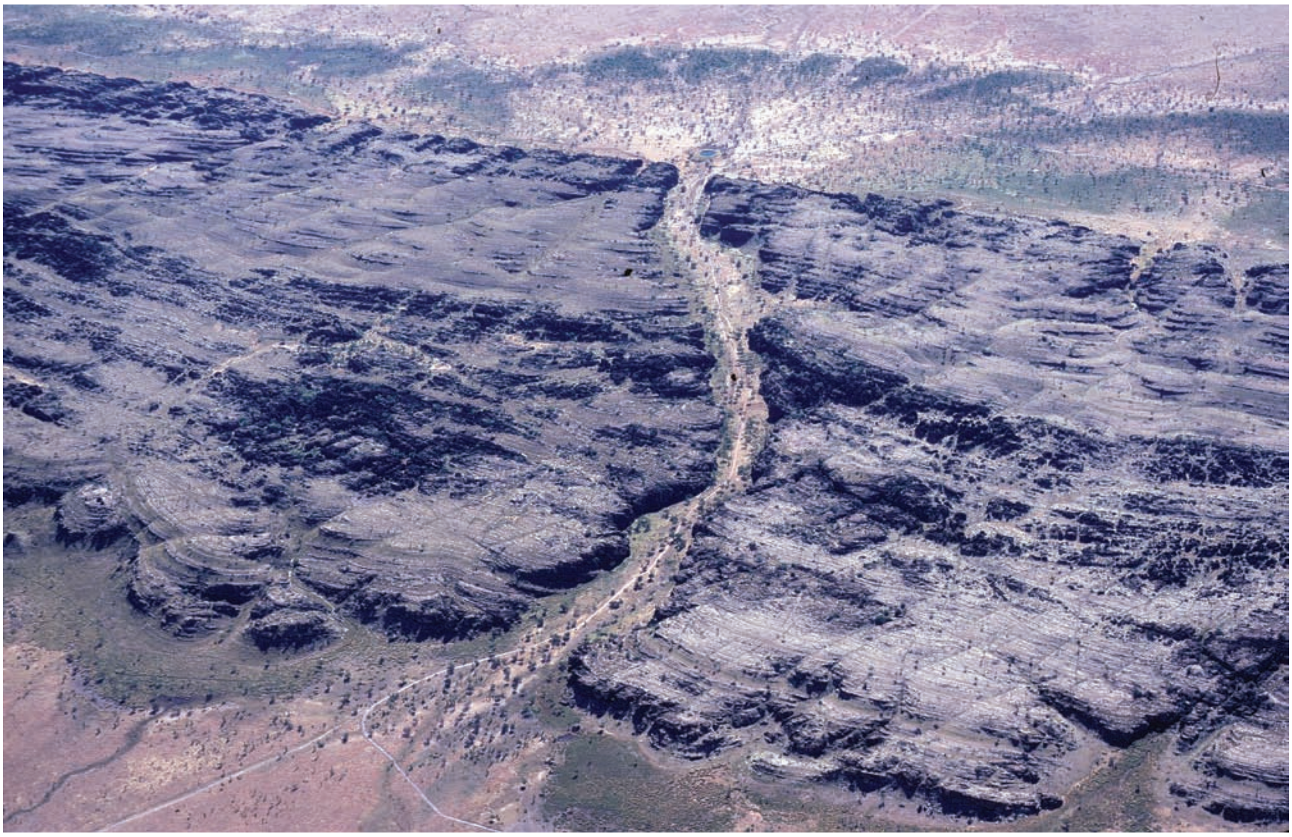

Figure 31 Menyous Gap in the Pillara Range from the air, looking north. This gap, 2 km long, is interpreted to be a large subglacial channel, exhumed through the removal of Lower Permian deposits by Cenozoic erosion.

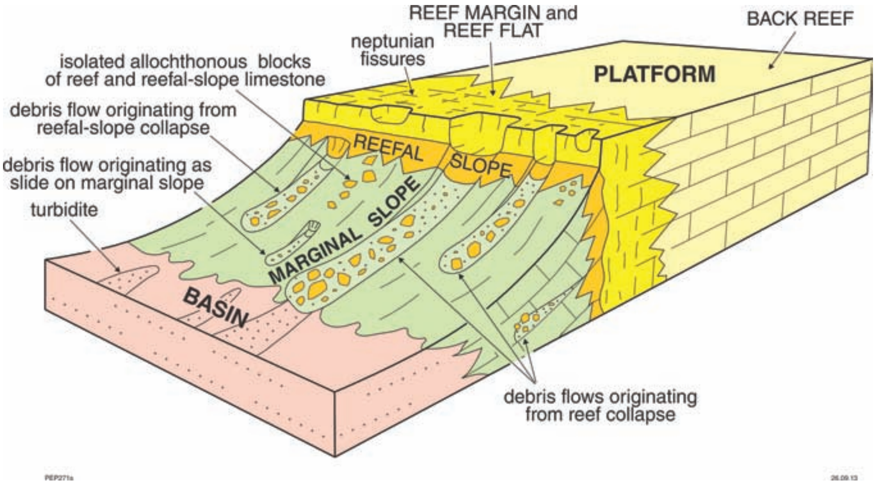

Figure 32 Block diagram illustrating the morphology of the reef complexes and relationships between platform, marginal-slope and basin facies, and associated features.

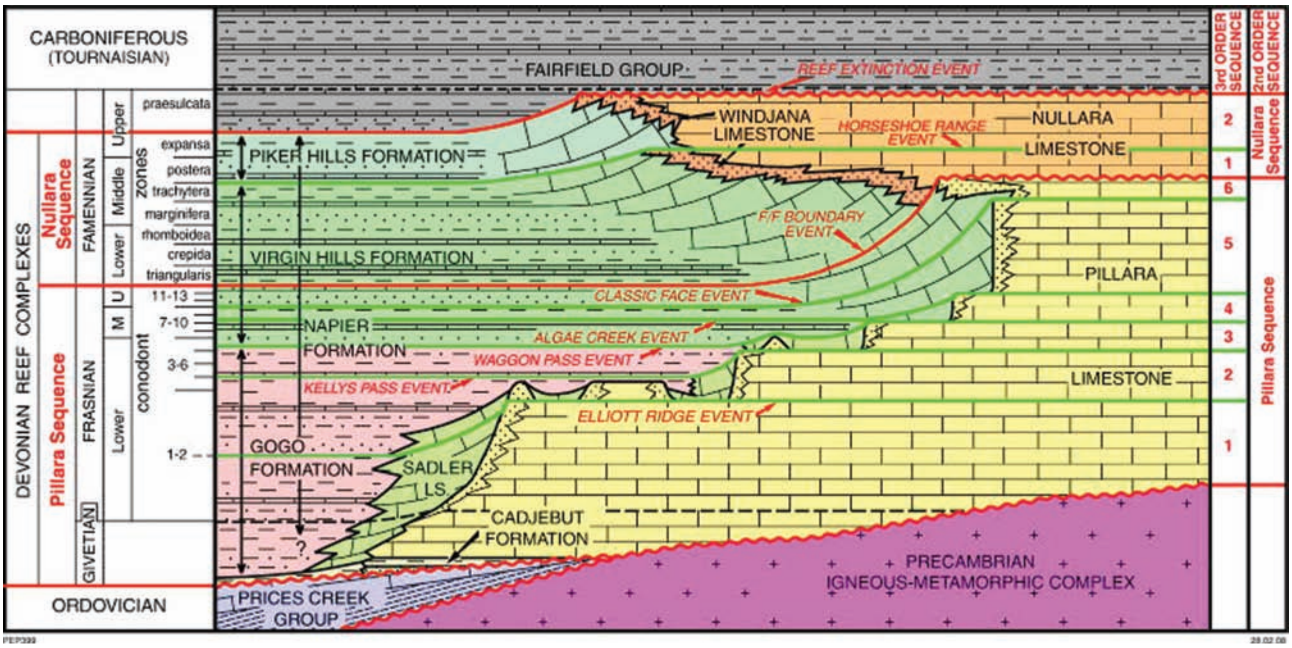

Figure 33 Diagrammatic section illustrating the lithostratigraphy, sequence stratigraphy and conodont biostratigraphy of Devonian reef complexes on the Lennard Shelf.

ACKNOWLEDGEMENT

This summary account of the reef complexes uses many illustrations from Playford *et al*. (2009), with minor changes. It is published with the permission of the Director, Geological Survey of Western Australia.

REFERENCES

Becker T R & House M R 2009. Appendix 2, Devonian ammonoid biostratigraphy of the Canning Basin. *Geological Survey of Western Australia Bulletin* **145**, 415–439.

Cockbain A E 1984. Stromatoporoids from the Devonian reef complexes, Canning Basin, Western Australia. *Geological Survey of Western Australia Bulletin* **129**.

Feist R & McNamara K J 2013. Patterns of evolution and extinction in proetid trilobites during the Late Devonian mass extinction event, Canning Basin, Western Australia. *Palaeontology* **56**, 229–259.

Foord A H 1890. Description of fossils from the Kimberley District, Western Australia. *Geological Magazine* **Dec. 3, v. 7**, 98–106, 145–155.

Guppy D J, Lindner A W, Rattigan J H & Casey J N 1958. The geology of the Fitzroy Basin, Western Australia. *Bureau of Mineral Resources Bulletin* **36**.

Hardman E T 1884. Report on the geology of the Kimberley District, Western Australia. Western Australian Parliamentary Papers, no. 31 of 1884; Government Printer, Perth.

Hinde G J 1890. Notes on the palaeontology of Western Australia, corals and Polyzoa. *Geological Magazine* **Dec. 3, v. 7**, 194–204.

Jell P A & Jell J S 1999. Crinoids, a blastoid, and a cyclocystoid from the Upper Devonian reef complexes of the Canning Basin, Western Australia. *Memoirs of the Queensland Museum* **43**, 201–236.

Kennard J M, Southgate P N, Jackson M J, O'Brien P E, Christie-Blick N, Holmes A E & Sarg J F 1992. New sequence perspective on the Devonian reef complex and the Frasnian–Famennian boundary, Canning Basin, Australia. *Geology* **20**, 1135–1138.

Kerans C 1985. Petrology of Devonian and Carboniferous carbonates of the Canning and Bonaparte Basins, Western Australia. *Western Australian Mining and Petroleum Research Institute Report* **12**.

King P B 1942. Permian of west Texas and southeastern New Mexico. *AAPG Bulletin* **26**, 535–753.

Klapper G 2009. Appendix 1, Upper Devonian conodonts in the Canning Basin. *Geological Survey of Western Australia Bulletin* **145**, 405–413.

Logan B W 1961. *Cryptozoon* and associate stromatolites from the Recent, Shark Bay, Western Australia. *Journal of Geology* **69**, 517–533.

Logan B W 1984. Pressure responses (deformation) in carbonate sediments and rocks, analysis and application, Canning Basin. *In:* Purcell P G (ed.) *The Canning Basin, Western Australia*, pp. 235–251. Geological Society of Australia and Petroleum Exploration Society of Australia, Canning Basin Symposium, Perth.

Logan B W, Frances D J & Economo M 1994. A carbonate dilaform, Brooking Springs, Canning Basin, W.A. *In:* Purcell P G & Purcell R R (eds) *The sedimentary basins of Western Australia*, pp. 703–726. Geological Society of Australia and Petroleum Exploration Society of Australia, West Australian Basins Symposium, Perth.

Logan B W & Semeniuk V 1976. Dynamic metamorphism, processes and products in Devonian carbonate rocks, Canning Basin, Western Australia. *Geological Society of Australia Special Publication* **6**.

Long J A & Trinajstic K 2010. The Late Devonian Gogo Formation Lagerstatte — exceptional preservation and diversity in early vertebrates. *Annual Reviews of Earth and Planetary Sciences* **38**, 665–680.

Nicholson H A 1890. Notes on the palaeontology of Western Australia, Stromatoporoidea. *Geological Magazine* **Dec. 3 v. 7**, 193.

Playford G 2009. Appendix 3, Review of Devonian palynology, Canning Basin. *Geological Survey of Western Australia Bulletin* **145**, 441–444.

Playford P E 1961. Upper Devonian reef complex at Windjana Gorge, Canning Basin, Western Australia. *Geological Society of America Special Papers* **68**, 247–248.

Playford P E 1967. Devonian reef complexes in the northern Canning Basin, Western Australia. *In:* Oswald D H (ed.) *International Symposium on the Devonian System*, Vol. 2, pp. 351–364. Alberta Society of Petroleum Geologists, Calgary.

Playford P E 1980. Devonian 'Great Barrier Reef' of Canning Basin, Western Australia. *AAPG Bulletin* **64**, 814–840.

Playford P E 1984. Platform-margin and marginal-slope relationships in Devonian reef complexes of the Canning Basin. *In:* Purcell P G (ed.) *The Canning Basin, Western Australia*, pp. 189–234. Geological Society of Australia and Petroleum Exploration Society of Australia, Canning Basin Symposium, Perth.

Playford P E 2002. Paleokarst, pseudokarst, and sequence stratigraphy in Devonian reef complexes of the Canning Basin, Western Australia. *In:* Keep M & Moss S J (eds) *The sedimentary basins of Western Australia 3*, pp. 763–793. Proceedings of the Petroleum Exploration Society of Australia Symposium, Perth.

Playford P E & Cockbain A E 1969. Algal stromatolites: deepwater forms in the Devonian of Western Australia. *Science* **165**, 1008–1010.

Playford P E, Cockbain A E, Druce E C & Wray J L 1976. Devonian stromatolites from the Canning Basin, Western Australia: *In:* Walter M R (ed.) *Stromatolites*, pp. 543–564. Elsevier, Amsterdam.

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**.

Playford P E & Johnstone M H 1959. Upper Devonian reef complex at Windjana Gorge, Kimberley District. West Australian Petroleum Pty Ltd Report (unpubl.).

Playford P E & Lowry D C 1966. Devonian reef complexes of the Canning Basin, Western Australia. *Geological Survey of Western Australia Bulletin* **118**.

Playford P E & Ruddock I 1985. Discovery of the Kimberley goldfield. *Journal and Proceedings of the Royal Western Australian Historical Society* **9**, 76–106.

Playford P E & Wallace M W 2001. Exhalative mineralization in Devonian reef complexes of the Canning Basin, Western Australia. *Economic Geology* **96**, 1595–1610.

Read J F 1973a. Carbonate cycles, Pillara Formation (Devonian), Canning Basin, Western Australia. *Canadian Petroleum Geology Bulletin* **21**, 38–51.

Read J F 1973b. Paleo-environments and paleogeography, Pillara Formation (Devonian), Western Australia. *Canadian Petroleum Geology Bulletin* **21**, 344–394.

Smith D N, Playford P E & Williams F B 1957. Oscar Range reef complex, Fitzroy Basin, Western Australia. West Australian Petroleum Pty Ltd Report (unpubl.).

Teichert C 1939. Nautiloid cephalopods from the Devonian of Western Australia. *Journal of the Royal Society of Western Australia* **25**, 103–121.

Teichert C 1941. Upper Devonian goniatite succession of Western Australia. *American Journal of Science* **239**, 148–153.

Teichert C 1943. The Devonian of Western Australia, a preliminary review. *American Journal of Science* **241**, 69–94; 167–184.

Teichert C 1947. Stratigraphy of Western Australia. *AAPG Bulletin* **31**, 1–70.

Teichert C 1949. Stratigraphy and palaeontology of Devonian portion of Kimberley Division, Western Australia. *Bureau of Mineral Resources Report* **2**.

Wade A 1924. Petroleum prospects, Kimberley District of Western Australia and Northern Territory. Commonwealth of Australia, Parliamentary Paper, Melbourne.

Wade A 1936. The geology of the West Kimberley District of Western Australia. Freney Kimberley Oil Company Report (unpubl.).

Won M-Z 1997. Review of the family *Entactiniidae* (*Radiolaria*) and taxonomy and morphology of *Entactiniidae* in the Late Devonian (Frasnian) Gogo Formation, Australia. *Micropaleontology* **43**, 333–369.

Wray J L 1967. Upper Devonian calcareous algae from the Canning Basin, Western Australia. *Professional Contributions of the Colorado School of Mines* **3**.

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