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RECORDS 1959/82.

DESERT DUNE SANDS FROM THE CANNING BASIN, WESTERN AUSTRALIA.

by

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INTRODUCTION

The sands on which the investigation was carried out were collected by officers of the Bureau of Mineral Resources during field trips to the area in 1954, 1955, and 1956. No samples were collected in 1957, when a helicopter survey was made of portion of the area. Fifty-six samples have been examined; these were collected from an area of about one hundred thousand square miles, included between latitudes 19° and 24° South, and between longitudes 120° and 129° East in the Canning Basin of Western Australia (Fig. 1.)

TOPOGRAPHY

A description of the topography of the south-western portion of the area is given by Traves, Casey and Wells (1956). The rest of the area is essentially the sameas the south-western part; dunes cover the central part of the Basin which is bordered by low hills and dissected ranges. Drainage channels occur only around the edges of the Basin, and are mostly dry. In the sand dune area, drainage is either subterranean or internal into playa lakes (Traves, Casey and Wells, 1956).

The dunes are long ridges of sand (seifs) generally 30 to 60 feet high, extending up to fifty miles. They vary only slightly in direction, and trend between west and north-west. Several distinct types of dunes can be recognised from aerial photographs, but they will not be discussed here. Barchan dunes have not been seen.

An important feature of these dunes, one in which they differ from dunes in deserts of other parts of the world, is the almost complete cover of vegetation. The interdune floors as well as the dunes themselves are covered with spinifex and low shrubs, and trees grow along the crests of some dunes. In general, however, the crests are the only part of the system which lacks dense plant growth, and usually, but not invariably, there is a strip along the crest about twenty yards wide which is free of vegetation. In places, the interdune areas contain dry salt lakes and clay pans. The dunes of many other deserts generally lack plants, and areas such as the great "ergs" of the Sahara are seas of sand separated by rock or gibber floors. The interdune areas within the ergs themselves are covered with sand and completely obscure the underlying rock over wide areas.

The dry salt lakes and clay pans, and the almost continuous cover of vegetation are important departures from the normal desert environment, and must be taken into consideration when the origin and movement of the dune sand in the Canning Basin is considered.

GEOLOGY

The Canning Basin is both a structural and a topographic depression which is bordered on the south, east and north by Precambrian rocks. The Indian Ocean lies to the west.

Almost everywhere the Basin is occupied by outcropping Permian, Triassic, Jurassic and Cretaceous rocks, overlain by Quaternary sand dunes. Fig. 3 is a geological sketch map of the area, adapted from the Tectonic Map of Australia.

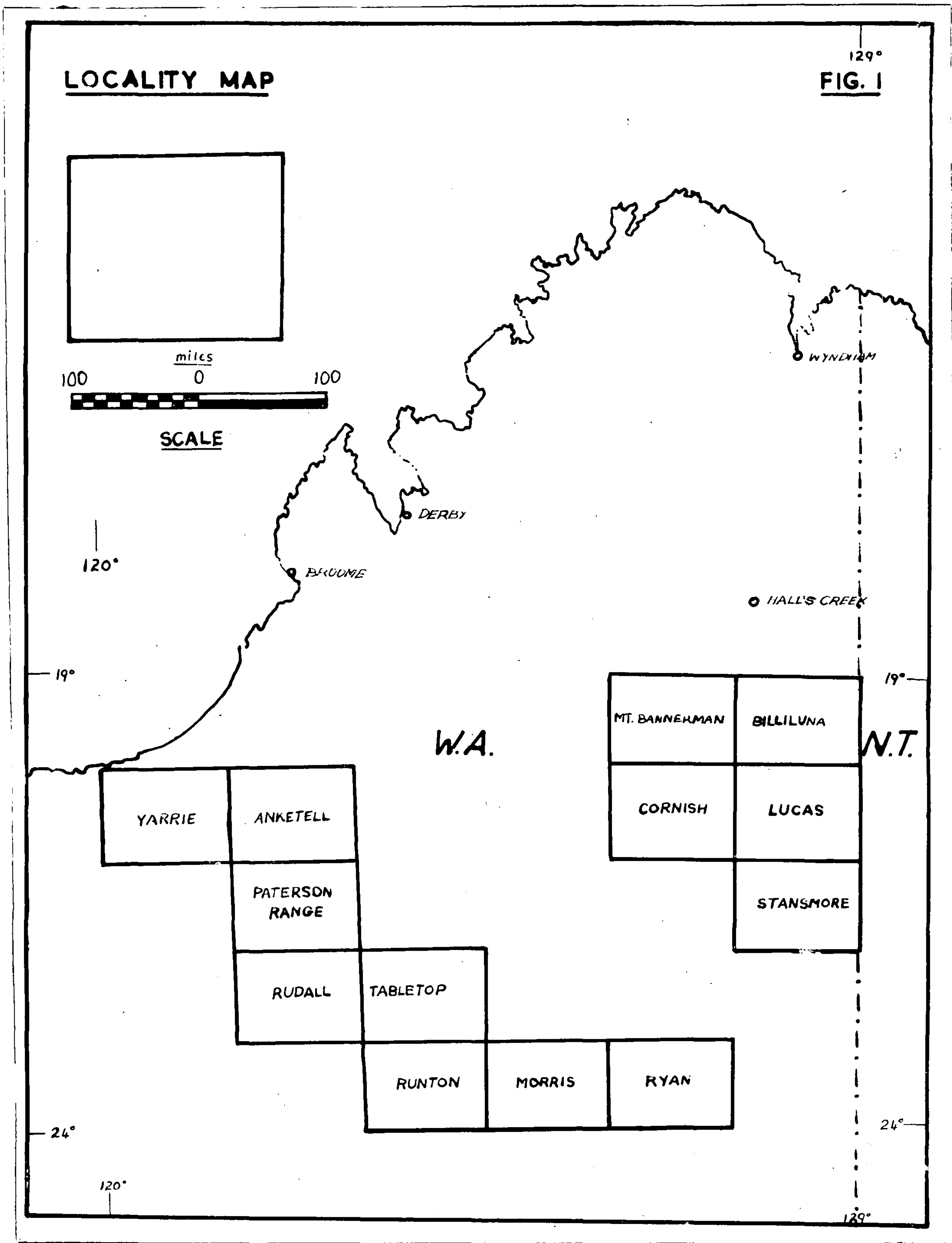


FIG. 1. Locality map, with reference to the Australian Four-Mile Map Series.

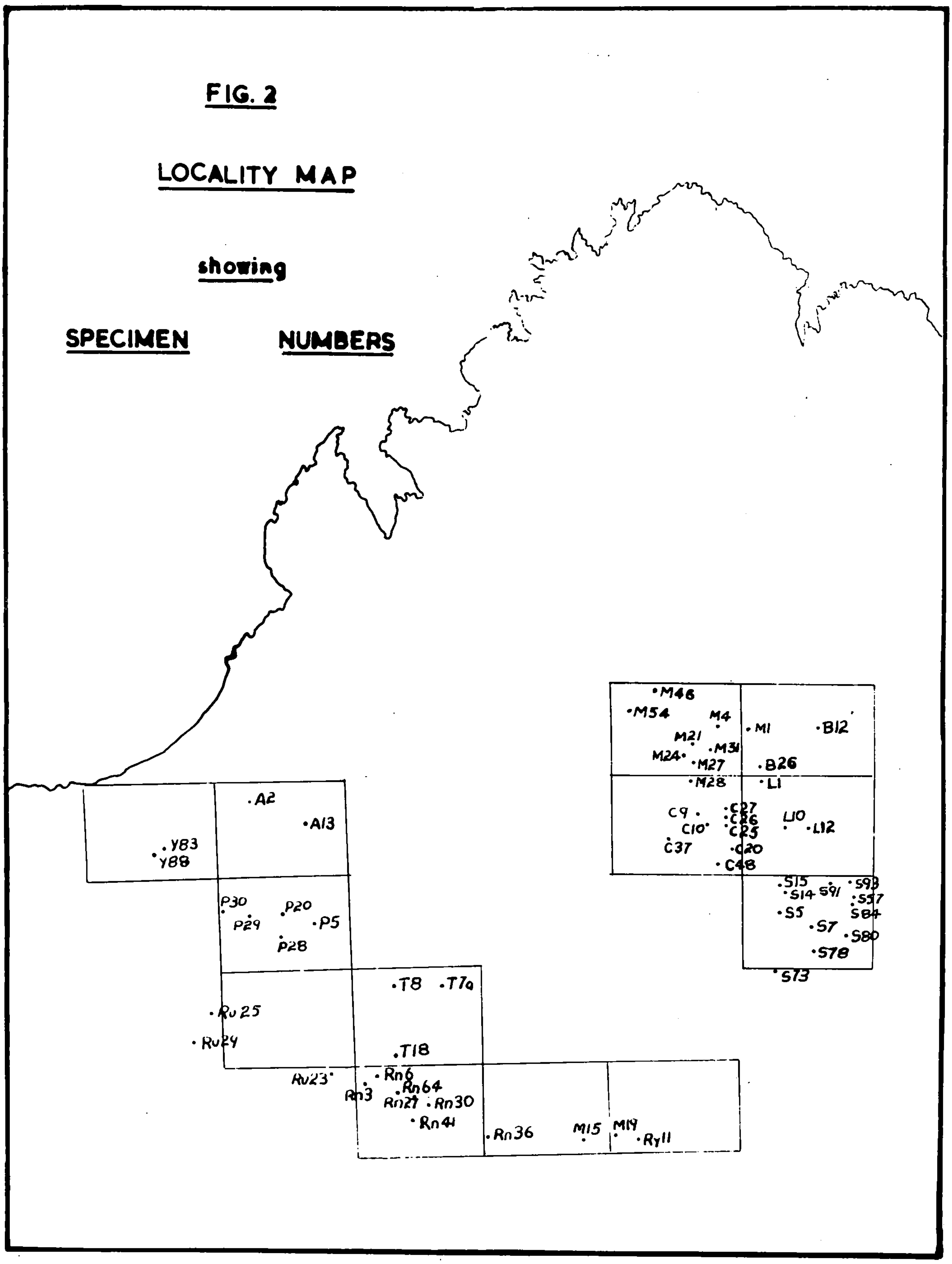


FIG. 2. Locality map, showing the specimen localities with reference to the Australian Four-mile Map Series.

SAMPLING

The sampling of the sand was random, and no sampling plan or control was used. The sand in all samples was collected from a depth of three to six inches below the surface, and all samples except C26 were crest samples. Sample C26 is an interdune sample. Some of the results may be uncertain owing to the uncontrolled sampling.

THE SANDS

The sands are bright red fine grained and fairly angular; they consist of quartz with very minor amounts of feldspar and heavy minerals.

THE ANALYSIS

Mechanical analysis, extraction and analysis of the heavy minerals, and roundness analysis were carried out in an attempt to trace the source and subsequent movements of the sand.

MECHANICAL ANALYSIS

Each sample ranged from 300 to 400 grams. This was reduced by a Jones sample splitter to about 50 grams. Exactly 50 grams were sieved for ten minutes in a mechanical sieve shaker. British Standard Sieves were used, the mesh numbers being 16, 36, 52, 72, 150, and 200. The results of the mechanical analysis are given in Table 1. The -200 grade was examined by sedimentation methods; about 99% of the grains are 60 microns or more across.

Fifty-six samples were examined, and of these, only one, C26, was not from the crest of a dune. This sample was taken from the trough between two dunes, and near a rock outcrop. Almost all samples have grains less than 1 mm. across, and although every sample was not tested, the smallest grains forming a measurable percentage of the samples appear to be about 60 microns across. The sands therefore range in grainsize from medium to very fine (Wentworth, 1922).

The results of the mechanical analysis were plotted on semi-logarithmic graph paper, and the median grain diameter (M) was recorded for each sample (Table 1). This ranges from 0.420 mm. (Rn27) to 0.185mm. (M31).

COMPARISON WITH OTHER SANDS.

The dune sands from the Canning Basin are generally coarser than dune sands from other deserts. A comparison is made in the Table below with sands from the Simpson Desert (Carroll, 1944), the Libyan Desert (vide Carroll, 1944), the Rajputana Desert, India (MacCarthy, 1935), and the north-west Sahara (Alimen, 1957). The results of the analysis of eolian sands from all parts of the world studied by MacCarthy (1935) are included.

TABLE 2.

	EOLIAN	CANNING	SIMPSON	LIBYAN	RAJPUTANA	SAHARA
max. grain size. (m.m.)	0.48	1+				1+
range of 95% of grains. (m.m)	0.25 0.08	0.50 0.08	0.24 0.06	0.80 0.08	0.25 0.08	0.50 0.05

The above Table shows the sand of the Canning Basin and the

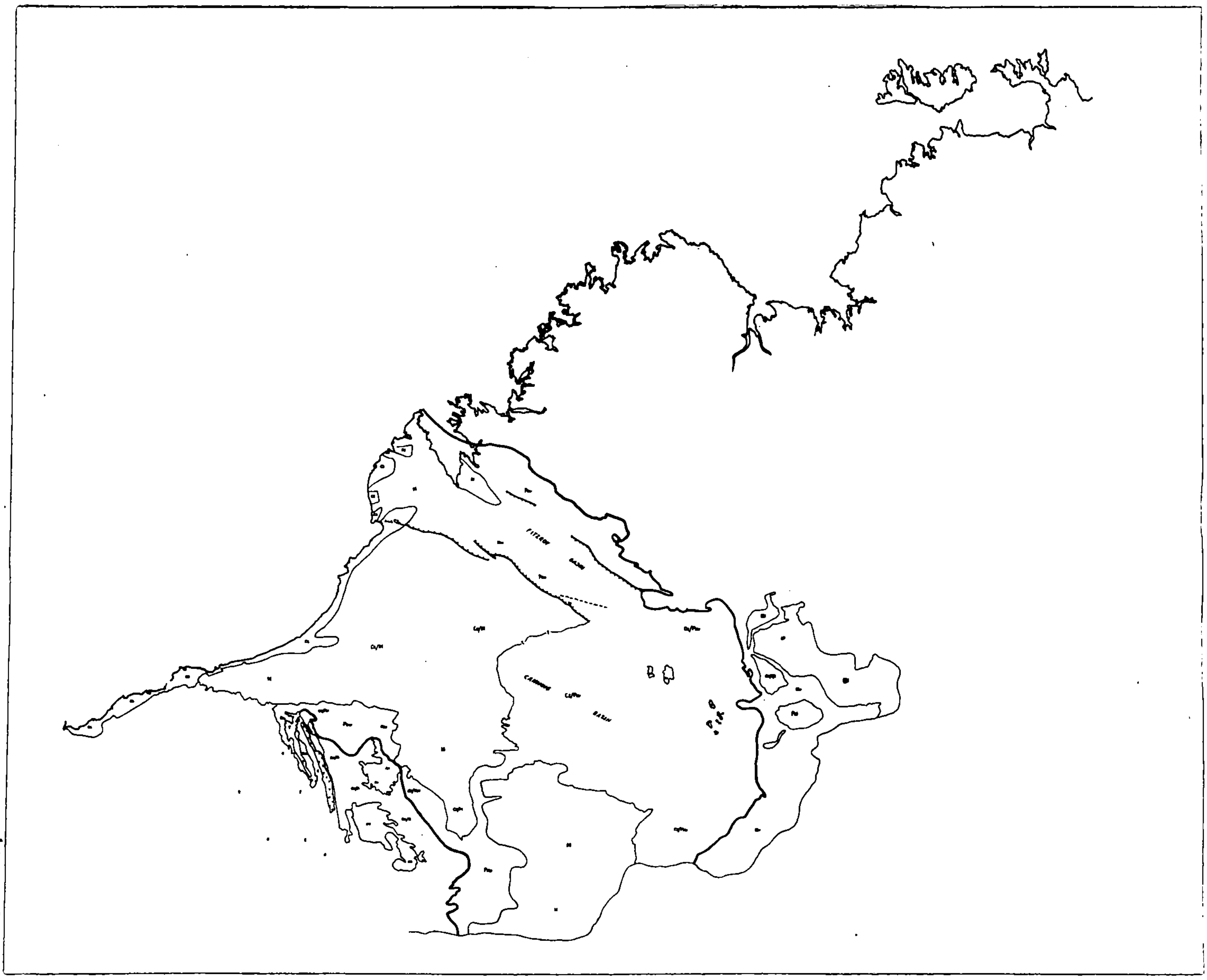


FIG. 3. Geological sketch map of the Canning Basin, adapted from the Tectonic Map of Australia.

Reference.

Cainozoic	Cz	Q	Quaternary		
Mesozoic	M	T	Tertiary	upper	u
Palaeozoic	Pz			middle	m
				lower	l
		Precambrian	pC		
Proterozoic	P	upper	Pu		
Archaeozoic	A	lower	Pl		

north-west Sahara Desert to be of a similar range of grain diameter, and slightly coarser than sands from other deserts. The sand of the Simpson Desert is much finer grained than that of the Canning Basin, the only other Australian Desert sand available for comparison. Fig. 4. illustrates Table 2.

The few available samples from the central portion of the Canning Basin indicate that the grain size of the sand is probably smaller in the centre than around the edges of the Basin. Work on further samples from the centre of the desert would be necessary to confirm this.

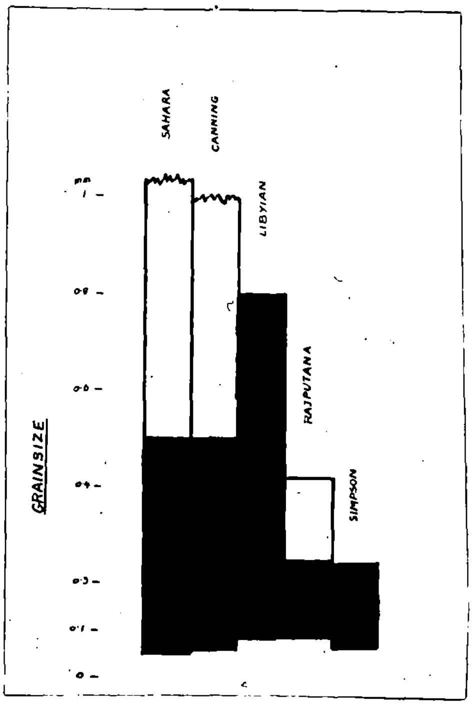


FIG. 4. Comparative grain sizes of dune sands from different deserts. The light areas represent minor percentages of the sands.

SORTING

From the cumulative weight percent curves, the two quartiles Q_1 and Q_3 were determined, and from these the sorting coefficient (So) was calculated. The formula used was So = $\sqrt{Q_3/Q_1}$ (Trask 1932). The values of So for all samples are given in Table 1.

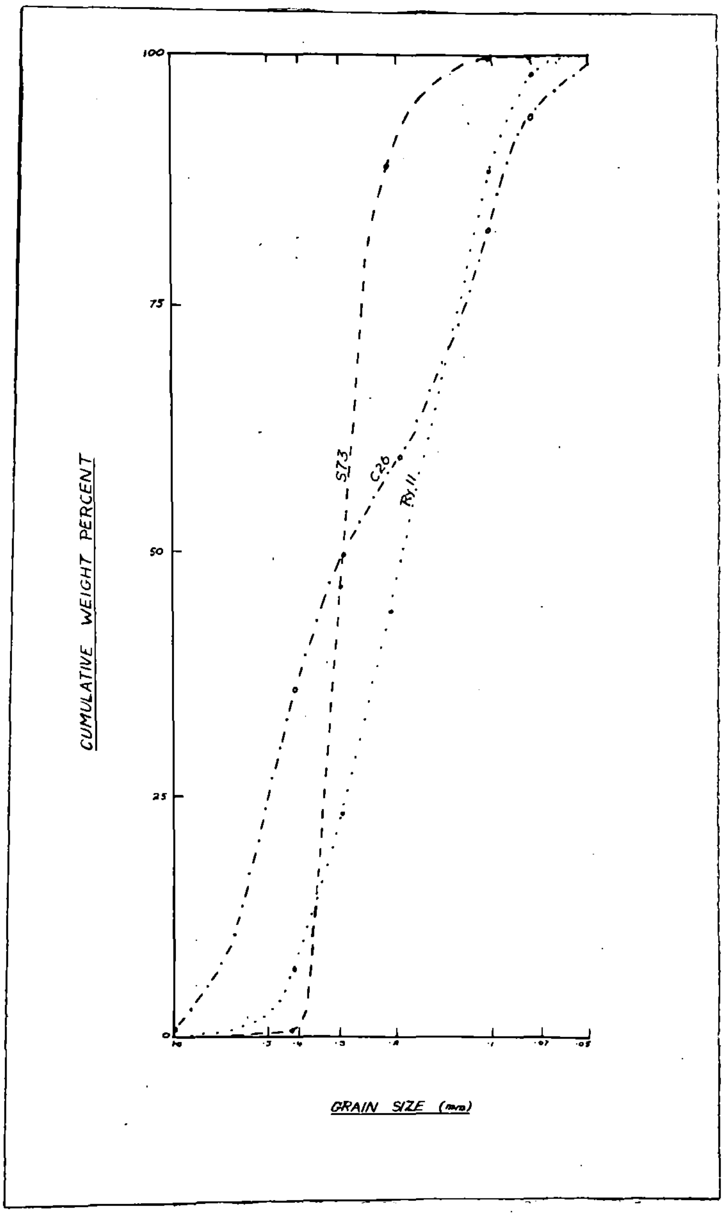


FIG. 5. Cumulative weight percent curves for the best sorted sample (S73) and for the most poorly sorted sample (Ryll) from the dune crests, and for the interdune sample (C26).

The So values for the crest samples of the Canning Basin sands range from 1.12 (S73) to 1.48 (Ry11). The sorting coefficient of the interdune sample is 2.03. The cumulative weight percent curves for these three samples are given in Fig. 5. The graphs of the other crest samples lie between the graphs for S73 and Ry11. The sands from the crests of the dunes have reached a remarkably uniform degree of sorting over the vast area sampled. The difference in sorting of sands from the crests and troughs of the dunes can also be seen, assuming that the one sample available from the trough is typical.

The frequency diagrams for the three samples described above (Fig. 6) show that the difference in sorting is accompanied by a difference in the spread of the grainsize, and in the development of points of inflexion and secondary modes. S73, the best sorted sample has a smooth curve, with no points of inflexion or secondary modes; Ry 11, the most poorly sorted sample has a point of inflexion; and C26, the interdune sample, has two well developed modes. It appears therefore that poorly sorted sands are the result of the contamination of sands from one source with sands from another. If the interdune sample is reasonably representative of interdune sands from this area, the two modes of sample C26 represent the mixture of two distinct populations of sand grains. These two populations are probably residual sands from the rocks of the desert floor, and wind-blown sand. Even if C26 is an extreme case of intermixing, it serves to illustrate how the residual and the wind-blown fractions of the sand mix. As the sand is blown into dunes, the sorting becomes better, and those sand grains which do not form part of the continuous distribution eventually resulting from the action of the wind are removed. Ry11 is an intermediate stage between the initial mixing of residual and wind-blown sand, and the formation of the normally distributed sand of S73. (Sample S73 is not perfectly normally distributed, but is slightly skewed).

To illustrate this more clearly, the three samples previously graphed have been plotted on Arithmetic probability paper (Fig. 7). On this paper a single population, representing a continuous normal distribution, plots as a straight line. S73 most closely approaches the normal distribution, and both C26 and Ry11 vary widely from the straight line. All the samples were plotted on this paper; the better the sorting of the sand, the more closely does the graph approach the straight line.

A similar conclusion was reached by Doeglas (1946) in experiments he conducted on the sorting of sands of many different depositional environments. He plotted the results of many analyses on arithmetic probability paper, and found that many curves were almost straight, but that many exhibited a sharp bend between two more or less straight portions. Experiments in mixing two symmetrically distributed sands showed that the composite curves resulted from the mixing of two such sands, and that each straight portion represented part of the symmetrical distribution of each component.

TABLE 1.

MECHANICAL ANALYSES OF CANNING DESERT DUNE SANDS

B.S.S. Sieve No.	16	36	52	72	150	200	-200		
Screen Opening mm.	1.003	0.422	0.295	0.211	0.104	0.076	-0.076		
Sample Number								So Sorting Coeff.	M Median Gram Diam(mm)
Y88	0.00	5.10	31.32	32.32	27.22	3.16	1.08	1.30	0.265
A13	-	1.88	29.90	34.45	31.09	2.40	0.28	1.29	0.250
P5	-	2.26	40.34	36.40	18.02	1.76	0.18	1.26	0.290
P20	0.08	14.74	30.98	25.48	25.32	2.60	0.08	1.36	0.280
P28	-	0.66	29.12	43.88	22.78	2.94	0.60	1.21	0.267
P29	-	2.10	40.34	34.42	21.64	1.20	0.30	1.24	0.285
P30	-	5.38	26.49	25.24	27.71	4.60	0.58	1.22	0.281
T7a	0.00	18.01	53.22	16.11	11.30	1.08	0.18	1.17	0.350
T8	0.00	4.22	46.90	31.74	16.24	0.82	0.14	1.21	0.300
T18	0.00	18.74	44.82	18.23	14.77	2.68	0.76	1.27	0.331
L1=(B15)	-	0.12	8.56	43.37	43.47	3.78	0.70	1.22	0.214
L10	-	1.40	18.48	32.78	40.46	7.02	1.66	1.37	0.218
L12	-	1.42	34.10	40.47	21.44	2.32	0.24	1.23	0.275
M1	0.00	0.46	16.06	36.86	39.86	5.48	1.28	1.31	0.220
M4	-	0.30	11.40	44.85	38.69	3.74	1.02	1.29	0.220
M15	0.01	7.79	41.28	28.21	20.87	1.55	0.29	1.25	0.290
M19	0.00	1.32	18.03	39.23	38.04	3.05	0.55	1.22	0.225
M21	-	0.04	4.70	44.64	48.10	2.20	0.32	1.18	0.208
M24	-	0.30	15.82	44.78	33.00	5.10	1.00	1.29	0.230
M27	-	0.12	10.54	49.29	34.23	4.72	1.10	1.19	0.288
M28	-	0.36	14.46	43.30	39.12	2.38	0.38	1.28	0.212
M31	0.00	0.08	4.02	28.63	56.03	9.24	2.00	1.28	0.185
M46	-	1.00	18.00	35.30	35.78	7.02	2.90	1.36	0.222
M54	-	0.40	16.08	45.81	34.73	2.32	0.56	1.36	0.241
B12	-	0.62	45.57	42.93	9.40	1.16	0.32	1.13	0.290
B26	-	0.29	25.99	41.43	29.04	2.22	0.40	1.27	0.260
C9	-	0.40	11.80	39.52	40.70	6.28	1.30	1.31	0.212
C10	-	0.60	22.78	38.97	31.67	4.74	1.24	1.32	0.240
C20	-	0.22	10.54	36.79	48.35	3.58	0.52	1.23	0.208
C25	-	5.04	40.98	27.98	21.62	3.80	0.58	1.32	0.285
C27	-	1.22	20.97	33.89	38.38	4.80	0.74	1.31	0.224
C26	0.40	34.61	14.69	9.94	22.95	10.75	6.66	2.03	0.292
C37	-	0.24	10.30	34.00	44.92	8.44	2.10	1.39	0.198
C48	-	0.90	22.00	31.72	39.80	5.10	0.54	1.32	0.220
S5	0.00	4.68	44.90	27.12	21.44	1.54	0.32	1.25	0.295
S7	-	0.48	25.66	34.13	36.53	2.96	0.24	1.28	0.253
S14	0.00	2.94	39.55	28.85	23.61	3.96	1.10	1.33	0.270
S15	-	0.80	18.82	34.98	39.30	4.96	0.92	1.34	0.219

TABLE 1 (continued)

S51	–	0.72	35.88	43.63	17.99	1.52	0.24	1.20	0.255
S73	–	0.64	45.72	42.40	10.90	0.32	0.02	1.12	0.290
S78	–	4.48	28.53	32.86	25.31	3.70	1.12	1.29	0.248
S80	–	0.12	14.38	50.33	33.89	1.10	0.18	1.18	0.236
S84	0.00	5.68	40.90	29.69	20.79	2.54	0.40	1.36	0.285
S91	–	0.16	26.13	41.14	30.16	2.22	0.19	1.23	0.250
S93	–	0.16	8.34	51.18	36.90	2.82	0.60	1.14	0.220
Ru23	–	0.80	18.82	34.98	39.30	4.96	0.92	1.34	0.219
Ru25	0.00	2.42	47.70	28.02	19.25	1.88	0.60	1.22	0.292
Ru29	–	0.38	50.65	36.81	11.96	0.18	0.02	1.14	0.295
Rn3	-0.06	4.58	31.42	32.60	28.69	2.18	0.30	1.26	0.253
Rn6	–	1.18	39.94	38.34	18.87	1.36	0.16	1.18	0.266
Rn27	–	10.54	52.68	20.38	14.58	1.64	0.20	1.20	0.420
Rn30	0.00	12.00	37.74	25.59	22.21	2.08	0.38	1.35	0.295
Rn36	0.00	39.87	31.57	10.08	15.34	2.70	0.44	1.35	0.375
Rn41	0.00	1.80	32.82	39.28	24.60	1.32	0.18	1.24	0.260
Rn64	0.00	1.07	43.35	37.00	17.15	1.27	0.18	1.18	0.290
Ry11	0.00	7.00	16.13	20.86	44.31	9.67	1.93	1.48	0.192

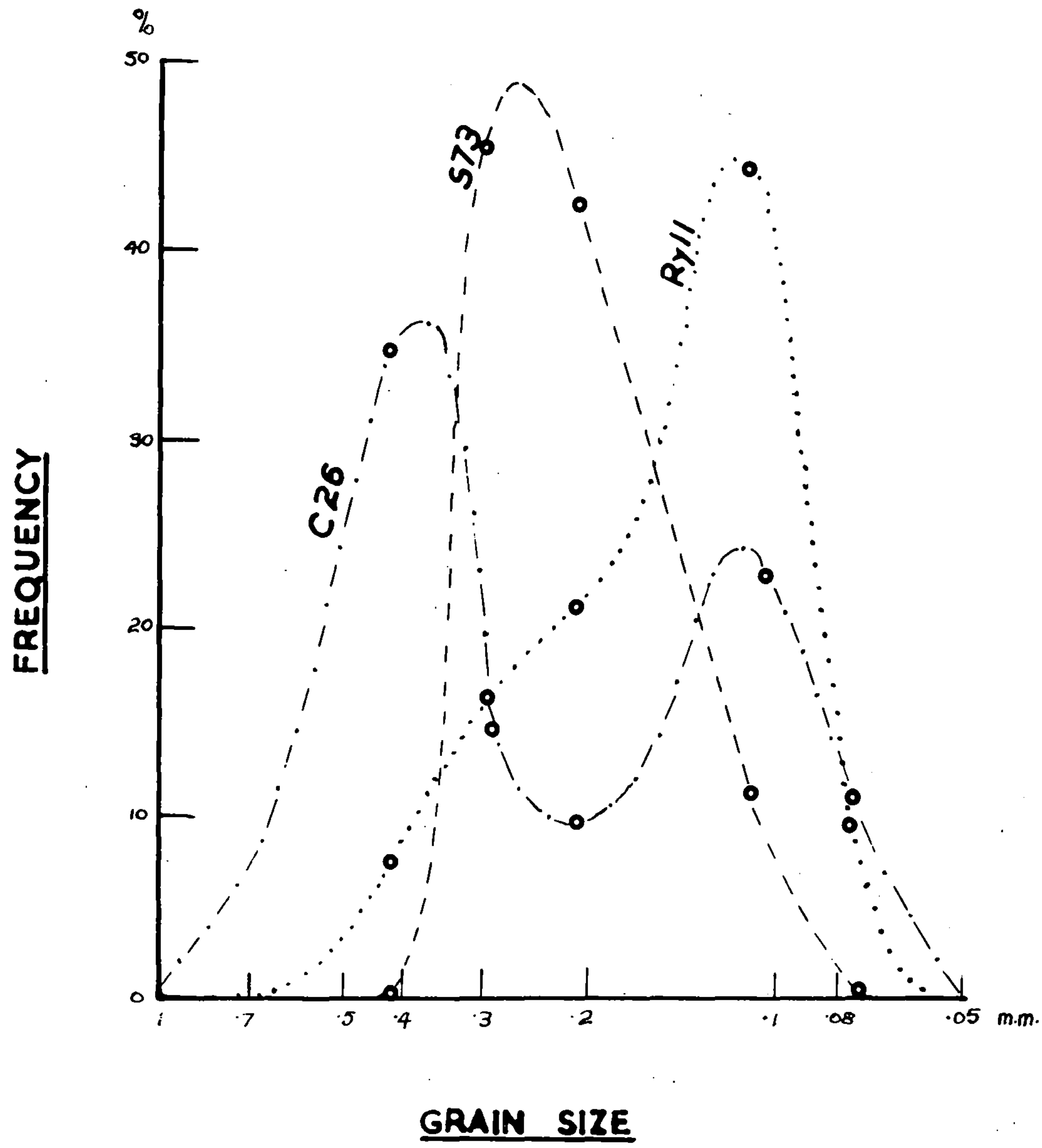


FIG. 6. Frequency diagrams for the three samples depicted in Fig. 5. Note the appearance of a point of inflexion on the curve for Ry11, and two distinct modes on the interdune sample C26.

However, this curve can result from one of two causes.

1. The sample represents a mixture of two naturally mixed sands.
2. The curve is caused by sampling two different layers in a deposit, each layer representing a homogeneous deposit which forms due to a variation in the carrying capacity of the transporting medium.

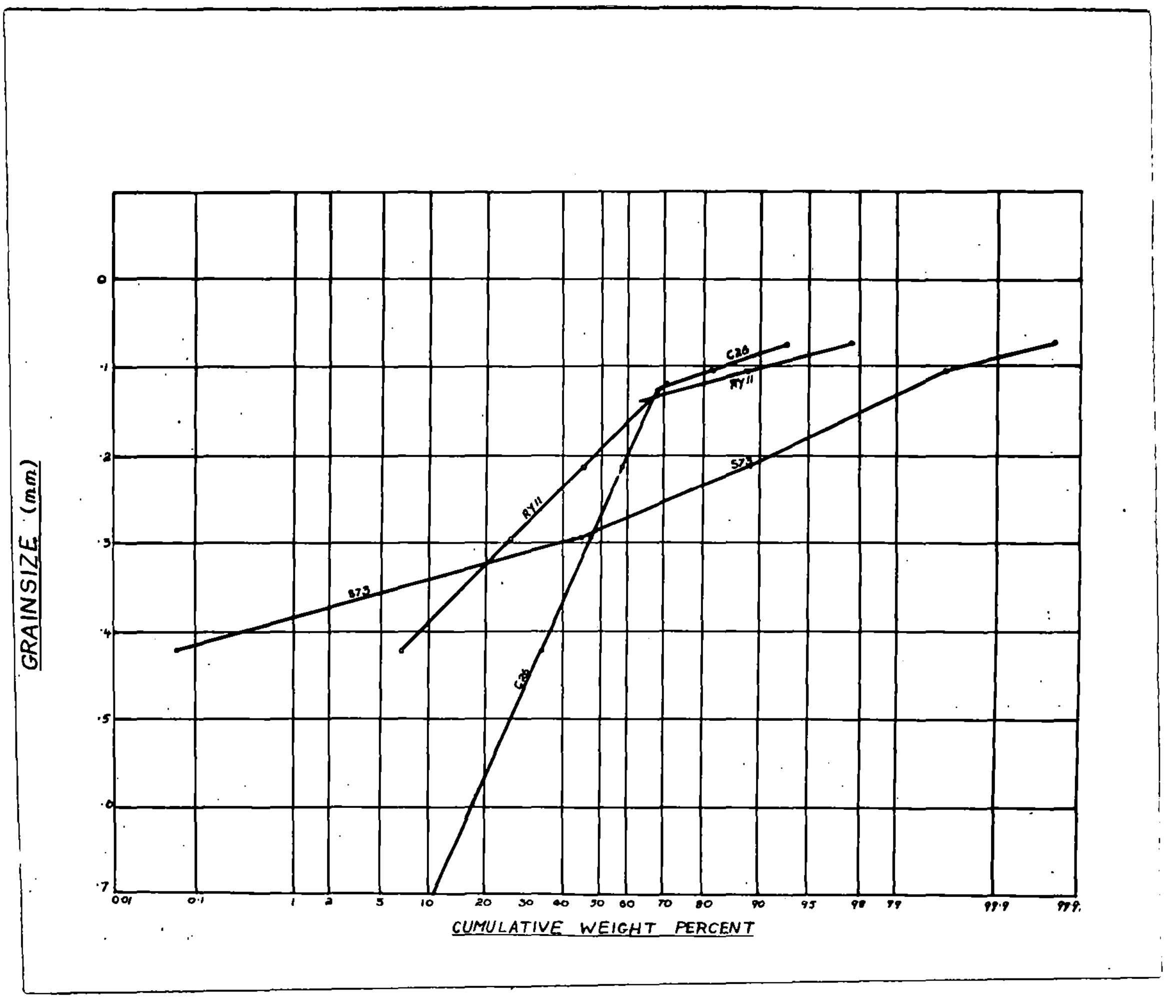


FIG. 7. Samples S73, Ryll, and C26 plotted on arithmetic probability paper.

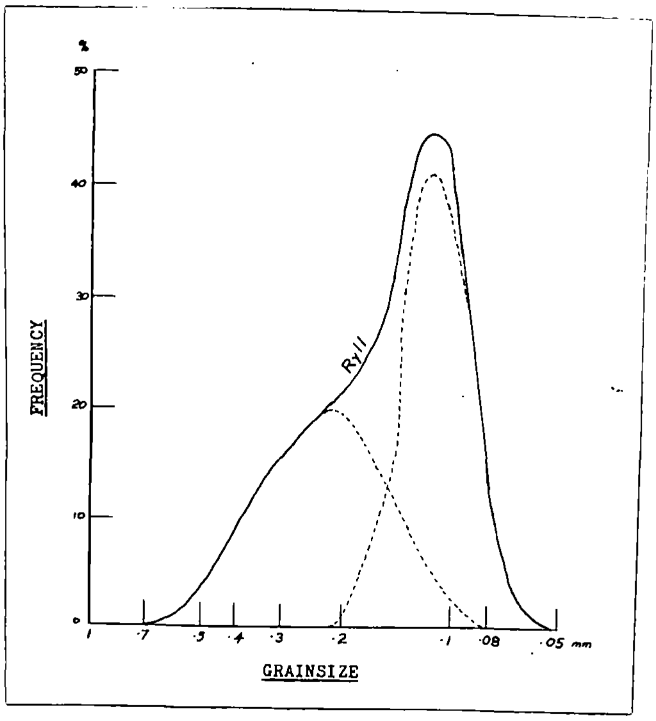
Wind mainly carries material by saltation and not by suspension, as water does, except the very finest particles (dust). Experiments by Bagnold (1941) showed that when the velocity of the wind increased, a value was reached when it could lift a sand grain of a certain size into the air and carry it forward for a short distance. On striking the ground again, the grain propelled into the air several more grains which were carried forward by the wind with a velocity about the same as that of the wind.

If the velocity of the wind is slightly reduced, the velocity of the sand grains carried forward by the wind is correspondingly reduced. These grains can only move correspondingly smaller grains, and a coarse layer tends to be deposited. A further reduction in the velocity of the wind will cause another layer to be deposited. When a relatively steady wind blows for a considerable time from one direction, a series of thin layers is deposited due to small variations in the wind velocity. A change in direction of the wind will deposit more layers, but in a different direction, thus building up the "current bedding" of the sand dune. Current bedding can also be the result of the movement of material by slippage down the dune face, and by migration of the dune.

If sampling is not strictly controlled, the sample collected may come from two of these layers. In this case, the resulting mechanical analysis will give an overestimate of the sorting coefficient of the sand, and will reveal a source from two separate distributions when plotted on probability paper.

The one available interdune sample was collected from near a rock outcrop. Therefore it is reasonable to assume that at least part of the sand is made up of sand derived from the rock of the desert floor. This sample is the most poorly sorted of all and shows two distinct modes when plotted as a frequency curve. It also shows two distinct straight lines, or more probably if more points were available, two straight portions with a sharp curve in between, when plotted on probability paper. It can therefore be assumed that this sand is the result of the mixing of sands from the rocks of the desert floor and wind blown material.

The best sorted sample is normally distributed, and therefore obviously only one layer has been sampled. If the origin of this sample is composite, it has been resorted into its present normal distribution. Diagrams of the interdune sample (C26) and the most poorly sorted crest sample (Ryll) - (Fig. 8, adapted from Bagnold, 1941) - illustrate how two sands which are mixed form the one frequency curve from their separate frequency curves. The coarser normal curve is probably the derived material, and the finer curve that of the wind-blown material, which grades down to fine dust. The problem of the origin of the wind-blown portion will be discussed after the evidence of the heavy minerals has been examined.



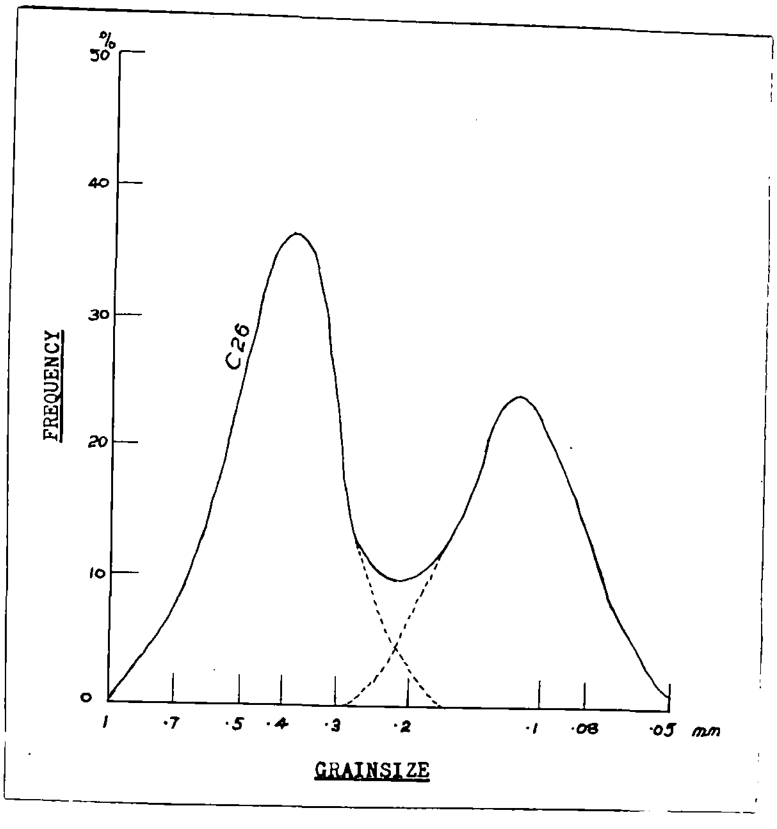


FIG 8. Frequency diagrams, adapted from Bagnold (1941), illustrating how two populations of sand grains can be merged to form the one population, but still show the characteristics of each population separately.

HEAVY MINERAL ANALYSIS

The heavy minerals were extracted from the -150 grade of each sample, by the centrifuge method (Appendix 1.)

It was not necessary to remove the coating of iron oxide from the minerals before the separation was carried out as the oxide is not heavy enough materially to affect the specific gravity of the light fraction, or dark enough to mask the nature of the heavy minerals.

Quantitative determinations of the total heavy mineral content of the samples collected in 1954 had been carried out previously by J. Ward, by the usual methods of separation. The results of this determination are given in Table 3 below.

TABLE 3.

SIZE FRACTION	100	120	150	-150	Total percent
GRAIN SIZE	0.15	0.15-0.12	0.12-0.10	-0.10	of heavy miner-
SAMPLE NO.	PERCENTAGE BY WEIGHT OF HEAVIES				als in sample.
A13	0.64	1.21	1.67	2.16	0.73
Y88	0.44	0.94	1.49	2.31	0.56
P20	0.21	0.66	1.00	2.50	0.33
P28	0.87	1.35	1.48	1.91	0.93
P29	0.16	0.86	1.49	2.64	0.25
P30	0.28	0.41	0.58	1.84	0.37
P5	1.84	3.47	3.56	5.19	1.99
T7	0.87	0.76	0.95	2.18	0.89

In all the samples except one, P5, the total heavy mineral content is less than 1%, and in all samples the heavy minerals are concentrated in the -150 grade. The heavy minerals separated from the sands of the Simpson Desert by Carroll (1941) have a similar concentration to those from the Canning Basin in the finer grades, which were the only ones separated by Carroll.

It is generally stated that the concentration of heavy minerals is greatest in the grade which is one less than the grade containing the largest quantity of material. This is apparently true for sands of aqueous origin, but for the dune sands tabulated above, the greatest concentration of heavy minerals is in the very finest fraction. This is probably due to the different carrying powers of water and air, wind being able to carry only much lighter, and therefore smaller, grains than water.

THE HEAVY MINERALS.

The results of the heavy mineral analysis are tabulated in Table 4. A considerable variety of minerals occurs in the sands; some are of restricted, others of wider occurrence. The most common non-opaque minerals have been divided into euhedral and rounded forms, euhedral referring only to grains with definite unabraded crystal faces (see plate 1). This classification was tabulated (Table 4) for the zircons and tourmalines, and was recorded but not tabulated for the other minerals.

ZIRCON

Several different types of zircon are easily differentiated. The three types classified in Table 4 are white, brown, and pink zircon, and these are divided into euhedral and rounded forms.

The white zircon is the common colourless type, and shows several variations which were not tabulated as the differing types were widely distributed. Many of the zircons are zoned, some showing only one zone, others having several well-defined zones. A few have a rounded or corroded core. Many of the nearly spherical grains completely lack inclusions, presumably because the zircons were derived from original grains which lacked inclusions, and which have undergone a great deal of transport. Some clear euhedral zircons were found. However, the clear zircons could also result from the fracturing of the grains across inclusions, which could be points of weakness, thus effectively eliminating the inclusions when the grains are worn due to transport. In either case the grains have undergone long periods of transport for them to have reached such a high degree of roundness.

The brown zircons are a deep orange-brown, and consist of a large number of zones. Almost all of these zircons are crowded with dark inclusions.

The pink zircons are a very pale pink, and water clear, with few inclusions. Pink zircons are not as common as the other types.

TOURMALINE.

Several well-differentiated types of tourmaline were recognised. The pleochroic schemes of the various types are given below.

DESCRIPTION	ϵ	ω
GREEN	dark green	pale yellow
BLUE	dark blue	pink
BROWN	dark brown	yellow
PINK	pale pink	colourless

One or two other types occur in single grains, and were not recorded.

The tourmaline ranges from rounded to euhedral (Table 4). The green and blue varieties are the most common. Many of the grains of green tourmaline are well rounded, and some are spherical. Several show large inclusions of rutile needles which almost fill the grain.

The coating of iron oxide on the tourmaline is thin and discontinuous. Some of the tourmaline grains are strongly zoned both from the inside towards the outer edges, and from end to end, especially in the euhedral blue and brown varieties. Euhedral crystals generally have double terminations.

TABLE 4 - HEAVY MINERALS IN THE CANNING BASIN

	Euhedral white zircon	Euhedral brown zircon	Euhedral pink zircon	Rounded white zircon	Rounded brown zircon	Rounded pink zircon	Euhedral green tourmaline	Euhedral blue tourmaline	Euhedral brown tourmaline	Rounded green tourmaline	Rounded blue tourmaline	Rounded brown tourmaline	Pink tourmaline	Kyanite	Andalusite	Staurolite	Sillimanite	Green Hornblende	Brown Hornblende	Garnet	Epidote	Spinel	Biotite	Chlorite	Monazite	Hypersthene	Corundum	Apatite	Titanium Minerals	Opaques	Sphene
B12				x	x		x	x		x		x	x		x														x	x	
B15	x			x	x	x	x	x		x		x	x		x														x	x	
B26	x	x		x			x				x				x														x	x	
L10	x		x	x			x			x	x			x	x					x									x	x	
L12				x	x			x	x	x	x	x		x	x														x	x	
S5	x	x		x	x	x		x	x	x	x	x		x	x	x													x	x	
S7	x			x	x				x	x	x		x	x	x										x				x	x	
S15	x			x						x	x				x			x		x									x	x	
S51			x	x	x					x	x		x	x	x	x	x		x				x				x		x	x	
S73				x						x	x				x														x	x	
S78		x		x		x	x			x	x				x				x						x				x	x	
S80				x	x			x		x		x			x														x	x	
S84				x	x	x	x			x	x				x														x	x	
S91				x	x				x	x	x				x					x									x	x	
S93	x			x	x		x			x	x	x		x	x			x									x		x	x	
R111				x	x		x			x	x			x		x				x									x	x	
C9		x		x		x	x			x	x		x	x				x											x	x	
C10				x	x	x	x		x	x	x				x									x		x			x	x	
C20	x			x	x				x	x	x				x			x		x						x		x	x	x	
C25				x	x		x	x		x		x				x				x									x	x	
C26	x	x		x	x		x				x	x		x	x	x				x			x						x	x	
C27	x	x		x		x	x			x	x				x	x			x										x	x	
C37	x	x	x	x				x		x	x				x										x				x	x	
C48	x		x	x	x					x	x	x		x	x					x							x		x	x	
M1	x			x						x	x	x																	x	x	
M4	x				x		x		x	x	x			x	x	x					x								x	x	
M21	x	x	x	x			x	x		x	x		x	x	x				x	x	x					x			x	x	
M24	x		x	x	x		x			x	x		x		x				x						x				x	x	x
M27	x		x	x	x	x				x	x				x				x	x									x	x	
M28	x		x	x		x	x			x	x		x		x				x										x	x	
M31	x	x		x					x		x	x		x	x				x	x									x	x	
M46		x		x	x			x	x	x	x	x		x	x									x					x	x	
M54	x		x	x		x	x		x	x	x			x	x	x			x	x									x	x	
M15				x		x		x	x	x	x	x		x	x		x	x	x	x				x					x	x	
M19		x		x			x			x	x	x		x	x	x		x		x									x	x	
Ru23			x	x		x	x							x		x													x	x	
Ru25		x		x						x	x	x				x					x								x	x	
Ru29				x						x					x			x											x	x	
T7a	x	x		x	x						x		x	x	x			x						x					x	x	
T8				x	x					x	x	x		x	x			x		x									x	x	
T18				x	x			x			x	x		x				x											x	x	
Rn3	x			x	x					x	x			x															x	x	
Rn6				x	x	x				x	x	x			x														x	x	
Rn27				x	x					x	x	x		x	x	x				x									x	x	
Rn30	x	x		x			x		x	x				x	x	x			x										x	x	
Rn36	x			x	x					x		x		x	x	x				x									x	x	
Rn41	x	x		x				x	x	x		x		x	x			x											x	x	
Rn64	x			x	x		x			x	x	x		x	x	x				x									x	x	
P5	x	x		x	x			x		x	x	x		x	x	x		x											x	x	
P20	x	x		x						x			x	x	x	x		x			x	x	x	x					x	x	x
P28	x	x		x							x		x		x	x				x									x	x	x
P29	x	x		x							x							x	x										x	x	
P30	x			x						x	x					x		x			x			x					x	x	
[illegible]13				x	x	x				x		x		x	x					x	x								x	x	
Y88	x	x		x			x					x	x	x							x		x						x	x	

KYANITE.

Kyanite generally occurs in euhedral grains or rounded laths, and shows good cleavages which are further emphasised by the appearance of iron oxides along them. The coating of iron oxide on this mineral is much heavier than that on the zircons or the tourmaline, but is still insufficient to mask the identity of the mineral.

ANDALUSITE, STAUROLITE, SILLIMANITE.

These three minerals are fairly common throughout the area, although sillimanite is rarer than the other two. They were differentiated on optic sign, 2V, extinction angle, and birefringence. They occur as euhedral and rounded grains, the rounded grains having a much heavier coating of iron oxides than the euhedral types. The coat of oxides covers the surface of the grains, with local thick patches.

HORNBLENDE.

Both green and brown hornblende occur, as rounded laths or spherical grains. The coating of iron oxide on this mineral is generally heavy, and fills the cleavage planes.

GARNET.

The garnet in these sands is commonly angular, but the edges of some are slightly rounded. It is pale pink, and except for bubbles, generally lacks inclusions.

TITANIUM MINERALS.

The titanium minerals include red to red-orange rutile, and a biaxial, yellow titanium mineral, possibly brookite or pseudobrookite. They occur in every sample as both euhedral and rounded forms. The rutile grains are often well rounded, and were probably derived from sediments.

BLACK IRON ORES.

The black iron ores occur in all samples, and include magnetite (extracted with a hand magnet), hematite, and ilmenite, together with its alteration product leucoxene. The leucoxene occurs on the surface of the ilmenite, and also as small white grains of irregular outline in some samples.

Limonite was found as well-rounded brown grains (reflected light) in all samples, and also as irregular grains in some samples.

ORIENTED CLAY SKINS.

Oriented clay skins surrounding heavy minerals were found in several samples. The clay surrounds iron ores, rutile and zircon. An illustration is given of an oriented clay skin around a euhedral zircon in transmitted light (Fig. 9a), and polarised light (Fig. 9b), and around an opaque core (Fig. 9c). Under polarised light, the clay skin gives 'isogyres' owing to the orientation of the clay minerals. The clay skins were not noticed in the light fraction.

The clay grains are well rounded and were therefore probably transported. Materials required to form the clay skins are not available in the sand dunes; the clay skins could possibly have formed in the clay pans which are common in the area. R. Brewer (C.S.I.R.O., personal communication) suggests that these clay grains, being very resistant, could have been transported into the area from outside.

PLATE 1.

Heavy minerals from the -150 grade of sample P30. Note the euhedral zircon in the centre of the field (A), the typical brown zircon (B), and the green tourmaline (C), The opaque grains are magnetite, ilmenite, leucoxene, hematite and limonite.

EVIDENCE FROM THE HEAVY MINERALS.

The heavy mineral zones are shown in Fig. 10. Three well-defined zones can be recognised: the garnet zone, the green hornblende zone, and the brown hornblende zone. All the zones are elongated in a north-westerly direction. This elongation

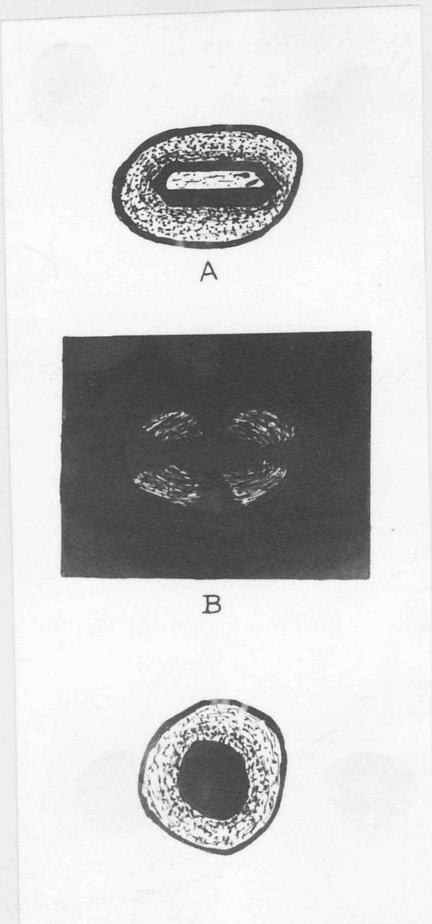


FIG. 9. Oriented clay skins about heavy minerals.

A. Clay skin sorrounding a euhedral zircon, ordinary light.

B. Clay skin in A, polarised light, showing 'isogyres'.

C. Clay skin surrounding an opaque core, ordinary light.

partly refers to the distribution of the samples, but an examination of the maps (Fig. 10) reveals an area of points in which these minerals do not occur on either side of the zones. The brown hornblende zone was probably deposited by water entering the internal drainage area of the Gregory Salt Lakes by rivers running in from the north. These watercourses run only after heavy rain, and lose themselves in the salt lakes and sand. The brown hornblende could possibly have its origin in the Cambrian volcanic rocks to the north, from which it has been recorded by Edwards and Clarke (1940).

The distribution of the heavy mineral zones shows that sand has moved from a source along the southern and eastern margins towards the north-west. However, it must be remembered that the dunes are now effectively fixed by the plant cover, and that little or no movement of the sand can take place, except perhaps along the crests for short distances. Therefore the sand in the dunes is probably reworked sand from dunes formed in a more arid time, with residual sand which has not moved far from its point of origin. A more arid climate is presumably necessary to account for a decrease in the density of the plant cover to allow free movement of the sand. Further work, including an analysis of the sediments of the Basin, would probably show that the coarser sand is residual and the finer sand is transported.

Features seen in aerial photographs indicate that the dunes have at some time migrated, and may at the present time be moving, although very slowly. The greatest influence on the formation of the dunes is, however, not the present wind pattern, but a wind pattern of of a previous and more arid climate.

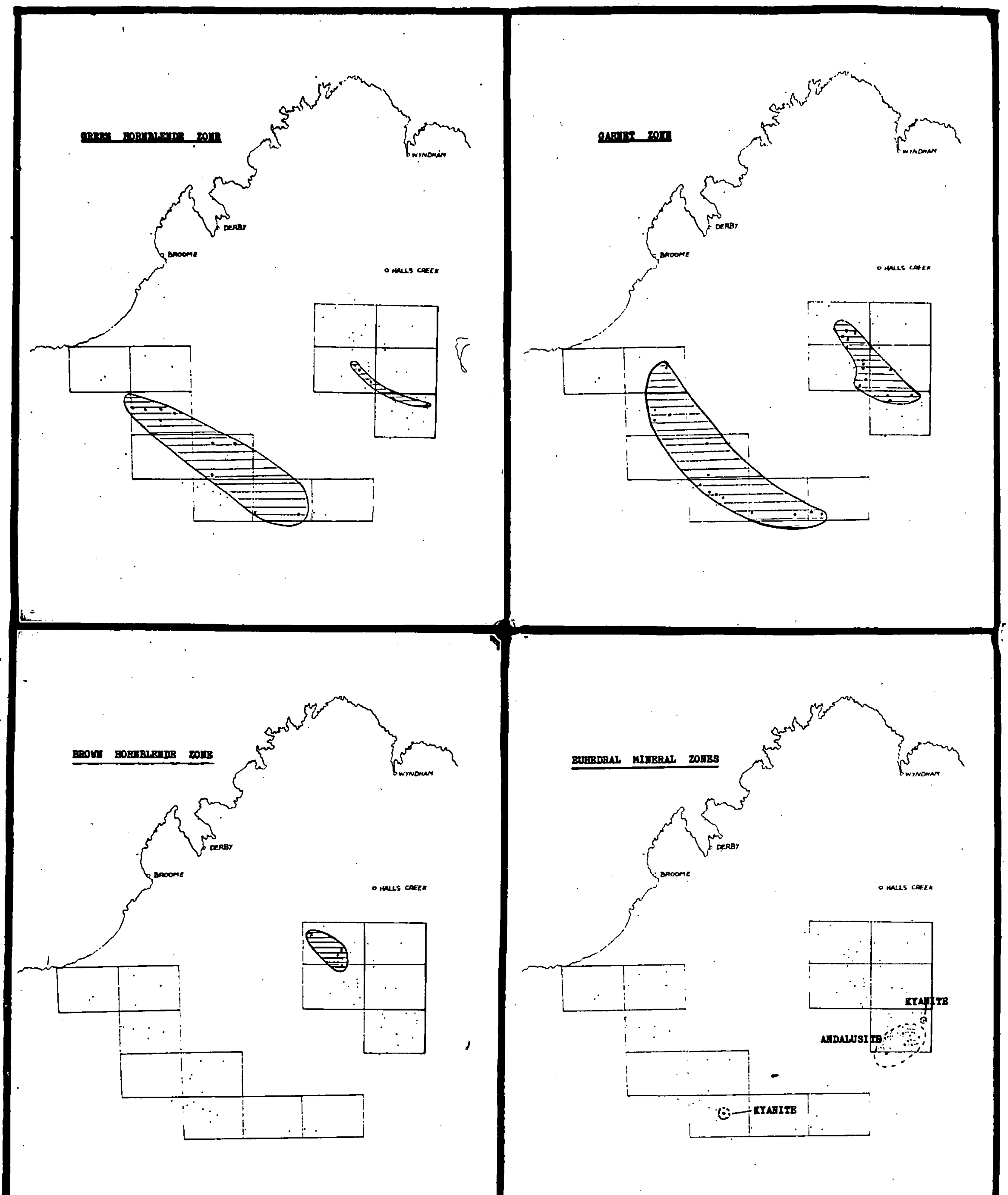


FIG. 10. Heavy mineral zones in the Canning Basin dune sands.

This wind pattern apparently agrees with the present pattern (Fig. 11), although data on the present day winds of the area are scanty.

According to Bagnold, seif dunes are formed in areas where expanses of free, unfixed sand is subject to a bidirectional wind regime. The major wind, that is, that blowing for the greater part of the year, is a relatively steady wind to which the major axes of the dunes are parallel. The sand in the dunes becomes stable to this wind, and is not moved to any extent by it. The second wind is a cross wind, and it is this which moves the sand and forms it into dunes. If this wind lasts for very long, the sand grains eventually become more or less stable to it, and when the major wind of the area resumes, the grains are moved by saltation along the dune. In this way the dunes move in the direction of their major axes, and 'march' across country at right angles to their length.

Examination of the dune directions, and the distribution of the heavy minerals, shows that a wind blowing from the east, with a subordinate wind from the south-east, would move the sand grains in the direction of the dunes, and spread the minerals from the Precambrian in a northerly direction. Winds roughly parallel to these still persist outside the area (Fig. 11), and extrapolation of the wind directions at Giles and Hall's Creek parallels the dune directions.

The sand from the Canning Basin is considered to be derived mainly from the rocks of the Basin underlaying the dunes because:

1. The sand samples overlying the sediments have less variety of heavy minerals than those overlying or close to the Precambrian rocks.

2. Well-rounded tourmalines crowded with rutile needles, and well-rounded zircons without inclusions are more common in the interior of the Basin than around the edges. The roundness of these mineral grains suggests derivation from pre-existing sediments.

3. If these rounded grains had been blown into the Basin from outside, they should be more common in the sands overlying the Precambrian around the margins. This would be especially true of the tourmaline, which is more easily destroyed than zircon, but the rutile tourmaline is scarce around the margins of the Basin.

CHARACTERISTICS OF THE LIGHT FRACTION.

A series of analyses of roundness, sphericity, and surface texture of randomly selected samples was conducted on the light fraction. Statistical tests were then carried out on the results to determine what significance, if any, these had in relation to the whole series.

It was discovered, using Student's 't' test, that a significant difference ($P = 0.001$) in the roundness of various samples could be detected by an analysis of only ten grains from each grade of each sample.

An insignificant result ($P = 0.05$) was obtained from an analysis of the sphericity results. As it was not proved statistically that the sphericity would show any difference in sand from different parts of the Basin, this part of the analysis was deleted.

The number of counts in each grade was reduced to ten, and only roundness and surface texture were determined.

Visual methods were used for determining roundness and sphericity, the charts being those of Rittenhouse (1943) for sphericity, and Krumbein (1941) for roundness. The results of the roundness determinations are given in Table 5.

The determination of roundness has long been a difficult task, and the solution to the problem has not yet been found. The chart of Krumbein is a useful tool for comparison of one sand with another, but as it only measures the projection roundness of the largest face, it is not a true measure in itself.

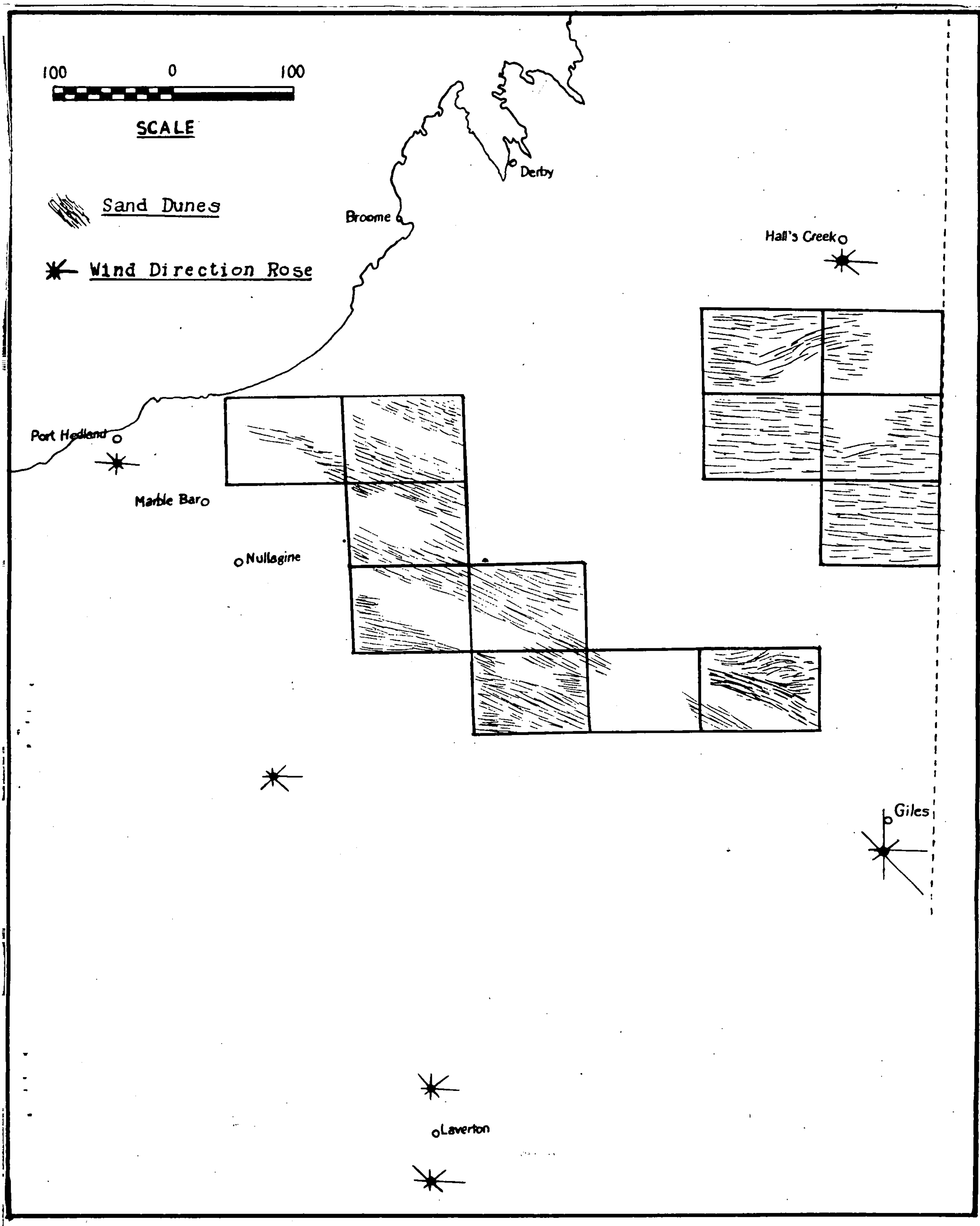


FIG. 11. Present-day dune directions in the Canning Basin. The wind roses give the directions and relative wind velocities about the Basin. They are not to scale. No wind information is available from within the Basin.

It was employed as the fastest and most convenient method available.

A map showing arithmetic mean roundness is given in Fig. 12. Roundness was determined to attempt an estimation of the rate of rounding of sand grains in an arid environment. The distribution of the roundness values does not give any indication of this, and no explanation is forwarded for the distribution as revealed in Fig. 12. The contours follow the general trend of the heavy mineral distributions, but why the roundness values should arrange themselves so that the roundest grains appear in the centre of the contours, and the most angular grains on the outside is not known. The number of points distributed over such a large area do not perhaps give an accurate enough picture of the distribution from which to draw any conclusions.

SURFACE TEXTURE.

No variation in the surface texture of the grains was noticed over the whole area. The surface was either frosted on the larger grains, or pitted on the very finest grains. No polished or broken surfaces were seen.

The roundness and surface texture of the quartz grains indicate transport by wind. No indication of the source of the sand can be found from these analyses.

CONCLUSIONS.

The sand dunes of the Canning Basin were probably formed during a much more arid climate than that at present. The sand was derived partly from the rocks forming the floor of the Basin, and partly from wind-blown sand which probably came from the rocks surrounding the Basin. The composite origin is revealed by differences in the coarse and the fine grades detected in the mechanical analysis. The coarse fraction has probably not moved far from its source.

To make these ideas more conclusive, a study of some samples from the central portion of the desert would be helpful, as well as a study of the heavy minerals of both the sedimentary Basin and the surrounding Precambrian areas.

ACKNOWLEDGEMENTS.

The author wishes to thank the Bureau of Mineral Resources for making this work possible as part of an M.Sc. thesis for the University of Melbourne, and to the many officers of the Bureau for valuable help and advice. Thanks are especially due to Dr. J.J. Veevers for help and constructive criticism throughout, and to Mr. J.N. Casey for suggesting the investigation.

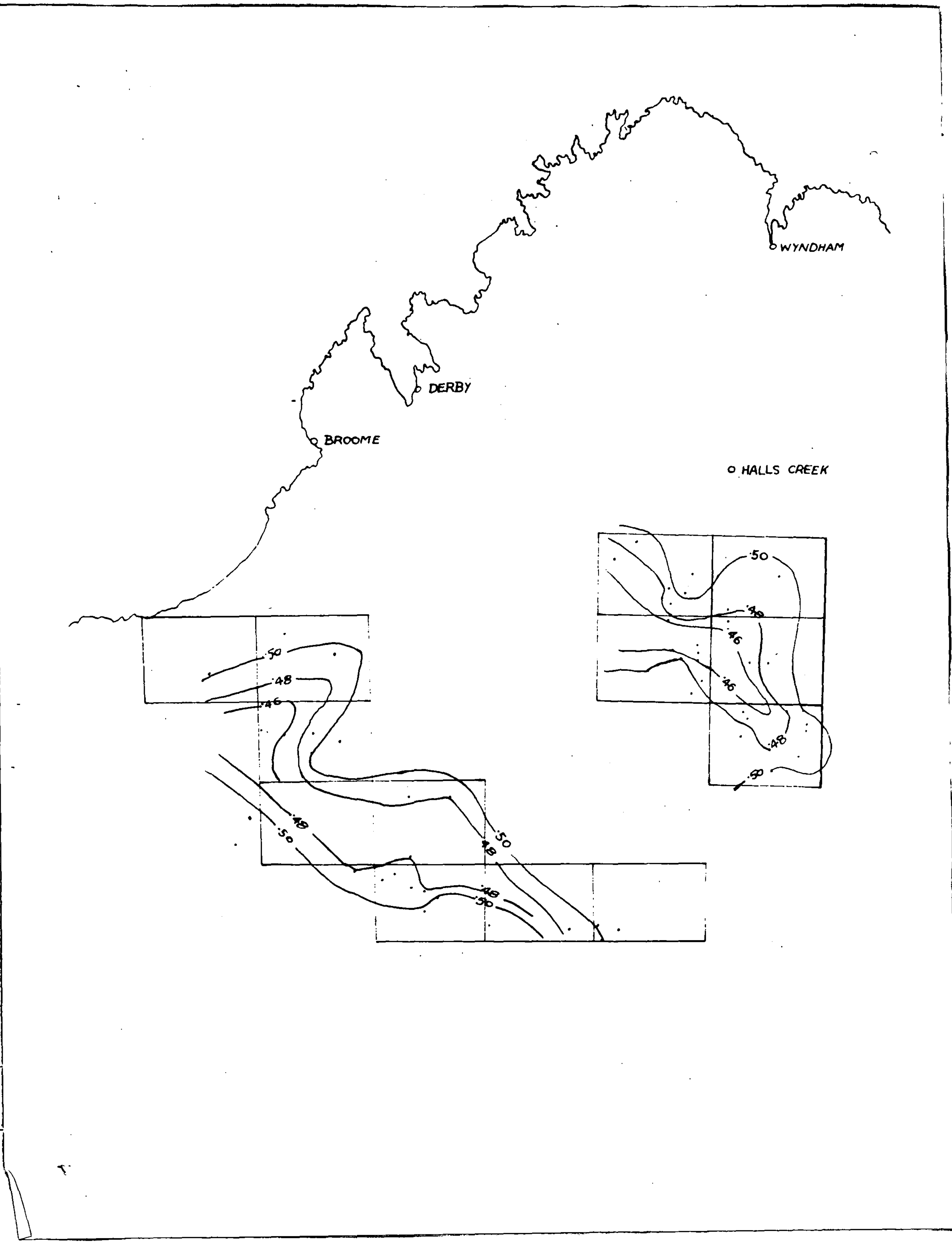


FIG. 12. Map of arithmetic mean roundness. Only a few points do not fit the contours, which are a roundness value of 0.02 apart.

TABLE 5.

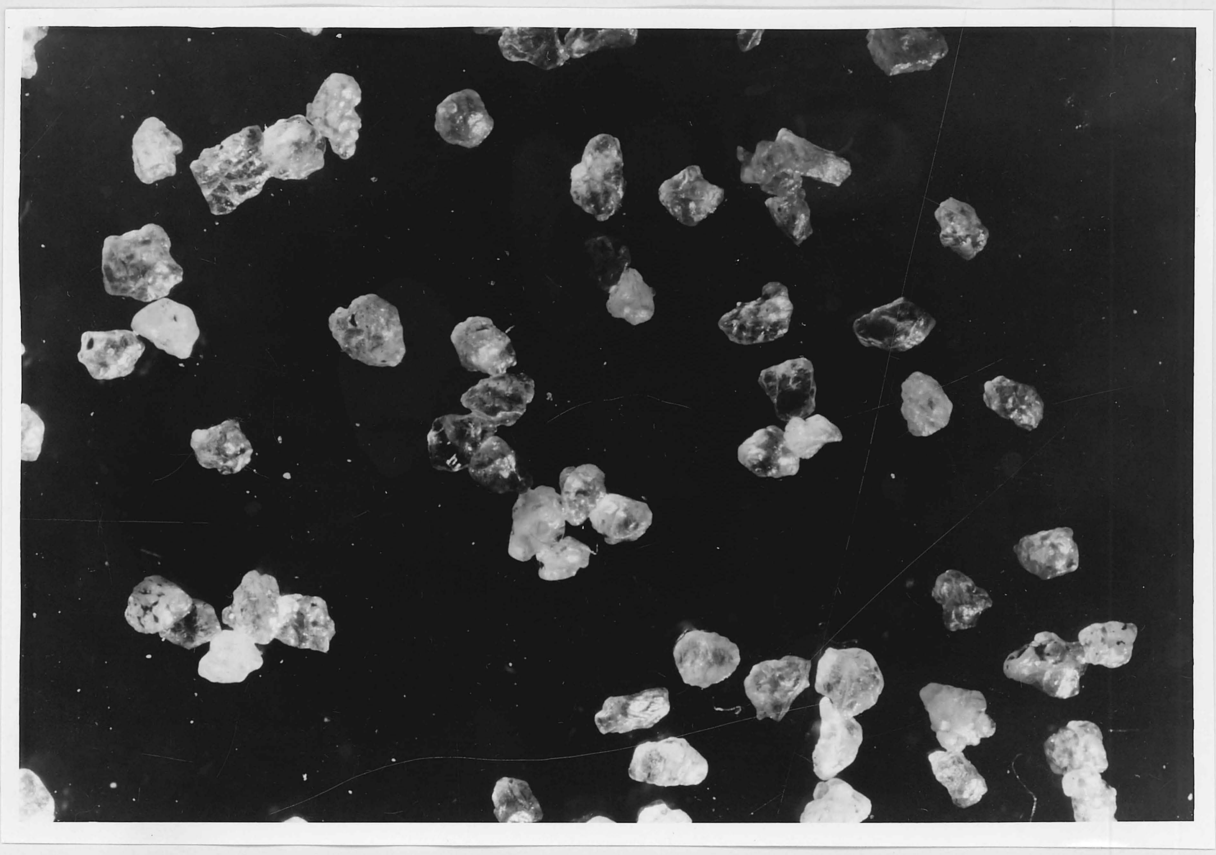
No.	16	36	52	72	150	200	-200	Av.
B12	-	.49	.52	.55	.49	.38	.50	.49
B15	-	.49	.55	.52	.54	.52	.51	.52
B26	-	.48	.49	.50	.47	.50	.50	.49
L1	-	.49	.55	.52	.54	.52	.51	.52
L10	-	.51	.46	.53	.46	.43	.46	.47
L12	-	.50	.49	.51	.49	.48	.50	.49
S5	-	.50	.48	.51	.55	.51	.42	.49
S7	-	.47	.48	.51	.48	.46	.51	.48
S14	-	.51	.52	.59	.50	.51	.43	.51
S15	-	.50	.48	.50	.47	.42	.43	.47
S51	-	.50	.48	.50	.51	.45	.51	.49
S73	-	.53	.52	.51	.49	.47	.47	.50
S78	-	.51	.50	.51	.50	.48	.51	.50
S80	-	.48	.47	.52	.52	.46	.50	.44
S84	-	.45	.50	.49	.50	.48	.50	.49
S91	-	.54	.51	.55	.44	.39	.42	.48
S93	-	.51	.56	.51	.47	.49	.52	.51
Ryll	-	.54	.51	.41	.47	.43	.50	.48
C9	-	.49	.46	.46	.50	.42	.46	.46
C10	-	?	.53	.49	.50	.41	.45	.48
C20	-	.52	.55	.54	.50	.50	.56	.53
C25	-	.47	.50	.45	.47	.53	.44	.46
C26	.44	.50	.50	.46	.46	.46	.47	.47
C27	-	.48	.51	.49	.45	.45	.51	.48
C37	-	.48	.46	.48	.51	.46	.51	.48
C48	-	.48	.46	.46	.53	.51	.46	.49
M1	-	.48	.50	.50	.45	.52	.53	.50
M4	-	.49	.49	.49	.48	.46	.48	.51
M21	-	?	.50	.49	.51	.43	.46	.48
M24	-	.50	.55	.45	.47	.45	.49	.48
M27	-	.50	.51	.48	.51	.45	.50	.49
M28	-	.48	.42	.49	.52	.43	.44	.46
M31	-	.53	.55	.51	.48	.50	.51	.51
M46	-	.53	.52	.54	.47	.48	.41	.49

TABLE 5 (cont.)

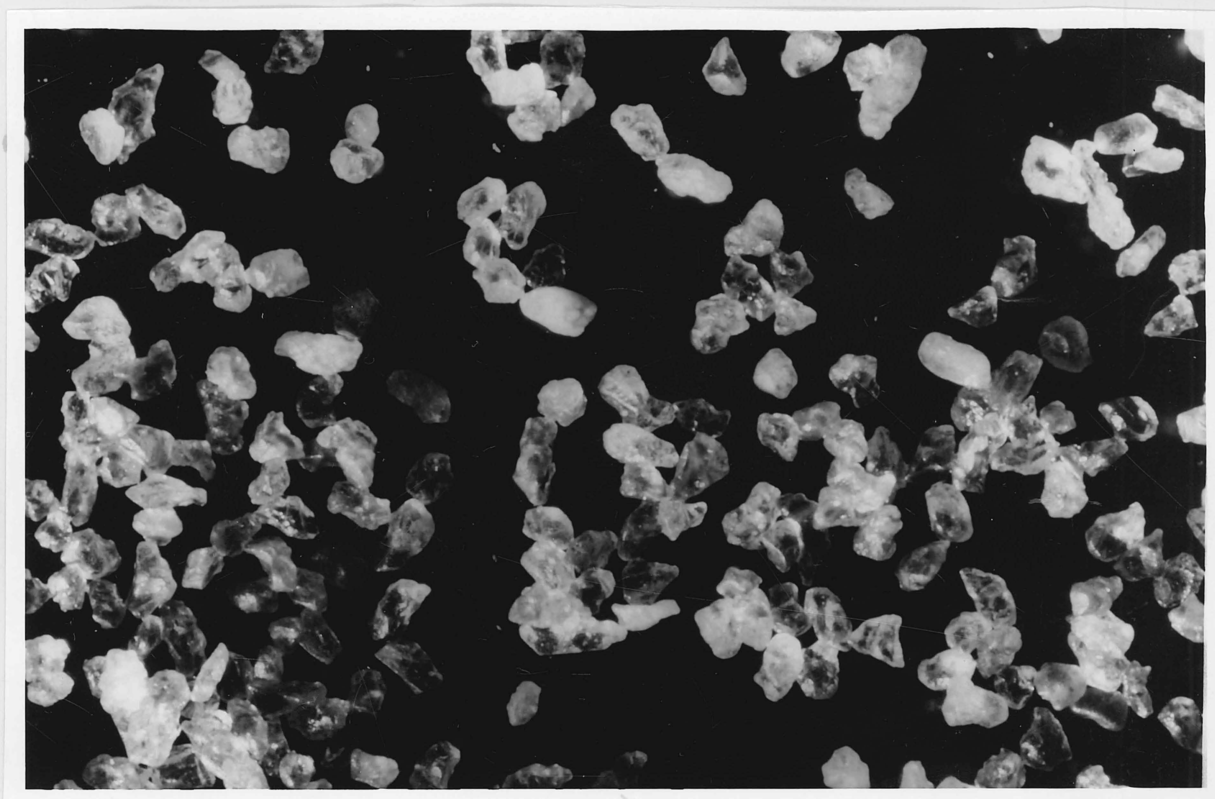
No.	16	36	52	72	150	200	-200	Av.
M54	-	.49	.51	.49	.47	.46	.40	.47
M15	-	.49	.50	.53	.45	.48	.47	.49
M19	-	.50	.51	.49	.50	.51	.53	.51
Ru23	-	.50	.47	.50	.44	.47	.49	.48
Ru25	-	.59	.53	.51	.51	.45	.51	.52
Ru29	-	.59	.53	.52	.50	.44	.46	.51
T7a	-	.51	.51	.49	.54	.49	.37	.48
T8	-	.52	.50	.51	.45	.46	.49	.49
T18	-	.50	.48	.50	.48	.47	.48	.48
Rn3	-	.49	.52	.50	.48	.43	.51	.49
Rn6	-	.53	.54	.48	.52	.44	.46	.51
Rn27	-	.51	.52	.50	.49	.42	.47	.48
Rn30	-	.48	.51	.50	.52	?	.51	.50
Rn36	-	.49	.49	.50	.50	.50	.56	.51
Rn41	-	.51	.51	.50	.51	.51	.52	.50
Rn64	-	.50	.49	.51	.52	.46	.49	.49
P5	-	.52	.58	.53	.45	.43	.45	.50
P20	-	.51	.53	.55	.52	.49	.49	.51
P28	-	.49	.50	.55	.51	.47	.47	.50
P29	-	.43	.47	.46	.47	.49	.47	.46
P30	-	.42	.48	.48	.46	.49	.46	.45
A13	-	.51	.50	.59	.50	.45	.39	.49
Y88	-	.52	.50	.51	.50	.49	.49	.50

TABLE 5. Table showing the mean reondness of each grade of each sample. The final column shows the arithmetic mean roundness for the sample.

PLATE 2.



A x20.



B x60

Quartz grains from the -36 (A) and the -150 (B) grades, sample S84.

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APPENDIX I

THE CENTRIFUGE METHOD OF HEAVY MINERAL EXTRACTION.

The procedure for the extraction of the heavy minerals was as follows:-

A standard quantity of sand sample (about one gram) was taken in every case and placed in a centrifuge tube. A standard volume of bromoform was added. The samples were then centrifuged for two or three minutes at about 1,000 r.p.m. After centrifuging, the heavy minerals are cleanly separated from the light fraction by about a half-inch of liquid. The base of the tube was then placed in dry ice (solid CO_2). The bromoform containing the heavies is frozen almost immediately, the freezing point of bromoform being 6^{o}-7^{o}C. The light fraction and liquid bromoform were then tipped into a sintered glass crucible over an evacuated flask. The filtering is immediate and clean. The crucible was transferred to another flask and the light fraction washed with alcohol. The heavy minerals have remained frozen into the centrifuge tube and can be removed when the bromoform thaws, a process which takes only a few minutes. They are filtered and washed as for the light fraction.

The advantages of this method are many; the main ones are given below.

1. There are no filter papers in use, which absorb and waste a considerable amount of bromoform.
2. Filtering is immediate and the sample is dry enough to be tipped out of the crucible when filtering is complete.
3. Almost all the bromoform is always ready for use and is not taken up filtering through filter papers.

The method is very much faster than usual methods and is also cleaner and safer, as all bromoform containers can be kept covered almost all the time. The method was first described by Matelski (1951) and has been modified by the use of dry ice, which is cleaner and faster than a normal freezing mixture.

APPENDIX II

SAND DUNE SAMPLES, 1954.

SPECIMEN NO.	DESCRIPTION	RUN/PHOTO NO.
YARRIE		
Y83		5179/R9
Y88		68/R10
ANKETELL		
A2		5069/R4
A13		5032/R6
PATERSON RANGE		
P5		5129/R7
P20	Sand dune near Granite o/c	
P28	Sand dune North West of Paterson Ra.	5209/R1cw
P29		07/R8
P30		03/R6
TABLETOP		
T7a		5104/R2

SAND DUNE SAMPLES, 1955.

Sheet	No.		Photo/No.
LUCAS			
	L10	Dune 20' high	12/5177
	L12	Dune 30-40' high	10/5087
BILLILUNA			
	B12	Dune 30' high	8/5099
	B15	Dune 15' high	4/5160
	B26	Dune 15' high	15/5176
MT. BANNERMAN			
	M1		9/5127
	M4		8/5108
	M21		11/5069
	M24		
	M27		15/5019
	M28		Cornish 1/5068
	M31	Dune 10' high	13/5157
	M46	Dune 5-10' high	1A/5034
	M54	Dune 20' high	
CORNISH			
	C9		7/5162
	C10		
	C20		11/5048
	C25		8/5100

Sheet	No.	Photo/No.
	C26 interdune sample near rock o/c	7/5159
	C27	7/5159
	C37 Dune 10' high	10/5022
	C41 Top of wide 15-20' dune	12/5062
	C48	15A/5045
STANSMORE		
	S5	6A/5172
	S7	8/5137
	S14 Dune 55-60' high	2A/5121
	S15 Dune 40' high	1/5096

SAND DUNE SAMPLES, 1956.

SPECIMEN NO.	DESCRIPTION	RUN/PHOTO NO.
RUDALL		
Ru23		15/5153
Ru25		
Ru29	7.6 miles west of Ru28	11 W-C/5145
RUNTON		
Rn3	Well 22	
Rn6	45' dune	1/5006
Rn27	¾ mile south of breakaways	3/5034
Rn30	40' dune	4/5021
Rn36	20' dune	11/5041
Rn41	110' dune	7/5161
Rn64		
TABLETOP		
T8	50' dune	15/5140
T18	35' dune	13A W-C/5196
MORRIS		
M3	End of 30' dune, not highest point but on crest	15/5120
M15	Small dune	13/5173
M19		13/5165
RYAN		
Ry11	25' dune	14/5019
STANSMORE		
S51		
S73		
S78		
S80		9A/5009
S84	25' dune Highland Rocks	3/5039
S91		3/5129
S93		1/5117

APPENDIX III.

RECOMMENDED SAMPLING PROCEDURE.

It is recommended that future sampling of sand dunes in Australia should be carried out with an eye to the problems discussed in this report.

The following recommendations are made:-

1. That, if possible, a planned sampling programme be embarked upon.

2. All samples should be collected by one operator, who should standardise a technique before sampling commences.

3. On the commencement of sampling in a new area, a complete set of samples should be obtained from ONE typical dune. These samples should start in the interdune area and a number of samples (ten or twenty) should be collected all the way over the dune in a straight line from one interdune area to another. A few samples should be collected along the crest of the dune and one each from an open and a vegetated area, if any. Each sample should be the same size, collected by the same method, by the same person and from the same depth. If possible, the above samples should be supplemented by a number of samples from a vertical hole in the crest of the dune. These samples should be collected about every three inches for a few feet only, to determine the thickness of any layering in the dune.

4. Each sample collected should be accompanied by an ACCURATE description of its position on the dune.

5. Each sample from a single dune should consist of two separate samples collected from the interdune area (or the base of the dune) and the crest of the dune.

6. The height of the dune should be estimated and included in the description of the sample.

7. ALWAYS USE A CLEAN SAMPLE BAG FOR A SAND SAMPLE. Plastic bags are best if available. Avoid contamination at all costs - one foreign grain can be troublesome if detected.

If the above recommendations are carried out some estimate of the accuracy of the results can be made. The initial sampling of one dune is necessary to determine what conditions of sorting and layering within the dune apply and how much these affect the results of the analysis can then be determined.

In this way problems relating to present day deserts in Australia can be to some extent solved and accurate data accumulated which will help in the solving of problems connected with eolian deposits found in the geological column.