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Radiocarbon ages of some coastal landforms in the Peel-Harvey estuary, south-western Australia

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Abstract

The stratigraphy and ^{14}C chronology of a tidal shoal, a stranded channel shoal complex, a relict tidal delta, a stranded estuarine embayment, a beachridge system, and a lobate delta in the Peel-Harvey estuary of southwestern Australia show that these landforms began forming as early as c. 7000 yr BP, when the sea first flooded the estuary, while others are relatively young (< 1000 yr BP). Estuarine-marine conditions had established by about 8500 yr BP, and relative sealevel had reached 2.2 m above present by about 7000 yr BP in the northern estuary. The radiocarbon ages and sealevel indicators obtained from northern estuary settings appear to conform to a falling sealevel curve from about 4000 yr BP to the present. Data from coastal peats buried under some beachridges show that relative sealevel was 2 m and 1 m below present level some 7000 and 6400 yr BP, respectively, in the southern parts of the estuary. Shell dated at c. 6000 yr BP from mud filling an abandoned channel in the Murray—Serpentine River delta indicate that this lobate delta first formed prior to that time, implying a possible pre-Holocene origin for the delta complex.

Introduction

The coastal landforms of the Peel-Harvey estuarine system consist of variably disposed beachridges, marginal platforms, fluvial deltas, tidal deltas and shoals, spit-lagoon complexes, and equivalents of some of these units stranded during times of higher Holocene sealevels (Brown *et al.* 1980, Semeniuk & Semeniuk 1990). To date, however, there has been no description of these coastal landforms in terms of their chronology. Brown *et al.* (1980) and Brown (1983), for instance, report only three radiocarbon dates for the whole estuarine system, but do not relate these dates to past sealevels by using sealevel indicators, nor do they determine the chronology of any of the estuarine sequences. During recent stratigraphic investigations into the coastal landforms and peripheral wetlands of the Peel-Harvey estuary (Semeniuk & Semeniuk 1990), as part of the ongoing studies by the authors into freshwater and estuarine wetlands (C A Semeniuk 1988), various shelly, peaty, and wood-bearing horizons were sampled for the purposes of dating the coastal stratigraphy of this estuary. This paper reports the results of these chronological studies, including the dating of sealevel indicators in some sequences. It also compares the sealevel history in the estuary with other sealevel records in the region.

Methods

The stratigraphy of the estuarine landforms of the Peel-Harvey estuary was investigated by soil sampling, trenches, cores, augering, reverse-air-circulation coring to 30 m, and topographic levelling along transects intersecting the main coastal landforms (Figs 1 & 2; see also Semeniuk & Semeniuk 1990). The structure, fabric, texture and composition of soil and underlying stratigraphic samples were studied in the laboratory to define the lithologic suites. Within trenches and cores, samples were collected for radiocarbon analysis from *in situ* layers. The reverse-air-circulation corer extracted samples in 0.5 m to 1.0 m segments as desired, and could extract material from precisely determined depths. The core material will be housed in the core storage facilities of the Geological Survey of Western Australia.

Eight types of samples for radiocarbon dating were collected from the sequences. These were:

1. mainly monospecific shell wholly within the estuarine sediments, in order to date the containing sequence and hence the landform;

2. mixed shell wholly within the estuarine sediments, in order to date the containing sequence and hence the landform;

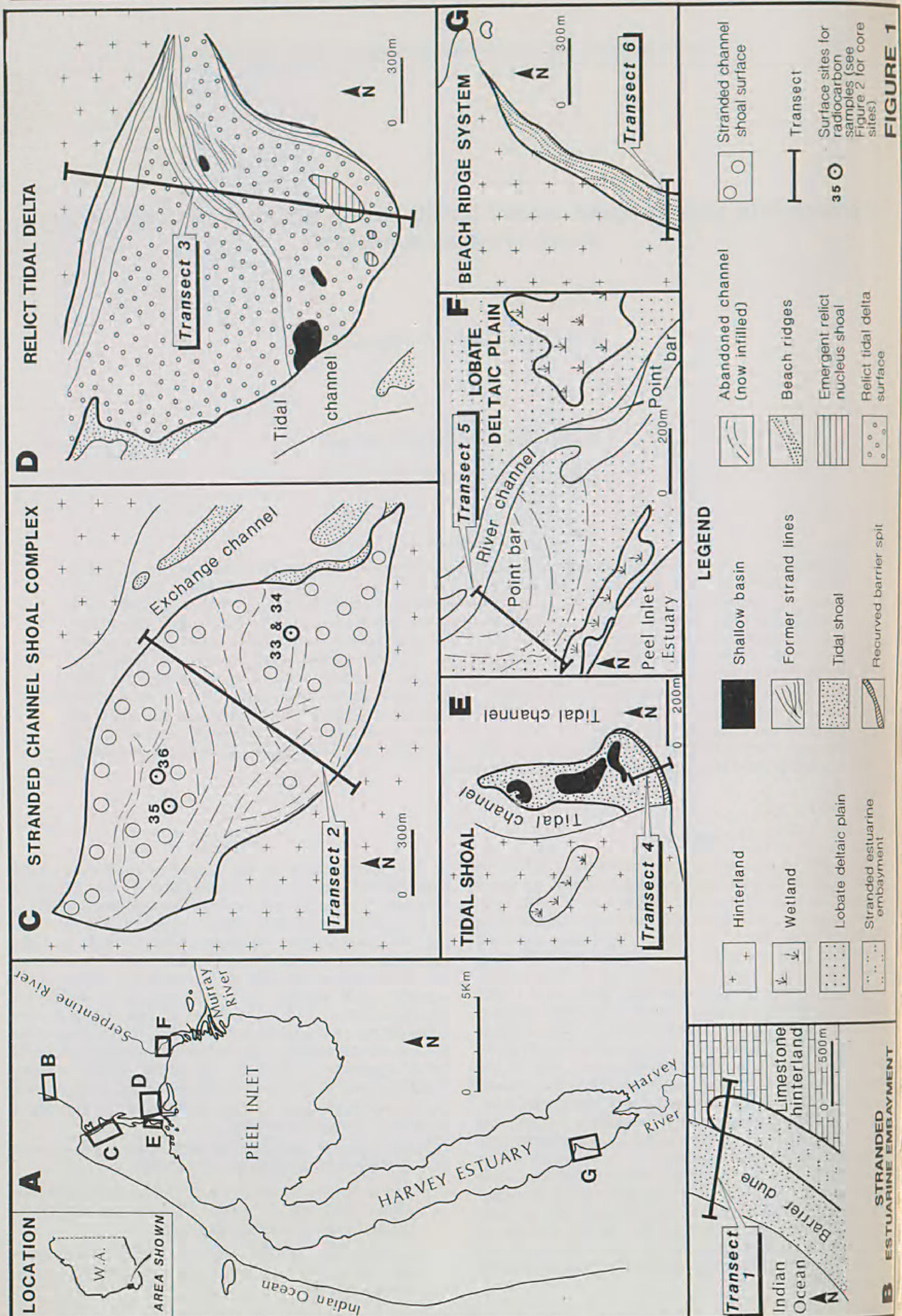

Figure 1 A Map showing study area and location of more detailed study sites; **B-G** Geomorphic maps of each of the study sites showing geomorphic components and location of stratigraphic transects and location of surface sample sites for radiocarbon material. Figure 2 shows location of subsurface sample sites for radiocarbon material.

3. mainly monospecific shell wholly within the estuarine sediments, but in association with a sealevel indicator, in order to date the sequence and the landform, and determine the position of past relative sealevel;

4. peat and peaty sand wholly within the shoreline estuarine sediments, in order to date the sequence and the landform, and determine the position of past relative sealevel;

5. wood imbedded in Pleistocene limestone to date the inundation by the Holocene transgression of the terrestrial surface;

6. mixed shell at the contact between the estuarine sediments and Pleistocene limestone in order to date the base of the estuarine sequence at the unconformity;

7. shell (chamiids and oysters) encrusting on pinnacles and islands of Pleistocene limestone protruding into the estuarine sediments in order to date the position of a former sealevel; and

8. shell wholly within the partially cemented Pleistocene limestone in order to confirm a pre-Holocene age for the limestone, thus ensuring that the sediments are not cemented Holocene materials.

Information on the samples used in radiocarbon analyses is presented in Table 1.

Shell, peat, and wood materials for radiocarbon analysis were thoroughly dried in a laboratory oven. Shells were washed, sorted into taxa, and clean, lustrous specimens of the abundant species, free of any adhering matrix, cementing agents, and discolouration, were selected. Where possible, only monospecific samples were used for analysis (Table 1). Where shells were abundant, enough material of two or more separate species could be sorted, thus providing replicate samples of different taxa for radiocarbon analysis at particular sampling sites and stratigraphic horizons. Where shells in samples were not abundant enough to extract sufficient of a single species, then clean, lustrous shells of various species were used in the analysis. Radiocarbon analyses were carried out by Kreuger Geochron Laboratories. In this paper radiocarbon dates are reported as "years BP", but we imply that these ages are in "^{14}C years BP".

While we accept in principle that there is some correction that needs to be applied to the radiocarbon dates of marine carbonates due to oceanic reservoir effects (Berger *et al.* 1966; Bowman 1985), we have not applied the correction to the radiocarbon dates of this study for the following reasons:

1. the shells of this study are mostly estuarine, and estuarine waters are derived from oceanic, fluvial and meteoric sources. The correction for reservoir effects due to fresh water input draining a Pleistocene limestone hinterland is unknown;

2. the results of Bowman (1985) for southern Australia are based on four samples, and this is not a statistically valid sample number;

3. the results of Bowman (1985) are based on benthos from rocky shores and seagrass environments; until the influences of the environmental, feeding, and physiological differences on the shell secretion of the various shelly benthos are better understood (see Crenshaw 1980, Rhoads 1980, Rosenberg 1980), radiocarbon dates obtained from modern organisms existing in markedly different environments and using different feeding strategies should be treated with caution.

Workers wishing to compare their data with the results of this study, or wishing to use the results of this study in the future can add the correction factor of 480 + 30 (Bowman 1985) to the results of this paper (Table 1) if necessary.

Regional setting

The Peel-Harvey estuary is a compound estuary barred by a Pleistocene barrier ridge of limestone and sand, and is essentially three coalesced estuary systems. The estuarine system is composed of the sub-circular Peel Inlet, which is the receiving basin for the Murray and Serpentine Rivers, the elongate Harvey Estuary, which is the receiving basin for the Murray River; and a narrow linear exchange channel, which connects the estuary with the Indian Ocean and is partly choked by an emergent channel shoal complex and tidal delta (Hodgkin *et al.* 1980). The main regional geomorphic components framing the system are a barrier ridge of Spearwood Dunes to the west, aeolian and fluvial lowlands of Bassendean Dunes and Pinjarra Plain to the east, and riverine discharge points (McArthur & Bettenay 1960).

The Peel-Harvey estuary can be subdivided into sublittoral, littoral, and supralittoral zones, and Brown *et al.* (1980) largely describe the sublittoral and some littoral zones of this system. Semeniuk & Semeniuk (1990) subdivided the littoral and supralittoral into various shore types. These shores encompass modern and stranded Holocene landforms, and Pleistocene landforms and sediments. Each shore type is a product of various estuarine, fluvial, and marine sedimentary processes, resulting in specific sediment types and geometry. Twelve shore types were recognised: tidal shoals, active tidal delta, stranded channel shoal complex, relict tidal delta, stranded estuarine embayments, spit-lagoon complexes, beachridge complexes, marginal platforms, erosional sandy shore, limestone cliff—pocket beach shore, lobate fluvial delta complex, and elongate fluvial delta complex.

Description of coastal landforms and their radiocarbon chronology

In this study, the stratigraphy and chronology of a tidal shoal, a stranded channel shoal complex, a relict tidal delta, a stranded estuarine embayment, a beachridge system, and the lobate delta are described (Figs 1F & 2). Information on each of these landforms (drawn from Semeniuk & Semeniuk 1990) and on the stratigraphy and radiocarbon chronology is presented below.

The position of the transects of Figure 1 in this paper generally correspond with the transect positions illustrated by Semeniuk & Semeniuk (1990), but the stratigraphic transect numbers in this paper do not necessarily correspond with the transect numbers of Semeniuk & Semeniuk (1990). Also transects 2 and 3 of this paper, although they are approximately in the same area as transects 2 and 4 of Semeniuk & Semeniuk (1990), are

Table 1

Description of Material used in Radiocarbon Dating

Sample no. this paper (1)	Field no.	Labor-atory no. (2)	Tran-sect No.	Stratigraphic setting	Rationale for sample	Height (m) of SL indicator if applic-able (3)	Sample type	Age in ^{14}C yrs BP C13 corrected	d ^{13}C (°/$_{oo}$ PDB)
1	MTDW.0 /3-4 *Katelysia*	GX-12897	2	Middle estuarine shelly sand within stranded channel shoal complex	Age of estuarine sand	—	*Katelysia scalarina*	5300±85	1.1
2	MTDW.0 /9-10 chamiid	GX-12898	2	Top of muddy estuarine sequence within stranded channel shoal complex	Age of estuarine mud	—	*Chama ruderalis*	7445±245	0.7
3	MTDW.0 /9-10 *Katelysia*	GX-12899	2	Top of muddy estuarine sequence within stranded channel shoal complex	Alternative taxonomic replicate for sample (2) above	—	*Katelysia scalarina*	7520±95	-0.1
4	PW7:50cm *Sanguinolaria*	GX-12657	2	Top of shelly estuarine sand within stranded channel shoal complex; shell disarticulated and some in situ.	Age of estuarine sand flat	Shallow sublittoral sand flat facies 1 m above AHD	*Sanguino-laria biradiata*	4240±80	2.5
5	MTDW.1 surface *Katelysia*	GX-12668	2	Shelly mud filling depression at top of channel shoal complex	Age of estuarine surface	Surface is 1.03 m above AHD	*Katelysia scalarina*	4895±85	1.1
6	MTDW.1 /12-13 *Katelysia*	GX-12667	2	Lower muddy estuarine sequence within stranded channel shoal complex	Age of estuarine sequence earlier in the Holocene	—	*Katelysia scalarina*	7670±260	0.5
7	MTDW.1 /14-15	GX-12666	2	Lower muddy estuarine sequence within stranded channel shoal complex	Age of estuarine sequence earlier in the Holocene	—	Mixed shell	8560±470	-1.7
8	PW2:50-70cm *Sanguinolaria*	GX-12662	2	Top of shelly estuarine sand within stranded channel shoal complex; shell disarticulated and some in situ.	Age of estuarine sand flat	Shallow sublittoral sand flat facies 1.5 m above AHD	*Sanguino-laria biradiata*	4400±120	2.1
9	PW2:50-70cm *Katelysia*	GX-12661	2	Top of shelly estuarine sand within stranded channel shoal complex; shell disarticulated and some are in situ.	Age of estuarine sand flat	Shallow sublittoral sand flat facies 1.5 m above AHD	*Katelysia scalarina*	4505±80	0.6
10	PW4: o/c oyster	GX-12659	2	Oyster encrusting small emergent limestone island	Age of oyster encrust -ation and hence age of marine-estuarine inundation	Shell encrustat-ions are 1.5 m above AHD	*Ostrea angasi*	5390±50	-0.4
11	MTDW.3 /2-3m top *Katelysia*	GX-12665	2	Base of shelly estuarine sand within stranded channel shoal complex; also base of Holocene in this drill site.	Age of estuarine sand	—	*Katelysia scalarina*	6640±200	0.9
12	PW4: o/c chamiid	GX-12660	2	Chamiids encrusting small emergent limestone island	Age of shell encrust -ation and hence age of marine-estuarine inundation; taxonomic replicate for (10)	Shell encrustat-ions are 1.5m above AHD	*Chama ruderalis*	6130±300	1.7
13	VCSRG MTDW BH2 3.5 m	GX-12540	2	Roots of tree penetrating Pleistocene limestone	Age of estuarine inundation	Root horizon is located 1 m below AHD	Wood	7645±100	-25.0

Table 1—*continued*

Description of Material used in Radiocarbon Dating

Sample no. this paper (1)	Field no.	Labor- atory no. (2)	Tran- sect No.	Stratigraphic setting	Rationale for sample	Height (m) of SL indicator if applic- able (3)	Sample type	Age in ^{14}C yrs BP C13 corrected	d ^{13}C (°/$_{oo}$ PDB)
14	MTDW.4 /8-9m large *Electroma*	GX-12664	2	Shells within partially cemented Pleistocene limestone	To confirm age of the Pleistocene limestone	—	large species of *Electroma*	>36,600	1.4
15	MTDW.4 /8-9m chamiids	GX-12663	2	Shells within partially cemented Pleistocene limestone	To confirm age of the Pleistocene limestone	—	Chamiids	>38,000	1.8
16	MTDE.5 /0-1m	GX-12669	3	Top of estuarine shelly sand overlying Pleistocene limestone at shallow depth	Age of estuarine sand flat	Surface of sand flat is 1.0 m above AHD	Mixed shell	6420±360	2.0
17	MTDE.5 /2-3m	GX-12670	3	Shells within partially cemented Pleistocene limestone	To confirm age of the Pleistocene limestone	—	Mixed shell	>32,000	1.5
18	MTDE.5 /4-5m	GX-12671	3	Shells within partially cemented Pleistocene limestone	To confirm age of the Pleistocene limestone	—	Mixed shell	>31,000	1.4
19	MTDE.4/5 /1-2m	GX-12672	3	Shells lying on surface of Pleistocene limestone	Age of estuarine shell (see note [4] below)	—	Mixed shell	12530±210	2.6
20	MTDW.3 /0.5-1m *Katelysia*	GX-12673	3	Upper part of shelly estuarine sand flat within relict tidal delta	Age of estuarine sand surface	Surface of sand flat is 0.87m above AHD	*Katelysia scalarina*	4835±185	1.7
21	MTDW.3 /1-1.5m	GX-12674	3	Upper part of shelly estuarine sand flat within relict tidal delta	Age of upper estuarine sand	—	Mixed shell	4500±175	1.9
22	MTDE.3 /4-5m	GX-12675	3	Shelly horizon with muddy sediment fill in channel	Age of channel fill	—	Mixed shell	5695±180	2.2
23	MTDE.2 /0.5-1m *Katelysia*	GX-12676	3	Upper part of shelly estuarine sand flat within relict tidal delta	Age of estuarine sand surface	Surface of sand flat is 1.07m above AHD	*Katelysia scalarina*	4740±80	1.5
24	MTDE.2 /1-2m *Katelysia*	GX-12677	3	Upper part of shelly estuarine sand flat within relict tidal delta	Age of upper estuarine sand	—	*Katelysia scalarina*	5000±190	1.6
25	No.17: Styx Transect A (Spit : wood)	GX-11395	4	Wood buried in tidal mud underlying an eroding spit	Age of surface of muddy tidal shoal	Wood horizon is located c 0.5m above AHD	Wood	–650±105 (contemporary)	–24.6
26	Sample 15. CS/RANGER—C2: peat & sand	GX-11104	6	Peat within buried lagoonal swale within beachridge sequence	Age of peaty lagoonal deposit, and hence age of enclosing beach ridges	Peat unit is 1 m below AHD	Peat	6365±115	–25.5
27	Sample 16. CS/RANGER—C3: 220cm, peat & sand	GX-11105	6	Peaty sand within buried lagoonal swale within beachridge sequence	Age of peaty lagoonal deposit, and hence age of enclosing beach ridges	Peat unit is 2 m below AHD	Peaty sand	6980±120	–27.4
28	VCSRG 22. CDP 4: 5-6m estuarine shell	GX-12021	5	Shells within mud filling an abandoned channel in a deltaic complex	Age of the estuarine channel fill	—	Mixed shell	6015±400	–0.6

Table 1—*continued*

Description of Material used in Radiocarbon Dating

Sample no. this paper (1)	Field no.	Laboratory no. (2)	Transect No.	Stratigraphic setting	Rationale for sample	Height (m) of SL indicator if applicable (3)	Sample type	Age in ^{14}C yrs BP C13 corrected	d ^{13}C (‰ PDB)
29	SSR.0 (NMB)	GX-12622	1	Upper estuarine shelly mud	Age of estuarine sedimentation	Shelly unit is located 2.2 m above AHD	*Katelysia scalarina* & *Sanguinolaria biradiata*	6910±235	-2.1
30	SSR.1 : 7-8m	GX-12623	1	Shelly gravel layer of estuarine species at the base of the Holocene sequence	Age of estuarine sedimentation	—	*Katelysia scalarina* & *Sanguinolaria biradiata*	7050±115	-2.3
31	SSR.3 : 8-9m	GX-12902	1	Shelly beach layer within beach/dune barrier	Age when estuarine conditions were terminated	Shelly unit is located 0.5 m above AHD	Mixed *Donax*, *Glycymeris* & *Donacilla*	3475±160	1.6
32	Mandurah Fossil Island *Katelysia*	GX-10962	3	Shelly layer underlying a small chenier at the edge of a stranded tidal shoal within the relict tidal delta complex	Age of surface of relict tidal delta	—	*Katelysia scalarina*	5930±105	0.6
33	Mandurah: Marsh/Bridge *Katelysia*	GX-10961	near transect 1; see Fig. 1	Shelly layer on surface of former estuarine sand flat	Age of estuarine sand flat	Within 1 m of former sealevel	*Katelysia scalarina*	5780±190	1.2
34	Mandurah: Marsh/Bridge *Sanguinolaria*	GX-10960	near transect 1; see Fig. 1	Shelly layer on surface of former estuarine sand flat	Age of estuarine sand flat; taxonomic replicate for sample (33)	Within 1 m of former sealevel	*Sanguinolaria biradiata*	4340±200	2.3
35	Sample 1: Mandurah Cottage *Sanguinolaria*	GX-11090	near transect 1; see Fig. 1	Shelly layer 0.5m below surface of former estuarine sand flat	Age of estuarine sand flat	Within 1 m of former sealevel	*Sanguinolaria biradiata*	4375±95	2.2
36	PW6: 50cm *Katelysia*	GX-12658	near transect 1; see Fig. 1	Shelly layer 0.5m below surface of former estuarine sand flat	Age of estuarine sand flat	Within 1 m of former sealevel	*Katelysia scalarina*	4355±50	1.1

1. Location of samples are shown in Figures 1 & 2.
2. GX numbers: Kreuger Geochron Laboratories
3. Relative to AHD.
4. Sample appears to be a mixture of Holocene and reworked Pleistocene shell.

composite sections derived from core information, trenches and outcrops located within a transect belt 100-150 m wide; thus the details of sequence and lithology within transects 2 and 3 in this paper differ in some respects from the profiles presented by Semeniuk & Semeniuk (1990).

Tidal shoals

Tidal shoals, situated in the tidal channel, are elongate, oval, sediment bodies, attached to the shore at their southern ends, and aligned with the channel by tidal currents. The shoals have developed as secondary features on the relict tidal delta and cuspate projections of the sandy hinterland, and may be bordered by recurved spits (Fig. 1E). The shoals are underlain by fine and medium sand at depth, and muddy sand and mud in upper parts; a recurved spit facies may occur as a perched thin shoestring (Transect 4, Fig. 2). Radiocarbon analysis of wood excavated from muddy sediment exposed in a small cliff by the eroding, retreating south part of the tidal shoal gave a contemporary age for the upper part of the tidal shoal sequence (Fig. 2). This implies that deposition of the upper part of the shoal to encase the wood, and the subsequent retreat of the barrier spit to bury and later expose the shoal stratigraphy, has occurred in near modern times.

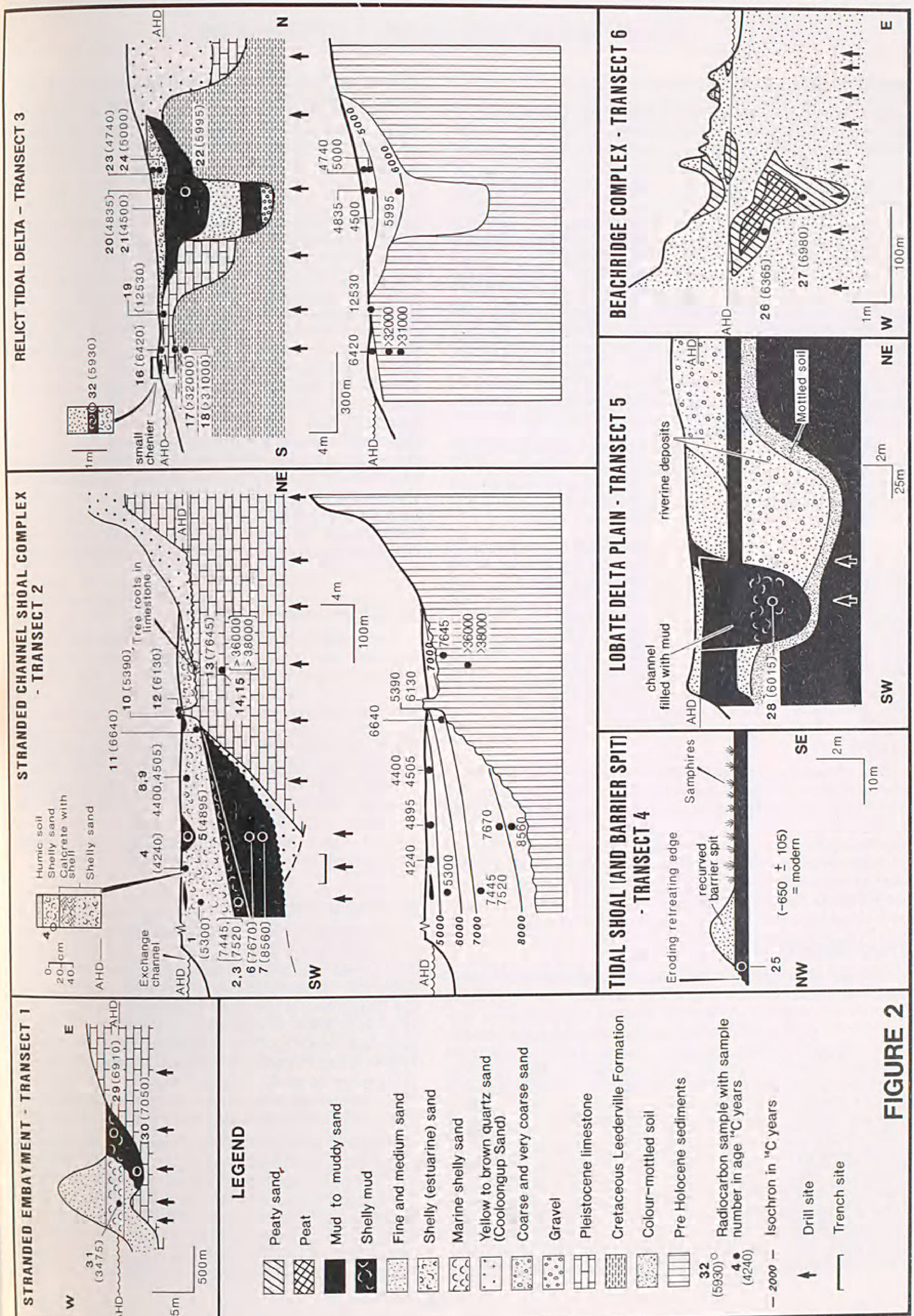

Figure 2 Stratigraphic profiles, location of subsurface sample sites for radiocarbon material, and, where applicable, age structure reconstructions for transects shown in Figure 1.

Stranded channel shoal complex

A stranded, or emergent, channel shoal complex adjoins the modern exchange channel (Fig. 1C). The surface of the landform is comprised of a series of very low relief sand ridges and ellipsoidal sand hummocks (former sand waves and shoals), that are elongated sub-parallel to the former exchange channel margin and are separated by low sinuosity shallow linear depressions and channels. The stranded channel shoal complex at shallow depths is underlain mainly by shelly sand (Transect 2, Fig. 2), similar to modern estuarine sand shoal and sand flat facies, with disarticulated and articulated estuarine shells such as *Sanguinolaria biradiata*, *Katelysia scalarina*, and *Katelysia rhytiphora*, and represents a littoral to shallow sublittoral surface formed when sealevel was relatively 2 m higher earlier in the Holocene. Depressions in the landform are filled with modern sand and mud sheets. At depths greater than 8 m, the sediments consist of channel-fill deposits, with large scale cut-and-fill structures.

Estuarine sand-flat bivalves (samples 4, 5, 8, 9, 34, 35 & 36) analysed for radiocarbon gave ages between c. 4200 and 4900 yr BP for the surface and near-surface of the former estuarine sand flat, thus showing reasonable consistency in the age of this sedimentary surface.

In situ encrustations of oysters and chamiids (samples 10 & 12), located 2 m above present MSL on former, small limestone-rock islands and on limestone pinnacles that gave ages of c. 5400 and c. 6100 yr BP, indicate that sealevel had reached this relative elevation by c. 6100 yr BP. Tree roots embedded in limestone at a level of 1 m below present MSL (sample 13) gave an age of c. 7600 yr BP, and the oldest radiocarbon age for shells, some 14 m below present MSL (sample 7), gave an age of c. 8600 yr BP, indicating that estuarine—marine conditions had established at these levels by c. 7600 and 8600 yr BP, respectively.

The chronology of sediments underlying the stranded channel shoal complex has been determined by drawing isochrons on stratigraphic sections using the available radiocarbon ages within the sequence (Fig. 2). The isochrons show that the sedimentary accumulation formed by upward shoaling processes, commencing c. 8600 yr BP and continuing until c. 4200 yr BP, with some 16 m of sediment accreting in 4000 yrs.

Relict tidal delta

A relict tidal delta, which also formed during a higher sealevel earlier in the Holocene, adjoins the south-east part of the modern exchange channel. The complex is a flat terrain with relict (abandoned, infilled) tidal channels, and emergent shoals, onlapped by sand and shelly sand and mud sheets which fill the depressions (Fig. 1D). The relict shoals exhibit geomorphic patterns such as stranded sand ribbons (low cheniers) on the margins of stranded former shoals, and former erosional scars, illustrating their accretional history from smaller nucleus shoals. The stratigraphy of the relict tidal delta is variable over short distances, with lensoid veneers of sand, shelly sand, and mud disconformably overlying shelly muddy sand, coarse quartz sand, or medium quartz sand, which in turn disconformably overlie an irregular surface of Pleistocene limestone and Cretaceous Leederville Formation. The complex stratigraphy reflects the origin of the terrain that formed by shifting fluvial and tidal channels (with their accompanying erosion and filling) and accreting shoals.

Estuarine, sand-flat bivalves (samples 20, 21, 23, & 24) gave ages between 4500 to 5000 yr BP for much of the surface and near-surface of the relict sand flat of the tidal delta, which formed when relative sealevel stood 2 m higher than present. These datings also show reasonable consistency in the age of this sedimentary surface. Sample 32 from a shell horizon beneath a stranded small chenier bordering the edge of a relict emergent shoal (Transect 3, Fig. 2) gave an age of c. 6000 yr BP, and indicates that the mounds of sediment of the tidal delta complex can be of various ages. The chenier is < 1 m thick and appears as a sand ribbon on the edge of the eroded shoal, and possibly formed when sealevel was falling and the shoals were being exposed. Mixed shell (sample 16), located in sand 1 m above present MSL and overlying a former limestone pavement at shallow depths, gave an age of c. 6400 yr BP, indicating that sealevel had reached this relative height by this time. The oldest Holocene date in the deeper parts of the sequence is sample 22 which gave an age of c. 5700 yr BP within a tidal channel fill deposit. The chronology of the stratigraphy underlying the relict tidal delta is shown in Transect 3 (Fig. 2). The isochrons also imply that the accretion of the tidal delta formed by upward shoaling, commencing at least by c. 5700 yr BP and continuing until c. 4500 yr BP.

Stranded estuarine embayment

A stranded estuarine embayment adjoins the exchange channel, and comprises an elongate estuarine lowland formed behind a barrier dune (Fig. 1B). The lowland is underlain by tidal estuarine deposits (Transect 1, Fig. 2), but was formerly connected to the exchange channel (see fig 12 B,C of Searle *et al.* 1988). The radiocarbon ages and height of the samples relative to AHD (samples 29 & 30) indicate that estuarine conditions were established by c. 7000 yr BP, with relative sealevel 2.2 m higher than at present. Sample 31 within the beach and barrier dune sequence indicates that the estuarine sequence was eroded and estuarine sedimentation terminated in this embayment by c. 3500 yr BP (Searle *et al.* 1988).

Beachridge complex

Beachridges occur extensively along the shore of Peel Inlet and Harvey Estuary, but it is only in the Island Point area where material suitable for dating was found in the sequence. Beachridge complexes are ribbon-shaped and are comprised of low sand ridges and intervening swales (Fig. 1G). Their stratigraphy in the Island Point area is complex, with surface and buried lenses of mud and coastal peat, deposited in swales, interspersed with sand spit/ridge deposits (Transect 6, Fig. 2). All ridges have been eroded by wind and sheet wash so that swales are partly infilled by sand, and capped by humic or peaty soil.

Samples 26 & 27 from within the peat lithofacies of the beachridge stratigraphy gave ages of c. 6400 and 7000 yr BP. The older age is from a layer within a peat and sandy peat lens, that is located 2 m below present MSL. The younger age is from a peat within the same lens but at a level 1 m below present MSL. The peats are coastal peats deposited generally at about sealevel, so these data would indicate peat accumulation with sealevel some 1-2 m below present c. 7000-6400 yrs ago. The ages of the peat deposits are used to infer the age of the containing beachridge sand sequence. Thus the sands under the beachridge complex at this study site appear to have commenced accumulation by c. 7000 yr BP.

Lobate fluvial delta complex

The lobate fluvial delta is the combined delta system of the Serpentine and Murray rivers. Although the delta is a high-constructive lobate type (Fisher *et al.* 1969), wave reworking of the shore has resulted in shore-parallel, low beachridges, separated by inter-ridge swales and flats. The Murray River is the dominant system for transporting sediment and constructing the delta. There is a large deltaic plain adjoining the main channel and distributary channels (Fig. 1F), and this has been subdivided by Semeniuk & Semeniuk (1990) into abandoned channels, levees, lakes (former, abandoned inter-distributary basins), flats, basins, ridges and hummock/swale system (degraded levee system). The stratigraphy of the deltaic plain is variable and complex, depending on formative environment, history, and age of particular units. There are interlayered sheets, lenses and shoestrings of various grain sizes of sand, muddy sand, sandy mud, mud, and at depth, coarse river gravel and gravelly coarse sand (Transect 5, Fig. 2).

Sample 28, comprised of estuarine shells from mud filling an abandoned channel cut into fluvial sands, gave an age of c. 6000 yr BP. This indicates that the bulk of the fluvial system was emplaced prior to that time.

Discussion

The results of this paper are discussed below in terms of 1) evaluation of the radiocarbon dates, 2) variability of ages of shore types, 3) the chronology of some shore types, and 4) the sealevel history recorded in this area.

Evaluation of radiocarbon dates

Many of the shells used in this study are whole and unfragmented *Sanguinolaria biradiata*. In modern estuarine environments such shells usually are rapidly fragmented if transported and reworked, or fragmented by burrowing crustaceans if they are not buried relatively soon after death (Semeniuk MS). In many of the horizons sampled during this study, these shells were found articulated, and some are found *in situ* in the living position. These factors suggest that the shells of *Sanguinolaria biradiata* are not reworked from older deposits, and that they would provide reasonable radiocarbon dates for the containing sediment.

Shells of *Katelysia scalarina* that occur in association with *Sanguinolaria biradiata* also were collected and dated and provided radiocarbon dates that were generally similar to *Sanguinolaria biradiata*, implying again that there has been little or no reworking of these shells. *In situ* shells of oysters and chamiids that are encrusting limestone pinnacles and islands provide direct evidence of the lack of reworking of these encrusting benthos. The lenses of peat and peaty sand within the beachridge sequences also provide direct evidence of *in situ* accumulations.

Only the mixed shell assemblages in this study are potentially problematical as to whether they are reworked accumulations (ie, mixtures of autochthonous shell and extraneous older shell) or reasonably autochthonous accumulations composed of biogenically fragmented shell. Six samples of mixed shell were used in this study. Five of the mixed shell samples (samples 7, 16, 21, 22 and 28) are wholly within the estuarine sediment sequence. The results from these mixed shell samples (Fig. 2) indicate that the radiocarbon date that each returned is in general agreement with the trends and patterns of the isochrons, and depth below AHD, as determined by the other monospecific and/or encrusting shell material described above. For instance, compare the results of the mixed shell sample 7 with the trends determined by monospecific shell samples 2, 3 and 6 in transect 2.

The sixth sample, sample 19, was comprised of shell fragments resting directly on the unconformity surface cut into fossiliferous Pleistocene limestone. The sample returned an age of c 12500 yr BP for the unconformity surface that has been dated by samples 10, 11 and 12 as c 5400-6600 yr BP. It appears, therefore, that sample 19 is a mixture of fragmented Holocene shell and remanie fossil grit reworked from the underlying Pleistocene limestone.

Variability of ages of the shore types

A wide range of shore types comprise the Peel-Harvey estuarine system, and these coastal landforms are of various ages. Some began forming as early as c. 7000 yr BP, when the sea first flooded the estuary. Other landforms are relatively young, ie, less than 1000 yr BP. Clearly the development of the coastal landforms, and hence the associated wetlands and their vegetation have not formed synchronously throughout the estuary. Some of the features are long term relict, formed with relative sealevel at higher positions, while others are comparatively recent. The ages of some of the Holocene deposits at the various study sites imply antiquity for some of the estuarine coastal landforms. That is, some of the coastal landforms may in fact be older, relict features, with very little accumulation and landform development occurring today (eg, the stranded channel shoal complex and the relict tidal delta). Some of the landforms may be pre-Holocene; for instance, the age of c. 6000 yr BP for deposits filling channels incised into fluvial facies of the lobate delta imply that the fluvial deposits may have been emplaced before Holocene sealevels reached their present position. Further research, however, is required to support this hypothesis, and will be reported in future studies.

Chronology of some shore types

This paper provides chronological reconstructions for estuarine stratigraphic sequences for the first time in Western Australia, and provides information on the pattern of sedimentary accretion in channel-shoal and tidal-delta settings. Where data are available, the chronology of the estuarine channel shoal and tidal delta accumulations suggests that a large component of their accretion involved upward shoaling, rather than lateral progradation. Beachridge sequences, on the other hand, exhibit by their geomorphology clear evidence of accretion by lateral progradation. The data also show that the sequences accrete sediment relatively rapidly, ie 4-8 m in 4000 years.

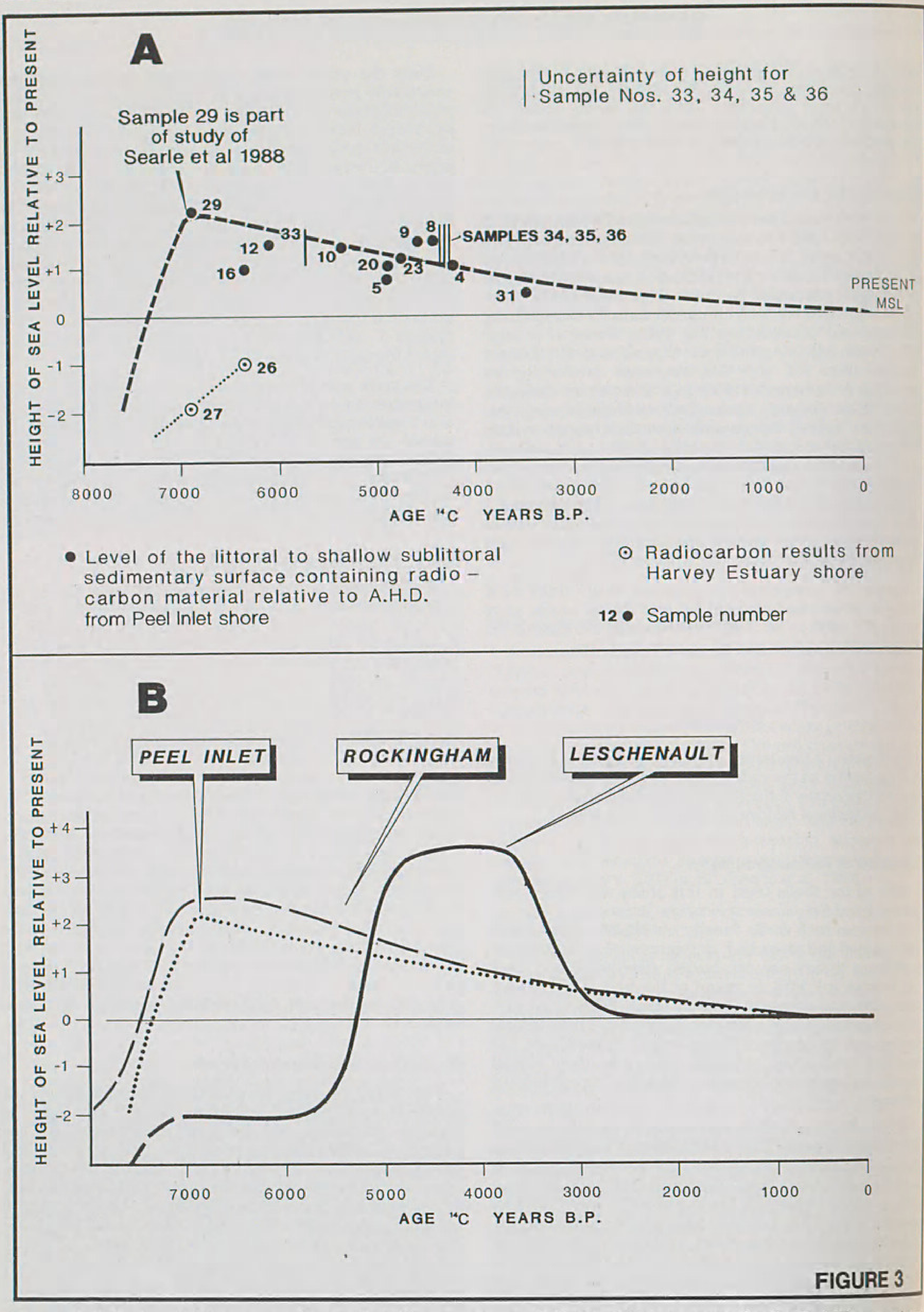

Figure 3 **A** Sealevel history curve for the Peel-Harvey estuary. **B** Sealevel history curve for the Peel-Harvey estuary compared to sealevel history of the Leschenault Peninsula and Rockingham-Becher areas (after Semeniuk & Searle 1986). Note that the curve from Searle *et al.* 1988 has had the reservoir correction factor removed to make it comparable with the curves of this study and with Semeniuk 1985. The radiocarbon results of Semeniuk 1985 had not been corrected by Semeniuk for oceanic reservoir effects because that study too was based mainly on estuarine shell.

Sealevel history

Sealevel history recorded in this area shows that in southern parts of the estuary, in the Harvey Estuary system, relative sealevel stood at 1-2 m *below* present MSL some 6400 and 7000 yr BP. The position of relative sealevel at this time is similar to that recorded in the Leschenault Peninsula barrier dune system (Semeniuk 1985). However, in the north of the estuarine system, ie in Peel Inlet, around 7000 to 6100 yr BP, and later, relative sealevel stood about 1.5-2 m *above* present. The position of relative sealevel at this time is similar to that recorded in the Rockingham-Becher beachridge plain (Searle *et al*. 1988). The other radiocarbon ages and sealevel indicators obtained from the northern estuary settings appear to conform to a falling sealevel curve from c. 6500 yr BP to the present. The resultant curve is similar to the established sealevel history curve for the Rockingham-Becher area (Fig. 3), but not similar to those for the Leschenault Peninsula (Semeniuk 1985) and Rottnest Island (Playford 1988). The results above suggest that the tectonic factors invoked to explain marked variation in sealevel history along the southwestern Australian coast (Semeniuk & Searle 1986) may also explain the variation of relative sealevel history in the Peel-Harvey estuarine system. On this basis, at this stage, it would seem preferable to construct sealevel history curves separately for the Peel Inlet sequences and the Harvey Estuary sequences.

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