Chapter

The Onshore Southern Carnarvon Basin in Coastal Western Australia during the Quaternary: Tectonic Setting and Facies-Complicated Heterogeneous Stratigraphic Patterns

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Abstract

The onshore southern Carnarvon Basin in Western Australia, in existence since the early Palaeozoic, has a history during the Palaeozoic and Tertiary of relatively uniform sedimentary styles with thick laterally-extensive sequences of sediment. Its sedimentary history became more complicated in the Quaternary period with complex tectonics and arrays of sedimentary facies and packages and basin complexity over relatively short distances, with several regions that are sedimentologically and stratigraphically distinct related to the factors of physiographic and geological setting, riverine input, arid climate, migrating climate, tectonism, and degree of protection from open ocean. For the Pleistocene and Holocene epoch, there are distinct north-trending stratigraphic packets, each with their environmentally distinctive shoaling facies sharply juxtaposed against each other or separated by Pleistocene non-marine sediments; in geographic order, from south to north, these are: a limestone aeolianite barrier along western Shark Bay; pocket seagrass bank carbonate complexes of central western Shark Bay that are nestled in the northerly-oriented inter-dune depressions developed as swales of the north-trending parabolic dunes deriving from the limestone aeolianite barrier; an aeolian red sand shoestring of the north-trending Peron Peninsula longitudinally bisecting central Shark Bay; metahaline to hypersaline shoaling carbonate sedimentary packages of south-eastern Shark Bay that fringe Hamelin Pool; the Wooramel delta, a wave-dominated delta composed of quartz sand and locally-generated carbonate sediment; the Wooramel seagrass bank (an extensive shore-parallel wedge of seagrass bank carbonate sequence along the eastern coast, central to northern Shark Bay); metahaline carbonate and quartz sand platforms fringing both sides of the red-sand Peron Peninsula; metahaline to hypersaline carbonate sediments that underlie the deeper-water axially-oriented embayments of Shark Bay; the Boodalia Pleistocene reddened (quartzose) deltaic sediment sequence; the Gascoyne Delta and laterally equivalent beach-ridge complex, the former comprising subtidal quartz-dominated sand capped by tidal sand-and-mud sequences, and the latter comprising subtidal quartz-dominated sand capped by beach-to-beach-ridge deposits; the Lake MacLeod evaporite basin filled with a shoaling sequence of carbonate sediments, halite, and gypsite; Tertiary limestone and Pleistocene aeolian sediments acting as a barrier to Lake McLeod; and the uplifted Tertiary limestone barrier of Cape Range that is fringed by Holocene coral complexes of the Ningaloo Reef. The coastal and onshore near-coastal southern Carnarvon Basin is an example of a complex sedimentary basin, where sedimentary packages can be markedly different over short distances, and illustrates the complexities a geologist would face if analyzing such a basin in the stratigraphic column. This feature of extreme diversity of sedimentary facies and packages within and between separate contemporaneous 'sedimentary basins' is the theme of this contribution.

Keywords: Carnarvon Basin, Western Australia, Quaternary, Shark Bay, Lake MacLeod, Gascoyne Delta, Quaternary tectonics, facies-complicated sedimentary basins

1. Introduction

The onshore epicratonic Carnarvon Basin in the mid western part of Western Australian has existed since the early Palaeozoic and its Palaeozoic and Tertiary history was generally one of relatively uniform sedimentary styles with thick laterally-extensive sequences of sediment [1, 2]. In this context, it conforms with many sedimentary basins throughout the World (*e.g.*, the Sydney Basin [3], the Kimberley Basin [4], the Eucla Basin [5], the Paris Basin [6, 7], the Paradox Basin [8, 9], the Tindouf Basin [10]; the Gourara Basin [11], the Karoo Basins [12], amongst many others). However, the sedimentary history of the Carnarvon Basin became more complicated in its southern part in the Quaternary period with complex tectonics and arrays of distinct but separated sedimentary facies and sedimentary packages.

During the Pleistocene-Holocene in the southern part of the Carnarvon Basin, the coastal and near-coastal onshore zone has basin complexity over its relatively short latitudinal distance of 500 km, with several separate regions distinct from both a sedimentologic and stratigraphic point of view, as related to several control factors, including the physiographic and geological setting, the river input, the arid climate, the tectonic setting, and the degree of protection from the open ocean. As a consequence of these controls, distinct south-north trending sedimentary packages have formed, each one extending tens of kilometres in length and several kilometres in width. These distinct sedimentary packages are completely different one from each other and are either generally sharply latitudinally and longitudinally juxtaposed one against each other or separated by Pleistocene uplands or fluvial non-marine sediments. Each one of the south-north trending stratigraphic sequences has environmentally distinctive shoaling facies and, being separated over short distances by uplands, gives the impression of a series of closely juxtaposed 'sub-basins'. In fact, particularly for the Holocene, the stratigraphic packages in the southern Carnarvon Basin illustrates the diversity and the complexity of laterally equivalent contemporaneous units that would provide a geologist working in the stratigraphic record a difficulty and a dilemma on how to interpret and to correlate various facies and intervening uplands.

2. The Carnarvon Basin: its geological and tectonic setting

The Carnarvon Basin is an epicratonic, faulted and folded basin some 535,000 km^2 in the offshore portion and some 115,000 km^2 in the onshore area.

Existing since the Palaeozoic Era, it is a basin elongated northeast-southwest, and is bordered by Precambrian rocks of the Pilbara Craton and Yilgarn Craton [13], and is adjoined by the Perth Basin to the south and the Canning Basin to the north (**Figure 1**). It has been subdivided into a range of sub-basins and tectonic ridges, the most important of which to this paper is the large-scale division into Northern Carnarvon Basin and Southern Carnarvon Basin (**Figure 2**). But while there is crustal sagging and crustal faulting on the regional scale in the general Carnarvon Basin [1], tectonism did not seem to play a major part at smaller scales during sedimentation of formational units as it has during the Quaternary epoch. The Palaeozoic, Mesozoic, and lower to middle Cainozoic sedimentary sequences of the

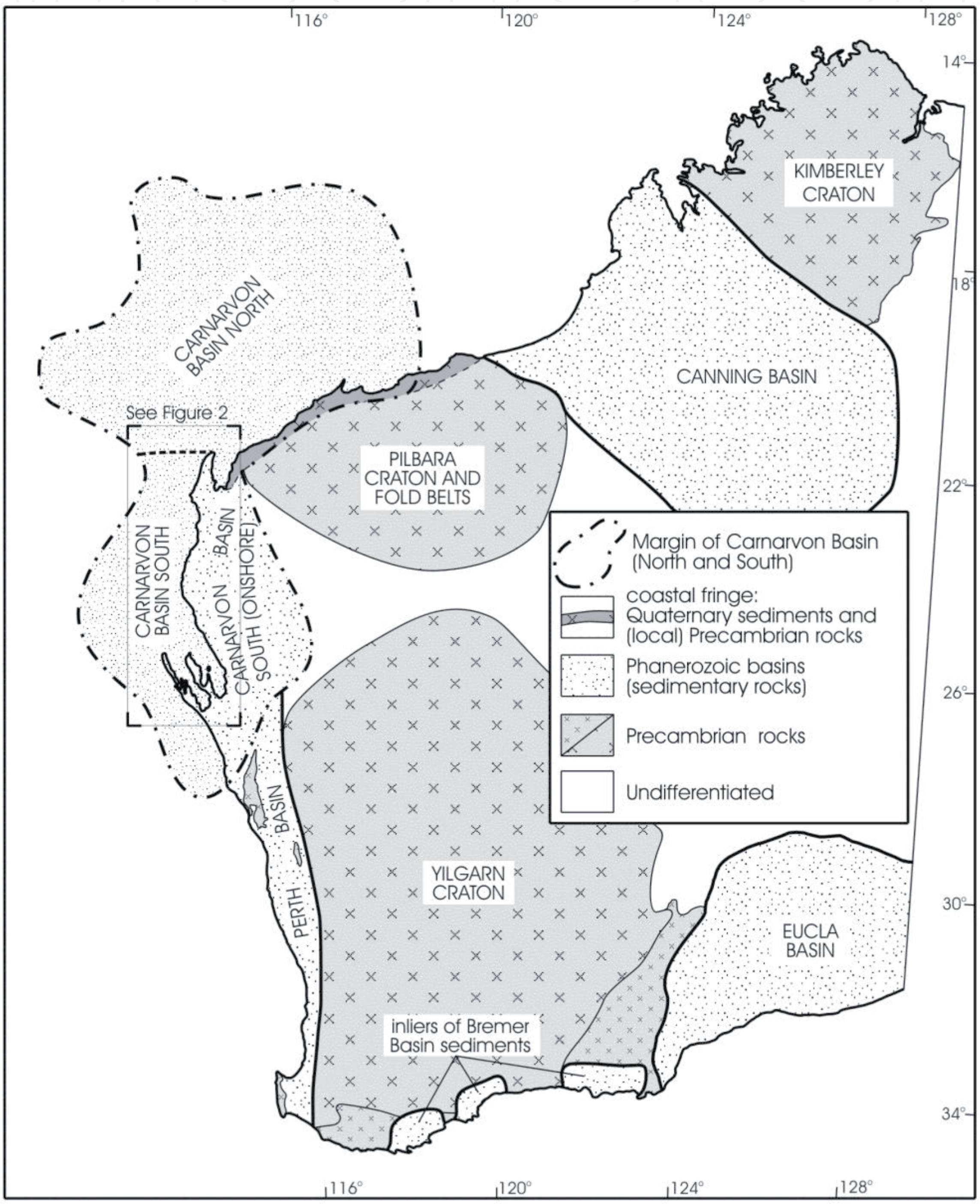

Figure 1.
Geological map of Western Australia (from Brocx and Semeniuk [14]) showing cratons and basins, the location of the Carnarvon Basin, and subdivision of the Carnarvon Basin into northern and southern basins.

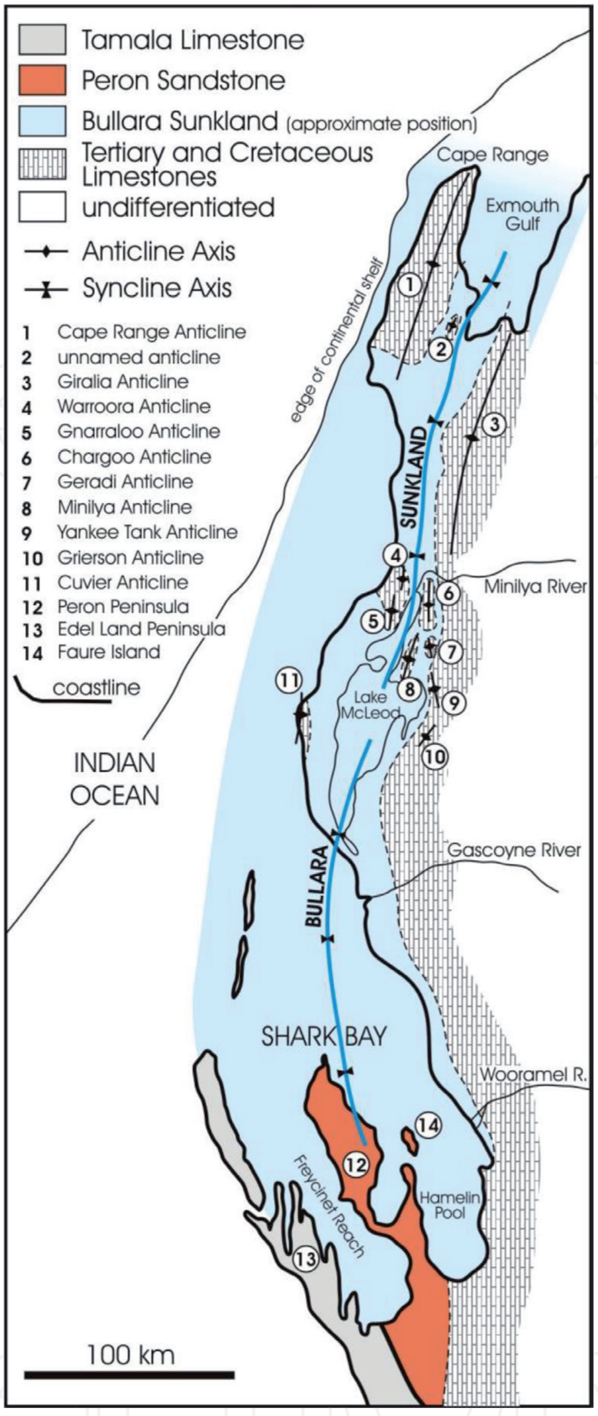

Figure 2.
Geological map of Southern Carnarvon Basin Western Australia (modified from [15]) showing the tectonic framework (with the main emerging tectonic structures as anticlines) and the major depositional depression, viz.*, the Bullara Sunkland. Logan [16] subdivided the Bullara Sunkland into a southern part termed the 'Shark Bay Depression', a central part termed the 'MacLeod Graben', and a northern part termed the 'Dingo Syncline'. Main geographic names are also shown.*

southern Carnarvon Basin comprise formational sheets that are laterally and basin-wide extensive [1, 2] (**Figure 2**). There is an extensive literature on the Northern Carnarvon Basin and the inland Southern Carnarvon Basin [17–22] but information on their geology, sub-basins, and stratigraphy is not relevant to the coastal and near-coastal onshore zone of the Southern Carnarvon Basin as presented in this Chapter as the latter in the Quaternary had a change in basin dynamics (with development of smaller isolated sedimentary packages formed in environmentally discrete areas), and is therefore distinct from the general geological setting of the Carnarvon Basin.

3. The southern Carnarvon Basin in the Quaternary: a mosaic of facies-complicated sedimentary basins

The Quaternary southern Carnarvon Basin, arrayed along some 500 km of the Western Australian coastal and near-coastal zone, shows tectonic and palaeogeographic complication and inter-basinal heterogeneity. There are a multitude of smaller-scale depositional sites (or 'depositional basins'), each one limited in area extent and each one sharply bordered by uplands or by a contrasting sedimentation style. There are thirteen main Quaternary (Pleistocene and Holocene) stratigraphic packages along the southern Carnarvon Basin; ordered geographically from south to north, these are (**Figure 3**): a limestone aeolianite barrier along western Shark Bay; pocket seagrass bank carbonate complexes of central western Shark Bay that are nestled in the northerly-oriented inter-dune depressions developed as swales of the north-trending parabolic dunes deriving from the limestone aeolianite barrier; an aeolian red sand shoestring of the north-trending Peron Peninsula longitudinally bisecting central Shark Bay; metahaline to hypersaline shoaling carbonate sedimentary packages of south-eastern Shark Bay that fringe Hamelin Pool; the Wooramel delta, a wave-dominated delta composed of quartz sand and locally-generated carbonate sediment; the Wooramel seagrass bank (an extensive shore-parallel wedge of seagrass bank carbonate sequence along the eastern coast, central to northern Shark Bay); metahaline carbonate and quartz sand platforms fringing both sides of the red-sand Peron Peninsula; metahaline to hypersaline deep basin carbonate sediments that underlie the deeper-water axially-oriented embayments of Shark Bay;

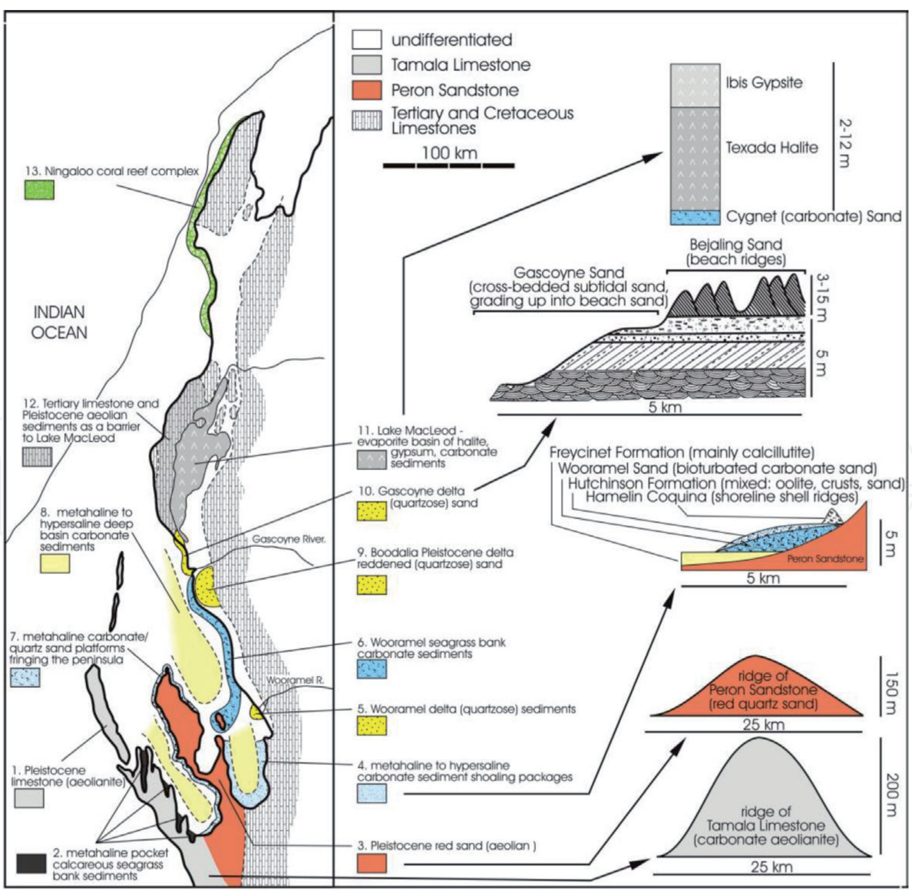

Figure 3.
Distribution of the 13 main Quaternary stratigraphic packages in the Southern Carnarvon Basin. Most of the stratigraphic packages are Holocene in age, with the Pleistocene and Tertiary rocks (and some Cretaceous rocks) noted in the Legend. Of special note is the south-to-north elongation of the various Holocene stratigraphic packages and the older stratigraphic units.

The Boodalia—a Pleistocene reddened (quartzose) deltaic sediment sequence; the Gascoyne Delta and laterally equivalent beach-ridge complex, the former comprising subtidal quartz-dominated sand and tidal sand-and-mud sequences and the latter comprising subtidal quartz-dominated sand capped by beach to beach-ridge deposits; the Lake MacLeod evaporite basin filled with a shoaling sequence of carbonate sediments, halite, and gypsite; Tertiary limestone and Pleistocene aeolian sediments acting as a barrier to Lake McLeod; and uplifted Tertiary limestone barrier of Cape Range that is fringed by Holocene coral-reef complexes of the Ningaloo Reef. Selected stratigraphic profiles of the thirteen packages are shown in **Figure 3**.

The stratigraphic packages are separated by 1. tectonically-uplifted Tertiary limestone, 2. emerging Quaternary anticlines form emergent ridges, or 3. aeolian-emplaced Quaternary sediments, with the packages occurring in relatively small and distinct self-contained well-defined depositional basins (such as the bowls of parabolic dunes; terms from Semeniuk et al. [23]). The stratigraphic sequences of the thirteen packages are described in **Table 1**, and their distribution is illustrated in **Figure 4**. Detailed stratigraphy and lithologies of the Holocene-age stratigraphic sequences are described in various publications [15, 16, 24–28, 30, 31], and summarised in **Table 2**. **Figure 4** illustrates the location of the distinct and discrete sedimentary packages and their inter-relationship as arrayed along the length of the southern Carnarvon Basin.

There are a number of reasons why these stratigraphic packages have developed as separate systems and separated in these sedimentologically distinct geographic regions; they are: physiographic and geological setting, riverine input, arid climate, migrating climate, tectonism, and degree of protection from open ocean.

The physiography and geology of this part of the coastal and near-coastal Carnarvon basin comprises 1. tectonically-emerging ridges (that Logan et al. [15] term 'anticlines'), 2. aeolian-emplaced coastal calcareous sand bodies (that when cemented form resistant upstanding ridges and, when mobilized into parabolic dunes and when later cemented form a limestone-rocky invaginated coast), and 3. aeolian-emplaced coastal quartz sand ridge. These large-scale and smaller-scale ridges and uplands form the cradle within which Holocene sedimentation was localised. As such, the Holocene sedimentation was/is occurring in lowlands, or along the open coast. The Pleistocene stratigraphic units generally form the uplands to the Holocene sediments as limestone aeolianites or red sand dune deposits [15].

Locally, riverine input has developed deltoid sedimentary accumulations along the coast, *viz*., the Wooramel Delta and the Gascoyne Delta. The Gascoyne Delta, since it is partly exposed to open Indian Ocean conditions and strong southerly winds, is an extremely asymmetric delta, with northerly-propelled deltaic sand forming a ribbon of shore-parallel beach ridges north of the river mouth.

The arid climate is a major factor determining sedimentation patterns and diagenesis of the Holocene sediments and, during the Holocene, with Earth axis precession the Tropic of Capricorn (separating the Tropical climate from Subtropical climate) has migrated northwards-centred on Shark Bay several thousand years ago it is now located near Exmouth Gulf [30]. This was one of the factors that changed the sedimentation styles in Shark Bay and along the coast of Cape Range.

In recent times, Shark Bay is partitioned into hydrochemical fields from its oceanic exterior to its protected interior (*e.g.*, Hamelin Pool, **Figure 2**), *viz*., the salinity changes from oceanic in the north to metahaline and then hypersaline in southern parts [31]. This is partly due to its south-eastern interior portions being isolated from oceanic influences and, as such, there is more restricted circulation from ocean to interior, but also is due to the extreme evaporation acting on the south-easterly restricted parts of the Bay and to the evolution of a circulation-restricting

Stratigraphic package (south to north)	Height, thickness, width, and length of the stratigraphic package[2]	Main stratigraphic units[3]	Relation to adjoining uplands and to adjoining stratigraphic packages
1. Limestone aeolianite barrier along western Shark Bay [15]	10–40 m above MSL. 10–20 km wide, 180 km long, up to 150 m thick	Tamala limestone: a Pleistocene aeolianite comprising carbonate and quartz calcarenite	Forms a barrier to Shark Bay
2. Pocket seagrass bank carbonate complexes of central western Shark Bay [24, 25]	In small packets within the inlets of eastern shore Edel Land 8 km × 3 km, up to 30 km × 6 km; 3–5 m thick seaward-thickening wedge	Boat Haven Sand[3], a stratigraphic unit of bioturbated sand formed under seagrass bank conditions	Packets of seagrass-bank-dominated calcareous sediment cradled between uplands in a limestone rocky shore invaginated coastline
3. Aeolian red sand shoestring of the north-trending Peron Peninsula longitudinally bisecting central Shark Bay [15]	120 km long × 20 km wide, with heights 20–70 m above MSL	Peron Sandstone: a Pleistocene red sand broadly elongate dune complex with cuspate, straight, curved, and irregular margins (former coastal barrier); stratigraphically, composed of several episodes of dune building separated by soils	Forms a peninsula partition within Shark Bay and the source of quartz sand within the Shark Bay depositional system
4. Metahaline to hypersaline shoaling sedimentary package of south-eastern Shark Bay [25]	3–10 km wide, 100 km overall length as measured along the Hamelin Basin shore	Wooramel Sand[3] (earlier Holocene metahaline seagrass bank sediments) overlain by Hutchinson Formation and (onshore) the shoreline ribbon of Hamelin Coquina	Ribbon-like (metahaline) calcareous seagrass bank sediments shore-parallel and flanking the south-eastern shore of Shark Bay lithologically passing up into (hypersaline) oolite sediment and tidally into stromatolites
5. Wooramel Delta, central-eastern Shark Bay [15]	Triangular wedge 15 km × 15 km of sand, 1–2 m thick, with local spits and cheniers	Un-named	Deltoid accumulation at the mouth of the Wooramel River
6. Wooramel seagrass bank deposits: extensive shore-parallel wedge of seagrass bank carbonate sequence eastern coast, central to northern Shark Bay [24–26]	5 km × 90 km, wedging up to 3 m thick	Wooramel Sand[3]	Wedge-like calcareous seagrass bank sediments flanking the eastern shore of Shark Bay

Stratigraphic package (south to north)	Height, thickness, width, and length of the stratigraphic package[2]	Main stratigraphic units[3]	Relation to adjoining uplands and to adjoining stratigraphic packages
7. Mainly wave-built platforms and some seagrass bank deposits: extensive shore-parallel wedge of sediment western and eastern coast of the Peron Peninsula, central Shark Bay [25]	30 km long, 5–6 km wide; subtidal units up to 3 m thick, tidal units up to 1 m thick, beach-ridge units 3–15 m thick	Denham Sand[3]—metahaline wave-built sand platform and seagrass bank sediments	Sharply adjoins the Wooramel (seagrass bank) Sand, and onlaps the red sand hinterland
8. Deep water marine embayment plains (10–15 m deep) underlain by calcareous mud, shelly mud, and sand [25]	100 km long, 20–25 km wide, 5–6 km wide, 0.5–1.5 m thick	Freycinet formation[3]	Sharply adjoins the shallow water seagrass bank sediments and wave-built platform sediments
9. The Boodalia, a Pleistocene reddened (quartzose) deltaic deposit, as a subset of the Gascoyne Delta, and its laterally equivalent beach-ridge complex north of Shark Bay [15]	25 km along coast, 25 km wide, up to 6 m thick [26], triangular seaward-lobed sedimentary deposit	Boodalia Formation[3]—reddened deltaic sediment complex	Sharply and laterally adjoins the Gascoyne Sand and Babbage Island Formation, and underlies and laterally adjoins the Wooramel (seagrass bank) Sand
10. Gascoyne Delta and laterally equivalent beach-ridge complex (Bejaling Beach Ridges) north of Shark Bay [27]	30 km long, 5–6 km wide; subtidal units up to 3 m thick, tidal units up to 1 m thick, beach-ridge units 3–15 m thick	Babbage Island Formation[3]—beach-ridge and tidal lagoon complexes at the river mouth; Gascoyne Sand[3]—the offshore and near-shore cross-bedded sand that forms the delta slope of the Gascoyne Delta; Bejaling Sand[3]—beach ridge complex to the north of the river mouth	Sharply and laterally adjoins the Wooramel (seagrass bank) Sand, and onlaps the red sand hinterland
11. Tertiary-limestone-barred evaporite sequence of Lake McLeod [16]	Evaporites 130 km long, 20–40 km wide, 8 m thick	MacLeod Evaporite comprised of the members Texada Halite, Ibis Gypsite, and Cygnet Carbonate Member [16]	Evaporite sequence cradled in a graben
12. Barrier of Tertiary limestone and cemented Pleistocene aeolian sediments as a barrier to Lake McLeod [16]	Tertiary and Pleistocene limestone barrier 20–50 m above MSL 130 km long	Thickness depending on height (*i.e.*, 20–50 m thick)	Sharply bordered by Holocene sediments

Stratigraphic package (south to north)	Height, thickness, width, and length of the stratigraphic package[2]	Main stratigraphic units[3]	Relation to adjoining uplands and to adjoining stratigraphic packages
13. Holocene Ningaloo coral-reef complex [28] fringing the uplifted Tertiary limestone barrier of Cape Range	Coral reef 150 km long, 2–5 km wide, up to 5 m thick	Ningaloo Limestone[3]	Plastered on and flanking rocky shore cut into Tertiary limestone

[1]*Location of stratigraphic packages shown in* ***Figure 3****.*
[2]*These geomorphic and stratigraphic systems are variable and the figures for length, width, and height, while providing an estimate of their dimensions, are indicative only.*
[3]*Some of the stratigraphic units were not properly defined in the various original publications on this region [15, 16, 27, 28], and are in the process of being formally named [29].*

Table 1.
Description and settings of the 13 major stratigraphic packages in generalised sequences.[1]

shallow-water submarine seagrass bank that evolved in the Faure Island area [31]. Seagrass bank sedimentation occurs in those parts of Shark Bay where there is oceanic and metahaline salinity, and is eliminated when salinity becomes hypersaline.

Much of Shark Bay is protected from the open ocean and, as such, many of the facies therein reflect this. Where the coast is exposed to the Indian Ocean, it is subject to prevailing swell, wind waves, and strong sea breezes, and wave-dominated conditions prevail, *e.g.*, the wave-dominated and asymmetric delta of the Gascoyne River. Further, where there is a rocky coast (such as the tectonically-uplifted Cape Range), with open ocean conditions and a tropical climate, coral reefs are developed (*e.g.*, the Ningaloo Reef).

4. Discussion and conclusions

The Quaternary Southern Carnarvon Basin in its modern sedimentology, palaeosedimentology, and palaeogeography is an array of facies-complicated patterns determined by megascale geomorphic architecture, tectonics, oceanography, and climate. It contrasts with other sedimentary basins mentioned above (*e.g.*, the Paris Basin, the Paradox Basin, the Sydney Basin, amongst others) that have more laterally-extensive formational sheets. Indeed, the Quaternary Southern Carnarvon Basin *does not have latitudinally and longitudinally extensive formational sheets*, and the individual sedimentary packages of significant thicknesses are discrete and cannot (axiomatically) be correlated from depositional basin to depositional basin. Each of these sedimentary packages would appear in the geological record as discrete isolated lenses (each with its own internal sedimentary signatures and sedimentary sequences indicative of an internal relationship of lithofacies within the package), and would be assigned to different formations.

To highlight and contrast this facies-complicated array within the Southern Carnarvon Basin, we use the coastal zone of the Perth Basin in the southwest of Western Australia, the Canning Coast in northwest of Western Australia, and selected basins from around the World. In this comparison, we have direct field experience with the Perth Basin, Canning Basin, Kimberley Basin, Eucla Basin, the Paris Basin, the Tindouf Basin, and southern parts of the Karoo Basins. The remaining information has been obtained from the literature.

The coastal zone of the Perth Basin extends for some 400 km and (apart from the occasional shore-normal narrow estuary) portrays a fairly consistent sequence

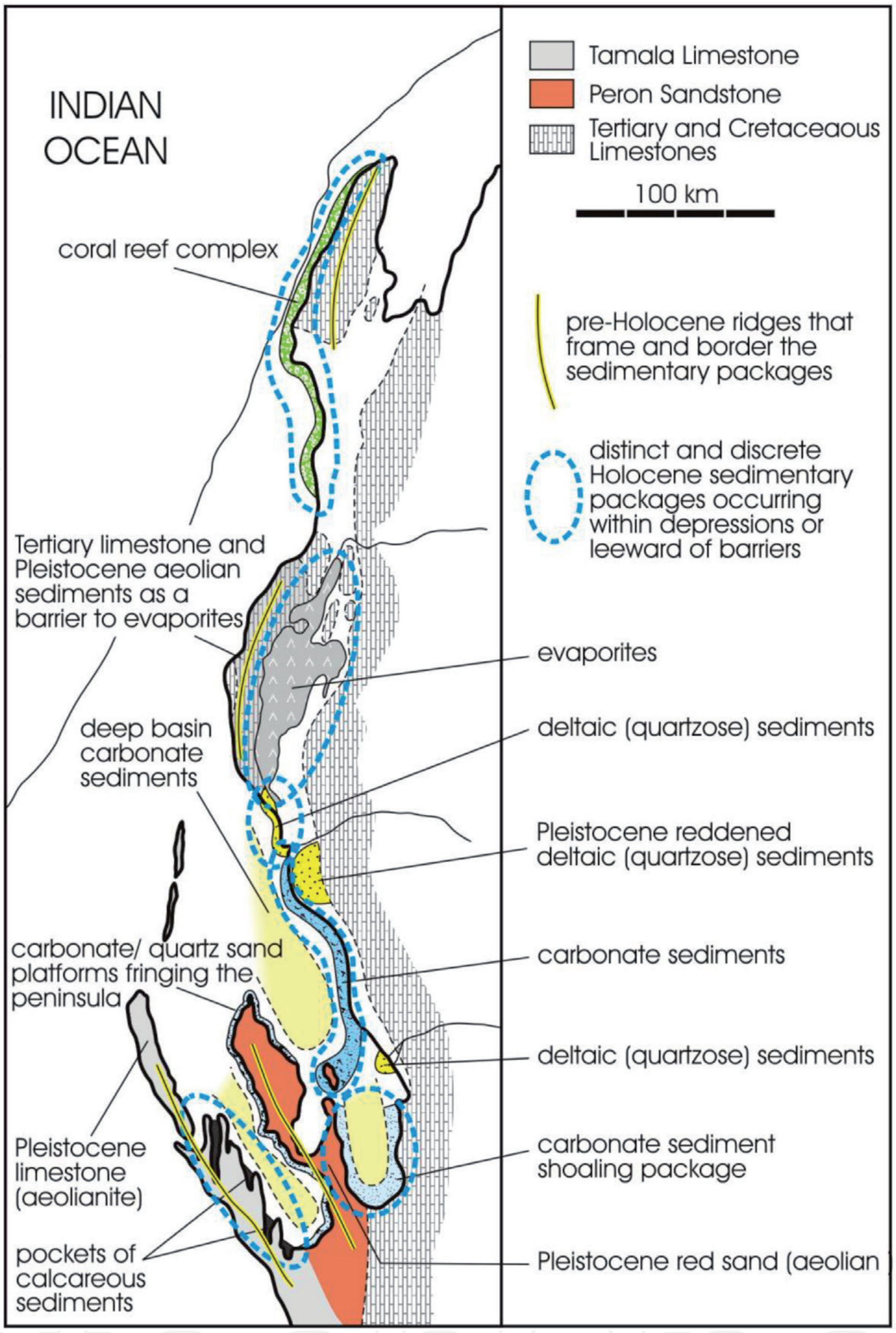

Figure 4.
The disposition of the lithologically distinct and spatially discrete sedimentary packages arrayed along the length of the southern Carnarvon Basin. Also shown are the south-to-north uplands of Pleistocene aeolian and aeolianite bodies and the uplifted Tertiary and Cretaceous limestone formations that either act as barriers to or cradle the Holocene depositional sites.

of beaches, beach ridges, and coastal dunes [23, 32, 33], that while largely shore-parallel and close to shore can extend inland for kilometres and, locally, have prograded seawards for over 10 km [33]. These coastal formations are composed of lithologically fairly uniform quartzose calcareous medium sand. Similarly, along 600 km of the Canning Coast [34], the coastal zone of the Canning Basin is relatively consistent comprising longitudinally-extensive beaches, beach ridges, and (in small embayments) limestone barriers sheltering calcilutite basins; the coastal sands are quartzose calcareous medium and coarse sand (*viz*., Shoonta Hill Sand and Cable Beach Sand of Semeniuk, respectively [34]).

However, prior to comparing the sedimentology and stratigraphy of the Southern Carnarvon Basin with other sedimentary basins globally, there are two

Stratigraphic package (south to north) (numbering follows that in Table 1)	Fine scale stratigraphy
2. Pocket seagrass bank carbonate complexes of central western Shark Bay	Boat Haven Sand[1]—bioturbated shelly calcareous quartzose and underlain by thin calcilutite, and overlain by laminated sheet laminated sand, laminated beach sand, and beach-ridge sand; inland, where hypersaline, there is development of carbonate crusts [24, 25]
4. Shoaling sedimentary packages of south-eastern Shark Bay	Bioturbated Wooramel Sand[1] overlain by laminated and cemented Hutchinson Formation, stromatoliths and Hamelin Coquina
5. Deltoid deposit of river sediments at the mouth of the Wooramel River central-western Shark Bay	Bioturbated Wooramel Sand[1] overlain by laminated and cemented Hutchinson Formation, stromatoliths and Hamelin Coquina
6. Extensive shore-parallel wedge of seagrass bank sequence eastern coast, northern Shark Bay	Wooramel Sand[1]—bioturbated seagrass bank sand overlying a thin calcilutite and overlain by laminated sand of beach ridges and spits
7. Mainly wave-built platforms and some seagrass bank deposits: extensive shore-parallel wedge of sediment western and eastern coast of the Peron Peninsula, central Shark Bay [25]	30 km long, 5–6 km wide; subtidal units up to 3 m thick, tidal units up to 1 m thick, beach-ridge units 3–15 m thick Denham Sand[1]—metahaline wave-built sand platform and seagrass bank sediments; sharply adjoins the Wooramel (seagrass bank) sand and the Boodalia Formation[1], and onlaps the red sand hinterland of Peron Sandstone
8. Deep water marine embayment plains underlain by sheets of calcareous mud, shelly mud, and sand	100 km long, 20–25 km wide, 5–6 km wide, 0.5–1.5 m thick Freycinet Formation[1] sharply adjoins the shallow water seagrass bank sediments and wave-built platform sediments
10. Gascoyne Delta and laterally equivalent beach-ridge complex north of Shark Bay	Cross-bedded Gascoyne Sand[1] overlain in the south by laminated to bioturbated (root-structured) beach-ridge sand and ribbons of tidal mud of the Baggage Island Formation, and overlain in the north by laminated to bioturbated (root-structured) beach-ridge sand referred to the Bejaling Sand
11. Evaporite sequence of Lake McLeod	Thin unit of the Cygnet Carbonate Member overlain by the crystalline 5–6 m thick Texada Halite and, in turn, by the Ibis Gypsite (*in situ* and reworked gypsum crystals)
13. Coral-reef complex of the Ningaloo Reef fringing the uplifted Tertiary limestone barrier	Coral framework (domal, arborescent, mixed, tabulate and encrusting corals), coral rubble, skeletal sand, and intercalated sheets of alluvial-fan sediment = Ningaloo Limestone

Stratigraphic nomenclature in preparation [29].

Table 2.
More detailed description of fine-scale stratigraphy of the Holocene stratigraphic packages.

inter-related factors that need discussion in order to establish a framework for these comparisons; these are: 1. systems can be inherently internally complex in terms of sedimentary dynamics and facies resulting in small-scale complex stratigraphy or, alternatively, relatively simple (even if reflecting an upward shoaling energy-related system) [35],and 2. the concept of a formation and its use within the comparative **Table 3**.

In the first instance, sedimentary systems can be inherently stratigraphically complex laterally and vertically. For example, floodplain sedimentology and the resulting stratigraphy, and the stratigraphic complexity associated with channel switching in fluvial settings are examples (*e.g.*, Figures 404, 409 & 410 in Reineck & Singh [37]) where there can be marked lateral and vertical lithological variation. So too for deltas –for instance, while a wave-dominated, sand-dominated delta

Sedimentary basin	Location, area, longest length	Key laterally-extensive, relatively thick basin-wide formations, their lithologies and thicknesses
Sydney Basin [3]	New South Wales, Australia; 64,000 km^2; 450 km	Basin-extensive Wianamatta Shale (300 m thick), Hawkesbury Sandstone (230–290 m thick), the Newcastle and Illawarra Coal Measures of coal seams, sandstone sheets, and shale (150–500 m thick)
Kimberley Basin [4]	Western Australia, Australia; 400,000 km^2; 500 km	Five major basin-extensive lithological sequences of Proterozoic sedimentary and volcanic rocks, accounting for a stratigraphic thickness of some 5000 m and assigned to formational and/or group level; sandstone dominates the sequences; lithologies are quartzose sandstones, felspathic sandstones, minor siltstones, and minor volcanic rocks
Eucla Basin [5]	Western Australia to South Australia; 1,141,000 km^2; 1200 km	Basin-extensive sheets of skeletal limestone (bryozoa, foraminifera, molluscs, calcareous algae forming calcarenites, rudstones, and calcareous muddy limestones) and some sandstone; lithologically fairly consistent and extensive across the basin (*e.g.*, Abrakurrie Limestone 120 m thick; Colville sandstone 25 m thick; Nullarbor Limestone 45 m thick; Wilson Bluff Limestone 335 m thick)
Paris Basin [6, 7]	Northern to central France; 140,000 km^2; 600 km	Basin-extensive sheets and lenses of limestone, sandstone, chalk, shale/marl, dolomite, oolite, and evaporites, each lithologic unit of relatively regular thickness, each either 300 m, 400 m, 500 m, or 600 m thick
Paradox Basin [8, 9]	United States of America: Utah, SW Colorado, extending into NE Arizona and NW New Mexico; 85,470 km^2; 280 km	Asymmetric basin with western basin dominated by thick salt (up to 2500 m thick) and eastern basin dominated by limestone with lesser dolomite, bioherms, shale (1400 m thick)
Tindouf Basin [10]	Anti-Atlas, Morocco, and Algeria; 100,000 km^2; 700 km	Basin-extensive sheets of sandstone, shale, limestone, marls, coral beds, conglomerate; individual formations comprise sandstone (500 m thick), interbedded limestone and shale (500 m thick), marls and marly limestone (700 m thick), and evaporite (up to 100 m thick)
Gourara Basin [11]	Algeria; 260,000 km^2; 320 km	Basin-extensive sheets of sandstone and siltstone, total thickness some 4000 m
Karoo Basins [12]	Scattered series of sub-basins over northern to southern Africa and Madagascar, the largest of which are the main Karoo Basin 700,000 km^2, 1500 km long, and the Kalahari Basin 2,500,000 km^2, 1500 km long	The main Karoo Basin: asymmetric, with basin-extensive sheets of mudstone and sandstone, totaling 7000 m in thickness for the uppermost unit, *viz*., the Beaufort Group of formations, sheets of shale, sandstones, wackestones, chert, dolomite and coal, totaling 3200 m for the middle unit, *viz*., the Ecca Group of formations, and diamictite, tillite, totaling 800 m for the lowermost unit, *viz*., the Dwyka Group of formations

Table 3.
Global perspective: generalized and simplified description of selected sedimentary basins and their stratigraphy (for Australian stratigraphy, refer to Geoscience Australia [36]).

may produce a relatively even and repetitive sequence of subtidal to tidal to beach-ridge facies, *cf*., Allen [38], a mixed sand-and-mud river-dominated system can result in a plethora of facies which are randomly arrayed and which become more complex where there has been major channel switching [27, 37]. In contrast, coastal beach-to-dune sequences and marine shelf sequences result in relatively predictable shore-parallel sheets of stratigraphic sequences reflecting gradients in wave energy, tides, and aeolian effects for the former [35], or vertically stacked lithologies of energy-related sequences for the latter [37].

In the second instance, in literature reviews of ancient sedimentary sequences globally that are to be used for comparative analyses in this Chapter, it is important to address the concept and definition of a formation as used by a given author, *i.e.*, whether an author in defining a formation was focused on small-scale features, or used a broad-scale approach. Given that sedimentary systems can be inherently stratigraphically complex (*e.g.*, fluvial systems as noted above, or deltaic systems, *cf*. Figures 452, 453, & 456 in Reineck and Singh [37]) or, conversely, stratigraphically relatively simple (*e.g.*, shelf systems), in our selection for comparative purposes of the ancient stratigraphic case studies, we focused on those examples where there was enough lithological detail to ensure that the stratigraphic sequences were adequately described and could be validly compared between the basins listed in **Table 3**. Following the criteria set out in the International Codes and Standards (*e.g.*, the International Commission on Stratigraphy; http://www.stratigraphy.org/index.php/ics-stratigraphicguide) for assigning formational status to rock bodies, in our review of the literature we assessed a rock body could be defined as a 'formation' if it had one of the following characteristics: 1. dominantly of one lithology (*e.g.*, the Hawkesbury Sandstone in the Sydney Basin [3]); 2. mainly of two or three recurring interbedded lithologies mappable as a suite; or 3. a mixture of interbedded lithologies complexly inter-related but the whole suite being clearly recognised as a heterogeneous unit against underlying and overlying rock strata. Our conclusions were that is a formation was valid, and if it was mapped and correlated as being basin-extensive then its lithologically defining characteristics were present from one end of the basin to the other.

As noted in Section 1, globally, there are numerous sedimentary basins that are filled with laterally and longitudinally extensive formations. For comparison with the southern Carnarvon Basin, we have selected the Sydney Basin [3], the Kimberley Basin [6], the Eucla Basin [7], the Paris Basin [4, 5], the Paradox Basin [8, 9], the Tindouf Basin [11], the Karoo Basins [12], and the Gourara Basin [12]. Most of these basins have experienced some degree of tectonism resulting in normal faults and low-amplitude folds, but the sedimentary formations therein are easily correlated across large tracts of their respective basins. Information on the size of these basins and the composition of the laterally-extensive formations is presented in **Table 3**. As is evident in **Table 3**, most of the basins selected for comparison with the southern Carnarvon Basin have basin-wide and extensive formations and *contrast markedly* with the Quaternary formations of the southern Carnarvon Basin of this Chapter in that they are thick, not markedly discontinuous, and can be correlated over large distances.

In this context, comparing the Quaternary Southern Carnarvon Basin with other Western Australia sedimentary basins and with other selected basins Worldwide, it is clear that the Southern Carnarvon Basin stands as an important model globally of basin development – there is interplay of megascale geomorphic architecture, tectonics, oceanography, and climate resulting in a series of disparate sedimentary packages that are in relative close proximity to each other.

In summary, the onshore Carnarvon Basin is an example of a complex sedimentary array of facies-complicated sedimentary small basins where distinct but separated sedimentary facies and sedimentary packages have formed over a relatively small scale. It is an example where sedimentary packages can be markedly diverse over short distances. As such, this coastal and near-coastal part of the southern Carnarvon Basin illustrates the complexities a geologist would face if analyzing a basin in the stratigraphic column.

Conflict of interest

We have no conflict of interest.

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