THE HOLOCENE EVOLUTION OF RHEBAN SPIT, TASMANIA

1. Age structure, geomorphic development and sediment characteristics

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(with four tables and five text-figures)

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Rheban Spit is a small prograded sand barrier located on the east coast of Tasmania in the lee of Maria Island. It consists of four disconformable sets of beach ridges. Shallow drilling at seven sites towards the eastern end of the spit yielded sediment samples for mineralogic and granulometric analyses and detrital shell for radiocarbon dating. The latter indicates that the three oldest sets of ridges were formed about 5 500, 4 200 and 3 100 calendar years ago, while the youngest set is known to have formed this century.

This age structure is unusual for a coastal barrier in eastern Australia because most started to prograde at the end of the Postglacial Marine Transgression (c. 7 000 calendar years ago) and ceased about 2 000 years ago. Rheban Spit has been severely eroded by northeasterly waves during its formation, probably as a result of periods of increased storminess in the Tasman Sea. If the sand isthmus between north and south Maria Island was also removed during these episodes, wave refraction/diffraction and sediment movement patterns near the eastern end of Rheban Spit would have changed significantly and this may account for the disconformable nature of the successive sets of beach ridges which form the spit.

Key Words: Rheban Spit, Tasmania, beach-ridge plain, coastal sand barrier, age structure, sediment characteristics.

INTRODUCTION

The distinctive beach-ridge patterns of Rheban Spit have attracted the attention of a number of coastal geomorphologists (Jennings 1955; Davies 1959, 1961, 1971; Thom *et al.* 1981a). Others have investigated vegetation distribution on the spit (Bowden & Kirkpatrick 1974) and podzol soil development within its sediments (Bowman 1979). The present paper is derived from the latter unpublished thesis, together with the revised radiocarbon data of Thom *et al.* (1981a) and more recent radiocarbon calibration tables, neither of which have been previously used to interpret the evolution of Rheban Spit.

The aim of this paper is to document the age structure of Rheban Spit, to examine the characteristics of the sediments forming the spit and to reconstruct its geomorphic evolution. A complementary paper discusses soil development within Rheban Spit (Bowman in press) using the age framework and sediment data provided here.

Rheban Spit is situated within Mercury Passage on the east coast of Tasmania, about 60 km northeast of Hobart (fig. 1). The Spit is subject to refracted waves approaching from both the north and the south along Mercury Passage but is more exposed to the northerly approach (Jennings 1955). The dual wave approach, combined with the irregularity of the bed of Mercury Passage (fig. 1) and the proximity of Lachlan Island, results in a complex wave refraction/diffraction pattern around the spit.

METHODS

Field Sampling

Large scale aerial photographs were used to examine and map the beach-ridge patterns on Rheban Spit, as well as the disconformable boundaries between the various sets of ridges. This was verified by field examination and was found to be similar to the map of Bowden & Kirkpatrick (1974, fig. 1).

Six sampling sites were located on a transect line previously established across the spit by Bowden & Kirkpatrick. This line intersected four discrete sets of beach ridges (fig. 2) and its use facilitated comparisons with the published soil, vegetation and topographic data. An additional sampling site (Site 2, fig. 2) was established 500 m off the transect line so that the full age range of the most extensive set of beach ridges could be included in the study.

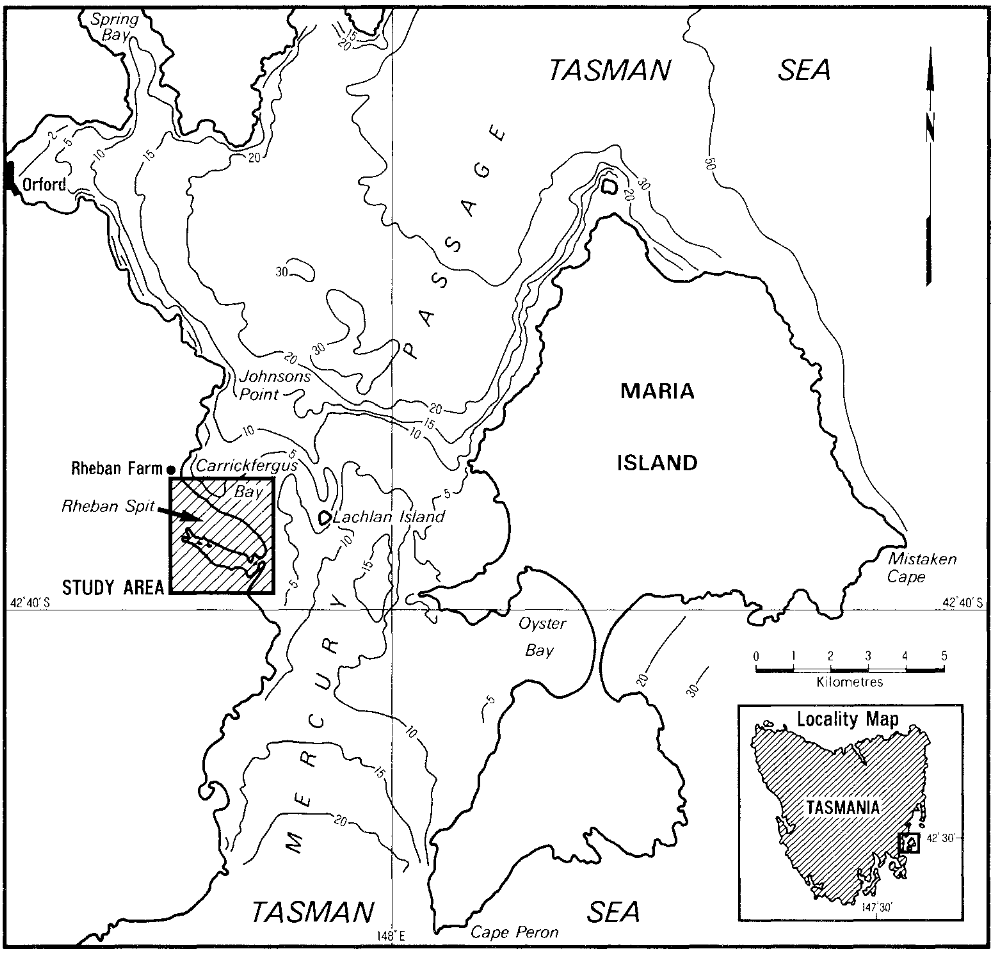

FIG.1 — Location map. Submarine contours in metres.

At each site sediment samples were obtained from pits, then a hand auger was used to sample down to the watertable. Below this level a hand-operated sludge pump yielded samples that were sieved in the field to separate comminuted pieces of shell or wood (.2 mm diameter) for radiocarbon dating (Thom *et al.* 1978).

Radiocarbon Analysis

The use of radiocarbon dating to determine the age structure of coastal barrier deposits in southeastern Australia has been documented by Thom *et al.* (1978, 1981a,b) and a review of other Australian applications of the technique is given in Bowman & Harvey (1986). Radiocarbon dates of shell material incorporated into regressive barrier sediments provide maximum ages for the deposition of those sediments, although systematic studies in several areas of Australia (Thom *et al.* 1978, 1981a,b; Bowman 1979; Bowman & Harvey 1986) have explicitly assumed that the delay between the death of the shell and its incorporation into the barrier sediments was not greater than the statistical error inherent in the radiocarbon age determination. If this assumption is correct for Rheban, the (maximum) ages obtained should closely approximate the true ages of sediment deposition. For a discussion of this problem see Nielson & Roy (1982), Thom *et al.* (1981a) and Thom & Bowman (1982).

Samples were submitted to Geochron Laboratories and the University of Sydney Radiocarbon Laboratory for age determination (GX- and SUA- respectively, table 1). Shell-hash samples were subjected to an HCl surface etch before CO_2 was evolved under vacuum for purification and conversion to benzene. The wood sample (SUA-768/2 was burnt in pure oxygen to produce CO_2. Sample activities were measured with liquid scintillation counters using as the modern reference standard 95% of the ^{14}C activity in 1950 of NBS oxalic acid, normalized to $\delta^{13}C$ = -19.0°/oo with respect to PDB (d^{14}C°/oo, table 1). The measured relative ^{14}C activity of each sample was corrected for isotopic fractionation to the base of terrestrial wood ($\delta^{13}C$ = -25.0°/oo w.r.t. PDB; Stuiver & Polach 1977) using the appropriate measured or estimated value of $\delta^{13}C$ as indicated in table 1 (Polach 1976, Thom *et al.* 1978).

Ages were calculated using the Libby half-life of 5568 years and, following the definitions of Thom *et al.* (1981a), the non-reservoir corrected shell dates are referred to as *apparent ages* (yrs b.p.) and the wood date as a *conventional age* (yrs b.p.*). The error terms represent ±1 standard deviation, based on sample, background and standard uncertainties. Subtraction of the revised oceanic reservoir correction for southern Australia of 480 ± 30 yrs (Bowman 1985) yields conventional ages for the shell samples. All conventional ages have been converted to *calibrated ages* (yrs B.P.) using the dendrochronology-based tables of Klein *et al.* (1982). However, rather than express each date as an age range representing a 95% confidence interval (following Klein *et al.* 1982), the mid-point of each age range is quoted in table 1, together with a 2σ error term (which closely approximates the original 95% confidence interval). These calibrated ages relate to the linear calendar time scale (unlike the non-linear radiocarbon time scale) and employ enlarged 2σ error terms to conform with the usual statistical use of confidence levels.

Granulometric and Mineralogic Analyses

Granulometric statistics for each sediment sample were computed by the *method of moments* (modified from Griffiths 1967), the data being obtained by mechanically sieving 100 g oven-dried samples through half-ϕ sieves for 15 minutes and weighing the resulting size fractions to 0.01 or 0.001 g (Griffiths 1967, pp.61-64). None of the samples yielded significant amounts (>0.001 g) of non-organic material finer than 4.00ϕ (i.e. mineral silt or clay).

Mineral composition of the sediment was determined by examining HF-etched, sodium cobaltinitrate-stained grains, previously mounted on glass slides (Bailey & Stevens 1960, Friedman 1971). Quartz, feldspar, heavy minerals, lithics (rock fragments and micas) and shell carbonate were differentiated by binocular microscope. Percentage composition of these components was determined from a count of >1 000 grains per slide, yielding stable and accurate estimates of mineral content (Griffiths & Rosenfeld 1954, Chayes 1956).

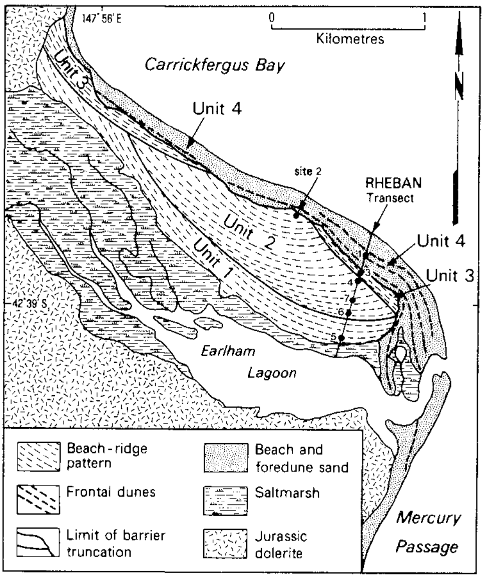

FIG.2 — Map of Rheban Spit showing depositional units and sampling sites.

BARRIER MORPHOLOGY

Rheban Spit is a small sand barrier with an area of 1.83 square kilometres. It is attached to bedrock at its northwestern extremity and is aligned roughly NW-SE (fig. 2). The spit confines Earlham Lagoon and surrounding marshland on its southwestern side and is bordered by Carrickfergus Bay and Mercury Passage on its northwestern and eastern sides, respectively.

Although morphostratigraphically a *prograded bay barrier* of the type described by Thom *et al.* (1978, 1981a), Rheban Spit is unusual in that successive phases of progradation and erosion have resulted in distinctive sets of beach ridges, each with a slightly different orientation and pattern to the preceding sets (fig. 2). Jennings (1955) attributed differences in the orientation of the Spit to varying

TABLE 1
Radiocarbon Age Determinations for Rheban Spit

Site & Lab. Number	Material	$\delta^{13}C^{o}/_{oo}$ w.r.t. PDB	$d^{14}C^{o}/_{oo}$ w.r.t. 0.95 NBS ox.	$D^{14}C^{o}/_{oo}$ w.r.t. 0.95 NBS ox.	Apparent Age yrs b.p.±1σ	Conventional Age yrs b.p.*±1σ	Calibrated Age yrs BP±2σ
R-2 GX4020	Shell hash	+1.2	−354.6±11.9	−388.4±11.3	3950±150	3470±150	3810±320
R-3 GX4021	Shell hash	0.0	−314.5±11.8	−348.7±11.3	3445±140	2965±140	3140±370
R-3 SUA768/1	Shell hash	#+1.0±1.0	−384.8±9.3	−416.8±8.9	4330±125	3850±130	4310±420
R-3 SUA768/2	Wood	#−25.0±2.0	−96.6±13.3	−96.6±13.3	N.A.	815±125	770±150
R-4 GX4363	Shell hash	#+1.0±0.5	−416.4±12.6	−446.7±12.0	4750±180	4270±180	4890±530
R-5 GX4022	Shell hash	+1.3	−445.0±10.1	−483.7±9.6	5310±150	4830±150	5570±270
R-6 GX4364	Shell hash	#+1.0±0.5	−384.5±12.5	−416.5±11.9	4330±170	3850±170	4310±420
R-7 GX4265	Shell hash	#+1.0±0.5	−385.1±9.1	−417.1±8.6	4340±120	3860±120	4330±270

Terminology is explained in the text and conforms with the usage of Thom *et al.* (1981a) except that the revised oceanic reservoir correction of 480 ± 30 years for southern Australian coastal waters.
(Bowman 1985) has been used to calculate the conventional ages. Note also that the enlarged error terms for the calibrated ages represent a 95% confidence interval. GX = Geochron Laboratories; SUA = Sydney University Radiocarbon Laboratory; N.A. = not applicable; # = estimated

exposure to dominant wave approach, but Davies (1959) noted that this does not adequately explain the greater concavity (in plan) of the older beach-ridge sets. Davies suggested that bathymetric changes in Mercury Passage and Carrickfergus Bay caused by a slight fall in sea level were probably responsible for the different patterns. However, during all phases of beach-ridge formation at Rheban accretion appears to have been in a shore-normal direction, rather than shore-parallel. This is apparent from the lack of ridge recurvature (fig. 2) and from a comparison of 1946 and 1966 aerial photographs of the spit, which show the development of the modern foredune ridges (Bowden & Kirkpatrick 1974, fig.1).

The latter study identified three discrete sets of beach ridges, plus the sets of modern foredune ridges. These sets are depicted as progradational Units 1 to 4 in figs 2 and 3. The erosional boundaries between the four units are herein referred to as *truncation limits* after Bowman (1979).

There is some disagreement in the literature as to the overall slope of the surface of Rheban Spit. On the basis of a transect surveyed across the northwestern end, Davies (1961, fig. 6) claimed that the barrier sloped down towards Earlham Lagoon whereas a survey by Bowden & Kirkpatrick (1974) across the southeastern end of the spit showed that it sloped down in the opposite direction towards Carrickfergus Bay (fig. 3). The latter authors maintained that this trend applied along most of the length of the spit, with the exception of the northwestern part surveyed by Davies. However, the two surveys do show that the average elevation of the barrier is approximately 3.5 m above MSL, that in the southeastern section some swales are only one or two metres above MSL, while the frontal dunes rise to over 6 m. Differences in ridge and swale elevations appear to be greatest at the southeastern end of the spit.

AGE STRUCTURE AND GEOMORPHIC DEVELOPMENT

The following reconstruction of the evolution of the regressive (progradational) beach-ridge units at Rheban is based on beach-ridge and truncation limit patterns, radiocarbon age determinations (table 1), and morphological observations by the author and Bowden & Kirkpatrick (1974). Evidence of Pleistocene deposits or Holocene transgressive lithofacies were not found during the fieldwork or the shallow drilling at Rheban.

The initial phase of Holocene barrier progradation at Rheban resulted in a beach-ridge plain which was probably quite extensive: at least as long as the present composite spit, and possibly as wide. The remnant of this initial progradational unit constitutes 25% of the area of the present spit (46.5 ha) and is shown as Unit 1 in figure 2. It consists of a narrow group of comparatively straight beach

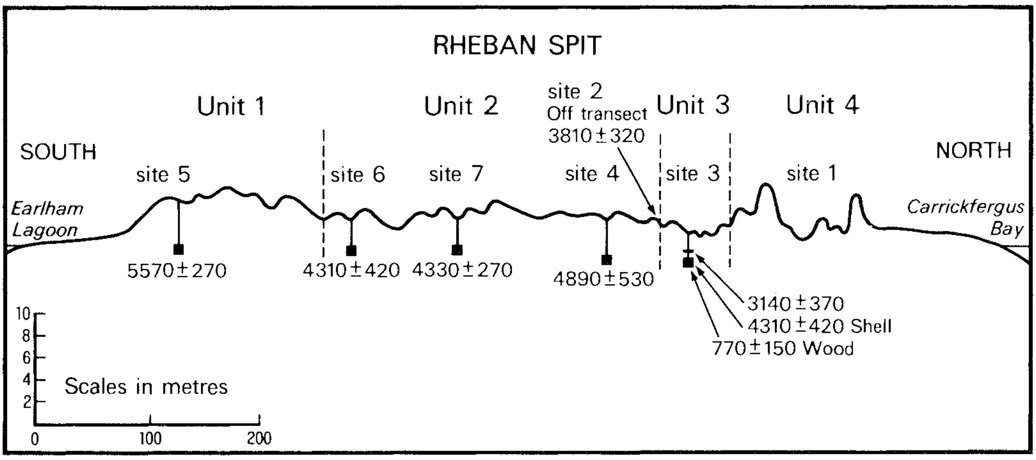

FIG.3 — Cross-section showing position of radiocarbon dated samples and ages in calendar years B.P. (± 2σ).

ridges along the rear of the spit, bordering the northern side of Earlham Lagoon. These ridges are quite distinct at the northwestern end of the spit, where they are obliquely truncated by a later beach-ridge sequence (Unit 3). Along the remainder of the barrier they tend to be less distinctive in plan but are quite distinctive in profile (fig. 3), and the junction with the ridges of Unit 2 is readily discernible.

Only one ^{14}C sampling site was established within progradational Unit 1 (Site 5). Shells from just below MSL at Site 5 were dated at 5 570 ± 270 yrs BP (GX-4022). This is somewhat younger than the initial progradational phase of many other Holocene barriers in eastern Australia (Thom *et al.* 1981a, b), most of which started to prograde soon after sea level stabilized following the Postglacial Marine Transgression, about 7 000 yrs BP.

The beach ridges in Unit 2 are slightly more curved in plan than those of Unit 1, and obliquely abut the latter along their common truncation limit (fig. 2). Radiocarbon dating of incorporated shell also differentiates Unit 2 from Units 1 and 3. Unit 2 comprises a larger proportion of the present spit (34%) than the remnant of any other progradational unit. Because of its width, a large age range was anticipated for the unit and four sites were established within its area, three on the transect line (Sites 6, 7 and 4) and one (Site 2) on the most seaward (youngest) beach ridge (see fig. 2). However, the radiocarbon ages do not support the anticipated age range. Shell hash from Site 6, at the rear of Unit 2, yielded an age of 4 310 ± 420 yrs BP (GX-4364) whilst the sample from Site 2 was dated at 3 810 ± 320 yrs BP (GX-4020), giving an age range of only 500 years for the unit.

The position of Site 4 in relation to the other sites within Unit 2 indicates that the date of 4 890 ± 530 yrs BP (GX-4363) obtained on shell from this site is out of progradational sequence and should be regarded as somewhat "anomalously old" (Thom *et al.* 1978, 1981a). However, application of the z and T statistics (Gillespie 1975, 1982) indicates that this date is not significantly different (at the 0.05 confidence level) from the ages of shell from either Site 6 or 7, although in the latter case the critical values are closely approached (table 2). On the basis of the anomalous age it would seem reasonable to reject the date for Site 4 and to calculate an error-weighted pooled mean age (Polach 1976) for Unit 2 incorporating dates from Sites 6, 7, 2 and 3 (SUA-768/1). The result is a mean age (± 2σ) of 4 180 ± 170 yrs BP. Both this average age for Unit 2 and the date from the progradationally oldest site in Unit 2 (Site 6) are statistically significantly younger (at the 0.001 level) than the 5 570 ± 270 yrs BP date obtained for Unit 1 ($z = 8.7$ and 5.05, $T = 75.9$ and 25.5, respectively).

Unit 3 is easily distinguished on air photos by its beach-ridge pattern, which more closely parallels the present shoreline than the ridge patterns of Units 1 and 2. Unit 3 truncates most of the beach ridges in Unit 2, and is itself truncated by the Unit 4 frontal dunes along part of its (former) length (fig. 2). Unit 3 now comprises only 10% of the spit, consisting of a few beach ridges, most of which are

TABLE 2

Statistical Significance Matrix for Radiocarbon Dates from Unit 2

^{14}C age **(± 2σ)**	**Site 6** **4310 ± 420**	**Site 7** **330 ± 270**	**Site 4** **4890 ± 530**	**Site 2** **3810 ± 320**	**Site 3** **4310 ± 420**
Site 6 4310 ± 420	—	z = 0.08 T = 0.01	z = 1.72 T = 2.94	z = 1.89 T = 3.59	z = 0 T = 0
Site 7 4330 ± 270		—	z = 1.88 T = 3.55	z = 2.48* T = 6.17*	z = 0.08 T = 0.01
Site 4 4890 ± 530			—	z = 3.49* T = 12.17*	z = 1.72 T = 2.94
Site 2 3810 ±320				—	z = 1.89 T = 3.59

Asterisk indicates z and T values statistically significant at 0.05 level and d.f. = 1. With one degree of freedom (where d.f. = n-1) the critical values for the z statistic at the 0.05, 0.01 and 0.001 confidence levels are 1.96, 2.58 and 3.2, respectively. The corresponding critical values for T (with the Chi squared distribution) are 3.84, 6.64 and 10.83.

low in elevation and rather difficult to distinguish on the ground. The northwestern and southeastern remnants of Unit 3 have been tentatively correlated on the basis of their surface morphology, stratigraphic position and orientation. Where the transect line intersects the southeastern segment of Unit 3, a single sampling site was established (Site 3), the elevation of which is only 1.4 m above mean high water level (fig. 3).

Three radiocarbon dates have been obtained on material from Site 3. Shell hash from 1.5 m below the groundsurface (just below MHWL) yielded a date of 3 140 ± 370 yrs BP (GX-4021), while shell hash from 2.5 m was dated at 4 310 ± 420 yrs BP (SUA-768/1). Although significantly different at the 0.1% confidence level (z = 4.18, T = 17.5), the two dates are not mutually inconsistent in terms of their stratigraphic position. Site 3 was located close to the truncation limit between Units 2 and 3 (but definitely within Unit 3, see figs 2 and 3). The date on the upper stratum shells (3 140 ± 370 yrs BP) relates to the initiation of Unit 3, whereas the lower stratum date (4 310 ± 420 yrs BP) is associated with the underlying shell and sediments of Unit 2. The latter date is not significantly different from the dates obtained from Sites 6, 7, 4 and 2 (see table 2) and therefore fits very well within the age structure of Unit 2. For this reason it was incorporated in the calculation of the mean age for Unit 2.

A third date from Site 3 (SUA-768/2: 770 ± 150 yrs BP) was obtained on wood fragments separated from the shell hash used to yield SUA-768/1. However, this anomalously young date relates to dead *in situ* tree roots and not to wood debris deposited with the sediments.

The fourth progradational unit at Rheban consists of a set of frontal dunes which are parallel to the present shoreline and comprise about 23% of the present Spit. Bowden & Kirkpatrick (1974) compared 1946 and 1966 aerial photographs of Rheban and concluded that during this period the spit had accreted considerably at the southern end and that some erosion had occurred near the northern end. They found that two frontal dunes had formed near the southern end since 1946 AD and that the older frontal dunes were undifferentiated from them. As all the frontal dunes are still subject to active sand movememt to some degree, Unit 4 has been assigned a geomorphic age of zero years (Bowman 1979).

SEDIMENT CHARACTERISTICS

Results of the granulometric analyses indicate that the sediment forming Rheban Spit is very well sorted, fine to medium sand (Krumbein 1938), with an overall mean grain size (all samples) of 2.14ϕ (0.23 mm) and a standard deviation of 0.10ϕ. The homogeneity of the sediment is apparent from table 3, in which the pooled mean grain size and sorting coefficients (standard deviations) of three lower samples from each site are compared. Sites 2 to 7 (from progradational Units 1, 2 and 3) differ

TABLE 3

Granulometry of Selected Rheban Sediment Samples

Progradational Unit	Approx. Age (yrs)	Sampling Site	Mean Grain Size ($x\phi$)	Coefficient of Sorting ($\sigma\phi$)
1	5500	5	2.02	0.16
2	4200	6	2.08	0.18
2	4200	7	2.15	0.17
2	4200	4	2.19	0.16
2	4200	2	2.15	0.19
3	3100	3	2.11	0.21
4	0	1	2.34	0.17

little in terms of their mean grain size or sorting coefficients and these differences are not statistically significant at the 5% confidence level ($z = 1.39$ max.).

A plot of mean grain size against standard deviation (sorting) is given in figure 4 for *all* Rheban sediment samples, except those near-surface samples which contained organic matter. This indicates that the sediment characteristics of progradational Units 1, 2 and 3 are very similar with the distribution fields overlapping, but that the Unit 4 samples form a discrete cluster near the top of the diagram. A general decrease in grain size (increase in $x\phi$) and a slight improvement in sorting (decrease in $\sigma\phi$) are evident if the progradational units are compared in order of decreasing age (Units 1, 2, 3 and 4 respectively).

The contrast between the Site 1 (Unit 4) sediments and those from the other Rheban sites is also reflected in the mineralogical composition. The percentage composition of quartz, feldspar, heavy minerals, lithics and shell carbonate for the deepest samples from each site are given in table 4. Variations between Sites 2 to 7 are slight, but the Site 1 quartz percentage is markedly lower than for the other sites, with the corollary that the proportions of feldspar, heavy minerals and shell carbonate are higher. The content of lithics does not appear to vary between the sites, but the resolution of the data precludes a definitive statement (Griffiths 1967).

DISCUSSION

In several respects Rheban Spit differs from other Holocene sand barriers in southeastern Australia. Whereas other prograded beach-ridge plains are composed of conformable ridges which are usually subparallel to each other and display little evidence of truncation or depositional hiatuses (Thom *et al.* 1978, 1981a), Rheban consists of

TABLE 4

Mineralogy of Selected Rheban Sand Samples

Progradational Unit	Approx. Age (yrs)	Sampling Site	Quartz %	Feldspar %	Heavy Minerals %	Lithics %	Shell Carbonate %
1	5500	5	96.8	2.0	1.1	0.1	—
2	4200	6	96.4	2.7	0.9	—	—
2	4200	7	96.5	2.5	1.0	0.1	—
2	4200	4	96.0	3.1	1.0	—	—
2	4200	2	97.4	2.0	0.2	0.4	—
3	3100	3	95.6	2.7	1.5	—	0.2
4	0	1	90.8	4.1	3.5	0.1	1.5

discrete sets of beach ridges, each of which is disconformable with the other sets. Morphological studies of Holocene barriers on other parts of the Australian coast indicate that conformable beach-ridge patterns predominate, although disconformable sets of beach ridges (as opposed to cheniers) have been reported from Western Australia (Shepherd 1981) and the Gulf of Carpentaria (Smart 1976).

Another point of contrast between Rheban Spit and other east Australian barriers is the delay that occured at Rheban between the termination of the Postglacial Marine Transgression and the initiation of regressive sedimentation. Many Australian barrier studies have shown that progradation of regressive lithofacies soon followed the stabilization of the sea at approximately its present level (Thom *et al.* 1978, 1981a, b; Bowman & Harvey 1986). In the majority of documented cases this sediment flux was rapid and prolonged and resulted from an equilibrium adjustment of the nearshore/onshore profile to the large quantities of sediment that had been swept up from the continental shelf by the transgressive sea (Thom 1984, Thom & Roy 1985).

Several alternative explanations could account for the apparent delay in progradation at Rheban. Firstly, it is possible that sedimentation did commence immediately after the Postglacial Marine Transgression but that this deposit was subsequently completely removed by erosion. Alternatively, deposition did not take place at Rheban prior to the formation of depositional Unit 1, and the time lag was caused by a lack of sediment accompanying the transgressing sea. This explanation would probably require the floor of Mercury Passage to have had only a minimal sediment cover during times of glacial low sea level. It is possible that the transgressing sea did bring sediment with it, but that it was initially deposited at locations other than Rheban. Given the present relative abundance of sediment around the shores of Mercury Passage this proposition would appear to be feasible. The uniform granulometry and mineralogy of the Rheban sediments indicate that they have been intensively reworked and are of "marine" origin (Roy *et al.* 1980). The slight but consistent granulometric trends apparent across the depositional units also suggest the repeated reworking of a limited reservoir of sediment.

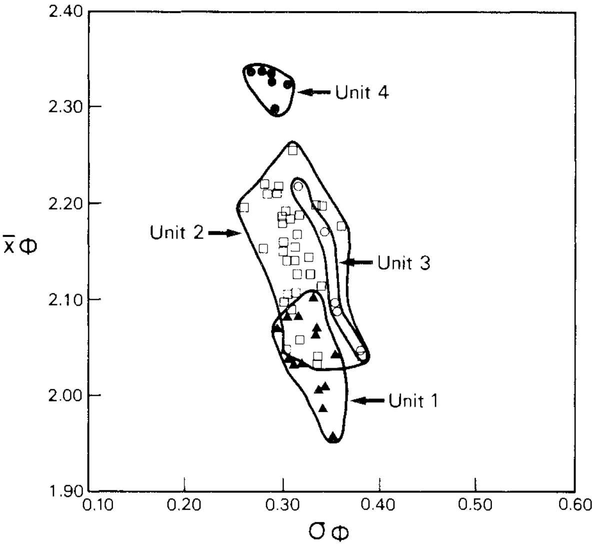

FIG.4 — Plot of mean grain size (± σ) against sorting coefficient (σφ) for selected sediment samples from the four progradational units comprising Rheban Spit.

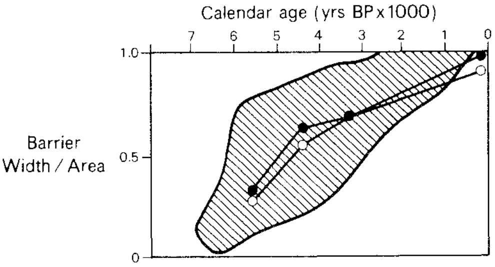

FIG. 5 — Plot against age of proportional barrier width along the cross-section (solid circles) and proportional barrier area (open circles) for progradational units at Rheban Spit. Shaded area encompasses range of barrier width: age values in Thom et al. *(1981b).*

Apart from the delayed start of progradation at Rheban, the sedimentation trends illustrated in figure 5 resemble those of the majority of prograded Holocene barriers reported in Thom *et al.* 1981b, fig. 2), where rapid progradation was followed by progressively slower rates as the initial sediment supply dwindled and was not augmented by fluvial sources or alongshore transport. However, one contrast is apparent: progradation continued until more recently at Rheban than at any of the New South Wales barriers, presumably because of erosion and redeposition of sediment within the littoral compartment (Thom *et al.* 1981b, p.324).

As discrete sets of beach ridges were not identified in the New South Wales barriers, it is not possible to make direct comparisons with progradational events at Rheban. However, the morphology and age structure of the sets of beach ridges at Rheban indicate that progradation was definitely episodic at this locality, that the episodes of sedimentation were temporally discrete, and that they were separated by periods of shoreline erosion. The latter were presumably caused by intense storminess and/or changes in the direction of wave approach, although less likely factors such as tectonic instability cannot be totally excluded. Although the general applicability of these results is not clear, they do represent an advance on the New South Wales studies which were not able to resolve problems associated with episodicity of progradation (Thom *et al.* 1981a, pp.29-30).

It is possible that the initiation of Rheban Spit was linked to the formation of a sand isthmus between north and south Maria Island (fig. 1). Although no information is available on the age structure of this deposit, a reconnaissance survey indicated that the sands forming the small barrier contiguous with the northern end of the isthmus were moderately-well podzolized, whereas the isthmus proper appeared to be free of soil development. It was also noted that the isthmus was subject to severe wave attack on the eastern side; also, evidence of aeolian reworking and washover deposition was abundant. From these observations it was deduced that at least part of the deposit between north and south Maria Island is probably as old as Rheban Spit (i.e. mid-Holocene), but that the narrow and relatively low isthmus has been substantially reworked by wind and wave activity, and could have been completely removed during periods of intense storminess in the Tasman Sea (Thom 1974).

The hiatuses between the depositional units forming Rheban Spit probably reflect three major erosional episodes during which dominant north-easterly storm waves substantially eroded the Carrickfergus Bay shoreline. It is postulated that the subsequent temporary presence of a passage between north and south Maria Island would have significantly influenced wave refraction/diffraction patterns near the eastern end of Rheban Spit. The resulting alteration in sediment deposition patterns might account for the differing orientations and patterns of the Rheban beach ridges.

On the basis of the age structure presented above, the ages of the inferred erosional phases can only be approximated as 5 500-4 200, 4 200-3 100, and <3 100 years BP. Additional dating would more clearly define the age limits of the depositional units at Rheban and might reduce the age ranges for the inferred erosional periods. Drilling and dating of the Maria Island isthmus would probably indicate whether this feature has been instrumental in the formation of Rheban Spit.

The ability to distinguish depositional units within beach-ridge plains by their surface morphology has implications for determining the age structure of such coastal deposits. Where this distinction can be made, radiocarbon dating can be more effectively used to determine an age (or age range) for each depositional unit rather than using dates to differentiate units on a purely statistical basis. Further, as the areal extent of individual depositional units can be measured where they are delineated by surface morphology, it is also possible to calculate the area of sediment accreted during specific time intervals. This is an improvement on the use of "dimensionless barrier width" measured along a single (or at best a few) transect lines (Thom *et al.* 1981a) but is still inferior to actual sediment volumes calculated from detailed stratigraphic and dating information (e.g. Harvey & Bowman in press).

CONCLUSIONS

Rheban Spit is composed of discrete sets of beach ridges which are not mutually conformable in section or plan. Each series of ridges is bound by truncation limits which represent periods of marine erosion, rather than simply periods of non-deposition of sediment. The age structure of the sediments, as determined by radiocarbon dating of detrital shell, shows that discrete sets of beach ridges were deposited approximately 5 500, 4 200 and 3 100 calendar years ago, with another set forming during this century. Reasons for the alternation between erosional and depositional phases are not known, but changes in the beach-ridge patterns could be associated with periodical removal of the isthmus between north and south Maria Island.

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