The nature and origin of beach ridges, western Cape York Peninsula, Queensland

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Two sets of beach ridges are known from the western side of Cape York Peninsula. The older set are thought to be late Pleistocene. They rest on a basement of older fan deposits and are regarded as a regressive sequence of barrier islands.

The younger ridges represents a progradational sequence post-dating the Holocene transgression. The earliest formed ridge, which is poorly developed, formed as a chenier. It was followed by a barrier island complex whose development lasted until about 3000 years B.P. Subsequently, there was rapid progradation and the development of two sets of chenier-type beach ridges, the younger of which is locally discordant to the ridges of the barrier island complex. These ridges rest on a marine sand and mud unit which appears continuous with a similar unit mapped offshore.

The Pleistocene ridges consist of quartzose sand, with negligible carbonate, while the Holocene ridges consist of quartzose sand, shell sand and shells. They show a progressive leaching with age.

Introduction

Extensive beach ridges border the southern and eastern margins of the Gulf of Carpentaria; they extend from the Roper River in Arnhem Land to Cape York, are patchily developed between the Roper River and Gove, and are also present on the Wellesley, Pellew and Wessel Islands and Groote Eylandt. The beach ridges on the Queensland coast of the Gulf have been examined by many workers and have been mapped by field parties of the Bureau of Mineral Resources (BMR) and the Geological Survey of Queensland (GSQ) between 1969 and 1973 (Doutch *et al.*, 1970, 1972, 1973). Smart (1976) reported the results of systematic drilling and levelling of beach ridges on the west coast of Cape York Peninsula from August to October 1973 and this paper summarizes the results. The purpose of the study was to elucidate the stratigraphy of the beach ridge complexes and to provide information on the late Pleistocene-Holocene geological history of the area, particularly in terms of sea-level changes. The results of C^{14} dating of shells from this and adjacent areas are also discussed and the history of beach-ridge formation in the region briefly reviewed.

Previous investigations

Twidale (1956) briefly described the beach ridges along the southern shore of the Gulf, between the Leichhardt and Gilbert Rivers. He divided the ridges into two groups: an older series of three ridges, whose formation was followed by a younger series of two ridges after a drop in sea level of about 6 m. The ridges were all considered to be formed as offshore bars, analogous to a present day feature. Twidale attributed the emergence to eustacy and said that the coastline displayed features characteristic of emergence. In 1966, Twidale presented a C^{14} date of 3320 ± 125 years B.P. for shells from the youngest beach ridge at Karumba and suggested that its emergence may be related to a eustatic fall in sea level during the Holocene (Twidale, 1966).

In the area south of Archer Bay, Valentin (1961) noted the two ages of beach ridges. He regarded the older ridges as having formed partly from many parallel dunes blown together by wind action and partly as old individual dunes.

Whitehouse (1963) discussed the beach ridges on the west side of Cape York Peninsula in a general review of sandhills in Queensland. He reported augering showing that the youngest ridges at Edward River Mission rested on marine muds and he postulated a sequence of beach ridges in three zones: firstly, young ridges with sharp profiles along the coast, secondly a series of older ridges having a more subdued relief with some incipient claypan development and finally an area, many kilometres wide, of sand with abundant claypans. The first two series are recognized in this paper as Holocene and Pleistocene beach ridge sequences respectively, but the area of sand with claypans is underlain by fluvial sediments. The claypans developed during an arid period in the late Pleistocene (Grimes & Doutch, in prep.).

Doutch *et al.* (1972) discussed the morphology and origin of the beach ridges in the area between latitudes 15° and 17°S. They presented a conjectural cross section of the ridge sequence which subsequent work (Smart, 1976) has shown to require revision.

Grimes (1974) described the beach ridges along the southwestern coast of the Gulf of Carpentaria in Queensland, and briefly discussed the results of C^{14} dating of ridges at Edward River Mission on Cape York Peninsula. He did not distinguish different ages of ridges on his maps, but his Figures 6 and 7 can be interpreted as showing two sets of ridges. Geological mapping in the area (Powell & Smart, in press; Smart, in press, a & b; Grimes, in press) has recognized two sets of beach ridges on the west coast of Cape York Peninsula, of Holocene and Pleistocene (?) age respectively. Whitaker & Gibson (in press) show similar features on the Charlotte Plain on the east coast of the Peninsula, and Gibson (1975) reported on an auger hole drilled through one of the younger ridges on that coast.

Beach-ridge nomenclature

The nomenclature of beach ridges has been unsystematic and confusing in the past. Two terms have been applied to beach ridges—bar or barrier, and chenier, but the distinction between them has not always been made clear. Todd (1968) made the distinction between ridges of barrier island origin and those of chenier origin, while Leblanc (1972) and Busch (1974) summarised the geometry and stratigraphy of the two types (Fig. 2). Essentially, the chenier is a sand body resting on coastal sediment associated with the progradation of the coastline, while the barrier island is a thick sand body which rests on basement, with its seaward margin underlain by marine sand and mud.

Cheniers

The original description of the chenier plains of Louisiana was by Howe *et al.* (1935) who wrote, 'Rising slightly above the surrounding marshes, several long, narrow, sandy ridges run roughly parallel to the coast of southwestern Louisiana and form the most conspicuous topographic features of the region. Sharply localized, well drained and fertile, they support naturally luxuriant vegetation cover . . . the ridges have been called cheniers by their Creole inhabitants.' Price (1955) used the term chenier plain for this type of coastal feature and described cheniers as 'shallow-based, perched, sandy ridges resting on clay'. Subsequent work, including extensive drilling (Byrne *et al.* 1959; Gould & McFarlane, 1959; Bernard *et al.* 1959; Coleman, 1966), has revealed the stratigraphy of the beach ridge sequence in detail. The typical chenier does not rest on swamp mud as assumed by some (Russell & Howe, 1935; Tanner, 1961), but on a firm base of marine sand and silty clay. Todd (1968) distinguishes cheniers from barrier islands and he noted that the near-shore gradient of the seabed was twice as steep where barrier islands had developed as where cheniers had developed; otherwise conditions were similar.

Todd (1968) suggests that three conditions are necessary for the formation of cheniers:

(1) Stability or fall of sea level;
(2) a variable supply of sediment from rivers;
(3) effective longshore currents.

However if the supply of sediment is fairly constant, the classical chenier plain will not develop, and in its place a continuous sequence of sand ridges overlying muddy sediments will form, for example Figure 4C. Ridges of this nature are similar in genesis to cheniers and quite distinct from barrier island ridges. They are referred to in this paper as chenier-type ridges. Cheniers tend to form on coasts of high sediment supply, near major rivers.

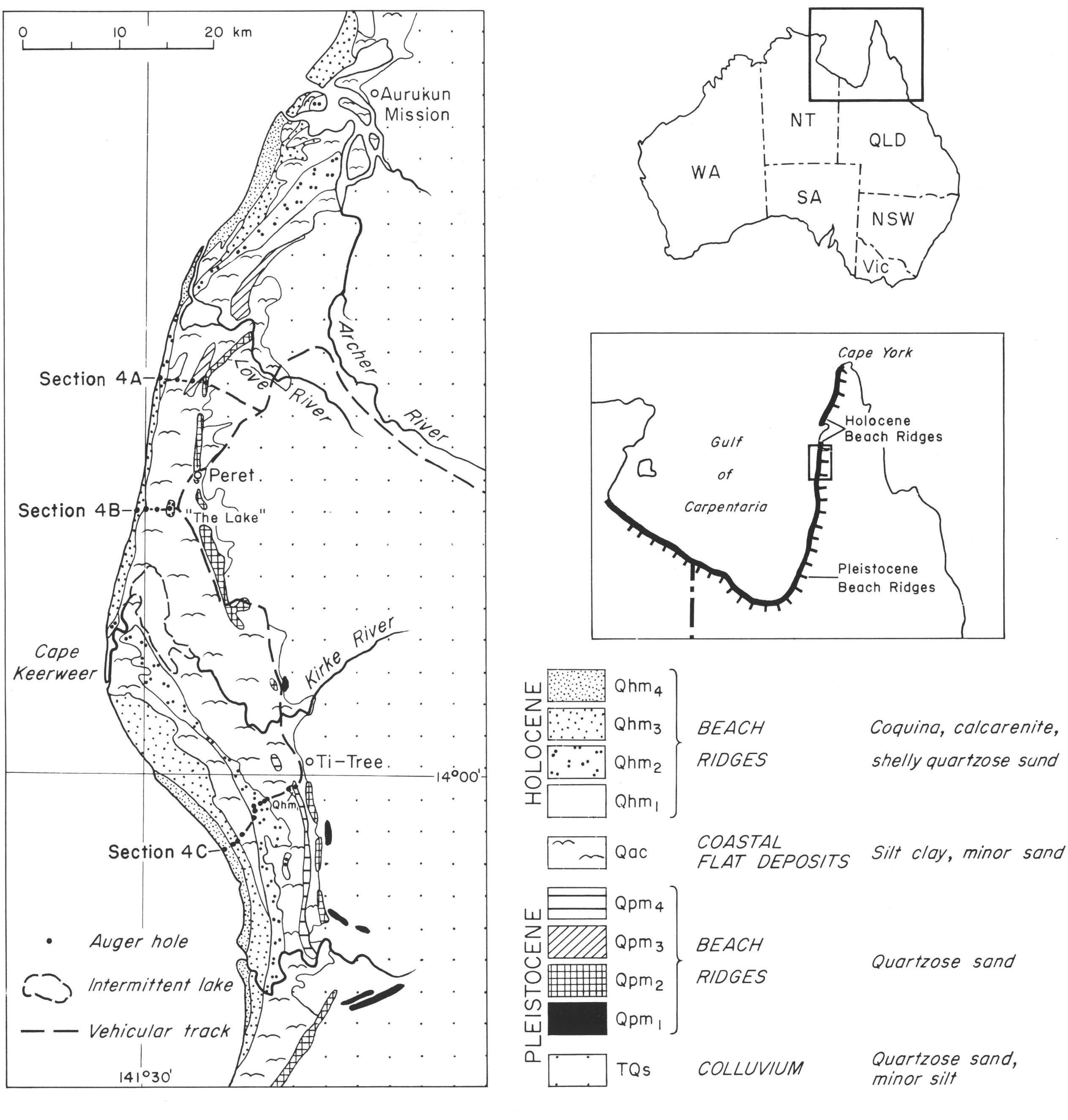

Figure 1. Locality map showing beach ridge distribution and location of sections

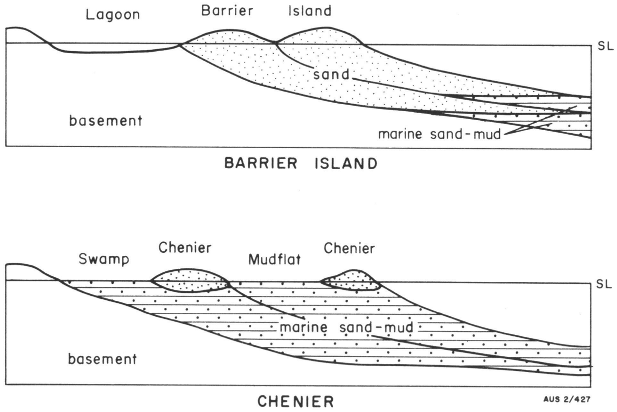

Figure 2. Diagrammatic cross sections of chenier and barrier island beach ridges, based on Leblanc (1972)

Barrier-island ridges

Barrier islands are well described in the literature, particularly those from the Gulf of Mexico and the Atlantic coast of the U.S.A. and their essential features are well known. They tend to be much larger than cheniers; generally up to three times thicker, and commonly tens of miles in length (Leblanc, 1972). As noted above, Todd (1968) showed that seabed gradients are much steeper off a barrier island than a chenier coast. Barrier islands appear to form on coasts where there is a limited supply of sediment, so that progradation is slow relative to a coast with cheniers. This allows a thorough sorting of sediment and the accumulation of a large, thick sand body.

General description

The results of the 1973 drilling are summarized as beach-ridge sections in Figure 4 and detailed logs are presented by Smart (1976). C^{14} dating results are shown in Table 1. The beach-ridge sections show that there is a group of ridges near the coast and more subdued ridges inland. These correspond to the younger (Qhm) and older (Qpm) ridges noted by previous workers. The map symbols Qhm and Qpm are used in this paper with appropriate suffixes to indicate the different sets of ridges.

Pleistocene beach ridges

Distribution

The older group of ridges has been mapped along the western coast of Cape York Peninsula as far south as latitude 15°. South of this, the older ridges have been recognized along the coast as far as the Northern Territory border (Needham & Doutch, 1973a, b: Ingram, 1973; Grimes, 1974) and can be recognized beyond on air photographs as far as the Roper River area.

Morphology

The older group comprises low, rounded ridges, which are covered by tall trees and contain, in a few places, deflation features (clay pans and minor blow outs) (Fig. 3). Air-photo interpretation suggests the presence of four sets of ridges within the older sequence, all of which can be traced over most of the coast. In this paper they have been mapped out, within the survey area, as Qpm_1, Qpm_2, Qpm_3 and Qpm_4 from the oldest to the youngest (Fig. 1).

The Qpm_1 ridges are poorly preserved as low, linear, sand ridges whose trends are generally discordant to the Qpm_2 and Qpm_3 ridges. No ridges of this group have been levelled but their crests appear similar in height to the Qpm_2 group.

The intermediate set, Qpm_2, is the best preserved set in the survey area and appears to be best preserved elsewhere on the coast. The crests of the Qpm_2 ridges are approximately 5 m above sea level but it is unlikely that this is their original height. They are present over all the survey area south of the Love River.

Witin the survey area, the Qpm_3 ridges are recognized only west of Don Yard, where they lie slightly discordant to the Qpm_2 ridges. Claypans characterize the Qpm_3 ridges but there are only a few deflation features on the other Pleistocene ridges. The present elevation of the Qpm_3 ridge crests is about 2 m above sea level.

The youngest of the group, Qpm_4, has a less degraded appearance than the older ridges although its crest lies at about the same elevation, about 3.5 m above sea level. Vegetation cover is similar to that on the older ridges except that there are fewer large trees.

The Qpm_4 ridges are present only in the south of the survey area (Fig. 1), and have been mapped both as Qpm (Smart, in press, b) and Qhm (Grimes, in press) in the recent 1:250 000 geological maps, as their affinities are less certain than those of the other ridges. However, the drilling and levelling data (Fig. 4) suggests their formation at a higher sea level than present and so they are probably part of the older group.

A possible explanation for the restriction of deflation features to the Qpm_3 ridges is that deflation occurred immediately after the formation of the Qpm_3 ridges and before deposition of the Qpm_4 ridges. If the previous climate had been more humid and the Qpm_1 and Qpm_2 ridges had developed a thick vegetation cover, they would have been little affected by the deflation episode. However no arid period has so far been established in that part of the Pleistocene.

Lithology and relationships

The Pleistocene beach ridges consist of slightly clayey quartzose sand, with local traces of shell material at depth. The sand is generally yellow or brown, locally red-brown, and is sub-horizontally bedded. A soil profile about 0.5-1.0 m thick is present on top of the ridges but no old soil layers or humic material have been encountered in drilling.

The oldest ridges (Qpm_1) have not been drilled, but photo-interpretation suggests they rest on the sequence of Pliocene-Pleistocene alluvial fan deposits in the survey area. Sections across the other ridges are shown in Figures 4A and 4C. The Qpm_2 ridges rest on the Pliocene-Pleistocene fan deposits (TQa), their bases being up to 1.5 m above present sea level. Qpm_4 ridges also rest on fan deposits (Fig. 4C); their bases are about 1.5 m above present sea level on the landward side, but the seaward side has not been drilled.

The Pleistocene ridges in the survey area are all of the barrier-island type, resting on a basement of older fan deposits.

Age

Negligible carbonate material has been recovered from the Qpm_1, Qpm_2, Qpm_3 and Qpm_4 ridges, and C^{14} dates have not been obtained. However the age of the ridges is almost certainly beyond the limit of radio-carbon dating. Consideration of late Pleistocene history in the region and comparison with other coastal features dated in eastern Australia by Marshall (1975) suggests an age of about 120 000 years B.P. for the group. The maximum age is probably younger than 170 000 years B.P., as Jongsma (1974) found a eustatic low of —200 before 170 000 years B.P., and the fan deposits on which the ridges rest postdate this sea level low.

Sea levels

The Pleistocene beach ridges formed at a sea level slightly higher than present. The exact height above present sea level is uncertain. B. G. Thom (pers. comm.) suggests a high of 4-6 m for 120 000 years B.P. in S.E. Australia, and other authors suggest highs of the same order elsewhere (e.g Chappell, 1974), but evidence of strand lines around the Jardine River and the Charlotte Plain indicates a higher stand, perhaps as much as 15 m. (H. F. Doutch, pers. comm.) The Pleistocene beach ridges appear to have formed during regression from this sea-level high.

Holocene beach ridges

Distribution

The Holocene ridges are present along most of the coast in the survey area. They can be traced on airphotos northwards as far as the mouth of the Jardine River, and are also present on the Torres Strait Islands and in New Guinea. Southwards they are present around the coast to the Roper River area and there is some patchy development further north.

Morphology

The Holocene ridges show fairly sharp relief, have a cover of small trees, shrubs or grass, and lack deflation features. Airphoto interpretation shows the presence of four sets of ridges, the younger three of which can be traced over most of the west coast of Cape York. The oldest is poorly preserved and can be recognized in only a few places. Within the survey area, the ridges have been mapped out as Qhm_1, Qhm_2, Qhm_3 and Qhm_4, from oldest to youngest (Fig. 1).

The Qhm_1 ridges are low and broad, and have crests, about 2 m above sea level, but they may have been higher originally, the loss in height being due to leaching. The Qhm_2 ridges are extensive and are present along most of the survey area as well as farther north and south. They are 3-4 m above sea level in the Cape Keerweer area, but 5-6 m

Figure 3. Air photograph, Kendal River area. RC9 Series, 1969; HOLROYD Run 2, Photo 46

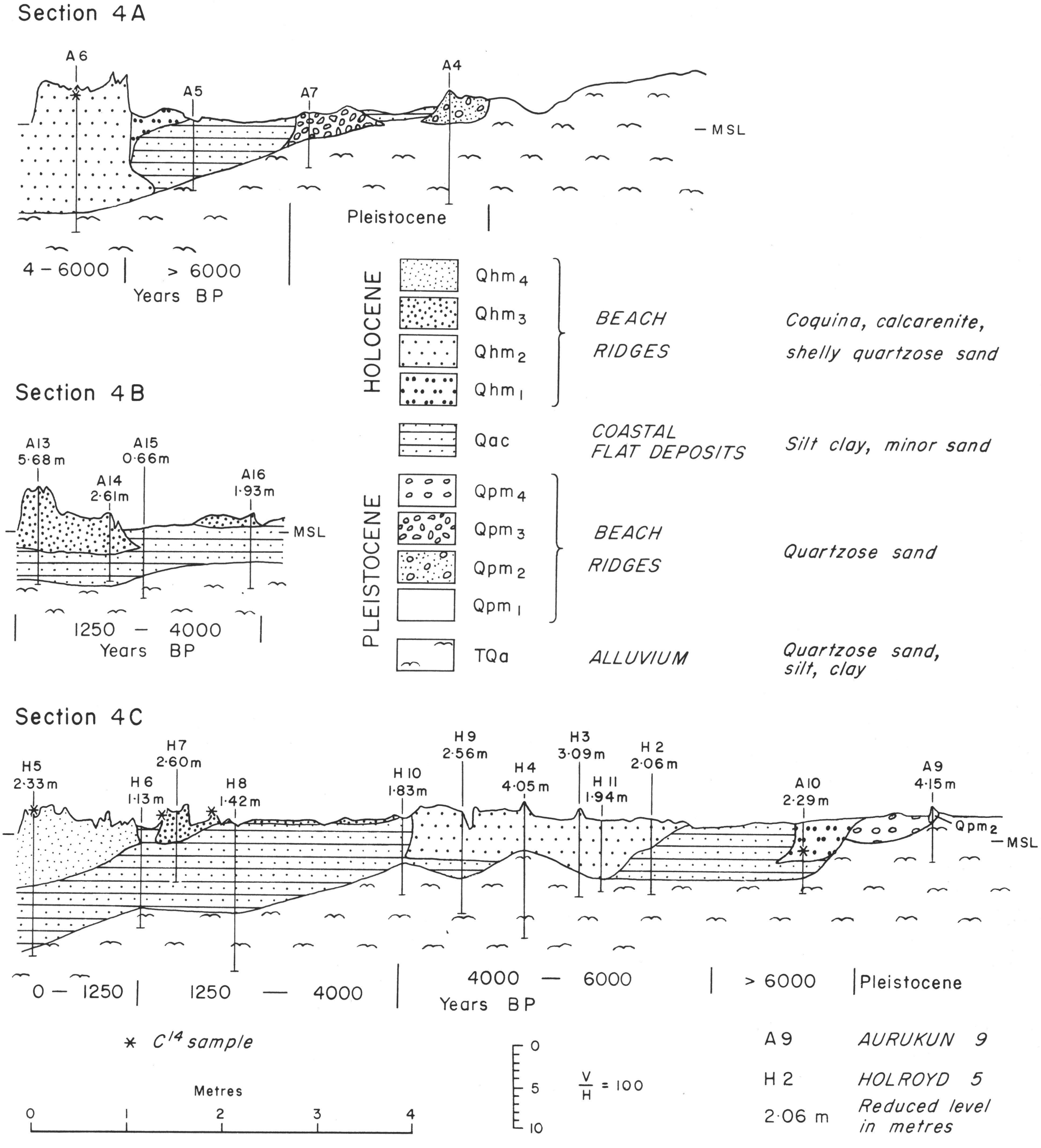

Figure 4. **Cross sections of beach ridges. Locations shown on Figure 1. Detailed drill logs were presented by Smart (1976)**

high farther north, west of Don Yard. The latter are the highest ridges in the survey area. The Qhm_2 ridges have sharper relief than the Qhm_1 ridges, but the relief is not quite so sharp as that of the younger ridges. In several areas fresh-water lagoons have developed in the swales (e.g. Bull Yard Swamp).

The Qhm_3 ridges are extensive and show a marked discordance with the Qhm_2 ridges just north of Cape Keerweer (Fig. 1). They are asymmetric, about 5 m above sea level on the seaward side, and about 2 m on the landward side. Their morphology is slightly sharper than that of the Qhm_1 ridges. Southwest of Don Yard, the Qhm_3 series appears to merge with and slightly overlap the Qhm_2 series.

The vegetation on the Holocene (Qhm) group of ridges is more dense than that on the Pleistocene ridges; the Qhm_1 and Qhm_2 ridges have small trees or large shrubs and the younger ridges have a cover of shrubs only. The ridges nearest to the coast are generally grassed and have few shrubs. On all the Holocene ridges, the trees and shrubs tend to be best developed on the ridge crests, and the intervening swales have a grass cover. Other workers have noted that crests are initially vegetated preferentially to swales, and Bird (1960) suggests that this is due to the lower salinity of the crests (due to more rapid leaching). Russell (1948) noted that the crests of cheniers in Louisiana had better developed soils than the flanks.

The Qhm_4 ridges are present only in the north and south of the survey area. The ridges are about 5 m above sea level and well defined with sharp ridge crests. They appear to be still forming.

Sample No.		*Beach Ridge*	*Lab. No.*	*Location*		*Age*	*Remarks*	
72797020		Qhm$_2$	SU 185	13°53′S;	141°23′E	4130 ± 80		
72797025		Qhm$_4$	SU 202	13°23′S;	141°38′E	1110 ± 85		
72797026		Qhm$_4$	SU 203	13°23′S;	141°38′E	910 ± 70		
72797011	A	Qhm$_2$	SU 201A	13°25′S;	141°41′E	5330 ± 85	bivalves	
	B		SU 201B			4430 ± 85	gastropods	
72797023		Qhm$_2$	NSW 156	13°51½′S;	141°29′E	4060 ± 100	bivalves	
72797506		Qhm$_2$	NSW 158	13°37′S;	141°30½′E	3350 ± 400	bivalves	
73797510		Qhm$_1$	NSW 159	14°00½′S;	141°38½′E	3500 ± 500		
72796243		Qhm$_3$	SU 197A	14°54′S;	141°37′E	1350 ± 75	bivalves	present
			B			470 ± 80	gastropods	beach
72796244		Qhm$_4$	SU 198A	14°54′S;	141°37′E	750 ± 70	bivalves	
			B			980 ± 75	gastropods	
72796245		Qhm$_4$	SU 199	14°54′S;	141°37′E	995 ± 75		
72796246		Qhm$_2$	SU 200	14°54′S;	141°37′E	3935 ± 85		
73797110	A	Qhm$_3$	NSW 120	14°04′S;	141°35′E	1780 ± 70		
73797111	A	Qhm$_3$	NSW 121	14°03′S;	141°36′E	2600 ± 80		
(Holroyd)			SU 427			2580 ± 115		
73797110	A	Qhm$_3$	SU 429	14°04′S;	141°35′E	1760 ± 95	bivalves	
(Holroyd)	B		SU 430			1700 ± 100	gastropods	
	C		SU 431			1790 ± 100	bivalves	
	D		SU 432			2510 ± 140		
73797111	B	Qhm$_3$	SU 428	14°03′S;	141°36′E	2150 ± 100		
7379108		Qhm$_4$	NSW 157	14°04′S;	141°34½′E	500 ± 80	bivalves	
70795047			SU 183	16°42′S;	141°15′E	5630 ± 120		
70795050			SU 184	16°42′S;	141°12′E	820 ± 70		

Table 1. Radio-carbon dating

NSW—University of New South Wales, SU—University of Sydney

Lithology and relationships

The younger (Qhm) ridges consist of slightly clayey, quartzose sand, with some shell sand and whole shells. Shell material is abundant in the Qhm$_4$ and Qhm$_3$ ridges (> 50% in Qhm$_4$) but less so in the older ridges of this group, which generally have no carbonate in the upper part (discussed below). On the ridge tops, a soil profile up to 0.5 m thick is present; its thickness increases with the age of the ridges. The bedding within the ridges is sub-horizontal; no cross bedding has been observed.

The Qhm$_2$ ridges rest on TQa (Fig. 4A, 4C), and their bases are up to 10 m below present sea level. The partly contiguous Qhm$_1$ ridges appear to rest on muddy silt and sand (Qac). The Qhm$_4$ and Qhm$_3$ ridges rest on muddy silt and sand (Qac) as noted by Whitehouse (1963). The base of the Qhm$_4$ ridges are 4-5 m below sea level but those of the Qhm$_4$ ridges range from 3 m below to 1 m above sea level.

The Qhm$_1$ ridges appear to rest on sandy mud and may represent a chenier-type ridge sequence which failed to develop fully because it was superseded by the development of a barrier island, the Qhm$_2$ ridges. The latter fit the barrier island model of Leblanc (1972) very well, being thick sand bodies, formed mainly below sea level, resting on 'basement' and locally having their seaward margin resting on sandy mud.

The Qhm$_3$ and Qhm$_4$ ridges are chenier-type ridges, relatively thin sand bodies, resting on sandy mud. They do not form a classical chenier plain, as ridge development has been almost continuous throughout the latter part of the Holocene, probably due to a fairly constant supply of sediment (cf. Todd, 1968).

Age

Results of C^{14} dating are presented in Table 1 and are summarized below. The Qhm$_1$ ridges have not been dated directly, but by comparison with the Qhm$_2$ ridges, a minimum age of about 6500 years B.P. seems likely. E. G. Rhodes (pers. comm.) has obtained an age of 6440 years B.P. for the most inland ridge north of Edward River. The latter date, combined with dates of marine sediments, led Smart (in prep.) to suggest the sea reached its present level at about 6500 to 7000 years B.P. The Qhm$_2$ ridges have ages of between 4130 and 4330 years B.P. in the survey area, and slightly older farther south (5630 years B.P.), so that a time span of 4000-6000 years B.P. seems probable. The time represented by the erosion between Qhm$_2$ and Qhm$_3$ sequences north of Cape Keerweer is uncertain. Ages for the Qhm$_3$ ridges go back to 2500 years B.P. in the survey area, but this specimen appears to be in the middle of the sequence. A specimen from the landward side of the sequence at Edward River Mission gave an age of 3935 years B.P. The youngest ages are about 1250 years B.P., giving a time span of 1250 to about 4000 years B.P., which suggests probable continuity of deposition without a break. The absence of Qhm$_2$ ridges between Cape Keerweer and Don Yard may have been due to erosion contemporaneous with beach-ridge formation to the south, or more likely, to non-deposition. The youngest ridges, Qhm$_4$1, have given ages between 1110 and 500 years B.P., which fits well with the ages of the Qhm$_3$ ridges.

The ages obtained for the Holocene ridges generally form a logical sequence, oldest inland and progressively younger seawards, which suggests that the ages are reliable. However, the age obtained for the Qhm$_1$ ridge west of Ti-Tree is younger than those obtained from the Qhm$_2$ ridges elsewhere. The sample was shell fragments, of mixed species, picked out of drill cuttings, from a level below the present water table. It is therefore suggested that the date is unreliable because of the mixture of material and the probability of contamination by younger carbonate.

It should be realized that the dates obtained are those of the death of the organism and that there may be a time lag between this and the incorporation of the shell in a beach ridge. In addition, reworking of a pre-existing ridge will lead to the incorporation of shells much older than the ridge itself. However, the logical sequence of ages obtained, from 500 years B.P. to over 6000 years B.P. suggests that these effects have not been significant in this area.

A sequence of Late Pleistocene and Holocene beach ridges is known elsewhere in Australia and is present along much of the southeast coast of the continent (e.g. Bird, 1965; Langford-Smith & Thom, 1969; Cook & Polack, 1973). Cook & Polack compared ages of individual ridges at Broad Sound on the east coast of Queensland with ages of Holocene beach ridges from other parts of the world and could find no direct correlation.

The rapid progradation of the coast after about 4 000 years B.P. (Qhm_3 and Qhm_4 sets) corresponds in time to increasing aridity in the Atherton Tableland to the southeast (Kershaw & Nix, in prep.) and the greater aridity, if present in the Peninsula, may have caused a higher rate of erosion and consequent supply of sediment.

Leaching

The removal of carbonate from beach ridges by leaching is a common process and has been severally reported (e.g. Salisbury, 1925; Russell, 1948; Bird, 1965). Salisbury (1925) showed that the carbonate content of sand dunes dropped from over 6 percent to zero in less than 300 years in a cool wet climate. Bird (1965) reports a steady reduction of soil pH with age and a consequence change of plant species on beach ridges in Victoria. Smart (1976) described a costean into a Holocene ridge (Qhm_3) west of The Lake which showed a cemented horizon at the dry season water table. He concluded that the cementation was due to the precipitation at the water table of carbonate leached from the upper part of the profile. If the process continued, the final profile would be a leached zone devoid of carbonate, over a hard pan of carbonate-cemented sand and shells (a 'groundwater podzol' of Stephens, 1962).

The bed of the Gulf of Carpentaria adjacent to the Holocene beach ridges is underlain by a shelly sandy mud (mapped as Qcm by Smart, in press, a, b) and the sand and shells of the Holocene ridges were derived by the winnowing of this by wave action. Similarly, the Pleistocene ridges had an analogous offshore provenance in the calcareous sandy clay which has subsequently been indurated during the late Pleistocene (Smart, *op. cit.*). However, the Pleistocene ridges are now essentially devoid of carbonate although their original composition was presumably similar to that of the Holocene ridges. It is therefore inferred that they have undergone leaching since their formation. Pleistocene ridges in South Australia contain abundant carbonate (P. J. Cook, pers. comm.), but the present rainfall in that area is less than half that of the survey area, and average temperatures are lower.

The Holocene ridges show a decline in carbonate content landwards, and an increasing depth of leaching. Drilling in 1973 showed a relatively low carbonate content in Qhm_1 and Qhm_2 ridges, but no indurated horizons were detected. The groundwater podzolization process has not proceeded to finality in the survey area; the reason is uncertain.

Sea levels

It is difficult to infer from the section of a beach ridge the sea level at which it was actually formed. Some chenier-type ridges have most of their volume above sea level, while others have a considerable volume below it (e.g. Fig. 4C); similarly with the barrier island ridges (Fig. 4A, 4C). In addition, leaching of carbonate may greatly reduce the volume of the ridge. It is not possible in this area to find evidence for or against a slightly higher sea level in the early Holocene as postulated by others in northern Queensland (e.g. Hopley, 1968, 1971). However, most workers do not accept a worldwide Holocene sea level high (e.g. Thom *et al.*, 1969, 1972).

Conclusions

1. The Pleistocene beach ridges formed as a series of barrier island complexes during a sea level high of at least 4-5 metres above present. By comparison with ridges in southeast Australia their age is probably around 120 000 years B.P. Subsequently sea level dropped, and was below the present level until the Holocene transgression.
2. The sea reached its present level or slightly higher about 6500-7000 years B.P., and small localized ridges developed (Qhm_1) associated with fairly rapid progradation of the coast. The transgression corresponds in time to the great increase in rainfall noted by Kershaw (1975).
3. From about 6000 to 4000 years B.P., a barrier island complex (Qhm_2) developed, but was probably absent in the central part of the area. Lagoonal sediments accumulated landward of the complex.
4. There was an increase in sediment supply and rapid progradation of the coast (over 6 km at Cape Keerweer) from about 4000 years B.P. to the present and chenier-type ridges developed in two sets (Qhm_3 and Qhm_4).

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