New Pleistocene and Holocene stratigraphic units in the Yalgorup Plain area, southern Swan Coastal Plain

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Abstract

Within the area of Yalgorup Plain (amended from the Yoongarillup Plain) between Mandurah and Bunbury, there are a variety of fossiliferous limestone, aeolian limestone, and quartz sand units. Three new Pleistocene formations are recognised: the Tims Thicket Limestone, the Myalup Sand, and the Kooallup Limestone. These formations, previously part of the Tamala Limestone, underlie distinct Pleistocene landforms and comprise distinct shore-parallel systems formed by coastal progradation, interrupted by subaerial unconformities. They represent sedimentation during the Pleistocene, which was dominated by cuspate forelands, barriers, and wave-built platforms.

The western edge of the Yalgorup Plain is bordered by Holocene barrier dunes which are a geomorphic extension of the Leschenault Peninsula barrier. Various Holocene formations underlie the barrier in the Yalgorup region. Generally, they can be assigned to the Safety Bay Sand, Becher Sand, Bridport Calcilutite, and Leschenault Formation, and to the Preston Beach Coquina, a new unit formally defined in this paper. Four types of large-scale standard Holocene stratigraphic sequences can be recognised in this region: Type 1, prograded bank, beach, beachridge sediments; Type 2, prograded shoreface to beachridge sediments; Type 3, retrograded barrier dune sediments overlying estuarine lagoonal sediment; and Type 4, retrograded barrier dune sediment unconformable on Pleistocene sediment. These standard sequences can be used to help unravel the Holocene history of the barrier dunes in the Yalgorup area, and specifically between Preston Beach and the Bouvard Reefs.

Introduction

The western part of the Swan Coastal Plain between Mandurah and Bunbury contains Pleistocene limestone (McArthur & Bettenay 1960; Playford *et al.* 1976), linear wetlands and estuarine lagoons, and a shore-parallel Holocene barrier dune system (Searle & Semeniuk 1985; Semeniuk 1985). Within this area is the Yalgorup Plain (amended here from the Yoongarillup Plain), a Pleistocene to Holocene surface developed on a variety of fossiliferous limestone, aeolian limestone, and quartz sand. Previous drilling in this area was conducted by Commander (1988).

Recent research has delineated a range of new Pleistocene to Holocene stratigraphic units in this area, which are described in this paper. Recognition of these new units has provided a tool to unravel the local Pleistocene and Holocene coastal history, as described in Semeniuk (1995a,b). Stratigraphic and geomorphic patterns derived from the Pleistocene terrain in the region show that there are distinct shore-parallel tracts of Pleistocene landforms that developed by coastal progradation, interrupted by subaerial unconformities. Sedimentation was dominated by narrow beachridge plains and cuspate forelands (Semeniuk 1995a). Defining a new Holocene stratigraphic unit in the region has also aided in the recognition of four key stratigraphic sequences that help unravel coastal history.

Stratigraphic data for this paper are from drill holes, road cuts, quarries and excavations. Description of stratigraphy and drilling transects, apart from those provided for the type sections in this paper, are presented more fully by Semeniuk (1995a,b).

Amendment of the Yoongarillup Plain to Yalgorup Plain

There has been a problem with the concept, nomenclature and application of the term Yoongarillup Plain in the Mandurah-Bunbury area (McArthur & Bartle 1980; Semeniuk 1990). Originally the term "Yoongarillup" was used to denote a quartz sand underlying a plain developed on fossiliferous limestone near Busselton, and named after locality in that area (McArthur & Bettenay 1958). Through application in mapping, the term "Yoongarillup" eventually came to encompass a wider range of landforms and soils. The term Yoongarillup Plain was first formally used as a landform/soil unit describing a melange of near-coastal plains and flats between Mandurah and Bunbury (McArthur & Bartle 1980) that included coastal plains underlain by fossiliferous limestone, supratidal to tidal estuarine flats, and geomorphically degraded Quindalup Dunes. An earlier attempt was made to rationalise the use of the term firstly, by excluding the terrain of Quindalup Dunes and estuarine-related flats from the definition, and secondly by restricting the term to refer to the genetically distinct fossiliferous limestone plains formed by Pleistocene marine progradation that are restricted palaeogeographically to the Mandurah-Bunbury area (Semeniuk 1990). At the time of this first amendment (Semeniuk 1990), the opportunity also existed to rectify the name, but this was not done. The term "Yoongarillup", deriving from the locality of Yoongarillup, south of Busselton, should refer to features in that region, and not to those restricted to the coastal tract between Bunbury and Mandurah. At present, following extended usage from the Busselton area into the Mandurah-Bunbury area by McArthur & Bartle (1980), and later amendment by Semeniuk (1990), the term "Yoongarillup Plain" now refers to a coastal plain quite removed from its origin. Following the results that clarify the Pleistocene palaeogeography in this region (Semeniuk 1995a), I propose that the situation be now rectified: firstly; that the term Yoongarillup Plain be restricted to the Busselton area; and secondly, that the term "Yalgorup Plain", derived from the local region, be applied to the set of coastal landforms that are palaeogeographically restricted to the Mandurah-Bunbury region. In this way, two genetically and geographically distinct plains will have different names.

The Pleistocene palaeogeographic system, and stratigraphic units within the Yalgorup Plain and adjacent systems

The Yalgorup Plain

The Yalgorup Plain is long and narrow, some 60 km long and 5–6 km wide (Fig 1), and is underlain by fossiliferous limestone, aeolian limestone and quartz sand. Though generally of low relief and undulating, there is local relief of 5–10 m (and up to 15 m) in the form of either calcarenitic aeolianite ridges or quartz sand ridges. The Plain is bordered to the east by a prominent ancestral hinterland ridge (the Mandurah-Eaton ridge; Semeniuk 1995a) that is a linear, moderately high (on average 20–40 m high, locally up to 70 m high, and itself on average some 20 m higher than the Yalgorup Plain), and 3–4 km wide, extending in a north-south direction for 90 km from Mandurah to Eaton (Fig 1), with a slight concavity in its form on the western margin. The junction of this ridge with the Yalgorup Plain is sharp, with the ridge descending steeply down to the Plain. The Mandurah-Eaton ridge is composed of Pleistocene aeolian quartz sand and aeolian limestone but has variable stratigraphy from south to north. To the south, it is mainly quartz sand and lesser limestone (Eaton Sand, Semeniuk 1983), with limestone occurring as aeolianite lenses (Semeniuk & Glassford 1987). To the north, limestone is more common. Even where limestone dominates, the ridge is mantled by yellow quartz sand. The Plain is bordered to the west by a Holocene coastal barrier aeolian ridge (the Leschenault-Preston barrier), or by Holocene estuarine lagoonal deposits.

Offshore from the Yalgorup Plain, the nearshore shelf is mostly an unconformity surface cut into Pleistocene limestone, with veneers of quartz sand or Holocene sediment (Semeniuk & Meagher 1981; Searle & Semeniuk 1985). Locally, particularly to the north of the study area, remnant shore-parallel ridges of Pleistocene limestone form discontinuous rocky reefs and islands (the Bouvard Reefs). Another line of former reefs, the Buffalo Reefs, occurs buried under Holocene dunes to the south (Semeniuk 1995a). Generally, there are no prominent limestone ridges or rocky reefs, buried or otherwise, in the central part of the area.

The age of the Plain is concluded to be Pleistocene, for the following reasons; 1, the formations that underlie the plain abut or overlie other units in the area are generally conceded to be Pleistocene in age (*e.g.* the Bassendean Sand, and the yellow sand and limestone that underlies the Mandrah-Eaton Ridge); 2, radiocarbon ages for the limestones at various sites returned ages >30–40,000 years.

Pleistocene lithologies

Ten types of sedimentary rock and sediment in the Pleistocene sequences occur in this region. These are (limestone terminology follows Dunham 1962):

1. Shelly/bioturbated calcarenite: fine to medium grained, bioturbated to structureless, skeletal quartz grainstone, with abundant calcareous algae and invertebrate skeletons. Shell locally present and randomly oriented by bioturbation;
2. Bioturbated foraminiferal calcarenite: fine to medium sand grainstone of calcareous algae, invertebrate skeletons, quartz, shell grit, whole molluscs, and abundant granule-sized foraminifera (*Marginopora*); bioturbation consists of vertical burrows 3–4 cm diam, penetrating downwards for 50–75 cm, otherwise bioturbation shows general swirling;
3. Laminated and cross-laminated marine calcarenite: medium grained skeletal quartz grainstone, generally without shell beds; conspicuously laminated, cross-laminated and trough-bedded;
4. Laminated to cross-laminated beach calcarenite: skeletal quartz grainstones, with variable structure and texture, but forming a set vertical sequence, usually over 2.0–2.5 m. Mollusc shells present (*Donax* most common); sedimentary structures and two diagnostic cephalopods distinguish four subfacies (Semeniuk & Johnson 1982) – lower part is trough-bedded, medium to coarse grained, with local shells, middle zone is medium to coarse grained, with oriented shell, and low inclined cross-lamination, then there is medium grained calcarenite, with bubble-sand structures, and upper part is crudely layered to bioturbated to structureless, medium to coarse grained, with diagnostic cephalopods *Sepia* and *Spirula*;
5. Cross-laminated to structureless calcarenitic aeolianite: large scale cross-laminated to structureless fine to medium grained skeletal quartz grainstone; cross-lamination sets 2–5 m high; calcrete rhizoconcretions and pipes common;
6. Calcreted limestone: this limestone is mainly calcrete in sheet-like form, 20–30 cm thick, or massive, within and on top of the parent limestone, or coating

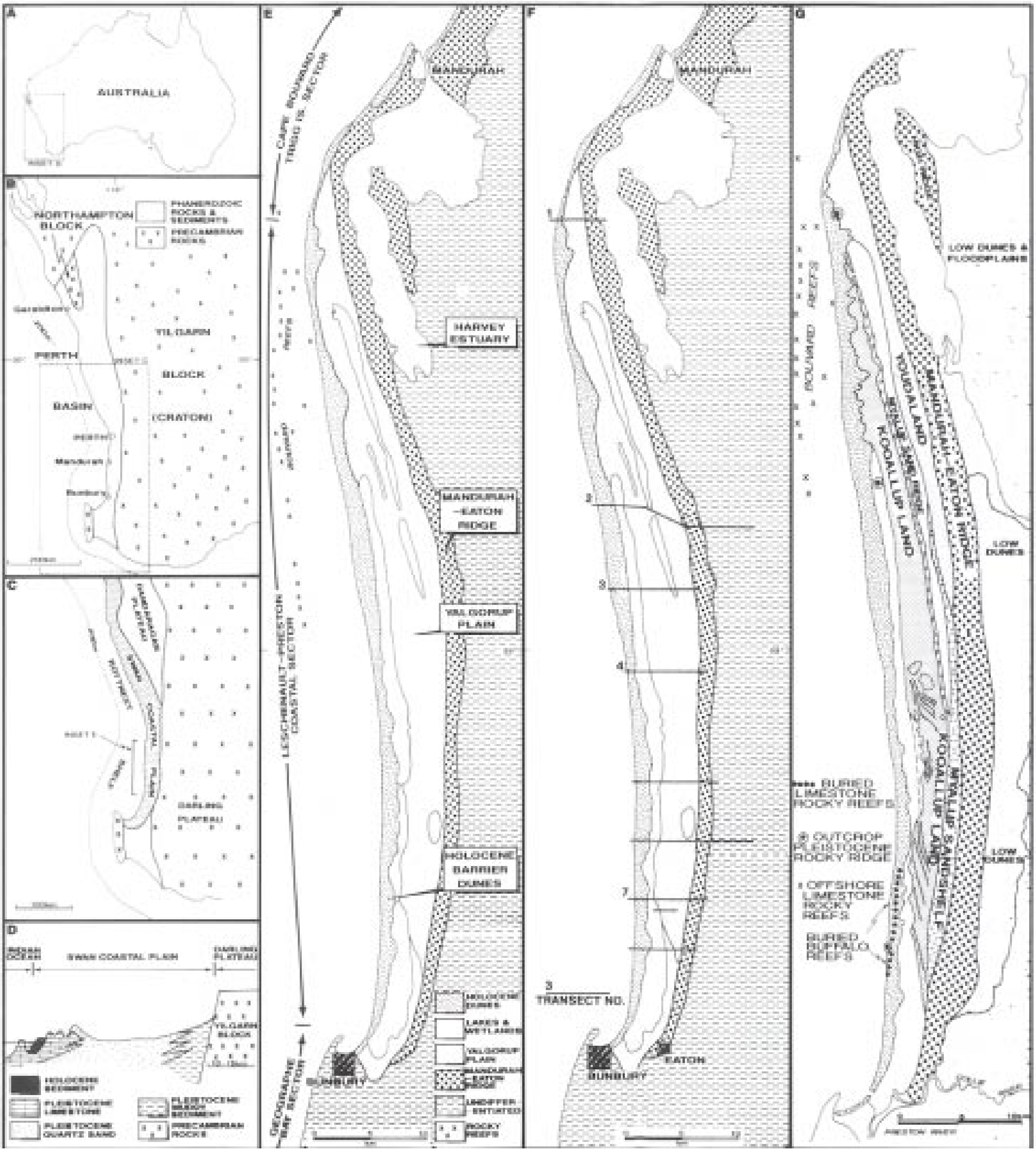

Figure 1. **A**, **B**, **C** & **D**: Location of study area in southwestern Australia in relationship to regional geology and geomorphology. **E**: Location of the Holocene Quindalup Dunes, Yalgorup Plain, and offshore reefs, and location of drill sites and quarries for type sections. **F**: Location of study transects (Transects 1–4 & 7 are presented in Figure 2; the full data including the un-numbered transects are presented in Semeniuk 1995a). **G**: Map of the Pleistocene geomorphic units (landforms) on the Yalgorup Plain.

pipes; lateral and vertical relationships and gradations, and palimpsest grains and textures indicate parent lithology was aeolianite;

7. Indurated, bored limestone: limestone varies from aeolianite to shelly limestone, and may also be calcreted; key features are induration by calcite cements (fine grained calcite, sparry calcite, calcrete), borings and pot-holes; borings are 1 cm diameter or less; limestone surface may be fissured, with local pot-holes some 10–30 cm diameter, and veneered with rounded limestone gravel and shells of *Ninella, Marmarstoma, Littorina*, limpets, barnacles;

8. Shelly calcilutite: structureless lime mudstone to skeletal lime mudstone;
9. Quartz sand: yellow, grey, or white, medium grained, and well to poorly sorted; grains mostly quartz, with some felspar and minor heavy minerals; quartz sand in this area is largely structureless (*cf.* Glassford & Semeniuk 1990); and
10. Shelly terrigenous mud: dark grey, structureless terrigenous mud with estuarine shells.

Some general features about these lithologies are noted here. All limestones are generally white, cream, tan to buff in colour. Grainstones are weakly to strongly cemented by sparry calcite, depending on location relative to the water table. Most limestones also are variably weakly indurated by calcrete, and additionally may be stained by iron oxides. Molluscs in the fossiliferous limestones (Table 1) are typically assemblages from seagrass bank environments (*cf.* Logan *et al.* 1970; Semeniuk & Searle 1985; Semeniuk 1995a). Calcreted limestone is a rock type best developed at unconformity surfaces, and indicates major subaerial exposure. Indurated, bored limestone (often with a gravel veneer of limestone lithoclasts and shells) is generally a micrite- or calcrete-indurated surface that had been exposed as a shore platform or hardground in the submarine shelf environment; this type of limestone has analogues in the Holocene and also indicates a major unconformity.

Pleistocene formations

Pleistocene limestones and quartz sand form distinct tracts of terrain on the Yalgorup Plain. Three new formations are described here to facilitate interpretation of the regional Quaternary history and palaeogeography. Previously, the limestone units in this area were referred to the Tamala Limestone, but they can be identified readily as distinct units by their lithology, stratigraphy and geography. They are lithologically distinct from the Tamala Limestone at its original location (Logan *et al.* 1970), at its type section (Playford & Low 1972), and from the calcarenitic aeolianite regarded as Tamala Limestone in the central Swan Coastal Plain of the Perth Regional area (Fairbridge 1953; Klenowski 1976; Gozzard 1983, 1986). Pleistocene limestones that comprise the offshore limestone ridges and the deeper sections of the Quaternary profile are left undifferentiated at present.

The new Pleistocene formations are:

3. Kooallup Limestone: a Late Pleistocene shoaling sequence of submarine, beach and aeolian calcarenites;
2. Myalup Sand: quartz sand, mostly grey to white, generally sandwiched between the Tims Thicket Limestone and Kooallup Limestone;
1. Tims Thicket Limestone: a shoaling sequence of submarine, beach and aeolian calcarenites deposited earlier in the Pleistocene.

The features of these formations are summarised in Table 2. The stratigraphy and relationships between the units are shown in Figures 2 & 3.

Table 1

List of molluscs in the Tims Thicket & Kooallup Limestones

BIVALVIA:	
Anodontia perplea	*Irus distans*
Brachidontes ustulatus	*Mactra australis*
Callucina lacteola	*Mactra matthewi*
Chlamys asperrimus	*Mysella* sp
Chionery cardioides	*Saccostrea cucculata*
Divalucina cumingi	*Paphies cuneata*
Dona francisensis	*Pinna* sp
Electroma georgiana	*Tawera coelata*
Eucrassatella sp	*Tawera lagopus*
Glycymeris strialularis	*Tellina tenuilirata*
Gomphina undulosa	*Thraciopsis subrecta*
Hemidona chapmani	*Wallucina cf jacksoniensis*
GASTROPODA:	
Acteocina sp	*Mitrella austrina*
Amalda monilifera	*Mitrella menkeana*
Amblychilepas oblonga	*Naccula punctata*
Astralium squamiferum	*Natica* sp
Bedeva paivae	*Notocochlis gualteriana*
Bittium granarium	*Notomella bajula*
Bulla quoyii	*Oliva australis*
Calyptraea calyptraeformis	*Parcanassa* sp
Cantharidus lepidus	*Phasianella australia*
Cantharidus irisodontes	*Phasianella solida*
Cantharidus sp	*Phasianella ventricosa*
Clanculus sp	*Phasiatrochus bellulus*
Collisella onychitis	*Polinices conicus*
Cominella tasmanica	*Proterato sulcerato*
Conus anemone	*Pyrene scripta*
Dicathais orbita	*Pyrenidae pseudomycla*
Drupa sp	*Syrnola* sp
Ethminolia vitiliginea	*Thalotia conica*
Gibbula lehmanni	*Thalotia lehmanni*
Gibbula preissana	*Thalotia pulcherrima*
Haminoea brevis	*Thalotia chlorostoma*
Hipponi conicus	*Turbo intercostalis*
Hipponi foliaceus	*Tanea sagittata*
Leiopyrga octona	*Veillum marrowi*
Mangelia sp	*Zafra vercoi*

Most identifications based on standards identified by G W Kendrick (Western Australian Museum) as cited by Semeniuk & Searle (1985); supplementary identifications from Roberts & Wells (1981) and Wells & Bryce (1985).

All molluscs listed, except for the gastropod *Parcanassa* are also present in Holocene seagrass assemblages, *cf* Semeniuk & Searle (1985)

Tims Thicket Limestone

Definition and characteristics: The Tims Thicket Limestone is a Pleistocene fossiliferous and non-fossiliferous calcarenite cropping out along the eastern Yalgorup Plain. Its lower to middle part is fossiliferous marine, and its uppermost part is aeolian.

Derivation of name: Tims Thicket area in the northern Yalgorup National Park.

Type section: A disused quarry at 32°39'06" 115°37'36", along Tims Thicket Road.

Distribution: The formation is restricted to the Yalgorup Plain area, and crops out almost along the entire length of the eastern part of the Plain (Fig 1). It also is intersected in cores underlying Holocene units.

Table 2

Limestone members in Pleistocene formations in the Yalgorup coastal area

FORMATION	MEMBER	LITHOLOGY	COMMENTS
KOOALLUP LIMESTONE	LAKESIDE MEMBER	cross-laminated to structureless, fine and medium calcarenite	aeolianites
	BELLEVUE MEMBER	white to cream shelly/ bioturbated calcarenite, laminated cross-laminated shelly calcarenite/coquina, laminated to crosslaminated beach calcarenite	submarine to beach zone facies
	SPRINGHILL MEMBER	calcilutite and shelly calcilutite	submarine basin facies
TIMS THICKETT LIMESTONE	WHITE HILL ROAD MEMBER	cross-laminated to structureless, fine and medium calcarenite	aeolianites
	CLIFTON DOWNS MEMBER	white to cream shelly/ bioturbated calcarenite, bioturbated foraminiferal limestone, laminated cross-laminated marine calcarenit laminated to cross-laminate beach calcarenite	submarine to beach zone facies

Table 3

Description of Holocene stratigraphic units[1] in the Yalgorup coastal area

SEDIMENT UNIT	STRUCTURE	LITHOLOGY	HOLOCENE DEPOSITIONAL ENVIRONMENT
Safety Bay Sand (aeolian facies)	large scale cross laminated to structureless	white, cream, orange fine and medium sand	dune
Safety Bay Sand (beach facies)	laminated to bedded; seaward sloping layers	white, cream, yellowish medium and coarse sand and shelly sand	beach
Preston Beach Coquina	bedded to crudely layered	white, cream, yellowish, & tan shell beds, shell grit, shelly sand, and coarse to medium sand	subtidal shoreface to beach
Becher Sand	structureless, bioturbated crudely layered	grey sand and shelly sand; shells from seagrass assemblage	subtidal seagrass bank
Bridport Calcilutite	structureless to bioturbated; shell layers	grey calcilutite and shelly calcilutite	deep subtidal basin
Leschenault Formation	structureless, bioturbated, crudely layered	grey sand, mud, muddy sand, locally shelly; estuarine shells	estuarine sand and mud flats

[1] Data from Semeniuk (1983), Semeniuk & Searle (1985, 1987), and this paper.

Thickness and geometry: At the type section, the formation has been logged as 9.1 m thick. Regionally, the unit is a ribbon to wedge, some 60 km long, up to 5 km wide and 5–10 m thick.

Lithology: The sequence of limestone at the type section (from 1 at the base to 5 at the top) is:

5. cross-laminated to structureless calcarenitic aeolianite: 2.0 m thick;
4. laminated to cross laminated beach calcarenite: 2.0 m thick;
3. laminated and cross laminated marine calcarenite: 1.3 m thick;

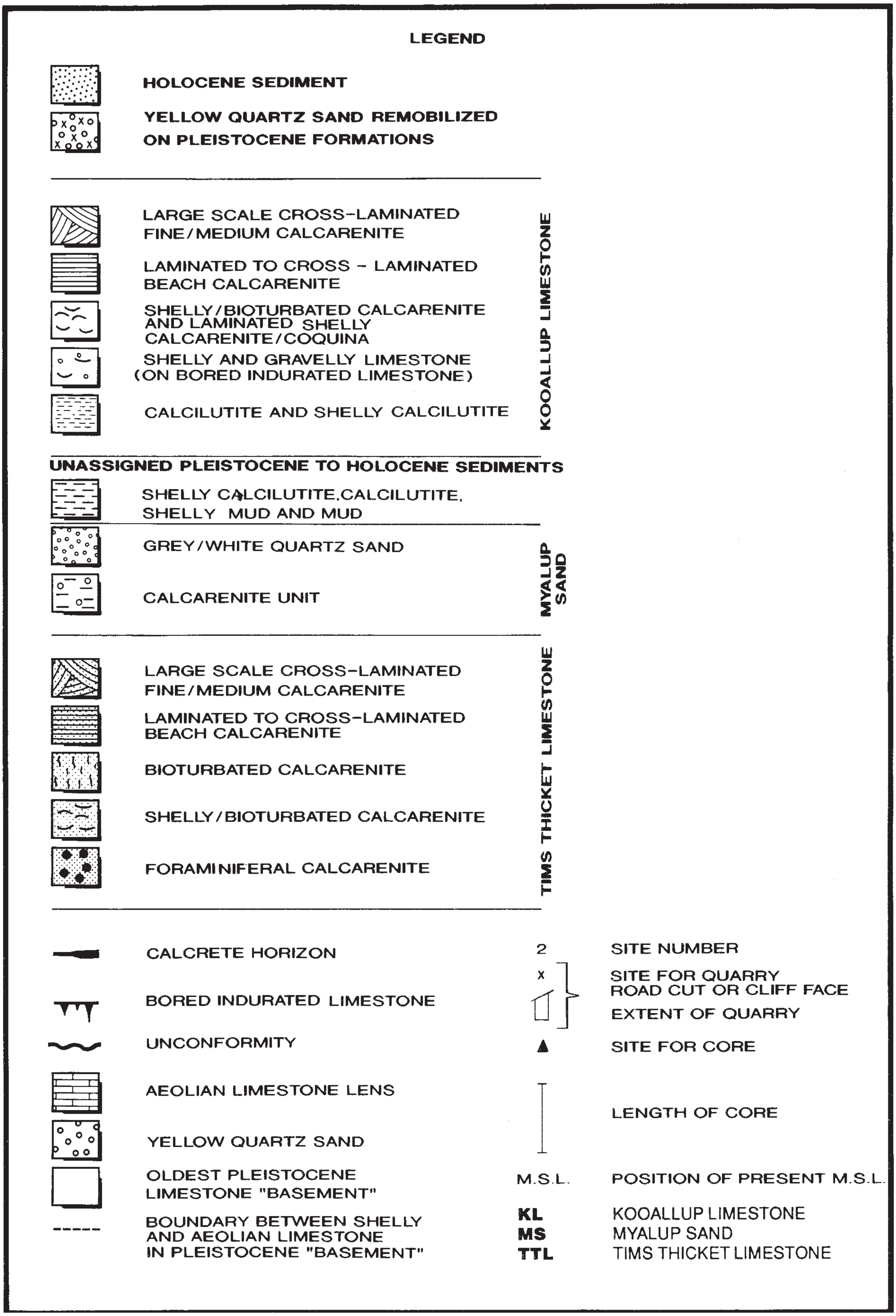

Figure 2A. Stratigraphy of transects. Legend to transects.

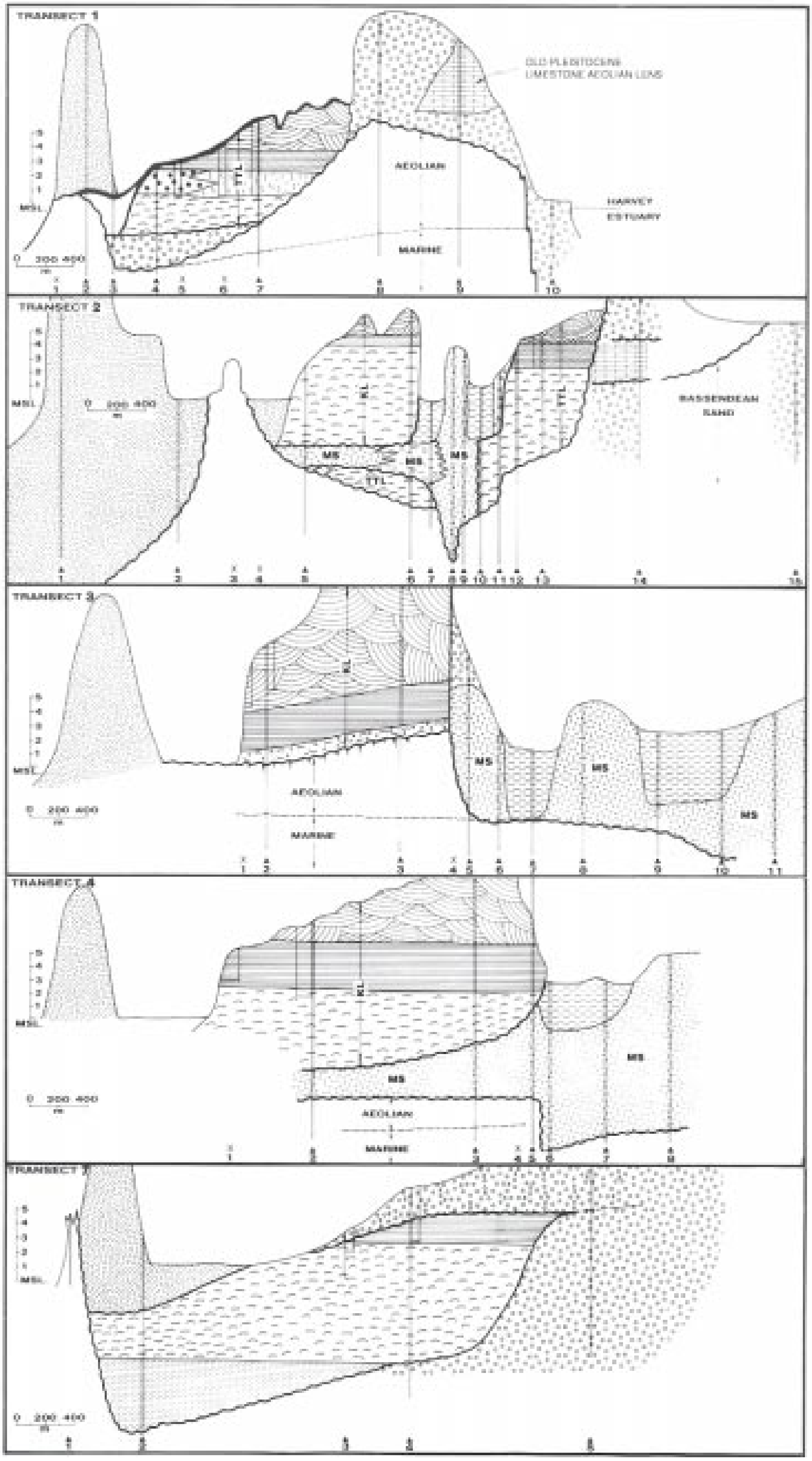

Figure 2B. The stratigraphy of the transects 1–4, 7.

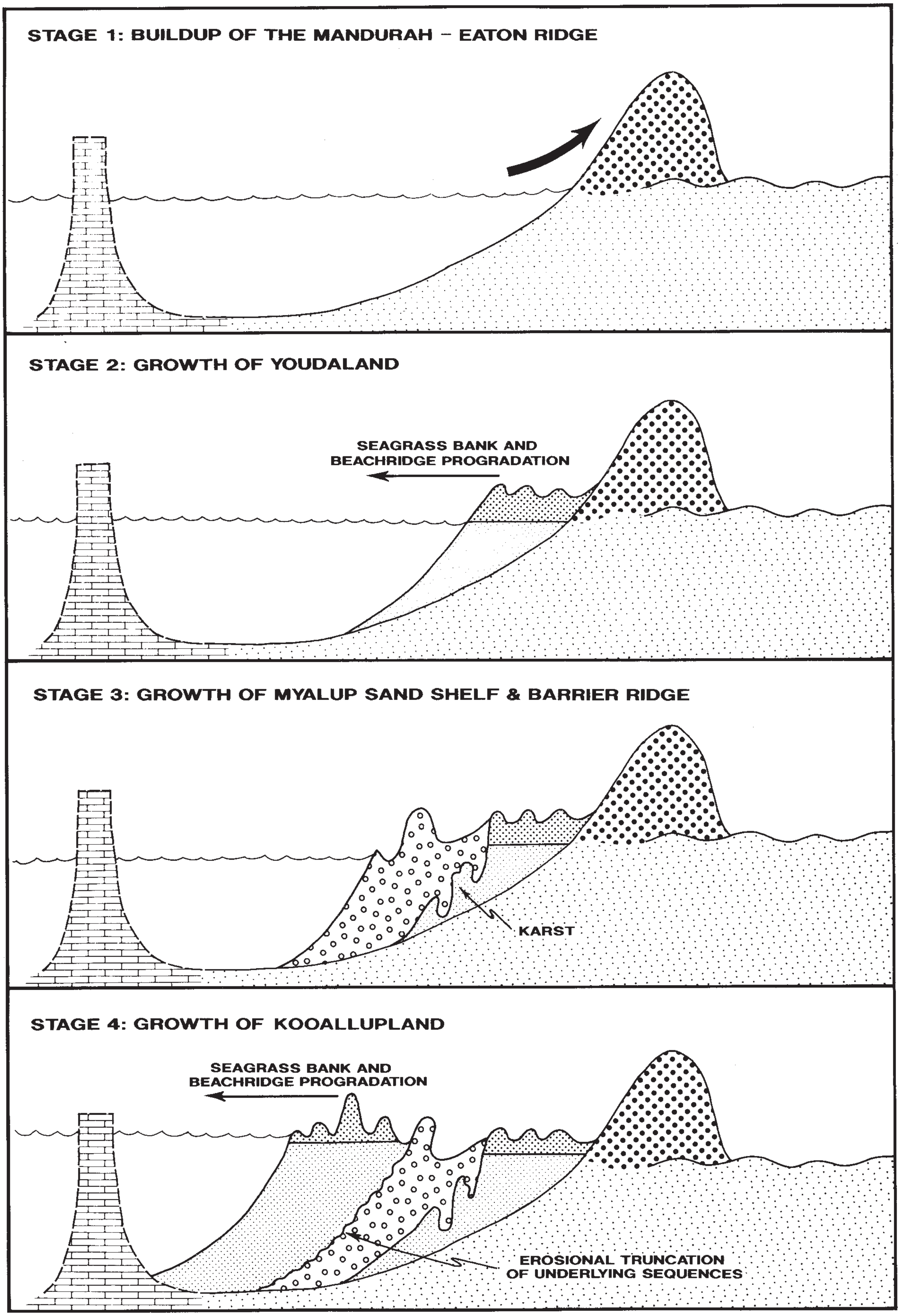

Figure 3. Summary of stratigraphic relationships between the Pleistocene formations (from Semeniuk 1995a).

2. bioturbated foraminiferal calcarenite: 1.8 m thick;
1. shelly/bioturbated calcarenite with seagrass assemblage biota: 2.0 m thick; unconformable on yellow quartz sand.

The bioturbated foraminiferal calcarenite is laterally equivalent to shelly/bioturbated calcarenite and laminated and cross-laminated marine calcarenite. The limestone types in the formation are in a shoaling-upward sequence, with seagrass bank lithofacies and the laterally equivalent sand wave lithofacies and bioturbated foraminiferal calcarenite lithofacies passing up into a beach sequence and then into a beachridge/dune sequence. Within the beach facies, the subfacies are also in a shoaling sequence: trough cross-bedded calcarenite passes up into laminated calcarenite with *Donax* (a beach zone indicator), into calcarenite with bubble structures, into structureless calcarenite with *Sepia* and *Spirula*, and then finally into large scale cross-laminated aeolian calcarenite.

Stratigraphic relationships: The formation unconformably overlies older Pleistocene limestone at depth, abutting and pinching out unconformably to east against yellow sand and limestone that underlie the Mandurah-Eaton Ridge, and pinches out downdip (westwards) as a natural palaeogeographic synoptic surface. In its eastern parts, it is unconformably overlain by the Myalup Sand filling karst features on the limestone; in its western parts it is unconformably overlain by Holocene sediment.

Fossils: Lower to middle parts of the formation contain molluscan and foraminiferan fossils, indicative of seagrass bank environments. The molluscs are listed and compared with the Holocene seagrass bank assemblage in Table 1. The upper part of the unit, the beach facies, contains *Donax* spp, *Paphies* sp, *Sepia* spp, and *Spirula spirula*.

Members in the formation: The natural lithologic sequence in the formation reflects a sequence of shoaling, with seagrass bank lithofacies and the laterally equivalent sand wave lithofacies and bioturbated foraminiferal calcarenite lithofacies passing up into a beach sequence and then into a beachridge/dune sequence. In a broad view, the formation consists of a distinctive mid-lower part of fossiliferous limestones passing up into aeolian limestones. It is proposed that the broad separation of the calcarenites from fossiliferous submarine to littoral to non-fossiliferous aeolian be the basis of recognising two members in the formation, as follows (Table 2):

***White Hill Road Limestone Member*:** upper part of formation consisting of aeolian calcarenite. The area along White Hill Road, south of Mandurah, exposes good sequences of this member, with relict beachridge patterns evident (see figure 5 of Semeniuk 1995a). The type location for the member is the same as for the formation.

Clifton Downs Member: lower to middle part of the formation consisting of fossiliferous marine calcarenite passing up into fossiliferous laminated beach calcarenite, exposed in the Clifton Downs area, east of Lake Clifton. The type location for the member is the same as for the formation. Additonal quarry reference sites are located along Tims Thicket Road in the Tims Thicket area.

Myalup Sand

Definition and characteristics: The Myalup Sand is a predominantly grey to white quartz sand unit between the Tims Thicket Limestone (below) and the Kooallup Limestone (above). There are local thin lenses of limestone in the formation.

Derivation of name: Myalup Swamp, in the southern Yalgorup Plain area, east of Binningup.

Type section: Sand ridge at 32°58'00" 115°42'57", south of the Yalgorup National Park.

Distribution: The formation is restricted to the Yalgorup Plain, cropping out almost along the entire length of its eastern and middle part. It also is intersected in core in this area.

Thickness and geometry: Where intersected in core and trenches, the formation has variable thickness from 5–15 m thick. Regionally, the unit is a ribbon to shoestring, some 60 km long, up to 5 km wide and 5–15 m thick.

Lithology: The type section, 15 m thick, is generally structureless grey to white quartz sand, mainly fine to medium sand-sized, and poorly sorted. The formation becomes progressively more iron-stained in the upper 3–4 m. Though quartz rich, it also contains minor feldspar. The upper parts of the formation may be stained yellow. Locally, there are carbonate-rich lenses, <1 m thick, located 2–3 m below present mean sea level. It was not generally possible to differentiate facies in the quartz sand sections of the Myalup Sand.

Stratigraphic relationships: Contact with the underlying Tims Thicket Limestone is sharp and unconformable, marked by prominent karst in the limestone. Contact with the overlying Kooallup Limestone is sharp and unconformable, with the base of the limestone truncating the ridge-and-depression sequence in the Myalup Sand which pinches out under the limestone. In the depressions on the Myalup Sand, there is an overlying undifferentiated suite of Pleistocene to Holocene shelly terrigenous mud, calcilutite and shelly calcilutite (wetland and estuarine facies). The contact of Myalup Sand with the sediments that underlie the Mandurah-Eaton Ridge is difficult to differentiate.

Fossils: No fossils has been retrieved from the formation, but the limestone lenses therein hold scope to be fossiliferous.

Kooallup Limestone

Definition and characteristics: The Kooallup Limestone is a Pleistocene fossiliferous and non-fossiliferous calcarenite that crops out along the western zone of the Yalgorup Plain. Subsurface sections may contain local calcilutite lenses. The lower to middle part of the formation is fossiliferous, and the uppermost part is aeolian.

Derivation of name: Kooallup Lagoon, east of Lake Preston and north of Myalup.

Type section (type locality): Quarry, east of Lake Preston, in the southern part of Yalgorup Plain area, at 32°02'46" 115°42'36".

Distribution: The formation is restricted to the Yalgorup Plain area, cropping out almost along the entire length of the western part of the Yalgorup Plain. Additionally, it has been intersected in core underlying Holocene units in this region.

Thickness and geometry: At the type section, the formation is 10.8 m thick. Regionally, the unit is a ribbon to wedge, some 60 km long, up to 5 km wide and 5–16 m thick.

Lithology: At the type section, there are four types of limestone; in stratigraphic order, from 1 at the base to 3 at the top, these are:

3. cross-laminated to structureless calcarenitic aeolianite: 1.8 m thick;
2. laminated to cross laminated beach calcarenite: 3.0 m thick;
1. laminated and cross laminated marine calcarenite and shelly/bioturbated calcarenite with seagrass assemblage biota: 6 m.

In a section further south from the type section, the same sequence of limestones occur but are underlain by calcilutite:

3. laminated to cross laminated beach calcarenite: 2 m thick;
2. laminated and cross laminated marine calcarenite: 9 m thick;
1. shelly calcilutite (5 m thick); unconformable on an older un-named shelly marine limestone.

In general, the Kooallup Limestone sequences exhibit shoaling: seagrass bank facies, and the laterally equivalent sand wave facies, are overlain by beach and then beachridge/dune facies. The beach sequence progresses from subtidal to supratidal, with preservation of bubble structures and shells of *Donax*, *Sepia*, and *Spirula*. Locally, in former inter-ridge marine depressions, there are lenses of calcilutite.

Stratigraphic relationships: The formation unconformably overlies an older as yet un-named Pleistocene limestone at depth, and pinches out unconformably to the east against the Myalup Sand. To the west, it pinches out downdip as a natural palaeogeographic surface, or abuts a buried ridge that is the extension of the Bouvard Reefs system.

Fossils: The fossil within the Kooalup Limestone is similar to that in the Tims Thicket Limestone. The lower to middle parts of this formation contain molluscs (Table 1) and foraminifera, derived from seagrass bank environments. The upper part of the unit, the beach facies, contains *Donax* spp, *Paphies* sp, *Sepia* spp, and *Spirula spirula*.

Members in the formation: As for the Tims Thicket Limestone, the sequence in the Kooallup Limestone reflects shoaling, with (local basin calcilutites and) seagrass bank lithofacies passing up into beach facies and then into a beachridge/ dune facies. The sequences essentially form a fossiliferous lower to middle part, and a non-fossiliferous (aeolian) upper part. It is proposed that this broad separation of limestones be the basis of recognising three members in the formation, as follows (Table 2):

Lakeside Limestone Member: upper part of formation consisting of aeolian calcarenite. The type location for the member is the same as for the formation; additionally, the pits and quarries around the Lakeside property east of Lake Preston, and the eastern shore of Lake Preston exposes good sequences of this member.

Bellevue Limestone Member: lower to middle part of formation consisting of fossiliferous marine limestones and fossiliferous laminated beach calcarenite. The type location for the member is the same as for the formation; additionally, local pits and quarries in the area of the Bellevue property, along the northeastern shore of Leschenault Inlet, expose good sections of this member.

Springhill Limestone Member: lower part of the formation consisting of calcilutite and shelly calcilutite. A local lens of this calcilutite occurs at depth under the Springhill property (located 2 km SE of Binningup). The type section for the member is Core Site 2, Transect 7 (Fig 2). [Note that use of the Springhill Limestone Member is to be distinguished from the previous use of the term Spring Hill, as two words, for the Palaeozoic Spring Hill Limestone in the Bonaparte Basin; though not formally defined to date in the Bonaparte Basin, the Spring Hill Limestone was first used by Druce 1963].

Distribution: An additional feature in the Kooallup Limestone is a south to north facies change; to the south, beachridge and dune facies above the seagrass bank and beach facies are quartz sand rich; to the north, they are more carbonate-grain rich. This transition is related to major inputs of quartz sand from two sources in the south: erosion of the Mandurah-Eaton ridge (with concomitant net northwards longshore drift), and the Collie, Preston and Wellesley rivers transporting quartz from the dunes further east.

Pleistocene palaeogeographic units

The Pleistocene formations are restricted to distinct, mappable tracts of country that represent discrete phases of coastal sedimentation, progradation, and geomorphic history in this region. In effect, their distribution reflects accretionary stages of the Swan Coastal Plain between Mandurah and Bunbury. In this context, they have been assigned palaeogeographic names to highlight their discrete palaeogeographic character (Semeniuk 1995a). The distribution of the Pleistocene formations in relationship to the Pleistocene landform units are as follows (Semeniuk 1995a):

1. *Youdaland*: the most eastern and oldest Pleistocene landform unit on the Yalgorup Plain, underlain by the Tims Thicket Limestone; the name derives from Youda, between Tims Thicket and Mandurah;

2. *Myalup Sand Shelf and Myalup Sand Ridge*: a sand shelf system that separates the Mandurah-Eaton Ridge from Kooallupland, and a linear ridge system generally sandwiched between the Youdaland and Kooallupland, respectively, and underlain by the Myalup Sand; the name derives from Myalup Swamp, between Myalup and Binningup; and

3. *Kooallupland*: the most western and youngest Pleistocene landform unit on the Yalgorup Plain, underlain by Kooallup Limestone; the name derives from Kooallup Lagoon, located to the east of Lake Preston.

The evolution of the Yalgorup (coastal) Plain is interpreted to have taken place in several stages related to sealevel still-stands in the Pleistocene (Semeniuk 1995a):

1. formation of an older Pleistocene limestone beachridge plain (Youdaland), within which there was shoaling from marine seagrass carbonate sedimentation to beach to beachridges/ dunes;

2. accumulation of quartz rich coastal sand barriers (Myalup Sand Shelf and Myalup Sand Ridge);

3. formation of a younger Pleistocene limestone beachridge plain (Kooallupland) within which there was, again, shoaling from marine seagrass carbonate sedimentation to beach to beachridges/dunes.

Thus the overall progressive accretion of the Yalgorup Plain records, with subaerial interruptions (Fig 3); 1, sedimentation and progradation in a coastal setting partly behind offshore rocky reefs; 2, changes in style from cuspate foreland and shoreface accretion to coastal barriers; and 3, alternation in sedimentation from carbonate-rich to quartz-rich. The results also provide several insights into the Quaternary history of the Perth Basin in southwestern Australia in regards to the alternations of carbonate/siliciclastic sedimentation in general, the control of the geometry of coastal sediment bodies by ancestral topography such as the offshore limestone ridges, the longevity of the limestone ridge ancestral topography, and the age structure of the Pleistocene coastal plains (Semeniuk 1995a).

Holocene stratigraphy

Much of the western edge of the Yalgorup Plain is bordered by Holocene barrier dunes. Though these are a geomorphic extension of the Leschenault Peninsula barrier (Semeniuk 1985), stratigraphically they present a different Holocene history to elsewhere. Various Holocene sediment types occur in this area and, generally, they can be assigned to previously defined formations. However, one unit remains undescribed, and is formally defined in this paper as the Preston Beach Coquina. The sediment types and their assigned formations are summarised in Table 3.

Preston Beach Coquina

Definition and characteristics: The Preston Beach Coquina is the name proposed for light-coloured, bedded, laminated, cross-laminated shell gravel and shelly sand along the shoreface of the Leschenault-Preston Sector, and in the subsurface.

Derivation of name: Preston Beach, south of Mandurah.

Type section: Preston Beach at 32°52'57" 115°38'40".

Distribution: The unit is widespread along the coastal zone of the Leschenault-Preston Sector, and additionally forms isolated units in the subsurface in other coastal sectors further north.

Thickness and geometry: The unit is up to 6–7 m thick. Regionally along the Leschenault-Preston Sector, the unit will appear as a discontinuous ribbon, some tens of kilometres long, up to 100–200 m wide and 6–7 m thick. Elsewhere it forms lenses, some 1–3 m thick, and hundreds of metres wide.

Lithology: At the type section, the formation is a light-coloured (yellowish, tan, buff, to cream), bedded, crudely layered, to locally laminated, to cross-laminated deposit of shell gravel, shell grit, shelly sand, and sand. Sand grains are quartz, or quartz, bioclasts and limestone lithoclasts. The upper 1 m of the unit also has a distinctive deposit of storm debris, with *Sepia* spp and *Spirula spirula*, mixed shell, and local horizons of pebbles of pumice.

Stratigraphic relationships: The formation overlies a variety of units, depending on locality and the extent of erosion along its base: it has an erosional contact with both the Becher Sand and Leschenault Formation, and an unconformable contact with Pleistocene sediment and sedimentary rock. The formation is overlain conformably and gradationally by dune deposits of the Safety Bay Sand. Laterally, the unit may pass into shelly sand and sand of the beach facies of the Safety Bay Sand. It may also pass laterally into Becher Sand.

Fossils: Molluscan shell remains in the formation include: *Donax* spp, *Glycymeris* sp, *Mactra* sp, and *Donacilla* sp, and in the uppermost part, *Spirula spirula* and *Sepia* spp.

Age: Radiocarbon ages show that the unit is wholly Holocene. In the Leschenault-Preston Sector, its age is 5455 ^{14}C yrs BP to present (Semeniuk 1995b). Elsewhere, such as at Quinns Rock, it is older, but still Holocene.

Distribution: The Preston Beach Coquina is a distinctive, widespread shell gravel unit formed in high energy beach to shoreface settings. The dominant, and consistent shell gravel content serves to separate it from other marine and strand units such as the Becher Sand and the beach facies of the Safety Bay Sand, respectively.

Holocene sedimentary sequences

In coastal southwestern Australia, there are four main large-scale standard Holocene stratigraphic sequences (Semeniuk 1995b, and Fig 4):

Type 1, prograded bank, beach, beachridge system composed of a shoaling sequence of subtidal basin sediment, seagrass bank sediment, beach sand, and dune sand;

Type 2, prograded shoreface to beachridge system composed of a shoaling sequence of shoreface shell/sand, beach sand/ shell, and dune sand;

Type 3, retrograded barrier dune system composed of dune sand overlying estuarine lagoonal sediment; and

Type 4, retrograded barrier dune system composed of dune sand unconformable on Pleistocene sediment.

Each type tends to be localised in a specific sector of coast. Type 1 occurs in settings of cuspate forelands behind barrier limestone reefs, ridges and islands, such as the Rockingham-Becher system (Searle *et al.* 1988) and the Whitfords Cusp (Semeniuk & Searle 1986). Type 2 occurs along the modern shore face of the Leschenault-Preston barrier (*e.g.* Preston Beach). Type 3 occurs in the Leschenault Peninsula area (Semeniuk 1985), and Type 4 occurs in the northern part of the Leschenault-Preston Sector and in coastal sectors further north (Semeniuk *et al.* 1989).

Barrier dune stratigraphy, Yalgorup area

The standard Holocene stratigraphic sequences have been used to help unravel the Holocene history of the barrier dunes in the Yalgorup area, and specifically between Preston Beach and the Bouvard Reefs. The Holocene stratigraphy under the barrier dunes here is complex;

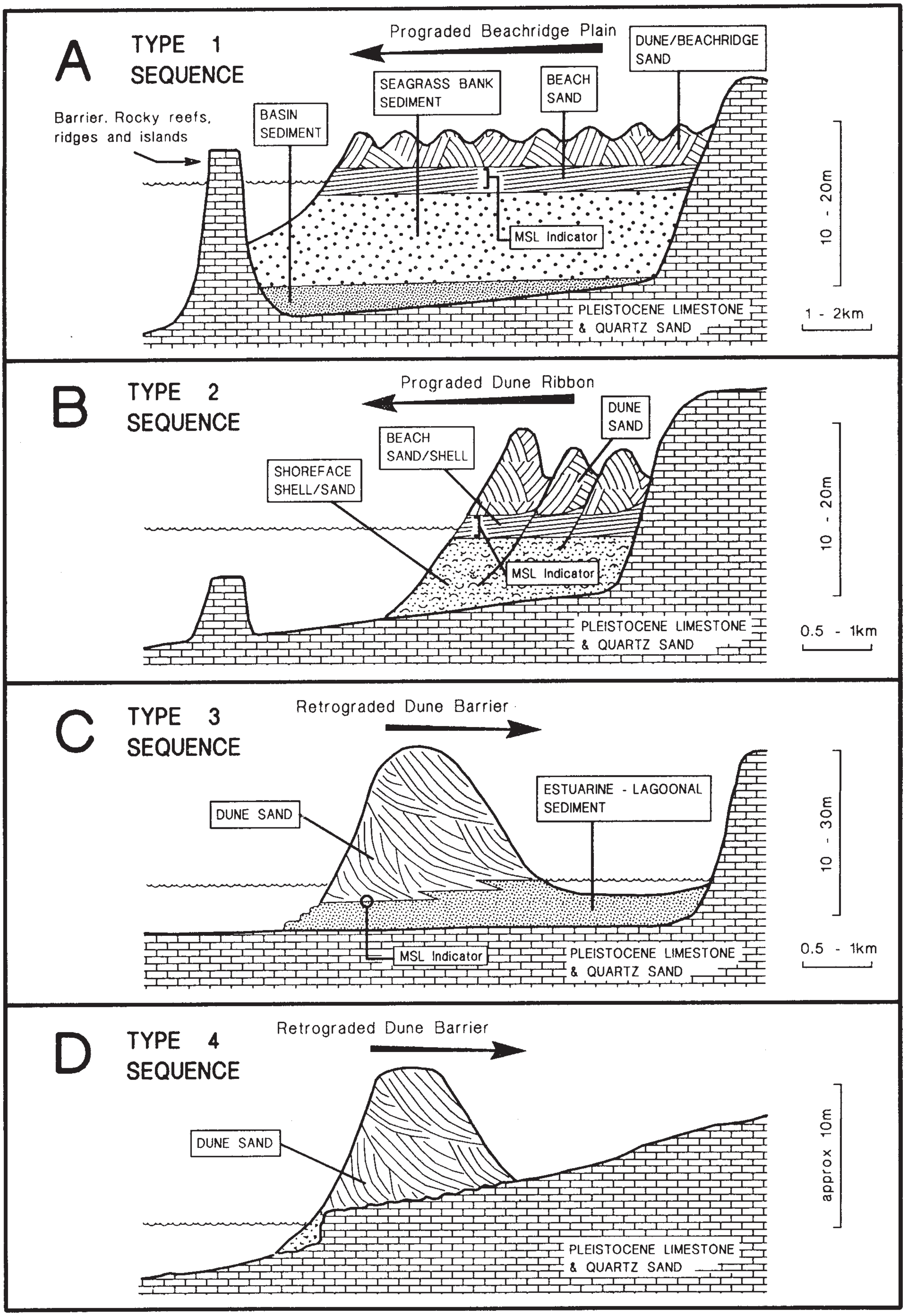

Figure 4. The four standard Holocene stratigraphic sequences in the southern Perth Basin (from Semeniuk 1995b).

the marine Holocene record begins with a Type 1 sequence, which is sharply overlain by a Type 3 sequence, with a final capping of Type 2 sequence (Semeniuk 1995b). The sedimentary sequence records dramatic coastal changes associated with rising Holocene sealevels; simple seagrass bank, beach, beachridge sedimentation/progradation was abruptly terminated, and succeeded by development of a barrier dune with its associated barred lagoon. The sequence developed is interpreted to be a response to seas rising into a bathymetrically complex area. The area between Preston Beach and Bouvard Reefs, being in a transition zone between a coastal sector of complex bathymetry to the north and one of simple bathymetry to the south, had the potential to record differing styles of Holocene sedimentation in response to varying sealevel (Semeniuk 1995b).

References

Commander D P 1988 Geology and hydrogeology of the superficial formations and coastal lakes between Harvey and Leschenaut inlets (Lake Clifton Project). Geological Survey of Western Australia Professional Papers, Report 23, 37–50.

Druce E C 1963 Devonian and Carboniferous conodonts from the Bonaparte Gulf Basin, northern Australia, and their use in international correlation. Bureau of Mineral Resources Bulletin 98.

Dunham R J 1962 Classification of carbonate rocks according to depositional texture. American Association of Petroleum Geologists Memoir 1: 108–121.

Fairbridge R W 1953 Western Australian Stratigraphy. Text Book Board Publication, University of Western Australia, Perth.

Glassford D K & Semeniuk V 1990 Stratification and disconformities in yellow sands of the Bassendean and Spearwood Dunes, Swan Coastal Plain, southwestern Australia. Journal of the Royal Society of Western Australia 72:75–93

Gozzard J R 1983 Fremantle Part Sheets 2033 I and 2033 IV, Perth Metropolitan Region, 1:50,000 Environmental Geology Series, Geological Survey of Western Australia, Perth.

Gozzard J R 1986 Perth, Sheet 2034 II and part 2034 III and 2134 III, Perth Metropolitan Region, 1:50,000 Environmental Geology Series, Geological Survey of Western Australia, Perth.

Klenowski G 1976 Geotechnical properties of the Coastal Limestone in the Perth Metropolitan area. Geological Survey of Western Australia, Annual Report for 1975, 42–46.

Logan B W, Read J F & Davies G R 1970 History of carbonate sedimentation, Quaternary epoch, Shark Bay, Western Australia. American Association of Petroleum Geologists Memoir 13:38–84.

McArthur W M & Bartle G A 1980 Soils and Land Use Planning. In: The Mandurah Bunbury Coastal Zone, Western Australia. Land Resources Management Series No 6, CSIRO, Melbourne.

McArthur W M & Bettenay E 1958 The soils of the Bussleton area, Western Australia. CSIRO Divisional Report 3/58.

McArthur W M & Bettenay E 1960 The development and distribution of the soils of the Swan Coastal Plain, W.A. Soil Publication No 16, CSIRO, Melbourne.

Playford P E & Low G H 1972 Definitions of some new and revised rock units in the Perth Basin. Geological Survey of Western Australia, Annual Report for 1971, Perth, 44–46.

Playford P E, Cockbain A E & Low G H 1976 Geology of the Perth Basin, Western Australia. Western Australia Geological Survey Bulletin 124, Perth.

Roberts D & Wells F 1981. Seashells of Southwestern Australia. Creative Research, Perth.

Searle D J & Semeniuk V 1985 The natural sectors of the inner Rottnest Shelf coast adjoining the Swan Coastal Plain. Journal of the Royal Society of Western Australia 67:116–136 .

Searle D J, Semeniuk V & Woods PJ 1988 Geomorphology, stratigraphy and Holocene history of the Rockingham – Becher plain. Journal of the Royal Society of Western Australia 70:89–109

Semeniuk V 1983 The Quaternary stratigraphy and geological history of the Australind-Leschenault area. Journal of the Royal Society of Western Australia 66:71–83.

Semeniuk V 1985 The Age Structure of a Holocene Barrier Dune System and its implication for sealevel history reconstructions in Southwestern Australia. Marine Geology 67:197–212.

Semeniuk V 1990 The geomorphology and soils of Yoongarillup Plain, in the Mandurah-Bunbury coastal zone, southwestern Australia: a critical appraisal. Journal of the Royal Society of Western Australia 73:1–7.

Semeniuk V 1995a Pleistocene coastal palaeogeography in southwestern Australia – carbonate and quartz sand sedimentation in cuspate forelands, barriers and ribbon shoreline deposits Journal of Coastal Research (in press).

Semeniuk V 1995b An early Holocene record of rising sealevel along a bathymetrically complex coast in southwestern Australia Marine Geology (in press).

Semeniuk V & Glassford D K 1987 Origin of limestone lenses in Perth Basin yellow sand. Journal of the Royal Society of Western Australia 70:35–47

Semeniuk V & Johnson D P 1982 Recent and Pleistocene beach and dune sequences, Western Australia. Sedimentary Geology 32:301–328.

Semeniuk V & Meagher T D 1981 The geomorphology and surface processes of the Australind – Leschenault Inlet coastal area. Journal of the Royal Society of Western Australia 64:33–51.

Semeniuk V & Searle D J 1985 The Becher Sand, a new stratigraphic unit for Holocene sequences of the Perth Basin. Journal of the Royal Society of Western Australia 67:109–115.

Semeniuk V & Searle D J 1986 The Whitfords Cusp – its geomorphology, stratigraphy and age structure. Journal of the Royal Society of Western Australia 68:29–36.

Semeniuk V & Searle D J 1987 The Bridport Calcilutite. Journal of the Royal Society of Western Australia 70:25–27.

Semeniuk V, Cresswell I D & Wurm P A W 1989 The Quindalup Dunes: the regional system, physical framework and vegetation habitats. Journal of the Royal Society of Western Australia 71:23–47

Wells F E & Bryce C W 1985. Seashells of Western Australia. Western Australian Museum, Perth.