Journal of the Royal Society of Western Australia, 94: 151–160, 2011

King Sound and the tide-dominated delta of the Fitzroy River: their geoheritage values

V Semeniuk[1] & M Brocx[2]

[1] V & C Semeniuk Research Group
21 Glenmere Rd, Warwick, WA 6024

[2] Department of Environmental Science, Murdoch University,
South St, Murdoch, WA 6150

Manuscript received November 2010; accepted April 2011

Abstract

There are numerous geological and geomorphic features in King Sound and the tide-dominated delta of the Fitzroy River that are of International to National geoheritage significance. Set in a tropical semiarid climate, the delta of the Fitzroy River has the largest tidal range of any tide-dominated delta in the World. Within King Sound, the Quaternary stratigraphy, comprised of early Holocene gulf-filling mud formed under mangrove cover and followed by middle to late Holocene deltaic sedimentation, and the relationship between Pleistocene linear desert dunes and Holocene tidal flat sediment are globally unique and provide important stratigraphic and climate history models. The principles of erosion, where sheet, cliff and tidal creek erosion combine to develop tidal landscapes and influence (mangrove) ecological responses also provide a unique global classroom for such processes. The high tidal parts of the deltaic system are muddy salt flats with groundwater salinity ranging up to hypersaline. Responding to this, carbonate nodules of various mineralogy are precipitated. Locally, linear sand dunes discharge freshwater into the hypersaline salt flats. With erosion, there is widespread exposure along creek banks and low tidal flats of Holocene and Pleistocene stratigraphy, and development of spits and cheniers in specific portions of the coast.

Keywords: King Sound, tide-dominated delta, Fitzroy River delta, tropical climate, geoheritage.

Introduction

King Sound and the tide-dominated delta of the Fitzroy River (Fig. 1) present a unique location globally. The region has one of the largest tide ranges in the World, resides in a tropical monsoonal semiarid climate, hosts the one of the few large tide-dominated deltas, and globally records one of the most complicated stratigraphic sequences for tidal flats. Moreover, in comparison to broadly similar other delta settings or funnel-shaped sedimentary accumulations elsewhere, King Sound and its tide-dominated delta are largely in a wilderness setting.

While the Fitzroy, May, and Meda rivers contribute to the development of tide-dominated deltas in King Sound and Stokes Bay, this paper is an account of King Sound and focuses on the tide-dominated delta of the Fitzroy River, with a description of the coastal forms in the gulf, the reasons underpinning the development of the various coastal types and patterns of sedimentation, and the geoheritage significance of the gulf and delta.

The principles and theory underpinning geoheritage, the scope and scale of features of geoheritage significance, the levels of significance afforded to geoheritage sites, coastal classification in relation to geoheritage, and methods of inventory-based site-identification and assessment have been discussed in Brocx (2008) and Brocx & Semeniuk (2007, 2010a, 2010b) and the reader is referred to those works. This paper is based on the studies undertaken by Semeniuk (1980a, 1980b, 1980c, 1982, 1983, 1993), with application of geoheritage principles undertaken by Brocx & Semeniuk (2010b).

A description of King Sound and the delta of the Fitzroy River

The depositional system of King Sound and Stokes Bay wherein occur the deltas of the Fitzroy River, May River and Meda River has been determined by the geological grain of the region (Brocx & Semeniuk 2011). The lithological trends, fold trends, faults, and boundary between the various geological units, such as between Precambrian rock massif and Phanerozoic rocks, and those within the Phanerozoic sequences, have been selectively eroded to form the major valley tracts of these rivers. The southern margins of the Precambrian massif also have been incised by short rivers that form tributaries and deliver sediment to these larger rivers. As such, King Sound and Stokes Bay have been partly filled with sediments at their proximal portions with voluminous sediment delivered from these drainage basins (Semeniuk 2011).

In terms of geological setting, King Sound resides at the boundary of the Kimberley Region and Canning Basin (*cf*. Brocx & Semeniuk 2011). Precambrian rocks form the boundary of the depositional system to the north. A peninsula of Mesozoic rocks (the Dampier

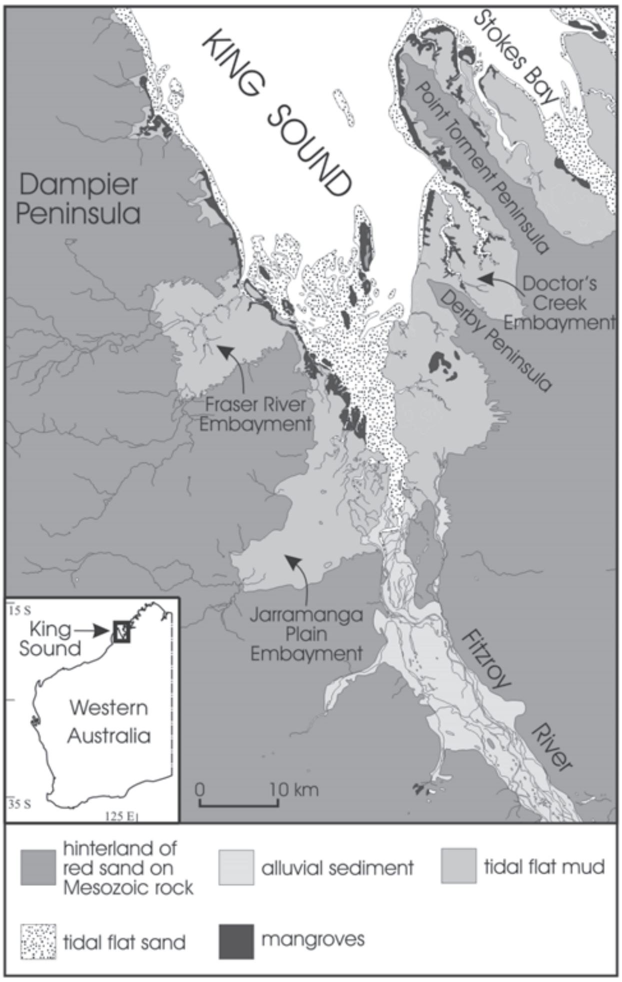

Figure 1. Location map showing King Sound and the tide-dominated delta of the Fitzroy River.

Peninsula underlain mainly by Broome Sandstone) borders the depositional system to the west. A smaller peninsula of Mesozoic rock, the Point Torment Peninsula, internally partitions King Sound in its southern part into two gulfs (King Sound proper, and Stokes Bay). Both terrains of Mesozoic rock are mantled by weathered sandstone, ferruginised sandstone, and Quaternary red sand dunes (Mowanjum Sand).

The greater King Sound is longitudinally partitioned into western and eastern sub-basins by the NW-trending peninsulae of Mesozoic rock (the Point Torment Peninsula and the Derby Peninsula). Though western King Sound is now funnel-shaped, as defined by the contour of MSL, its pre-Holocene shape was more irregular, with a number of embayments to its south. There were/are subsidiary lobate to rectangular to digitate smaller sub-basins such as the Jarrananga Plain embayment, Fraser River embayment, and the Doctors Creek embayment, and were/are sites of relative protection/shelter. In finer detail, the margins of King Sound are crenulate at the scale of 100–200 m because the edge of the funnel-shaped system is demarcated by east-west oriented linear dunes. This crenulate pattern resulted in smaller scale basins of sedimentation located in the inter-dune depressions, which also were sites that were relatively protected/sheltered. In terms of coastal classification of Brocx & Semeniuk (2010a) it is Coastal Type 7, *i.e.*, landforms constructed by Holocene coastal sedimentary processes that have superimposed erosional features.

Within the depression of King Sound there is a variable Quaternary stratigraphy (Semeniuk 1980c). The sequence consists of Pleistocene Mowanjum Sand (the red sand unit), the Airport Creek Formation (a partially cemented Pleistocene tidal flat unit), the Double Nob Formation (a Pleistocene palaeosol), and the Holocene units of Christine Point Clay (an early Holocene grey mud formed under mangrove cover) and the Doctors Creek Formation (a shoaling sequence of tidal sand to muddy sand and interlayered mud and sand to mud formed in the latter Holocene). Holocene sedimentation and erosion in King Sound followed several basin-filling and erosional episodes (Fig. 2):

1. with rising sea level after the last glacial period, there was an extensive reworking of fine-grained sediment in the region and its shoreward transport, leading to filling of the southern parts of the King Sound embayment and its sub-basins with (mangrove-inhabited) mud, resulting in the accumulation of the Christine Point Clay some 7000 years ago, followed by an erosional episode;

2. in the middle to latter Holocene, deltaic sedimentation resulted in a sedimentary lobe comprised of a sand-to-mud shoaling tidal sediment sequence, capped by (mangrove-inhabited) mud, with delta-land accretion progressing from south to north; the deltaic landscape was dominated by tidally-oriented shoals whose internal stratigraphy is a basal sand to mud sequence; the leading edge of this accreting lobe comprises sand shoals of the interior of King Sound that form the stratigraphically basal sand of the deltaic sequence, and proximal parts of this accreting lobe are the sand-to-mud tidal sequences capped by alluvial sediments that occur to the south of King Sound;

3. concomitant with deltaic accumulation, mud in suspension was delivered beyond the northern margin of the accreting delta (as delineated by the basal sand) to the central and northern parts of King Sound, in advance of the accreting edge of the delta; this mud accumulated in the various relatively protected smaller sub-basins; these accumulations can be considered to be the distal parts of the delta and equivalent to prodelta muds in classic delta sedimentary patterns;

4. throughout this history, the Fitzroy River deposited subaerial floodplain sediments that filled the alluvial valley tract in southern parts of King Sound; these cap the deltaic sediment sequence.

In addition, with erosion cutting into linear dunes along middle to northern margins of King Sound, various spits and cheniers were formed from the eroding tips of the dunes (Jennings & Coventry 1973; Semeniuk 1982). Cheniers also developed on the eroding northern extremity of the central peninsula that faces wind waves, swell, and cyclones.

The delta of the Fitzroy River is a classic tide-dominated delta. The landforms comprise tidally oriented shoals and tidally oriented inter-shoal channel ways. The sequence of sand to mud is also classically deltaic (Morgan 1970) though the difference between the delta of the Fitzroy River and other tide-dominated deltas

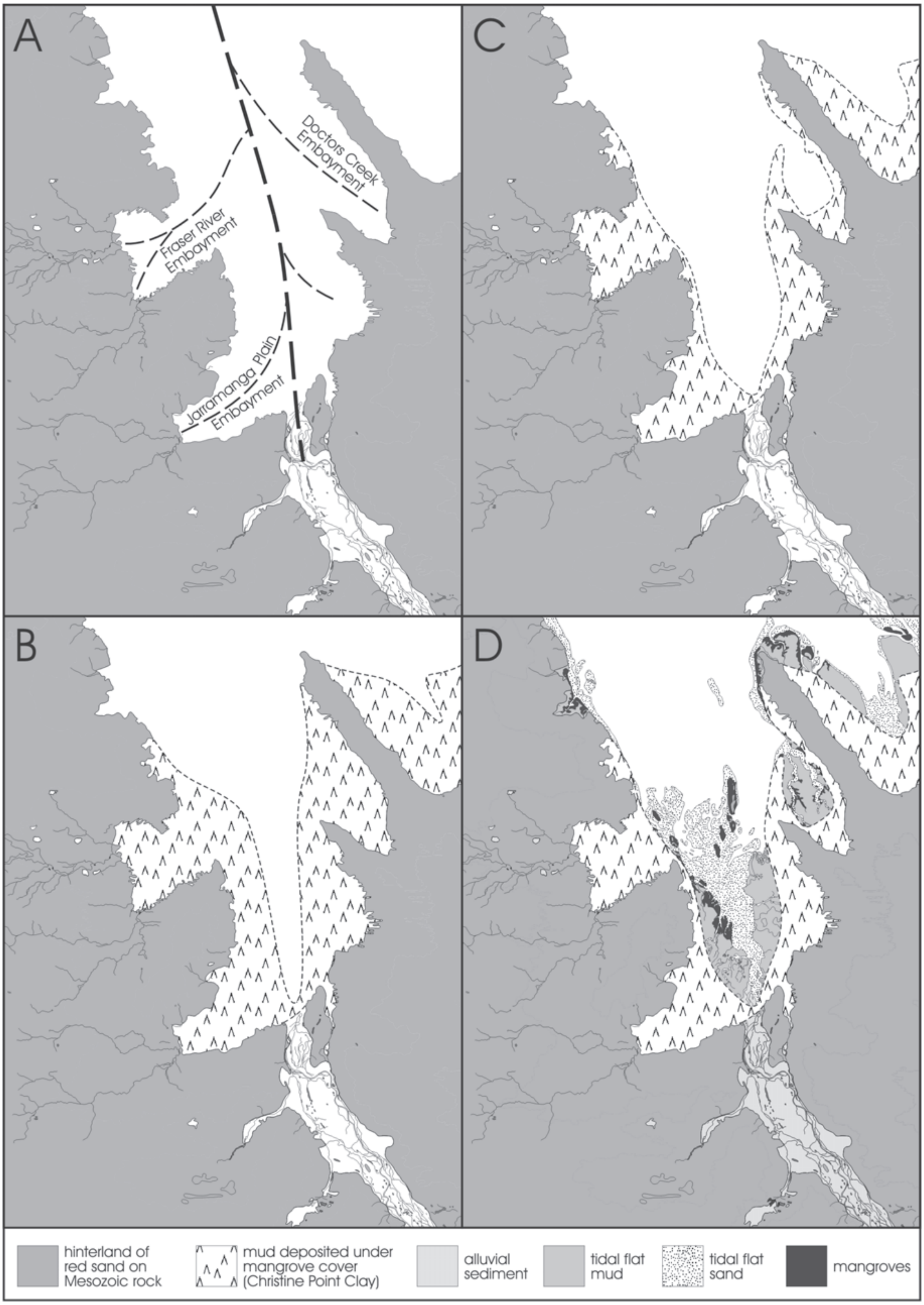

Figure 2. Palaeogeography of the early Holocene King Sound depression and the progressive filling of the gulf with sediments. A. Pre-Holocene and early Holocene palaeogeography showing the course of the Fitzroy River, and subsidiary drainage basins (these subsidiary drainage basins become sub-embayments during the Holocene marine flooding of the area). B. With the Holocene transgression 7000 years ago, southern King Sound was preferentially filled with tidal flat mud (under mangrove cover) forming the Christine Point Clay. C. A major erosional episode followed, resulting in the scouring of the Christine Point Clay. D. On-going deltaic deposition filling the central King Sound depression and the erosional scours cut into the Christine Point Clay, with erosion becoming more dominant in the latest Holocene.

is that it is framed within a bedrock basin and thus was semi-enclosed, whereas other such deltas are open to the sea (*e.g.*, the delta of the Ganges-Brahmaputra Rivers).

The geomorphology of the tidal flats today consists of wide low-tidal flats, underlain by sand or by pavements of partially cemented Pleistocene sediments, followed upslope in turn by narrow mid-tidal flats underlain by Christine Point Clay (with exposure of fossil mangrove stumps) or by modern mangrove-vegetated tidal mud, and extensive high tidal salt flats. Ramifying and meandering across the salt flats are tidal creek networks ranging in width from centimetres to hundreds of metres, and extending in length from tens of centimetres to several kilometres. Tidal creek geomorphology dominates the high tidal flats of King Sound, and is the determinant of tidal landforms (see later). Tidal creek erosion has been a long-term process (Jennings 1975; Semeniuk 1980b, 1982) based on stratigraphic and aerial photographic evidence. Several other features reinforce the conclusions about erosion: nodules under the tidal flats; the imprint of (supratidal) vegetation roots on the substrate; and dieback of modern strandline terrestrial vegetation. The dominantly erosive nature of King Sound results in excellent exposures of Quaternary stratigraphy. Low tidal flats and lower banks of deeply incised tidal creeks expose the Airport Creek Formation, the Double Nob Formation, and the Christine Point Clay and their inter-relationships. Deeply incised tidal creeks exposure the Christine Point Clay and overlying Doctors Creek Formation, and their inter-relationships.

Extensive areas of salt flat in surface layers are riddled with fine rootlet structures that are *unlike* the coarse root structures of mangrove environments. The modern analogue for fine rootlets are grasses on supratidal grassy plains. Such grasses have long since retreated from areas of the now salt flat, but the rootlet structures record the former supratidal conditions, showing that the present salt flats have been developed by sheet erosion of supratidal flats.

Over the Holocene there has been alternating episodes of sedimentation and erosion, with deposition of Christine Point Clay in the early Holocene (some 7000 years ago), followed by its large scale scouring, followed by deposition of a shoaling tidal flat sediments of the Doctors Creek Formation, and then the present phase of large scale net erosion, with cliff, tidal creek, and sheet erosion(Semeniuk 1980b, 1982). This erosion provide a global classroom of such processes on macrotidal tidal flats. In fact, the tidal landscapes of King Sound largely have been determined by tidal erosion, and in particular tidal creek erosion.

Tidal creeks begin their history in crevices of mud cracks and in time deepen, widen and extend their headwaters to landward, progressively evolving to become large and deep meandering systems (Fig. 3). The array of mud cracks coupled with the tidal flat slope generates meandering channels which become entrenched and remain fixed in form through all stages of creek growth. Creeks continue to deepen/widen until the floor is deep enough to intersect the permanently waterlogged muds or sands at a depth where slumping is initiated, and there is a more rapid widening and deepening of the channels; creek cross-sections then change from a shallow v-shape to a deeper u-shape. Thereafter, erosion is rapid, and creeks widen and deepen in time to form major tidal creek networks the size of Doctors Creek (stage 6 in Figure 3).

Across the tidal flats, groundwater increases in salinity from ~ 40,000 ppm at MSL to ~ 240,000 ppm near the upper edge of salt flats. This salinity gradient transcends various mineral precipitation fields: carbonate is precipitating under tidal flats above MHWS, and gypsum is precipitating under tidal flats further upslope. Nodules of Mg-calcite, aragonite, dolomite, calcite (or their mixtures), often nucleated on crustacean skeletons, such as *Thalassina anomala* and *Uca*, are imbedded in Holocene formations and related to the hypersaline groundwater. Nodules precipitated from hypersaline groundwater within Holocene formations can indicate the extent erosion has proceeded as such nodules, originally formed under salt flats, are being exhumed along seacliffs forming gravel lags.

Fairbridge (1961) identified an important climatic and stratigraphic relationship of Quaternary red sand dunes bordering/underlying the Holocene tidal flat deposits, best developed on the western edge of the Doctors Creek embayment. Later, Jennings (1975) investigated the relationship of these red dunes to the tidal flat deposits, describing the history of the Holocene transgression into the dunes. In the light of the works of Fairbridge (1961) and Jennings (1975), this area has become known internationally and is of International geoheritage significance. It will continue to be a site of stratigraphic and climatic research, as the basic work carried out by those authors is re-explored, refined, and amplified. The red sand dunes descending stratigraphically below tidal flat sediments also provide conduits for freshwater seepage that discharges under the salt flats, *e.g.*, Jennings (1975) documented "dune ghosts" of vegetation surrounded by vegetation-free hypersaline salt flats, and Semeniuk (1980a) documented groundwater salinity diluted by this seepage within buried fingers of dune sand under the salt flats.

The erosional patterns in King Sound influence mangroves ecology and zonation, with different mangrove responses related to cliff, sheet and tidal creek erosion, providing a model of coastal erosion and its relationship to mangrove habitats (Semeniuk 1980a, 1980b). While globally most mangrove areas are viewed as sites where mangrove habitation is linked to coastal accretion, King Sound was the first location where coastal erosion and mangrove ecology were described to provide insight into coastal erosion and mangrove responses. As such it stands as a global classroom for mangrove ecology in relationship to macrotidal coastal erosion (geomorphic geodiversity).

The King Sound area hosts several stratigraphic type sections (Semeniuk 1980c), *viz.*, Mowanjum Sand, Airport Creek Formation, Double Nob Formation, Christine Point Clay, and Doctors Creek Formation (Fig. 4). The Doctors Creek embayment, as the stratigraphic type section for the Christine Point Clay (Semeniuk 1980c) at Christine Point, is the most southern occurrence of the sedimentary unit known as the "Big Swamp" complex of Woodroffe *et al*. (1985) and is an important Holocene climate, stratigraphic, and sedimentologic unit. The "Big Swamp" phase of northern Australia records an early Holocene history of rapid sedimentation, with large mangrove

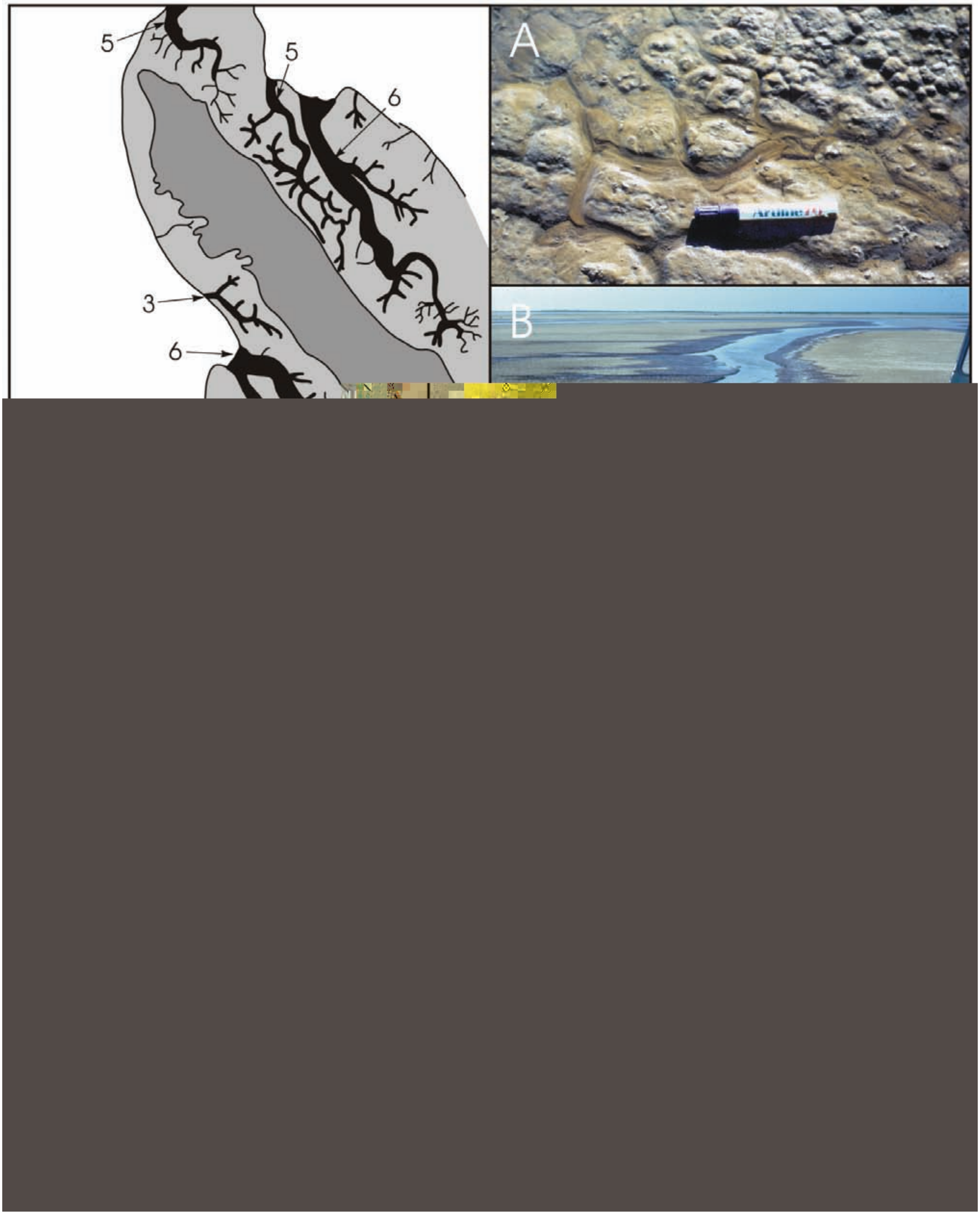

Figure 3. Tidal creek erosion leading to various sizes of creeks in King Sound (after Semeniuk 1980b). Images (A) to (F) show the gradation from creek initation in mud cracks to large scale meandering creeks; ruler for scale in 'C' is 30 cm. The numbers refer to representative examples of the stages of tidal creek development by widening, deepening and lengthening as described by Semeniuk (1980b) with 1 = the smallest creek and 6 = the largest creek.

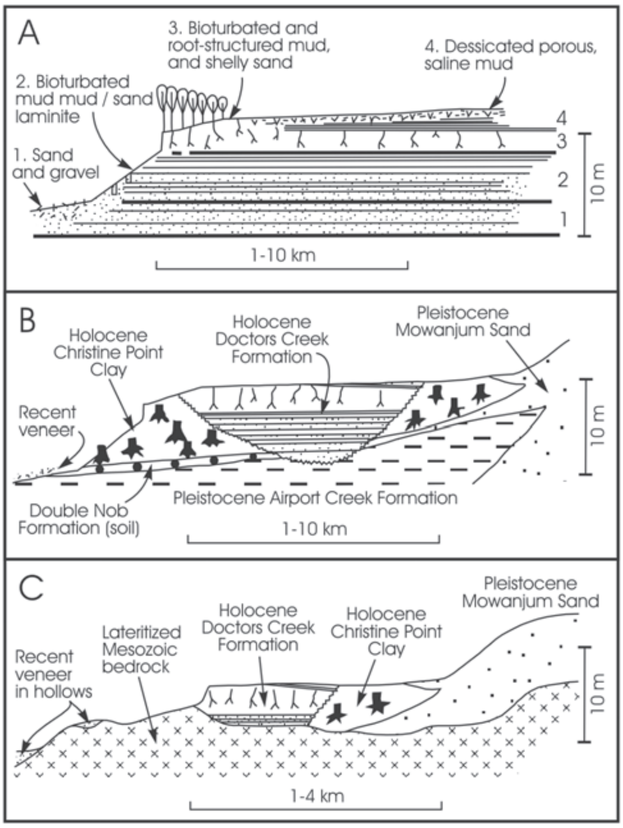

Figure 4. Stratigraphic cross-sections of the tidal flats in southern to central King Sound. A. Doctors Creek Formation of sand-to-mud shoaling stratigraphy. B. Doctors Creek Formation occurring in scours cut into the Christine Point Clay. C. Erosion of Mowanjum Sand to form spits/cheniers, and high-level (truncated) occurrence of Christine Point Clay.

forests, and humid climate, unlike that occurring today in the region. Embedded in this stratigraphic unit at Christine Point, therefore, is the history of this part of Australia in terms of sedimentation style, sedimentation rates, mangrove ecology, and climate.

The geoheritage essentials of King Sound and the delta of the Fitzroy River

From a consideration of the geology and geomorphology of King Sound, the features comprising its "geoheritage essentials" are listed in Table 1. The key features of geology and geomorphology are described in Table 2 with respect to their main characteristics, category of geoheritage site, classification of coast, the scale of the feature, and its level of significance (following Brocx & Semeniuk 2007, 2010a). Many sites of geoheritage significance in King Sound also have cultural significance to the Traditional Owners (*e.g.*, coastal freshwater springs, coastal ecology linked to landscape). It is beyond the scope of this paper to identify such sites and we do not consider that it our place as Western scientists to identify such areas. However, many of the areas assigned below to specific geoheritage categories from an Earth Science perspective could additionally be assigned to one of Cultural Significance by the Traditional Owners of the region.

Table 1

Geoheritage essentials of the King Sound and the Fitzroy River delta
i.e., features of geoheritage significance

tide-dominated delta of the Fitzroy River
principles of erosion (tidal creek erosion and formation of tidal landscapes)
carbonate nodules
Holocene stratigraphy
relationship between Pleistocene linear dunes and Holocene tidal flat sediment
Holocene stratigraphy at Christine Point
Pleistocene stratigraphy
exposure of Holocene mangrove stumps
spits and cheniers
mangroves in response to coastal development
freshwater seepage
stratigraphic type sections

A comparison of the delta of the Fitzroy River with other tide-dominated deltas and macrotidal sedimentary systems

King Sound and its tide-dominated delta are compared with other macrotidal locations globally that have maximum tidal ranges > 10 m (Table 3). King Sound is ranked within the first seven sites globally, but it is clear that it has the largest macrotidal tide-dominated delta in the World. These macrotidal areas are described briefly in terms of their characteristics of climate setting, geomorphic setting, tidal ranges, and occurrence of mangroves. The occurrence of mangroves is noted because they can be an integral part of sedimentation and sedimentary facies, and in King Sound they develop a thick diagnostic lithofacies and the species richness form a rich biostratigraphy not present in sites such as Bhavnagar.

Macrotidal areas that occur in high latitudes lack mangroves and usually have samphires in the upper tidal zone. The estuary of the Sabarmati and the Mahi at Bhavnagar in India is the only other funnel-shaped embayment in a tropical environment that has extreme tidal range. This embayment, however, is an estuary, and it lacks the wide salt flats comparable to King Sound. Further, it is markedly altered by anthropogenic land uses (it is not in a pristine state).

There are numerous other macrotidal estuaries, deltas and tidal flat systems with tidal ranges > 5 m (but generally < 8 m) that do not support mangroves (*e.g.*, the Colorado River Delta; Thompson 1968) – these are not dealt with further here. It should be noted that Bhavnagar, King Sound, and Broome are the only macrotidal systems listed in Table 3 that have mangroves. A comparison of the mangrove-vegetated tide-dominated delta of the Fitzroy River and King Sound with other tide-dominated deltas and other funnel embayment filling sediments systems also shows that the King Sound system is globally unique. Though macrotidal, the Bay of Fundy, The Wash and The Thames (U.K.) are not deltaic, being either tidal embayments or estuarine in terms of sedimentation (Klein 1963; Evans 1965; Yeo & Risk 1981; Prentice 1972). The Klang-Langat delta (Coleman *et al*. 1970) and the combined deltas of

Table 2

Features of geoheritage significance in King Sound and the tide-dominated delta of the Fitzroy River, and the rationale for their assessment

Geological feature	Type of site[1], and its scale	Significance	Rationale for assigning the level of significance
tide-dominated delta of the Fitzroy River	modern landscapes and setting (active processes); megascale	International	geomorphic, sedimentologic and stratigraphic description of a tide-dominated delta in a tropical semiarid climate; this is a tide-dominated delta globally with the largest tide
principles of erosion	modern landscapes and setting (active processes); leptoscale to macroscale	International	tidal creek erosion and formation of tidal landscapes provides an international model of coastal development in a tropical, macrotidal environment, particularly in the transition of the small scale to the large scale which provides a powerful natural laboratory
mangroves in response to coastal development	modern landscapes and setting (active processes); mesoscale to macroscale	International	an example of geodiversity where landscape evolution determines mangrove response
carbonate nodules	modern landscapes and setting (active processes); microscale	International	first description of the variety of Holocene carbonate nodules under tropical tidal flats; sets a standard as a type location for Holocene carbonate nodules under tidal flats
Holocene stratigraphy	geohistorical site; mesoscale to macroscale	International	one of the most stratigraphically complex tidal flat systems in the world and also unique because of its tropical and macrotidal setting; well exposed along Airport Creek
Pleistocene linear dunes and Holocene tidal flat sediment	geohistorical site; mesoscale	International	important site for stratigraphic relationship of Quaternary tidal sediments and linear desert dunes, for the model of coastal geomorphic adjustments with sea level rise, and climatic history
Holocene stratigraphy at Christine Point	geohistorical site; mesoscale to macroscale	National	the most southern occurrence of the deposits of the "Big Swamp" phase of the early Holocene of sedimentation in northern Australia and an important indication of climate history and fossil mangrove biogeography
Pleistocene stratigraphy	geohistorical site; mesoscale to macroscale	National	first and only description to date nationally of Pleistocene tidal flat stratigraphy; an important record of Pleistocene climate history, sedimentation, and diagenesis
Holocene mangrove stumps	geohistorical site; microscale to mesoscale	National	outcrop of fossil mangrove stumps embedded *in situ* in grey clay, extending to below MSL
spits and cheniers	geohistorical site and modern landscapes and setting (active processes); mesoscale to macroscale	National	response of linear dunes to coastal erosion and the effect of coastal process on the exposed northern tip of the Point Torment Peninsula
freshwater seepage	modern landscapes and setting (active processes); mesoscale	National	example of coastal freshwater seepage from dune sand aquifer that has been onlapped by tidal flat sediments
stratigraphic type sections	reference sites; mesoscale	State-wide/ Regional	the area contains a number of stratigraphic type sections

[1] category of site from Brocx & Semeniuk 2007

Table 3

Seven of the largest macrotidal systems globally listed in decreasing order of tidal range

Location	Climate	Geomorphic setting	Max. tidal range (m)	Mangroves
Bay of Fundy (Nova Scotia)	Temperate	rectangular embayment	17.0	none
Mont St Michel (France)	Temperate	funnel-shaped estuary	15.3	none
Severn Estuary (U.K.)	Temperate	funnel-shaped estuary of the Severn	14.6	none
Puerto Gallegos (Argentina)	Temperate	funnel-shaped estuary of Gallegos	13.2	none
Bhavnagar (India)	Tropical semi-arid	funnel-shaped estuary of the Sabarmati and the Mahi	12.2	1 species
King Sound (Australia)	Tropical semi-arid	gulf with tide-dominated delta of Fitzroy River	11.5	11 species
Broome (Australia)	Tropical semi-arid	carbonate-mud tidal embayment	10.5	12 species

(Australian tides from Anonymous 1996; other tidal information from Yeo & Risk 1981; Admiralty Chart 2010; Allen 1970; Knight & Dalrymple 1975; Lasonneur 1975)

the Ganges-Brahmaputra Rivers (Allison 1996) are tropical deltas with dense mangroves (where still intact, though much of the terrain is anthropogenically altered) but with tidal ranges of ~ 4 m. The deltas of the Ganges-Brahmaputra Rivers are particularly interesting as a comparison because they are tide-dominated but open to the sea, and not land-locked like those of the Fitzroy River and Colorado River. The tide-dominated delta of the Yangtze River (Xiqing 1996) is in a subtropical climate and is mesotidal.

The nearest equivalents of King Sound in terms of gulf form and tide-dominated delta of King Sound are the Colorado River delta (Thompson 1968) and Cambridge Gulf, Western Australia (Thom *et al*. 1975). The Colorado River delta is broadly similar to the tide-dominated deltas of both King Sound and Cambridge Gulf in that it is in a semi-arid climate, manifests salt flats, and is of comparable size. However, it is dissimilar in that it is mangrove-free (and hence lacks the mangrove-generated lithofacies), has a smaller tidal range, mud dominates its stratigraphy, and doesn't contain the complex Holocene stratigraphy of the King Sound area. Cambridge Gulf is broadly similar in form to King Sound and also hosts a tide-dominated delta, but its tidal range is 8.4 m, and it has a completely different geological setting (*i.e*., without linear dunes), being bordered by relatively high-relief landforms of Precambrian and Palaeozoic rocks, and lacks the basal sand that is characteristic of the Fitzroy River delta, *i.e*., it is a mud-dominated system.

Discussion and conclusions

Microtidal regimes are numerous across the globe (for instance, the well documented systems along the North Sea coast, and the mangrove-vegetated coast of Florida), and they have provided an abundance of sedimentary and ecological/palaeoecologic models for use in Earth-science history in the stratigraphic record. Macrotidal systems are not so abundant, and so any macrotidal system, even if solely a sedimentary system provides important Holocene analogs for the stratigraphic record (Allen 1970; Thompson 1968). In this context, it is important to note that each of the macrotidal systems located around the globe, such as King Sound, Mont St Michel, the Bay of Fundy, and Broome, provide a different pattern of sedimentation useful to the interpretation of the ancient stratigraphic record (Ginsburg 1975; Semeniuk 2005).

The tide-dominated delta of the Fitzroy River is the only delta globally that is extreme macrotidal and set in a tropical species-rich mangrove biogeographic zone. As such, in terms of geoheritage, it is globally significant. The sediment assemblages of this delta also are globally distinct. Semeniuk (2005) compared stratigraphic sequences from tidal flats around the World with that of the tide-dominated delta of the Fitzroy River – the latter was globally unique in terms of thickness of lithofacies (as related to tidal range), sequence of lithology, and details of lithology. Further, with the occurrence of the early Holocene Christine Point Clay, its scouring and burial with later Holocene deltaic and tidal flat sediments, King Sound manifests the most complex tidal flat stratigraphy recorded to date globally.

As noted in the description of the geoheritage essentials in this paper, there are numerous other geological and geomorphological aspects of the King Sound area that are of geoheritage significance as examples of modern processes operating in tidal environments. King Sound provides a model of tidal landscape development under processes of sheet, cliff and tidal creek erosion, and the development of habitats for mangroves deriving from these processes. Within the stratigraphy and sediments resides information on sedimentation patterns driven by rising post-glacial sea levels, climate changes, and the dynamics of deltaic sedimentation and geomorphic change (Jennings 1975; Semeniuk 1980a, 1980b, 1980c). Within the stratigraphy resides information on Pleistocene aridity during glacial periods and Quaternary coastal sedimentation during inter-glacial periods, and their inter-relationship. The tidal flats also provide a global model for carbonate nodule development, a feature that is often documented in fossil sequences but not in modern environments (*cf*. Semeniuk 2010). The range of carbonate nodules nucleating on Holocene fossils, and the hydrochemistry underpinning these features are a natural laboratory for unravelling the processes of nodule development, their mineralogy, and environmental setting that would be useful in studies of ancient stratigraphic sequences.

One of the most important aspects of the King Sound area is the natural laboratory that is embedded in the tidal creek systems geomorphically. For those tidal creeks that are meandering and ramifying, the small scale patterns reflect the large scale patterns, and the small scale patterns are embedded in and control the development of the larger scale forms (Semeniuk 1980b). The small scale creek systems, and all intervening creek sizes, could be viewed as miniatures of the larger scale. This aspect of the scalar and geometric nature of the tidal creek erosion contrasts with other tidal systems in the region (e.g., Broome; cf. Semeniuk 2008), because of the climatic, sedimentologic, and vegetational setting of the King Sound. This scalar and geometric property is a powerful and Internationally significant feature of the area, which will provide important insights into the processes shaping tidal flat forms.

Many of the other macrotidal systems outside Australia, for instance Mont St Michel, and the Bay of Fundy, and the tide-dominated delta of the Ganges-Brahmaputra Rivers are anthropogenically modified, and in this context, the King Sound system with its tide-dominated delta becomes important in that it is pristine, and constitutes a macrotidal-flat wilderness, unique globally as being a terrigenous and erosional system with the largest tide for a tide-dominated delta and tropical mangrove setting.

Acknowledgements: This study is part of VCSRG P/L R&D endeavour registered as Project # 3 & 12 with AusIndustry. Costs of coloured plates were met by VCSRG. Drafting was carried out by CAM Graphics.

References

Admiralty Tide Tables 2011, Admiralty Publications.

Allen J R L 1970 Sediments of the modern Niger Delta: A summary and review. *In*: J. P. Morgan (ed), Deltaic Sedimentation Modern and Ancient, Society of Economic Paleontologists and Mineralogists, Special Publication No. 15, Tulsa, Oklahoma.

Allison M 1996 Geological framework and environmental status of the Ganges-Brahmaputra delta. Journal of Coastal Research 14: 826–836.

Anonymous 1996 Australian National Tide Tables 1996. Australian Government Publishing Service.

Brocx M 2008 Geoheritage: from global perspectives to local principles for conservation and planning. Western Australian Museum, Western Australia.

Brocx M & Semeniuk V 2007 Geoheritage and geoconservation – history, definition, scope and scale. Journal of the Royal Society of Western Australia 90: 53–87.

Brocx M & V Semeniuk 2010a Coastal geoheritage: a hierarchical approach to classifying coastal types as a basis for identifying diversity and sites of significance in Western Australia. Journal of the Royal Society of Western Australia 93: 81–113.

Brocx M & Semeniuk V 2010b A tool-kit for assessing geoheritage values: a case study using the Leschenault Peninsula and its estuarine lagoon, south-western Australia. Proceedings of the Linnean Society of New South Wales.

Brocx M & Semeniuk V 2011 The global geoheritage significance of the Kimberley coast. Journal of the Royal Society of Western Australia 94: 57–88.

Coleman J M, Gagliano S M & Smith W G 1970 Sedimentation in a Malaysian high tide tropical delta. *In*: J. P. Morgan (ed), Deltaic Sedimentation Modern and Ancient, Society of Economic Paleontologists and Mineralogists, Special Publication No. 15, Tulsa, Oklahoma, pp 185–197.

Evans G 1965 Intertidal flat sediments and their environments of deposition in the Wash. Quarterly Journal of the Geological Society of London 121: 209–241.

Fairbridge R W 1961 Eustatic changes in sea level Physics and Chemistry of the Earth, 4: 99–185.

Ginsburg R N (ed) 1975 Tidal Deposits: A Casebook of Recent Examples and Fossil Counterparts, Springer-Verlag, New York..

Jennings J N 1975 Desert dunes and estuarine fill in the Fitzroy estuary North-Western Australia. Catena, 2: 215–262.

Jennings J N & Coventry R J 1973 Structure and texture of a gravelly barrier in the Fitzroy estuary, Western Australia, and the role of mangroves in the short dynamics. Marine Geology, 15: 145–167.

Klein G D 1963 Bay of Fundy intertidal zone sediments. Journal of Sedimentary Petrology 33: 844–854.

Knight J & Dalrymple R W 1975 Intertidal sediments from the south shore of Cobequid Bay, Bay of Fundy, Nova Scotia, Canada. *In*: R. N. Ginsburg (ed), Tidal Deposits: A Casebook of Recent Examples and Fossil Counterparts, Springer-Verlag, New York.

Larsonneur C 1975 Tidal deposits, Mont Saint-Michel Bay, France. *In*: R. N. Ginsburg (ed), Tidal Deposits: A Casebook of Recent Examples and Fossil Counterparts, Springer-Verlag, New York.

Morgan J P 1970 Depositional processes and products in the deltaic environment. *In*: J. P. Morgan (ed), Deltaic Sedimentation Modern and Ancient, Society of Economic Paleontologists and Mineralogists, Special Publication No. 15, Tulsa, Oklahoma, pp 31–47.

Prentice J E 1972 Sedimentation in the inner estuary of the Thames, and its relation to the regional subsidence. Philosophical Transactions of the Royal Society of London. Series A, Mathematical and Physical Sciences 272: 115–119.

Semeniuk V 1980a Mangrove zonation along an eroding coastline in King Sound, north-western Australia. Journal of Ecology. 68; 789–812.

Semeniuk V 1980b Long-term erosion of the tidal flats King Sound, north western Australia. Marine Geology 43: 21–48.

Semeniuk V 1980c Quaternary stratigraphy of the tidal flats, King Sound, Western Australia. Journal of the Royal Society of Western Australia 63: 65–78.

Semeniuk V 1982 Geomorphology and Holocene history of the tidal flats, King Sound, North Western Australia. Journal of the Royal Society of Western Australia 65: 47–68.

Semeniuk V 1983 Regional and local mangrove distribution in Northwestern Australia in relationship to freshwater seepage. Vegetatio 53: 11–31.

Semeniuk V 1993 The mangrove systems of Western Australia: 1993 Presidential Address. Journal of the Royal Society of Western Australia 76: 99–122.

Semeniuk V 2005 Tidal flats. *In*: Schwartz M.L *(ed)* Encyclopaedia of coastal science. Springer.

Semeniuk V 2008 Sedimentation, stratigraphy, biostratigraphy, and Holocene history of the Canning Coast, north-western Australia. Journal of the Royal Society of Western Australia 91: 53–148.

Semeniuk V 2010 A note on calcite precipitates as encrustations around sea rush roots and as microlaminae in high tidal zones of western Leschenault Inlet estuary. Journal of the Royal Society of Western Australia 93: 195–199.

Semeniuk V 2011 Stratigraphic patterns in coastal sediment sequences in the Kimberley region: products of coastal form, oceanographic setting, sediment types, sediment supply, and biogenesis. Journal of the Royal Society of Western Australia 94: 133–150.

Thom B G, Wright L D & Coleman J M 1975 Mangrove ecology and deltaic-estuarine geomorphology: Cambridge Gulf – Ord River, Western Australia. Journal of Ecology 63: 203–232.

Thompson R W 1968 Tidal flat sedimentation on the Colorado River Delta, Northwestern Gulf of California. Geological Society America Memoir 107, 133pp.

Woodroffe C D, Thom B G, & Chappell J 1985 Development of widespread mangrove swamps in mid-Holocene times in northern Australia. Nature 317: 711–713.

Xiqing C 1996 Changjian (Yangtze) River delta, China. Journal of Coastal Research 14: 838–858.

Yeo R K & Risk M J 1981 The sedimentology, stratigraphy, and preservation of intertidal deposits in the Minas Basin System, Bay of Fundy. Journal of Sedimentary Petrology 51: 245–260.