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Texture, Composition and Provenance of Beach Sands, Victoria, Australia

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ABSTRACT

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Analysis of foreshore beach samples from 26 locations along the Victorian coast between Lakes Entrance in Gippsland and near Port Fairy shows great local variability in both texture and composition. The entire coast is exposed to waves from the Southern Ocean and beach orientations range over a spectrum of 150 degrees. Numerous headlands locally restrict shore-parallel transport except in the Ninety-Mile Beach region of eastern Victoria.
Mean grain size of foreshore beach sediments ranges from very coarse sand to fine sand. Sorting is typically very good. Both slightly positive and slightly negative skewed sediments occur. Few textural patterns are apparent however, coarsest samples are from Cape Otway and Cape Schank with a decrease in grain size away from the Cape Otway headland. The common general relationship between mean grain size and sorting is not displayed because the coarsest beaches are among the most well-sorted.
The composition of Victorian beach sediments ranges greatly with quartz and biogenic skeletal fragments being most common. Feldspar is locally abundant. Most beach sediment is derived from proximal sources but there is indication of transport along significant portions of each coastal section.

ADDITIONAL INDEX WORDS: *Beach sediments, composition, textures, provenance, Australia.*

INTRODUCTION

The coast of Victoria, Australia, is extremely varied in its morphology, orientation, composition and continuity. It is bounded by a spectrum of rock types including granites, volcanic rocks, terrigenous sedimentary rocks, and eolianites. This great variety has given rise to a correspondingly broad variety of beach sediments. The Victorian coast affords an excellent opportunity to examine the texture, composition and distribution of beach sediments, and to try to relate these properties to the nature of the source materials that border the coast and the processes of sediment transport that occur along it.

Geology and Geomorphology of the Victoria Coast

The area of study extends from Lakes Entrance on the east to Portland on the west, a distance of nearly 700 km which includes most of the coast of Victoria. This coast can be subdivided into four subequal sections based on general shoreline orientation, with two sections that trend northeast-southwest and two that trend northwest-southeast (Figure 1).

The easternmost of these sections is comprised primarily of the Ninety-Mile Beach barrier system, one of the longest uninterrupted barrier islands in the world. At Wilson's Promontory the coast turns abruptly toward the northwest. In this section which terminates at the mouth of Port Phillip Bay, there are several short reaches of coast anchored by bedrock headlands and interrupted by inlets (Figure 1). This is the only one of the four sections that lacks continuity.

The next section extends from the western side of the Port Phillip Bay (Port Phillip Heads) to Cape Otway. The westernmost section trends to the northwest and ends near the city of Portland. Both of these coasts consist largely of high relief bluffs of sedimentary rocks of Mesozoic and Cenozoic age. These include limestone, coarse terrigenous sand and gravel and uniform quartz sand as well as widespread eolianite

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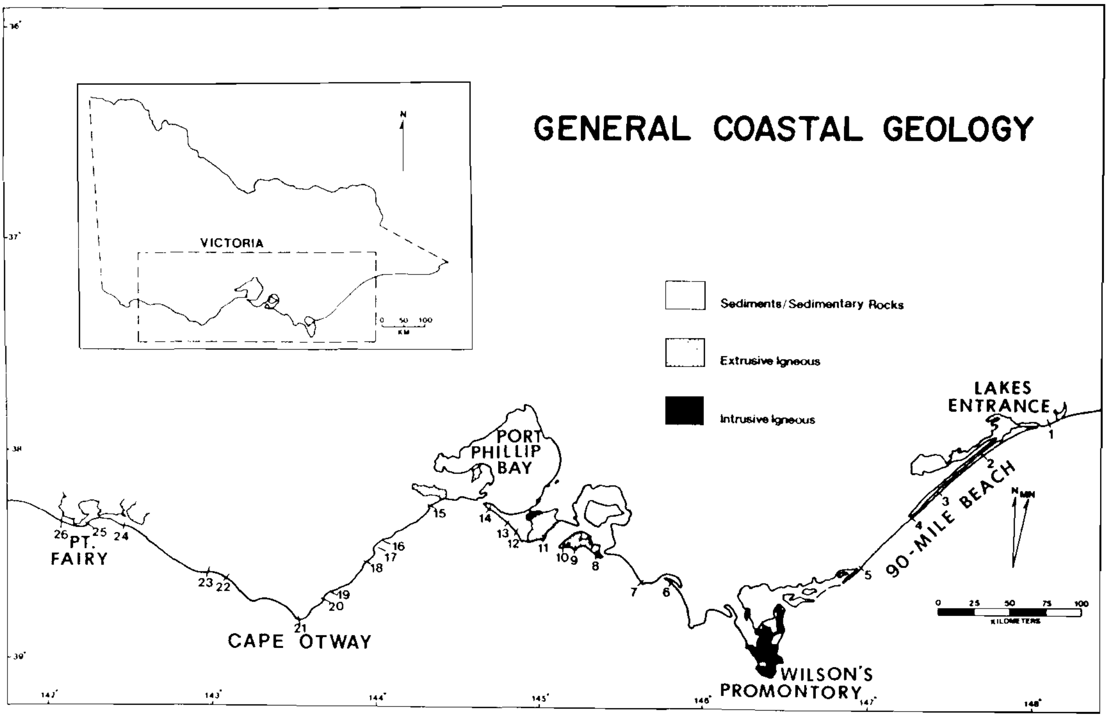

Figure 1. Map of the Victoria coast showing distribution of general rock types and locations of beach sites included in this study.

which is composed of a mixture of quartz and carbonate grains.

Although the regional pattern of shoreline orientation can be divided into four sections with essentially two general orientations, the shoreline orientation at a given sample location ranges widely (Figure 2). This is especially true at sites 6-15 which comprise the section of the coast that has local headlands and is interrupted by numerous inlets and embayments. The other major deviation from the general trend is at location 25 where there is a local reversal in coastal orientation (Figure 2).

The size and configuration of Victorian beaches varies greatly. Although both depositional and erosional coastal regimes are present, all sections of the coast contain at least some beach material. The profile ranges from that of a well-developed berm and backshore such as is common along the Ninety-Mile Beach, to narrow beaches that are all foreshore, such as are present west of Cape Otway. Seasonal energy patterns tend to change these profiles in the typical fashion but even during the high energy winter season, beaches are present along most of the Victorian coast.

There is variety in the potential source material for these beaches. In southeast Gippsland adjacent to Ninety-Mile Beach the barrier-estuary complex is surrounded by low terraces of Tertiary sand and gravel; almost a coastal plain type of morphology. These strata along with the reworking of older coastal and shelf sediments provide the material that forms the present barrier island.

The coast between Wilson's Promontory and Port Phillip Bay has great variety in its geology. In addition to granitic masses there are extrusive volcanic rocks, a variety of terrigenous sedimentary rocks and eolianites along the coast. This is a high relief coast where waves directly attack bedrock cliffs on the headlands and where short, arcuate barrier spits develop.

The western half of the study area shows broad similarities in its geology in that it is a rugged, high-relief coast bounded almost exclu-

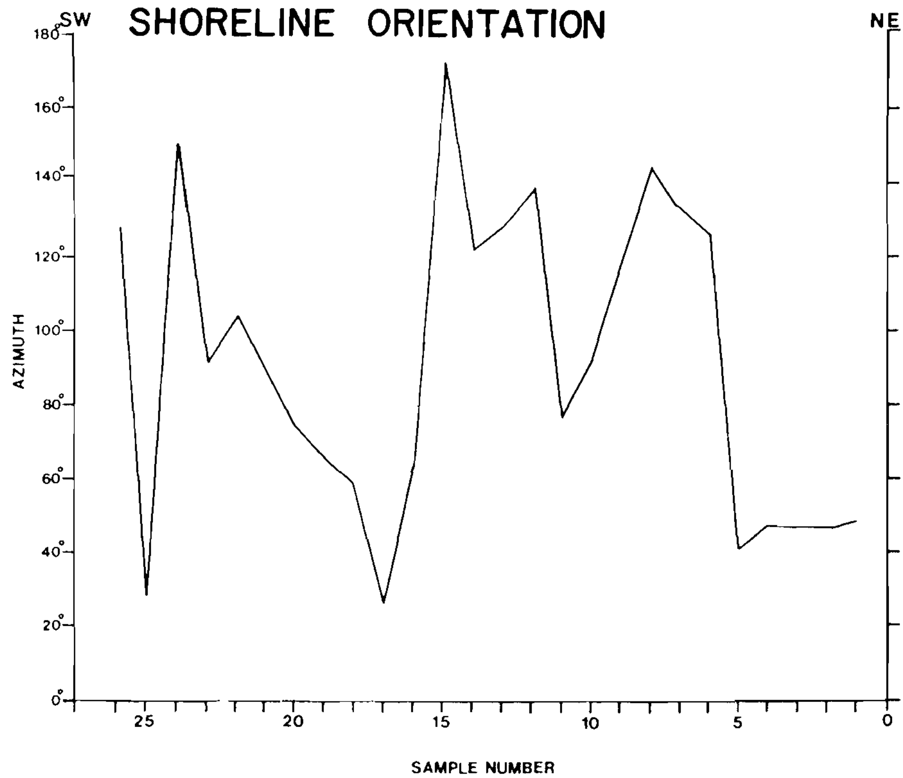

Figure 2. Plot of shoreline orientation for each of the beach sites sampled. Note that sample number 1 is to the right or west thus keeping the locations in the same relative position as shown on the location map (Figure 1).

sively by sedimentary rocks and sediments. A few local areas of potential volcanic source rocks occur at either end (Figure 1).

Coastal Processes

The entire Victorian coast is exposed to the wave climate of the Southern Ocean. Prevailing direction of wave approach is from the southwest with a secondary mode from the south-southeast. These waves have long periods of 8-14 seconds and they tend to be refracted completely prior to breaking along the coast (John Hinwood, *personal communication*). Another major factor that affects the wave climate of the Victorian coast is the presence of the broad shelf which underlies Bass Strait south of Wilson's Promontory and on which Tasmania as well as numerous other islands are located. The shelf is less than 100 m deep throughout most of its extent and it provides excellent protection for the coast of Victoria. Very large waves are generated in the Southern Ocean with periods in excess of 15 seconds and significant heights of 3-5 m being commonly associated with storms (HINWOOD *et al.*, 1982). Rare events generate even larger waves with periods of more than 25 seconds and heights > 5 m (John Hinwood, *personal communication*).

Because of the generally shallow water and rather long period waves in Bass Strait, there is little littoral drift that can be attributed to swell waves. They tend to be completely refracted and approach the shore essentially parallel to it. Locally generated waves of much shorter wave length tend to be the dominant factor in longshore currents and littoral transport of beach sediment. Wind rose patterns for the entire Victorian coast show a rather uniform distribution of prevailing wind; from the southwest or northwest. The littoral transport is also by nearshore bathymetry and the local orientation and continuity of the coast. Consequently, the three western sections of the coast in question show great variety in direction of littoral transport. This results from the range in coastal morphology and shoreline orientation with numerous local depositional features indicating bidirectional transport along each of these sections.

The Ninety-Mile Beach coast is continuous, displays a uniform orientation and has a rather smooth inner shelf. Consequently, there is a relatively uniform littoral transport of sediment although the rate is not known. The entire section of coast except for a small section near Corner Inlet, is subjected to wave-generated currents that result in a net sediment transport toward the northeast (BIRD, 1978; THOM, 1984).

SAMPLE COLLECTION AND ANALYSIS

Surface samples were collected from 26 locations during the fall and winter months (March-July) from the mid-foreshore of beaches throughout most of the Victoria coast (Figure 1). Spacing was intended to be more or less uniform but this was not possible due to problems of access, headlands and the distribution of rock types providing potential source material. An effort was made to locate sampling sites near a variety of rock types along the coast. Each sample was collected by scraping only the upper few millimeters of sediment on the active swash zone of the foreshore.

Textural analysis of the samples was done by using a settling tube housed in the Department of Geology, University of Melbourne. Calculations of mean grain size, sorting and skewness were made using the inclusive graphic relationships suggested by FOLK (1974).

Samples were split and a volume of about 30 cm^3 was impregnated with epoxy for preparation of thin sections. Modal analyses were made for the thin sections using 200 grain counts for each. Initial data were tabulated using the following compositional categories; polycrystalline quartz, monocrystalline quartz, modern biogenic grains, reworked biogenic grains, orthoclase, microcline, volcanic rock fragments, opaques, chert and miscellaneous. These were combined into five categories for the final tabulation and analysis; quartz, biogenic fragments, feldspar, volcanic rock fragments, and miscellaneous. It was not possible to distinguish between modern and reworked biogenic grains from eolianites. Other categories were present in small numbers so that combining certain grain types seemed appropriate.

BEACH TEXTURE

The three textural parameters measured, mean grain size, sorting and skewness, show few surprises. Grain size ranges from -0.24ϕ to 2.24ϕ with the coarsest samples from locations 12 and 21 and the finest from location 25 (Figure 3). A few trends in grain size distribution are present. Samples in the Ninety-Mile Beach section are all in the coarse sand range except for location 5 which is in the area of littoral drift reversal near Corner Inlet. Most of the section between Wilson's Promontory and Port Phillip Bay are in the medium sand range except for the westernmost three sites (locations 12-14) which are located on the Mornington Peninsula and have coarser sediments than the others. Mean grain size from the section extending from near the mouth of Port Phillip Bay to Cape Otway is medium sand which is similar in grain size to locations 5-11. Samples at two locations in the westernmost section deviate greatly from the others; Cape Otway is the coarsest of all samples and location 25 near west of Port Fairy is the finest of all samples. Overall, the mean grain size shows some patterns that relate to the four coastal sections but there are several exceptions.

As is typical of the foreshore beach environment, the sediment is universally well-sorted. Values for individual samples range from 0.28ϕ to 0.81ϕ (Figure 3). There is no pattern of sorting relative to mean grain size with both coarse and fine samples displaying very good sorting.

Skewness values show that all samples have fairly symmetrical distributions with values ranging from -0.39 at location 13 to $+0.27$ at location 23 (Figure 3). There is a general trend of coarse samples having a negative skewness or an excess of coarse particles and for fine samples to have a positive skewness due to an excess of fine particles. Exceptions are present to this generalization also (Figure 3).

Comparison with Previously Published Beach Textures

The only previous data on beach textures for the Victorian coast is that provided by THOM

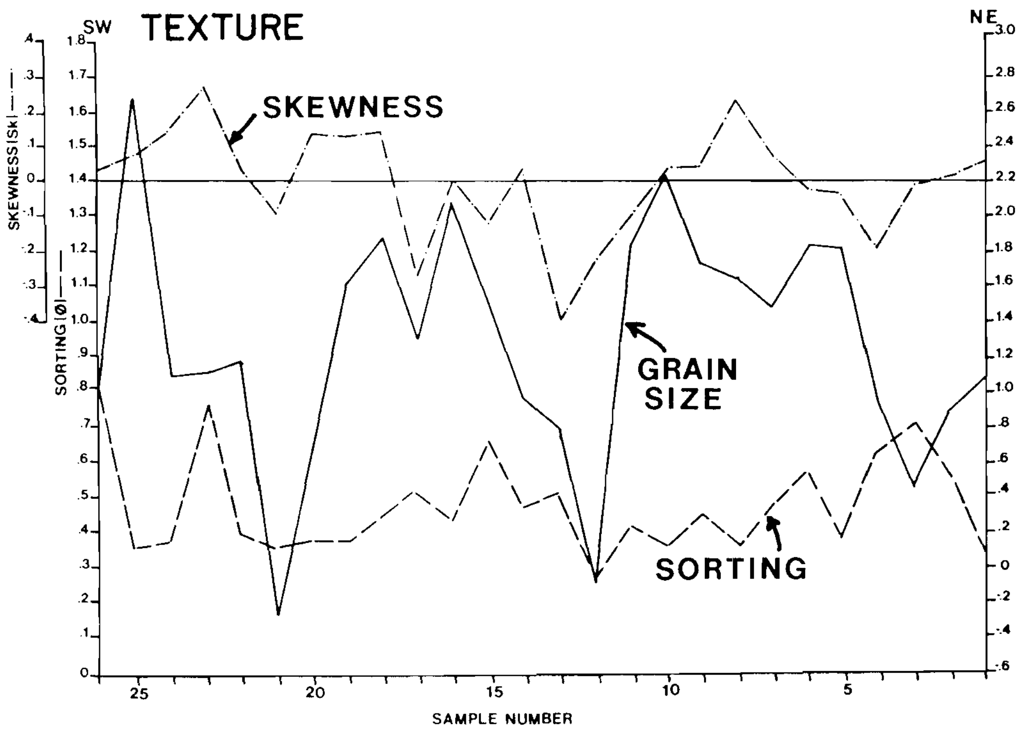

Figure 3. Plot of mean grain size, sorting and skewness for each of the beach sites showing their relative geographic distribution.

Table 1. *Comparison of Beachface Sediments, Ninety-Mile Beach, Victoria.*

Location	Carbonate Content		Mean Grain Size	
	Thom, *et al.* 1983	This study	Thom, *et al.* 1983	This study
1	2.8%	2.8%	1.06ϕ	1.20ϕ
2	9.5	9.5	0.88	1.10
3	10.5	8.5	0.43	0.95
4	6.0	6.0	0.92	1.30
5	8.0	7.3	1.80	1.55

et al. (1983) who did some detailed analysis of beach sediments along the Ninety-Mile Beach coast. Five of the sites studied by Thom and his colleagues correspond to locations 1-5 of the present study. A comparison of the mean grain size of the foreshore beach samples shows significant differences (Table 1). The differences are in the absolute values but the relative values are the same for all five locations. Because these two sample sets were taken at different times this is not an unexpected result. Differing wave conditions can result in variation of foreshore beach sediment that may occur from day to day. The fact that the values of THOM *et al.* (1983) and those of this study show the same relative values suggests that there is some stability in the grain size trend along this reach of coast.

COMPOSITION

There is considerable variation in the composition of Victoria beaches although there are distinct patterns in the three most abundant constituents (Figure 4). Feldspar, the least abundant of the three major components is relatively abundant at locations 1-14 except for location 12. This coincides with the two eastern sections and with potential sources from both intrusive and extrusive igneous rocks (Figure 1). In the western part of Victoria only location 21 at Cape Otway had over 5% feldspar.

Quartz is abundant but ranges widely except at sites 23-26 where it is less than 10%. Bio-

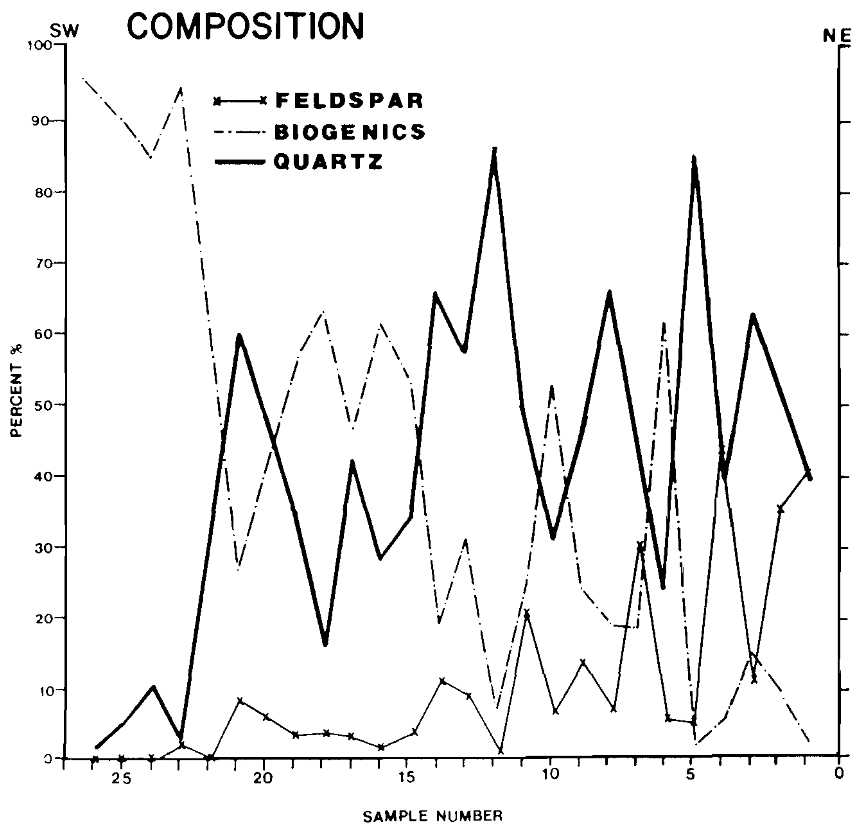

Figure 4. Plot of major constituents of each of the beach samples showing their relative geographic distribution.

genic grains show a distribution that is also quite varied but that is nearly the reciprocal of quartz. This component comprises nearly all of the beach sediment at locations 23-26 (Figure 4).

Another way to visually and graphically consider the composition of these beaches is by histogram (Figure 5). These graphs show both the composition at each location and the breakdown by geographic section. All five components are included with the addition of volcanic rock fragments and the miscellaneous category. Most of the grains in the latter category are chert.

Ninety-Mile Beach Section

The composition of the Ninety-Mile Beach samples shows a dominance of quartz with abundant feldspar except at locations 3 and 5. The abundance of feldspar is rather easily explained in that these sediments are reworked from Tertiary and Quaternary sands and gravels that were derived from the nearby granitic and arkosic rocks of southeastern Victoria (McANDREW and MARSDEN, 1973; JENKIN, 1965). The low concentration of feldspar at location 5 may be due to local conditions of littoral drift reversal and lack of mixing with the bulk of this barrier system. The low concentration at location 3 is about twice that of location 5 but is unexplainable with existing data.

The concentration of volcanic rock fragments and biogenic grains is understandably low. There are no source rocks in the vicinity to provide these materials. The biogenic constituent is all produced by modern organisms, principally mollusks. A comparison of carbonate concentrations from the five locations of this study with the same locations as reported by THOM *et al.* (1983) shows remarkable similarity

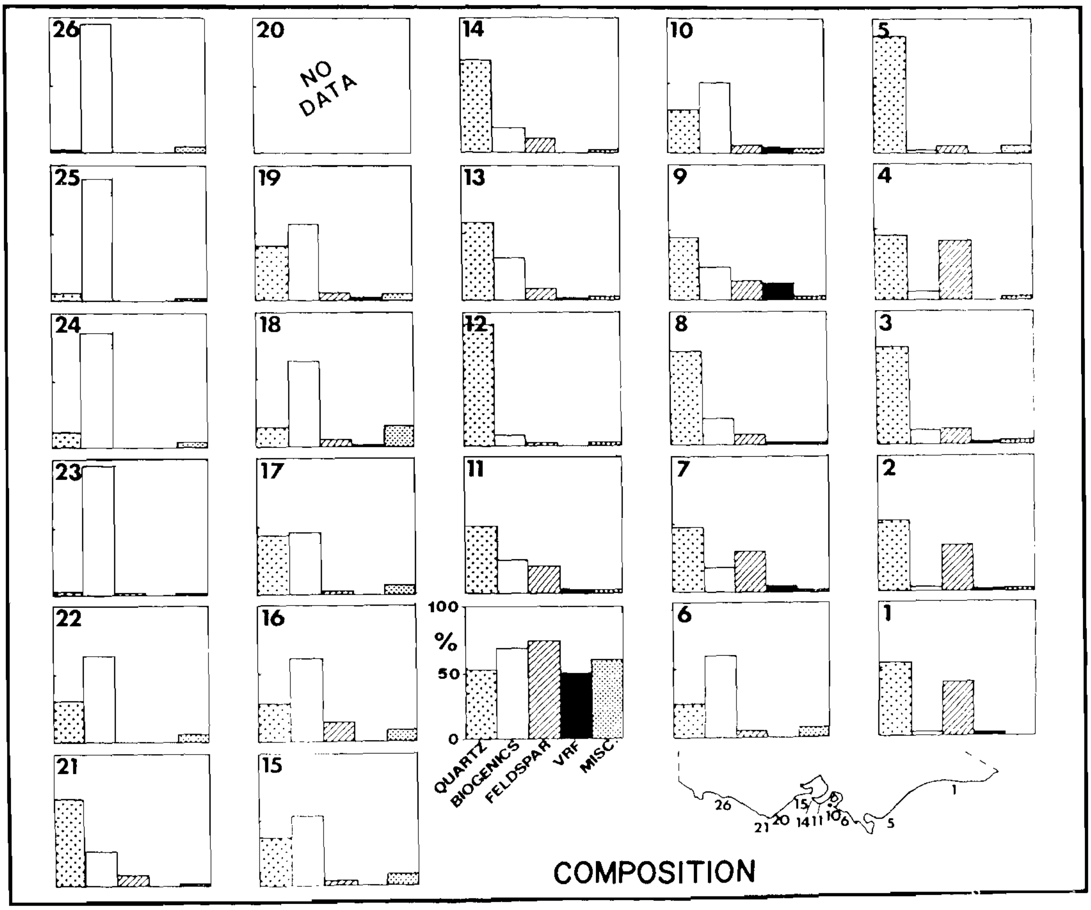

Figure 5. Histograms of mineralogic composition for each of the beach sites arranged geographically by major coastal section.

(Table 1). These data suggest that whereas grain size would be expected to show temporal variation as conditions change, the carbonate shell concentration remains essentially constant through time.

Wilson's Promontory to Port Phillip Bay

This coastal section displays the greatest variety in all respects including composition of the beach sediment. The dominant mineral throughout this seciton is quartz except for locations 6 and 10 where biogenic carbonate grains are dominant (Figure 5). The reason for the abundance of biogenic grains is that Pleistocene eolianite strata are locally present along this coast as far east as near the Darby River on Wilson's Promontory. These easily eroded, carbonate-rich strata provide a ready supply of biogenic beach sediment which is supplemented by skeletal debris from modern shelled organisms.

Feldspar and volcanic rock fragments show great variation throughout this section of the Victorian coast (Figure 5). This is due to the broad spectrum of source rock types along the coast and the somewhat cellular nature of the coast. There are terrigenous sedimentary rocks, intrusive and extrusive igneous rocks and eolianites. The headlands, spits and inlets present a series of short segments of coast that interrupt any littoral transport that might occur. As a consequence there is little uniformity to the composition of beach sediments (Figure 5).

Port Phillip Bay to Cape Otway

The composition of beach sediment between the mouth of Port Phillip Bay and Cape Otway is fairly consistent. The dominant constituent in all samples is biogenic carbonate grains with varying amounts of quartz. This section of coast has only one location (#16) where feldspar is above 5% of the total and it is the section where the miscellaneous category is the most abundant with most being chert.

These compositions reflect the nature of the strata exposed along the coast. These strata consist primarily of Cretaceous and Tertiary terrigenous sandstone and limestone along with some scattered Pleistocene eolianites. A general breakdown of composition can be made along the coast with the terrigenous sediments being most abundant in the southwestern portion and limestones most abundant in the northeastern part of the coast. Eolianites are scattered throughout (SINGLETON, 1973). It is not possible to distinguish petrographically between the carbonate grains derived from eolianites, limestones, or from the modern organisms. It can be assumed that chert grains came from the limestones due to their typical occurrence in this rock type.

Cape Otway to near Point Fairy

The westernmost coastal section also displays a great deal of homogeneity in terms of beach sediment composition. In all samples except the one at Cape Otway (#21) there is a distinct dominance of carbonate biogenic grains. In fact most samples show more than 90% carbonate. All other categories are present in very small amounts except for quartz at locations 21 and 22 (Figure 5).

This distribution pattern is directly related to the composition of the strata that crop out along this section of coast. Near Cape Otway there are Cretaceous sandstones and conglomerates exposed, accounting for the relatively high quartz content of samples from locations 21 and 22. Westward of this area the entire coast is dominated by Tertiary limestones and Pleistocene eolianites which produce the biogenic grains.

DISCUSSION

The nature of Victoria beach sediments shows some distinct patterns which can be related to both coastal processes and adjacent source rocks and which are related to four coastal sections. Although the four coastal sections have only two different general trends in direction, there is great variety of coastal geology and geomorphology along which the beaches are located.

The textural properties of these beach sediments are similar to those of most beaches. The sediments are well sorted, they display a rather wide range in grain size and they are nearly symmetrical in their distribution. Based on a comparison with beaches in the Gulf of Mexico (DAVIS and FOX, 1975; MOIOLA and SPENCER, 1973) and the Atlantic coast of the United States (MARTENS, 1935), Victorian beaches are generally better sorted. This is probably due to the overall more energetic wave climate of the Victoria coast as compared to either of the others.

The composition of Victorian beaches strongly reflects the composition of the strata that are exposed along the coast and that are being eroded by Southern Ocean waves. The modal analysis at each of the locations studied can be related to the composition of nearby strata exposed along the coast. All coastal sections except the Ninety-Mile Beach area are dominated by bedrock, thus providing a ready supply of beach material.

There are four potential sources for beach sediments along any coast; (1) rivers carrying their load to the coast, (2) erosion of bedrock along the coast, (3) longshore transport from along the coast, and (4) from the adjacent continental shelf.

No major rivers empty directly onto the Victorian coast. There are large rivers and drainage basins in the Gippsland area of southeastern Victoria, however, they empty into large estuaries far from the open coast. Only small streams carrying a volumetrically insignificant sediment load are directly emptying onto the coast in the other three sections.

Erosion of coastal strata is a major contributor to beach sediments in the three western sections of the Victorian coast. Only the Ninety-Mile Beach area is not bounded in large part by bedrock cliffs or bluffs. These high-relief features are impacted directly by Southern Ocean waves along much of the coast during storms. As expected the rate of retreat of these bluffs is high in areas bounded by eolianites and other sedimentary strata but it is less locally where igneous complexes are intersected by the shore.

Longshore transport along the Victorian coast is important to the composition of beach sediments along some sections. The two western sections display rather smooth and continuous coasts that allow for longshore transport of coastal sediments over long reaches of each section. The directions of dominant wave approach from the southwest (HINWOOD *et al.*, 1982) and nearly total refraction of waves prior to reaching the beach results in only modest longshore currents. The section between Wilson's Promontory and the entrance to Port Phillip Bay has the least amount of longshore transport of the four coastal sections. This results from the combination of the above mentioned wave climate characteristics coupled with the discontinuity of this coastal section. By contrast the easternmost section experiences probably the greatest longshore transport of coastal sediments. Waves approach with some angle from the south (BIRD, 1978) and this, coupled with the smooth and continuous nature of the shoreline cause a prominent northeasterly transport of coastal sediments (THOM, 1984).

The fourth source of beach sediments is from the adjacent continental shelf. Wave-generated currents can carry sediment from relatively deep water into the surf zone and eventually come to rest upon the beach. BIRD (1983) attributes much of the sediment on Victorian beaches to this onshore transport. These sediments can come from erosion of Pleistocene and older strata that are under shelf waters or from reworking of sediments that were originally derived from coastal bedrock and deposited during lower stands of sea level during the Pleistocene.

Data collected from this study indicate that most sediment now located on the beaches of Victoria is derived from the adjacent or nearby strata along the coast with the exception of the section from near Corner Inlet to Lake Entrance along the southeastern coast. There is also some longshore and onshore transport that tends to mix sediments. This conclusion is supported by the modal composition of samples from throughout the Victoria coast. In all cases there is good correspondence between the composition of the beach sediments and that of the adjacent coastal strata. Sections of coast that are rather homogenous geologically and geomorphologically show this homogeneity in their composition (Figure 5). The most complex coastal section between Wilson's Promontory and the mouth of Porth Phillip Bay shows this complexity in the modal composition of beach sediments (Figure 5).

This generalization is somewhat in contrast to the findings of BIRD (1983) who concluded that the beach sediments come primarily from offshore. The carbonate-dominated beach sediments are ascribed by Bird to a combination of extant shelled organisms and reworking of submerged Pleistocene calcarenites. The low percentage of carbonate in the Ninety-Mile Beach samples (Figure 5) where no bedrock is present to provide a source of sediment is indicative of the extant population of benthic carbonate shelled organisms. It is unreasonable to expect that the population of organisms off the coast of the area to the west of the entrance to Port Phillip Bay is several times that of the Gippsland coast in order to provide the abundant concentration of carbonate biogenic material in the beaches of this area. It is much more likely that the eolianites and limestones along this part of the Victorian coast are major contributors of carbonate to the beaches.

Another indication that coastal bedrock is the primary contributor to beach sediment is in the amount of feldspar in the section from Cape Otway to the east. This coast is comprised largely of the Otway Range and its contained sedimentary strata which include some arkosic sandstones (KENLEY, 1976). Although BIRD (1983) states that the feldspar in these strata weathers to silt size and is then carried away from the beaches, there is a significant amount of sand size feldspar in these beaches ranging up to 15% at location 16. The distribution and abundance of feldspar in the modal analyses is compatible with the composition of Otway strata and the northeasterly longshore transport that is present along this coast.

CONCLUSIONS

Textural and modal compositional analyses of foreshore beach sands from nearly all of the Victorian coast show great variation but also display patterns that are consistent with the coastal geology and geomorphology as well as the processes acting upon this coast. For purposes of generalization the coast can be divided into four sections each of which has its own set of conditions and resulting patterns of beach sediment composition.

The foreshore beach sediments of Victoria show a broad range of grain size but all are well sorted and nearly symmetrical. Because of rapid change in conditions along the coast and the equally rapid response of beach texture, it is not possible to generalize further about patterns in the texture of beach sediments.

Southwesterly winds control wave climate in the Southern Ocean which is dominated by long period waves that are strongly refracted upon reaching the coast. Littoral drift tends to be controlled by locally generated waves and may show local variation. The only coastal section that displays continuous longshore transport is the Ninety-Mile Beach barrier.

Composition of Victorian beaches is dominantly a reflection of the adjacent bedrock strata for the three westerly sections. In each of these there is a common theme to the composition as a result of the partial homogenization by onshore and longshore transport. This is well shown in the two westernmost sections and is shown least in the discontinuous coastal section between Wilson's Promontory and the entrance to Port Phillip Bay. Only the Ninety-Mile Beach coast is not directly related to adjacent bedrock.

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□ RESUMEN □

El análisis de 26 muestras de playa seca a lo largo de la costa Victoria entre Lakes Entrance en Gippsland y Port Fairy, han mostrado una gran variabilidad tanto en textura como en composición. La costa está expuesta a oleaje oceánico de sur y la orientación de las playas as abarca un espectro de 150: Varios cabos restringen localmente el transporte paralelo a la costa excepto en Ninety-Mile Beach, región de la Victoria oriental.

El tamaño medio de las muestras está entre arena muy gruesa y arena fina. La ordenación de la muestra es normalmente muy buena.
La composición de los sedimentos varia considerablemente, siendo el cuarzo y los fragmentos de esqueleto biogénico la composición más común. El feldespato abunda localmente. La mayor parte del sedimento proviene de zonas próximas aunque existe indicación de transporte significante a lo largo de tramos de costa.—*Department of Water Sciences, University of Cantabria, Santander, Spain.*

□ Zusammenfassung □

Die Sedimentanalyse an 26 Lokalitäten aus dem küstennahen ("Foreshore")—Strandbereich entlang der Küste zwischen Lakes Entrance (Gippsland) und Port Fairy zeigte eine große Variabilität in Textur und Zusammensetzung. Die gesamte Küste ist den Wellen des "Southern Ocean" ausgesetzt und die Orientierungen des Strandes variieren über 150 Grad. Verschiedene Landzungen begrenzen den küstenparallelen Sedimenttransport mit Ausnahme des Ninety-Mile Strandabschnittes in Ost-Victoria.—Die Korngröße der Sedimente reicht von Grob- bis Feinsand mit einem guten Sortierungkoeffizienten und einer leicht positiven wie negativen Abweichung des Schiefekoeffizienten. Die gröbsten Sedimente stammen vom Cape Otway und Cape Schank; ab der Landzunge von Cape Otway nimmt die Korngröße ab. Es zeigt sich keine generelle Beziehung zwischen mittlerer Korngröße und Sortierung, da die grobsandigsten Strände zu den am besten sortiertesten gehören.—Die Zusammensetzung der Strandsedimente von Viktoria varriert stark—am weitesten verbreitet sind Quarz und Skelettfragmente, Feldspat tritt nur lokal auf. Zwar entstammt der überwiegende Anteil der Sedimente benachbarten Zuflüssen, doch zeigen sich auch Indikatoren für einen küstenparallelen Transport.—Ulrich Radtke, Geographisches Institut, Universität Düsseldorf, F.R.G.