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Beach Rock Ridges/Bands along a High-Energy Coast in Southwestern Australia—Their Significance and Use in Coastal History

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ABSTRACT

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Beach rock is developing under the beach of a retreating barrier in southwestern Australia and is exhumed as the coast erodes. As the barrier retreats, the underlying estuarine sediments are exposed, and exhumed beach rock is left as residuals on the submarine shelf. Consequently it develops a definitive small scale geomorphic unit that reflects its mode of formation and the subsequent coastal history. The resultant geomorphic unit consists of submerged shore-parallel ridges, bands and linear slabs of beach rock separated by ribbons of sand. The usefulness of the beach rock residuals is that they record marked coastal retreat over a relatively short period of the late Holocene. Their configuration provides information about the dynamic nature of a retreating shore and allows a reconstruction of geomorphic history.

ADDITIONAL INDEX WORDS: *Beach rock, coastal erosion, Holocene coastal history, southwestern Australian coast.*

INTRODUCTION

Beach rock, *i.e.* indurated beach sediment, has been documented from a considerable range of tropical and subtropical beach environments (BRICKER, 1971; SCHOLTEN, 1971). Much of the literature is concerned with its origin (KUENEN, 1933; GINSBURG, 1953; MAXWELL, 1962; DAVIES and KINSEY, 1973; HANOR, 1978; HOPLEY and MACKAY, 1978; MOORE and BILLINGS, 1971), its age and rate of formation (FRANKEL, 1968; TACHIBANA and SAKAGUCHI, 1971), the type of cementing agents (KNOX, 1974; FOLK, 1974; TAYLOR and ILLINGS, 1971; MOORE, 1971; TIETZ and MULLER, 1971) and its use as a sea level indicator (LOVELL, 1975; STEARNS, 1974; SCOFFIN, 1977; MCLEAN *et al.*, 1978; HOPLEY, 1980). Some studies also have concentrated on the significance of beach rock either as a component of coastal geomorphology or as a tool useful in reconstructing coastal geomorphic processes (COORAY, 1968; STRASSER and DAVAUD, 1986; ULZEGA *et al.*, 1986; STEFANON, 1969, 1971; STEARNS, 1974; SIESSER, 1974; RUSSELL, 1959).

Cemented sand and shelly sand referable to beach rock is developing under the beach of a retreating barrier in southwestern Australia. This beach rock is exhumed as the coast erodes and consequently it develops a definitive small scale geomorphic unit that reflects its mode of formation and the subsequent coastal history. The resultant geomorphic unit consists of submerged shore-parallel ridges, bands and linear slabs of beach rock separated by ribbons of sand. This paper describes these submerged nearshore beach rock residuals and provides a case history of late Holocene coastal erosion to illustrate the use of beach rock in coastal geomorphologic reconstructions.

REGIONAL AND GEOLOGICAL SETTING

Coastal Plain

The study area is the exposed shore of Leschenault Peninsula, a barrier dune system located in subtropical, southwestern Australia (Figure 1). The coastal lowlands (the Swan Coastal Plain) of this part of Western Australia are composed of dunes,

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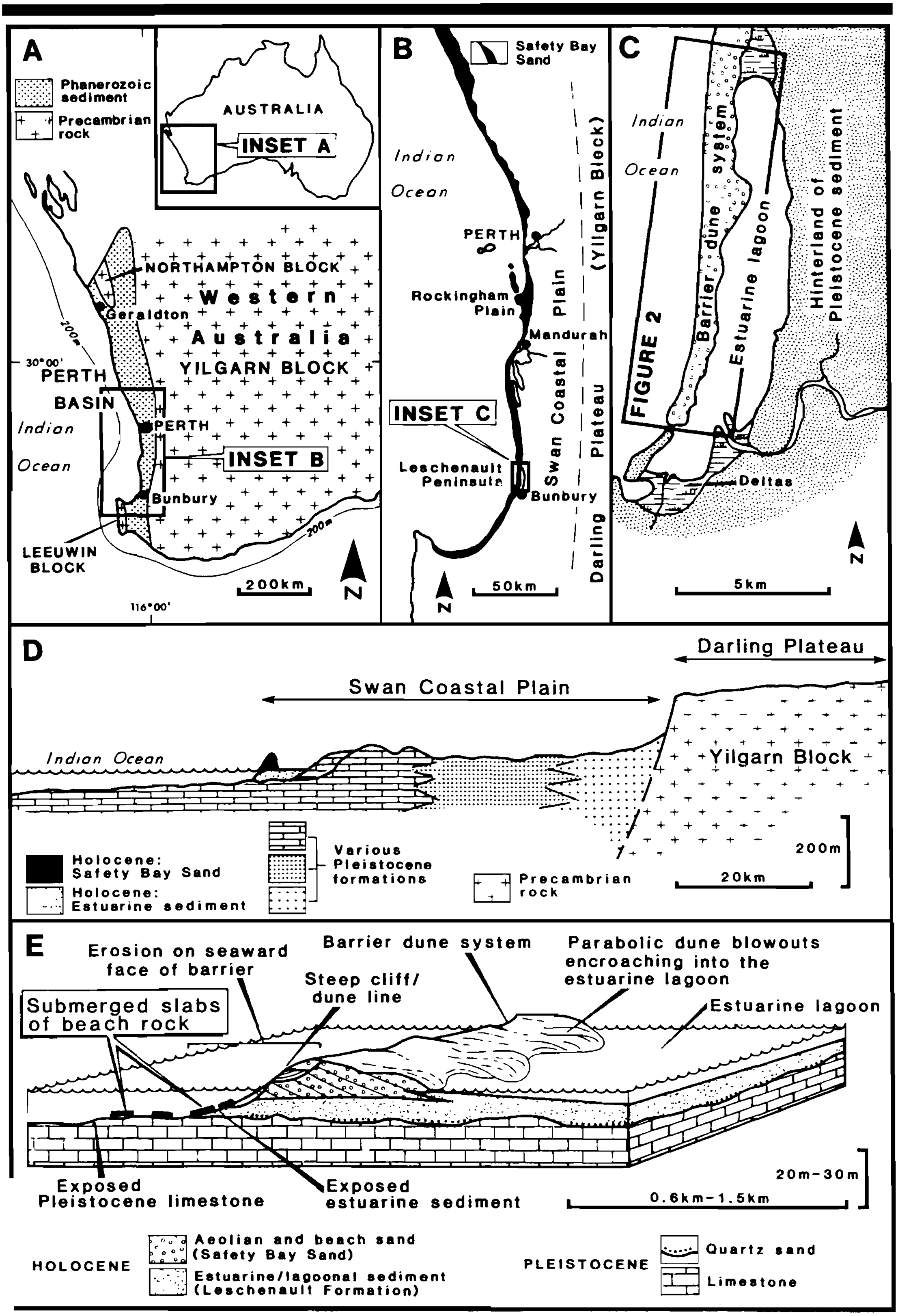

A
Phanerozoic sediment
Precambrian rock
AUSTRALIA
INSET A
NORTHAMPTON BLOCK
Western Australia
Geraldton
200m
30°00'
PERTH BASIN
YILGARN BLOCK
Indian Ocean
PERTH
INSET B
Bunbury
LEEUWIN BLOCK
200km
N
116°00'
B
Safety Bay Sand
Indian Ocean
PERTH
Rockingham Plain
Mandurah
INSET C
Leschenault Peninsula
Bunbury
Swan Coastal Plain
Darling Plateau (Yilgarn Block)
50km
N
C
Indian Ocean
FIGURE 2
Barrier dune system
Estuarine lagoon
Hinterland of Pleistocene sediment
Deltas
5km
N
D
Darling Plateau
Swan Coastal Plain
Indian Ocean
Yilgarn Block
Holocene: Safety Bay Sand
Holocene: Estuarine sediment
Various Pleistocene formations
Precambrian rock
200m
20km
E
Erosion on seaward face of barrier
Barrier dune system
Parabolic dune blowouts encroaching into the estuarine lagoon
Submerged slabs of beach rock
Steep cliff/ dune line
Estuarine lagoon
Exposed Pleistocene limestone
Exposed estuarine sediment
20m-30m
0.6km-1.5km
HOLOCENE
Aeolian and beach sand (Safety Bay Sand)
Estuarine/lagoonal sediment (Leschenault Formation)
PLEISTOCENE
Quartz sand
Limestone

fluviatile deposits, estuarine units, wetlands and strandline deposits that form the Quaternary portion of the Phanerozoic Perth Basin (JUTSON, 1949; MCAARTHUR and BETTENAY, 1960; SEDDON, 1972; PLAYFORD *et al.*, 1976). The youngest coastal deposit on the Swan Coastal Plain is the Safety Bay Sand, a formation that occurs discontinuously as Holocene beach/dune sequences along the shore (PASSMORE, 1970; PLAYFORD *et al.*, 1976; SEMENIUK and SEARLE, 1985).

Stratigraphy

The main stratigraphic units in the area relevant to this study are (Figure 1): Safety Bay Sand (Holocene), Leschenault Formation (Holocene), and Tamala Limestone (Pleistocene). The Safety Bay Sand comprises the barrier dunes (Figure 1) that protect a lagoon with estuarine deposits (Leschenault Formation). The Holocene history of this coast is described in SEMENIUK (1983, 1985); a brief summary is presented below.

Stratigraphic relationships and radiocarbon ages indicate that the Holocene sediments were emplaced in three principal stages. Stage 1, with sea level 2-3 m below present, involved development and retreat of barrier dunes and deposition of estuarine sediments. Stage 2 with sea level 3-4 m above present resulted in coastal progradation on the west side of the barrier to develop a shoaling sequence of subtidal, beach, beachridge and dune units. Stage 3 is the present dynamic situation and again involves barrier retreat, further accumulation of estuarine sediment, and development of beach rock.

Meteorology/Oceanography

The summer and winter patterns of meteorology and oceanography in this region are distinct and are related to the eastward-travelling high/low pressure systems (GENTILLI, 1972; SEMENIUK and MEAGHER, 1981; STEEDMAN and CRAIG, 1983). Winter is characterized by storms with intervening relative calms. During storms wind has mean speeds up to 20 m/s for 6-24 hour duration, and mainly prevails from the northwest, west and southwest. Two to four such storms may be expected each winter, with minor storms occurring approximately every two weeks. Major storms occur approximately every (5-)10-20 years. During summer, seabreeze/landbreeze systems control the winds in the coastal area; seabreezes with speeds up to 15 m/s originate from the west to southwest. In summer there also is the possibility of infrequent tropical cyclones reaching the area; although they are weakening, these storms are still capable of significant coastal erosion (SEMENIUK and MEAGHER, 1981).

Important factors in beach erosion are tide and storm-surge levels. This region is microtidal (HODGKIN and DI LOLLO, 1957; AUSTRALIAN NATIONAL TIDE TABLES, 1985), but MSL is influenced markedly by barometric pressure. During storms, low barometric pressure together with wind stress on the sea toward the coast, combine to result in wave attack high up the beach.

The Leschenault Peninsula faces the Indian Ocean and there are no other barriers or reefs offshore. Waves impinging on the coast are a combination of wind waves and swell. Wind waves emanate from west and southwest; swell also is predominantly from west and southwest. In combination wind waves and swell result in net erosion and a net northward littoral drift. This pattern is reversed during periodic storms that emanate from the northwest.

Geomorphic Processes

Erosion is the process most important to the development of Holocene geomorphology on the exposed portion of the barrier. The influence of erosion on coastal morphology is direct: (1) the western shoreface is cliffed with exposure of living tree roots and internal dune features (soils, large-scale cross laminae and cross bedding, and cemented zones such as groundwater calcrete); and (2) surficial sediments periodically are stripped and older stratigraphic units along the shoreface are exposed.

Two types of erosion are evident, wave erosion and wind erosion. Wave erosion is more important. The foreshore along the barrier changes seasonally from a full summer beach to a depleted winter beach and seasonally there is minor net retreat. Calcrete and soils that crop out on the shoreface are also exposed seasonally and may be eroded by

Figure 1 *(Preceeding page)*: Regional setting of the study area. (A) Location in the Perth Basin; (B) distribution of Holocene sand along the Swan Coastal Plain; (C) the coastal barrier dune system of the Leschenault Peninsula; (D) schematic diagram showing regional Quaternary stratigraphic framework at Leschenault Peninsula (compiled from data in MCARTHUR and BETTENAY, 1960; SEDDON, 1972; PLAYFORD *et al.*, 1976; SEMENIUK, 1983); (E) the stratigraphy and geomorphology of the Leschenault Peninsula and the occurrence of beach rock.

up to 1-2 m. Periodically major storms and cyclones result in more severe erosion. In 1978, for instance, the coast retreated locally up to 30 m during the storms associated with Cyclone Alby (SEMENIUK and MEAGHER, 1981). Storms exhume large expanses of groundwater calcrete, truncate soils, and truncate beachridge debris which has been deposited in the preceding decades (see Figure 7 of SEMENIUK and MEAGHER, 1981). Aerial photographs between 1941 and 1983 corroborate these observations and show an overall net erosion of the coast in the past 42 years. Wind erosion of the exposed face of the barrier continually exposes roots of living plants and develops deflation lags of cemented materials. The effect of wind is relatively slow, but the result is still a net erosion. In summary, coastal retreat is proceeding consistently and slowly by wind erosion, more moderately by seasonal winter storms, and rapidly but sporadically by periodic large storms and cyclones.

Earlier studies of coastal erosion in this area have been undertaken by SEMENIUK and MEAGHER

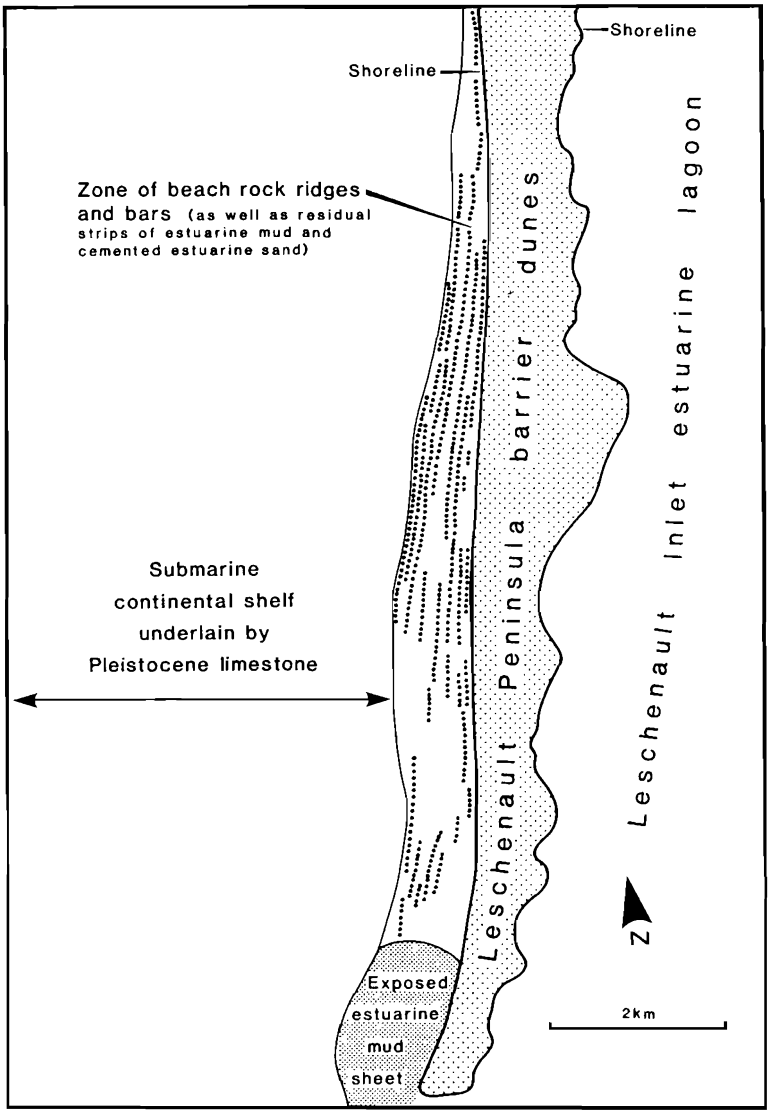


Figure 2. Map showing occurrence of beach rock in the submarine environment.

(1981), and PUBLIC WORKS DEPARTMENT (1983). SEMENIUK and MEAGHER determined erosional rates of up to 1-2 m/yr. Their short-term studies between 1976 and 1979, however, were undertaken during a period of extreme storms and cyclones; their long-term analysis used aerial photographs between 1941 and 1971. The PUBLIC WORKS DEPARTMENT (1983) produced maps by photogrammetry using aerial photographs taken between 1955 and 1982. Analysis of these maps at 18 transects along a 10 km stretch of coast shows net erosion along the coast but variable rates of erosion spacially along the coast. The mean retreat rate is 0.5 ± 0.4m/yr. Overall both studies indicate net

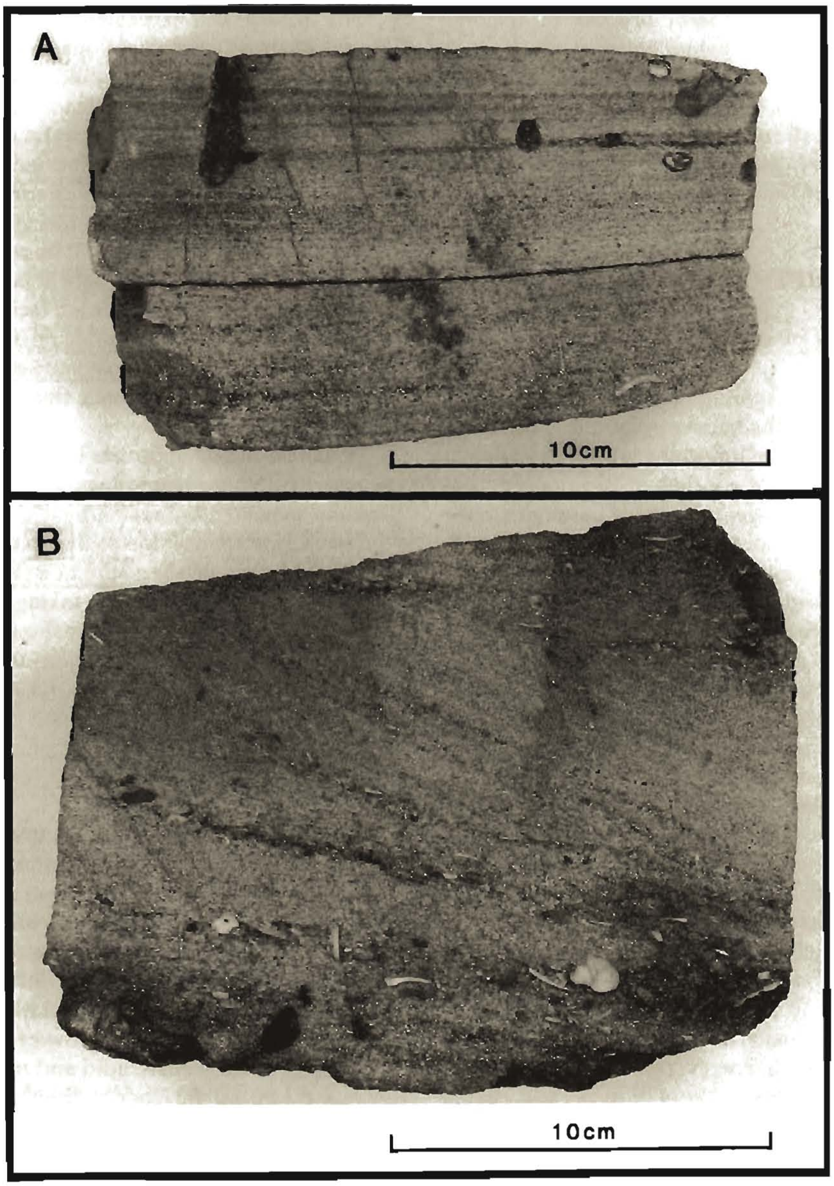


Figure 3. Photographs of beach rock slabbed to illustrate sedimentary features. (A) Laminated beach rock with upper surface bored by lithophagic bivalves. (B) Cross-bedded gravelly beach rock.

retreat but with a variable retreat rate from 0.5-1.0 m/yr.

Extrapolation would suggest that, even with the use of the lower erosional rates, an extraordinary width of at least 500 m of coast has been lost every 1,000 years. It appears that erosion has been dominant in the late Holocene for this area since sea level reached its present position some 3,000 years ago (SEMENIUK, 1983, 1985). The evidence of exhumed stratigraphic units also indicates that erosion has been a long-term process of the late Holocene rather than a short-term event.

As the coast retreats it exposes recently formed beach rock and this retreat is clearly reflected in the parallel bands of beach rock that occur up to 1000 m offshore. The beach rock forms the submarine ridge system of the shelf as described in the next section.

DESCRIPTION OF BEACH ROCK

Geomorphic Occurrence

The submarine shelf immediately offshore from the beach face of the barrier system is gently sloping and extends from low water to over 20 m depth. Most of the sea floor consists of Pleistocene limestone which forms a generally hard basement to the unconsolidated Holocene units (Figure 1). The submarine topography of this limestone varies mainly from a flat pavement to a rugged reef.

In an elongate zone parallel to the shore between low water and 6 m depth, and up to 1000 m offshore, the shelf is dominated by ridges, strips and linear slabs of beach rock (Figure 2). There are also strip outcrops of estuarine mud and other small outcrops of cemented residuals such as estuarine shelly sand (cemented in the phreatic zone beneath the barrier dunes but now exhumed and exposed in the submarine environment). Beach rock residuals, however, are clearly discernable from the other materials as laminated and cross-laminated limestone containing beach shell.

The ridges and linear slabs of beach rock, 1 to 4 m thick, are 30-150 m apart, and are subparallel to shore. Marine erosion and the bedding lamination have resulted in a craggy terraced morphology. Sand locally veneers these ridges and forms shallow accumulations in inter-ridge depressions.

Description

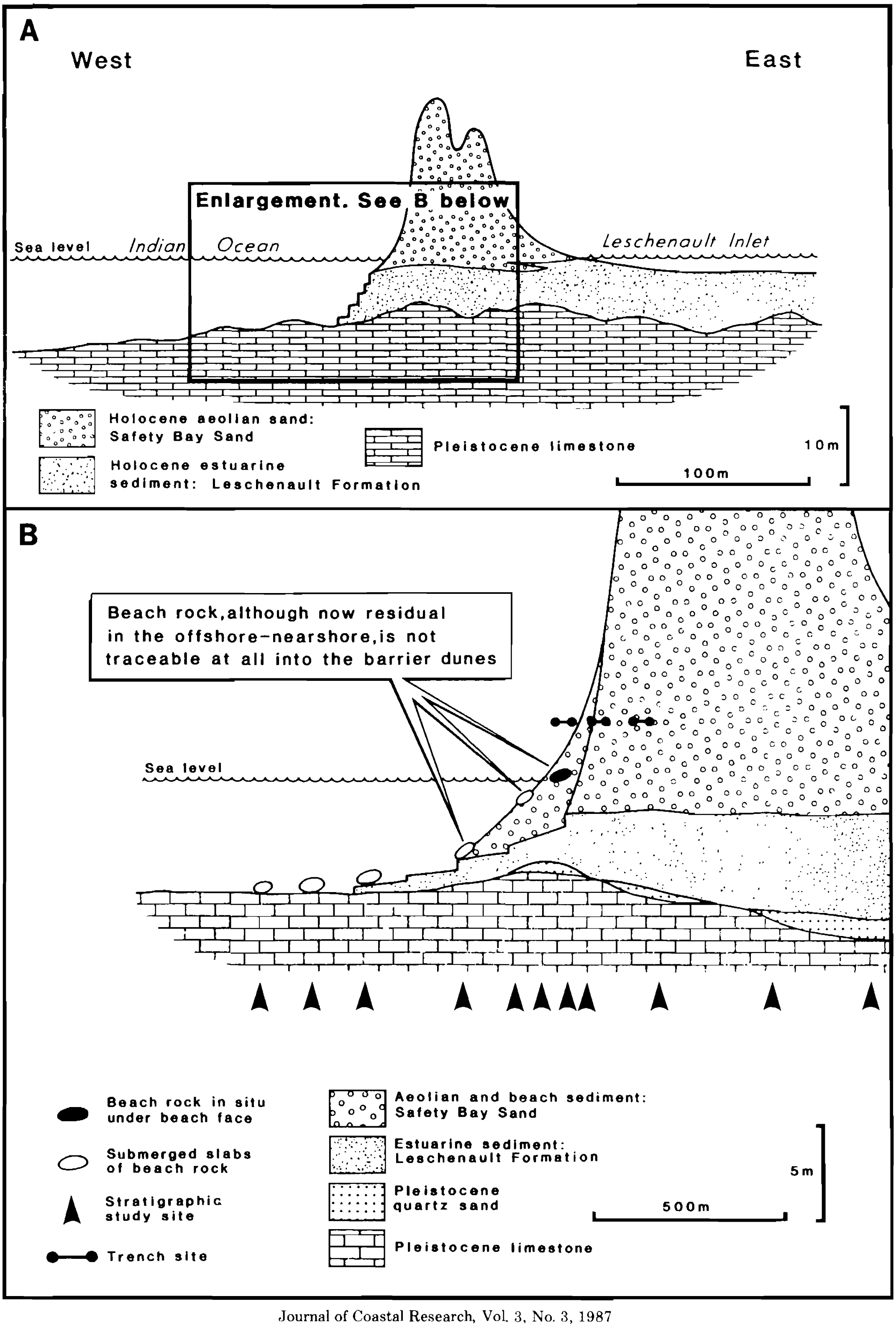
The beach rock is an indurated sand, gravelly sand or shelly sand similar to modern beach sediments onshore (Figure 3). The sequence of sediment types within the beach rock forms an incomplete beach sequence as described by SEMENIUK and JOHNSON (1982). Only the lower two facies of the normally threefold beach sequence are present (*i.e.* subtidal trough-bedded sands, shelly sands, and lithoclastic gravelly sands, overlain by swash zone laminated sand and shelly sand).

The beach rock is cemented by short rhomboidal/stumpy crystals of magnesian calcite *c.* 1μm in size. Microprobe analyses of 8 samples showed a content of 4.0 ± 1.0 mol % Mg, and no Sr. In contrast, both the Pleistocene limestone and the indurated dune sands of the barrier are cemented by low-magnesium sparry calcite and calcrete. The beach-rock cementation is quite apparent in the submarine environment and in patches in the phreatic zone under the beach face where the stratigraphic sequence of beach facies are cemented *in situ.* The cementation occurs in a zone up to 4 m thick, but the zone of most marked cementation is generally less than 1 m thick, thus forming a slab-like induration zone.

Whilst residuals of former intertidal beach rock remain in offshore strandlines, and cementation is present beneath the present beach, the zone of induration is not traceable to any extent under the barrier inwards of the shoreface (Figure 4). Apparently the induration is taking place where marine water and outflowing freshwater mix, and is similar to beach rock formation described from tropical regions (BRICKER, 1971; HANOR, 1978).

Processes of Exhumation

Beach rock is exhumed from under the beach face by coastal retreat. Slow coastal erosion (<0.5 m/year) results in the development of a broad ribbon of beach rock parallel to the coast, and if such erosion were to continue uninterrupted then a sheet of beach rock would be left because the generation and exposure of beach rock would keep pace with rates of erosion. However, infrequent large storms that cause rapid and marked coastal retreat (*c.* 30 m) for short periods (*c.* 1-2 days), interspersed with periods of normal prevailing conditions of slow erosion, will produce parallel bands of beach rock. The bands of beach rock are thus the product of cementation where a beach is slowly eroding; the intervening areas represent


A
West
East
Enlargement. See B below
Sea level
Indian
Ocean
Leschenault Inlet
Holocene aeolian sand: Safety Bay Sand
Holocene estuarine sediment: Leschenault Formation
Pleistocene limestone
10m
100m
B
Beach rock, although now residual in the offshore-nearshore, is not traceable at all into the barrier dunes
Sea level
Beach rock in situ under beach face
Submerged slabs of beach rock
Stratigraphic study site
Trench site
Aeolian and beach sediment: Safety Bay Sand
Estuarine sediment: Leschenault Formation
Pleistocene quartz sand
Pleistocene limestone
5m
500m

periods of very rapid coastal retreat. It seems that intermittent coastal erosion in its wake leaves ridges, strips, linear slabs and sheets of beach rock.

Once exhumed, slabs of beach rock undergo wave attack and degradation. All stages of beach rock exhumation, reworking and disintegration are evident along the nearshore area adjacent to the barrier system. Beach rock is readily reworked because it is imbedded in uncemented host sand. Wave attack results in undercutting and shifting of sand in such a way so that gradually the beach rock slab settles onto topographically lower portions of the shore face. The process of settling down is terminated when the slab finally comes to rest on the underlying Pleistocene limestone pavement or exposed estuarine sediment (Figure 5).

The beach rock degrades (disintegrates) mainly by biological processes (*cf.* MCLEAN, 1967, 1974). Its surface is rapidly colonised by algae, grazing molluscs, echinoderms and lithophagic organisms (Figure 3). As a result the surface is bored, honeycombed and generally degraded. Near the shore young beach rock is generally of marked relief and relatively more continuous along its strike length. Disintegrated and degraded beach rock residuals are more common offshore.

Age of Beach Rock Ridges/Bands

Since the bands and linear slabs of beach rock are residuals left as the coast retreats, it is assumed that the oldest would be farthest seaward and the youngest would be either still forming beneath the beach face or lodged in the inshore zone. Thus the parallel array of ridges or bands would represent isochrons providing a relative chronology for coastal retreat, and would also provide an indication of the periodicity of major storms that caused the marked retreat.

It is not possible, however, to easily date the beach rock of the Leschenault Peninsula by radiocarbon using mollusc shell. This is because the shells that are incorporated into modern beaches and thus the beach rock have the following sources: (1) modern nearshore benthos (of which *Donax* is most abundant); (2) reworked relict shells (*c.* 4,800-3,600 ^{14}C yrs) from stranded relict beach deposits deposited during stage 2 of the history of the barrier; *Donax, Donacilla* and *Glycymeris* are common and frequently have adhering $CaCO_3$ cement (calcrete or spar-cemented nodules); (3) reworked shells (*c.* 7,000 years BP) from exhumed estuarine molluscs (for faunal list see SEMENIUK, 1983); (4) reworked shells from Pleistocene limestone.

The order of abundance of these shells are: modern shells = relict beach shells > estuarine shells > Pleistocene shells.

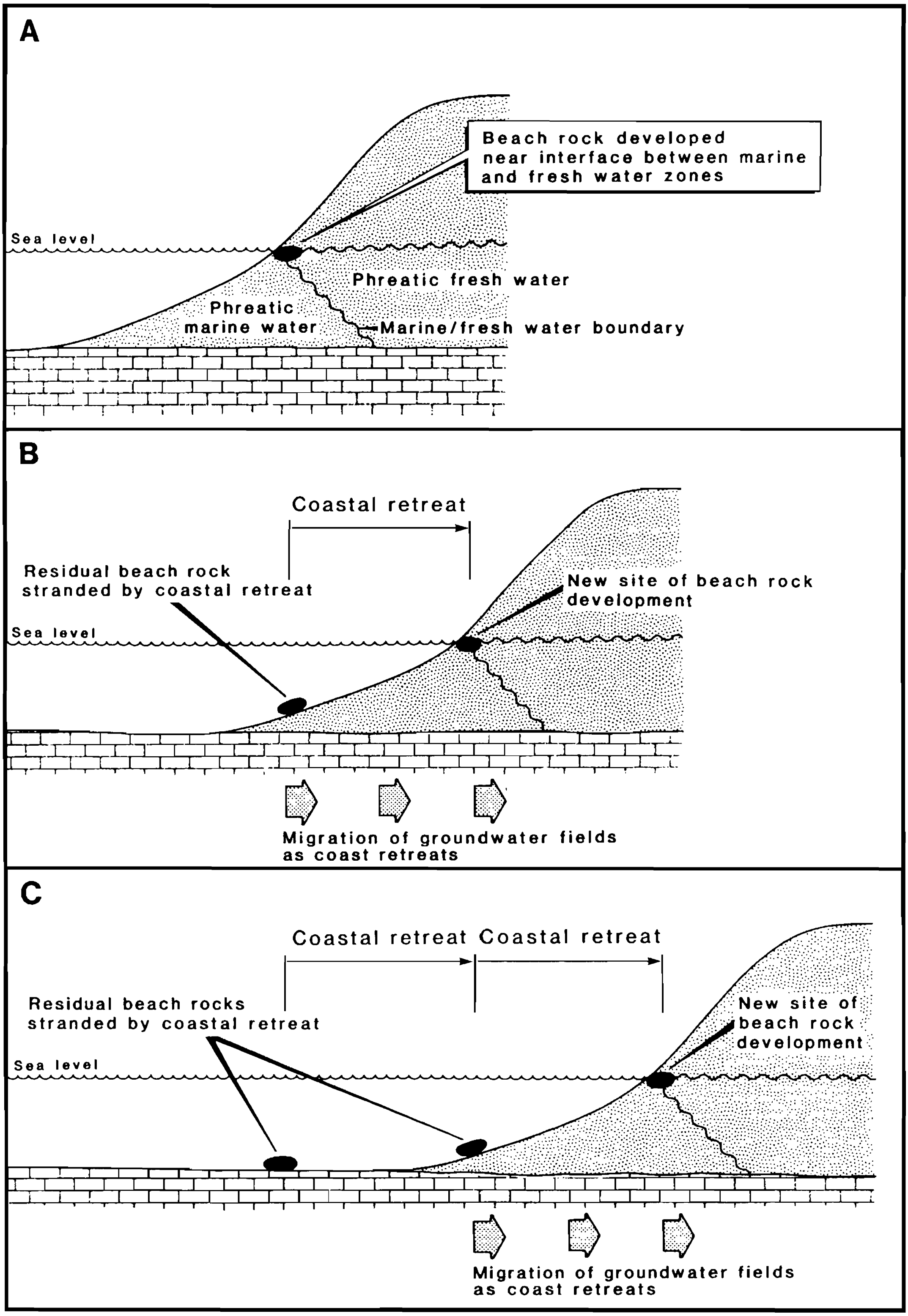
If these molluscs were bulk analyzed, the age determinations would be meaningless. Even ages from selected distinct species *(e.g., Donax)* would provide erroneous results because second-cycle shells reworked from the Stage 2 depositional unit some 3,600-4,800 ^{14}C yrs BP are indistinguishable in many instances from modern shells.

The beach rock slabs in the nearshore to offshore environment rest on exhumed estuarine sediment containing shell dated at 7,765-7,890 ^{14}C yrs BP. This at least indicates a Holocene age for the beach rock, but because a disconformity separates the slabs and the estuarine sediment the dates cannot be used to deduce the age of the beach rock. Until the magnesium calcite cement of the beach rock itself is processed for radiocarbon the age of the beach rock will have to be determined from gross stratigraphic relationships and other data on age structure and history of the barrier.

The Holocene history of the area described earlier in this paper suggests that the barrier was emplaced in 3 stages. Each of these stages has been dated (SEMENIUK, 1985) and potentially could be of use in deducing the age of beach rock in the area. The first stage involving a retreating barrier cannot be considered because sediments deposited at this time have since been eroded and reburied by sediment of Stage 2. The sequence of Stage 2 also is out of the question for dating the beach rock because this stage involved net coastal progradation and not erosion. The third stage in the development of the coastal barrier is the current phase that began about 2,800 ^{14}C yrs BP with reactivated erosion on the exposed face of the barrier which is associated with renewed mobilisation of parabolic dunes across the barrier into the protected estuarine lagoon. The date of 2,800 ^{14}C yr records the reactivation of erosional conditions leading up to the present day, and thus records the maximum possible age of the most seaward beach rock.

Given the modern rates of bioerosion and physical degradation it is unlikely, however that the most seaward occurrence of beach rock is as old as 2,800 ^{14}C yr. The rates of erosion of the coast determined by shoreline monitoring over the past 10 years and

Figure 4 *(preceeding page):* Transect from nearshore to onshore showing stratigraphic distribution of beach rock. Beach rock is not traceable to landward beyond the backshore.


A
Beach rock developed near interface between marine and fresh water zones
Sea level
Phreatic fresh water
Phreatic marine water
Marine/fresh water boundary
B
Coastal retreat
Residual beach rock stranded by coastal retreat
New site of beach rock development
Sea level
Migration of groundwater fields as coast retreats
C
Coastal retreat
Coastal retreat
Residual beach rocks stranded by coastal retreat
New site of beach rock development
Sea level
Migration of groundwater fields as coast retreats

determined by photogrammetric analysis over 40 years of aerial photography are in the order of 0.5-1.0 m/yr. Accordingly the most seaward occurrence of beach rock now located some 1,000 m offshore would be in the order of 1,000-2,000 years old. Thus the most seaward portion of the residual beach rocks some 1,000 m offshore are interpreted to be most likely 1,000-2,000 years old, but possibly up to 2,800 yrs old. Beach rock has been observed in the phreatic zone under the backshore of beaches that have formed only in the last 40 yrs and therefore the youngest age of the most shoreward occurrence of beach rock is contemporary.

DISCUSSION

The results presented here lead to several conclusions, firstly concerning the development of nearshore rocky reefs and ridges and geomorphic units of any age (Quaternary, Tertiary, *etc.*), secondly on the significance of linear slabs and bars of beach rock, and thirdly on the usefulness of linear beach rock trends in reconstructing coastal history.

It is evident that nearshore and offshore rocky reefs and residual carbonate-cemented rock pavements and slabs can be developed under a combination of shoreline processes that include beach rock formation in the phreatic zone of a beach, followed by coastal erosion (*cf.* HATTIN and DODD, 1978; COORAY, 1968; RUSSELL, 1959). This process provides coastal sedimentologists and geomorphologists with explanations for the occurrence of submerged nearshore rocky slabs and submarine residuals of cemented rock that need not represent abandoned beach rock shorelines developed by a rising sea level.

Slow coastal erosion concomitant with phreatic cementation which has enough time to develop indurated horizons under the retreating beach face will result in a broad zone or sheet of beach rock. The width of the zone will be determined by the rate of erosion keeping pace with beach-rock cementation and by the interval of this prolonged slow erosion. Coastal erosion of 0.5 m/yr for 100 years, for instance, could develop a beach rock ribbon or zone (albeit fractured and disrupted) some 50 m wide. However, parallel bands of beach rock separated by beach-rock-free zones indicate that coastal retreat is occurring by a process of slow erosion punctuated by rapid erosion through periodic large storms. Slow erosion of 0.5 m/yr interspersed with a rapid rate of erosion of 50 m, say every 50 years, would result in parallel bands of beach rock perhaps some 25 m wide separated by beach-rock-free zones some 50 m wide. The width and spacing of bands of beach rock when used in conjunction with known prevailing rates of slow coastal erosion, give an indication of the history of coastal erosion. The model of periodic large-scale storm-induced erosion alternating with prevailing slow erosion that results in the development of linear beach rock trends therefore is useful for reconstructing geomorphic history along high energy, beach-rock lined coasts.

Figure 5 *(preceeding page)*: Stages in the development of beach rock ridges/bands.

Beach rock indicates the former occurrence of a specific linear environment—*i. e.*, the shoreline and the interaction of freshwater and seawater in the phreatic zone under the beach face (Figure 5). Once it is exhumed and left as an isolated residual it can then delineate former shorelines. Unconsolidated coastal sands on the other hand once eroded from the shoreline can be removed from the immediate coastal area, or can be imprinted by different processes in their new site of emplacement, or can be reworked, or stranded elsewhere. Such coastal sands thus may offer little or no information about former coastal history. On the other hand, beach rock is relatively resistant and can be viewed as a long-term residual product and a useful record of shore position. Beach rock has been used in this manner by ULZEGA *et al.* (1986), SIESSER (1974), STEARNS (1974) and others for the identification of Pleistocene and early Holocene shorelines.

Beach-rock ridges/bands up to 1,000 m offshore in the Leschenault area indicate the position of the strandline to have been at least 1,000 m farther seaward earlier in the Holocene. However, the usefulness of the beach-rock residuals in this area is that they record marked coastal retreat over a relatively short period of the Holocene and indicate by their configuration and distribution the varying rates of coastal retreat. As such the beach rock residuals now submerged offshore provide an additional indicator of the history and extent of retreat of a retrograding barrier. The width and spacing of the submerged beach rock zone also indicates differential retreat along the Leschenault Peninsula barrier. To the north the retreat has occurred over 500 m or less, to the south retreat has occurred over 1,000 m, indicating that erosion has been consistently of a greater magnitude along southern parts of the barrier.

LITERATURE CITED

AUSTRALIAN NATIONAL TIDE TABLES, 1985. Australian Hydro-graphic Publication 11, Australian Government Publishing Service, Canberra.

BRICKER, O.P. (ed.), 1971. *Carbonate Cements.* Baltimore: The John Hopkins Press. No. 19, 376p.

COORAY, P.G., 1968. A note on the occurrence of beachrock along the west coast of Ceylon. *Journal of Sedimentary Petrology,* 68, 650-654.

DAVIES, P.J. and KINSEY, D.W., 1973. Organic and inorganic factors in recent beach rock formation, Heron Island, Great Barrier Reef. *Journal of Sedimentary Petrology,* 43, 59-81.

FOLK, R.L., 1974. The natural history of crystalline calcium carbonate; effect of magnesium content and salinity. *Journal of Sedimentary Petrology,* 44, 40-53.

FRANKEL, E., 1968. Rate of formation of beach rock. Earth Planetary Science Letters. 4, 439-440.

GENTILLI, J., 1972. *Australian Climate Patterns.* Melbourne: Nelson, 285.

GINSBURG, R.N., 1953. Beach rock in South Florida. *Journal of Sedimentary Petrology.* 23, 85-92.

HANOR, J.S., 1978. Precipitation of beachrock cements; mixing of marine and meteoric waters vs. CO_2-degassing. *Journal of Sedimentary Petrology,* 48, 489-501.

HATTIN, D.E. and DODD, J.R., 1978. Holocene cementation of carbonate sediments in the Florida Keys. *Journal of Sedimentary Petrology,* 48, 307-311.

HODGKIN, E.P., and DI LOLLO, V., 1957. The tides of southwestern Australia. *Journal Royal Society of Western Australia,* 41, 42-54.

HOPLEY, D., 1980. *The Geomorphology of the Great Barrier Reef: Quaternary Development of Coral Reefs.* New York: Wiley Interscience. 453p.

HOPLEY, D. and MACKAY, M.G., 1978. An investigation of morphological zonation of beach rock erosional features. *Earth Surface Process,* 3, 363-377.

JUTSON, J.T., 1950. The physiography (geomorphology) of Western Australia. *Western Australia Geological Survey Bulletin,* 95.

KNOX, G.J., 1974. An aragonite-cemented volcanic beach rock near Bilbao, Spain. *Geologie en Mijnbouw,* 53, 9-12.

KUENEN, Ph.H., 1933. The Snellius-Expedition, 5. Geologist Results, 2: *Geology of Coral Reefs.* Utrecht: Kemink, 125p.

LOVELL, E.R., 1975. Evidence for a higher sea level in Moreton Bay, Queensland letter. *Marine Geology,* 18, 87-94.

McARTHUR, W.M. and BETTENAY, E., 1960. The development and distribution of the soils of the Swan Coastal Plain, Western Australia. *Soil Publication* No. 16. Melbourne: C.S.I.R.O., 55p.

MCLEAN, R.F., 1967. Measurements of beachrock erosion by some tropical marine gastropods. *Bulletin of Marine Science,* 17, 551-561.

McLEAN, R.F., 1974. Geologic significance of bioerosion of beachrock. *Proceedings of the 2nd International Coral Reef Symposium,* 2, 401-408.

McLEAN, R.F.; STODDART, D.R.; HOPLEY, D. and POLACH; H., 1978. Sea level change in the Holocene on the northern Great Barrier Reef. *Philosophical Transactions Royal Society London,* A, 291, 167-186.

MAXWELL, W.G.H., 1962. Lithification of carbonate sediments in the Heron Island Reef, Great Barrier Reef. *Journal Geological of the Society Australia,* 8, 217-238.

MOORE, C.H. Jr, 1971. Beachrock cements, Grand Cayman Island, B.W.I. In: Bricker, O.P. (ed.), *Carbonate Cements.* Baltimore: The John Hopkins Press, No. 19, 9-12.

MOORE, C.H. Jr, 1973. Intertidal carbonate cementation, Grand Cayman, West Indies. *Journal of Sedimentary Petrology,* 43, 591-602.

MOORE,C.H. Jr and BILLINGS, G.K., 1971. Preliminary model of beachrock cementation, Grand Cayman island, B.W.I. In: Bricker, O.P. (ed.), *Carbonate Cements.* Baltimore: The John Hopkins Press, No. 19, 40-43.

PASSMORE, J.R., 1970. Shallow coastal aquifers in the Rockingham District, Western Australia. *Water Research Foundation Australia Bulletin,* 124, 311.

PLAYFORD, P.E.; COCKBAIN, A.E., and LOW, G.H., 1976. Geology of the Perth Basin, Western Australia. *Geological Survey of Western Australia Bulletin,* 124.

PUBLIC WORKS DEPARTMENT, 1983. Coastline movements: Robert Point (Mandurah) to Bunbury Breakwater, Map Nos. 55010-23-1 to 55010-26-1. Department of Marines and Harbours, Perth.

RUSSELL, R.J., 1959. Origin of beach rock. *Zeitschrift für Geomorphologie,* 6, 1-16.

SCHOLTEN, J.J., 1971. Beach rock; a literature study with special reference to the recent literature. *Zentralblatt für Geologie und Palaontologie,* Teil I (9-10), 655-672.

SCOFFIN, T.P., 1977. Sea level features on reefs on the northern province of the Great Barrier Reef. *Proceedings of the 3rd International Coral Reef Symposium,* 2, 319-324.

SEDDON,G., 1972. *Sense of Place.* Perth: University of W.A. Press, 214p.

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 sea level history reconstructions in southwestern Australia. *Marine Geology,* 67, 197-212.

SEMENIUK, V. and JOHNSON, D.P. 1982. Recent and Pleistocene beach/dune sequences, Western Australia. *Sedimentary Geology,* 32, 301-328.

SEMENIUK, V. and 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. and SEARLE, D.J., 1985. The Becher Sand, a new stratigraphic unit for the Holocene of the Perth Basin. *Journal of the Royal Society of Western Australia,* 67, 109-115.

SIESSER,W.G.,1974. Relict and Recent Beachrock from Southern Africa. *Geological Society of America Bulletin,* 85, 1849-1854.

STEARNS, H.T., 1974. Submerged shorelines and shelves in the Hawaiian Islands and a revision of some of the eustatic emerged shorelines. *Geological Society America Bulletin,* 85, 795-804.

STEEDMAN, R.K. and CRAIG, P.D., 1983. Winddriven circulation of Cockburn Sound. *Australian Journal of Marine and Freshwater Research*, 34, 187-212.

STEFANON, A., 1969. The role of beachrock in the study of the evolution of the North Adriatic Sea. *Memorie di Biogeografia Adriatica*, 8, 79-87.

STEFANON, A., 1971. Submerged beachrock in the Gulf of Venice (Italy); key to the knowledge of the local coastline evolution in the last few thousand years. In: Les niveaux marins quaternaires, part 1, Holocene, *Quaternaria*, 14, 191-193.

STRASSER, A. and DAVAUD, E., 1986. Formation of Holocene limestone sequences by progradation, cementation, and erosion: two examples from the Bahamas. *Journal of Sedimentary Petrology*, 56, 422-28.

TACHIBANA, K. and SAKAGUCHI, K., 1971. Age of beachrock containing the Jomon Pottery in the Goto Islands; beachrock of the Goto Island (Part 2). *Quaternary Research* (Jap. Assoc. Quat. Res.), 10, 54-59.

TAYLOR, J.C.M. and ILLING, L.V., 1971. Variation in Recent beachrock cements, Qatar, Persian Gulf. In: Bricker, O.P. (ed.), *Carbonate Cements*. Baltimore: The John Hopkins Press, No. 19, 32-35.

TIETZ,G. and MULLER, G., 1971. High-magnesian calcite and aragonite cementation in Recent beachrocks, Fuerteventura, Canary islands, Spain. In: Bricker, O.P. (ed.), *Carbonate Cements*. Baltimore: The John Hopkins Press. No. 19, 4-8.

ULZEGA, A., LEONE, F. and ORRU' P., 1986. Geomorphology of submerged late Quaternary shorelines on the south Sardinian Continental Shelf. *Journal of Coastal Research*, 73-82.

☐ ZUSAMMENFASSUNG ☐

Strandstein entwickelt unterm Strand einer zurücktretenden Barriere auf der südwestlichen Küste Australiens; dieses Stein wird enthüllt, als die Küste ausgewäscht wird. Es ist einen Rest vom Prozess, worin die zurücktretenden Barriere die unterliegende Sedimente auf der Unterseesandbank enthüllt. Es entwickelt dann in kleinen eine bestimmte geomorphische Anlage, die ihre Entwicklungsweise und daher die Küstengeschichte reflektiert. Diese Anlage besteht aus küstenparallelen Unterseekämme, Gürteln und linearen, durch Sandbänder getrennten Streifen vom Strandstein. Die Strandsteinreste sind nützlich, da aufnehmen sie einen merkwürdigen küstlichen Rückzug im Lauf einer relativ kurzen Zeit des späten Holozänabschnitts. Ihre Gestaltung liefert Information über die dynamische Natur einer zurücktretenden Küste und ermöglicht eine Wiederherstellung geomorphischer Geschichte.--*Stephen A. Murdock, CERF, CHarlottesville, Virginia, USA*