JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 9, NO. 3, PP. 95–104, FIGS. 1–4, TABLES 1–3,
DECEMBER, 1939

BEACH SANDS FROM BUNBURY, WESTERN AUSTRALIA

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ABSTRACT

The textural and mineralogical features of 15 samples of beach sand from Bunbury, Western Australia are described. The different textures are due to sorting by wave activity which differs on the various beaches. An outline of the geology and physiography of this part of Western Australia is given, and the probable sources of the heavy minerals in the sands suggested.

INTRODUCTION

This examination of the mechanical and mineralogical composition of beach sands was undertaken because it was felt that something could be added to our knowledge of sandy sediments by studying the sands that are accumulating at the present time on seashores. Beach sands, although they do not form any great part of geological formations, may vary considerably within any small area. A record of such textural variation may throw light on similar variations encountered in sediments.

The amount of heavy residue varies in sands and sandstones which are considered to be derived from similar source rocks. The mineral variation in these sands, examined in the light of the conditions under which they are accumulating, shows that the local environment is of great importance, since differences in wave action produce marked variation in mineral contents.

Bunbury, the principal seaport of the southwest of Western Australia, is situated on Koombana Bay, a small inlet off Geographe Bay about 90 miles due south of Perth, the capital (see inset, figure 1). The harbor is, unfortunately, rather shallow, and constant dredging is necessary.

Fifteen samples of sand were collected from the beaches around Bunbury at the positions shown in figure 1. The local conditions vary slightly for each sample. Taking those from the ocean beach first, the most southern, no. 5 and no. 6 are from a moderately wide beach with a fringing platform of sandy limestone. Numbers 7a and 7b, a little farther north, are from a beach between two small headlands of sandy limestone but the water near the beach is moderately deep. Number 14 is from the main wide beach, about half a mile long, which lies between platforms of tholeiite (at the north) and sandy limestone (at the south). The water is deep and the sand is coarse and yellow with abundant shell fragments. Numbers 8 and 11 occur under similar conditions. Numbers 9, 10, 12, and 13 are from within Koombana Bay where there are no rocks except those brought to build the breakwater. These sands are soft, pale yellow, and contain abundant foraminifera. Numbers 4, 3, 2, 1, and 15 are from the southeastern beach of Koombana Bay and are fine white sands with few shell fragments. Each sample was collected just above the waterline, at the landward edge of Johnson's foreshore zone (4, 161).

Before discussing the details of these sands, it is necessary to give a brief outline of the geology and physiography of the surroundings of Bunbury.

GEOLOGICAL AND PHYSIOGRAPHIC SETTING

Geology:—There has been no detailed geological survey of Bunbury since that made by Gibb Maitland in 1897 (7). The information used in compiling figure 1

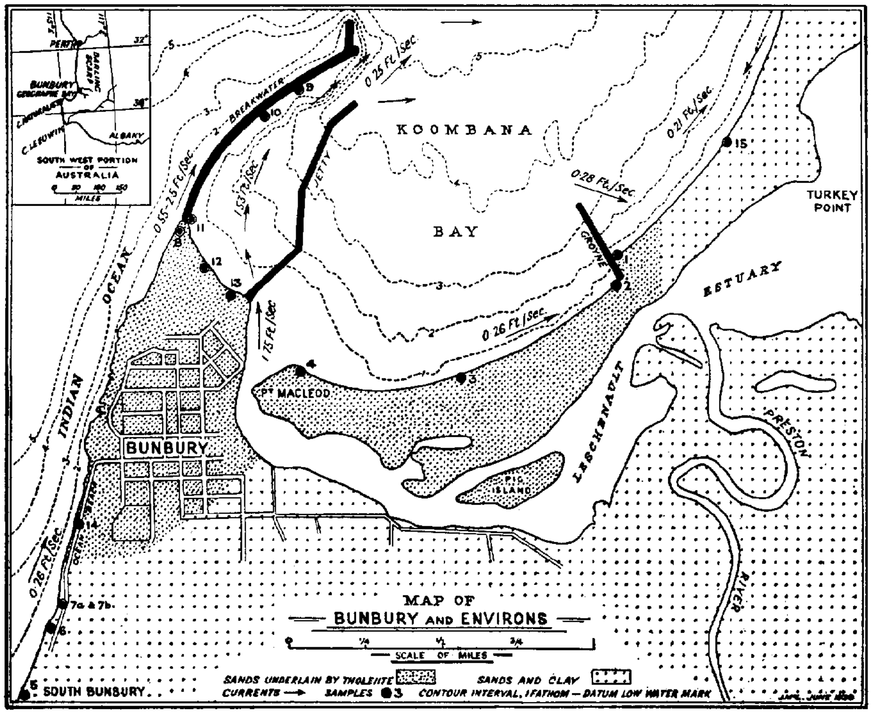

FIG. 1.—Map of Bunbury showing the geology, depth of harbor, direction and strength of currents, positions of sands collected. (Tholeiite extending beneath the harbor has been omitted for clearness.)

Compiled from Public Works Dept. W. Australia plan No. 21923 and Admiralty Chart No. 1034. Geology from bore records.

was obtained from the Public Works department, Western Australia, through the courtesy of Mr. J. Stevenson Young, who made many unpublished plans and bore records available. The soundings were obtained from Admiralty charts.

The principal geological formations are sands and clays, and a flow of tholeiite (3) exposed on the ocean front between the breakwater and the ocean beach, but elsewhere covered by sand dunes. The flow has been encountered by borings at depths between 20 and 35 feet below low water mark in the harbor. The tholeiite is considered to be Tertiary, whereas the sands and clays are Recent, but some, encountered in various bores, may be much older.

A coastal plain extends between the ocean and the Darling Scarp which is the western edge of the great Western Australian plateau (5, 83–85). The coastal plain is composed of the above mentioned sands and clays, with scattered remnants of the tholeiite flow.

Pre-Cambrian gneisses, granites, and greenstones occur on the plateau and Darling Scarp and also in the Naturaliste-Leeuwin area in the southwest. Flanking the western side of the Scarp about 15 miles southeast of Bunbury, and running south, there is a series of sandstones which are correlated with the Permian sediments of a coal basin to the east.

Physiography:—At Bunbury the coastline is broken by the outcrop of tholeiite, and by fringing platforms of sandy limestone. Elsewhere it is smooth and consists of sandy beaches backed by dunes of considerable height for this part of the coast is exposed to the full force of westerly winds.

At Cape Naturaliste, the coast is steep and rocky with deep water up to the cliffs. Rivers immediately north of the Cape are almost stagnant and only reach the sea by artificial channels. They differ from those near Bunbury which have been rejuvenated at least twice in fairly recent times. The coastline between the Cape and Bunbury is smooth with narrow sandy beaches and low sand dunes.

The tholeiite flow at Bunbury formed a reef against which the materials brought down by the Preston and Collie Rivers was deposited. (The Collie River is about three miles north of the Preston at its mouth, and therefore not shown on figure 1.) These rivers now discharge into the Leschenault Estuary, a wide shallow sheet of water which is gradually becoming dry land at its northern end. Separating the Estuary from Koombana Bay is a narrow belt of sand dunes, standing in part on the eastern continuation of the tholeiite flow.

Admiralty charts show that the continental shelf slopes very gently, and not until the Naturaliste Reefs have been passed at about 35 miles west of Bunbury is a depth of 30 fathoms reached. West of the Reefs the slope is rapid and within a few miles 100 fathoms is reached. Soundings in Geographe Bay show that the floor is covered with fine sand, and occasional accumulations of gravel and shells, but no mud. In winter when the Preston and Collie Rivers flood, a great deal of muddy material can be seen entering the sea, but this is mostly removed, as the soundings show, to some distance out to sea.

This part of Western Australia has a winter rainfall of about 36 inches. The prevalent winds during winter are from the northwest, west, and southwest, and often reach gale force. In summer land and sea breezes are of almost daily occurrence, but there are also strong easterly winds. All these winds influence the waves on the beaches and cause currents which are longshore drifts. The main current up the Western Australia coast is from the south.

In order to protect the harbor from the westerly and northwesterly gales in winter, a breakwater was built in about the year 1900, and later extended. This breakwater was built on a reef through which there was a natural discharge channel for the water from the Leschenault Estuary. Sand accumulated quickly in Koombana Bay as can be gathered from a report by F. J. Ramsbotham (10), "From a survey . . . it was ascertained that the beach between jetty and breakwater had advanced at the level of low water 200 feet since 1903, or 20 feet per year." No figures are available for the next 25 years, but the accumulation, though continuing, does not appear to be so great, possibly because of dredging.

Pt. MacLeod is another part of Koombana Bay where sand accumulates, and a spit is forming. A comparison of old and new charts shows that in places near Pt. MacLeod the one fathom line has moved towards the center of the Bay 200 yards since 1885. It is on record that over 4,300 cubic yards of sand accumulated on the shore in this vicinity after a particularly severe gale. A groyne has lately been built to prevent sand from drifting down the eastern side of the Bay to the center. The groyne was finished about three years ago and has been responsible for the accumulation of 7,000 cubic yards of sand annually. The increased size of the beach due to this accumulation is shown in figure 1, while the shallowness of the Bay can be seen from the fathom contour lines. The new land at Pt. MacLeod is already considerable for a line of low cliffs marks the inner edge of a former beach, several hundred yards south of the present beach.

MECHANICAL COMPOSITION OF THE SANDS

The sands were dried and sieved through a set of Tyler sieves giving the Wentworth grades.

Direct cumulative plots were made from these figures, and the Equivalent Grades and Grading Factors calculated by Baker's method (1, 363).

Figures 2 and 3 show the Equivalent Grades and Grading Factor respectively. In these diagrams the samples are arranged in sequence from the most southerly part of the ocean beach to the most easterly part of the Bay beach.

From the variation in Equivalent Grade it is readily seen that the sands from the ocean beaches are much coarser than those from Koombana Bay. Figure 3 shows that all the sands are fairly well-sorted, the most perfectly sorted being from the Bay where the water is quieter and less subject to violent waves.

TABLE 1. *Mechanical analyses of the sands*

Percentage retained on:	9	16	32	60	115	250
Screen openings (mm.):	1.98	0.99	0.49	0.24	0.12	0.06
	%	%	%	%	%	%
Sample no. 1	0.06	—	0.25	77.3	18.5	3.9
Sample no. 2	—	0.03	5.08	61.34	30.1	3.47
Sample no. 3	—	—	3.92	82.86	11.4	1.78
Sample no. 4	—	—	0.72	65.9	32.3	1.05
Sample no. 5	—	0.02	7.86	47.93	42.1	2.09
Sample no. 6	0.16	1.13	6.54	17.6	69.0	5.48
Sample no. 7a	—	0.49	36.1	56.5	6.4	0.44
Sample no. 7b	—	0.54	19.1	32.8	45.1	2.46
Sample no. 8	0.04	0.67	38.6	54.8	5.7	tr.
Sample no. 9	—	0.01	0.63	39.3	54.8	5.23
Sample no. 10	—	—	0.04	41.8	55.1	3.03
Sample no. 11	0.07	0.47	58.1	37.7	3.3	0.33
Sample no. 12	0.03	0.18	4.6	84.7	9.9	0.56
Sample no. 13	—	—	0.9	55.9	40.8	2.3
Sample no. 14	0.43	1.57	43.0	42.8	11.2	0.97
Sample no. 15	—	—	2.4	76.8	16.8	3.87

The figures of table 1 were drawn as curves in figure 4.

From figure 4 it is seen that there are three distinct texture groups of sand:—

1. Rather poorly sorted with the maximum in grade +32 and a secondary maximum in the next finer grade. Numbers 11 and 14 from the ocean beach.
2. Well-sorted sands with the maximum in the +60 grade. Numbers 1, 2, 3, 4, 12, and 15, from Koombana Bay.

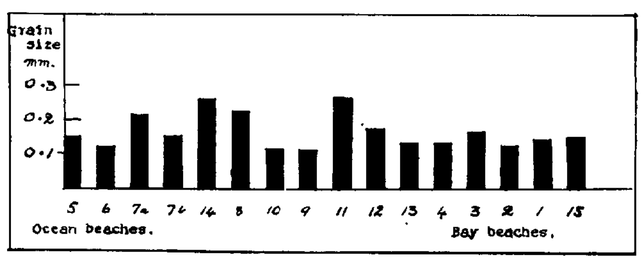

FIG. 2.—Equivalent grades of the sands.

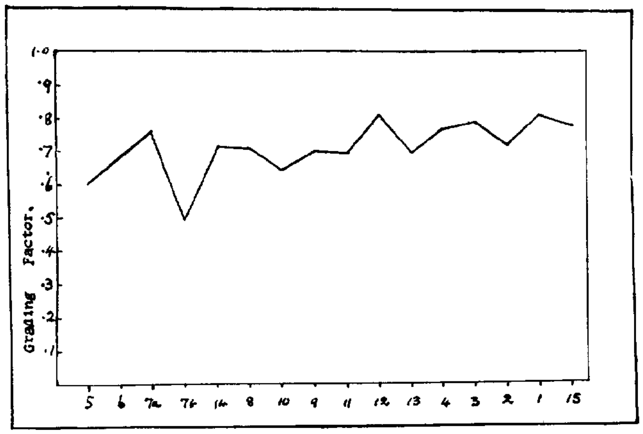

FIG. 3.—Grading factors of the sands.

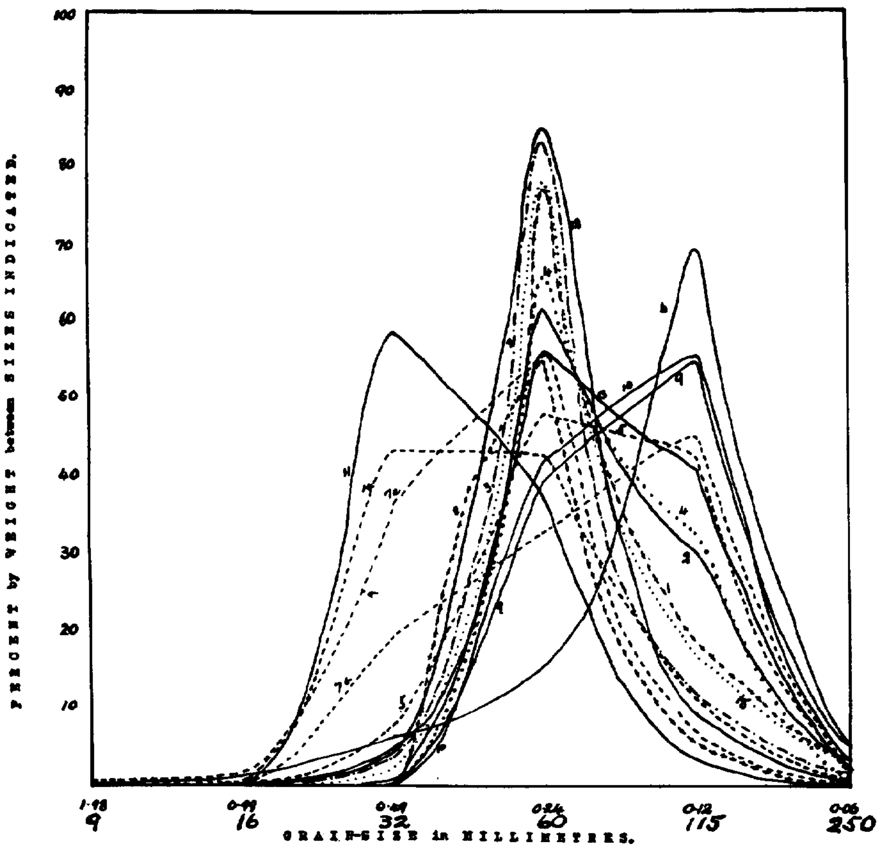

FIG. 4.—Frequency curves of mechanical analyses of Bunbury beach sands. The sieve numbers have been added beneath the grain-sizes.

3. Fairly well-sorted with the maximum in the +115 grade. Numbers 6, 9, 10, 13. With the exception of no. 6, these are from the beach between the jetty and breakwater.

Numbers 5, 7a, and 7b, 8, do not seem to fit into any of these groups.

The sands from the ocean beach are coarse and possess secondary maxima which indicate that the sorting is not complete. An interesting point is that this beach is never hard and firm, like some of those in the Bay. This softness has been explained by Kindle (6) as being due to the shell fragments which "reduce the effective operation of the binding influence of capillarity and thus prevent the formation of a hard beach." Another factor here is that fairly deep water comes in near the platform of tholeiite at the northern end of the main beach and stronger wave action takes place causing the accumulation of coarse material at the expense of fine which is swept out to sea.

Number 6 is a sand in which some coarse material still remains, but the sand as a whole is fine-grained. Number 5 is a typical sand from the southern portion of the beach.

The sands from Koombana Bay near the groyne show nearly perfect sorting. Numbers 9, 10, and 13 contain a great deal of organic material in the form of minute spicules, foraminifera, and shell fragments. It is difficult to know whether this should be removed before a mechanical analysis is made or not. It was felt that the whole of the material represented the sand, so it was not removed.

Number 7b is an imperfectly sorted sand, and the mixing was obviously done by waves just prior to collection, for swash marks of sand and seaweed still were fresh. It was collected to compare with 7a, the sand from a small bank which had been cut into by the sea. This locality has rather deep water almost to the shore as it is in a little bay between headlands of sandy limestone.

The movement of sand on beaches is due principally to wave activity, but it is beyond the scope of this paper to discuss the many aspects of wave action on sands. Sorting by waves and currents has been summarized elsewhere (9, 87).

Within Koombana Bay the waves strike the eastern shore obliquely and a longshore drift is set up. The waves gradually work along the beach with a creeping action which is excellent for lifting out the finer grains and moving them slightly towards the south all the time. On fine days the gently lapping waves can be seen doing this work, and ripples parallel to the shore are also formed. That this wave sorting is effective is shown by the accumulation on the east side of the groyne as mentioned before. Heavy minerals are concentrated on the beach east of the groyne, and when this beach is cut into banks by waves, the heavy dark-colored minerals are seen in thin bands, similar to those described by Thompson (13, 726, and pl. 1). The sand dunes behind the beach also contain a large quantity of heavy minerals.

Most of the currents shown in figure 1 would not alone be effective in moving sand, as it has been found (12) that a current of 0.5 feet per second is required to move sand grains 0.01 inch in diameter, or about equal to those just retained on a no. 60 Tyler screen. The current flowing from the mouth of the Estuary is sufficiently strong to move sand and is responsible, with the co-operation of wave activity, for the sand accumulating within the breakwater. Even before this breakwater was built sand tended to accumulate on a tholeiite reef, but the breakwater is a much more effective barrier. Sand has also been forced around the end of the breakwater by waves and winds from the west and southwest, but this has been partially stopped by building a northwest extension. Sand and seaweed have been carried right up on to this end of the breakwater, 20 to 30 feet above the sea.

The tides in Koombana Bay have very little influence on sand movement. There is only one tide every day, and that only of a foot or two.

From observations at the Ocean Beach it was found that under strong westerly winds the beach is cut back almost to the roadway (in summer the beach is 200 to 300 yards wide) and well-rounded tholeiite boulders are exposed in places. The sand is carried out from one end of the beach, and, when the wind conditions are favorable, returned to the other. Any fine sand is moved away, and the sand appears to be a coarse residue in the process of being ground finer. Occasionally in summer fine sand is found in the sea within 100 yards of the beach, but it is never on the beach. The currents along this part of the coast are from the south, but are of low velocity. Nevertheless when waves have moved out the finer grains in suspension these will tend, because of the current, to be moved slightly northwards, hence there is a potential sorting of the finer sand towards the breakwater. Another factor assists the production of coarse sand on this beach, the depth of water here is greater than it is in Koombana Bay, and the beach faces the open ocean so that waves are bigger and stronger. Cornish (2) states as a general law for the movement of material on beaches that "the grain (size) of the beach is coarser where the beach is exposed to the heaviest breakers," and this is found to be true of the sands examined.

MINERALOGY AND ORIGIN OF THE SANDS

An inspection of the mechanical analyses shows that for most of the sands the +60 grade is the most prevalent, although the +32 is the most prevalent in the two coarsest sands. Accordingly grades +115 and +250 were separated in bromoform to obtain the heavy minerals (+ here means retained on; +250 indicates that the sample has passed the 115 mesh sieve and is retained on the 250).

TABLE 2. *Beach sands, Bunbury. Heavy minerals in the +115 grade.*

Max. in grade	+115											•		+60		
	+60	+60	+60	+60	+60	+115	+60	+115	+60	+115	+60	+32	+60	+60	+32	+60
Index Fig.*	25.5	.35	6.3	.65	.25	.10	3.2	.45	.35	.15	.40	.61	.20	.10	1.43	33.2
Sample no.	1	2	3	4	5	6	7a	7b	8	9	10	11	12	13	14	15
Minerals																
Magnetite	A		a													A
Ilmenite	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a
Calcite		a		+	+	+	+	+	+	a	a	+	a	a	+	
Amphibole	+	a	a	a	a	a	+	a	+	+	a	+	+	+	+	+
Tourmaline	+	+	+	+	+		+	+			+	+		+	+	+
Leucoxene	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+
Garnet	a	+	+	+	+	+	a	+	+	+	+	+	+	+	+	+
Epidote	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Kyanite	+		+		+	+	+	+	+						+	+
Zircon	+					+	+	+	+						+	
Rutile	+					+			+						+	+
Monazite						+									+	
Zoisite								+								
Staurolite	+							+			+					+
Corundum									+							
Sphene												+				

A = very abundant; a = abundant; + = present but not in large amounts.
* Index figure is the per cent by weight of heavy minerals in the sample.

The concentration of heavy minerals by natural panning similar to that of a beach placer deposit is very high in numbers 1, 3, and 15. After the magnetite was removed with a small electromagnet the remaining dark-colored grains, presumably ilmenite, were removed by fusing part of the heavy residue with $KHSO_4$ in a small crucible. The light colored infusible grains were recovered by taking the fused mass into solution with *warm* water. The use of this salt

TABLE 3. *Beach sands, Bunbury. Heavy minerals in the +250 grade.*

Index Fig.*	100	4.9	80	6.6	12.5	2.4	11.4	11.4	.95	3.9	3.0	1.7	.42	31.9	100
Sample No.	1	2	3	4	5	6	7a	7b	9	10	11	12	13	14	15
Minerals															
Magnetite	A		A											A	a
Ilmenite	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Calcite		+	+	+	+	+	+	+	+	+	+	+			
Amphibole	+	a	+	a	+	a	+	+	a	a	a	+	a	+	+
Tourmaline		+		+	+	+		+	+	+	+	+	+	+	
Leucoxene	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
Garnet	+	a	+	a	+	+	+	a	+	+	+	+	+	+	
Epidote	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
Kyanite		+		+	+	+		+	+			+	+	+	
Zircon	+	+	a	+	+	+	+	+	+	+	+	+	+	a	a
Rutile	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Monazite	+		+											+	+
Zoisite					+	+	+				+	+	+		
Staurolite		+		+	+	+			+		+		+		
Sillimanite		+	+					+	+			+			
Sphene			+	+	+	+			+	+	+	+	+		+
Apatite					+	+			+	+	+	+	+	+	
Pyroxene		+	+	+	+	+	+	+	+	+	+	+	+		
Spinel															+
?Topaz			+												

A = very abundant; a = abundant; + = present but not in large amounts.
* Index Figure is the per cent by weight of heavy minerals in the sample.

was first advocated by Mackie (8). The remaining grains were thus concentrated and appeared to better advantage.

It is noticeable that with the increase of the index figure in the finest sand examined (table 3), there is also an increase in the number of minerals. No percentage figures for individual minerals were obtained, and the relative abundances given are estimates.

There are a number of possible sources for these heavy residues:—

1. The Recent to Sub-Recent sands, clays, and limestone of the coastal plain.
2. The tholeiite flow underlying the town of Bunbury and outcropping on the beach.
3. Permian sandstones.
4. Pre-Cambrian complex of the Darling Scarp and plateau.
5. Pre-Cambrian rocks brought from the Scarp to build the breakwater.
6. Pre-Cambrian gneisses of the Naturaliste area.

1. Little is known of the Tertiary to Recent geological formations in this part of Western Australia, but it appears that the sands and clays have been derived from the weathering and transportation of Pre-Cambrian material, for the Darling Scarp is in a complex of gneisses and granites. The Collie and Preston rivers must have been responsible for much of the material of the plain. From the worn appearance of zircon, kyanite, tourmaline, and monazite it is probable that they have passed through several cycles of sedimentation.

2. Magnetite, ilmenite, and pyroxene occur in fresh angular grains. The tholeiite has doubtless provided pyroxene, and probably much magnetite and ilmenite; but it is difficult to be certain that magnetite and ilmenite do come only from the tholeiite, as they are, especially ilmenite, common to a great many beach sands where no basic source rock is present. When tholeiite weathers to soil the pyroxene is quickly changed to a clay mineral, whereas under marine disintegration some of the pyroxene remains. Pyroxene is a fairly persistent, though not a prominent, constituent of the heavy residues.

3. Permian sandstones are cut through by the Preston River when it leaves the Scarp and flows out on the coastal plain. The redistributed sand from these sandstones may have given rise to some of the unconsolidated sands of the plain. The sandstones contain abundant zircon in worn grains, tourmaline, worn kyanite

and rutile. All these are similar in appearance to the same minerals in the beach sands.

4. As the rivers have short courses from the Scarp to the sea it is probable that some fresh material has been brought down. Amphibole is almost certainly from this source, and it is possible that epidote and zoisite may have come in as well. The former is a stable mineral which can survive long transport so that it may also be present in the sands of the plain. Zoisite is regarded as less stable than epidote, and it is not recorded from sediments and sands nearly as often as epidote. It is a mineral characteristic of metamorphic rocks, and its source is likely to be in the Pre-Cambrians of the drainage area.

5. The influence of the breakwater rocks, fresh gneisses, granites, and greenstones brought from the Darling Scarp, is not easily determined, though presumably some weathering and disintegration must have taken place during the last 35 years or so. These rocks are potential sources of hornblende (the actinolite variety common to epidiorites), zoisite, epidote, apatite, and zircon. No attempt was made to distinguish between the different types of zircon found in the sands; most of the grains were of the rounded prismatic type, but a number of fresh unworn grains were also seen.

6. Garnet is a mineral which is present in practically all the sands. It occurs in fresh angular fragments and occasional small dodecahedra. So far as is known to the writer no garnetiferous rocks are in the breakwater, so that the source of this mineral must be sought elsewhere. It may have come in with the sands and clays of the coastal plain, but its angularity suggests a source nearer at hand; or, a source which has been tapped later in the history of the sands. The nearest known garnetiferous rocks occur in the valley of the Preston River, some 35 to 40 miles southeast of Bunbury, and the grains may have come in with others carried down by the river. Another possible source for garnet is the gneiss which outcrops on the coast near Cape Naturaliste. In a direct line the Cape is about 30 miles south-southwest of Bunbury. Ilmenite-garnet sands occur in patches on the beaches near the Cape, and it is possible that garnet and ilmenite from this source have been distributed to all the beach sands.

The light fraction of the sands was examined in three grades, the +60, the +115, and the +250. Quartz is the principal constituent, but feldspar, shell fragments, and Foraminifera are also present. The feldspar includes orthoclase, plagioclase, microcline, and microperthite. The +250 grade contains the greatest amount of feldspar. The plagioclase is probably derived from the tholeiite or from the breakwater rocks. The quartz grains are not rounded, angular to subangular grains being predominant. The grains are rather more rounded in the coarser grades, but the general appearance is that of angularity.

The carbonate content of the sands is as follows:—

Sample No.	% $CaCO_3$*
5	32
10	15
12	54
14	20
15	7

The quantity of calcium carbonate indicates to a certain extent the quantity of organic remains. Number 12 is from a part of Koombana Bay where the conditions are quiet, and therefore suitable for the growth of animals, particularly Foraminifera; whereas number 15 is on a shore which is subject to continual wave action which causes the removal of the lightest material.

CONCLUSIONS

The textural features of these sands reflect the local conditions of wave activity to which they have been subjected. The consideration of such a series of mechanical analyses from a small area may help to elucidate the conditions

* By leaching with NCl.

under which textural variations have been caused in sediments which are now consolidated.

The grade in which the heavy minerals occur is of importance when describing sediments, for if the grade containing the maximum amount of the sediment is examined for heavy minerals it does not give a true idea of the quantity of minerals present. This has already been pointed out by Rubey (11). The variation in heavy mineral content is interesting, for it shows that even in one small area great differences occur. In a consolidated sediment such a variation might be considered to represent different periods of deposition.

This investigation shows, too, that lateral variation, in amount if not in the minerals present, due to local conditions of accumulation or sedimentation will be the usual rather than the unusual occurrence in beach sands, and may also be so in other sediments deposited under more uniform conditions.

ACKNOWLEDGMENTS

I wish to acknowledge my indebtedness to Mr. J. Stevenson Young, chief of the Harbours and Rivers branch of the Public Works department, Western Australia, who willingly made available many unpublished reports and maps of the Bunbury Harbour without which this paper could not have been written.

My thanks are due to Professor E. de C. Clarke for his ready interest in the progress of the investigation, and for the many suggestions he has put forward. I wish to thank Mr. H. A. Ellis, acting government geologist, for having figure 1 drafted ready for reproduction.

This investigation was carried out as part of a program of research under a Commonwealth Research grant to the University of Western Australia.

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