SOURCES OF SHORE SEDIMENT ON THE NORTH COAST OF TASMANIA

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(with five tables and eight text-figures)

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Following a conclusion that beach sands on the north coast of Tasmania have been subjected to little longshore translocation, an attempt is made to establish their immediate provenance by examining a range of sedimentological characters. It is concluded that most of the sand body was immediately derived from the shelf at and after the postglacial marine transgression. Almost all of the remainder was supplied in the last 6000 years by erosion of coastal bedrock or accession of biogenic carbonate, with little or no contribution from the rivers.
Key Words: Sediment source, shoreline sediment, northern Tasmania.

INTRODUCTION

In a report to be published elsewhere, Davies & Hudson (in press) conclude that the north coast of Tasmania can be divided into three segments (fig. 1), each with a distinctive hinterland lithology, nearshore sediment and morphology. The strong correlation between the characteristics of hinterland and shore within each of the three segments indicates that beach sediments are autochthonous and there has been little if any longshore transport. An unresolved question which is addressed here concerns the extent to which shore sediments in each segment have been supplied most recently from the shelf or from the hinterland and in particular the extent to which rivers have supplied material in Holocene times.

Use of natural tracers to help answer the question of onshore or offshore provenance is made more difficult by the way in which the predominant geological grain everywhere runs at a high angle to the coast. Thus lithology changes along the coast in a manner which facilitates determination of degrees of longshore movement but makes distinction between river, coastal and offshore sources much less easy. At any point on the coast the lithology of catchments, cliffs and offshore outcrops is likely to be the same. In this paper an attempt is made to tackle the question of source by examining the details of sediment variation along the coast and relating these as far as possible to river mouths and coastal outcrops.

THREE COASTAL SEGMENTS

The western segment from Robbins Island to Table Cape is largely backed by arenaceous sedimentary and metamorphic rocks of Precambrian to Cambrian age. However there are outcrops of Tertiary basalt in the river catchments and on the coast at Circular Head. The shore sediments are highly quartzose with little carbonate and very small amounts of ancillary minerals. Of the heavy minerals present, tourmaline, anatase and andalusite are typical components. Prograded, ridged, barrier beaches form an apron occupying most of the shoreline, and estuaries are well filled with marine sand, indicating an abundant sediment accumulation, at least in the mid-Holocene. Levels of wind and wave energy in this segment are particularly low.

A central segment from Table Cape to Point Sorell has a hinterland with extensive sheets of Tertiary basalt, which commonly intersect the coast and crop out offshore. A quartz-deficient hinterland is paralleled by quartz-deficient shore sediments, where carbonate levels are high and rock fragments abundant. Titanaugite and kaersutite are characteristic heavy minerals. Beaches have only small foredunes at the rear and commonly there are pebble ridges at high tide mark, the pebbles originating from fluvioglacial outwash of the bigger rivers in the Pleistocene. Estuaries remain largely unfilled and the coastal sediments are also limited offshore by extensive submarine rock outcrops. This is clearly a segment where sand supply has continued to be meagre and where, in

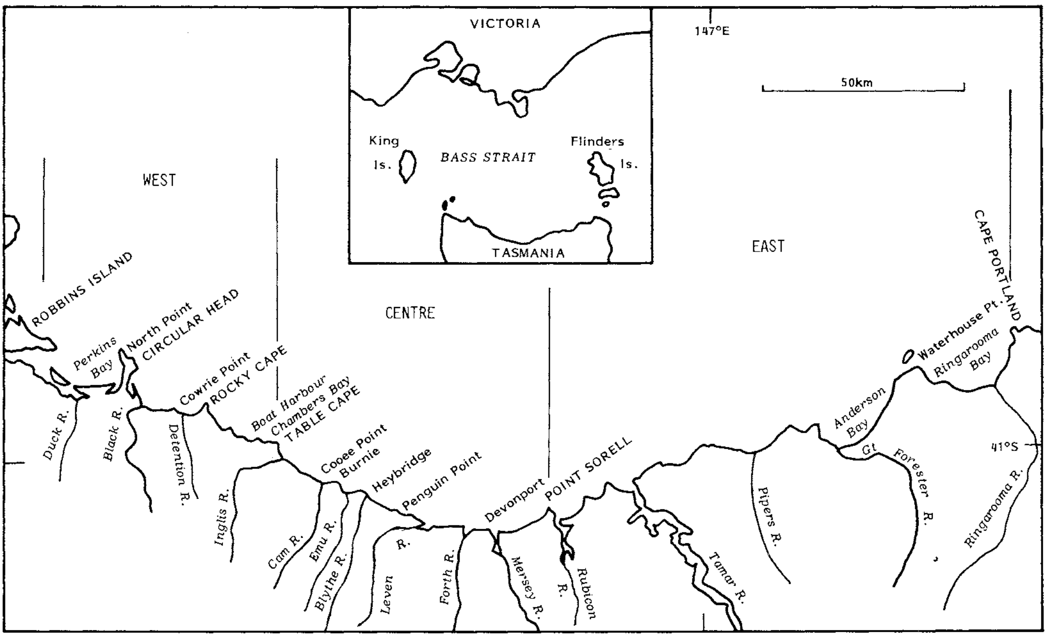

FIG.1 — Location of places and the three coastal segments mentioned in the text.

contrast to the other two segments, coastal outline has been controlled by bedrock rather than by wave forces.

The eastern segment from Point Sorell to Cape Portland is longer than the other two, with higher levels of wind and wave energy. Although there are small outcrops of Tertiary basalt and Jurassic dolerite on the shore, the hinterland is dominated lithologically by Devonian granitic rocks and by Siluro-Devonian sedimentary rocks which are commonly quartzwackes. In consequence shore sediments are rich in quartz and show a markedly higher feldspar content than in the other two segments. Hornblendes and garnets are especially abundant among the heavy minerals present. Beaches are extensive and are offset to the main coastal trend so as to face the most important waves coming from the northwest. They are backed by large transgressive dune systems apparently related to the much greater sand-moving potential of the strongly unidirectional onshore winds in this segment. Estuaries are filled with marine sand and in total there is every evidence of an abundance of shore sediment.

Taken as a whole the north coast of Tasmania, which is about 300 km long, is one of low wave energy. It faces the comparatively sheltered waters of Bass Strait and is shielded from open ocean swell. Important waves are generated by winds in Bass Strait blowing mainly from the northwest. Mean significant wave height falls from about 0.5 m in the eastern segment to about 0.3 m in the west, in contrast to the open ocean coast of New South Wales where the mean is about 1.5 m.

SEDIMENT SOURCES

The three potential sources of shore sediment in northern Tasmania are onshore transport from the shelf (referred to here as "marine"), erosion of the present shore ("coastal") and supply by rivers ("fluvial").

From experience elsewhere in southeastern Australia and indeed most of the world, the bulk of marine sand is likely to have been emplaced at and for varying times after the end of the mid-Recent sea-level rise. In southeastern Australia this is the period from about 6 500 to about 3 500 b.p. (Thom *et al.* 1981a). In northern Tasmania there is direct evidence from radiocarbon dating that the barrier systems of the western coastal segment were emplaced at this time (Thom *et al.* 1981b) and every probability that much of the sediment caught up in the transgressive dunes of the eastern segment had a similar origin. This first major accession of sand from the shelf effectively appears to have ceased by about 3 000 b.p., but much smaller quantities of marine sand in the form of biogenic carbonate have continued to come ashore to the present day.

On a world scale, coastal erosion is usually considered to produce a very small proportion of shore sands except where erodable quartzose rocks occur (e.g. Inman 1960). Ordinarily, fluvial sediments are much more important. However research in southeastern Australia and elsewhere has demonstrated that, except on deltaic coasts, most fluvial supply occurred in the past, probably during low sea levels in the Pleistocene. Relatively little is occurring in the Holocene when most river sands have been trapped in estuaries (see Roy & Thom 1981, for instance, for New South Wales).

A distinction between the petrology of marine and fluvial sands has been made and utilised by a number of authors (e.g. Roy & Crawford 1977, Roy *et al.* 1980, in New South Wales). Because they have been reworked by waves over relatively long periods, marine sands are considered likely to be more rounded, better sorted and have a smaller proportion of less stable grains such as feldspars and rock fragments. Conversely they will have a proportion of carbonate, which is effectively missing in the rivers. Marine sands are also considered by some to be more likely to be iron stained. This has been attributed to subaerial weathering at earlier low sea levels (e.g. Emery 1965) but there are good reasons to believe that staining may occur contemporaneously in submarine conditions (Roy 1983) and the question is returned to in a later section. Sediments derived from marine erosion of bedrock outcrops on the coast are likely to be akin to fluvial sands in appearance — more angular, less well sorted, more lithic, carbonate-free and possibly not stained by iron.

In a situation of close to zero longshore transport, such as is found on the Tasmanian north coast, an assessment of the relative importance of the three sources — marine, fluvial and coastal — may be attempted by examining sediment characteristics along the coast to see whether there is any discernible correlation with river mouths and the lithology of bedrock shores. Characteristics considered in the following sections are carbonate content, sand size and sorting, quartz roundness, iron staining of quartz and carbonate, and mineralogy.

The data are derived from 165 beach samples taken to a depth of 100 mm from the mid-swash point with tidal range at springs varying from 1.8 to 3.3 m. Every beach is represented at least once, the longer ones many times. Also considered for comparison are 32 river samples in which sufficient sand for analysis was recovered, and 75 samples from the inner shelf beyond the nearshore zone.

CARBONATE CONTENT

There appear to be three probable reasons why there might be a connection between river mouths and low carbonate content in neighbouring beach sands. First, it may result directly from recent sand supply by the river itself so that marine or estuarine carbonate is diluted. Second, it may result from recycling of older leached coastal sands in the embayment associated with the river mouth, since sediments from previous depositional phases are often retained in such locations. Third, it may be a consequence of enhanced carbonate production on rocky offshore substrates between river mouths. It is extremely likely that at least echinoderms and bryozoans are more productive in these areas than in those adjacent to estuaries. The three factors are not mutually exclusive and weight should be given to all three when interpreting variations in the carbonate content of beach sands.

Figure 2 shows carbonate distribution in beach sands as measured by acid digestion. It also shows a breakdown between grains recognised as molluscan in origin and those recognised as non-molluscan — mainly echinoid, foraminiferoid and bryozoan. Unrecognisable grains have been included with the molluscan total in figure 2 since they were thought most likely to have had such an origin, but this means that the non-molluscan proportion has been artificially depressed by some variable and unknown amount. It should also be borne in mind that sample variability makes it unwise to read too much into the smaller inequalities in figure 2.

With these reservations we believe that some broad conclusions can be drawn, best considered perhaps in terms of the three coastal segments described earlier and indicated in figure 2. The sands of the western segment have low ambient levels of carbonate which occur throughout the major embayments and are unrelated to the estuaries of individual rivers. The low levels are almost certainly a result of the mass of the sand having been recycled from Pleistocene barrier systems from which carbonate had already been leached. The remains of such systems occupy most of the lowland through which flows the Duck River, outcrop in Duck Bay and at low sea levels in

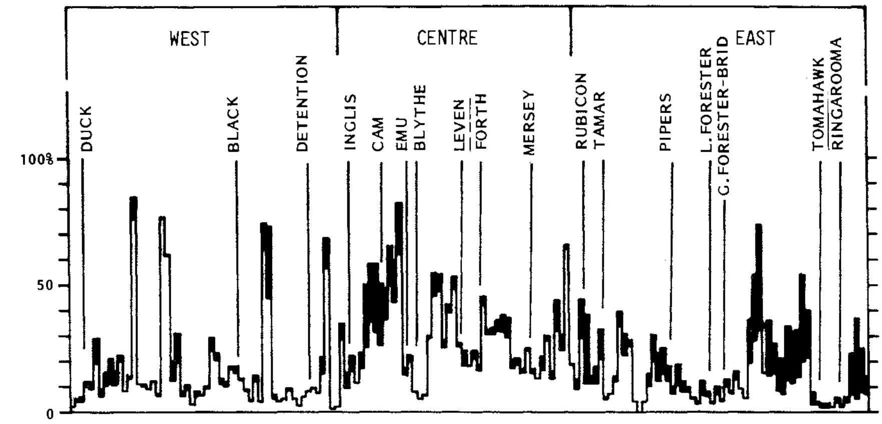

FIG.2 — Carbonate particles as a percentage of total beach sand. The identified non-molluscan content is shown in black.

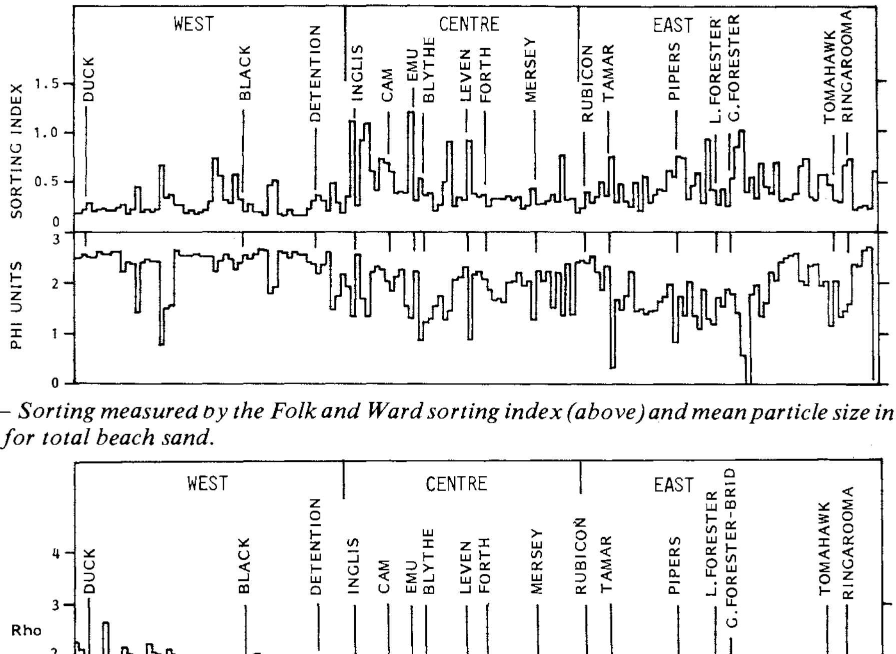

FIG.3 — Sorting measured by the Folk and Ward sorting index (above) and mean particle size in phi units (below) for total beach sand.

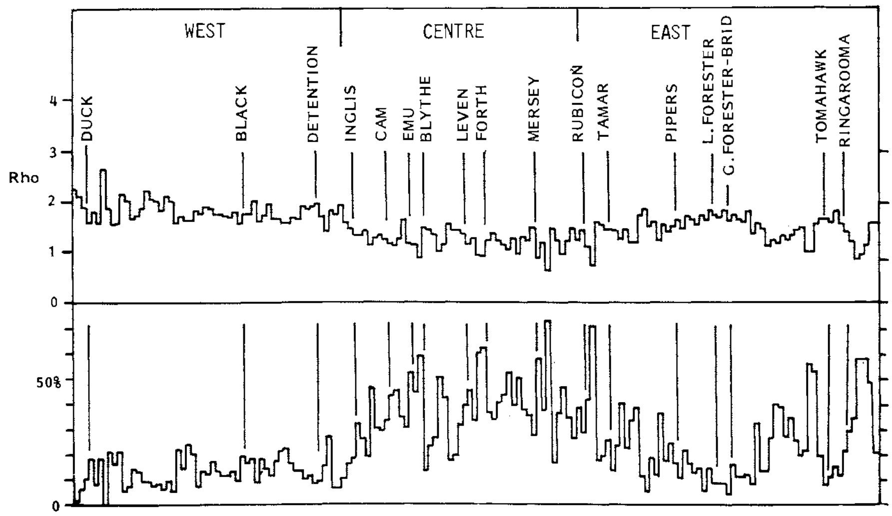

FIG.4 — Mean roundness in rho values for 2.0-2.5 phi quartz fraction (above) and percentage of 2.0-2.5 phi quartz fraction in the very angular (rho <2) class (below).

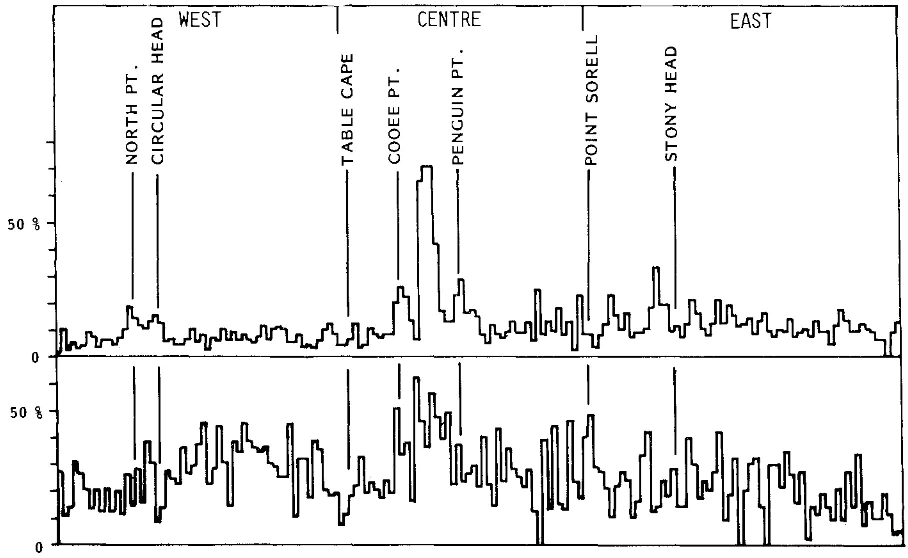

FIG.5 — Percentage of particles iron-stained in 2.0-2.5 phi quartz fraction (above) and in total carbonate fraction (below).

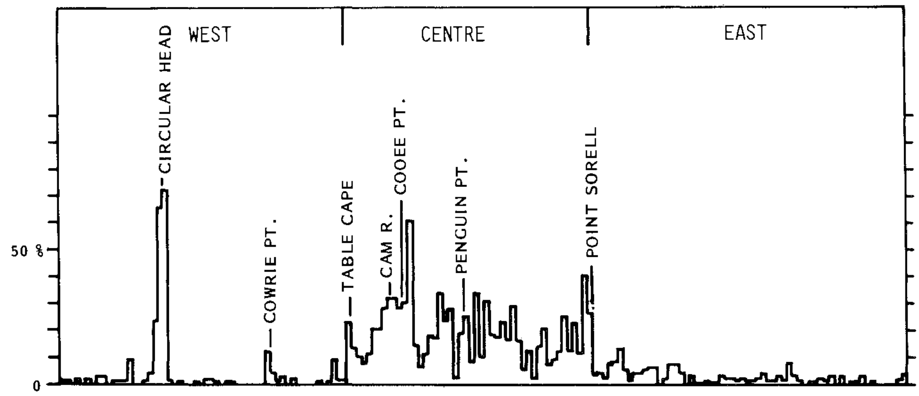

FIG.6 — Distribution in beaches of rock fragments as a percentage of rock fragments plus quartz.

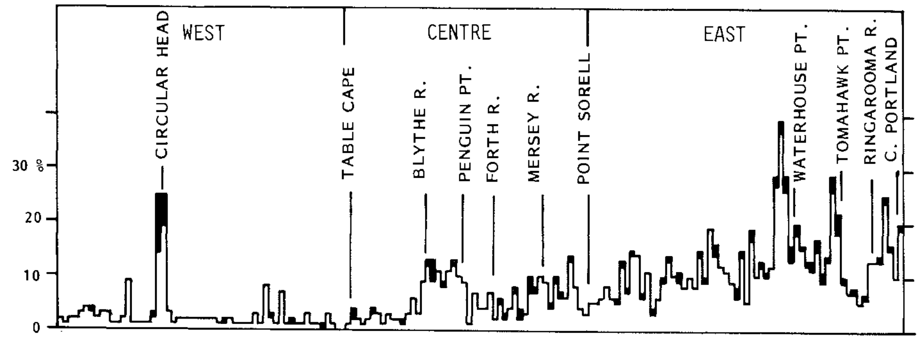

FIG.7 — Distribution in beaches of feldspars as a percentage of feldspars plus quartz. Plagioclase is shown in black.

glacial stages would have extended further north into what is now Perkins Bay. The four spectacular peaks on the graph represent small pocket beaches on headlands at North Point, Circular Head, Cowrie Point and Rocky Cape. It seems probable that little quartz was lodged in these isolated locations at the time of the postglacial marine transgression and locally produced carbonate has been the only major subsequent source of sand.

The central coastal segment is that in which the percentage carbonate content is consistently highest, reflecting its deficiency in terrestrial sediments. The rivers have high modern discharges, particularly the Forth and Mersey, but drain extensive areas of basalt and carry predominantly suspended loads. The carbonate curve in figure 2 appears depressed around the estuaries of the Inglis, Leven, Forth and Mersey and more strikingly depressed around those of the Emu and Blythe. It is worth noting that the coast around the Emu and Blythe has been markedly polluted during the last half century by effluent from factories at Burnie and Heybridge; but until we know more about rates of carbonate turnover the question of whether this has had a measurable impact remains open. On the other hand, the Blythe and Emu are unusual for central segment rivers in having significant areas of granite in their catchments — about 16% of the Emu catchment and about 40% of the Blythe — and this may have enhanced quartz supply locally in the Holocene. Sediments near the mouth of the Cam show only a slight decrease in carbonate content, which is not surprising since the Cam has the highest proportion of basalt (about 66%) in its catchment of all the major streams on this coast.

In the eastern coastal segment the proportion of carbonate in beach sands is intermediate between that in the other two. The most marked features of the curve are the reduced levels in Anderson and Ringarooma Bays. However, as in the western segment, the reductions are not related to the mouths of particular rivers. Here also there has been a degree of recycling of Pleistocene and older Holocene sands in the embayments, so that low carbonate levels may well be due to incorporation of more ancient leached dune and beach sediments. What is termed the Tamar River is in reality the submerged section of a tectonic trough into which the North and South Esk Rivers have brought great quantities of mud from predominantly dolerite catchments in the interior of Tasmania. Its mouth is occupied by a large subaqueous tidal delta of marine sand and there is no apparent likelihood of fluvial sands having been moved through this system to the coast in the Holocene. Indeed Greens Beach, which is the only marine beach actually within the Tamar mouth, shows up as a peak on the carbonate curve in figure 2. The Rubicon estuary also occupies a tectonic depression, but one which is shallower and filled with marine sand: it does not appear to be associated with a local reduction in beach carbonate.

In summary we believe that recycling of older leached coastal sands is probably responsible for the lower levels of carbonate in Perkins and Sawyer Bays in the west and in Anderson and Ringarooma Bays in the east. It is only in the centre, where there has been much less retention of Pleistocene sand, that there is a clear association between carbonate reduction and the mouths of individual rivers. On first consideration this may be due to recent fluvial sand supply, but it is evident from figure 2 that the interfluvial carbonate peaks owe much to a bigger non-molluscan component here than near the estuaries and this suggests that the differential productivity factor may have had at least some effect.

SAND SIZE AND SORTING

Cumulative curves of particle size of the sand fraction were obtained by settling tube and this was the total sample in all but a few cases. Statistical dispersion of grain size for each sample as measured by the Folk and Ward sorting coefficient is shown in figure 3, which also displays mean grain size in phi units. Expectably there is a good correlation between sorting and grain size, with coarser sands being more poorly sorted. A visual impression of this can be obtained from figure 3, where the curve for sorting approaches a mirror image of the residual of the mean phi curve. A statistical indication can be gained by simple regression which gives, with 165 pairs, a highly significant correlation coefficient of -0.699 for sorting against mean grain size.

The sands of the western segment are particularly well sorted: mean sorting coefficient is 0.28 compared with 0.46 in each of the other two segments. They are also markedly finer: mean phi is 2.35 compared with 1.88 in the centre and 1.76 in the east. Uniformity of sand in the western barrier embayments is broken by headland beaches where coarser, more poorly sorted sand contains more numerous carbonate particles and rock fragments. This coincidence between size parameters and mineralogy is common elsewhere along the coast.

In table 1 mean grain size and sorting values for the coastal samples are compared with those from rivers and from the inner shelf. Here and also

TABLE 1

Mean grain size and sorting (Folk and Ward sorting coefficient) of river, shore and shelf samples. Standard deviations in brackets.

		Number of samples	Mean phi	Mean sorting
WEST	river	6	1.48(0.63)	0.54(0.20)
	shore	56	2.35(0.38)	0.28(0.13)
	shelf	23	2.24(0.80)	0.35(0.12)
CENTRE	river	14	1.33(0.80)	0.60(0.14)
	shore	48	1.85(0.43)	0.46(0.25)
	shelf	27	2.05(0.92)	0.46(0.15)
EAST	river	17	1.58(0.70)	0.69(0.19)
	shore	61	1.76(0.60)	0.46(0.19)
	shelf	25	2.58(0.38)	0.33(0.14)

TABLE 2

Carbonate content, quartz staining and roundness of river, shore and shelf samples. Standard deviations in brackets.

		Number of samples	Percent carbonate content	2.0-2.5 phi quartz	
				% iron staining	quartz mean rho
WEST	river	7	0(0)	27(17)	2.5(0.2)
	shore	56	18(21)	7(4)	2.8(0.2)
	shelf	23	26(21)	7(4)	2.8(0.3)
CENTRE	river	14	1(1)	39(17)	2.3(0.1)
	shore	48	33(18)	16(16)	2.2(0.2)
	shelf	25	33(14)	26(22)	2.3(0.2)
EAST	river	17	1(1)	22(16)	2.4(0.3)
	shore	61	19(15)	12(5)	2.5(0.3)
	shelf	25	12(7)	11(5)	2.4(0.2)

TABLE 3

Percentage of quartz and carbonate grains which are iron stained. Standard deviations in brackets.

	West	Centre	East
Number of samples	56	48	61
% 2.0-2.5 phi quartz iron stained	7(4)	16(16)	12(5)
% 1.0-1.5 phi quartz iron stained	11(6)	26(16)	17(8)
% quartz in total sand	78(22)	53(17)	68(16)
% carbonate iron stained	26(10)	29(13)	20(11)
% carbonate in total sand	18(20)	33(18)	19(15)

in table 2 the river samples were necessarily restricted to those which contained enough sand for analysis, while the shelf samples come from the innermost shelf outside the nearshore zone.

The mean values show a contrast between coarser, more poorly sorted fluvial sands and finer, better sorted shore and shelf sands. However, bearing in mind the likely limitations placed on the curve by the sampling intensity, there seems no consistent suggestion in figure 3 of poorly sorted, coarser beach sands near river mouths due to fluvial sand input. Minor peaks of mean particle size and poor sorting which occur near some estuaries are based on only one sample, reflecting very local conditions and may be misleading. For instance, the sample immediately west of the Mersey River mouth comes from a small beach, pocketed in basalt, with a large proportion of rock fragments and little connection with the river itself. The only peaks in the curves based on several samples appearing near estuaries are at the Cam and Pipers Rivers, but many more peaks occur away from rivers than are near them. In sum we do not find the distribution of particle size or sorting helpful in illuminating the possibility of recent sand supply by rivers.

QUARTZ ROUNDNESS

Roundness of the 2.0-2.5 phi quartz fraction was determined by visual comparison on the Powers scale. This size class was chosen because it was the only half-phi interval common to all the samples. Determinations were also made for the 1.0-1.5 phi component although this reduced by five the total of samples available. Figure 4 shows mean roundness for 2.0-2.5 phi quartz, as measured by the rho scale of Folk (1955), a logarithmic version of the Powers verbal classes. Results for the 1.0-1.5 fraction are very similar. The means for almost all samples fall between 2 and 3 rho, or in the subangular class. Since a large amount of operator judgement is involved in the analysis, it is relevant to note that independent analysis of 15% of the samples by a second operator gave substantially the same result.

Table 2, compiled on the same basis as table 1, suggests that there is no significant difference in northern Tasmania between fluvial and marine sands in degree of roundness. The use of grain roundness as evidence of modern river supply is thus made especially difficult. However the general distribution patterns of mean rho values shown in figure 4 display broad differences in degree of rounding of beach sands coinciding closely with the three coastal segments. Quartz sands are least angular in the west, most angular in the centre and become less angular again in the east. Mean figures for 2.0-2.5 phi quartz are 2.80 rho in the west, 2.24 in the centre and 2.45 in the east. For the 1.0-1.5 phi component the corresponding figures are 2.63, 2.14 and 2.60. The same general patterns are evident in the other histogram in figure 4, which gives percentages of grains in the angular and very angular classes (rho values of less than 2.00).

It was suggested earlier that reduced carbonate levels in the large embayments of the western and eastern coastal segments can be associated with the reworking of older sediments and it is evident from figure 4 that these embayments are also characterised by reduced levels of quartz angularity. This is consistent with the notion of repeated recycling in the embayments with recurring episodes of aeolian action, since wind transport is generally regarded as the most effective process in rounding sand grains and selectively concentrating those already rounded (Kuenen 1960, Mazzullo *et al.* 1986). An important consideration is that, in the west and east, there always appears to have been a much greater quantity of sand above high water mark available for reworking by winds exceeding the appropriate threshold velocity.

The central segment stands out as that with a high proportion of angular quartz grains, though it seems impossible to associate angular quartz with particular rivers, other than perhaps the Forth (fig. 4). If the greater rounding of grains in the west and east owes something to aeolian influence during recycling phases, it may be that the greater overall angularity in the centre is due to the paucity of dunes and much smaller potential for wind action now and in the past.

IRON STAINING

The percentage of grains judged by eye to exhibit staining by iron oxides was determined for quartz in the 2.0-2.5 phi fraction. The 1.0-1.5 phi fraction was also examined, although again this meant five samples were unavailable and results were closely parallel. The data for 2.0-2.5 phi quartz are portrayed in figure 5, which also purports to show the distribution of iron-stained carbonate grains. Difficulty was experienced in judging by eye the degree of staining of carbonate because naturally pigmented grains could not always be separated with confidence. The technique used eventually was to make an initial assessment of the apparently stained grains in a sample and then place the

TABLE 4

Quartz, feldspar and rock fragments as percentages of river, shore and shelf samples. Standard deviations in brackets.

		n	Quartz	Feldspar	RF's
WEST	river	5	80(12)	2(1)	17(10)
	shore	56	94(13)	2(2)	4(12)
	shelf	23	91(11)	2(2)	7(11)
CENTRE	river	11	61(17)	7(6)	31(18)
	shore	48	77(10)	5(3)	18(11)
	shelf	27	71(18)	3(2)	26(19)
EAST	river	16	86(7)	8(5)	5(4)
	shore	61	85(7)	13(7)	2(2)
	shelf	25	85(5)	7(3)	8(5)

TABLE 5

Rock fragments in sands near the Cam River.

	Sample number	% fragments in light minerals	% clastics in rock fragments
River	1246	45	19
Shore	230	31	66
	212	32	69
	231	33	77
	232	33	84
	234	57	77
Shelf	C4	72	63
	C5	59	87
	C6	54	91

sample in 150 ml of water at 70-80° C to which 2-3 g of sodium dithionite was added. The water was kept at starting temperature and agitated for 5 minutes; then allowed to cool. The sample was rinsed, oven dried and the percentage of apparently stained grains was recalculated. The difference between the first assessment and the second assessment was taken to represent the amount of discolouration actually due to iron staining. The double assessment has the disadvantage of introducing a second sampling error into the procedure because different subsamples are used for counting on the two occasions. This is reflected in the histogram for carbonate in figure 5 which shows even more random "noise" than the histogram for quartz, but we have no reason to doubt that the general levels shown are indicative of reality.

Table 3 confirms the visual impression given by the histograms that carbonate grains were found to be more iron-stained than quartz grains and that coarser quartz is more stained than finer quartz. This latter difference may be explicable at least in part by suggesting that the finer quartz grains have suffered greater abrasion and rounding, but Judd *et al.* (1970) concluded that this was not a supportable explanation for a similar situation in eastern U.S.A. In any event the differences help to pose the question of the origin and significance of the iron staining.

Table 2 gives values for iron staining of the 2.0-2.5 phi quartz fraction in rivers, on shore and on the inner shelf on a basis already described. It shows river sands to be more stained than both shore and shelf sands in all three segments. The differences are statistically significant at better than the 95% level in all cases except between river and shelf sands in the centre where the level of confidence falls to about 93%. There is no support for the idea of rivers supplying relatively clean quartz to the marine environment where it becomes iron-stained by subaerial processes at low sea level. The suggestion in table 2 is rather that the rivers have supplied stained quartz at low sea levels; that this has been piled into dunes which have been leached and that it has then been recycled into the beach deposits at the present sea level. Such a scenario would help to explain why staining of shore and shelf sands is more significantly lower than that of river sands in the western and eastern coastal segments where dune building and recycling have been especially prevalent. It seems evident that the iron oxides responsible for the original staining of the river sands came primarily from breakdown products of the basalt. These occur in nearly all stream catchments but particularly in the centre, which accounts for the high level of iron staining in this coastal segment.

That this is not the complete explanation is shown by the fact that percentage iron staining of carbonate particles is consistently higher than that for quartz and the carbonate of course is not supplied from rivers. Iron staining of carbonate must either have taken place in the marine environment or have occurred on the shelf in subaerial conditions at low sea level. The possibility of the second explanation being correct seems remote, because carbonate leaches readily from subaerial sands in Tasmanian conditions and is scarce or absent in the Pleistocene dunes of the western and eastern segments. Even in the oldest of the Holocene beach ridges, dating presumably from about 6 000 b.p., most carbonate has been leached. The conclusion seems inescapable that iron staining of marine carbonate particles is a modern process and we note that Roy (1983) obtained a date of 1 500 ± 135 C^{14} years b.p. for iron stained shell off the Sydney coast.

Although some quartz grains have been iron-stained in the modern marine environment the evidence points to carbonate grains being distinctly more susceptible to staining and this is what would be expected on theoretical grounds. Professor P.B. Hostetler, School of Earth Sciences, Macquarie University, has pointed out to us that in a laminar flow environment, where a diffusion gradient for soluble iron is readily visualised, ferric hydroxide is more apt to precipitate from aqueous fluid immediately surrounding a grain of calcium carbonate than from the fluid around a quartz particle. This is because a solution reaction between the carbonate grain and its surrounding fluid will cause a local increase in hydroxide which in turn will favour precipitation of ferric hydroxide from the sea. No such hydroxide enrichment occurs around quartz grains in a similar situation.

It appears that iron stained quartz has been supplied by rivers at Pleistocene low sea levels and only to a small extent by processes operating on the Holocene sea bed. Leached quartz coming from the erosion of old shore sediments has served to reduce the ultimate percentage of grains observed to be stained by iron. Iron stained carbonate on the other hand has resulted from the more efficient submarine absorption of iron in the last 6 000 years.

Returning to the distribution patterns in figure 5, it is necessary to note that the most striking peak in both curves is man-made. This is associated with effluent from the titanium dioxide factory at Heybridge which locally causes staining of bedrock and sediments with hydrous ferric oxide. The curves suggest that the effect may extend from Cooee Point to Penguin Point and may be more widespread on carbonate sands than on quartz sands. They also confirm that both quartz and carbonate particles are stained in the contemporary marine environment where favourable conditions are present.

From the residual natural curves it is not possible to determine any clear association of staining peaks or depressions with river mouths. The only apparent correlations in detail are between increased staining and areas where basalt occurs to landward and there are unusual numbers of volcanic rock fragments and iron ore minerals in the beach sands. The generally high values throughout the central segment and the peaks which occur at North Point-Circular Head and west of Stony Head provide examples of such correlations.

LITHIC FRAGMENTS

Sand particles that have not yet broken down into their constituent mineral grains are usually considered unstable in high energy environments such as ocean beaches. Their presence in beach sediments may therefore be indicative of recent supply. Figure 6 shows the distribution of rock fragments in northern Tasmanian beaches expressed as a percentage of rock fragments plus quartz, and in table 4 the mean percentages for beaches are compared with those for available river and shelf samples in the three coastal segments. It will be seen that lithic fragments are particularly prevalent in the central coastal segment, where they appear to originate from the Tertiary basalts and the Pre-cambrian Burnie Formation — a series of strongly folded, sheared and foliated micaceous quartz-wackes.

Table 4 suggests that, on the whole, rock fragments are less common in beaches than in rivers or on the contiguous shelf and this difference is statistically significant in all cases at better than 95%. Given the high proportion of rock fragments in river sands it is notable that figure 6 gives no indication (except perhaps for the River Cam) of increased lithic content in beaches near estuaries. The most prominent isolated peaks are around headlands, notably Circular Head, Table Cape, Cowrie Point and Cooee Point. Between Penguin Point and Point Sorell basalt occurs regularly in cliffs, on shore platforms and offshore, and lithic fragments are being supplied to beaches from these sources all along this stretch of coast.

The peak in the figure 6 histogram around the mouth of the Cam calls for more detailed examination. About 66% of the catchment of this river is floored by basalt and about 17% by the Precambrian Burnie Formation. The basalt covers the upper part of the catchment, with the Precambrian rocks cropping out in the lower parts of the main valley close to the sea. The coast on either side of the Cam estuary for at least 15 km is formed in the Precambrian, which is also found offshore. There are only three very minor coastal occurrences of basalt. A sediment sample from the river bed 1 km above tidal limit contained 55% silt and clay, but among the light minerals separated from the sand fraction 45% were found to be rock fragments. In table 5 this sample is compared with beach samples around the mouth of the river and with three samples from the shelf 0.7, 1.7 and 2.7 km off Cooee Point. It will be seen that, although the river sample contains a higher proportion of rock fragments than all but one of the beach samples, the proportion of clastics in the rock fragments is far higher in the beaches and on the shelf than in the river, indicating that the major supply is from the Precambrian rocks on the coast and offshore.

Lithic fragments are an important volumetric constituent of beach sands only in the central coastal segment, but here they average about 18% of inorganic sand and about 12% of the total shore sediment. Their probably short life span suggests that they have been supplied mainly since the postglacial marine transgression, but from erosion of coastal bedrock and not from rivers.

FELDSPARS

In New South Wales the occurrence of feldspar concentrations in beach sands has been used as evidence for recent sand supply by rivers (Bird 1967, Roy & Crawford 1977). The distribution of feldspars in northern Tasmanian beach sands is shown in figure 7, where abundance is expressed as a percentage of feldspar plus quartz. The proportion of constituent plagioclase is also shown. The overall distribution pattern demonstrates a strong connection between feldspathic sands and granitic rocks, with particularly large feldspar concentrations in the eastern coastal segment where granites and granodiorites occur in catchments and in places on the coast. On average, feldspars contribute about 13% of inorganic beach sand in this segment and about 11% of the total sand body.

The dolerites and basalts are also potentially large sources of feldspar, but overwhelmingly of sodic feldspars. The fact that we found only relatively small amounts of sodic feldspar supports the general view that it has a relatively short life in the detrital state, even though this may depend on the nature of the local weathering environment (Todd 1968). Plagioclase appears to be common as a component of volcanic rock fragments but uncommon in the form of independent sand grains. Alkali feldspars are only a minor constituent of the dolerites and are even scarcer in most of the basalts (Edwards 1942, 1949), but may be derived from these rocks in significant amounts where there is a relatively large source.

The histogram in figure 7 shows a detailed relationship of feldspar peaks to headlands rather than to estuaries. A marked peak occurs around Circular Head where the basalt has been observed by Edwards (1941) to contain abnormally high quantities of alkali feldspar and the plagioclase content of beach sands is also exceptionally great. Other prominent peaks are associated with Waterhouse Point and Tomahawk Point, where dolerite and granite outcrop extensively and with Cape Portland-Petal Point, where dolerites and appinites form the shore (Jennings & Sutherland 1969). The only indication of a river source is the rise in feldspar content east of the mouth of the Blythe which has 40% of its catchment floored by granitic rocks.

The evidence indicates that, particularly in the east, weathering and erosion of coastal bedrock has been a source of feldspar sand since the postglacial marine transgression and that the River Blythe may also have been a source. The data in table 4, suggesting that the highest proportion of feldspar in the east occurs on the shore but in the centre occurs in the rivers, are in sympathy with this conclusion. However it is necessary to exercise some caution regarding the time of supply. Alkali feldspar grains do not appear particularly unstable in marine conditions and are known to have

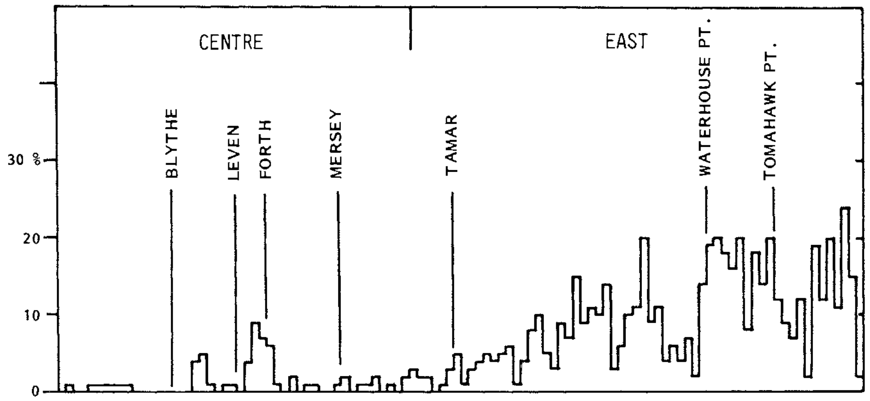

FIG.8 — Hornblende as a percentage of heavy minerals in beach sands in the central and eastern segments.

survived on the shelf and in the beaches of south-eastern U.S.A. through at least the Late Pleistocene (Field & Pilkey 1969). On a coast where longshore transport has been severely limited, the possibility that particular concentrations may have had a pre-Holocene origin can not be ruled out.

HEAVY MINERALS

The general distribution of heavy minerals has been outlined elsewhere (Davies & Hudson in press). Although they rarely make up more than 1% of beach sand in northern Tasmania, their distribution may be relevant in so far as those with a hydraulic equivalence closer to quartz may serve as natural tracers. The least stable minerals are those most likely to be indicative of recent supply and, as in the case of rock fragments and feldspars, observable relationships are with headlands and not estuaries. Thus, although olivine is infrequent in beach sands, an unusually large amount was found adjacent to North Point, where it must have emanated recently from weathered basalt at the shore. Of the pyroxenes, titanaugite is especially common because of its considerable representation in the basalt, but its detrital distribution in the beaches is strongly related to coastal basaltic outcrops such as Circular Head, Table Cape and Penguin Point (see discussion and fig. 5 in Davies & Hudson in press). A strong concentration of the titaniferous amphibole, kaersutite, was found near Burnie and there is probably a source in the small basalt outcrop close to the beaches where it is very plentiful.

The only evidence for possible river supply is provided by a hornblende concentration in beaches near the mouth of the Forth. Figure 8 shows that hornblendes are largely confined to the eastern coastal segment where granitic rocks are wide-spread. They are particularly prevalent around Waterhouse Point where granites crop out on the shore. However there is a distinct hornblende peak around the mouth of the River Forth, which has some granite and amphibolite in its catchment and where there seems no likely coastal source for abnormal amounts of hornblende. Recent work by one of us (Hudson 1986) has shown that horn-blendes have survived one or more cycles of sea level change on the New South Wales coast and this casts some doubt on the time of supply.

DISCUSSION

Although much of the evidence is equivocal and difficult of precise interpretation in isolation, some conclusions can be reached by drawing different strands together. In the western coastal segment there is no evidence of Holocene river supply. Beach sands here show great internal homogeneity broken only by the local influence of the basalt at Circular Head which has supplied feldspars, rock fragments and pyroxenes in small quantities to contiguous shores. It is evident that the finer, better sorted, less angular, highly quartzose sands which make up almost all the beach sediments here result from the recycling of older shore bodies at different times in the Quaternary, most recently at and immediately after the postglacial marine transgression. Their ultimate source appears to have been in the Precambrian rocks of the Black and Detention catchments and the Rocky Cape Range.

In the eastern coastal segment the picture is less simple but again there is no compelling indication of Holocene river supply. Quartz sand is actually less rather than more angular in Anderson and Ringarooma Bays and around the mouths of the Great Forester-Brid and Ringarooma Rivers than it is in interfluvial sections, suggesting that here, as in the west, the bulk of the sand has been recycled from old dunes and beaches. The reduced carbonate levels in sands around these rivers and in their contiguous embayments are also best explained in terms of quartz being added from this source. The Ringarooma, which has much the highest discharge of rivers in the east, is at present cutting into older transgressive dunes above its estuary and carrying sand back to the shore. To this mass of recycled quartz, coastal erosion of weathered shore outcrops of dolerite and granite has added small amounts of feldspathic sand in Holocene times.

In total the evidence from the eastern segment points again to sediments having been emplaced from seaward by the postglacial marine transgression, having been deflated and recycled to varying extents and supplemented in minor degree by erosion of weathered bedrock on the present shore. However the ultimate (Pleistocene) source of the bulk of the sand seems to have been in the granites and granodiorites of the river catchments and in the associated terrestrial sand mantles mapped as being Tertiary in age (for example Geological Survey of Tasmania, 1:250 000 series, sheet 4, 1975).

The central coastal segment contains much the biggest concentration of rivers and in particular the Forth and Mersey which, leaving aside the rivers of the Tamar system, are easily the two largest along the whole coast. Yet it also has much the smallest nearshore sand body, which very rarely contains more than 75% quartz and usually much less. Since longshore transport appears to have been absent, the scarcity of sand in general and quartz in particular must be attributed primarily to low sediment inputs and the relative scarcity of quartz in the rocks of the hinterland. Biogenic carbonate fragments and lithic particles derived mainly from weathering and erosion of coastal bedrock have made exceptionally large contributions to the beach sands. Longstanding quartz deficiency and lack of longshore translocation has also meant that the sand body emplaced from the shelf by the postglacial transgression was meagre and only a small amount of sediment has been available for transfer into the estuaries. The relative lack of infilling of estuaries in the centre can not be attributed to their having had a large initial volume. Because the rivers have been adjacent to a wide shallow shelf, there has been little downcutting during low sea-level phases by even the biggest of them — a maximum of only 15 m below present sea-level by the Mersey at Devonport for instance (Moore 1968).

The Forth and Mersey estuaries are wide, with small tidal deltas separated from upstream fluvial deltas by residual mud basins (compare Roy 1984). They appear very unlikely to be transporting bedload through to the shore. Conversely the Cam, Emu and Blythe have very narrow estuaries into which there has been hardly any incursion of marine sand and where the ratio of river discharge to tidal discharge is high for much of the time. These rivers appear *a priori* the most likely to have carried fluvial sand to the shore. The remaining estuaries are of an intermediate nature.

Against this background it is not surprising that the evidence for recent river supply to the coast is slender. The best evidence is for the Blythe and the Emu, where there is the most marked carbonate depression and a distinct feldspar peak. Both rivers have granite in their catchments and, along with the Cam, are most likely to have been suppliers judging by morphology and hydrology. The Cam has a strongly basaltic catchment and is mostly delivering mud, but it may also supply some volcanic rock fragments to augment the high proportion of lithics in the beaches derived mainly from the erosion of Precambrian bedrock. There is only a small depression in the carbonate curve opposite the Cam. The next best evidence is for the Forth, where a less specific reduction in carbonate is accompanied by a hornblende peak and perhaps more angular quartz. However the morphology of this estuary suggests that this river is very unlikely to be carrying sand to the coast at present and the hornblende peak may be inherited from the Pleistocene.

Elsewhere in the centre the only possible indication of recent sand supply by rivers is that of reduced carbonate content, for instance around the Leven, Mersey and Inglis mouths. Earlier, less detailed work suggested to one of us (Davies 1980, p.124) that this was good testimony to recent quartz infusion, but the lack of supporting evidence from other criteria used in the present enquiry suggests that the factor of varying carbonate productivity between estuaries and headlands may be more important than was originally thought. It may also be that too much of the unidentified carbonate has been allocated to the molluscan category in figure 2. On the total evidence we conclude that the Blythe, Emu and Cam may have supplied some shore sediment since the postglacial marine transgression but there seems no convincing evidence for any other river. Such a conclusion is supported by the limited amount of shore sand in the central coastal segment and the difficulty of pointing to specific sediment accumulations which can be associated with particular points of fluvial injection. The absence of such accumulations on a coast of close to zero transport must be significant.

In summary it appears that in the central segment the postglacial marine transgression brought only a relatively small body of sand from the shelf. In the Late Holocene this has been augmented by lithic fragments produced from coastal erosion, by biogenic carbonate and possibly by injection of some sand from the Blythe, Emu and Cam Rivers.

CONCLUSION

The shore sands of northern Tasmania, like those of other southeastern Australian coasts, were derived almost entirely from the shelf at the time of the postglacial marine transgression and during subsequent periods of adjustment of the nearshore profile. They incorporated older beach and dune sands, especially in the west and east, sands which had been brought to the lower reaches of the rivers at low sea level times and coarser material weathered from bedrock outcrops, of which there are many on the shelf in the central and eastern segments. Since the transgression there have been accessions of carbonate sand, mainly around the rocky interfluvial areas, and small quantities of lithic and feldspathic sand have come from coastal erosion, principally of weathered granite, dolerite, basalt and quartzwackes. Of the rivers, the Blythe, Emu and Cam may have supplied a very small amount of sand, but, if so, this has been insignificant in terms of the total sediment body.

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REFERENCES

BIRD, E.C.F., 1967: Depositional features in estuaries and lagoons on the south coast of New South Wales. *Austr. Geogr. Studies*, 5: 113-124.

DAVIES, J.L., 1980: *GEOGRAPHICAL VARIATION IN COASTAL DEVELOPMENT.* Second edition. Longman, London.

DAVIES, J.L. & Hudson, J.P., in press: Differential supply and longshore transport as determinants of sediment distribution on the north coast of Tasmania. *Marine Geol.*

EDWARDS, A.B., 1941: The crinanite laccolith of Circular Head. *Proc. R. Soc. Vict.*, 53: 403-415.

EDWARDS, A.B., 1942: Differentiation of the dolerites of Tasmania. *J. Geol.*, 50: 451-480, 579-610.

EDWARDS, A.B., 1949: The petrology of the Cainozoic basaltic rocks of Tasmania. *Proc. R. Soc. Vict.*, 62: 97-120.

EMERY, K.O., 1965: Geology of the continental margin off eastern United States. *In* Whittard, W.F. & Bradshaw, E. (Eds): *SUBMARINE GEOLOGY AND GEOPHYSICS.* Butterworth, London: 1-20.

FIELD, M.E. & PILKEY, O.H., 1969: Feldspar in Atlantic continental margin sands off the S.E. United States. *Geol. Soc. Amer. Bull.*, 80: 2097-2102.

HUDSON, J.P., 1986: Evidence for littoral drift at Holocene low sea levels on the south Sydney inner continental shelf, southeastern Australia. *Abstracts 12th Int. Sed. Congress, Canberra*: 146.

INMAN, D.L., 1960: Shore processes. *In McGRAW-HILL ENCYCLOPEDIA OF SCIENCE AND TECHNOLOGY.* McGraw-Hill, New York.

JENNINGS, D.J. & SUTHERLAND, F.L., 1969: Geology of the Cape Portland area with special reference to the Mesozoic(?) appinitic rocks. *Tech. Repts Dept Mines, Tasm.*, 13: 45-82.

JUDD, J.B., SMITH, W.C. & PILKEY, O.,H., 1970: The environmental significance of iron-stained quartz grains on the southeastern United States Atlantic shelf. *Marine Geol.*, 8: 355-362.

KUENEN, P.H., 1960: Experimental abasion, 4: eolian action. *J. Geol.*, 68: 427-449.

MAZZULLO, J., SIMS, D. & CUNNINGHAM, D., 1986: The effects of eolian sorting and abrasion upon the shapes of fine quartz sand grains. *J. Sed. Petrol.*, 56: 45-56.

MOORE, W.R., 1968: Site investigation. Victoria Bridge, Devonport. *Tech. Rept Dept Mines, Tasm.*, 11: 83-89.

ROY, P.S., 1983: Quaternary geology. *In* Herbert, C. (Ed.): *GEOLOGY OF THE SYDNEY 1:100 000 MAP SHEET 9130.* New South Wales Geological Survey, Sydney: 41-91.

ROY, P.S., 1984: New South Wales estuaries: their origin and evolution. *In* Thom, B.G. (Ed.): *COASTAL GEOMORPHOLOGY IN AUSTRALIA.* Academic Press, Sydney: 99-121.

ROY, P.S. & CRAWFORD, E.A., 1977: Significance of sediment distribution in major coastal rivers, northern New South Wales. *Proc. 3rd Austr. Conf. Coasal & Ocean Eng., Melbourne*: 177-184.

ROY, P.S. & THOM, B.G., 1981: Late Quaternary marine deposition in New South Wales and southern Queensland — an evolutionary model. *J. Geol. Soc. Aust.*, 28: 471-489.

ROY, P.S., THOM, B.G. & WRIGHT, L.D., 1980: Holocene sequences on an embayed high energy coast: an evolutionary model. *Sedim. Geol.*, 26: 1-19.

THOM, B.G., BOWMAN, G.M., GILLESPIE, R., POLACH, H.A. & BARBETTI, M., 1981a: Progradation histories of sand barriers in New South Wales. *Search*, 12: 323-325.

THOM, B.G., BOWMAN, G.M., GILLESPIE, R., TEMPLE, R. & BARBETTI, M., 1981b: *RADIOCARBON DATING OF HOLOCENE BEACH-RIDGE SEQUENCES IN SOUTH-EAST AUSTRALIA*. Dept Geogr. Roy. Military College, Duntroon, Canberra, Monograph No.11.

TODD, T.W., 1968: Paleoclimatology and the relative stability of feldspar minerals under atmospheric conditions. *J. Sed. Petrol.*, 38: 832-844.

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