THE UNIVERSITY OF ADELAIDE

A BEACH SAND STUDY OF THE FLEURIEU PENINSULA.

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A Beach Sand Study of the Fleurieu Peninsula

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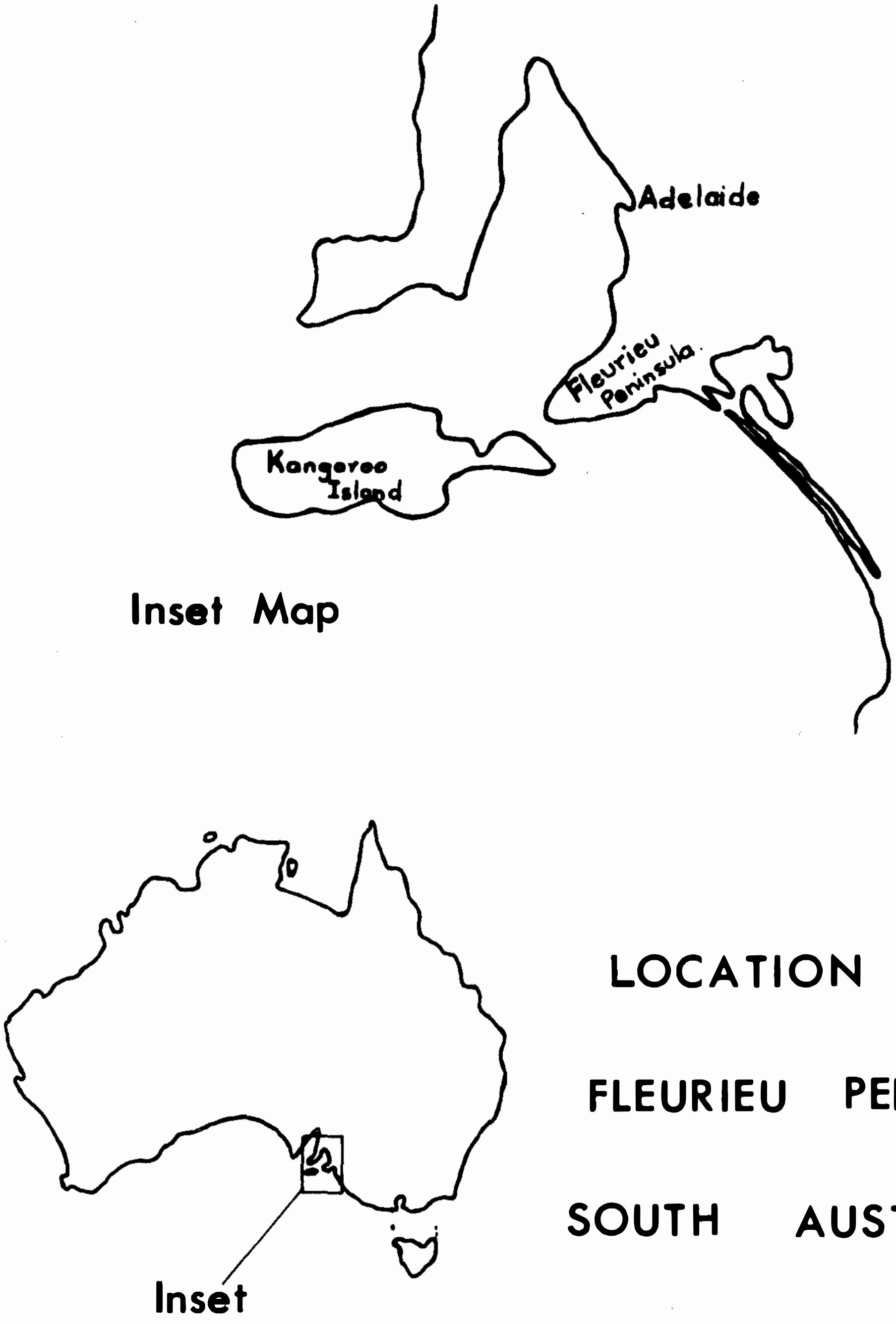
Thesis for B.Sc. (Hons.).

CONTENTS

LIST OF TABLES, GRAPHS, MAPS AND FIGURES.

ABSTRACT

Heavy red sand accumulations are prominent along the Fleurieu Peninsula coastline. The mineralogy of the accumulations were determined along with compositional variations and distribution of the mineral species in average back beach samples. Mechanical analysis of the back beach samples showed that the median, sorting and skewness varied between southern and western coastlines. The southern coastline samples appeared to be finer grained, better sorted and less skewed. Provenance of the heavy mineral content of the sand differs for the respective coastlines of the peninsula. The southern coastline reflects the Cambrian metamorphic terrain while the western coastline reflects the Pre Cambrian inliers and the Tertiary.



LOCATION MAP

FLEURIEU PENINSULA

SOUTH AUSTRALIA

MAP 1

INTRODUCTION

This work was undertaken primarily to determine the nature of the minerals in numerous red-sand accumulations, the composition of the heavy minerals in average back beach samples and to determine the distribution of such constituents along the Fleurieu Peninsula coastline, in South Australia. The coastline examined was between Christies beach and the Murray Mouth (see Map 1 and 2).

The provenance of the heavy mineralogy in the sand was attempted, along with a mechanical analysis of the limited number of back beach and dune samples collected.

1. COASTAL PHYSIOGRAPHY AND GEOLOGY.

The reader is referred to map 2. A more detailed account of the geology of the Fleurieu Peninsula will be given in Appendix 2., but a brief mention of the coastal geology with the physiography will be made here. The coastline consists principally of youthful cliffs cut in Tertiary, Cambrian and Pre-cambrian rocks. The more resistant rock strata form prominent headlands, while the softer lithologies have been eroded away to form embaymants with wave-cut platforms. This is especially evident in the Willunga and Noarlunga Basins on the Western Fleureiu Peninsula, where the beaches are a thin veneer of sediments on Tertiary rock wave-cut platforms.

Rocks of the Kanmantoo Group of Cambrian age outcrop extensively along the southern and south-western coastlines of the Fleureiu Peninsula. The rock types are mainly phyllites, greywackes and quartzitic schists. Granites are exposed at Victor Harbour and Port Elliott and have a localized effect on coastal physiography. On the western side of the peninsula Pre-cambrian rocks outcrop from Rapid Bay to Yankallila Bay. Younger Pre-cambrian rocks of Adelaidean age are exposed in cliffs as marbles, schists, tillites and titaniferous haematite-rich quartzites. The older Pre-cambrian is exposed at Little Gorge Beach as gneisses, schists and pegmatites. Much of the hinterland is covered with till and fluvioglacials of Permian age. Greywacke and limestone of Cambrian age outcrop from Carrickalinga Head to Aldinga Bay. Talus outwash and alluvial clays cover the flat coastal plain from Sellick Beach to Port Noarlunga with sand and limestone formations of Tertiary age outcropping in cliffs along the coast. Embayments and headlands have been carved from these soft rocks. On associated wave cut platforms small areas of sandy beaches and dunes are developed.

The general coastal succession is interrupted by the mouths of small creeks and rivers running into the sea. The major rivers on the western side of the peninsula are the Onkaparinga, Yankallila and the Myponga, while the most important larger creeks are Pedlar's, Canyon, Bennett's, Aldinga and Mt. Terrible. On the southern side the Inman and Hindmarsh river systems are important. Short creeks such as Deep, Tunkilla, Callawonga and Waitpinga have some importance too. Further north on this side of the peninsula the Angas, Finniss, Bremer Rivers and Currency, Tookyerta and Mt. Barker Creek systems drain into the Murray Lakes. Sediment from these northern rivers could eventually reach the sea via these lakes. The rivers usually flow all the year, but in summer months this flow is very limited. The creeks are ephemeral in nature, in that they are small raging torrents carrying sediment to the sea after heavy winter rains, but in summer months they are dry or have a restricted flow. In the summer the stream mouths at the sea are usually barred with sand. There is evidence in the form of enlarged valleys with respect to the present streams to suggest that these streams were much larger in Pleistocene times.

2. MECHANICAL ANALYSIS

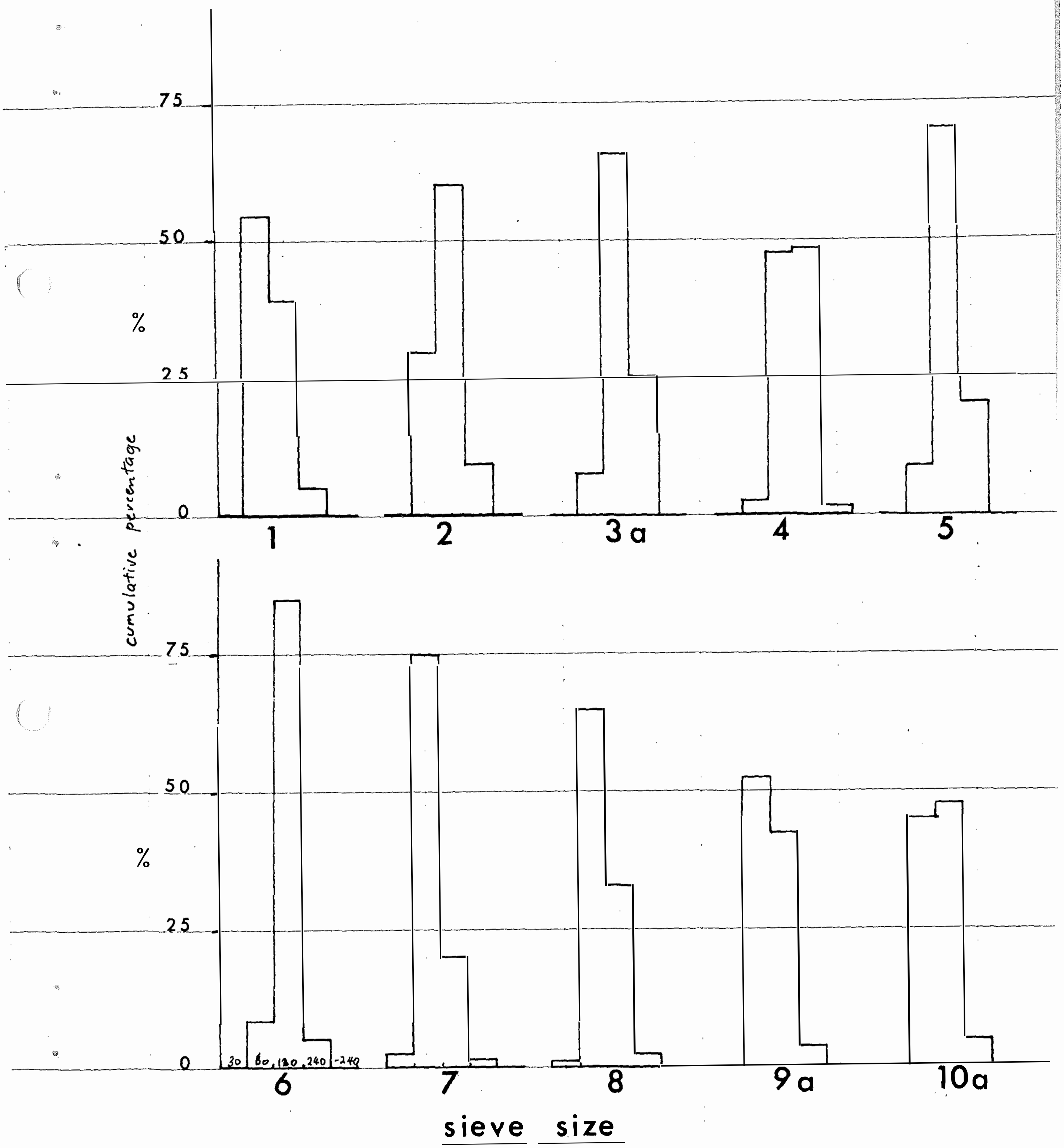
(1) General

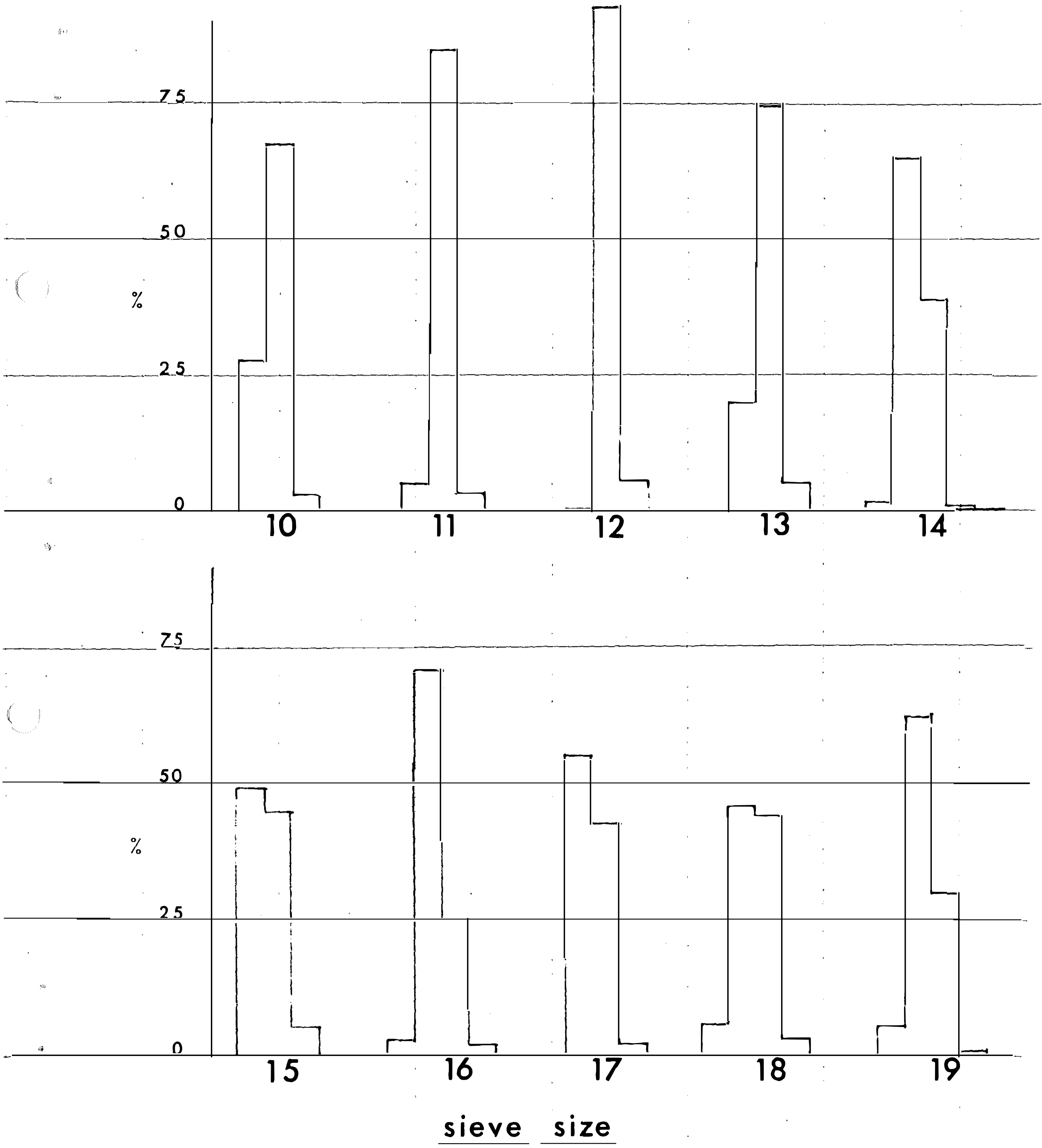
Samples were collected along the Fleurieu Peninsula coastline from Christies' Beach to the Murray Mouth. The approximate position of sample location along this 120 mile stretch of coastline is shown in map 2. A vertical cut of six inches to one foot was made at or

TABLE 1 - MECHANICAL ANALYSIS RESULTS

NO.	B.S.S. SIEVE 30	60	120	240	-240	SL	Md. (mms)	Q1.	Q3.	So.	Sk.
1.	.56	54.07	39.53	5.77	.05	.01	.265	.190	.360	1.37	1.36
2.	.62	29.17	61.65	8.50	.04	.02	.195	.150	.260	1.32	1.03
3a.	.04	7.08	66.96	25.62	.29	.02	.155	.125	.200	1.26	1.04
3b.	.05	1.29	54.09	44.51	.05	.03	.130	.096	.160	1.29	.91
4.	.02	2.59	47.85	48.13	1.38	.03	.090	.125	.170	1.37	.98
5.	.07	9.35	70.47	20.00	.09	.02	.165	.128	.210	1.28	.99
6.	.02	8.32	86.12	5.30	.22	.03	.170	.145	.205	1.31	1.25
7.	2.82	75.95	20.50	.68	.03	.04	.315	.260	.390	1.22	1.01
8.	.61	64.34	33.64	1.37	.01	.02	.290	.220	.360	1.28	.94
9a.	.29	52.66	43.86	3.15	.01	.03	.250	.200	.310	1.18	.99
9b.	.26	55.61	39.26	4.86	.01	.05	.270	.190	.340	1.33	.88
10.	.01	45.94	48.86	5.15	.01	.02	.240	.200	.300	1.22	1.04
11.	.23	5.92	89.44	3.97	.42	.07	.155	.170	.145	1.08	1.03
12.	.01	.58	92.39	6.56	.44	.10	.125	.128	.130	1.04	.99
13.	.56	19.33	75.12	4.84	.15	.03	.190	.160	.235	1.21	1.04
14.	1.08	59.42	38.61	.87	.01	.02	.250	.240	.225	1.03	.98
15.	.04	49.66	44.62	5.64	.03	.11	.250	.200	.290	1.20	.79
16.	2.63	71.10	25.00	1.19	.06	.02	.270	.250	.310	1.11	1.06
17.	.49	55.77	42.46	1.23	.03	.04	.260	.250	.275	1.05	1.34
18.	6.13	46.46	44.41	2.97	.02	.08	.260	.250	.360	1.20	1.02
19.	5.49	62.63	30.96	.88	.02	.06	.290	.245	.370	1.23	1.08
20.	1.12	17.33	80.40	1.08	.04	.07	.120	.120	.120	1.00	1.00
21.	5.65	75.69	18.56	.07	.01	.04	.148	.135	.165	1.10	1.02
22.	.39	83.94	15.42	.19	.03	.02	.135	.130	.140	1.03	.99
23.	.17	39.28	57.89	2.54	.10	.07	.115	.102	.128	1.12	.99
24.	4.2	64.58	30.41	.74	.04	.01	.134	.125	.145	1.08	1.01
25.	3.0	50.73	44.61	1.61	.04	.03	.125	.135	.150	1.05	1.29
26.	28.83	66.72	4.39	.04	.01	.05	.155	.125	.180	1.20	.94
27.	3.7	58.83	36.58	1.12	.37	.07	.127	.120	.135	1.05	1.00
28a.	1.47	68.74	27.13	2.64	.01	.02	.135	.127	.150	1.08	1.00
28b.	.09	13.45	78.44	7.97	.03	.01	.095	.082	.110	1.16	.99
29.	.62	20.11	43.47	35.68	.11	.05	.078	.057	.086	1.24	.78
30.	2.40	62.21	32.38	20.95	.04	.02	.127	.122	.130	1.06	1.04
31.	1.78	22.52	42.9	32.13	.63	.03	.082	.059	.115	1.39	1.01
32a.	.11	27.40	47.01	48.90	1.18	.04	.063	.059	.078	1.15	1.16
32b.	.04	13.75	70.57	15.58	.05	.02	.083	.070	.107	1.23	1.09
33.	.25	6.83	69.10	23.42	.38	.09	.072	.065	.085	1.14	1.07

Figure Ia,b,c,d. Sieve results expressed in histogram form.




75
50
%
25
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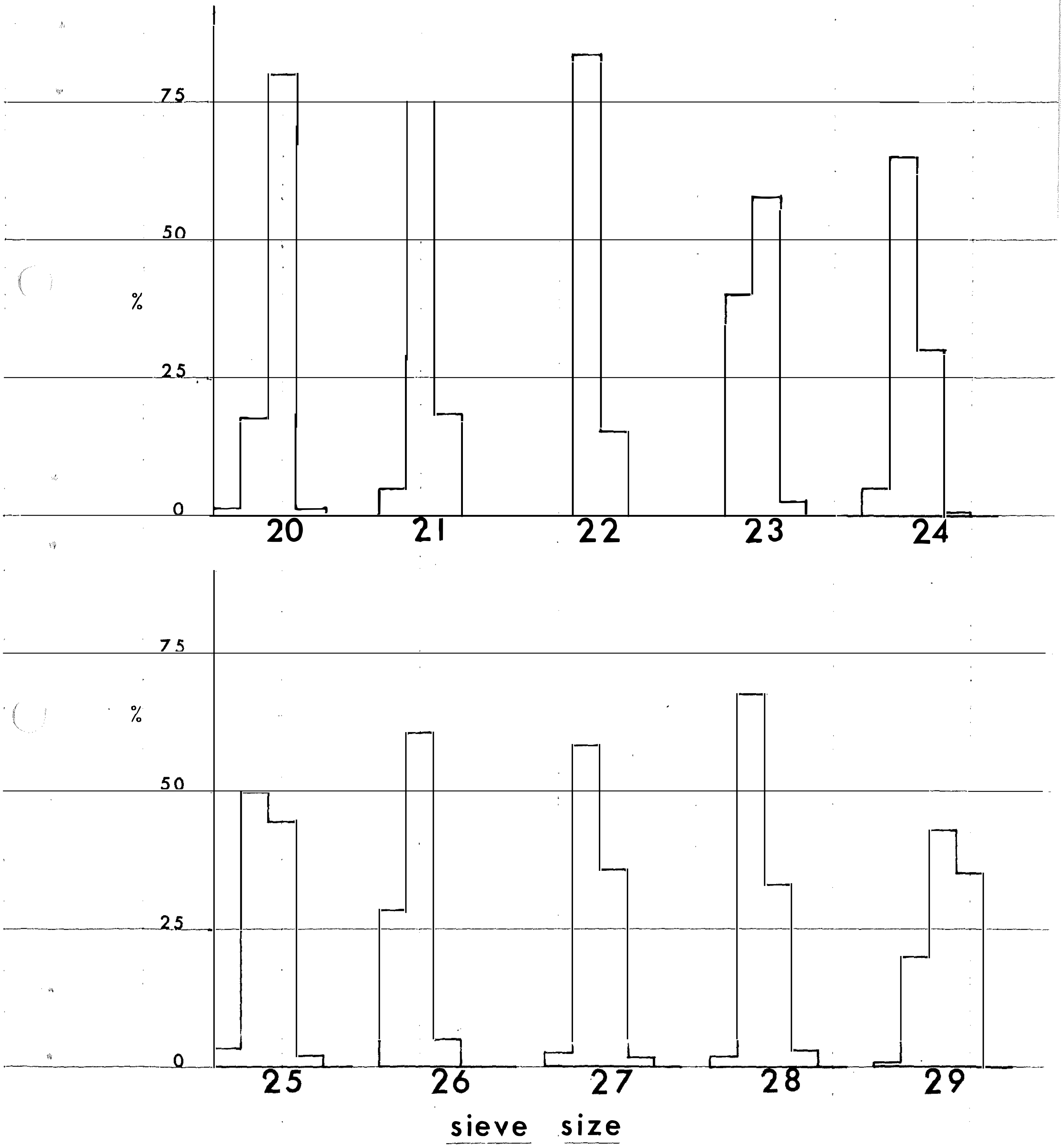
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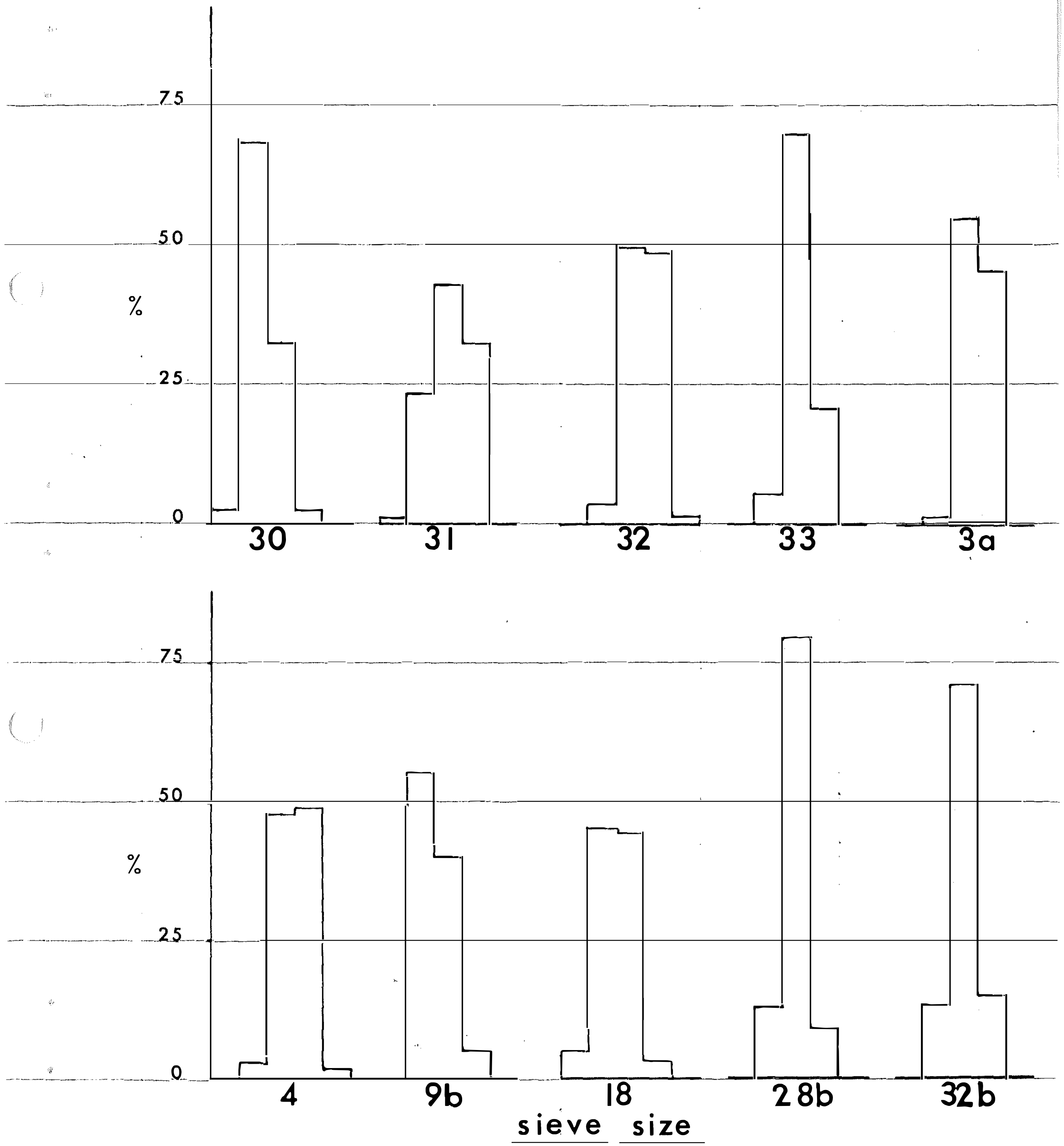
sieve size

Nos. 3a,4,9b,28b, 32b, heavy mineral concentrate results.



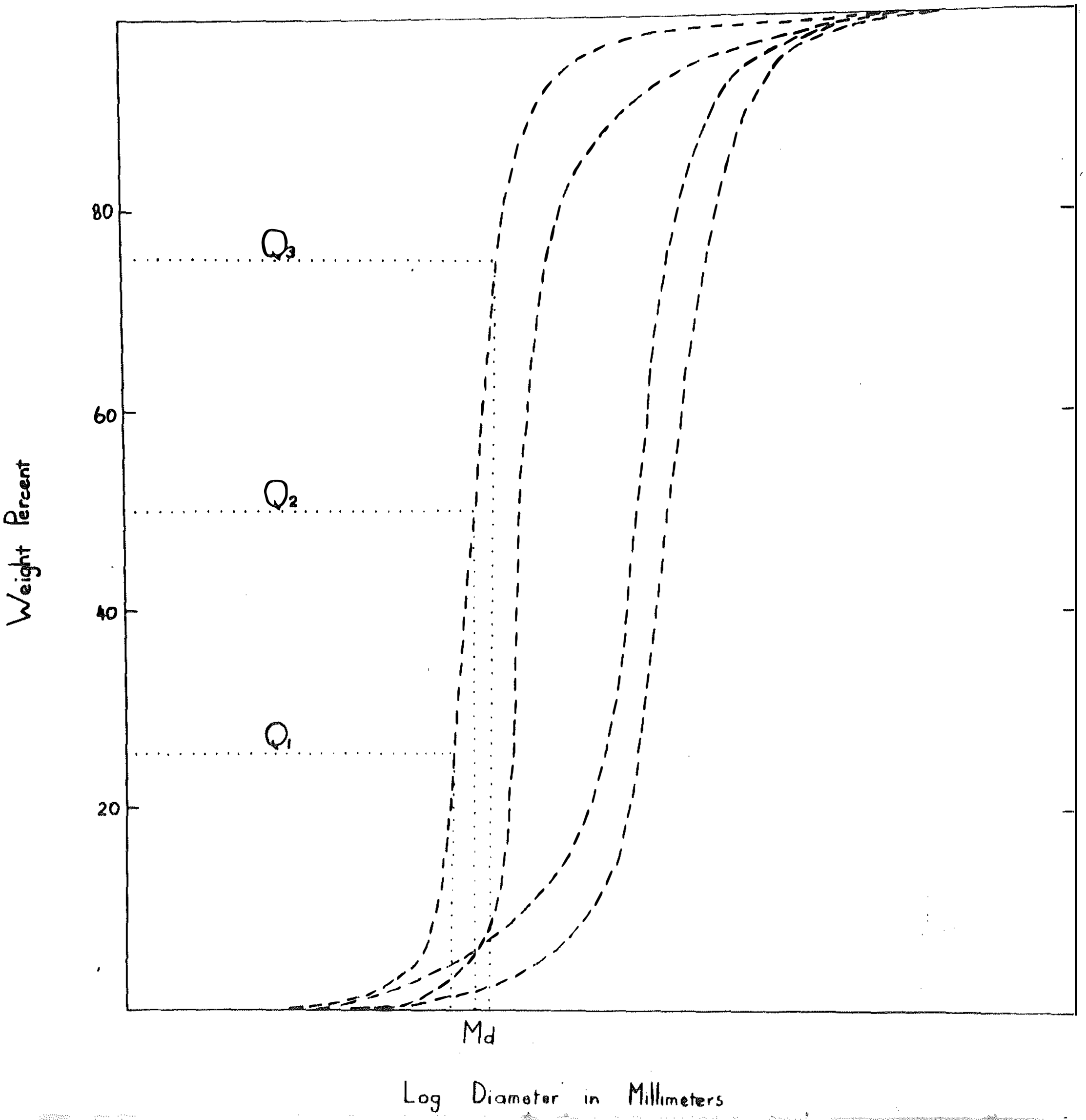


Figure 2a - Examples of cumulative mechanical analysis curves for various back beach samples.

First Quartile (Q1) - 25% of the sample.
Second Quartile (Q2) - 50% of the sample.
Third Quartile (Q3) - 75% of the sample.

Median (Md).

near high tide line. A sample of approximately one kilogram in weight was taken from the bottom and side of this cut by means of a flat bottom trowel. At most localities the composition and texture of the sand varies with seasonal weather conditions, position between high and low tide and along the beach. It was not practical to collect and examine enough samples to study these variations in the time available. The majority of samples collected were representative of the back beach, but a few single layer "paystreak" and dune samples were also taken.

Table 1 shows the results of the mechanical analysis of the sand samples. The samples obtained were brought back to the laboratory to be split, washed, dried, weighed and then sieved using 30, 60, 120, 240, - 240 British Standard Size Sieves. The result of the sieving was expressed in terms of percentages retained on each sieve. These percentages show the distribution of grains according to size. Histogram plots of these results (Figure 1a, b, c, d) showed a symmetrical or assymetrical distribution. The assymetry was marked by a dominance of medium or fine admixtures. These differences are in part a reflection of the condition of deposition.

A better method of comparison of the coarseness, degree of sorting and other textural characteristics is to compute certain statistical constants, these being the median diameter (Md) coefficient of sorting (So) and the coefficient of skewness (Sk) from the cumulative mechanical analysis curve. Figure 2 is an example of this type of curve. The results are plotted on a semi-logarithmic scale causing the central part of the curve to approximate to a straight line. The parameters of the frequency distribution can now be read or calculated from certain points on the cumulative curve.

The most easily determined parameter of size analysis is the measure of "average" size, the median (Md). The median is determined by the point of crossing of the cumulative curve and the 50% line. Thus, the median is that size where 50% of the material is coarser and 50% are finer. There are two other diameters in the size distribution that separate each half of the curve into equal parts. These are called the first and third quartile diameters, designated by Q_1 and Q_3 respectively. Q_1 represents 25% of the weight of the sample composed of particles larger than Q_1, while Q_3 represents 75% of the weight of the sample consisting of particles larger in diameter than Q_3. The quartiles and median are scaled from the mechanical analysis curve and can be used to measure the spread of the grain size in the samples and skewness.

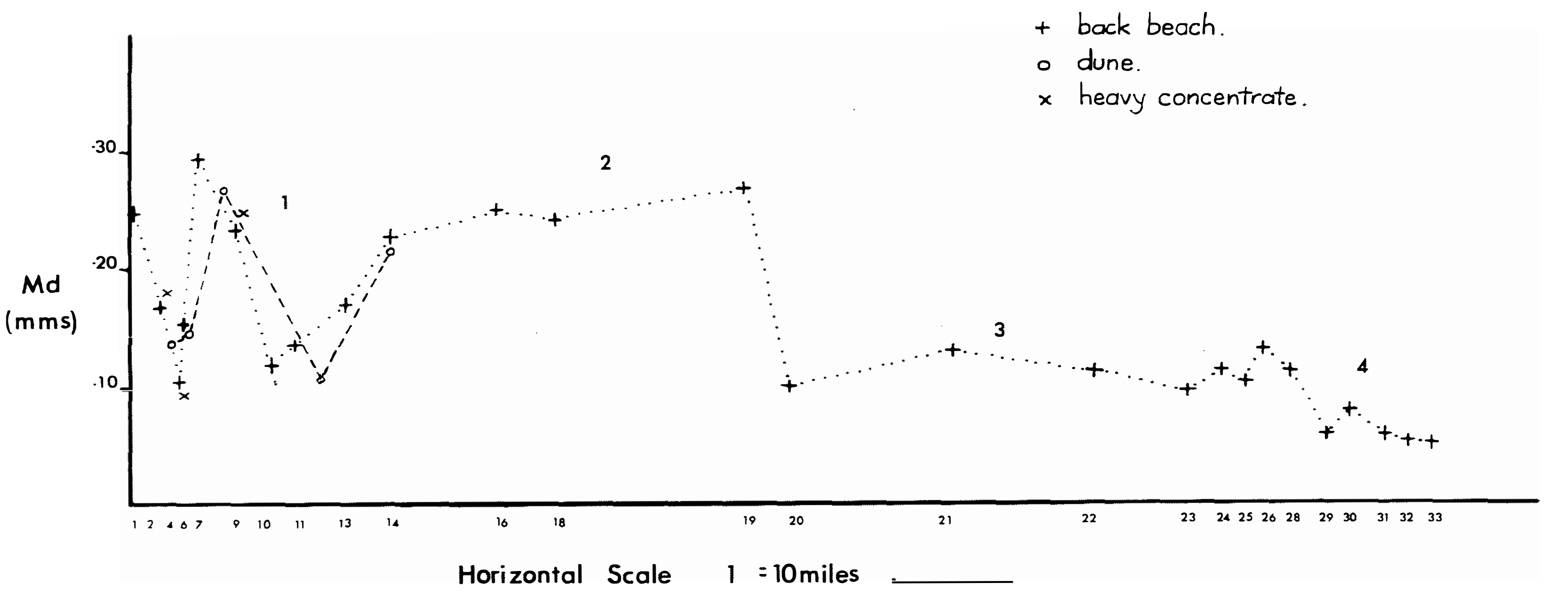
The sorting or spread of the curve is measured by the coefficient or sorting (So) which is given as the square root of the ratios of the quartiles Q_3 / Q_1 where Q_3 is greater than Q_1. The skewness (Sk) measures the symmetry of the curve. This may be measured by the product of the quartiles divided by the square of the medium i.e. $Q_1 \cdot Q_3/(Md)^2$. If Sk is used, perfect symmetry has a value of unity, and all values are either positive or negative depending on the direction in which the curve is skewed. With positive skewness, (i.e. Sk greater than unity), coarse exceed the fine particles and with negative skewness, (i.e. Sk less than unity), the converse is true.

(2) <u>Interpretation of Results</u>

(a) Median

Back beach median range from .315 mms (sample 7) to .063 mms (sample 32). Dune median range from .290 (sample 8) to .125 mms (sample 12). Heavy back beach concentrate range from .270 mms (sample 9) to .083 mms (sample 32). Following the Wentworth Classification of grain size the sands would be described as medium to very fine grained.

The median results of the back beach, some dune and heavy concentrate samples were plotted in graph 1 against geographic location on the coastline. The effect of coastal geology may be evaluated by considering map 2 with graph 1. From the graph there ~~appears~~ appear to be four distinct regions numbered 1 - 4. The medians of the four regions were analysed statistically by the application of the unrelated t test.



GRAPH 1 - Median results of back beach, dune and heavy mineral accumulations.

The following points emerge.

(1) Back beach medians of regions 1 and 2 (= western coastline) differ significantly from regions 3 and 4 (= southern coastline) to the .01 probability level. At this level for 26 samples, the critical value is 2.797. The obtained value was 6.59. Thus at this level for 26 samples, significant difference exists between the medians of the respective coastlines.
The average median for the western coastline is .229 mms, while the average for the southern coastline is .115 mms.

(2) Back beach heavy concentrate medians of the western coastline differ significantly from the southern coastline to the .05 probability level. At the .05 significance level for 5 samples the critical value is 3.182. The obtained value was 3.65. At this level, for the number of samples considered, significant difference exists between the medians. The average median for the western coastline is .218 mms while the southern coastline is .079 mms.

(3) Not enough dune samples were collected from southern and western coastlines for any statistical analysis to be made.

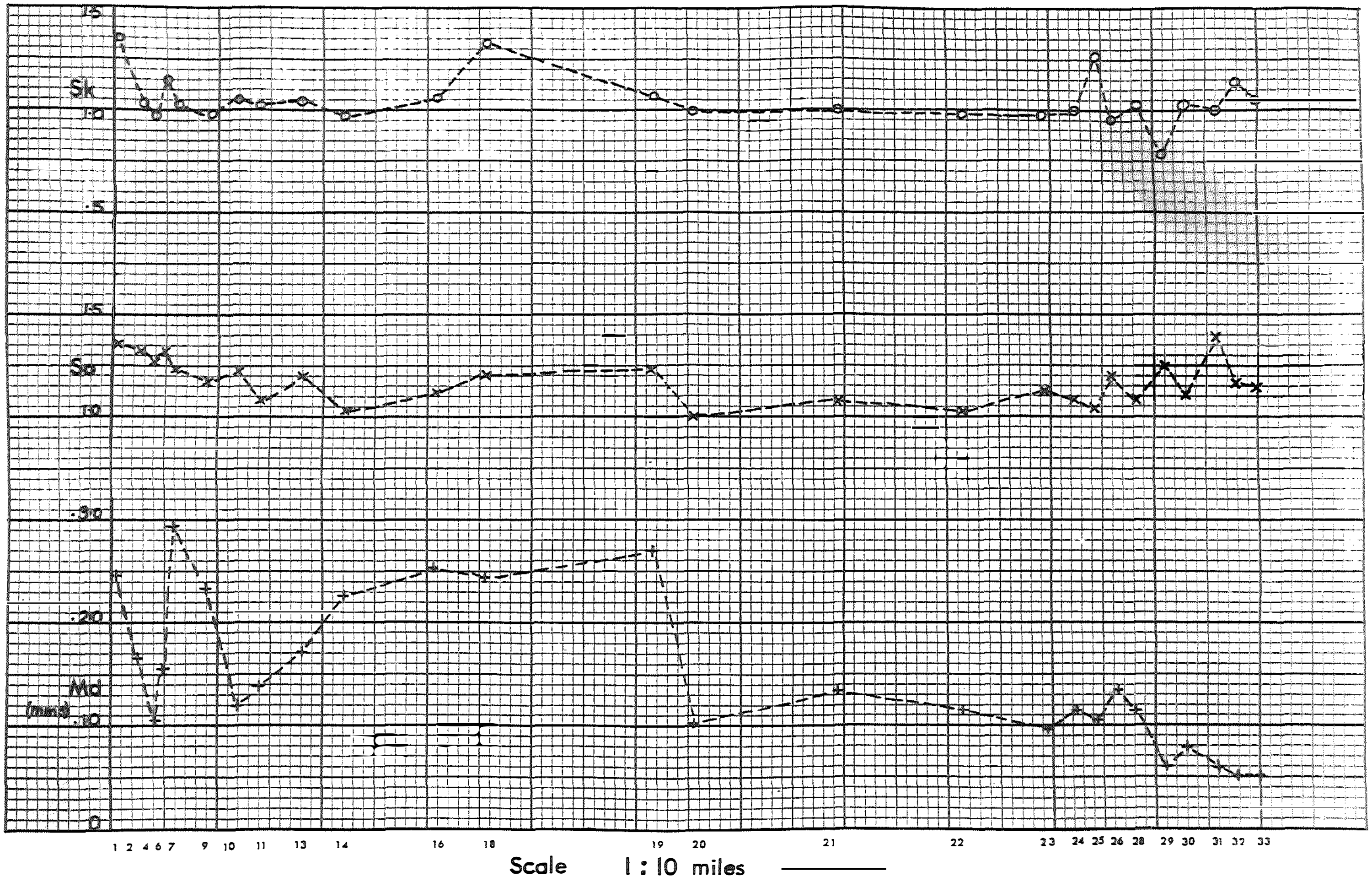
(4) When medians of region 1 and 2 of the western coastline were compared, it was found that there was no real significant difference at the .05 level of probability. A similar result was obtained when regions 3 and 4 of the southern coastline were compared.

(5) Within region 1 two peaks and corresponding lows may be distinguished. This may be a random effect due to sampling error or the variation may be real as the plot of dune medians closely reflect the plot of the back beach medians.

As stated above there is a significant difference in median values between the western and southern coastlines. It does not necessarily mean that variation between regions 1 and 2, 3 and 4 and within region 1 does not exist. A more intensive sampling program and analysis of the samples is needed to ascertain whether there is or is not a significant variation between and within regions. Region 1 does lend itself to interesting speculation more than the other three. From map 2 it can be seen that the coastal geology of the region corresponds to the Tertiary of the Noarlunga and Willunga Basins. A detailed description of the geology is found in appendix 2 of this thesis. The Tertiary becomes younger and the sediments less sandy and more clayey and limey, in the southern section of each basin. The peaks in region 1 may correspond to the effect of local coastal erosion of wave cut platforms and seacliffs. These are composed of the basal Tertiary, North Maslin Sand and South Maslin Sand and lie in the north of the respective basins. These formations are essentially a coarse grained sand with their medians ranging from .211 mms to .420 mms (Mining Review 105). The lows could be interpreted as sand derived from the finer and more limey and argillaceous sediments comprising the younger portion of the Tertiary sequence.

(b) Sorting Coefficient

A perfectly sorted sediment has a coefficient of 1.0. Trask (1932) states that So value less than 2.5 indicates a well sorted sediment, a value of about 3.0 is normal and a value greater than 4.5 is indicative of a poorly sorted sediment. These values according to Pettijohn are too high. He quotes the work of Stetson (1938) and Krumbein and Tisdel (1940). The latter workers found that crystalline rocks which have disintergrated in place have a coefficient of sorting that places them within the range of Trask's well sorted sediments. Stetson (1938) showed that near shore marine sediments of sand grade have a sorting coefficient between 1.0 and 2.0. Stetson considers 1.45 to be average. Back beach So were plotted against geographic location on the coastline and the resulting distribution is shown in graph 2. It can be seen that the majority of sediments have a So less than Stetson's average of 1.45. The average value for the western coastline is 1.22 while the southern coastline is 1.13. The sorting coefficient data from



GRAPH 2 - Median, sorting coefficients and skewness of back beach samples versus geographic location.

the western and southern coastline was tested statistically to see if a significant difference existed. At the .05 significance level for 26 samples the critical value is 2.064. The obtained value was 2.12. At this level significant difference exists between the sorting coefficients. This difference probably reflects a difference in transporting and depositional conditions. The difference in transporting conditions is well exemplified when the So of a dune and back beach sample are compared. The dune sample approaches closely to unity (e.g. sample 17, So = 1.05) showing that the action of the transporting agency, the wind, is very selective and hence appears more efficient in sorting action than water.

(c) Skewness

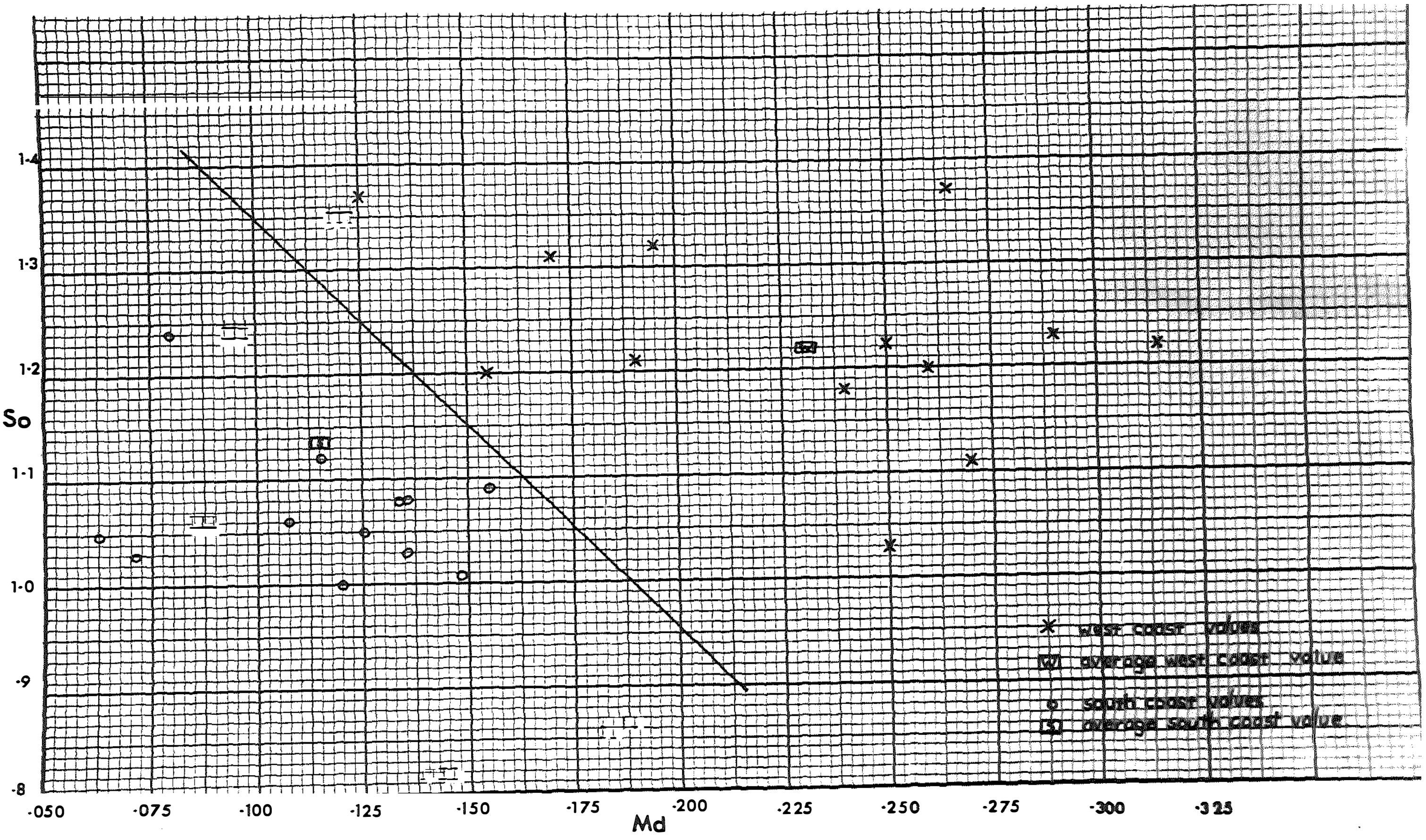
The values for skewness of the back beach samples were plotted against the geographic location on the coastline (see graph 2). It can be seen that samples are positively skewed and closely approach unity. Dune samples if plotted are negatively skewed and closely approach unity also. The selective action of the transporting medium in load carrying is shown once more in these results. Dune samples have their Sk less than unity. This reflects the obvious fact that the number of fine particles far exceeds coarse particles in a dune sample.

(3) Interelation of Sedimentary Properties.

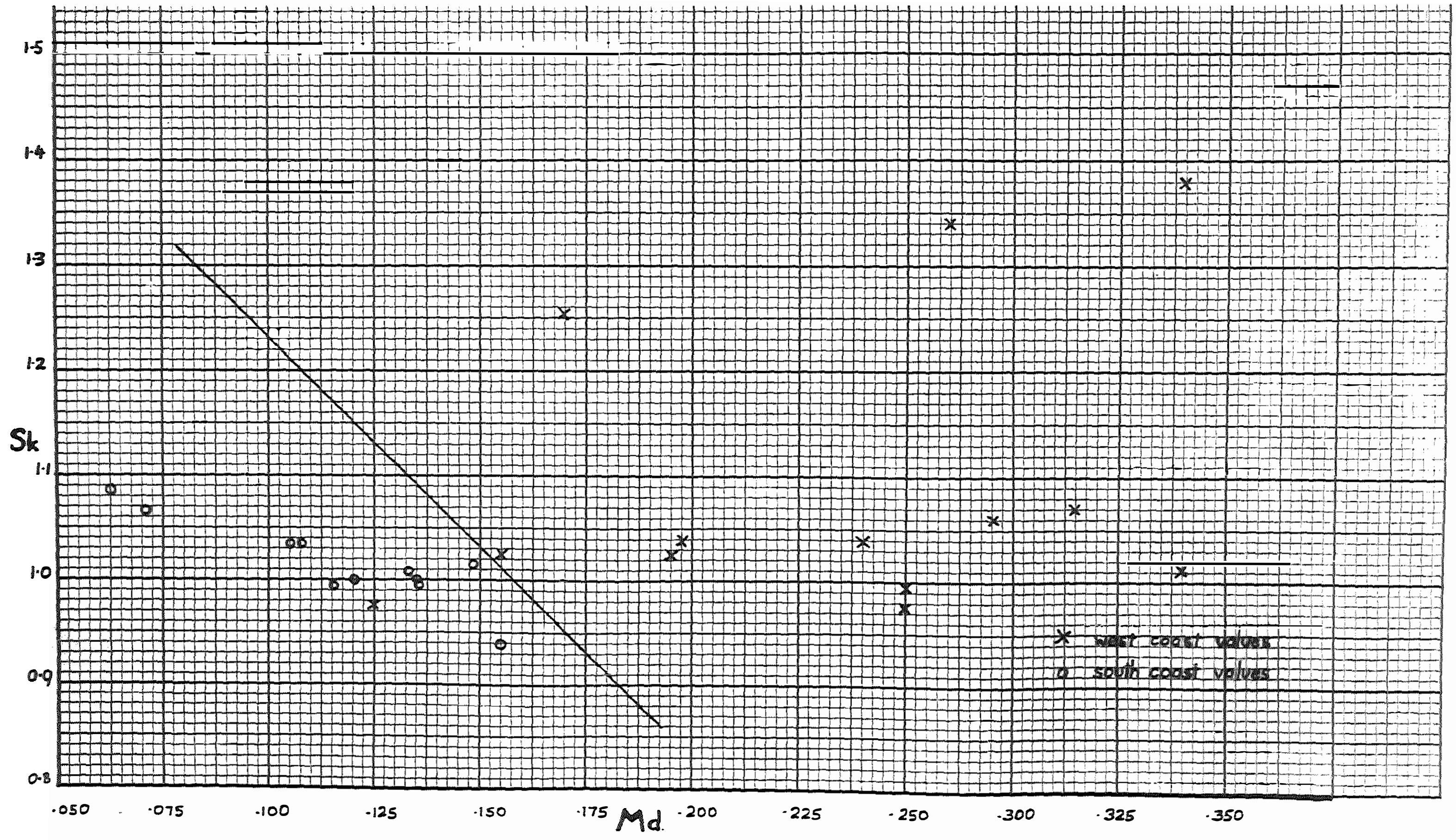
The statistical measures derived from the cumulative size distribution curve may be related to each other and to other properties such as coastal geomorphology, current systems and the nature of the site of deposition itself. The results of such relationships may not always be clear or understood, but the trends which appear to be developed by such comparisons may be indicative of environmental conditions present at the time of deposition or variations in the littoral forces.

(a) Size and Sorting.

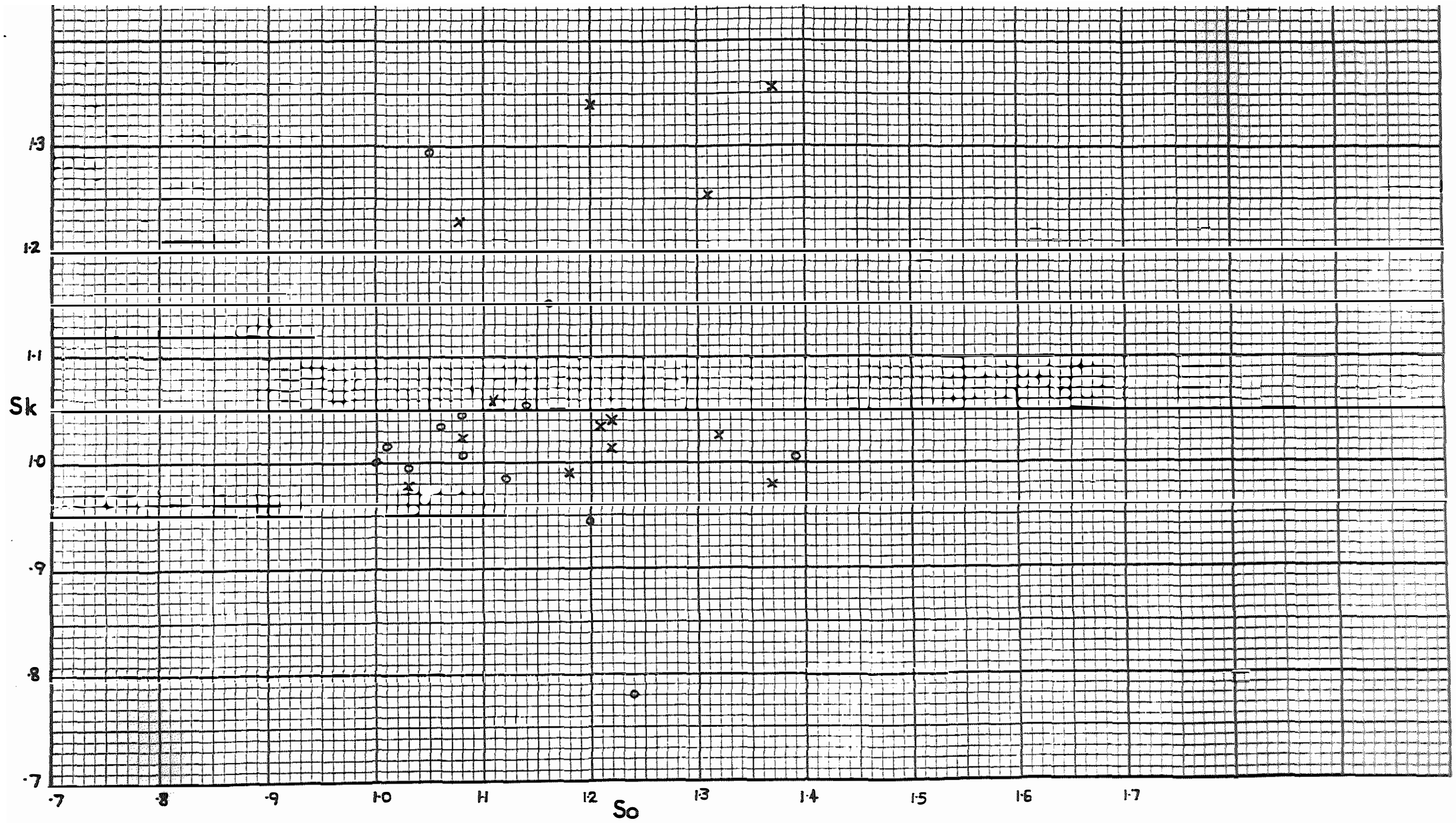
A comparison of the coefficients of sorting and the median diameters of the back beach samples were made for the western and



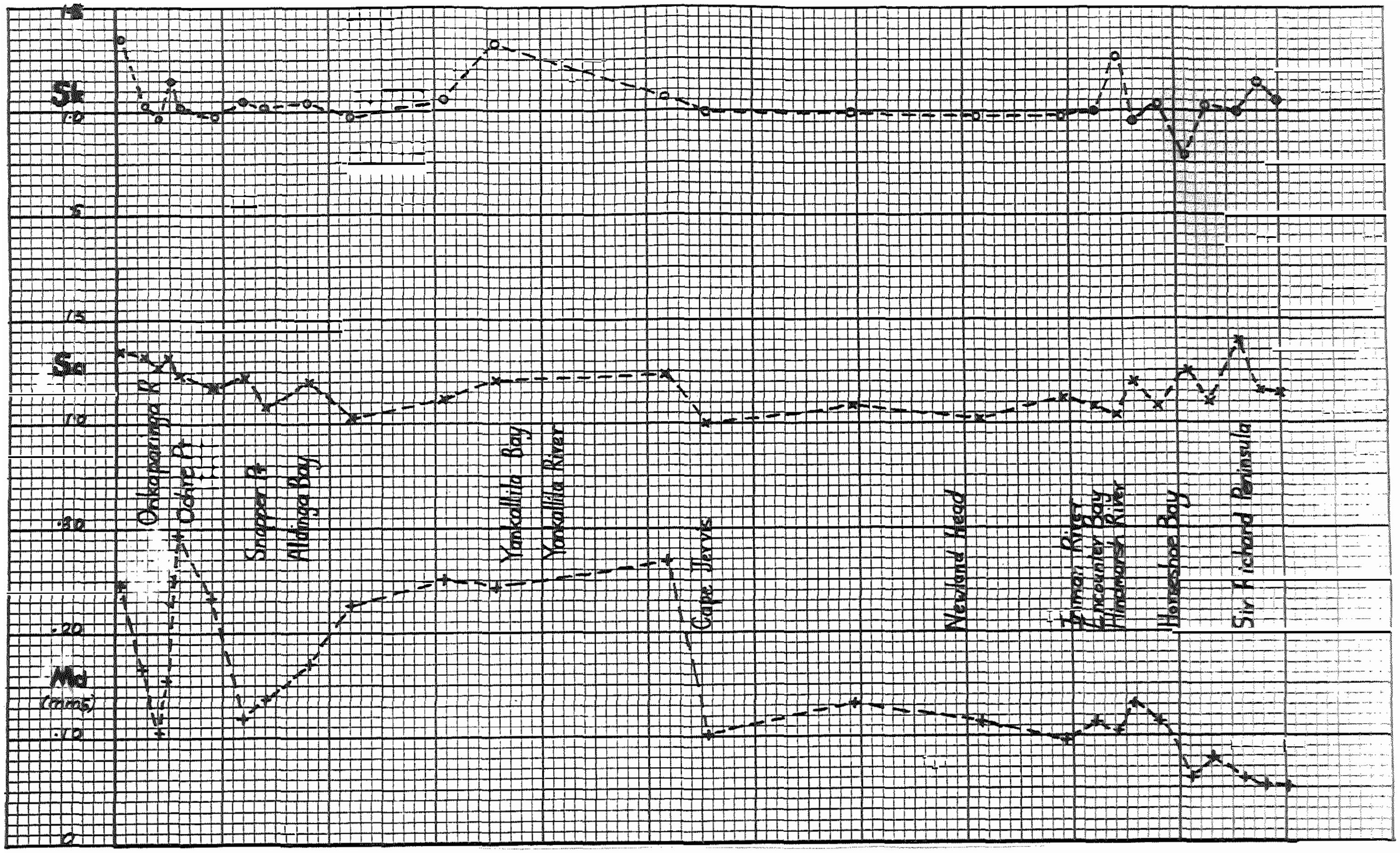
<u>GRAPH 3</u> - Coefficient of sorting versus median diameters for back beach samples.



GRAPH 4 - Skewness versus median diameters for back beach samples.



GRAPH 5 - Skewness versus sorting for back beach samples.



<u>GRAPH 6</u> - Effect of major coastal geographic features on median, sorting coefficient and skewness for back beach samples.

southern coastlines (graph 3). From the graph it can be seen that the majority of sediments are well sorted in that values of the coefficient of sorting lie between 1.0 and 1.38. A line can be drawn on the graph separating the western and southern coastline samples. The southern coastline samples are extremely well sorted, having a very narrow range in sorting coefficient and a fine grain size. The western coastline samples have a wider range in sorting coefficients and are more coarse in grain size.

(b) Size and Skewness

A similar comparison was made of the skewness value and the median diamèters. (graph 4). Two fields of values are again evident although one sample from the western coastline plots in the southern coastline field. The significance of this is not known. There appears to be a greater clustering of skewness values about unity for the southern samples.

(c) Sorting and Skewness

A similar comparison was made with respect to sorting and skewness values for the back beach samples (graph 5). The majority of the data cluster about the 1.0 and 1.25 values of the coefficient of sorting and .95 to 1.03 values of skewness. As the value of the coefficient of sorting increases some of the samples appear to become more skewed. This appears to be more evident with the western than southern samples. Small values for both So and Sk indicate a well sorted sediment, in which the peak of the size distribution lies near the median diamèter. This means the sediment is in adjustment with its environment and has therefore been transported, deposited and maintained by a narrow range of conditioning factors.

(d) Geographic Features related to Sedimentary Properties.

No obvious relationship exists between sedimentary properties (sorting, median and skewness) and major coastal features from graph 6.

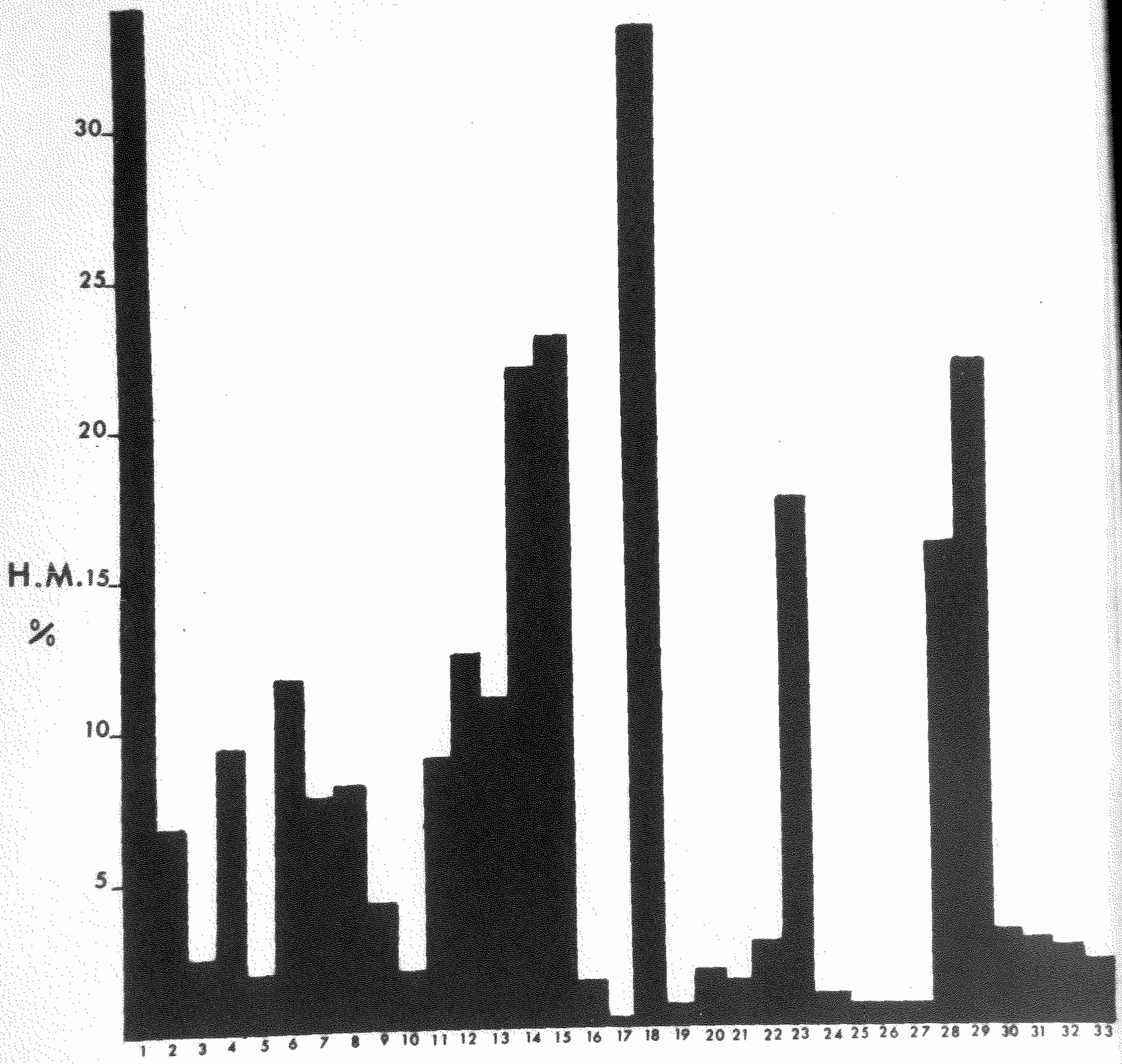


Figure 2 Heavy mineral percentages in back beach samples

Cape Jervis may have an effect because it is this coastal feature that separates the western and southern coastlines. The coastal bays do affect the accumulation of heavy minerals. (see fig. 2)

3. MINERALOGY.

Heavy mineral samples from Port Elliot and Maslin Beach on the southern and western side of the Fleurieu Peninsula respectively were taken as type mineralogical examples of the peninsula. The heavy fractions of both samples (greater than SG2.8) were separated by heavy liquid methods using tetrabromo-ethane and then washed with acetone and dried. A powerful hand magnet was then used to remove magnetite and other ferromagnetic materials. This removed material was called the ferromagnetic fraction. The remainder of the heavy fraction was passed through a Franz Isodynamic Separator. This was set at a fixed slope and tilt with successive increases in the field strength of the electromagnet by increasing the coil current. A slope of 20° and a tilt of 15° was found to be satisfactory for all operations. (NB:- The slope is the inclination of the long axis of the chute while tilt is the inclination of the transverse axis of the chute, both of which are measured from the horizontal.) The final fraction is non magnetic at almost the maximum setting of the instrument. This contains heavy minerals, such as zircon and rutile, and some light minerals such as quartz, calcite and feldspar. The light minerals were removed from the final fraction by heavy liquid separation using methyliodide (SG3.3). The various fractions were then examined by making slides, mounts in oils and briquettes. These were viewed under transmitted and reflected light microscopes. Some hand picking of the garnet rich fractions were done for X ray analysis. The original light fraction, material with SG2.8, consists mainly of quartz, calcite, feldspars, micas, fragments of both calcareous and siliceous organic remains and some rock fragments. Although this is found in heavy fractions as well, a detailed investigation of this material has not been made.

Franz fraction result.

Notation
(after Hutton, (1952)

p = predominant > 60%
a = abundant 20-60%
c = common 5-20%
tr = trace < 5%
⑤ = rare

(1) PORT ELLIOT

Ferromagnetics = magnetite, titaniferous haematite

0.25A Magnetics = garnet (p), opaques (a), staurolite with opaque inclusions (tr), zircon (r), spinel (r), tourmaline (r).

0.50A Magnetics = garnet (a), opaques (a), (leucoxenized ilmenite, haematite), staurolite (tr), quartz (tr), spinel (r), monazite (r), pyroxene (r).

0.75A Magnetics = staurolite (a), garnet (a), opaques (c), sphene, spinel, monazite (tr), rutile (r), zircon (r), hornblende (r).

1.0A Magnetics = monazite (a), tourmaline (c), staurolite (tr), spinel (tr), garnet (tr), zircon (tr), rutile (tr), kyanite (r), opaques (c).

1.4A Magnetics = opaques (leucoxene) (p), rutile (a), staurolite (tr), spinel (tr), calcite and foraminifera test (tr), sillimanite (tr), zircon (tr), tourmaline (tr), kyanite (r).

1.4A Nonmagnetics

Me I Heavy = rutile (a), zircon (p), kyanite (c), staurolite (tr), monazite (r), leucoxene (r), quartz rare.

Me I Light = quartz (a), calcite (a), foraminifera (c), feldspar (c), kyanite (c), andalusite (tr), sillimanite (r), leucoxene (tr).

(II) MASLIN BEACH

Ferromagnetics - magnetite (a), titaniferous haematite (a).

0.25A Magnetics - opaques (haematite, ilmenite) (p), garnet (a), amphibole (tr).

0.50A Magnetics - opaques (ilmenite, haematite) (p), garnet (a), staurolite (tr), spinel (r), monazite (r).

0.75A Magnetics - staurolite (p), opaques (a), limonite, ilmenite, haematite , garnet (a), spinel (tr), sphene (tr), epidote (tr), monazite (tr), zircon (tr), rutile (tr), kyanite (r), andalusite (r).

1.0A Magnetics - monazite (c), tourmaline (c), spinel (c), opaques (leucoxene) (p), epidote (tr), zircon (tr), rutile (tr), kyanite (r), sillimanite (r).

1.4A Magnetics - rutile (a), zircon (a), spinel (c), opaques (leucoxene and rutile) (c), tourmaline (tr), monazite (tr), calcite (tr), quartz (tr), epidote (r), staurolite (r), kyanite (tr), andalusite (tr), sillimanite (r).

1.4A Nonmagnetics

Me I Heavy - zircon (p), rutile (a), leucoxene (tr), kyanite (r), andalusite (tr), tremolite (tr).

Me I Light - kyanite (a), andalusite (a), calcite (c), quartz (c), feldspar (c), leucoxene (c), rutile (tr), zircon (tr), sillimanite (r).

(1) Mineralogy of the Heavy Minerals

(1) Amphibole Group

At least one member of the amphibole group is present in the sands studied. The amphiboles recognized are tremolite-actinolite and hornblende, both of which have been derived from a metamorphic environment. In general the frequency of amphiboles present in the sand appears to be greater along the southern coast.

(i) Tremolite - actinolite

Members of this group are rarer than hornblende and occur as very pale green coloured ragged fragments with moderate pleochroism.

Pleochroism recognized was X = pale green, Z = darker green.

(ii) Hornblende

Green hornblende in the form of elongated platy cleavage flakes with frayed ends were recognized. These were usually 70-90 microns in size. Pleochroism was moderate to strong, with maximum absorption in the direction parallel to Z. The colour scheme commonly observed was X = pale green, Y = green, Z = deep green, where Z Y X. Inclusions were often present and consisted mainly of quartz, feldspar and opaques.

(2) Andalusite

Andalusite grains are very variable in form ranging from rounded to irregular, subangular grains. Prismatic grains are also found although irregular subangular types are the most common types encountered. The grains are generally colourless with an occasional "pinkish" tinge. Inclusions of carbonaceous matter (graphite) with other opaques are common. Quartz, mica and gas bubbles are rarer inclusions. Sometimes the mineral appears clouded due to dust inclusions or alteration to sericite or kaolinite. Andalusite along with fellow members, kyanite and sillimanite of the polymorphous $Al_2Si_2O_5$ family are prominent constituents of sample 23.

(3) Epidote Group

Epidote and clinozoisite are grouped together owing to the difficulty in distinguishing between them. Clinozoisite-epidote were present in most samples examined, but occurred with greater frequency along the southern coast. Irregular angular grains are common, varying in colour from colourless to pale greenish yellow. Pleochroism was weak and restricted to the larger grains. Y = green yellow, Z = colourless, X = pale yellow $Y > Z > X$.

Inclusions of opaques and dust-like clouds of material are present in grains examined.

(4) Garnet

Garnet has been recognized in every concentrate examined to date and often constitutes up to 50% of the mineralogy. The mineral form ranges from occasional small rhombic dodecahdrons to well-rounded forms and to very angular fragments. The angular fragments exhibit typical conchoidal and sub-conchoidal fractures. Triangular etch pitting and grooving was occasionally exhibited. On some angular fragments, with a slight negative relief, rectangular patterning is developed. This pattern does not appear to be a crystal growth as there is no tendency to develop the typical crystal forms of garnet. The very sharp faces and angles, as contrasted with the abraded shapes of associated grains suggests that it is an authigenic effect. Bramlette (1929) reports similar observations and conducted experiments etching crushed garnet with hydrofluoric acid. He noted that after several days of treatment an etch-patterned surface, similar to that found in natural grains, resulted. The acidic or alkaline conditions needed in nature to produce this effect are not known.

From the localities studied a distinct, though not a wide range of colours was noted. The grains are translucent to transparent, with colour ranging from light pink to red-orange. This colour variation is probably due to variation in chemical composition. X ray and refractive index work was done on light pink and red orange garnets that were separated. It was found that when the results were plotted on a pyrope-spessartite-almandite diagram (after Sriramadas 1957), three fields occurred. The light pink garnets fell into a field which had a composition ranging from almandine (55-65) pyrope (5) spessartite (35-40). The red-orange garnets fell into two fields. One field has a composition ranging from almandine (85-90), pyrope (10-15) and spessartite (0-5) while the other ranges from almandine (50-60), pyrope (0-8) spessartite (35-45). More detailed chemical and physical work should be done to elucidate these garnet compositions more accurately.

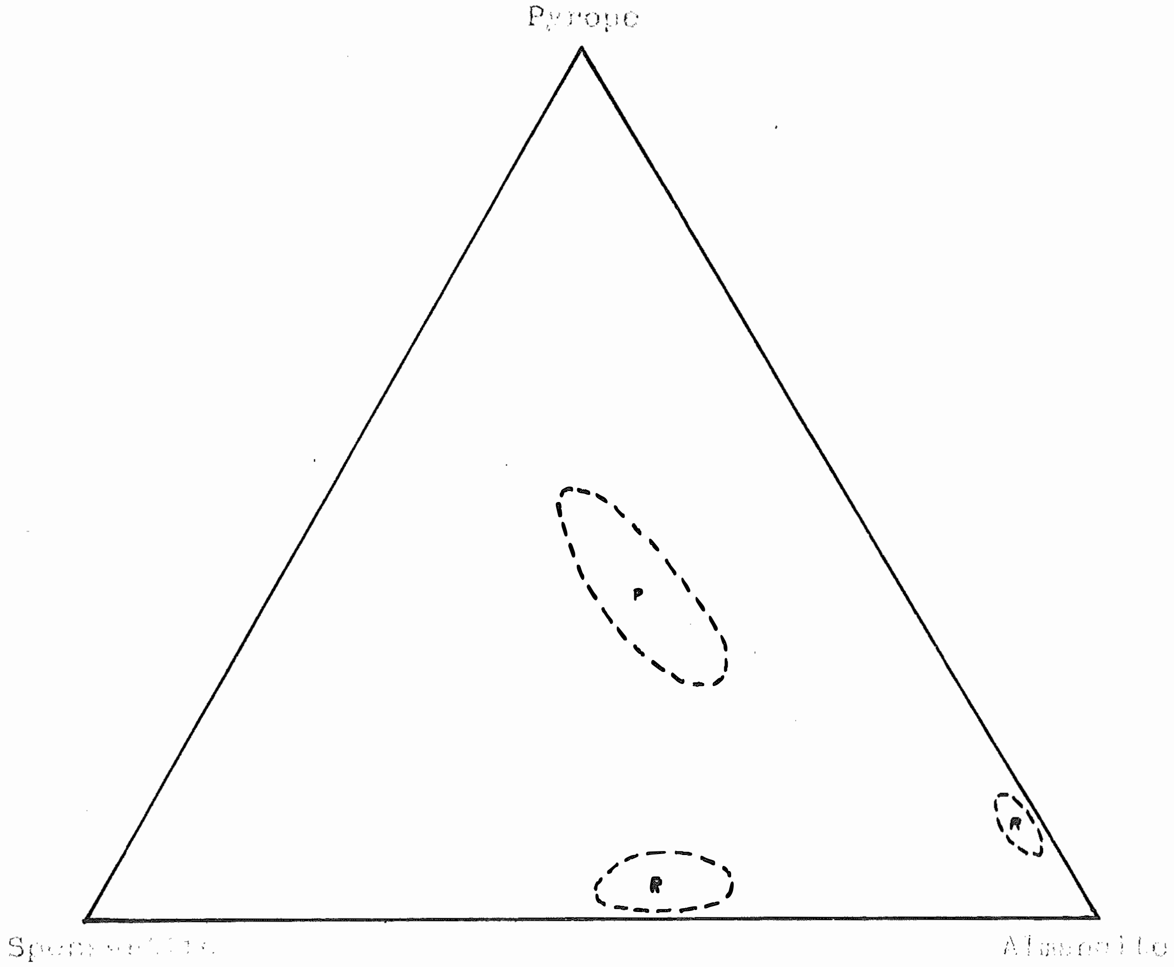


Fig. 5 Composition of garnets on a pyrope-spessartite-almandite diagram after Sriramadas (1957).

Light pink garnets

	Sample 1	Sample 2
Cell-size	11.53	11.54
R.I.	Range 1.765-1.794	

Dark red-orange garnets

	Sample 1	Sample 2
Cell-size	11.52	11.57
R.I.	1.817	1.81-1.82

Garnet free from inclusions are uncommon. The inclusions are usually arranged haphazardly, with an occasional specimen showing evidence that distribution of the inclusions have been influenced by crystallographic properties. In some crystals inclusions were more densely aggregated in the central areas. Inclusions could not always be identified accurately, but quartz, abundant solid black iron oxides and feldspar were noted.

(5) Kyanite

Kyanite varies greatly in physical characteristics, the commonest type being the elongated subangular to subrounded prismatic (100) grains. On these grains the (001) cleavage is at right angles to the grain length and an (010) cleavage parallels the prism margins. Short, stumpy, well rounded grains also occur. On the (100) grains good interference figures were obtained. These were biaxial negative with a 2V in the vicinity of $80 - 85^{\circ}$. Extinction was oblique with $Z \wedge C = 28 - 30^{\circ}$. Grains flattened parallel to the (010) gave straight extinction. Colour exhibited was colourless with a faint tinge of blue, altering to a brown along the cleavage and cracks in the grains. Many of the grains showed colourless borders with blue centres. Pleochroic grains were rare and when present pleochroism was very weak. The pleochroic scheme observed was X = colourless, Y = light blue, Z = darker blue. A variety of inclusions were found. Opaque material consisting of iron oxides and carbonaceous matter was most common, with some gas bubbles, fluid filled vacuoles and dust suspensions. Alteration was evident along the (001) cleavage and cracks parallel to it.

(6) Micas

Micas are not usually well represented in mineral assemblages on exposed oceanic beaches, but biotite and muscovite are recognizable in most sand samples on the southern coast. Here granites and a well developed metamorphic terrain provide a good source for the mica in the beach sands.

(i) Biotite

This mineral occurred as ragged brown-black flakes, but with some grains remnant hexagonal outlines were evident. Inclusions of quartz, zircon and rutile were noted with pleochroic halos surrounding a few zircon crystal inclusions. Most of the grains seen were non-pleochroic due to the tendency of the grains to lie on their perfect (001) cleavage. Some alteration to chloritic matter was visible.

(ii) Muscovite

The muscovites seen were platy with sub-rounded outlines. The cleavage plates (001) gave good interference figures. The figures exhibited were biaxially negative with a 2V in the order of 38 - 40°. The biregringence was low, with blue grey interference colours of the first order.

(7) Monazite

The cerium rare earth phosphate monazite occurs as slightly abraded egg-shaped to well-rounded grains. These well rounded grains fail to exhibit easily recognizable interference figures and thus are interpreted to be abraded (100) tablets. Well rounded crystals were found in very few of the slides examined. The size of the monazites examined was usually less than 85 microns. The colour ranged from a clouded yellow to light yellow. Pleochroism was slight and was restricted to the thicker grains. The colour scheme noted was Y = dark yellow, X = light yellow, Z = greenish yellow. Many inclusions were noted, but all could not be successfully diagnosed. Gas filled inclusions were the most common. Opaque dust, stumpy euhedra of zircon, rutile, quartz and feldspar were also identified. A good monazite concentrate can be obtained from the beaches examined on the Franz at 1.0 ampere current with a 20° slope and 15° tilt.

(8) Opaques

Minerals identified were magnetite, ilmenite, leucoxene, haematite, limonite and rutile. Identification of minerals that are opaque to light at 100 microns diameter is no easy matter. Such material may be briquetted in bakelite, polished and diagnosed in reflected light using reflectivity, hardness and microchemical tests. This method has been used partly where Franz fractions were briquetted and examined. Unfortunately when the investigator has a large number of samples to examine the number of polished briquettes to be made in a limited time is prohibitive. Identification instead, especially in grain counting was based on grain morphology and to an extent appearance under incident light from the removable microscope lamp. Ilmenite would occupy 15-20% of the total opaques, opaque rutile about 10-15%, haematite, magnetite and others 70% of the total.

(i) Ilmenite, haematite and magnetite

The dominant opaque is haematite or titaniferous haematite which is not a true ilmenite. Ilmenite and haematite occur as rolled, well rounded grains, angular fragments and euhedra. In many instances anhedral grains of the three minerals could not be differentiated by visual means alone. A small concentrate of magnetite (and some martite?) could be collected by using a weak magnet leaving ilmenite and haematite behind. Crystal form is rarely preserved in beach sands. Ilmenite usually has squat tabular crystals with the development of a prominent basal plane (0001) and rhombohedrons (1011). In beach sands, grains range from remanants of basal planes and rhombohedrons to more anhedral grains with a hackly fracture.

Magnetite too shows a wide range of grain shapes, but occasionally characteristic octahedrons are present. These are usually highly abraded when present. Conchoidal fractures and a shining metallic lustre were more noticeable in magnetite than ilmenite. It has been stated by a variety of writers (Kerr, Milner) that ilmenite has a stell-grey lustre with a distinct purple sheen, but this property was observed in magnetite too. In addition to the purple irridescence magnetite can appear dull and rusty due to a fine coating of red brown oxide. This feature will only occur if the grains are not in a state of constant motion. Some of the grains are martitised along the octahedral cleavage directions of the magnetite.

Exsolution effects were common in both haematite and magnetite. White exsolution lamellae of haematite occurred in the (111) planes of the magnetite. Exsolution intergrowths of ilmenite lamellae occurred too, in the (111) planes of some grey magnetite, which was largely oxidized to white haematite.

(ii) Altered Ilmenite

Altered ilmenite has been studied by many writers. (Bailey 1956, Diadchenko 1960, Kharkanovala 1959, Lynd 1960, Overholt 1950, Welch 1958, 1964). Much conjecture has arisen over the weathering products of ilmenite and it is now generally accepted that leucoxene is not a true mineral species. The name is convenient to retain for describing ilmenite alteration products formed during subaerial weathering.

It now seems likely that the most common course followed by the process of ilmenite decomposition is that described in the following stages -

(1) Initial distortion and breakdown of the ilmenite crystal lattice.
(2) Oxidation of iron and the formation of hydrous, amorphous iron and titanium compounds.
(3) Leaching of iron in a low pH environment.
(4) Recrystallization forming haematite and rutile.
(5) Further leaching of hydrated iron oxides and haematite leaving recrystallized rutile.

Leucoxenization is a progressive process proceeding from grain boundaries inwards to the grain centre. Rarely does a grain consist of only one of the recognizable stages of the process. Bailey (1956, Welch 1964) advocate the name ilmeno-leucoxene, to describe grains which have a core of ilmenite surrounded by alteration products leaving the name leucoxene restricted to grains in which ilmenite is no longer detectable.

The writer recognized all four stages of leucoxenization first described by Bailey (1956). These are -

(1) Ilmenite altered to patch and stringers. Alteration accompanied by decrease in anisotropism and reduction in the plane of polarization.

(2) Isotropic and apparently hydrated amorphous iron and titanium oxide.

(3) Brown orange leucoxene consisting of hydrous iron oxides and possibly hydrous titanium dioxide and haematite.

(4) White leucoxene consisting of rutile and hydrated TiO_2.

Bailey also showed that there is a decrease in general magnetic susceptibility as leucoxenization occurs. This has been observed in Franz fractions taken at a 20° slope and 15° tilt setting with current in .25 ampere intervals. The general trend observed with a sample from Maslin Beach was as follows:-

amorphous state	.10	-	.25	ampere fractions
brown-orange leucoxene	.25	-	.75	ampere fractions
white leucoxene	.75	-	1.25	ampere fractions

Thus as the amperage increased the degree and amount of leucoxenized product increased.

(iii) Limonite

Well rounded grains of cracked dark-brown limonite with some haematite remants with in the limonite were visible. The limonite was orange-brown in reflected light and isotropic.

(9) Pyroxene

These grains were extremely cloudy and very ragged in appearance. Cleavage was prominent. Due to the cloudiness and inclusions identification was difficult, but orthopyroxene and clinopyroxene were both distinguishable.

(i) Orthopyroxene

These were ragged, cloudy pleochroic grains, biaxially negative with a high 2V in the order of 70 - 75°. The grains exhibit green to yellow-green colours with a straight extinction. Inclusions of rounded or irregularly shaped ilmenite, titaniferous haematite or magnetite occur in the pyroxene. The orthopyroxene could be a hypersthene.

(ii) Clinopyroxene

These grains again were ragged in appearance. The grains exhibited an inclined extinction, but a typical clinopyroxene biaxial positive figure could not be obtained. Pleochroism observed was a dark green to a brown green. Diopside could be the mineral species present.

(10) Rutile

Rutile is a constant minor constituent never rising above 4.5%. Rutile grain morphology is variable ranging from stumpy, prismatic crystals with rounded edges to broken anhedral grains. In grains where abrasion was less evident, long striations parallel to the prism edges occurred. Colour exhibited in the typical prismatic crystals were either a golden yellow to red-brown dichroism, with absorption in a few cases, being intense in the direction parallel to the c-axis, or golden yellow to yellow-brown for the ordinary and extraordinary ray, with little difference in absorption in the two ray directions. The grains varied from being translucent to opaque. The opaque grains can still be recognized as rutile due to either the presence of striations, red internal colours or their adamantine to brilliant, metallic lustre. A few rutiles examined exhibited geniculate twins.

(11) Sillimanite

Sillimanite is present in trace amounts. It is more common in the south coast beach sands where it is present as flattened fibres with a tendency to show splitting. Curved grains are present. Often in kyanite solid inclusions may be arranged in a felt-like swarm, giving the habit and optical properties corresponding to Sillimanite.

(12) Sphene

Sphene commonly occurs as irregularly shaped to sub-rounded grains. Colour exhibited was yellow green. Pleochroism seen was X = colourless, Y = greenish yellow, Z = paler yellow. Grain relief was high with grain extinction absent and interference figures difficult to obtain. Positive identification of this mineral was very difficult.

(13) Spinel

Spinel grains are generally very well rounded. Sometimes an octahedral form was present. Under crossed nicols the grains are isotropic. Two types of spinel appear to be present. This division has been based on colour, magnetic susceptibility, and abundance along the coast.

Mineral species	Magnetic Susceptibility	Colour	Area of Abundance
A	.75 - 1.0 amps	Emerald green	South Coast
B	1.0 - 1.25amps	Light pale blue	West Coast.

Even though their abundance may vary both are found together.
The Colour variation may be due to substitution of more iron in the spinel lattice.
The dark emerald green species may be the mineral hercynite.
Inclusions are rare although acicular rods may occur.

(14) Staurolite

Staurolite can be as high as 7% of a sample. Although very variable in appearance most of the grains are anhedral and irregular in shape, with a pronounced rough surface due to an abundance of solid inclusions. Well formed crystals are rarely present. Staurolite shape in beach sands is largely determined by the (010) cleavage. Conchoidal fracturing is well exhibited in the more angular and irregular grains.

The grains are translucent to opaque with colour varying from yellow to yellow-brown in the opaque grains. In the rarer transparent varieties the colour is a deeper reddish brown. The clearer grains show strong pleochroism, (X = pale yellow, Y = yellow, Z = yellow-brown orange) and exhibit straight extinction.

Inclusions are common. Often there is a symmetrical arrangement of particles parallel to a cleavage direction or crystallographic axis. The nature of the inclusions vary considerably. Quartz, rutile, iron oxides and carbonaceous material and occasionally gas bubbles were observed.

(15) Tourmaline

Tourmaline is abundant in the south coast and occupies 5.25% of sample 33. It is rather common as well rounded grains, but is more frequently euhedral in nature. Five main types of detrital tourmaline were described by Krynine (1946), as having characteristics enabling them to be traced back to their primary source rocks or to earlier formed sediments. These are:-

(1) Granitic tourmaline
(2) Pegmatitic tourmaline
(3) Tourmaline from pegmatized, injected metamorphic terranes
(4) Authigenic tourmaline
(5) Well rounded grains of tourmaline reworked from older sediments.

Tourmalines noted in the various samples examined exhibit a variety of pleochroic colour schemes reflecting variations in composition and source. Probably granitic, pegmatitic, authigenic and reworked tourmalines may be identified.

Pleochroic schemes recognizable where Z> X

Z	X	Probably tourmaline type
brown	yellow	Mg-Fe dravite
green, yellow green	pale brown grey brown	dravite-elbaite with some Fe substitution
deep pink	pale pink, colourless	Mg schorlite
blue	mauve, lavender	Na-Mg dravite
black	brown	Fe schorlite
black	blue-black	Fe schorlite

Pleochroism exhibited was usually strong with light coloured varieties giving complete absorption of the ordinary ray. No cleavage is shown. Euhedral prismatic forms gave straight extinction.

Inclusions are common. Those exhibited are opaque particle (haematite and carbonaceous matter), gas vacuoles, granular particles of quartz, muscovite, magnetite, zircon and dust-like clouds of particles. Some grains appear to have their inclusions crystallographically orientated.

Zoning and authigenic growths are rare. Zoning and authigenic growths occur in the pale pink and pale blue varieties. It is usually noticed because of variations in colour schemes, refractive indices and relief along the contacts of the zones. The trend of the zones or growths are parallel to the external shape of the crystals, but sometimes the growths are developed more strongly at either end of the c-axis of prismatic crystals.

(16) Zircon

Zircon was found to occupy up to 22% of the heavy mineral fraction in the samples examined. From counting data it appears that Zircon is much more abundant on the west coast. The zircons observed were extremely variable in morphology. Grains ranged from well rounded, ovoid and elongate species, to angular, fractured pieces and cleavage. The angular and less rounded grains are much larger than the rounded varieties. Crystal form ranged from long to stumpy prisms and bipyramids. Grains less than 80 microns usually exhibit perfect euhedral form.

Zircon ranges in colour from water clear to yellow in common varieties to rose pink, mauve, clouded white, brown and orange. The colourless varieties have a brilliant lustre in contrast to abraded grains which have a frosty appearance. Smaller yellow crystals were found to exhibit zoning. Generally the zones were faint variations of the same colour. Angular fragments exhibited double colours, with the fragment being white or clear at the centre and yellow near the outside.

Inclusions were numerous, varying in shape, orientation, composition and colour. The common forms of inclusions observed are -

(i) Randomly orientated dark red needle-like material. This could be rutile.
(ii) Thread-like and gas-filled channels.
(iii) Quartz bleb and crystals of zircon, monazite and opaques. The opaques are probably haematite, rutile and ilmenite.
(iv) Inclusions within inclusions. A monazite inclusion with a possible zircon within it was noted.
(v) Orientated elongate rutile grains parallel to the c-axis.
(vi) Dust suspensions which may give some grains a clouded appearance.

Some length : breadth ratios on grains were taken. These were as follows:-

(i) $\frac{L}{B} = 1$ = usually white abraded grains
(ii) $\frac{L}{B} \pm \frac{2}{1}$ = these are large colourless prisms or single elongate, white to yellow crystals.
(iii) $\frac{L}{B}$ may be as high as $\frac{5}{1}$ with small elongate crystals.

Three varieties of zircon were recognized. These were jargoon, hyacinth and malcon.

(i) Jargoon

This is the colourless, to pale pink variety and is predominant.

(ii) Hyacinth

Hyacinth occurs in trace amounts and is a transparent rose-pink to purple variety.

(iii) Malcon

Malcon is a rare metamict, brown coloured variety occurring in the samples examined.

Variations in Mineralogy

A study of the distribution of the mineral species along the coastline revealed the following (See Fig. 4)

(1) Garnet, zircon and opaques are the dominant mineral species in all samples examined.

(2) Garnet, tourmaline, staurolite appear to be more abundant on the southern coastline.

(3) Monazite, rutile, zircon and opaques are more abundant on the western coastline.

This variation in abundance is a reflection of provenance of the heavy mineralogy.

TABLE 2

QUANTITATIVE DETERMINATION OF PERCENTAGES OF VARIOUS HEAVY MINERALS IN BACK BEACH SAMPLES

	SAMPLE NUMBER														
MINERAL	1	2	4	6	7	9	10	18	19	20	21	22	24	28	33
OPAQUES	21.5	26.0	26.0	32.0	36.5	46.0	50.0	76.5	42.2	29.7	28.5	21.0	25.8	15.4	34.7
GARNET	50.5	20.5	47.5	27.0	25.5	9.5	10.0	18.1	27.7	44.5	42.5	19.5	21.8	56.1	24
ZIRCON	7.5	21.1	14.0	21.0	22.0	13.0	19.5	3.3	2.6	2.6	10.0	8.0	3.4	6.9	9.5
RUTILE	2.5	2.0	4.5	1.5	3.5	2.5	4.0	.75	1.1	1.3	2.5	2.5	1.0	2.5	4.25
STAUROLITE	3.5	1.0	2.0	2.0	2.0	1.0	tr	.4	1.1	3.9	2.0	1.0	3.0	6.6	4.5
MONAZITE	1.0	3.0	1.0	2.5	1.5	2.0	2.5	.2	.25	.26	0.5	0.5	0.7	0.45	1.75
TOURMALINE	2.0	1.0	1.0	0.5	1.0	2.0	1.0	tr	5.1	2.1	1.5	2.5	3.4	3.2	5.25
OTHER HEAVY MINERALS	7.5	4.5	0.5	1.5	1.5	5.0	7.0	1.7	3.4	4.5	4.0	11.0	11.2	4.8	2.25
OTHER LIGHT MINERALS	2.0	11.5	4.5	12.5	6.0	6.0	18.0	tr	17.1	8.5	7.0	33.0	22.1	4.0	15.5

NB. 1. Other Heavy Minerals inc. amphibole, pyroxene, mica, andalusite, kyanite, sillimanite, spinel, apatite, epidote rock fragments.

2. Other Light Minerals inc. calcite, ironstained foraminifera tests, quartz, feldspar

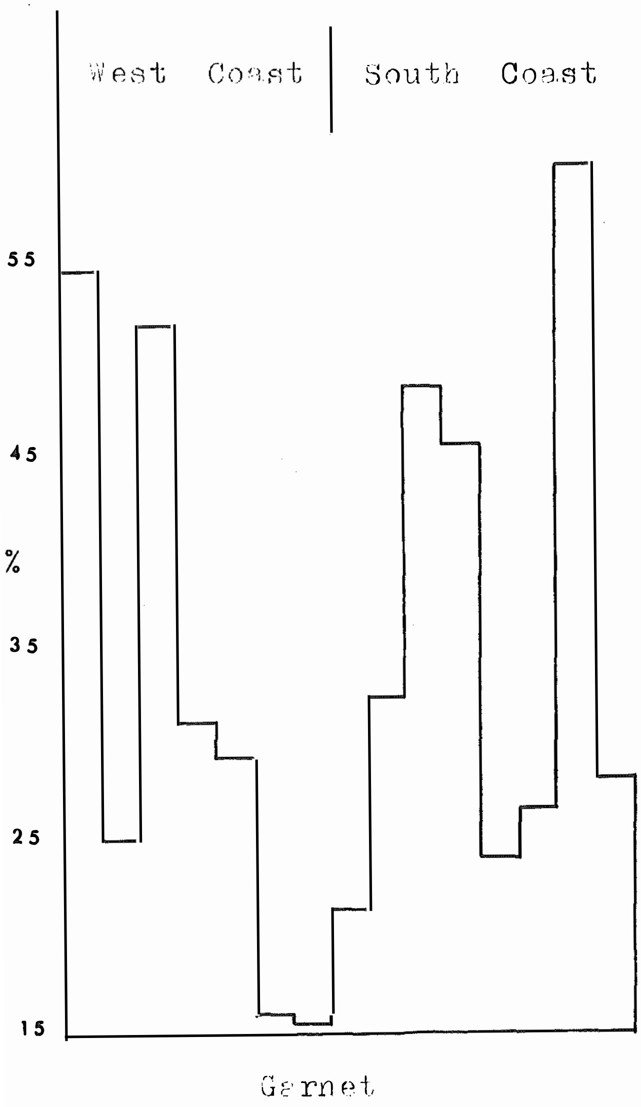
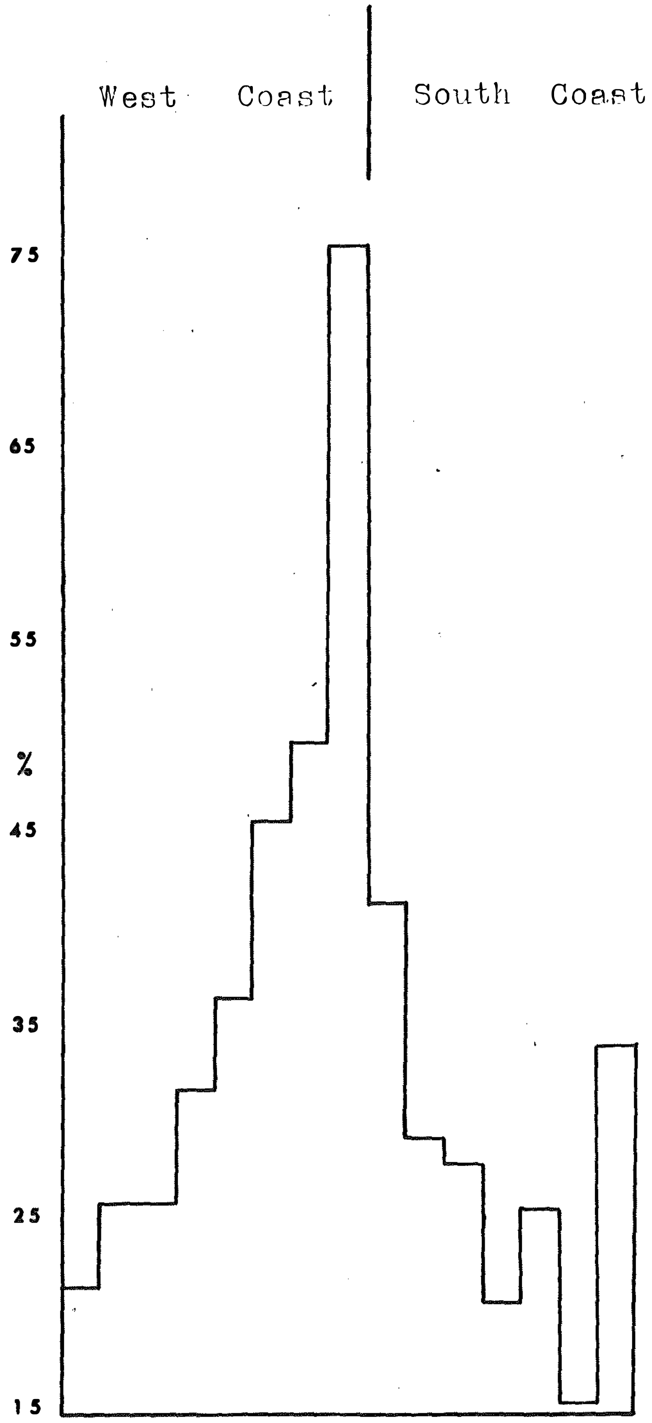
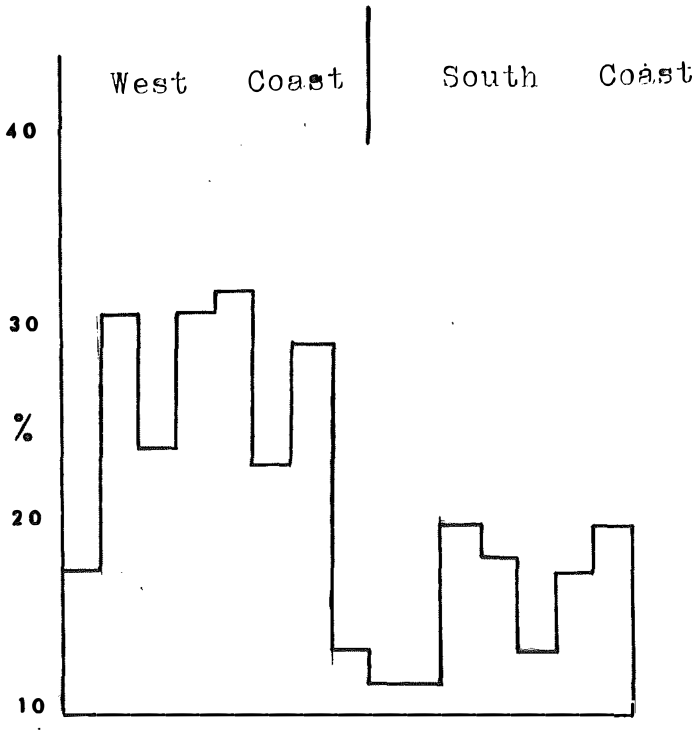


Figure 4 Percentage abundance of various heavy mineral species represented in histogram form.



Opaques



Zircon

4. PROVENANCE

The primary source of all heavy mineral accumulations are igneous rocks, especially the more acid plutonic and the basic volcanics which almost invariably contain as accessory minerals, zircon, rutile, monazite, tourmaline, ilmenite, magnetite and garnet. A secondary source of heavy minerals are sedimentary and metamorphic rocks. These may have a low percentage, heavy mineral fraction that may be concentrated during subsequent erosion and deposition.

The heavy mineral assemblages of the beaches are no doubt largely derived from inland areas and locally from submarine outcrop, cliff faces and shore platforms. Most of the heavy mineral constituents have passed through the fluviatile placer stage, during some period of geological time and have been redistributed by floods to be carried out to sea and locally reconcentrated under marine conditions. The more durable and rounded grains, such as zircon, rutile and tourmaline, have passed through a number of cycles of erosion, transportion and deposition. Since their initial release from primary igneous source rocks they have been incorporated into progressively younger arenaceous sediments. Much of the heavy mineralization on the beaches represents the end product of a complex cycle of erosion, the ultimate primary source being the Precambrian rocks of the inliers (see Fig. 3). The most immediate source of the mineralogy on the Western Fleurieu Peninsula coastline is the basal Tertiary, North Maslin Sand Formation which outcrops at the coast in the northern parts of the Noarlunga and Willunga Basins. The Southern Fleurieu Peninsula coastline mineralogy is a reflection of the extensive Cambrian metamorphic terrain, which is developed both inland and along the coastline, and the granitic rocks of Encounter Bay. Present day contributions to both coastlines also come from the extensive Permian glacials, developed in the Myponga, Yankillila, Hindmarsh and Inman Valleys, and the Precambrian inliers and their cover rocks. The Precambrian inliers appear to have a greater influence on the mineralogy of the western than southern coastlines. This influence is via the intermediate source, the basal Tertiary Sands, and the present day drainage system. Consequently monazite, rutile, zircon and opaques, which occur abundantly in acidic igneous rocks and metamorphics in the inliers, are more prominent on the western coastline. (See appendix 2 for detailed mineralogy of stratigraphy).

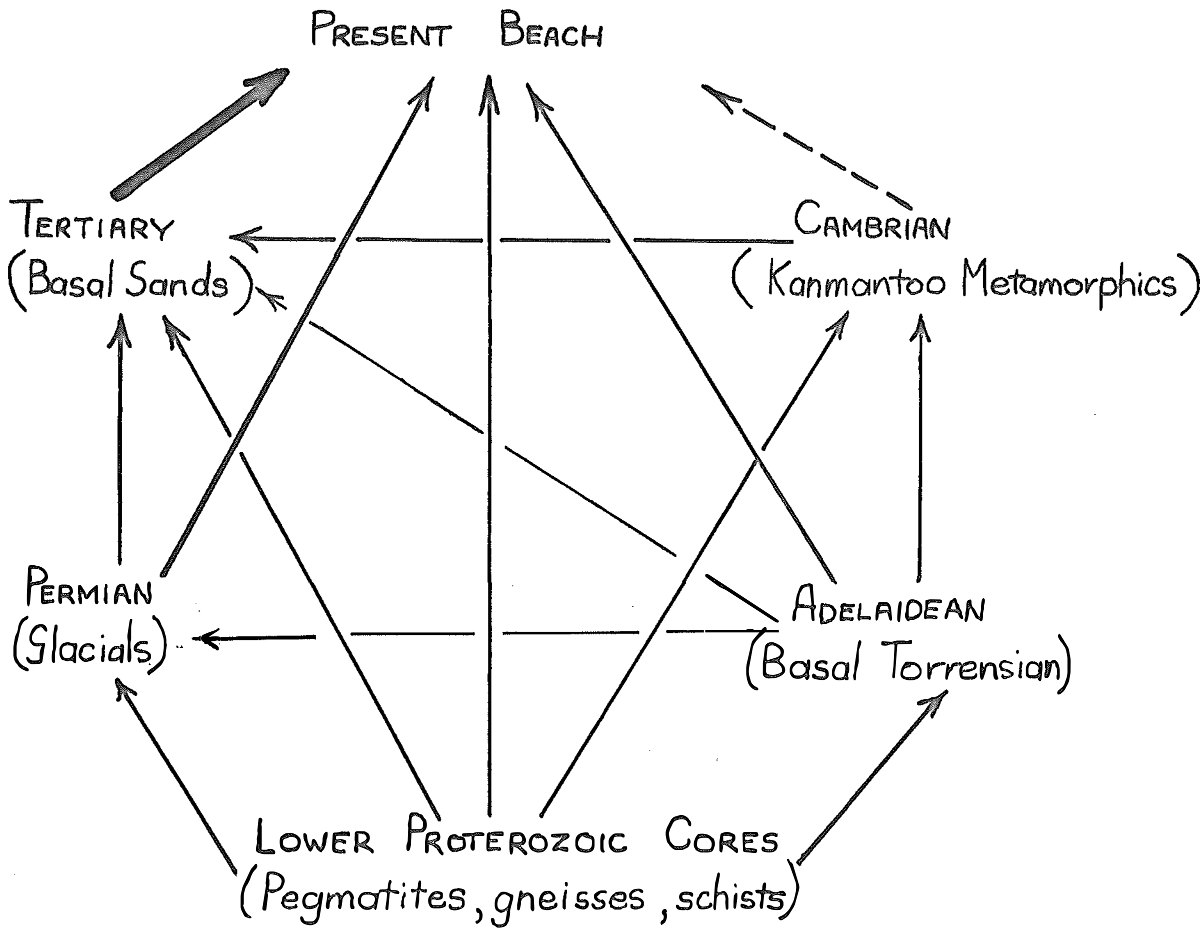


Figure 3 Heavy mineral cycle Western Fleurieu Peninsula.

5. CONCLUSIONS

The mechanical analysis shows that there is a difference in grain size, sorting and skewness between back beach samples taken along the western and southern coastlines of the Fleurieu Peninsula. The southern samples appear to be finer in grain size, better sorted and less skewed. This is probably a reflection of slightly different conditions in the transportational and depositional environment. Further detailed sampling is needed to show if variations exist within the respective coastlines.

The study of the mineralogy has shown that the predominant constituents are garnet, opaques and zircon. Rutile, tourmaline, staurolite, monazite, spinel, amphibole, kyanite, andalusite, sillimanite, pyroxene and mica occur in lesser amounts. The variation in mineral species along the coastline reflects provenance. The western coastline mineralogy is derived either directly from the Precambrian inliers or via an intermediate source, the basal Tertiary sand formations. The southern coastline mineralogy is principally a reflection of the Cambrian metamorphic terrain.

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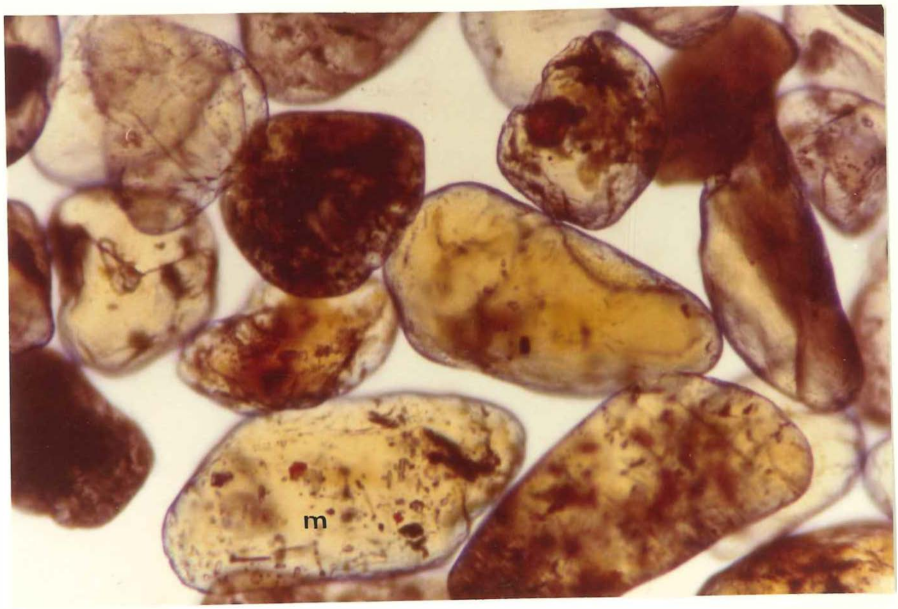
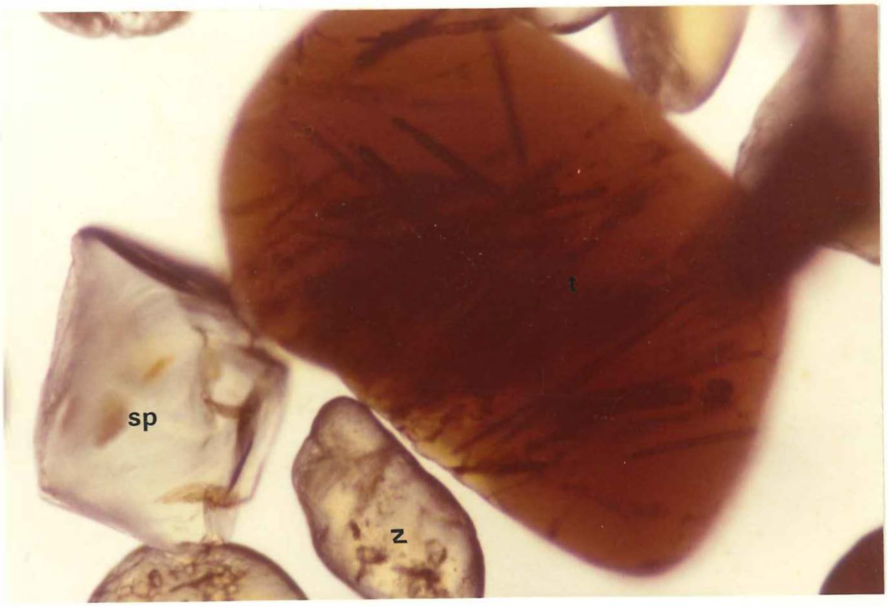
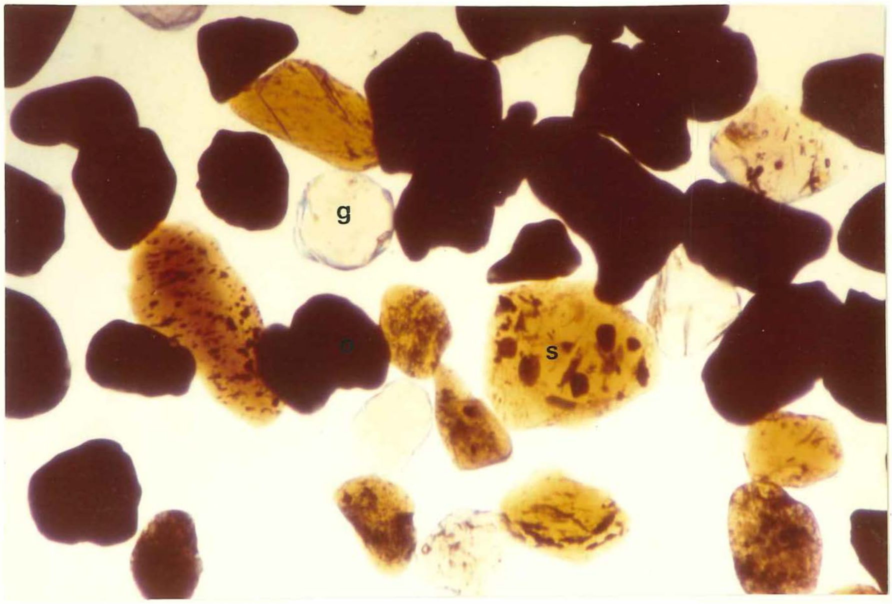


1. Monazite (m) concentrate from 1.0 ampere Franz fraction showing variable grain morphology and inclusions. Photo X125

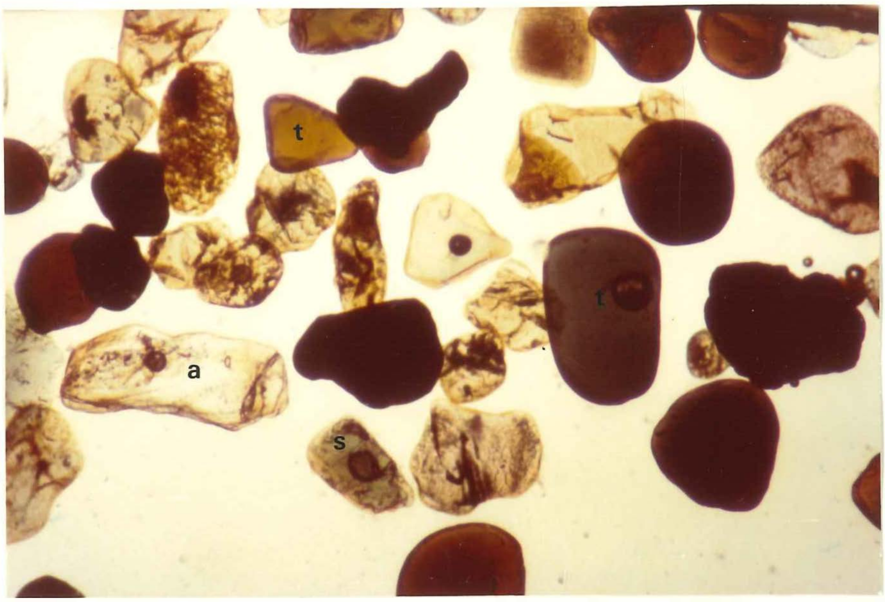


2. Large tourmaline (t), zircon (z) and spinel (sp) grains. Note the randomly orientated needle-like rutile inclusions in the brown tourmaline. The spinel is a light blue variety exhibiting an octahedral form. Photo X125

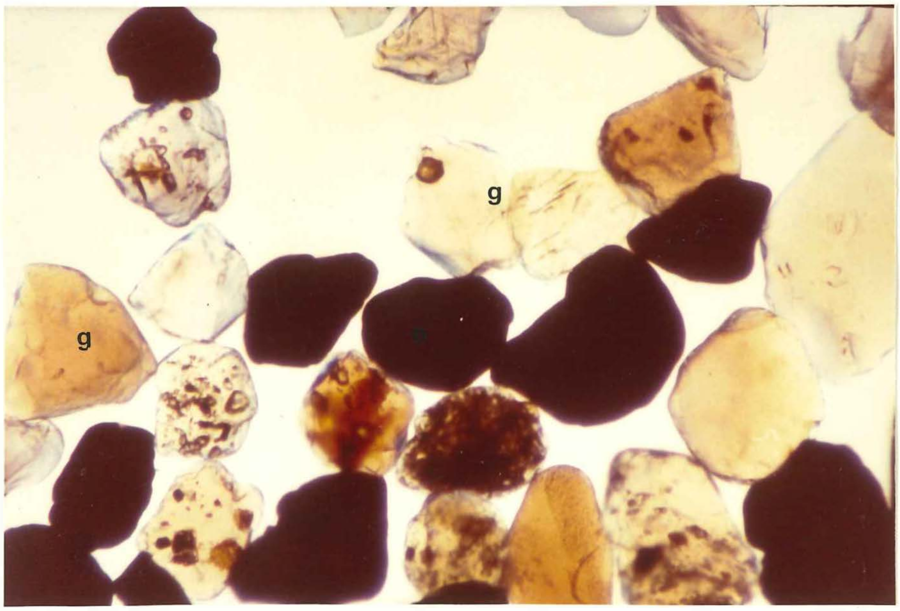


3. Staurolite (s) and opaques (o), .75 ampere Franz concentrate. Some light pink coloured garnets (g) occur as well. Note the irregularity of shape of the staurolite and the abundance of inclusions. In one grain they appear to be orientated parallel to a cleavage direction.
Photo 35X

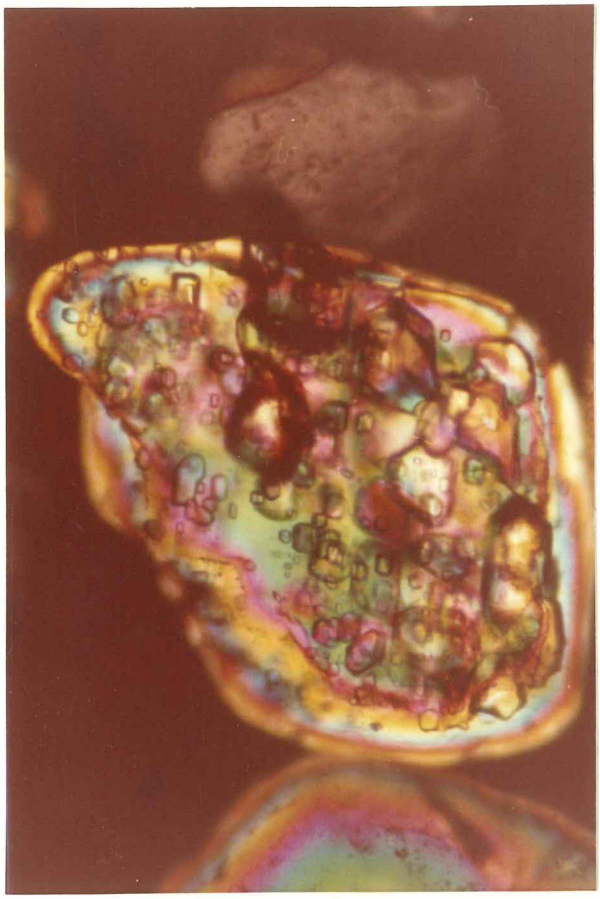
4. Zircon (z) and rutile (r). Note the yellow, euhedral, zoned metamict zircon.
Photo 125X



5. Tourmaline (t), andalusite (a), spinel (s). Note the roundness and variable colours (brown, green, mauve) of the tourmalines.
Photo X35



6. Garnet (g) and opaques (o). The garnet show variation in colour (light pink to dark orange red), shape and amount of inclusions.
Photo X35.



7. Kyanite viewed under polarized light. Note the inclusions orientated in the (001) cleavage direction. Photo 125X.

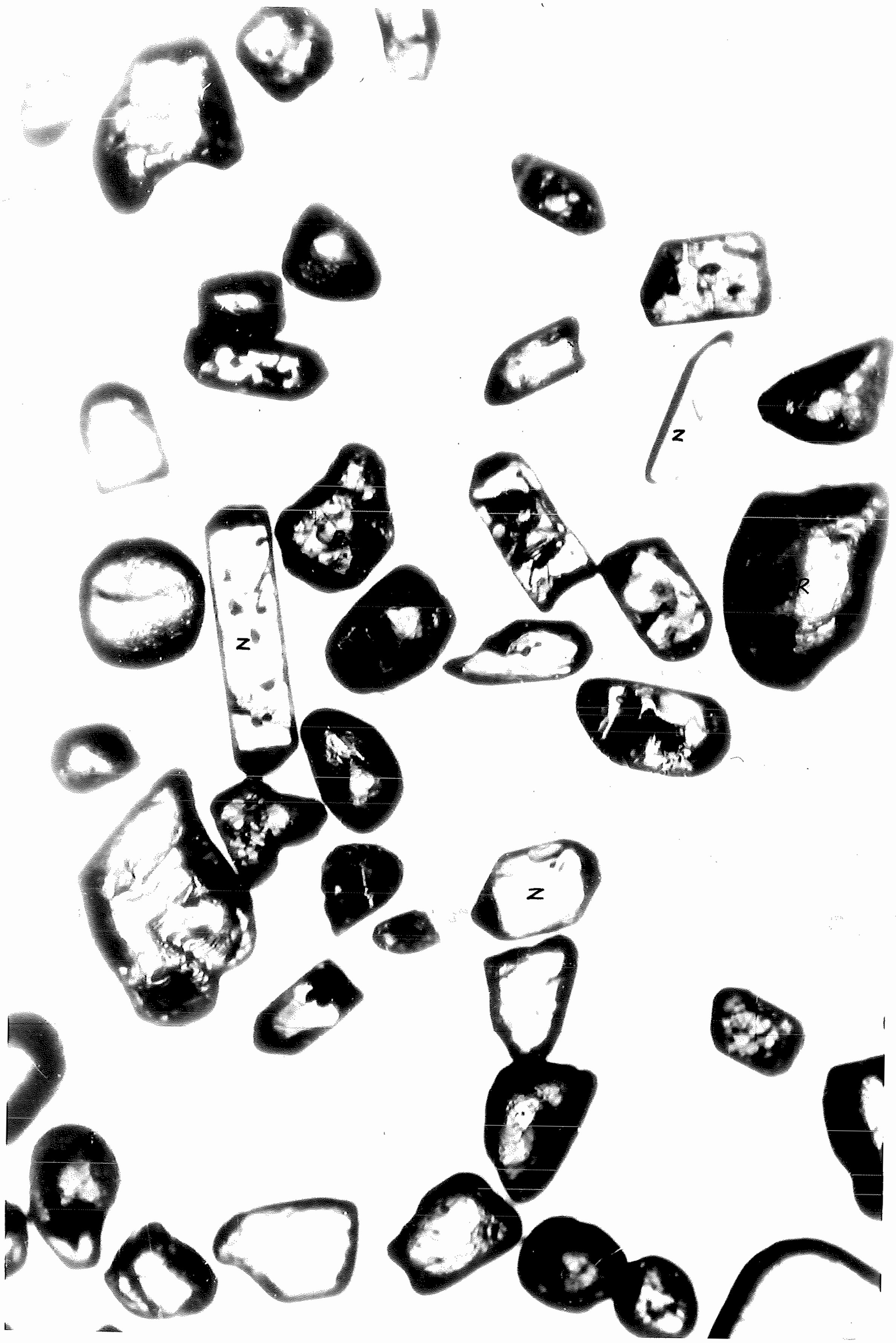
PLATE 1

1 a, b, c, d, e, g, i Zircons 125X of variable morphology.

Zircon i is a zoned metamict filled with numerous opaques.

f, h subrounded to rounded staurolites 125X filled with iron oxides.

j Angular clear garnet 125X.



Zircon and rutile concentrate

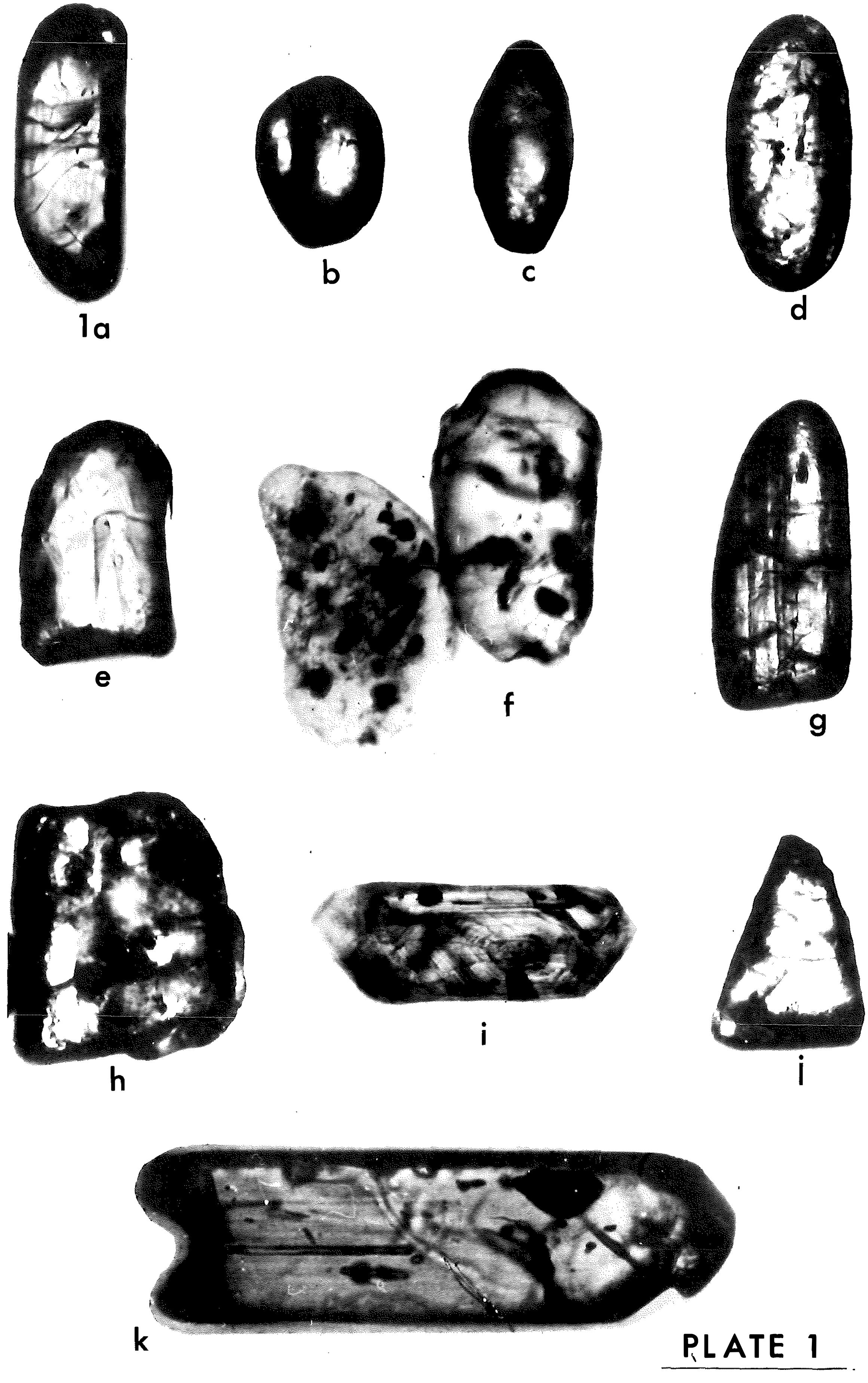


PLATE 1

PLATE 2

Grains 1 a-c Monazite 125X

Yellow rounded egg-shaped (100) grains. Note the dusty opaque inclusions.

Grain 2. Andalusite 35X

Typical irregular, near prismatic grains with opaque inclusions.

Grain 3 a,b Kyanite 125X

Pale blue (100) prismatic grains with opaque inclusions.

Grain 4. Staurolite 35X

Typical subangular staurolite highly filled with iron oxides.

1a b c d

2

3a

b

4

PLATE 2

APPENDIX 1.

ACCESSORY MINERALS IN THE LITTLE GORGE PEGMATITE

Extensive pegmatization occurs in the Archean - Lower Proterozoic rocks at Myponga, Yankalilla and Mt. Compass. It is probable that many pegmatites lie unexposed beneath glacial debris or hidden in the fern undergrowth. The veins carry ilmenite, rutile, monazite, tourmaline and xenotime.

The most well known pegmatite occurs at "Little Gorge" in section 219 Hundred of Yankalilla. Jack (1921) reported on the possible commercial value of the pegmatite as a source of rutile, - Grenfell Thomas (1924) gave an excellent account of its mineralogy; Wylie (1950) examined the rare earth content of the monazite; and Rowley (1954) mentioned the pegmatite in a review of the South Australian Mines Department's search for radioactive mineral deposits.

The pegmatite crops out in sea cliffs and in "Little Gorge" at a height of 200 above sea level. Lenses of pegmatite 1 to 5 feet wide occur in schists and gneisses for 70 feet along the sea cliff. On the slope facing "Little Gorge" the outcrop extends for 200 feet. The width of the body on this slope is variable. The pegmatite dips 40° south-east and strikes 60° north east, being approximately conformable with the foliation of the host metamorphic rocks. The pegmatite is a medium to coarse grained felspathic rock containing a considerable amount of cracked bluish quartz. There is a tendency for graphic intergrowths of the quartz and feldspar to develop. Overall colour of the rock is cream to buff. Plates of greenish-brown biotite are developed on the margins of the pegmatite veins. In finer parts of this biotite rich zone rutile, monazite and tourmaline are developed as accessory minerals.

(a) <u>RUTILE</u>

In the hand specimen (68 F-2) the rutile is typically massive and shattered with little development of crystal form. Cleavage is interrupted by rough fractures. Colour varies from dark red to grey with an overall irridescent tarnish. Under the microscope the rutile is opaque and has a submetallic lustre. The grains are fractured. Cleavage is well shown and twinning is present. Strong anisotropism and internal reflections are evident. The anisotropism varies from light grey to dark brownish grey, internal reflections being yellow-brown red. Ilmenite is common as inclusions and veinlets traversing cracks in the rutile. It also occurs as dusty aggregates following cleavage cracks.

(b) MONAZITE

Monazite can be mistaken for rutile when weathered but on a freshly slabbed surface the differences are immediately apparent. The monazite is massive and although cracked there is no tendency for granular aggregation. The colour ranges from light reddish brown, pink brown to a deeper chocolate brown material which has sharply defined boundaries. The mineral is opaque, brittle and has a variable hardness, but approximates to 5 on the Moh scale of hardness. Orange-brown veins traverse the monazite in an irregular network. In parts the veins are radial in nature. Also present are white to yellow brown alteration patches. Few monazite crystals have euhedral outlines. The crystals present exhibit the tabular monoclinic symmetry characteristic of monazite.

The monazite has been analysed for the rare earth content a number of times. (See Table 1 & 2). All analyses reveal that the monazite is of unusual composition. A high thoria content is prominent. Samples analysed ranged from 8% ThO_2 (prospectors sample of the South Australian Mines Department), 10.7% ThO_2 (Grenfell Thomas 1923) to 19.4% ThO_2 (Wylie 1950). The thoria content is abnormally high when compared to other Australian monazites, which contain between 5-7% ThO_2.

Table 1 **Analysis of "Little Gorge" Monazite (after Grenfell Thomas 1923).**

P_2O_5	26.88
Ce_2O_3	25.09
La_2O_3 Di_2O_3 etc.	24.32
ThO_2	10.70
Y_2O_3 Er_2O_3	4.00
CaO	2.60
TiO_2	1.70
SiO_2	1.65
Fe_2O_3	.85
PbO	.55
H_2O	1.92
TOTAL	100.26

Table 2 **Analysis of Monazite (after Wylie 1950)**

Sample	% of Total (Light) Lanthanon Oxides				
Normanville	La_2O_3	Ce_2O_3	Pr_2O_3	Nd_2O_3	Sm_2O_3
	21.3	44.4	6.11	23.8	4.51

Composition of Parent Normanville Monazite (Lanthanon Oxide and thoria content only)						
	La_2O_3	Ce_2O_3	Pr_2O_3	Nd_2O_3	Sm_2O_3	ThO_2
	10.5	21.9	3.03	11.7	2.23	19.4

The high thoria (Th O_2) content of the monazite is responsible for the marked radio-activity of the mineral which may be demonstrated by its effects on a Geiger-Muller counter and a photographic plate. A polished face of the mineral was left on a photographic plate undisturbed in a light free box in a photographic dark room for a week. A radiograph of the mineral taken with the aid of its own natural radiation results when the film is processed. The radiograph shows irregularly distributed patches of higher radio-activity (See plate 1). These patches were found to correspond approximately to the chocolate-brown patches of the mineral (See plate 2). However petrological examination revealed very little differences in optical properties except for a slight birefringence difference in the two coloured areas.

Grenfell Thomas's analysis (Table 1) indicate that there is a relatively high percentage of uncombined water. This is unusual, for monazite is normally one of the anhydrous phosphate group. This high percentage suggests that alteration of the mineral has taken place. The autoradiograph and microscopic structure of the thorium mineral suggests that the change involved hydration of the rare earth bases with simultaneous leaching of phosphoric acid.

X-ray diffraction showed little differences between the altered spots, normal monazite and alteration veins. Some electron probe work may elucidate the compositional differences.

Microdescription (Slide 68F - 1)

Large fractured grains of monazite and rutile set in a matrix of green-brown mica folia and cracked anhedral quartz and feldspar grains.

Feldspar	-	Albite and orthoclase - fractured grains showing strain structures.
Quartz	-	Cracked anhedral grains, variable size - largest up to 6mm
Biotite	-	Unusual mica, fine aggregate with small rutile inclusions. Light brown to grey-green in colour.
Rutile	-	Reddish brown to yellow in colour, fractured grains.
Monazite	-	Ranges from colourless to yellow brown, traversed in all directions by an irregular network of light brown altered material. Refractive index and birefringence is high. The mineral is optically continuous and shows no strain shadows under crossed nicols.

Microdescription (68F - 2)

Rutile is massive. Does not form distinct crystals. Fractured cleavage is interrupted and fracturing is rough. Colour varies from dark red to grey. Iridescent tarnish.

Microdescription (68F - 2) Briquette

Cleavage well shown, twinned. Grains fractured. Colour varies strongly anisotropic from light grey to dark brown grey. Strong internal reflections, yellow brown-red. Ilmenite is a common inclusion as small veins following cleavage and may be of secondary origin.

Microdescription (68F - 1)

Rutile similar to 68F-2. Monazite is also present. Polarized light shows compositional differences. Grey to maroon-grey at the edges.

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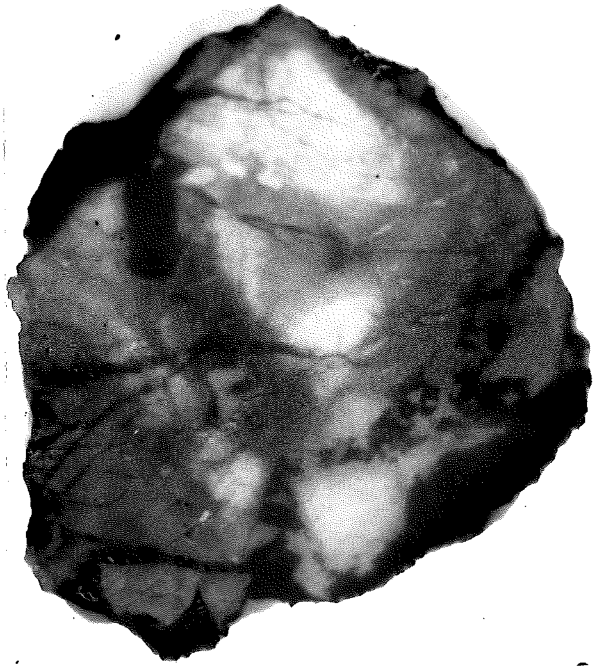


PLATE 1 - AUTORADIOGRAPH OF MONAZITE

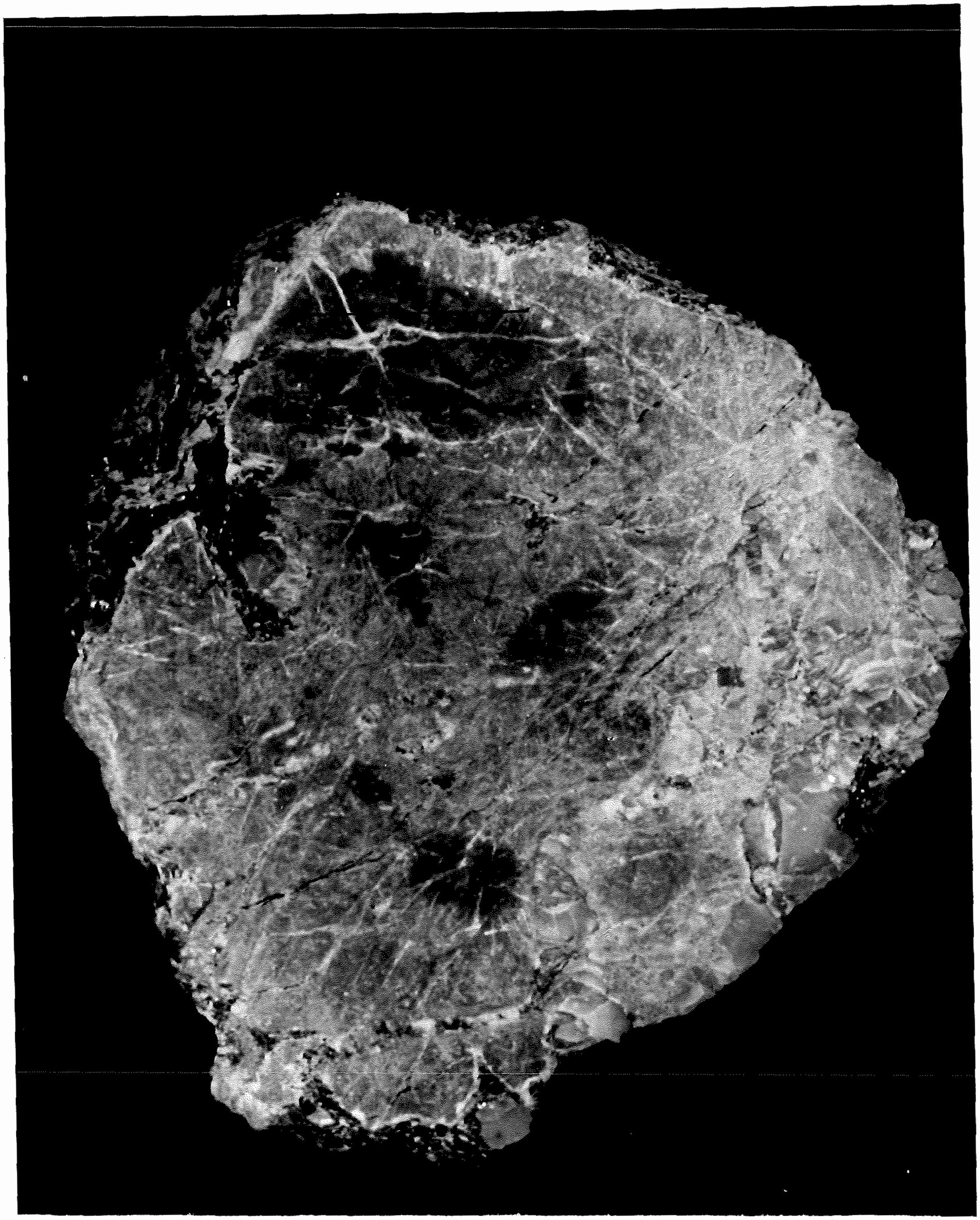


Plate 2 Little Gorge Monazite. Note the dark spots have a higher thorium content than the lighter background monazite. Autoradiograph data shows a difference in radioactivity.

APPENDIX II

GEOLOGY OF THE MOUNT LOFTY RANGES

The most striking feature of the Fleurieu Peninsula is the Mt. Lofty Ranges which extends in a continuous arc like succession of ridges to Cape Jervis. These ridges rarely rise to more than 1,500' above the bordering plains, but their slopes are often steep, and the wide expanse of flat ground which flanks them both to the west and east, throw into sharp relief their marginal scarps. The ranges rise abruptly from the Gulf St. Vincent sub-basins in the west and from the Murray Basin in the east. This elongated arc marks the site of portion of the Adelaide Geosyncline which existed from Late PreCambrian to Early Palaeozoic times. Sediments in this geosyncline were folded and uplifted in early Palaeozoic times to give rise to the Mt. Lofty Ranges. This range has been planed down and partially buried under beds of Permian and Tertiary age. The present relief is due to later tectonic stresses mostly of Late Tertiary and Quaternary age which caused some doming and blocking. Rejuvenation by differential erosion of Permian glacial depressions has also contributed to the relief.

GEOLOGICAL SUCCESSION

Archaean - Lower Proterozoic Inliers.

The cores of the regional anticlines may be distinguished from north to south as the Crafers - Aldgate Inlier and the Mt. Compass - Yankalilla Inlier. They consist of a complex suite of metamorphic rocks among which the most common types are mica schists, banded gneiss, augen gneiss, stressed granite gneisses and migmatites. The schists comprise quartz-sericite, quartz-chlorite, plagioclase-quartz-sertcite and pyritic varieties with subordinate bands of kyanite and sillimanite schists.

Recrystallized original argillaceous sandstones appear to have produced well bedded gneisses composed of quartz, mica, feldspar and chlorite with occasional grains of tourmaline, zircon and apatite. Many of the gneisses are garnet and sillimanite bearing.

Granitoid rocks are most commonly found as lenticular bodies invading the metasediments. They are often kaolinized and vary from pegmatitic albitic leucogranites to a normal potassic granites. Microdiorites occur as sills or dykes of limited extent. The more common and characteristic rocks of inliers are the so called epidote syenite of early workers. These may be recognized easily in the field by their unusual appearance. They are dark green to light pink and form conspicuous outcrops owing to their resistance to weathering and erosion. They are well exposed in the Mt. Compass - Yankalilla Inlier where they vary from an epidote-bearing gneiss to an albite-amphibole-pyroxene gneiss with quartz, hornblende, biotite, zircon, sphene and rutile as accessory constituents. Similar rocks are largely represented in the Houghton-Barossa Inlier north of the area under review. These rocks were thoroughly investigated by Spry (1951). The name Houghton "Diorite," given to the rocks by Benson (1909) is still retained by some authors, but it is now considered they are metasomatic rather than magmatic in origin.

Iron formations are also a common feature of these inliers. Iron rich material from these cores contributed to younger sediment of Torrensian, Marinoan, and Cambrian ages. Whitten (1966) discusses deposits at M●on Hill and Mt. Jagged in the Mt. Compass - Yankalilla Inlier. The Mt. Jagged deposit consists of massive haematite in veins striking across the metasediments. The haematite is coarse grained, with well developed twinning and numerous exsolution blebs and lamellae of rutile. An average assay of the ore is 64.9% Fe with 6% Tio_2. At Moon Hill the ore is a coarse grained magnetite in quartz-feldspar-mica schists. The magnetite is martized almost completely along (111) clearage direction. The ore is often cut by veins of earthy and colloOform goethite. Samples range from 33.3% Fe to 67.6% Fe with .16% to .43% Tio_2 content.

Adelaidean (Upper Proterozoic)

Rocks of Adelaidean age overlie unconformably the Archaean-Lower Proterozic basement. In dealing with the Adelaidean succession it is convenient to make a distinction between the normal unmetamorphosed facies and local metamorphic facies of the western and eastern portions respectively of the Fleurieu Peninsula. The type area for the Adelaidean is in the foothills surrounding the city of Adelaide. The beds are the normal unmetamorphosed facies and have been grouped into Torrensian, Sturtian and Marinoan. Rocks of Willouran age are not evident in this area and the sequence begins with the Torrensian characterized, by basal grits, sands and magnesian deposits. Then comes the Sturtian, a sandy argillaceous sequence with thick interbeds of tillites. The succession ends with the Marinoan marked by characteristic red bed development.

Normal Unmetamorphosed Facies:

(a) Torrensian

The succession begins with coarse-bedded grits and conglomerates (Aldgate Sandstone) containing well rounded quartz and quartzite pebbles with heavy mineral laminae. This basal formation varies from a few feet to 3,000' in thickness resting unconformably on the Archaean basement at a number of localities. The sandstone is overlain by alternating slates, quartzites (Stonyfell - Mt. Lofty Quartzite) and dolomites (Castambul, Montacute and Beaumont Dolomites) which grade into magnesites.

(b) Sturtian

A major climatic change brought about a long period of glaciation and sediments were laid down by glacial and fluvioglacial agencies. In the type area the Sturtian begins with a group of slates and quartzites (Belair Group) which includes the Mitcham Quartzite. These are conformably overlain by an alternation of boulder tillites (Sturt Tillite) and fluvioglacial beds. The Tapley Hill Slates, blue calcareous well laminated slates succeed conformably the tillitic beds. At their top blue to buff in colour and partly oolitic is developed the Brighton Limestone.

(c) Marinoan

This succession overlies the Sturtian conformably and consists of a monotonous alternation of purple, grey or greenish shales, slates and siltstones with subordinate sandy and dolomitic intercalations. Reddish tints are due to the presence of small amounts of ferric oxide. The Marinoan is conformably topped by a sand formation, often cross bedded and ferruginous which has been adopted by convention as the base of the Cambrian (Mawson 1938).

Metamorphic Facies of Eastern Mt. Lofty Ranges.

Compared with the area occupied by the normal unaltered beds of the Adelaidean the metamorphic equivalent in the eastern portion of the Mt. Lofty Ranges have a vast extent. The boundary with the basement is overturned and the basal grits are extremely sheared especially in the Yankalilla area. The rock types in the grit grade from a haematite-quartzite containing minor mica to banded feldspar quartz-mica gneiss containing acessory haematite. Shaly members of the Adelaidean gave rise to quartz-mica-shists and spotted and knotted schists. These are locally albitized and contain numerous talc and pegmatite bodies, especially in the Gumeracha area. The calcareous and magnesian beds of the series are represented by marbles having a coarse crystalline structure and containing non carbonate material, viz. Macclesfield Marble (Torrensian), Rapid Bay Marble (= Brighton Limestone of Sturtian age). Marly shales and calcareous sandstones have been changed to epidote hornsfels and calc-silicate rocks of varying mineralogical composition.

Cambrian.

Again it is convenient to make the distinction between the essentially unmetamorphosed shelf facies of the Western Mt. Lofty Ranges and the metamorphosed flysch facies of the South-eastern and Eastern Mt. Lofty Range.

Western Mt. Lofty Ranges.

The Cambrian unconformably overlies the Marinoan and begins with the arkosic Mt. Terrible Formation. Above this lies a sequence of argillaceous limestones, fossiliferous limestone, limey shales, phosphatic shales and greywacke. In ascending order of time the formations represented are the Wangkonda Limestone, Sellick Hill Limestone, Fork Tree Limestone, Heatherdale Shale and the Carrickalinga Head Formation. The sediments were deposited in a stable shelf environment.

Eastern Mt. Lofty Ranges.

In early Cambrian local uplift and folding, initiated a period of subsidence along the southern and eastern portions of the Mt. Lofty Ranges. Under tectonically unstable conditions a great thickness of Flysch facies sediments accumulated. The sequence begins with phosphatic slates and marble horizons which grade into greywacke. The phosphatic shales appear to be equivalent to the Heatherdale Shale and the overlying greywacke to the Carrickalinga Head Formation of the Western Mt. Lofty Ranges. These beds pass into the Kanmantoo Group. This group begins with cross-bedded arkoses which in many places have been called the Inman Hill Formation. Above this is the Brukunga Formation which includes at its base the Nairne Pyrite Member. This formation consists dominantly of greywacke schists and phyllites with pyritic and calc-silicate lenses. Orogenic movements terminated sedimentation in late Cambrian or early Ordovician. During the orogenic phase zonal metamorphism occurred and reached andalusite grade of the amphibolite facies. Accompanying the metamorphism granites were emplaced at Victor Harbour - Pt. Elliot, Murray Bridge, Tailem Bends, Monarto and Palmer. These granites are not all of an igneous origin.

Permian.

Deposits representing this time include glacial sediments which outcrop at Hallet Cove, Mt. Compass, Hindmarsh - Inman Valleys and in the Cape Jervis area. These outcrops represent patchy remnants of moraines and fluvioglacial deposits. Clay and sand interspersed with pebbles and boulders form the bulk of moraines. Varved beds are interstratified or overlie them. Fluvioglacial sands and gravels are common although there is difficulty in separating them from deposits which infilled the glacial basins in post glacial times.

Tertiary.

Sedimentation occurred in the St. Vincent Basin and Murray Basin on the flanks of the Mt. Lofty Ranges during this time. In the Mt. Lofty Ranges sediments are found as marginal outliers only, marking local embayments of the sea in the old land mass. Sedimentation in the Willunga and Noarlunga Sub - Basins of the larger St. Vincent Basin, will only be considered as the arenaceous sediments here affect the distribution of the heavy mineralization in present day beach sand on the western coast of the Fleurieu Peninsula. The Noarlunga and Willunga Sub-basins are separated from each other by an anticlinal core of Marinoan rocks. The Tertiary sequence of these basins are revealed in coastal cliff sections.

The oldest strata are Mid Eocene terrestial sands which overlie the weathered basement rock with pronounced unconformity. These sands extend from the central and northern portion of the Willunga Basin into the Noarlunga Basin. In their southern-most occurrence in the Willunga Basin they have been described as the North Maslin Sands. These are variable in nature, ferruginous and crossbedded with angular quartz grains of varying size, grading to dark, carbonaceous lignitic sands. Coarse basal conglomerates occur locally. These basal terrestial and deltaic sands are followed by marine glauconitic sands, i.e. (South Maslin Sands) in both basins. This is overlain by a glauconitic shelly limestone (Tortachilla Limestone), containing a rich fauna of molluscs, echinoids, foraminifera and bryozoa. This limestone grades upwards into the finer grained Blanche Point Marls. Abundant sponge spicules and molluscan shells occur in this bed. A facies change has been observed in the Blanch Point Marls. The marls give away to fossiliferous silty and sandy strata with local lignite intercalations and siliceous bands rich in molluscs in the eastern portion of the basin. The end of the Eocene is characterized by thin, non marine, unconformable, red and green clays and sands (Chinaman's Gully Beds) above the marls. This is well exposed near the mouth of the Onkaparinga River and in Chinaman's Gully, north of Port Willunga.

Marine conditions prevailed again in the middle Tertiary (Oligocene-Miocene). The Port Willunga Beds overlie the non-marine Chinaman's Gully Beds with slight disconformity. These beds consist of bryozoal limestones and calcarenites with interbedded glauconitic clays. Their extent is such that they overlie the Cambrian slates of the Willunga scarp, and dip steeply south of them at Sellicks Beach, and rest on Permian glacials in the Myponga and Hindmarsh Valleys.

Continental deposits on the Mt. Lofty Ranges proper differ in facies, thickness and age. They are usually of two types fluvio-lacustrine beds and lateritic residual deposits of the uplifted surface. Fluviolacustrine deposits are exposed in a number of places (e.g. Echunga) and consist essentially of strongly cross bedded gravels, sands, laminated clays and silts with cut and fill effects. They contain silicified tree trunks and carbonaceous remains with occasional leaf impressions. They were probably laid down in land of moderate relief well drained by rivers, with the sediments filling local depressions. Age is uncertain, but they antedate the Oligocene-Miocene marine deposits of the bordering plain. Their long preservation on the uplifted surface is due to ironstone cappings which provide evidence that these deposits were laterized. Laterization began in Eocene and lasted until Pliocene times.

A pronounced stratigraphic and diastrophic break occurs between the Miocene and Pliocene sediments of the basins. The Pliocene is exposed, outcropping in cliff sections along the coast as alternating white and yellow sands and fossiliferous sandy limestones.

The fossiliferous beds contain abundant molluscs, foraminifera, echinoids, crab claws and bryozoa. The limey sequence passes into mottled clays and sands which represent a truncated lateritic profile. A gradual transition can be observed upwards and southwards in the Pliocene, especially in the

Willunga Basin. This is noted at Sellick Hill where mottled sands grade into coarse fanglomerates at the foot of the Willunga Hills. The non-marine sediments after the dated Lower to Middle Pliocene limestone range from late Pliocene to Pleistocene. Alluvial clays and sandy clays with outwash gravel fans near the foot of the hills range from Pleistocene to Recent. Near the coast the top of the series is formed by Recent (Post-Pleistocene) beach deposits and underlying clays, kunkar, sands and gravels which could be Late Pleistocene in age.

TABLE 3 HEAVY MINERAL PERCENTAGES ALONG FLEURIEU PENINSULA FOR BACK BEACH SAMPLES

Sample No.	Percentage H.M.	Location
1.	34.0	Christies Beach
2.	6.7	Southport Beach
3.	2.6	North Moana (Dunes)
4.	8.7	North Moana Beach
5.	1.8	South Moana (Dunes)
6.	11.8	South Moana Beach
7.	7.8	North Maslin Beach
8.	8.1	North Maslin (Dunes)
9.	4.3	South Maslin
10.	1.9	Port Willunga Beach
11.	8.9	Aldinga Beach
12.	12.5	Silver Sands (Dunes)
13.	10.9	Sellick Beach
14.	22.0	Myponga Beach
15.	23.0	Myponga (Dunes)
16.	1.5	Carrickalinga Beach
17.	.1	Carrickalinga (Dunes)
18.	33.0	Little Gorge Beach
19.	.40	Cape Jervis Beach
20.	1.7	Fishery Beach
21.	1.4	Tunkilla Beach
22.	2.7	Waitpinga Beach
23.	17.6	Petrel Cove
24.	.95	South Encounter Bay
25.	.21	North Encounter Bay
26.	.20	Chiton Rocks Beach
27.	.25	Chiton Rocks (Dunes)
28.	16.1	Port Elliot Beach
29.	22.0	Middleton Beach
30.	3.1	East Middleton Beach
31.	2.8	Goolwa Beach
32.	2.6	East Goolwa Beach
33.	2.2	Murray Mouth

PREPARATION AND COLLECTION OF SAND SAMPLES

Sand samples were taken in dunes and on beaches at the backshore mark from 9" to one foot holes dug in the sand. The bottom and half way up the sides of these holes were sampled. The initial large field sample were dried, split and quartered in the laboratory so that about 75 - 100 grams of the original sample was obtained. This was washed, dried and weighed. The samples were now sieved using 30, 60, 120 and 240 B.S.S. sieves. Each sieve size was then weighed, converted to a percentage of the original sample and sieve loss calculated.

The original sample was again split down to 5-10 grams. This smaller sample was washed, dried and weighed too. Heavy media separation using bromoform or tetrabromoethane was then carried out. Bromoform was used initially and was found to be less viscous, hence filtration and sedimentation was much quicker. This factor is of importance when a large number of separation are to be undertaken even though tetra-bromo-ethane is slightly denser. Acetone was used as a washing liquid on the heavy mineral product collected. Tetrabromoethane and bromoform can be recovered later from the acetone washings. After washing with acetone, the samples are dried and weighed. The percentage heavy mineral in the sample can now be calculated. A representative sample of the original heavy mineral sample for grain count analysis is obtained by further splitting with a microsplitter. This is then mounted in araldite for grain counting.

PROVENANCE

HEAVY MINERALS FOUND IN ROCKS OF VARIOUS AGES.

(1) Archaean - Lower Proterozoic

(I) Gneisses, and schists

Tourmaline, zircon, and apatite occur occasionally but garnet, sillimanite and kyanite are more prominent.

(II) Granitoid rocks

Zircon and ilmenite are present.

(III) Epidote gneiss ("Houghton Diorite" Rock Type)

Hornblende, epidote, ilmenite, haematite, sphene, zircon and rutile are accessory constituents.

(IV) Iron Formation

Martized magnetite, and titaniferous haematite occur.

(V) Pegmatites

Widespread pegmatization occurs in the inliers. A typical example and most well known of these pegmatites is at Little Gorge, Normanville. A detailed description of the Little Gorge Pegmatite occurs in the appendix I.

In the pegmatites rutile, tourmaline (dravite-schorlite), monazite and ilmenite occur.

(2) Adelaidean (Upper Proterozoic)

a. Western Mt. Lofty Ranges Non Metamorphic Facies

Torrensian

(i) Basal Grits (Aldgate Sandstone)

Mills in his analysis reports that opaques consisting of titaniferous haematite and ilmenite occupy 20% of the heavy minerals by weight. On the basis of frequency analysis the non opaques are zircon, 12%, monazite 2%, garnet 2%, pyroxene 2% and rutile 1.5%. Similar results were obtained by the writer from analysis of the sandstone from Yankalilla.

(ii) Stonyfell - Mt. Lofty Quartzite

Heath (1960) in his detailed study of the Stonyfell Quartzite reported 15 heavy mineral species. Of the species observed zircon occupies 60%, garnet 15%, tourmaline (13 varieties) 25% and rutile (3 varieties) 1%. Others species occurring are haematite, ilmenite, leucoxene, limonite, magnetite, monazite, pyrite, sphene, spinel, topaz and andalusite.

Sturtian

No heavy mineral analysis have been made on arenaceous members of the sequence. It is highly probable that resistant minerals such as zircon and garnet would be major constituents of the heavy fraction of the Mitcham Quartzite.

Marinoan

The colour of this red bed sequence is due to the high iron oxide content. Under reflected light abundant opaque iron oxide minerals can be seen. Red bed material from Hallet's Cove, Sellick Hill and Delemere have an opaque mineral content of 2.5% of the rock. Brotherton (1967) has shown the minerals present are martized magnetite, some ilmenite, limonite.

b. Eastern Mt. Lofty Ranges Metamorphic Facies.

A sample of Torrensian basal grit from Normanville was found to consist mainly of titaniferous haematite (predominant), ilmenite (common), zircon, pyrite (trace), garnet, rutile and monazite (rare).

A wide variety of accessory minerals occur in the metamorphics, many of these are purely metamorphic in origin. Many authors in their description of the petrology of the area mention the following minerals occuring in various rock types:

(i) "Granite" - zircon, magnetite, apatite.

(ii) Gneisses and schists - zircon, magnetite, tourmaline, rutile, apatite, garnet, epidote, hornblende, zoisite.

(iii) Pegmatites - beryl, rutile, tourmaline and iron oxides.

In the pelitic rocks at Delemere, Leslie (1962) noted obvious idiomorphic magnetite and other opaques. Brotherton (1967) described the opaques as magnetite, martite, haematite, ilmenite and lencoxene.

(3) Cambrian

a. Western Mt. Lofty Ranges Non Metamorphic Facies.

Arenaceous beds such as the Carrickalinga Head Greywacke are reported by Abele and McGowran (1958) to contain epidote, muscovite and opaques.

b. Eastern Metamorphic Facies of the Mt. Lofty Ranges.

(i) In greywacke mica schists, quartzites, cak-silicates, phyllites and siltstones of the Kanmantoo Group, a variety of original accessory minerals are preserved, besides minerals of purely metamorphic origin. Tourmaline, rutile and zircon are original accessory minerals. Staurolite, andalusite, sphene, kyanite, apatite, sillimanite, pyrite, magnetite and garnet are common constituents of the schists. Offler (1960) in a determination of the composition of garnet from Strathalbyn area reports that two specimens approximate to a composition of almandine 75, spessartite 14, pyrope 5, andradite 3, grossular 3.

(ii) Tourmaline, rutile and sphene are the common accessories in pegmatites with apatite, garnet, monazite, zircon, ferberite and molybdenite being rarer species.

(iii) Granites are well developed being either igneous in origin or a product of granitization. Granites developed are the Palmer Granite, Monarto Granite, Murray Bridge Granite and the Victor Harbour - Port Elliot Granite.

(a) Palmer Granite - Rattigan and Wegener (1950, 1958) report ilmenite, sphene, magnetite and apatire as accessories in the granite. Fander (1963) also adds epidote, zircon and hornblende. See table.

(b) Rathjen Gneiss - Ilmenite, leucoxene, sphene, apatite and zircon occur as accessories (Rattigan and Wegner 1950, 1958). See table.

(c) Monarto Granite, Fander (1963) reports zircon, monazite, apatite, magnetite, martite and zircon occur as accessories.

(d) Murray Bridge Granite - Petrographic characteristics have been discussed by Kleeman (1934), Johns and Kruger (1949) and an accessory study by Fander (1963). Accessories include fluorite, magnetite zircon, sphene, apatite, chalcopyrite, ilmenite and monazite.

(e) Victor Harbour Granite - Primary accessories reported in the various phases of the granite by Milnes (1967), are apatite, zircon, ilmenite and rutile. Detailed work on the accessories by Fander (1963) adds to this list pyrite, gold, molybdenum, monazite, sphene, epidote, garnet, staurolite and pyrrohotite.

(4) <u>Permian</u>

The heavy fraction of the till and fluvioglacials occupy up to 1% with the dominant heavy mineral being garnet. See table.

(5) Tertiary

Heavy minerals are well developed in the basal Eocene sand formation, the North Maslin Sands. Opaques predominent but other minerals such as zircon, garnet, sillimanite, kyanite, andalusite, monazite, staurolite and spinel are well represented. Pyrite and pyrohotite are the most abundant of the opaques with ilmenite, haematite, limonite and magnetite occurring to a lesser extent.

The South Maslin Sand, the overlying formation has a heavy mineral suite which is mainly limonite with some other opaque mineral species, zircon, garnet, glauconite and mica.

Pliocene sands represented by the Hallet's Cove Sandstone have a heavy mineral content which is dominated by opaques consisting of haematite, magnetite, limonite and ilmenite. Zircon, garnet, spinel, mica, pyrite and staurolite occur in lesser amounts.

ANALYSIS OF TILL (Courtesy of S.A. Dept. of Mines).

	A %	B %
Light fraction	99.2	98.9
Heavy fraction	.8	1.1
Minerals of light fraction		
quartz	90	65
feldspar	10	20
clay	-	15
rock fragments	-	-
Grain size (Diam. mms.)	.22 - .37	.15 - .45
Minerals of heavy fraction		
zircon	1.7	13.1
rutile	2.0	4.7
tourmaline	9.8	26.2
garnet	70.0	-
staurolite	5.2	10.7
hornblende	1.0	.9
muscovite	-	3.7
biotite	-	1.9
hydromica	.5	-
kyanite	-	2.3
opaques	9.8	36.3

A. Till west of Sugarloaf, Hallets Cove.

B. Fluviogalcial south of Sugarloaf, Hallets Cove.

Coastal Sedimentation Photographs.

CHRISTIE'S BEACH

(a) Looking south toward Christie's Beach proper showing flat bedded heavy mineral laminae in the beach. Profile was cut by the creek here in flood.

(b) Back beach and dune profile cut by Christie's creek.

(c) Close up of profile showing types of bedding.
See Plate for detailed examination.

(a)

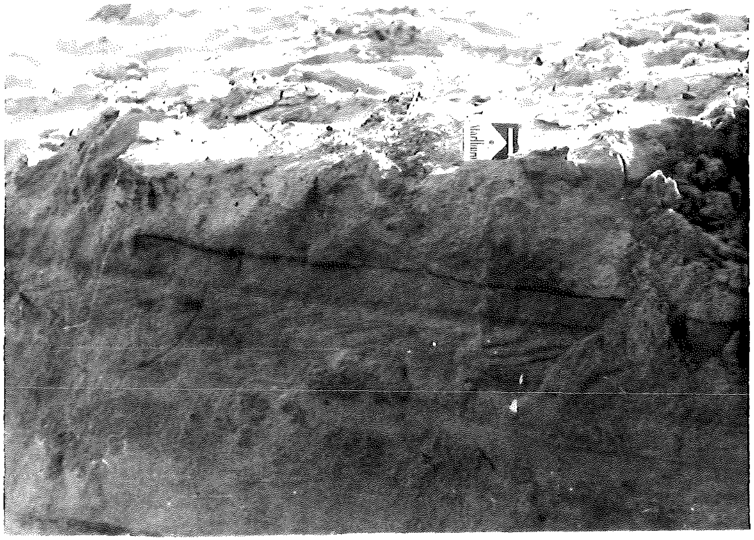
(b)

(c)

CHRISTIE'S BEACH

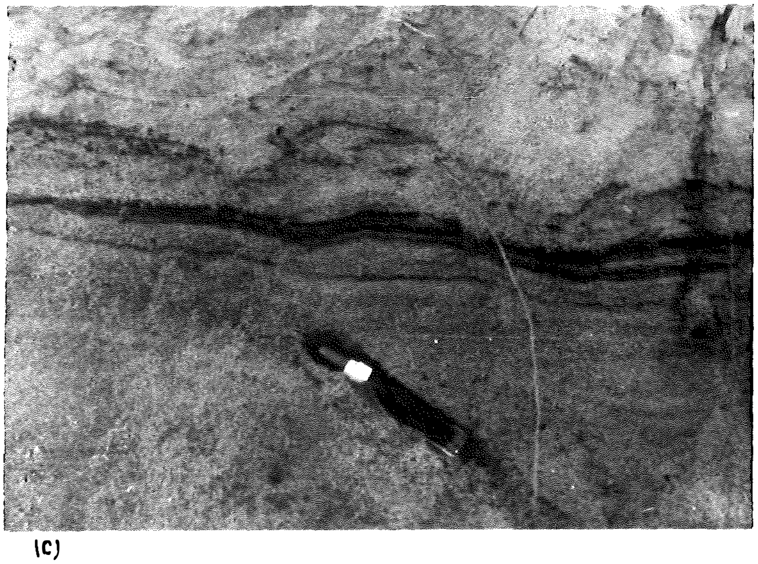
(a) & (b) Mixture of herring bone and flat bedded heavy mineral laminae. At this spot there is an interaction between back beach and stream environments. The herring boned laminae are inclined upstream. The trough sets are a product of the large scale turbulence in upper flow regime of this ephemeral stream. The flat bedding is characteristic of the back beach environment produced under less turbulent conditions but still of the upper flow regime.

(c) Section of the flat bedding in detail.



(a)

(b)



(c)

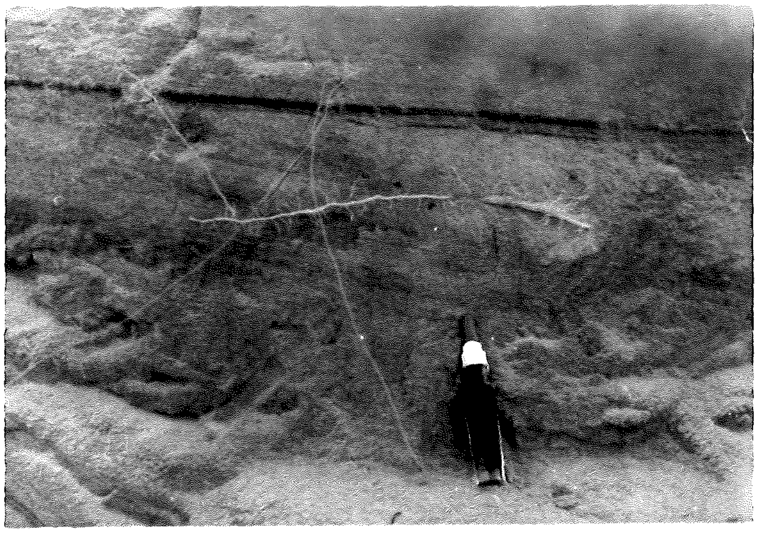
SOUTHPORT BEACH

(a) Large scale cross bedding with heavy mineral laminae in coastal dunes. Note the coastal dunes appear to overlie a back beach deposit. This is evidence by the flat bedding at the base of the photo.

(b) Close up of cross bedding. Pen in 3 inches. Individual heavy mineral banding ranges from a pencil streak to a half an inch in thickness.

(c) Close up of flat bedding typical of the upper flow regime on a back beach.


(a)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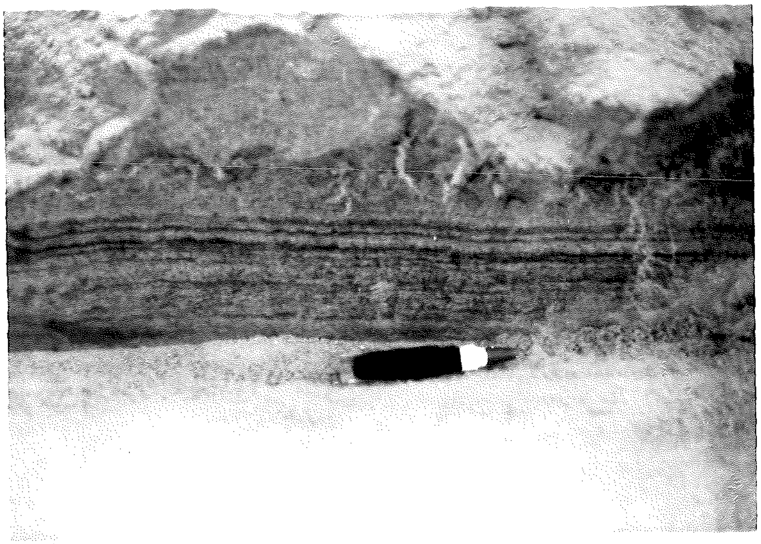

(c)

PLATE

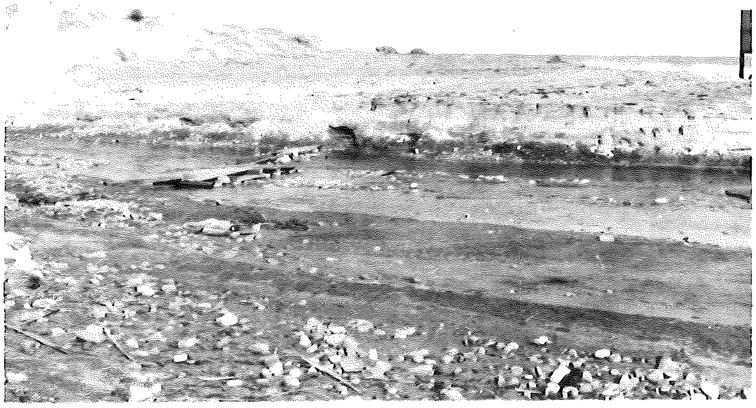
MOANA BEACH

(a) View from vegetated coastal dunes showing heavy mineral concentrated by wind action on the dunes, and a heavy mineral sheet on the cobbly back beach.

(b) View looking south from the other side of Pedlar's Creek after the creek level has dropped. Note again the thick heavy mineral sheet on the back beach and the sharply eroded coastal dunes.

(c) Close examination of bedding in the back beach accentuated by the heavy mineralization. Overall bedding flat typical of the upper flow regime. Some slump disturbed bedding is visible. This is a reflection of a fluctuating water table.

(a)



(b)

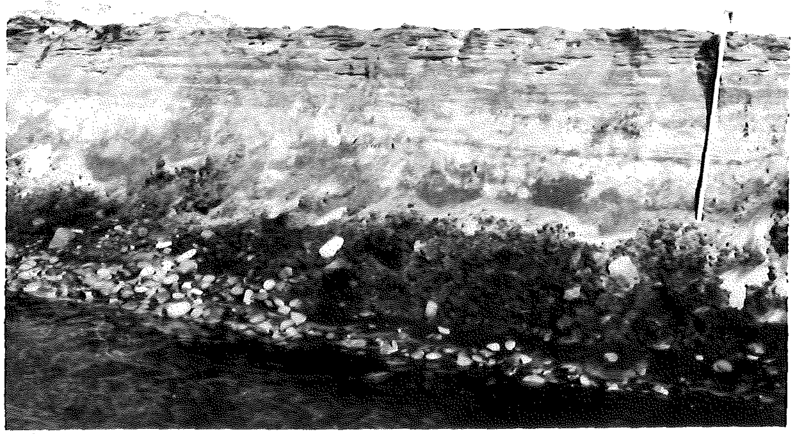
(c)

MOANA BEACH

(a) Moana Beach looking south to Ochre Point with red heavy mineral sand on the beach. Coastal dunes on the left. Beach near the water line is composed of rounded quartz pebble. The beach as a whole has a typical steep winter profile.

(b) and (c) Solid heavy mineral sheet, flattly bedded typical of the upper flow regime. The transverse section has been cut by Pedler's Creek in Winter flood. The stick is approximately 3 feet long.

(a)



(b)

(c)

MASLIN BAY

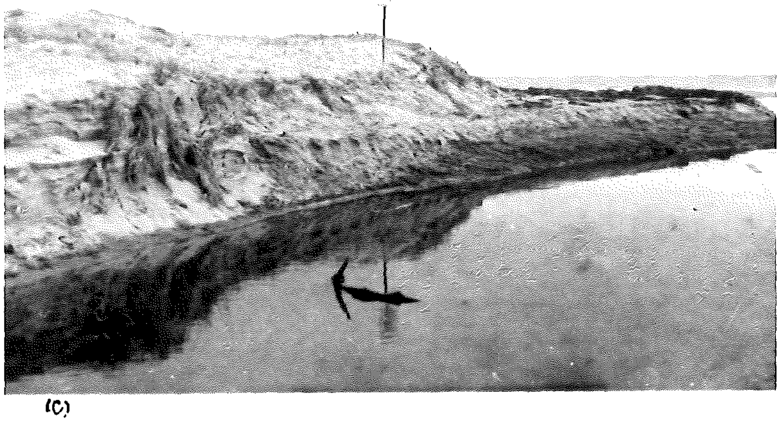
(a) Top of cliffs, looking south over Maslin Bay. In the background is Blanche Point with a heavy mineral sheet in the centre of the bay. Bennet's creek in the foreground is in flood.

(b) Top of the cliffs looking north towards Ochre Point and the sand quarry where the North Maslin Sand is exposed. The cliff in the foreground is composed of the South Maslin Sand.

(c) Bennett Creek showing truncated coastal dunes and portion of the wave cut platform in the South Maslin Sand.


(a)

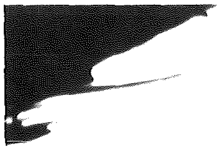

(b)


(C)

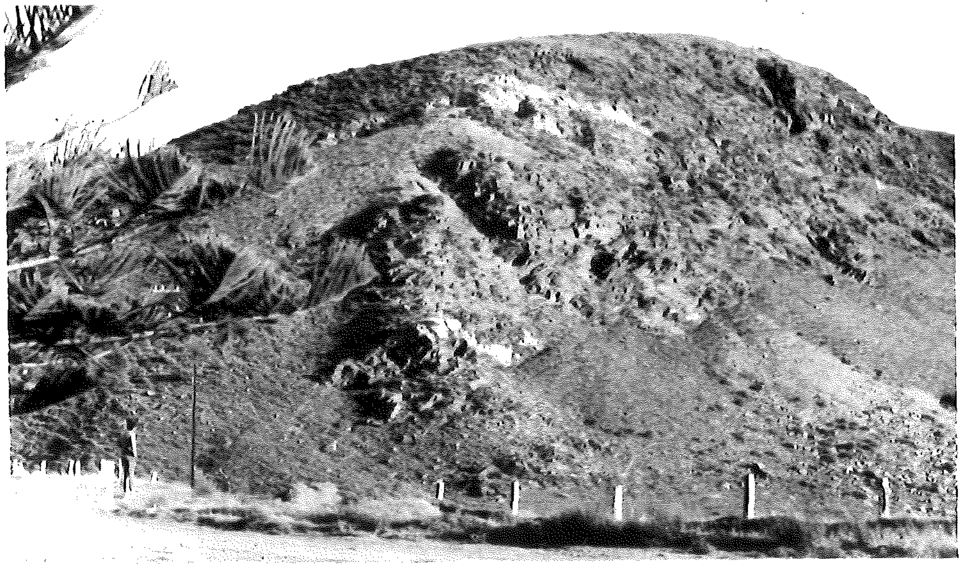
(a) Little Gorge Beach looking across Yankallila Bay. The hills in the background are composed of limestone and greywacke of Cambrian Age. The foreground is a wavecut platform composed of titaniferous sandstone and grits of Torrensian Age.

(b) Section of the Yankallila Inlier, with pegmatite lenses (white) exposed in seacliffs at Little Gorge, Normanville.

(c) Mouth of the Yankallila River in winter showing a steep winter sandy beach and coastal dunes. Across Yankallila Bay is the Lower Proterozoic Inlier (darkened area).



(a)



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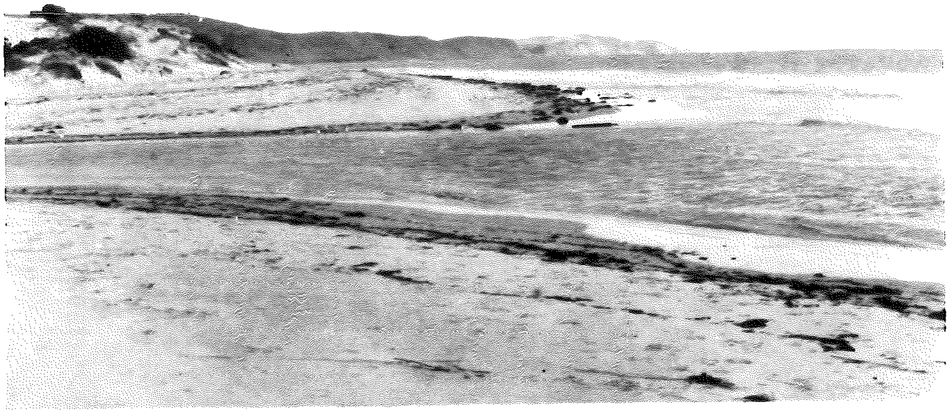


(c)

MAP 2. Geology & sample maps of Fleurieu Peninsula - a

CAINOZOIC

? PLEISTOCENE

Qpa Outwash deposits; sands and clays locally with piedmont boulder beds, usually capped by kunkarised surface. Marine shell beds east of Meningie.

PLIOCENE

Tp Laterised deposits and ferruginised sands and gravels, of uplifted plateau areas. Mottled sands, clays of western coastal regions, underlain by HALLETT CŌVE SANDSTONE: marine sands, sandy limestones. NORWEST BEND FORMATION: marine sandy limestone of Murray River area.

TERTIARY — MIOCENE, OLIGOCENE

To-m PORT WILLUNGA BEDS: marine sandy limestones and clays in western coastal areas. MANNUM FORMATION: sandy limestones, gritty at base where transgressive in eastern areas.

To ETTRICK MARLS. glauconitic marls.

EOCENE

Te-o BLANCHE POINT MARLS: gastropod marls, underlain by TORTACHILLA LIMESTONE: glauconitic limestone.

Te SOUTH MASLIN SANDS: marine limonitic sands underlain by NORTH MASLIN SANDS: cross-bedded sands and gravels, local lateritic developments.

UPPER PALAEOZOIC — PERMIAN

P Glacial and fluvioglacial deposits: cross-bedded silts and sands with boulders, green clays. Marine shales and mudstones near Second Valley. Possibly including reworked deposits of younger age.

CAMBRIAN SUCCESSION EAST AND SOUTH OF ARCHAEAN ANTICLINAL CORES

LOWER PALAEOZOIC — CAMBRIAN — KANMANTOO GROUP

€k BRUKUNGA FORMATION: interbedded phyllites and greywacke with lenticular pyritic and calc-silicate lenses.
BROWN HILL GREYWACKE MEMBER.
Pyritic phyllite and low grade schist, in part carbonaceous, including NAIRNE PYRITE MEMBER.
INMAN HILL FORMATION: coarse-grained impure arkose, locally cross-bedded and with slump structures. Polymictic pebble beds locally towards top.
Greywacke with siltstones and phyllitic shales; quartzites.
Marble lens.

€ Phyllitic shales and siltstones, locally pyritic, phosphatic or carbonaceous.
Marble.
Quartzites. (Stratigraphic position uncertain).

CAMBRIAN SUCCESSION WEST OF ARCHAEAN ANTICLINAL CORES

LOWER PALAEOZOIC — LOWER CAMBRIAN — KANMANTOO GROUP

€k Chloritic greywacke of Carrickalinga Head and Myponga Jetty.

€ HEATHERDALE SHALES: mottled and nodular carbonaceous shales with phosphate nodule bands, locally calcareous at base.
FORK TREE LIMESTONE: massive and bedded calc-dolomite with Archaeocyatha.
Banded limestone, calcareous shales and siltstones with sandstones and oolitic dolomite; (SELLICKS HILL LIMESTONE AND WANGKONDA FORMATION). Pebbly arkose at base.

UPPER PROTEROZOIC — ADELAIDE SYSTEM

MARINOAN

Pmu Mud-pellet rich, ripple marked quartzites and siltstones overlain by purple argillites north of Mount Terrible.
Chocolate and grey siltstones and shales with greywacke and coarse siltstones. Phyllites east of Archaean anticlinal cores.

UPPER GLACIAL

Pml, Pmm Felspathic quartzites, tillitic grit and grey pebbly mudstones with massive greywacke lenses, locally calcareous and purple. Includes MARINO ARKOSE.
BRIGHTON LIMESTONE: oolitic limestone, flaggy limestones and dolomitic limestones, recurring in overlying and underlying beds. Marbles in Mt. Barker and Ashbourne regions.

STURTIAN — INTER GLACIAL

Psu TAPLEY HILL SLATES: blue-grey laminated, alternating siltstones and slates locally phyllitic. Blue ferruginous slates at the base.

LOWER GLACIAL

Psl STURT TILLITE: boulder tillite.

Ptu Quartzites and arkoses, locally pebbly with interbedded siltstones, locally calcareous.
Laminated, blue-grey alternating siltstones and slates, with local arkose bands, scattered pebbles in siltstone matrix; locally calcareous. Actinolitic slates and sericite schists east of Archaean anticlinal cores.
Tillite north of Second Valley. (Stratigraphic position uncertain).
Calcareous occurrences.
Felspathic, argillaceous quartzite with purer quartzitic and arkosic bands; conglomeratic at base where transgressive upon Archaean.

TORRENSIAN

Ptm STONYFELL QUARTZITE in northern part of sheet.
Dark pyritic shales, quartzitic and sandy at base. Contain reworked chert pebbles at base in Scott Creek region. Calcareous and fine-grained at base in Mt. Bold region.

Ptl Calcareous beds with interbedded black chert bands and magnesite (MONTACUTE DOLOMITE equivalent).
Sandstone and carbonaceous shales with black chert lenses and nodules.
Sandstones and carbonaceous slates.
ALDGATE SANDSTONE: heavy mineral banded quartzite and arkose with conglomerates.

ARCHAEAN

A Felspathic schists and gneisses and quartz felspar augen gneisses with zones of sericite schists. Local leucocratic granitic units.
Epidote gneiss and epidote metaquartzite.

IGNEOUS ROCKS OF LOWER PALAEOZOIC AGE

VICTOR HARBOR GRANITE, CAPE WILLOUGHBY GRANITE: porphyritic, coarse-grained adamellite with large zoned felspar phenocrysts (euhedral and rounded) and bluish quartz phenocrysts; local sodic phases (albitite).

MURRAY BRIDGE GRANITE: pink, coarse-grained, granite. Smoky quartz phenocrysts.

MONARTO GRANITE: light grey, fine-grained, even-grained adamellite, occasionally gneissic.

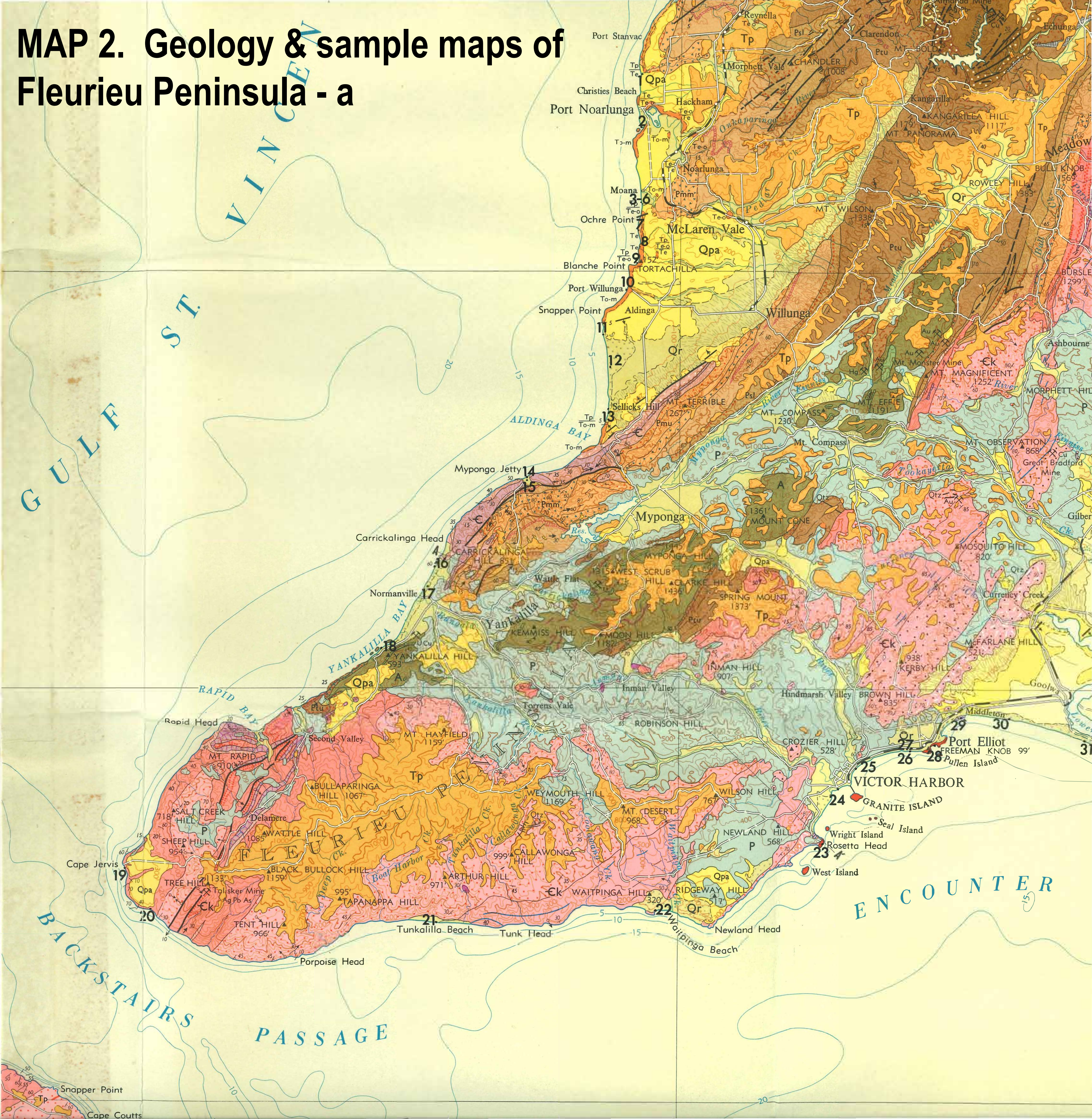
VEIN AND DYKE ROCKS OF VARIOUS AGES

Diorite dykes and plugs.

Qtz Quartz, quartz-tourmaline (B), quartz-haematite (Fe) veins.

Peg Pegmatite.

ZONES OF MORE PRONOUNCED METAMORPHISM



MAP 2. Geology & sample maps of Fleurieu Peninsula - b