THE SIGNIFICANCE OF GRAIN-SIZE AND HEAVY MINERALS VOLUME PERCENTAGE AS INDICATORS OF ENVIRONMENTAL CHARACTER, GRAND BEACH, MANITOBA: A CASE STUDY.

A Thesis

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by

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ABSTRACT

Beach and aeolian deposits of Grand Beach, Lake Winnipeg are examined using grain-size and heavy mineral analyses to determine environmental characteristics. The raw data is then examined in more detail using Q-Mode factor analysis. The first approach is on the basis of their total textural composition using raw data in the form of 0.25Ø (phi) intervals from the basic sieve population. The second approach is on the basis of the volume percentage of heavy minerals in each sieve population.

The results are analysed by two methods: (1) the normalized factor components method proposed by Klovan (1966); and (2) the more commonly used factor scores technique.

As Bradley (1959) and Lockery (1971) suggest, the amount of heavy minerals appears to be valuable in characterizing depositional environments. Even though the grain-size distributions are not markedly different, the volume percent of heavy minerals does vary between aeolian and beach deposits. The cause appears to be related to the efficiency of the energy in relation to the 'hydraulic size' of the heavy mineral.

Of the techniques used, the combination of volume percent of heavy minerals analysed by factor analysis and plotted by factor scores, appears to give the best results in discriminating between aeolian and beach deposits in a low energy lacustrine environment.

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INTRODUCTION

Statement of the Problem

A continuing problem in sedimentology is the ability to discriminate between sedimentary environments on the basis of measurable sediment parameters. To be significant these parameters must be quantitative, not subject to diagenetic change, and applicable in both recent and ancient sediments (Miller and Olson, 1955). The objective of this study is to obtain a number of measured sediment parameters from a set of beach and aeolian samples. With the aid of the resulting quantitative measures it is hoped to show that the textural parameters of grain-size and volume percentage of heavy minerals can be used as a predictive model for depositional environment discrimination.

Friedman (1967, p.352) states that "... textural parameters permit separation of ..." "... sands of different origin." The predictive model presented will attempt to show that it can permit separation of sands of similar origin, and that mineralogy is a very sensitive indicator of sedimentary process, even in a low energy lacustrine environment.

Method of Study

Grand Beach was selected as the sample site on the grounds that both the dune and beach sands are locally derived. Provenance studies by Wallace and McCartney (1928) showed that Grand Beach recent sand

> "... differs from glacial sands only in that it contains much material derived from the Winnipeg Sandstone which outcrops in the vicinity of Grand Beach."

They further concluded, and Solohub (1967, p.48) confirms, that, "The beach is the only source for the aeolian sands." This eliminates from the study the argument that a different source material was responsible for environmental variations.

Sediment samples collected were sieved to determine the weight percentages of sediment in standard Phi (Ø) size classes. Each weight percent per sieve was then separated between light and heavy minerals to determine a ratio.

The resulting data was then used to determine the depositional environments by means of the Q-Mode factor analysis developed by Klovan (1966). A second Biomed Q-Mode factor analytic program was run to provide comparative results with the Klovan method.

Method of Presentation

There are three main parts to this study. The first part discusses the methodologies used in field and laboratory research. The second part examines the statistical method of analyzing the grain-size and heavy mineral data. The third part presents a comparison between the two methods of analyzing the output from the application of Q-Mode factor analysis. A discussion of the geologic significance of these results completes the presentation.

ACKNOWLEDGMENTS

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Chapter II

DESCRIPTION OF THE STUDY AREA

Lake Winnipeg is a large freshwater lake located in the Province of Manitoba, Canada. It lies at an altitude of 713 feet above sea level, between latitude 50° 20' and 53° 50' North, and longitude 96° 20' and 99° 15' West. It is 275 miles long and varies in width from 25 to 70 miles. It receives the surplus waters of Lakes Winnipegosis and Manitoba and drains by the Nelson River to the northeast into Hudson Bay. The principal rivers flowing into the lake are the Red River from the south; the Dauphin and Saskatchewan Rivers from the west; and the Winnipeg River from the east.

Despite the overall length of 275 miles, the lake is effectively viewed as two bodies of water. The separation occurs at a point called The Narrows. The southern section is approximately 55 miles long and 25 miles wide (Figure 2), with an average depth of 40 feet. It is this portion of the lake that concerns this study.

Due to its small size Lake Winnipeg is not affected by lunar or solar tidal forces. There are, however, water level fluctuations of several feet. These are caused by strong winds blowing in one direction over a period of time. Because of the orientation of the lake the greatest level fluctuations are created by either strong northerly or strong southerly winds. Peak daily wind velocities fro the southern region of the lake are shown in Table 1. It has been shown that there is a strong correlation between the fluctuating water level and the peak wind velocity, although there is usually a lag between the wind and the change in lake level (Einarsson and Lowe, 1968).

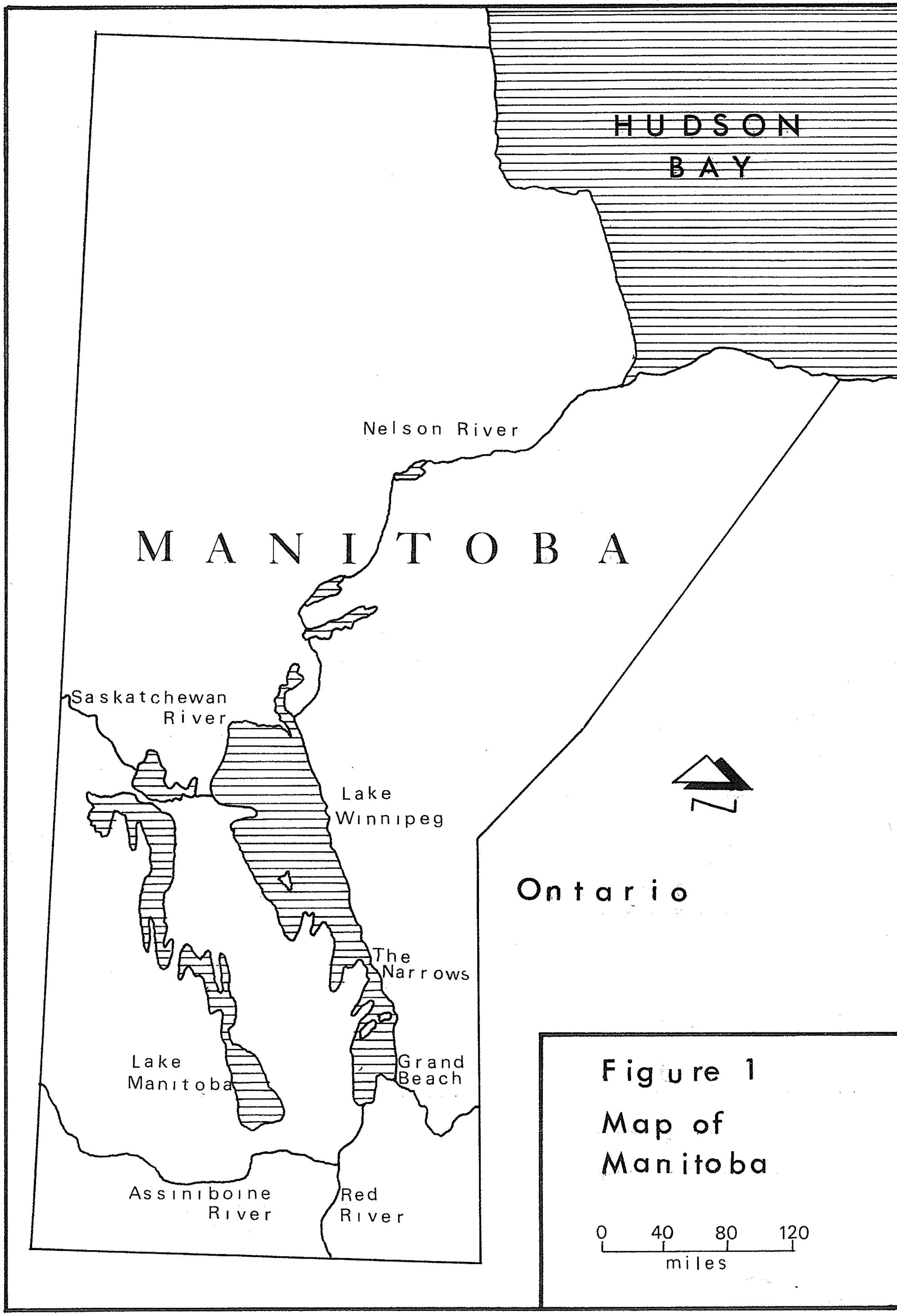

Figure 1
Map of Manitoba

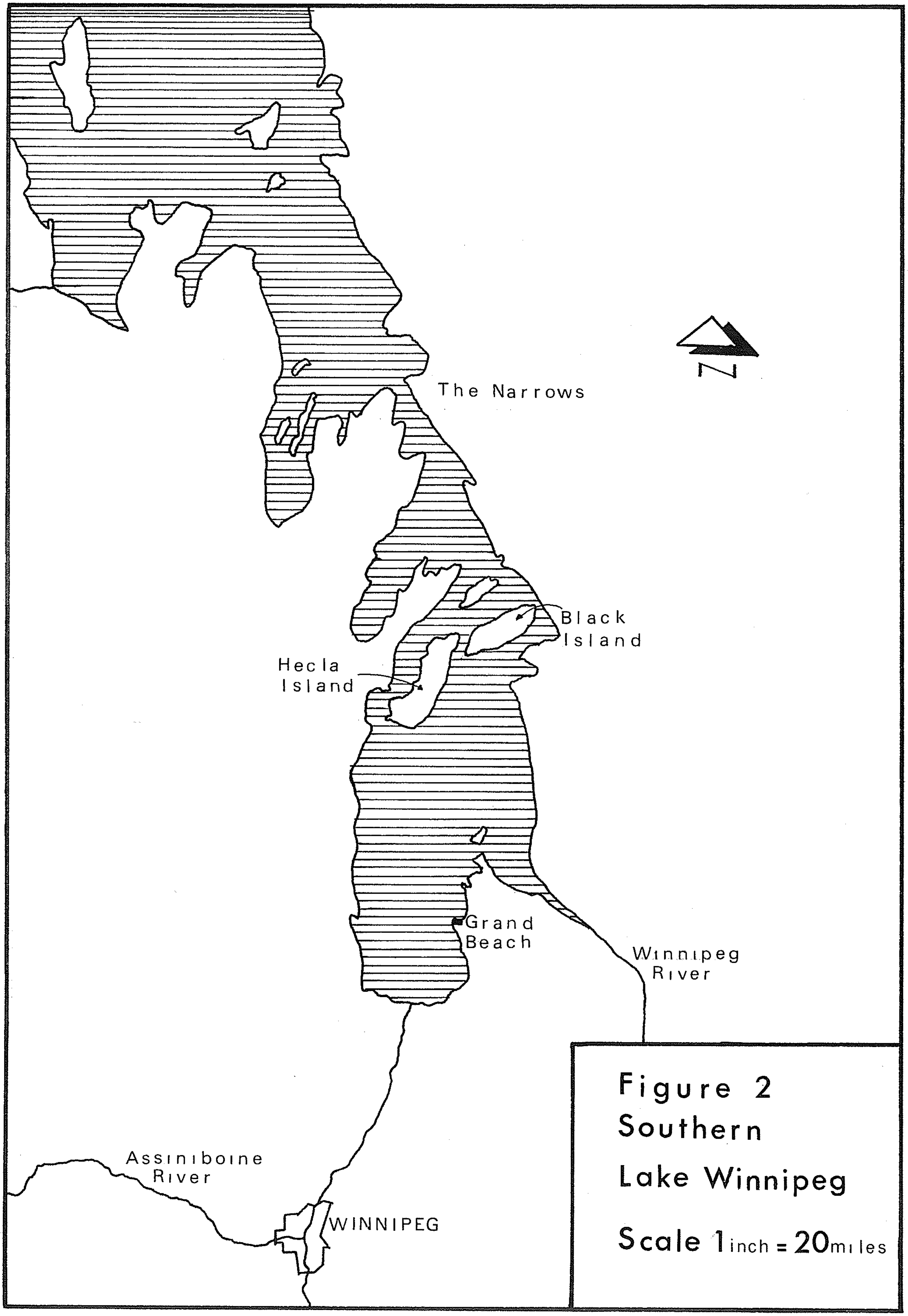

Figure 2
Southern
Lake Winnipeg

Scale 1 inch = 20 miles

Air Photograph of Grand Beach showing the study area.

An important element of the wind velocities at the study area is the period of time when they are effective. The lake, and also the foreshore of the beach, is frozen from the end of November to May. Therefore, any sorting or deposition of sediment occurs only in the remaining portion of the year. The aeolian deposits do not freeze but are covered by snow. Protection tends to be discriminatory, thus causing an overemphasis of the leeside. This occurs because the snow is drifted from the face of the dune and deposited in the lee. The result is an exposed dunal face and an over-lengthened lee drift. It was not determined what effect this has on the form or texture of the dune deposits. Observation of snow drifting, and sections dug through the lee side snow showed layers of clean snow separated by layers of drifted sand. Obviously these sand layers are deposited during snowmelt. Whether this results in 'abnormal' deposition was not established.

A second important aspect of the location of the study area is the relationship of the winds to the fetch. As King (1959) points out,

> The size of wind waves depends on three factors; these are the wind speed, the wind duration and the fetch. Anyone of the three can set a limit to the size of the waves.

From Figure 2, it can be seen that the maximum fetch for the Grand Beach area is approximately 50 miles in a northerly direction. The average fetch would appear to be approximately 30 miles. For the five months of the year when the beach is unfrozen the wind direction tends to be dominated by southerly and southwesterly winds. Table 1 shows that for the months of August, September and October, southerly winds either dominate or are at least equal to northerly winds. This has the effect of greatly reducing the average fetch. When this reduced figure

TABLE 1

PEAK DAILY WIND VELOCITIES. SUMMARY OF HOURLY WINDS AT GIMLI (1971)

Month	Frequency in Hours SE - SW	Frequency in Hours NE - NW	Maximum Hourly Speed	Highest Speed
January	104	313	29	41
February	140	218	28	42
March	174	274	34	43
April	224	260	26	39
May	146	316	30	48
June	139	269	28	41
July	190	263	22	35
August	292	188	26	39
September	226	240	30	45
October	209	248	21	33
November	220	246	28	42
December	233	240	23	35

Department of Transport Weather Records

for selected stations, 1971.

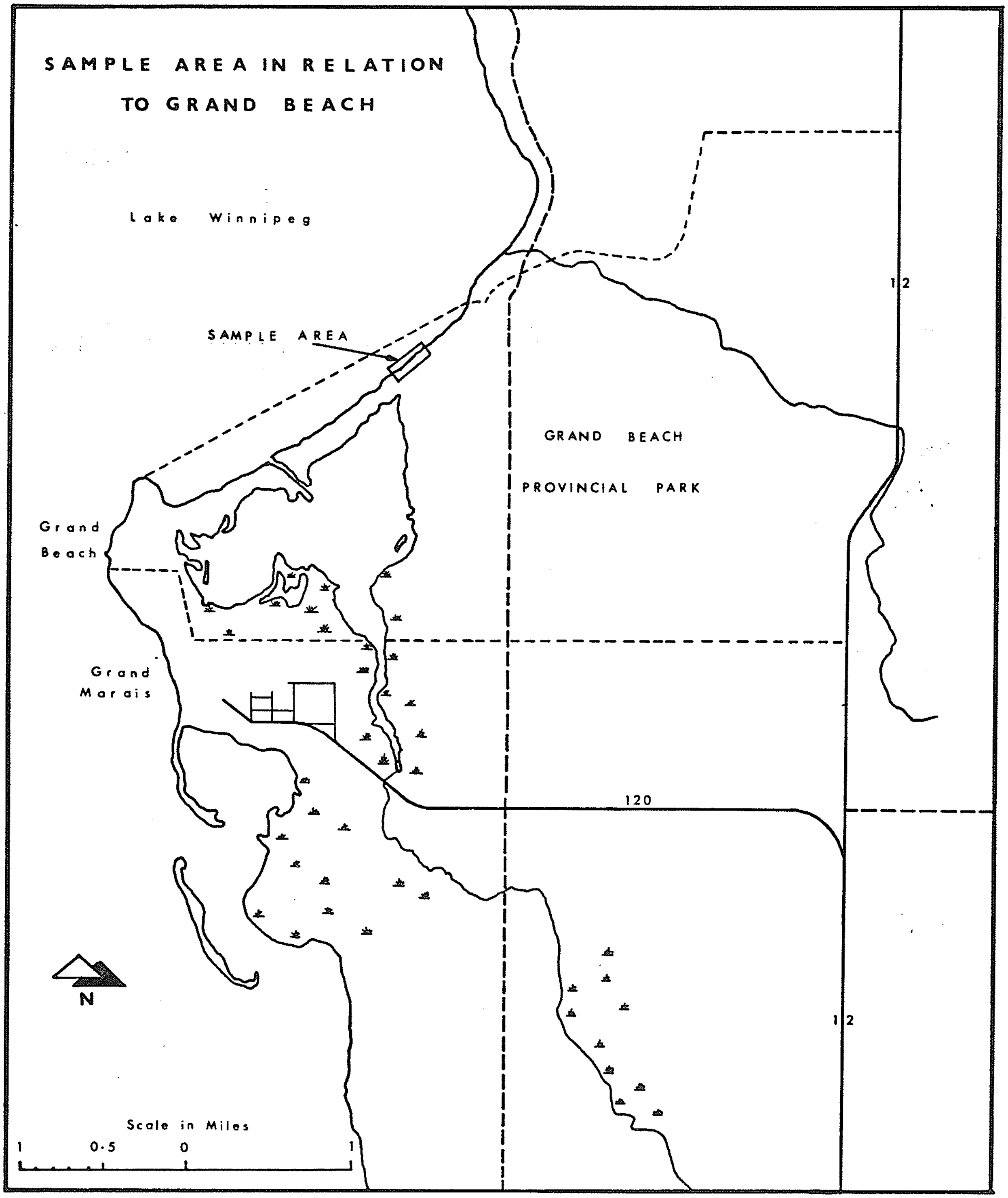
SAMPLE AREA IN RELATION
TO GRAND BEACH
Lake Winnipeg
SAMPLE AREA
GRAND BEACH
PROVINCIAL PARK
Grand
Beach
Grand
Marais
12
120
12
N
Scale in Miles
1 0.5 0 1

FIGURE 4

is viewed in conjunction with the highest wind speeds recorded, an indication of the wave height that can be generated is seen. Figure 4 shows that the average wave height is something less than 1 foot. If the mean wind speed is used, the figure is further reduced.

Regional Geology and Physiography

Southern Manitoba was subjected to continental glaciation during the Pleistocene epoch. The present surface forms are primarily the result of the Wisconsin ice advance and retreat. Glacial drift covers most of the eastern shore of Lake Winnipeg. The drift occurs over a bedrock of Paleozoic limestone and sandstone, which is rarely exposed. Most of the local topography is created by the drift which varies in thickness from 50 to 200 feet.

A major portion of the Grand Beach sand deposit is in the form of a bay-mouth bar enclosing a lagoon. The bar is a result of longshore transportation. The study area is located immediately northeast of the bar to ensure that the beach deposits were not a result of channel deposition. It also ensured that the aeolian deposits originated from the lakeside beach rather than from exposed lagoon deposits (Figure 3).

The beach averages approximately 40 feet wide at the sample area, ranging from 28 feet wide at the eastern end to 55 feet wide at the western end. There is a distinct berm visible, with a clearly defined foreshore and backshore.

The dunal zone varies in width over the entire length of the beach. In the study area it is approximately 200 feet wide. As with the beach, it decreases in width, from 400 feet in the west to 100 feet in the east. Rising abruptly from the backshore of the beach, the

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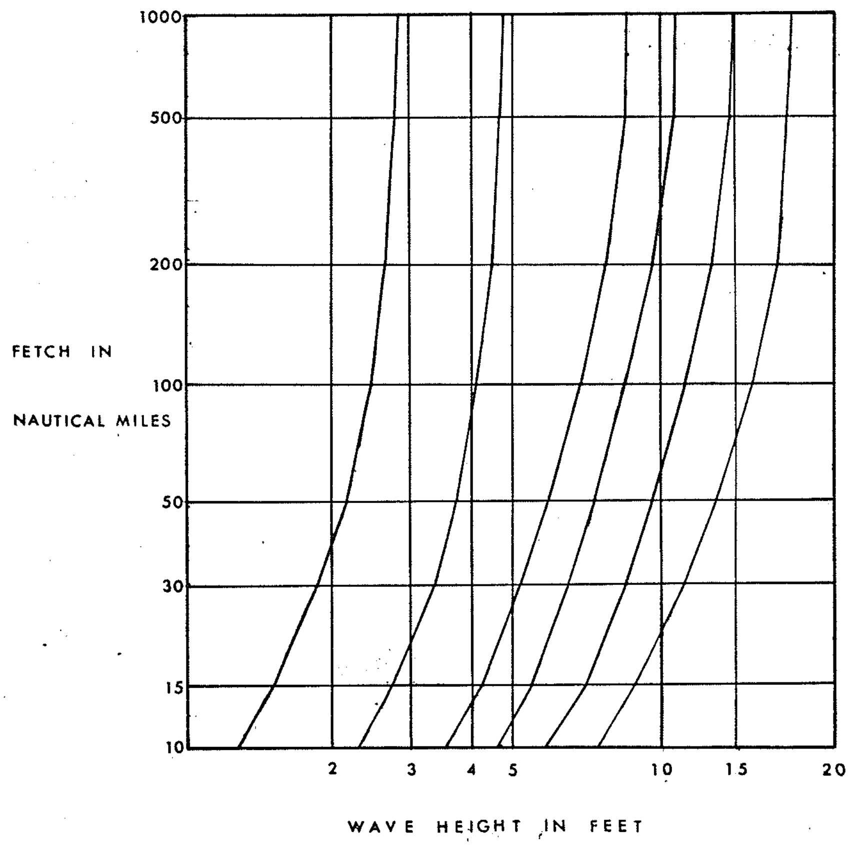
FIGURE 5



GRAPH OF FETCH TO WAVE HEIGHT

(After KING, 1959)

dunes average 20 feet in height and gradually decrease away from the beach. An intermittent vegetation cover of willows and low shrubs provide some stability to the dunes.

Figure 6

Beach looking South

Figure 7

Beach looking North

Note the proximity of the dunes to the beach

Figure 8

Dunes looking South

Note the sparse vegetation and blowout areas

Figure 9

Dunes looking North

Chapter III

FIELD AND LABORATORY STUDY PROCEDURES

Sampling

Samples were collected from the beach and adjoining dunes in the area shown in Figure 3. The area was selected because of: (a) the proximity of the aeolian area to the beach; and (b) the necessity to ensure that the aeolian material did not originate in the lagoon. A total of 60 samples were collected, 30 from the beach and 30 from the dunes.

The beach samples were collected within the foreshore area to ensure that they consisted of wave sorted sediments. Each sample of approximately 500 grams was carefully skimmed off of the upper one half inch of surface sediment. In this way each sample represents the same sedimentation unit.

The aeolian samples were collected in a similar manner as those of the beach. A larger collection area, from a sparsely vegetated dune, was necessary in order to encompass a complete dune deposit. The reason for this was because Folk (1970), suggested that there is a variance in the grain-size distribution dependent upon the location of the sample on the dune.

Mechanical Analysis

Each of the 60 samples was sieved into grade sizes based on the Phi (Ø) scale (Krumbein, 1934). The samples were treated with hydrochloric acid to ensure the removal of aggregates and shell fragments. After oven drying they were split using an Endicott sample splitter.

100 grams was weighed out and sieved for 15 minutes on a Ro-Tap shaking machine. One quarter phi (Ø) sieves were used ranging from 0.0Ø to 3.75Ø inclusive. The sediment remaining on each sieve was weighed to 0.01 grams on a Sartorius electric balance.

Heavy Minerals

The sediment yield from each sieve was retained separately. After spreading the contents of a sieve over a paper to a depth of one grain, magnetite was removed using a hand magnet. The remaining sample was then run through a Frantz Isodynamic Separator. The technique followed in using the Isodynamic Separator were those suggested by Mueller, (1967). Appropriate slope angles and amperage settings ensured that all heavy minerals in the sample would be separated. Each sample was run through three times to ensure a clean separation.

Although the Bromoform technique is the generally accepted method of heavy mineral separation, the isodynamic technique was used for the following reasons:

a) It is a fairly rapid technique.

b) It provides an adequate separation if the results are to be converted to percentages.

c) It allows complete recovery of a dry sample for subsequent analysis.

Chapter IV

FIELD AND LABORATORY STUDY RESULTS

Data Presentation

Location of the samples, 30 from the beach and 30 from the dune, are shown in Figure 11. Results of the sieve analyses are given in the Appendix. The weight in grams retained by each sieve is shown in the last column for each sample. Beach samples are identified by the symbols B1 to B30 inclusive. Dune samples are identified by the symbols D1 to D30 inclusive.

Appendix 1 shows the actual amount of heavy minerals in grams recovered from each sieve. It also shows the percentage of heavy minerals for each sieve.

The figures presented in the Appendix represent the raw data used in the statistical analysis. Figure 15 and Figure 16 are the cumulative percent curves of selected samples of beach and dune sands respectively.

Mineralogy and Texture of the Sediments

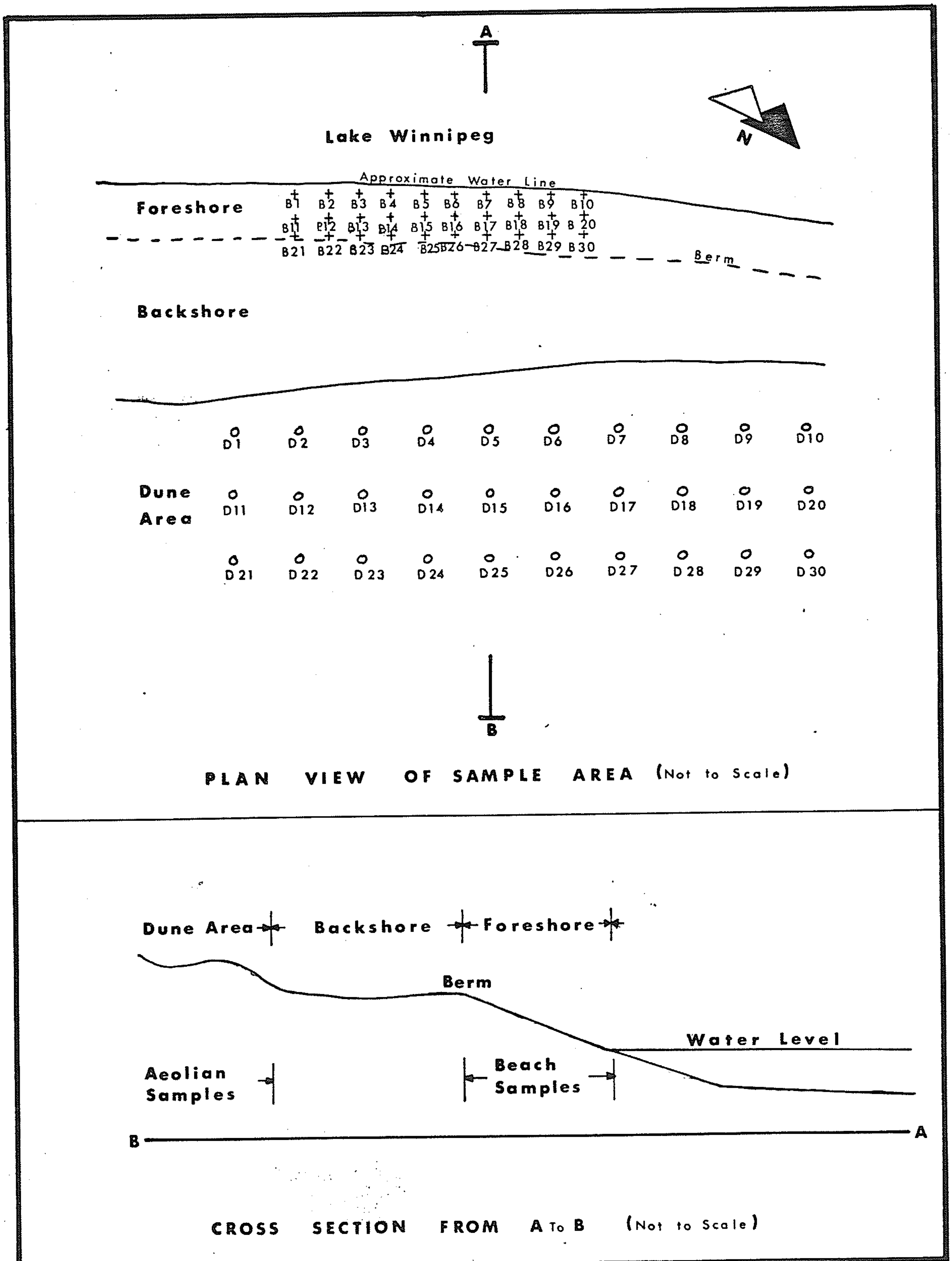
The mineralogy of the sands can be separated into three groups. Quartz makes up by far the largest group, comprising approximately 96 percent of each sample. Feldspar represented approximately 2 percent, while heavy minerals made up the remainder.

The quartz grains vary from sub-rounded to rounded. These display frosted and pitted surfaces. Approximately 20 percent of the Quartz grains are angular to sub-angular. These have fresh fractures and a vitreous lustre.

Figure 10

Beach looking South

Note the distinct line of heavy mineral concentrations along the water line



PLAN VIEW OF SAMPLE AREA (Not to Scale)

CROSS SECTION FROM A To B (Not to Scale)

FIGURE 11

Figure 12

A Closeup of the Heavy Mineral Concentrations

Note the difference between the already exposed line on the left and the more dispersed concentrations still within the swash zone.

Figure 13

A Closeup of the Heavy Mineral Concentrations

Note the cusp formations in the top centre of the picture

FIGURE - 14 CUMULATIVE CURVES OF SELECTED BEACH SANDS

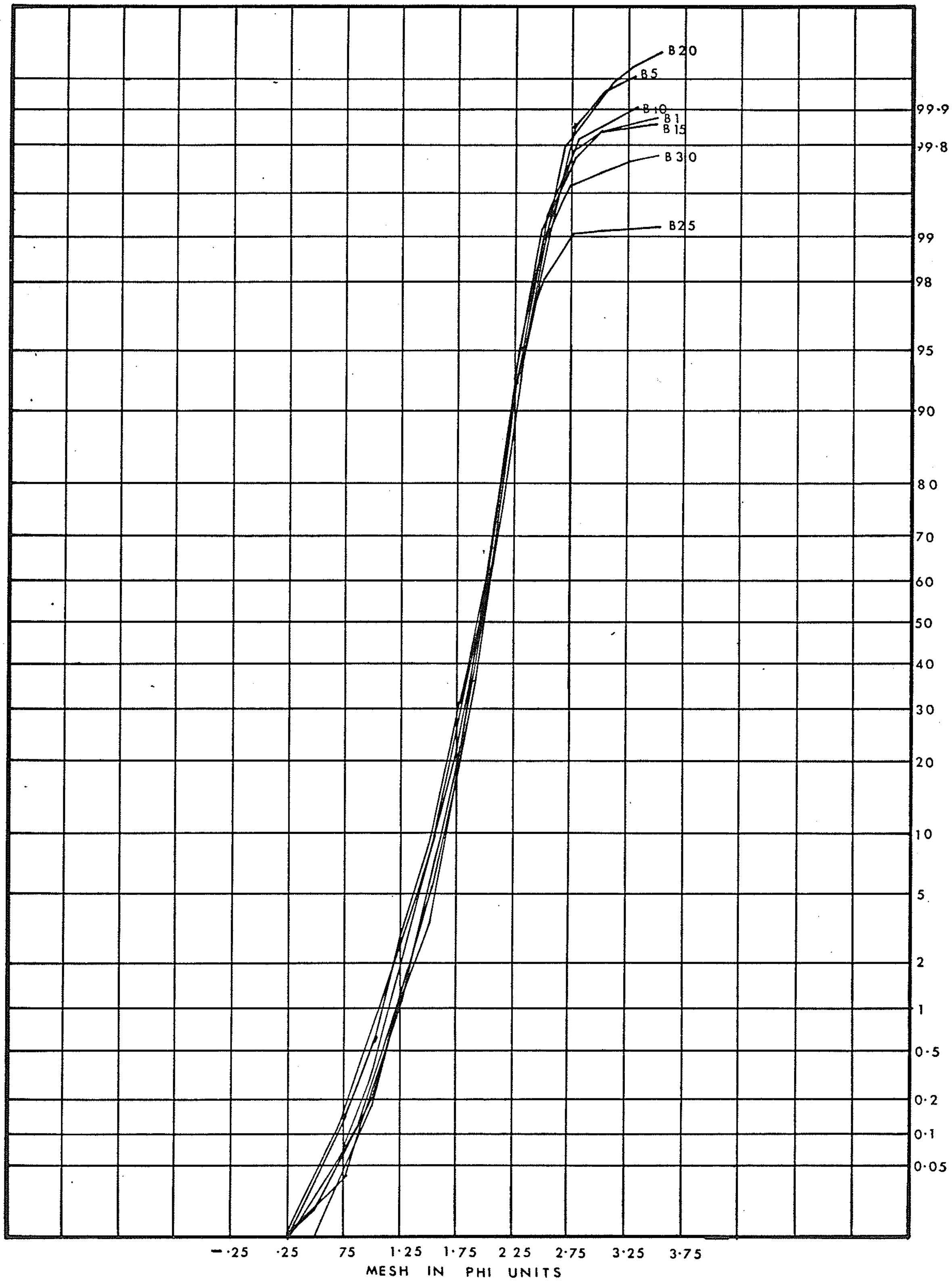
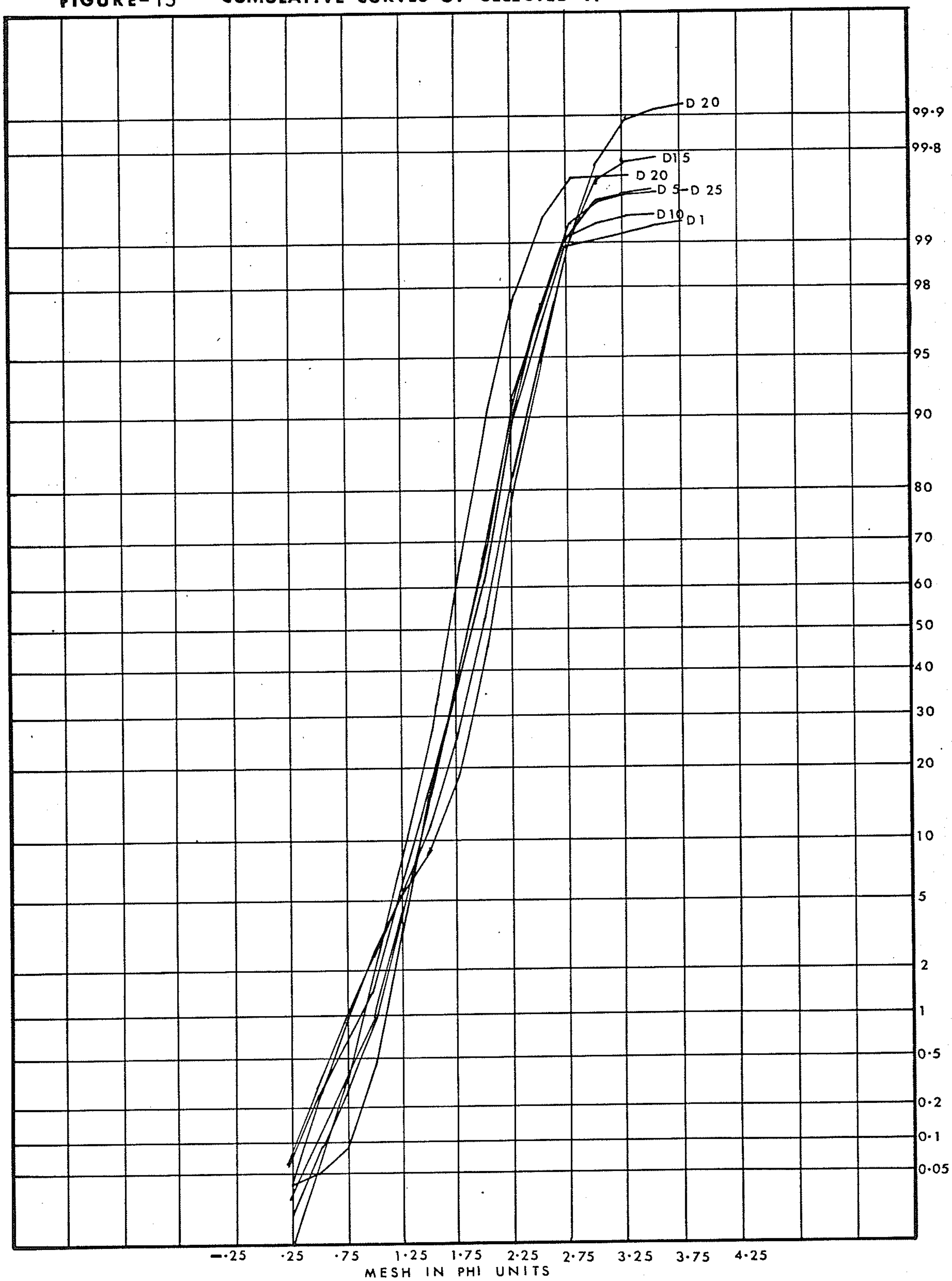


FIGURE-15 CUMULATIVE CURVES OF SELECTED AEOLIAN SANDS



Chapter V

STATISTICAL ANALYSES OF GRAIN-SIZE AND HEAVY MINERAL DATA

Introduction

The differentiation of sands on the basis of textural composition has been a preoccupation of sedimentologists for some time. A major reason for this is the apparent similarity in textural composition of sediments deposited within a particular environment despite the variety of processes active within that environment. If textural responses can be related to specific sedimentary processes, the problem of differentiating deposits will be greatly eased.

The problem of differentiating deposits by textural characteristics has two distinct parts. One is the actual measurement of parameters unique to the sample. The second is the ability to statistically and graphically differentiate between the measured parameters.

Particle Size

An early attempt at measurement and distinction of sedimentary environments was the Log-normal distribution of grain-size established by Krumbein (1937, 1938). Early work by Doeglas (1946) showed that grain-size distributions followed an arithmetic probability law. His analyses yielded an empirical classification of curve shapes which he related to specific sedimentary environments.

One of the more significant papers on the relationship between texture and process was published by Inman (1949). He defined three basic modes of transport; surface creep or traction; suspension; and saltation (1949, p.55). The basis for this work had been carried out by various researchers, most notably Gilbert (1914), and Bagnold (1941).

It was Inman's work that formed the basis for much of the work on statistical measures of the grain-size distribution and sediment transport. Folk (1954), Miller and Olson (1956), Folk and Ward (1957), Friedman (1961, 1967), Klovan (1966), and more recently Visher (1969) and Greenwood (1969), have all presented attempts to distinguish between depositional environments using various statistical measures. In response to the varying methodologies, there have been tests to determine the efficiencies of these statistical measures. An example of this approach is a paper by Solohub and Klovan (1970), which examines the techniques of Passega (1957), Mason and Folk (1958), Friedman (1961), Sahu (1964), and Klovan (1966). Solohub and Klovan conclude that Klovan's use of factor analysis was able to produce the most acceptable results. This was based on the finding that grain-size distributions reflect depositional processes, not environment, because the two are not necessarily the same. For example, the grain-size for beach and dune deposits are similar, even though the energy environments are different.

Heavy Minerals

Ruhkin (1937) was one of the first workers to recognise that current energy responds to grain density as well as shape and size. His work was not given the attention it deserved. It was not until the laboratory tests and field confirmations of such workers as Leliavsky (1955), Bagnold (1954, 1956), and King (1954), that the sensitivity of grain density to sorting agents was re-examined. This has led to speculation that particle density differences should occur in various depositional environments. Studies have been completed which attempted to differentiate between environments on this basis, notably those by Bradley (1957), White and Williams (1967), and Hand (1967). Lockery (1971) suggests that it is not so much the total content, but the distribution of heavy minerals within the sample size range which provides the key to environmental identification.

Lockery's study of sedimentary deposits in the Lower Tees Basin of northeast England, suggested that in both beach and dune sands selective sorting results in a concentration of heavy minerals in the finer size fractions (Lockery, 1971). Bradley's similar conclusion that the amount of heavy minerals may be important in characterizing the environment of deposition serves as a basis for part of this study.

Factor Analysis

Factor analysis was developed as an analytical technique by psychologists. Its basic objective is a reduction of data into distinct patterns of occurrence. The Q-technique of factor analysis used in this thesis, attempts to identify the centroids of sample groups. Samples are compared on the basis of similarities in their characteristics that can be measured. Mathematically, the approach treats each sample as a vector. The exact location of this vector is determined as follows.

> "If, for example, a sediment sample is sieved into ten class intervals, the sample can be defined as a vector in ten-dimensional space whose position is uniquely determined by the amount of sediment in each of the ten classes." (Klovan 1966, p.116)

The cosine of the angle between each sample vector represents the " ... degree of proportional similarity between the sediment samples." (Klovan 1966, p.116). Samples that are highly correlated will cluster together. Factor analysis defines each of these distinct clusters of vectors as a factor.

Once the cluster of vectors has been established, an axis is mathematically projected through them. The projection of each vector point onto this axis defines the cluster. These projections are called factor loadings and are usually presented in a matrix. The factor loadings show to what degree each variable is involved in the factor pattern.

The number of factors obtained represents the number of independent patterns of relationships between the variables. The amount of variation accounted for by these patterns is termed the eigenvalue. These are obtained by adding the squared loadings for each factor. The sums of squares are obtained by dividing the eigenvalue by the number of variables times one hundred.

One of the first applications of factor analysis in geology was the work of Imbrie (1963). He attempted a reduction of data from two environment matrices, where the dependent variables were combined into fewer variables. Klovan applied a Q-Mode factor analysis to the data of Krumbein and Aberdeen (1937), collected from Barataria Bay on the Mississippi delta. His objective was to answer two questions:

> "Can sediment samples be grouped into categories on the basis of their grain-size distributions along?" And further, "Can some environmental significance be attached to the categories without a priori knowledge of their geographic and environmental positions?"
> (Klovan 1966, p.116)

He concludes that the technique provides an efficient method of delineating groups and trends between " ... environmentally distinct sediment samples." (Klovan, p.124).

Klovan lists three advantages of factor analysis over other statistical techniques.

1. The full spectrum of the grain-size distribution is used.
2. As a result of (1), it does not make use of arbitrary statistical descriptions such as quartiles or percentiles.
3. No previous knowledge of the geographic location or environment is required to group the samples as environmentally distinctive.

It is assumed by Klovan that the grain-size distribution is log-normal. The only subjective decision required is selection of the class interval. In Klovan's case a 1/2 Ø (Phi) interval was used.

The results obtained by Klovan showed that three factors accounted for 97.5 percent of the information. He suggested that the three factors are representative of different types of energy at the site of deposition, the three energy types being, wind-wave action, current action, and gravitational settling. It is important to note the combination of wind and wave action in this classification grouping. These are the dominant sorting agents in dune and beach environments. By grouping them together Klovan is acknowledging the difficulties encountered in trying to separate them on the basis of reaction to energy environment.

An empirical application of Klovan's technique was carried out by Solohub at Grand Beach, Manitoba, (Solohub, 1970). In this study several statistical techniques were applied to the same sample data. The author found that none of the techniques was able to distinguish between environments previously established by field investigation. It was determined however, that factor analysis produced a pattern of energy variation that agreed with known processes at the sample site.

Test of the Klovan Technique

The first Q-Mode factor analysis was computed for the 60 combined beach and dune grain-size samples. Raw data comprised the weight in grams of sediment retrieved from each sieve. The eigenvalues, percent sums of squares, and cumulative sums of squares for the principal components factor analysis are listed in Table 2. Six factors were required to account for 95 percent of the information contained in the data matrix. The first three factors account for 87 percent of the variance of the data.

It is significant to note that both Klovan and Solohub accounted for 95 percent of the variance with only three factors. In contrast, Beall (1970) required three factors to explain 87 percent and five factors for 90 percent of the variance. Klovan and Solohub used 1/2 Ø class intervals. Beall's results coincide almost identically with those of the present study. Both utilized 1/4 Ø class intervals showing that the sieve interval has a direct bearing upon the results of the factor analytic technique.

The Q-Mode factor analysis of the heavy mineral data provided the eigenvalues, percent sums of squares, and cumulative sums of squares listed in Table 3. Eight factors were required to account for 95 percent of the variance. Only 80 percent of the data in the matrix is accounted for by the first three factors. The first factor in the grain-size analysis accounts for 77 percent. In the heavy mineral analysis this factor accounts for 67 percent.

A graphic presentation of the factor loadings was used by Klovan to show the relationships between the samples from each of the environments. This was achieved by converting the factor loadings to factor components, thus accentuating the higher loadings (Table 4, 4a, 5, 5a). The factor component is obtained by adding the sums of the squares of

TABLE 2

EIGENVALUES, PERCENT SUMS OF SQUARES, AND CUMULATIVE SUMS OF SQUARES FOR GRAIN-SIZE FACTOR ANALYSIS

FACTOR	EIGENVALUES	% SUM OF SQUARES	CUMULATIVE SUM SQUARES
1	46.132	76.886	76.89
2	3.882	6.469	83.36
3	2.266	3.777	87.13
4	1.965	3.275	90.41
5	1.848	3.081	93.49
6	1.139	1.898	95.39

TABLE 3

EIGENVALUES, PERCENT SUMS OF SQUARES AND CUMULATIVE SUMS OF SQUARES FOR HEAVY MINERAL FACTOR ANALYSIS

FACTOR	EIGENVALUES	% SUM OF SQUARES	CUMULATIVE SUM SQUARES
1	40.569	67.615	67.72
2	4.823	8.039	75.65
3	3.080	5.133	80.79
4	2.684	4.473	85.26
5	2.299	3.831	89.09
6	1.404	2.339	91.43
7	1.206	2.101	93.44
8	1.138	1.897	95.34

TABLE 4

NORMALIZED VARIMAX FACTOR LOADINGS AND SAMPLE CUMMUNALITIES FOR GRAIN-SIZE DATA - BEACH

F_1^2	F_2^2	F_3^2	Sample Communality	F_1%	F_2%	F_3%
.1249	.0829	.0327	.2405	.5193	.3447	.1360
.1124	.0325	.0130	.1579	.7118	.205-	.0824
.1317	.0085	.0065	.1467	.8978	.0579	.0443
.1064	.0091	.0008	.1163	.9149	.0782	.0069
.0697	.0113	.0013	.0823	.8469	.1373	.0158
.0504	.0144	.0013	.0661	.7625	.2178	.0197
.0173	.0236	.0011	.0420	.4119	.5619	.0262
.0096	.0275	.0007	.0378	.2540	.7275	.0185
.0144	.0265	.0006	.0415	.3470	.6386	.0144
.0427	.0189	.0008	.0624	.6843	.3029	.0128
.0812	.0095	.0009	.0916	.8865	.1037	.0098
.0925	.0080	.0008	.1013	.9131	.0790	.0079
.0774	.0114	.0011	.0899	.8610	.1268	.0122
.0972	.0076	.0012	.1060	.9170	.0717	.0113
.1311	.0037	.0010	.1358	.9654	.0272	.0074
.1168	.0094	.0009	.1271	.9190	.0740	.0070
.1069	.0031	.0023	.1123	.9519	.0276	.0205
.1144	.0037	.0023	.1204	.9502	.0307	.0191
.0920	.0058	.0014	.0992	.9274	.0585	.0141
.0590	0.145	.0013	.9748	.7888	.1938	.0174
.0404	.0224	.0007	.0635	.6362	.3528	.0110
.0173	.0258	.0008	.0439	.3941	.5877	.0182
.0093	.0270	.0007	.0370	.2514	.7207	.0189
.0155	.0258	.0008	.0421	.3682	.6128	.0190
.0570	.0213	.0007	.0790	.7215	.2696	.0089
.0927	.0060	.0012	.0999	.9279	.0601	.0120
.1055	.0047	.0008	.1110	.9505	.0423	.0072
.0661	.0086	.0018	.0765	.8641	.1124	.0235
.0630	.0043	.0031	.0704	.8949	.0611	.0440
.0790	.0001	.0038	.0829	.9530	.0012	.0458

TABLE 4a

NORMALIZED VARIMAX FACTOR LOADINGS AND SAMPLE COMMUNALITIES FOR GRAIN-SIZE DATA - DUNE

F_1^2	F_2^2	F_3^2	Sample Communality	$F_1\%$	$F_2\%$	$F_3\%$
.0372	0.359	.0002	.0733	.5075	.4898	.0027
.0872	.0176	.0001	.1049	.8313	.1678	.0009
.0738	.0168	.0000	.0906	.8146	.1854	.0000
.0710	.0186	.0001	.0897	.7915	.2074	.0011
.0594	.0162	.0007	.0763	.7785	.2123	.0092
.0408	.0187	.0010	.0605	.6744	.3091	.0165
.0265	.0225	.0010	.0487	.5175	.4620	.0205
.0122	.0272	.0007	.0401	.3042	.6783	.0175
.0118	.0267	.0008	.0393	.3002	.6794	.0204
.0313	.0218	.0009	.0540	.5796	.4037	.0167
.0771	.0141	.0012	.0924	.8344	.1526	.0130
.1004	.0102	.0008	.1114	.9013	.0916	.0071
.0706	.0152	.0014	.0872	.8096	.1743	.0161
.0563	.0159	.0029	.0751	.7497	.2117	.0386
.0305	.0133	.0076	.0514	.5934	.2588	.1478
.0028	.0185	.0034	.0247	.1134	.7490	.1376
.0260	.0077	.0044	.0381	.6824	.2021	.1155
.0392	.0061	.0043	.0496	.7903	.1230	.0867
.0321	.0117	.0034	.0472	.6801	.2479	.0720
.0268	.0194	.0017	.0479	.5595	.4050	.0355
.0251	.0224	.0012	.0487	.5154	.4600	.0246
.0179	.0253	.0006	.0438	.4087	.5776	.0137
.0149	.0266	.0006	.0421	.3539	.6318	.0143
.0183	.0255	.0008	.0446	.4103	.5718	.0179
.0416	.0157	.0016	.0589	.7062	.2666	.0272
.0650	.0050	.0026	.0726	.8953	.0689	.0358
.0690	.0030	.0027	.0747	.9237	.0402	.0361
.0442	.0061	.0032	.0535	.8262	.1140	.0598
.0297	.0053	.0048	.0398	.7462	.1332	.1206
.0116	.0008	.0068	.0192	.6041	.0417	.3542

TABLE 5

NORMALIZED VARIMAX FACTOR LOADINGS AND SAMPLE COMMUNALITIES FOR HEAVY MINERAL DATA - BEACH

F_1^2	F_2^2	F_3^2	Sample Communality	$F_1\%$	$F_2\%$	$F_3\%$
.1390	.0000	.0149	.1539	.9032	.0000	.0968
.0049	.4284	.0167	.4500	.0109	.9520	.0371
.1500	.2831	.0248	.4579	.3276	.6183	.0541
.4787	.0809	.2904	.8500	.5632	.0952	.3416
.8383	.0455	.0213	.9051	.9262	.0503	.0235
.7992	.1031	.0366	.9390	.8512	.1098	.0390
.7857	.1365	.0583	.9804	.8014	.1393	.0594
.8125	.1082	.0551	.9759	.8326	.1109	.0565
.7846	.1202	.0511	.9559	.8208	.1257	.0535
.8330	.0735	.0461	.9526	.8745	.0772	.0484
.8481	.0388	.0372	.9241	.9177	.0420	.0403
.7832	.0005	.0843	.8680	.9023	.0005	.0972
.7215	.1032	.0861	.9107	.7922	.1134	.0945
.1218	.5213	.2541	.8972	.1358	.5810	.2832
.0588	.4017	.0470	.5076	.1158	.7914	.0928
.0043	.4295	.0164	.4502	.0095	.9540	.0364
.0031	.2289	.0059	.2378	.0129	.9624	.0247
.1072	.0746	.5651	.7469	.1435	.0999	.7565
.4083	.0776	.1168	.6026	.6776	.1287	.1939
.8415	.0922	.0351	.9724	.8691	.0949	.0361
.8486	.0720	.0371	.9578	.8860	.0752	.0388
.7891	.1087	.0717	.9695	.8139	.1121	.0739
.8078	.0978	.0630	.9687	.8339	.1009	.0651
.8113	.0878	.0684	.9674	.8386	.0908	.0707
.8256	.0451	.0935	.9642	.8562	.0467	.0970
.9141	.0257	.0201	.9600	.9522	.0268	.0210
.7379	.0001	.1427	.8806	.8379	.0001	.1620
.7193	.1151	.0416	.8759	.8212	.1314	.0475
.2703	.4305	.0136	.7144	.3784	.6026	.0190
.0056	.7443	.0338	.7836	.0072	.9498	.0431

TABLE 5a

NORMALIZED VARIMAX FACTOR LOADINGS AND SAMPLE COMMUNALITIES FOR HEAVY MINERAL DATA - DUNE

F_1^2	F_2^2	F_3^2	Sample Communality	$F_1\%$	$F_2\%$	$F_3\%$
.1702	.0139	.0104	.1946	.8748	.0717	.0537
.1627	.0107	.0367	.2102	.7742	.0511	.1748
.2179	.1643	0.448	.4270	.510-	.3847	.1049
.3352	.4258	.0330	.7941	.4222	.5361	.0416
.7795	.0611	.0302	.8709	.8951	.0702	.0347
.8813	.0555	.0230	.9600	.9181	.0578	.0240
.7957	.1430	.0313	.9700	.8203	.1475	.0323
.7815	.1526	.0404	.9746	.9018	.1566	.0415
.7271	.1783	.0188	.9242	.7867	.1930	.0203
.7670	.1290	.0319	.9278	.8267	.1390	.0344
.6926	.1363	.0540	.8829	.7844	.1544	.0612
.8414	.0014	.0112	.8541	.9852	.0017	.0131
.7634	.1034	.0819	.9486	.8047	.1090	.0863
.2039	.6469	.0106	.8613	.2367	.7511	.0123
.0128	.0228	.7928	.8285	.0154	.0276	.9569
.0619	.0379	.5670	.6667	.0928	.0568	.8505
.0126	.0001	.8847	.8974	.0140	.0001	.9859
.0708	.0867	.6435	.8011	.0884	.1083	.8033
.4882	.0836	.0660	.6378	.7654	.1311	.1036
.8252	.0559	.0522	.9333	.8842	.0599	.0559
.8947	.0629	.0154	.9729	.9196	.0647	.0158
.7923	.1465	.0362	.9750	.8126	.1503	.0371
.8283	.1090	.0368	.9742	.8502	.1119	.0378
.8091	.1229	.0232	.9551	.8471	.1286	.0243
.8701	.0827	.0108	.9636	.9030	.0858	.0112
.8261	.0842	.0333	.9437	.8754	.0892	.0353
.7707	.0012	.1449	.9168	.8407	.0013	.1580
.6646	.1222	.0003	.7870	.8444	.1553	.0004
.2721	.4450	.0008	.7179	.3790	.6199	.0011
.0071	.8075	.0125	.8271	.0086	.9763	.0151

the factor loadings. These are normalized by dividing the factor components of each sample by the sample communality.

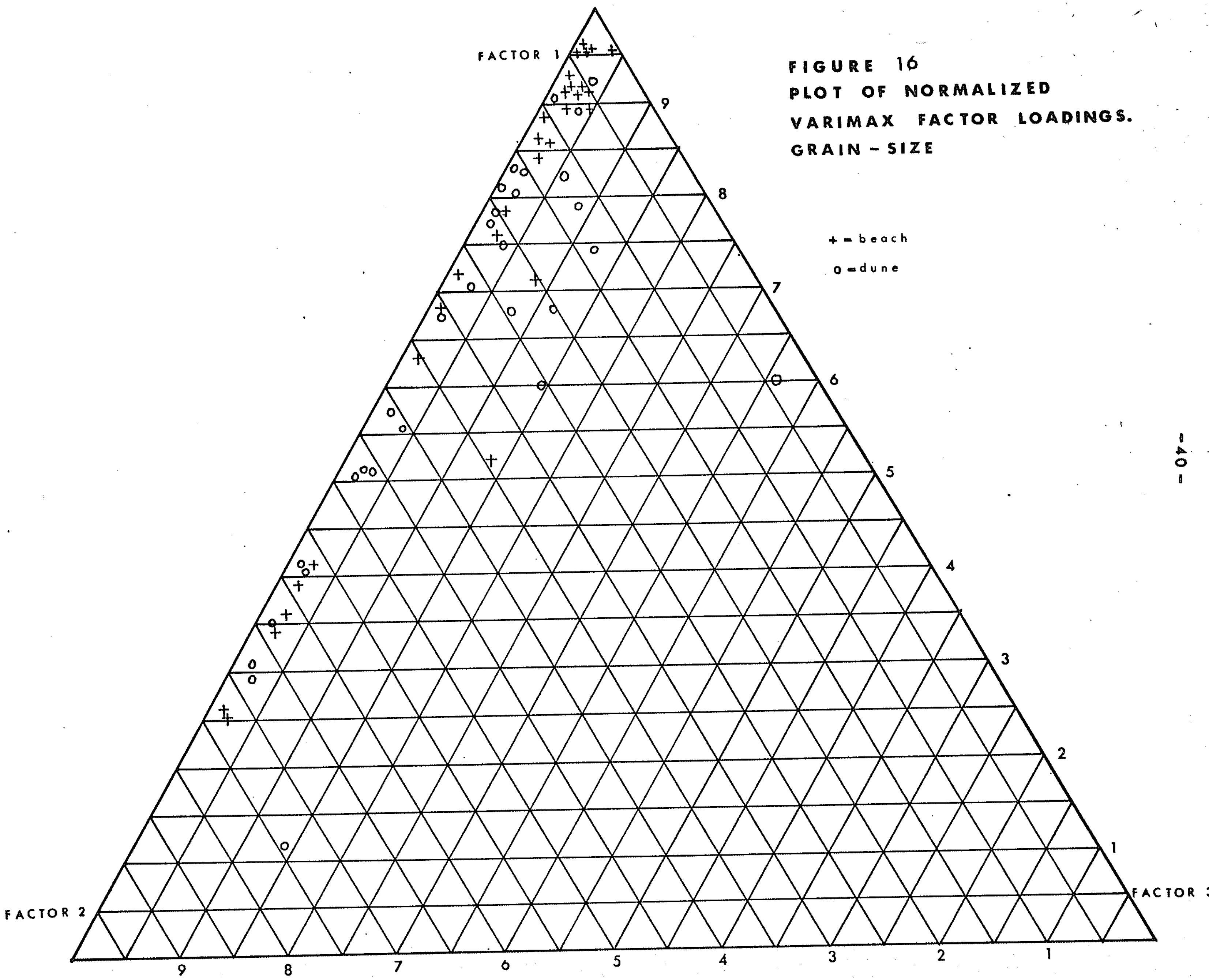
Results of these computations are plotted on a triangular graph (Figures 17 and 18). Solohub and Klovan (1970), suggest that the three factors presented on the graph represent different energy types. It is assumed that mean grain-size is a crude measure of energy conditions at the time of deposition. Therefore, on the basis of mean grain-size the depositional environments can be distinguished. The empirical test carried out at Grand Beach seemed to support the theory in some cases. The most notable exception is between surf and gravitational energy environments. Unfortunately these energy conditions are the most dominant for the formation of beaches and dunes. The result is that the technique fails to discriminate between the two environments.

Figure 18 shows a plot of normalized factor components of heavy minerals. They represent data obtained from the volume percent of beach and dune heavy minerals. The four trends observed by Klovan for his samples can be noted. These are:

1. The concentration of samples at the apices,
2. The lack of samples on the bottom edge,
3. The lack of samples in the centre,
4. The tendency for samples to occur along the two sides.

A majority of the samples are clustered in the corner representing Factor 1, with a slight gradation occurring towards Factor 2. Klovan suggests that Factor 1 represents a medium energyeenvironment, Factor 2 a low energy environment, and Factor 3 a high energy environment. However, these terms are used only in a relative sense. For example, a sample located at Factor 1 would have been deposited under higher energy

FIGURE 16
PLOT OF NORMALIZED
VARIMAX FACTOR LOADINGS.
GRAIN - SIZE



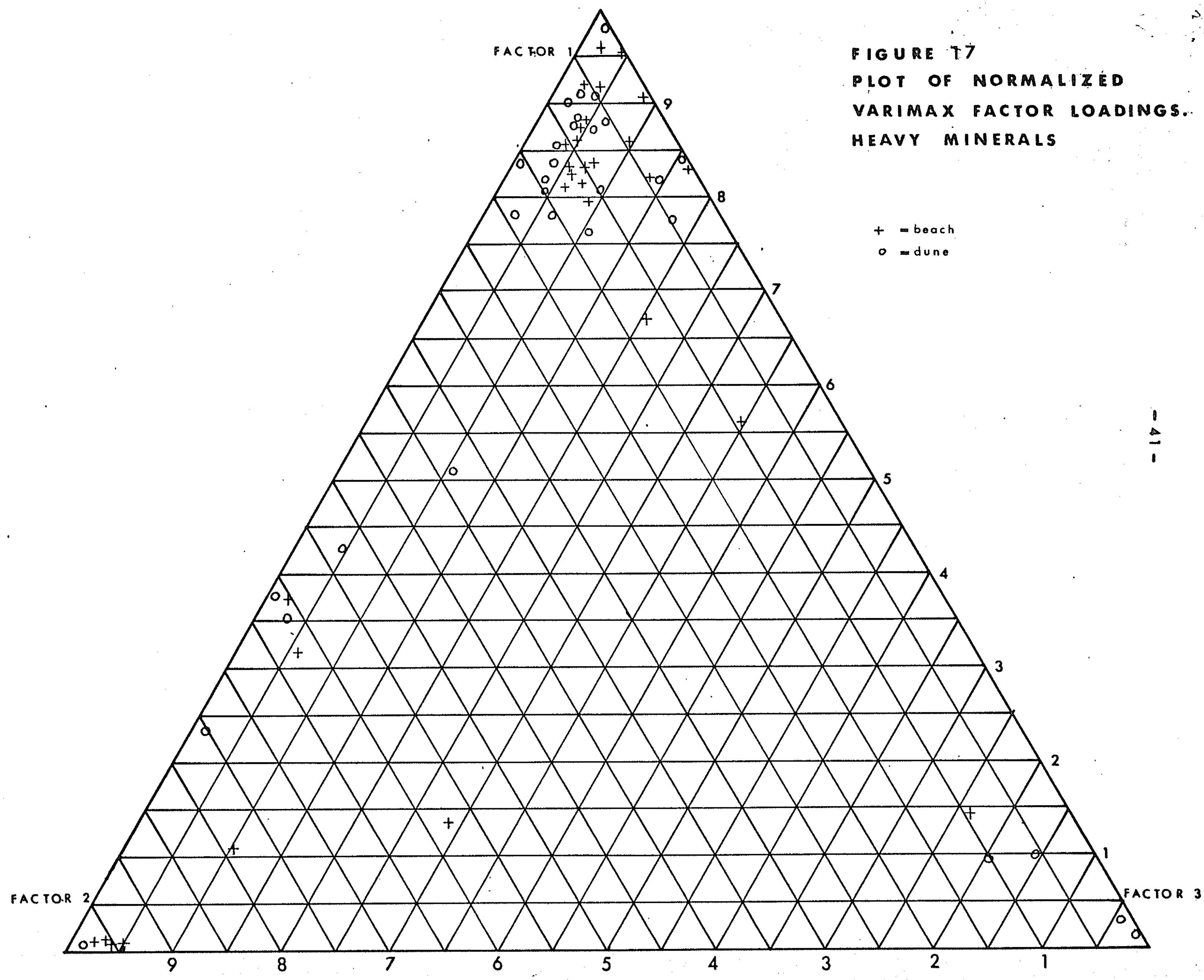


FIGURE 17
PLOT OF NORMALIZED VARIMAX FACTOR LOADINGS. HEAVY MINERALS

conditions than one located at Factor 2. There is no apparent discrimination between beach and dune samples.

Figure 17 is a plot of normalized factor components for grain-size. In contrast to the heavy minerals, the sample points are all grouped between Factor 1 and Factor 2, with a majority of the samples located toward Factor 1. Klovan shows by the use of cumulative frequency curves that this trend is a reflection of a gradual increase in mean grain-size. Again there is no apparent discrimination between beach and dune samples. They both appear to respond to different energy types in a similar manner.

Q-Mode Analysis and Factor Scores

It was apparent from the grain-size and heavy mineral data that there was a difference between the beach and dune samples, the difference being more pronounced in the heavy mineral data. The problem was to establish a technique that could clearly delineate the difference between beach and dune samples.

A principal components Q-Mode analysis was run on the same data used for the Klovan technique. The results obtained for the grain-size data are shown in Table 6. It can be seen that eight factors were required to account for 91 percent of the information in the correlation coefficient matrix. The first factor accounts for 53 percent of the data, while three factors cover 85 percent. This latter figure is comparable to the results obtained by Klovan.

The first factor of the heavy mineral data (Table 7) accounts for only 28 percent of the matrix. Also only 61 percent of the data is accounted for by 10 factors. Three factors account for 48 percent of

TABLE 6

GRAIN SIZE

	Eigenvalues	% Sum of Squares	Cumulative Sum of Squares
Factor 1	8.089	53.93	53.93
2	2.916	19.44	73.37
3	1.701	11.34	84.71
4	0.598	6.01	88.70
5	0.181	1.31	89.90
6	0.144	0.96	90.86
7	0.050	0.33	91.19
8	0.003	0.12	91.21

EIGENVALUES, PERCENT SUMS OF SQUARES AND CUMULATIVE SUMS OF SQUARES FOR GRAIN-SIZE DATA USING THE BIOMED Q-MODE FACTOR ANALYSIS

TABLE 7

HEAVY MINERALS

	Eigenvalues	% Sum of Squares	Cumulative Sum of Squares
Factor 1	4.180	27.86	27.86
2	1.843	12.29	40.16
3	1.204	8.025	48.18
4	0.658	4.39	52.57
5	0.511	3.41	55.98
6	0.351	2.34	58.32
7	0.261	1.74	60.06
8	0.157	1.05	61.10
9	0.036	0.24	61.35
10	0.009	0.06	61.41

EIGENVALUES, PERCENT SUMS OF SQUARES AND CUMULATIVE SUMS OF SQUARES FOR HEAVY MINERAL DATA USING THE BIOMED FACTOR ANALYSIS the correlation coefficient data. These figures are in marked contrast to the previous Q-Mode results.

A more accepted method of presenting the results of factor analysis is by plotting factor scores. These can be computed in several ways, the basic principle being to obtain the weighted combination of the tests that best predict a factor. The scores for three factors were computed as an integral part of the Biomed Q-Mode program. Appendix 2 shows the factor scores for a Q-Mode analysis of the grain-size data. Each factor is plotted against the other two factors as shown in Figures 19, 20, 21, 22, 23, and 24. There are three trends to be noted in each plot.

1. The beach samples are well grouped in the negative/negative quadrant.
2. There is a reasonably good separation between beach and dune samples.
3. The dune samples are well distributed in all areas except the negative/negative quadrant.

The best separation of beach and dune samples is achieved with the comparison of Factors 1 and 2 for the heavy mineral percentages (Figure 22). For grain-size the best discrimination between environments is achieved by plotting Factor 1 against Factor 3. Finally, the dune samples only show a tendency to group when Factor 2 is plotted against Factor 3 for the heavy minerals.

FIGURE 18
PLOTTED FACTOR SCORES
FOR GRAIN-SIZE

FACTOR I against FACTOR 2

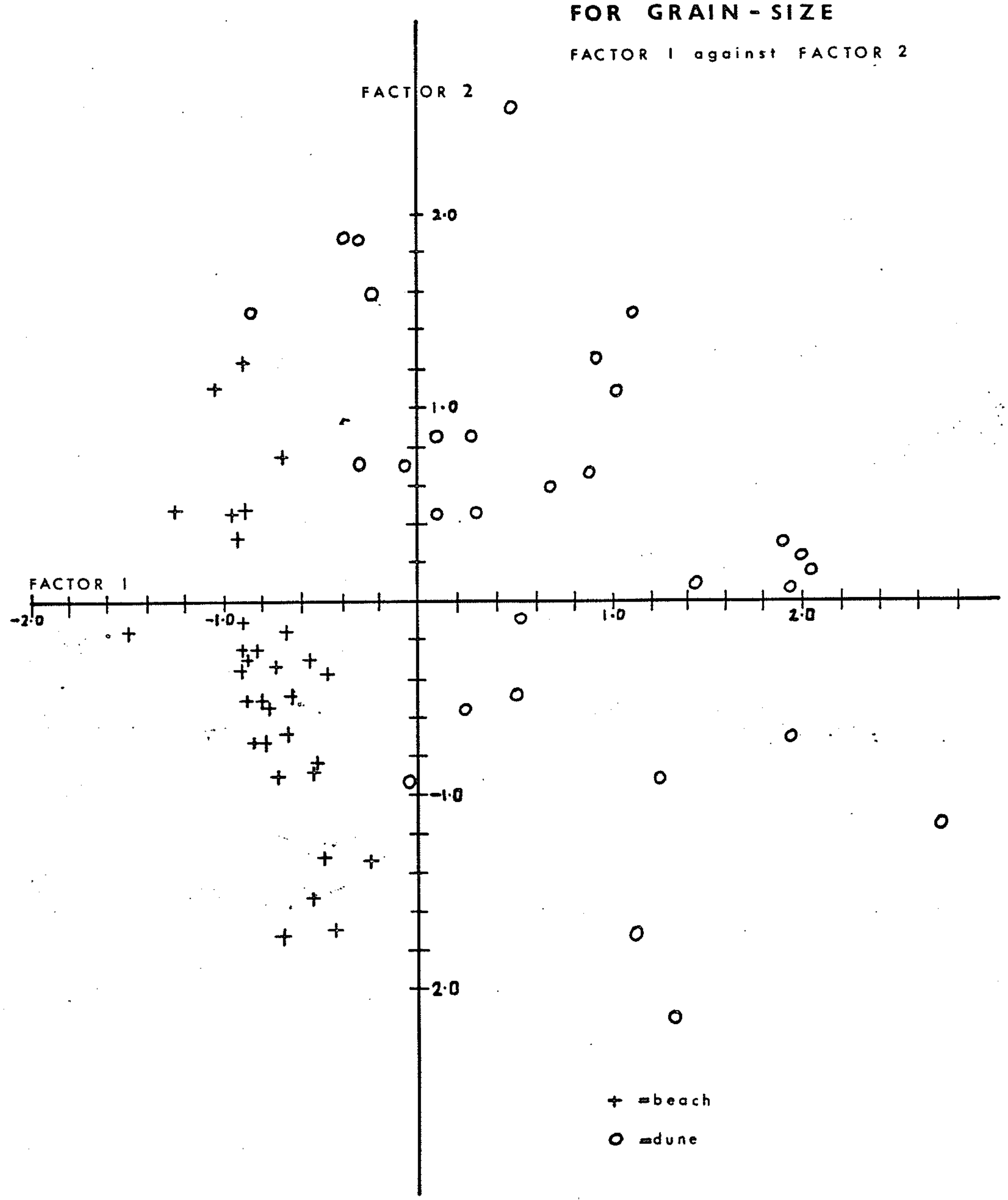


FIGURE 19
PLOTTED FACTOR SCORES FOR GRAIN-SIZE
FACTOR 1 against FACTOR 3

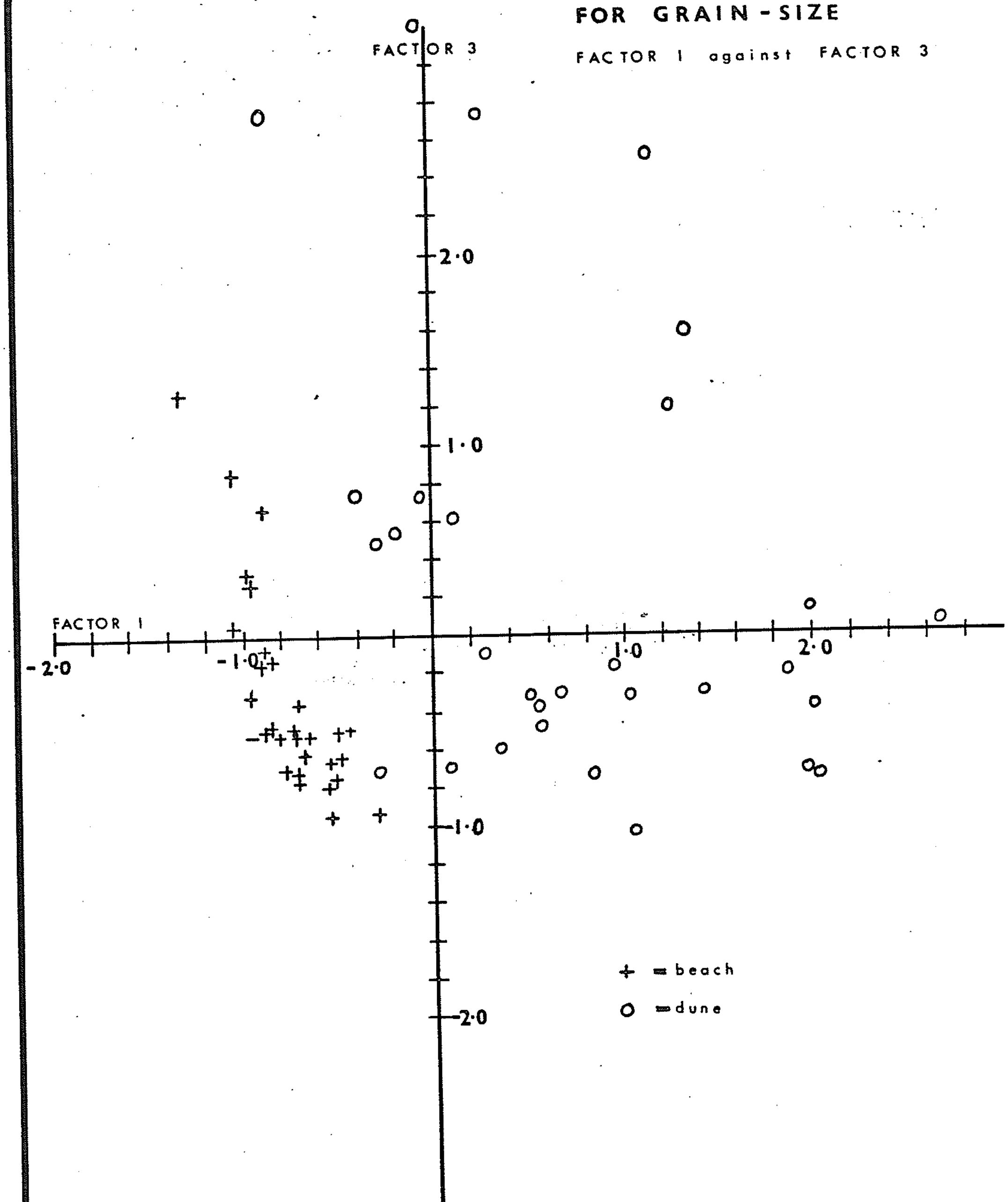


FIGURE 20
PLOTTED FACTOR SCORES
FOR GRAIN-SIZE

FACTOR 2 against FACTOR 3

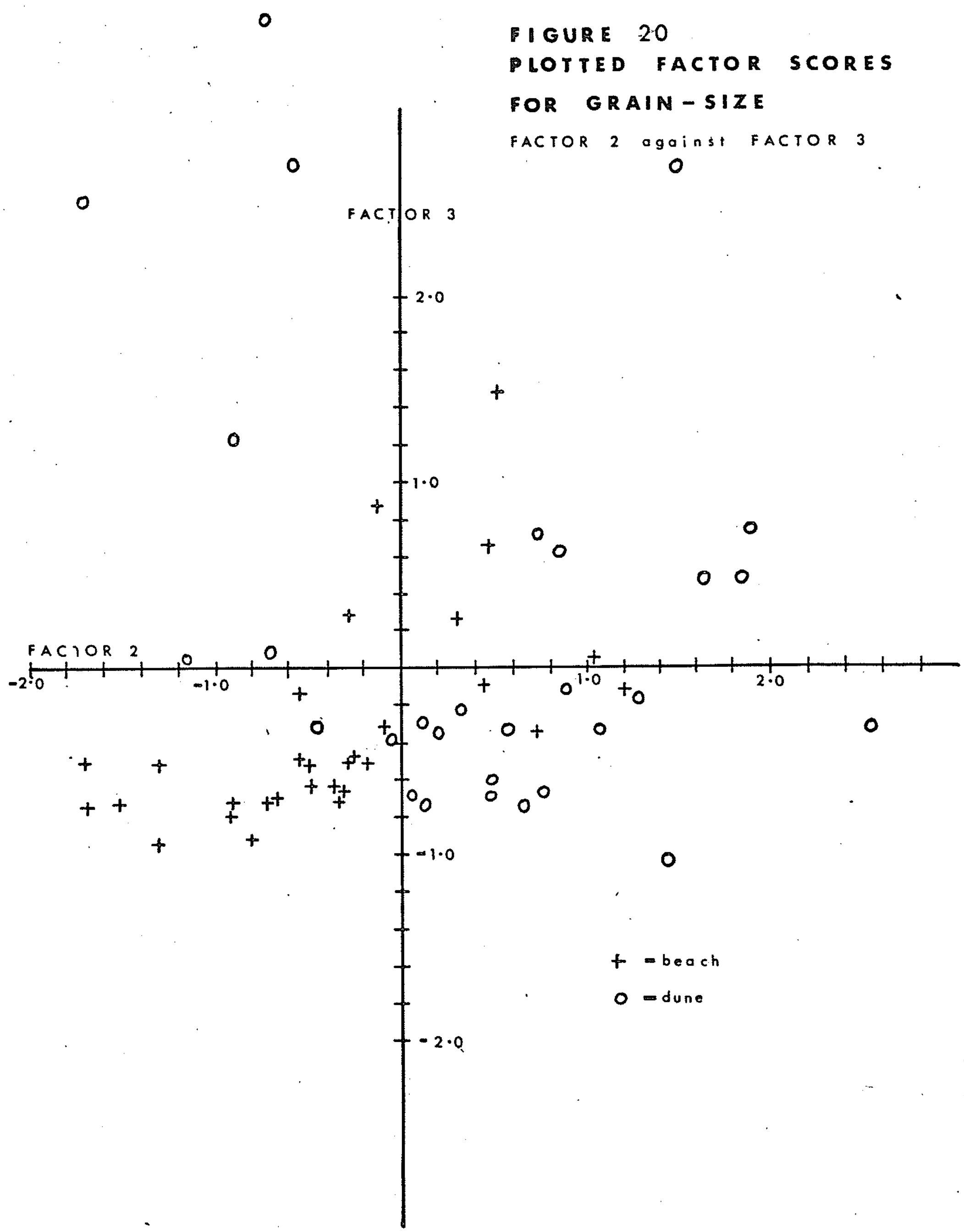


FIGURE 21
PLOTTED FACTOR SCORES
FOR HEAVY MINERALS
FACTOR 1 against FACTOR 2

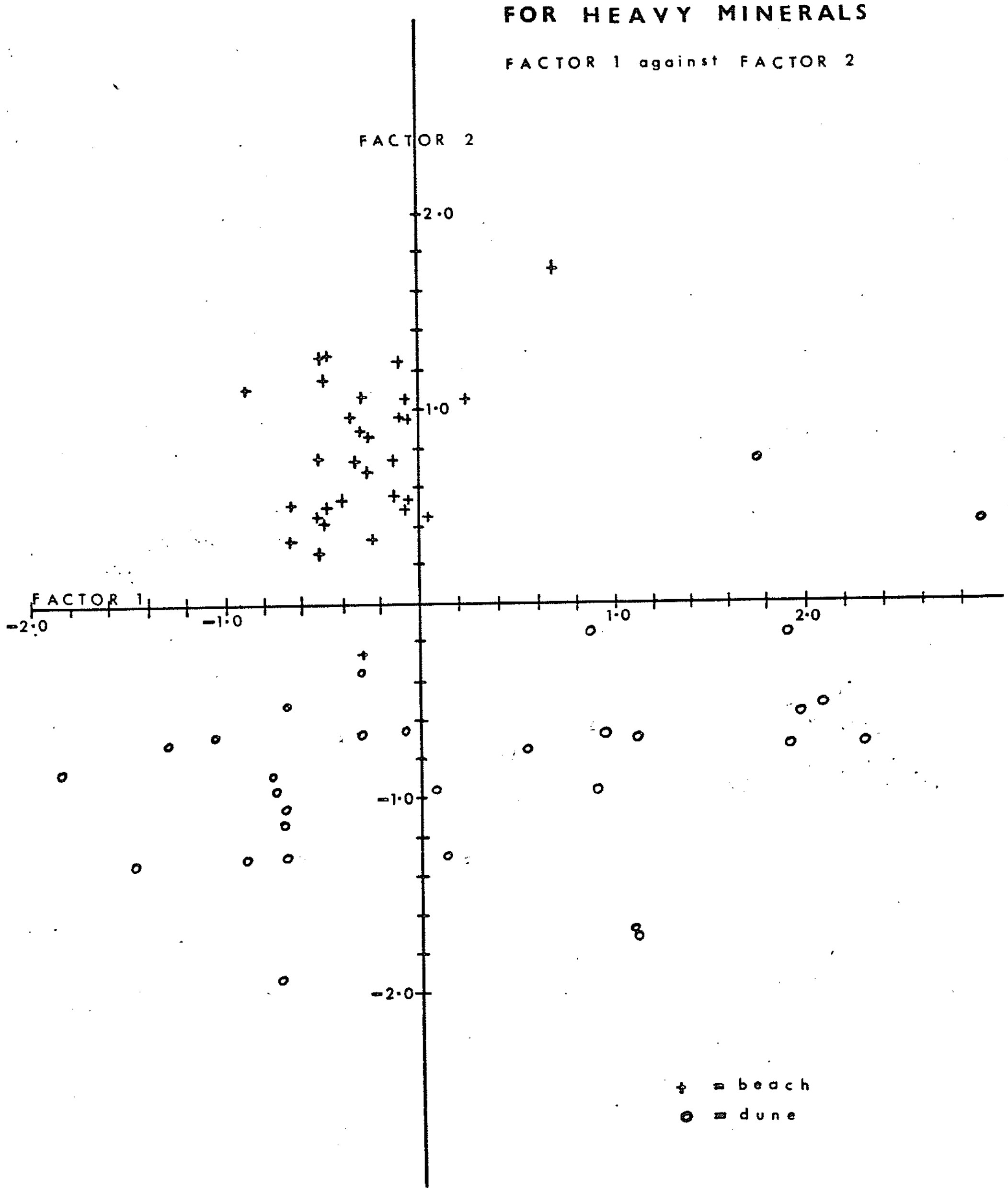


FIGURE 2·2
PLOTTED FACTOR SCORES FOR HEAVY MINERALS
FACTOR 1 against FACTOR 3

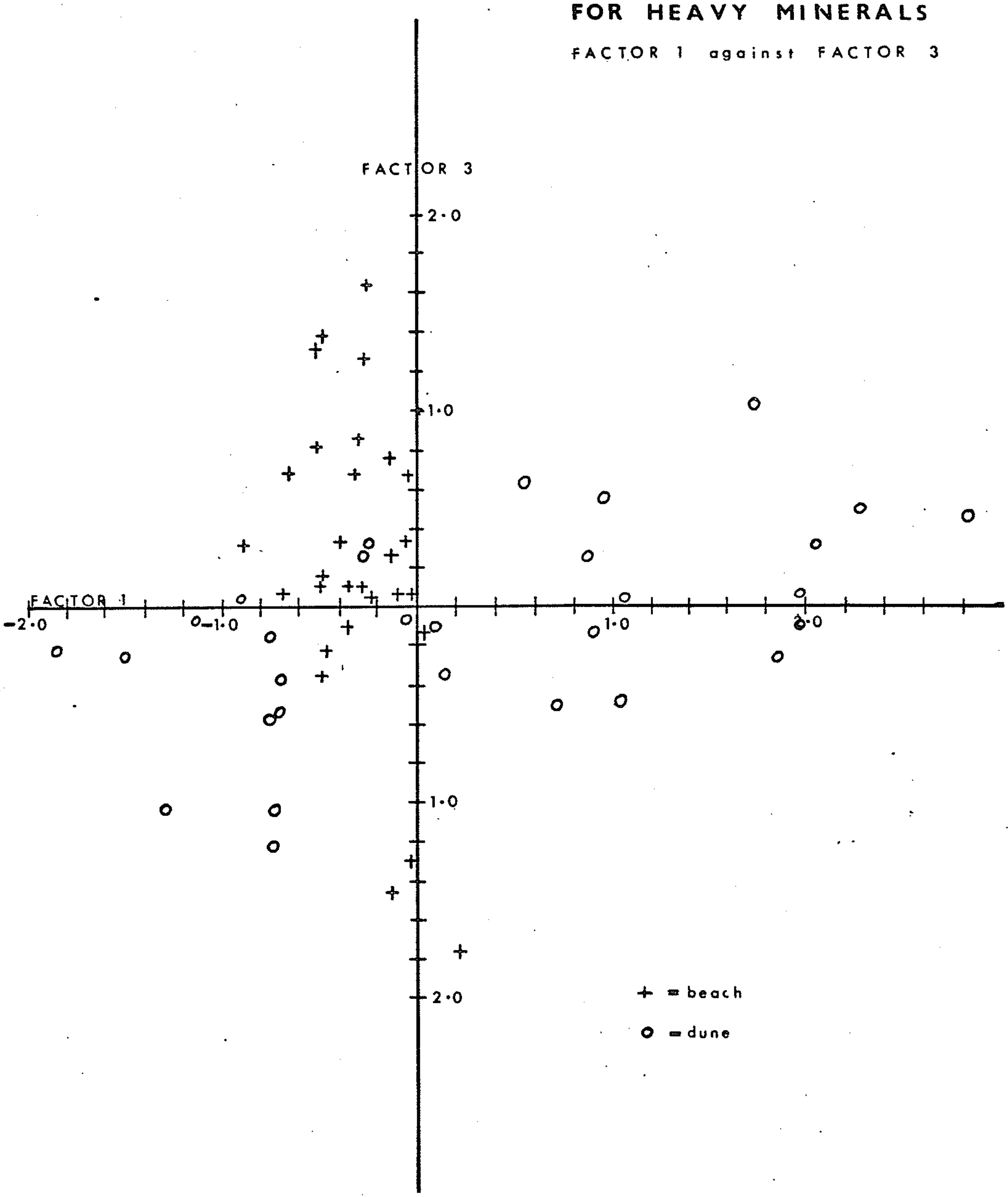
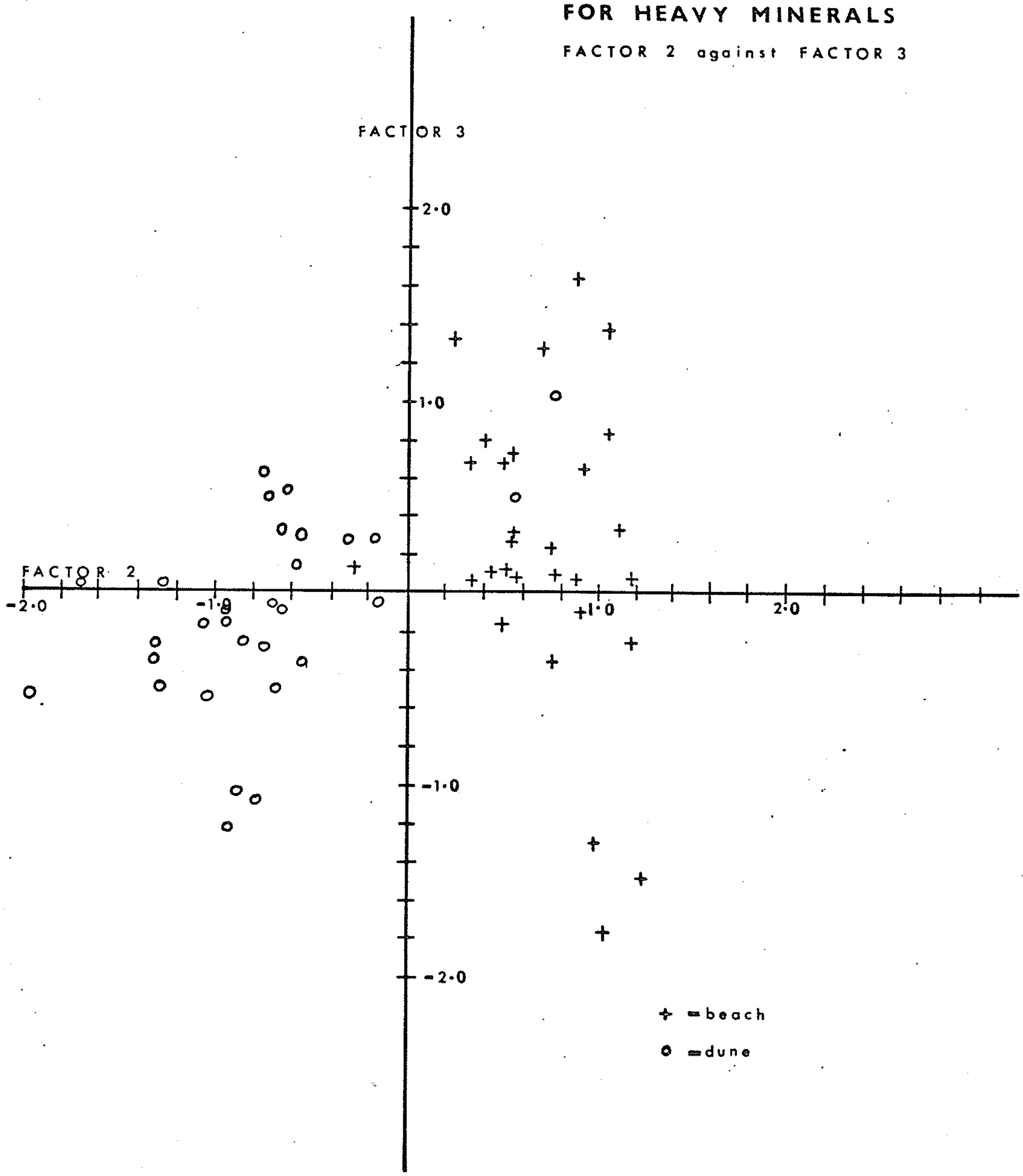


FIGURE 23
PLOTTED FACTOR SCORES FOR HEAVY MINERALS
FACTOR 2 against FACTOR 3



Chapter VI

DISCUSSION OF THE RESULTS

Introduction

Greenwood (1969) notes that the problem with factor analysis lies in interpreting the new variables obtained. He suggests that although the variables may differ between two environments, it is difficult to determine the geomorphological significance of the factors. The use of factor analysis in this manner is termed causal. In geologic terms it can be equated with process.

It is beyond the scope of this study to associate the factors obtained with specific geologic processes. However, there are several points that need to be examined. These indicate how the results obtained can be related to process.

Failure of the Klovan Technique

The first point to be examined is the reason for the failure of the Klovan technique to distinguish between the beach and dune samples. In Solohub's study at Grand Beach it was argued that the lacustrine environment could be compared to a marine environment. Discussion on the maximum wave heights possible at the site has already been presented. Further evidence of the difference was found by Miller and Zeigler (1958), in a study relating fluid dynamics to sediment pattern. They observed that in all marine beaches examined there was an increase of median size toward the shore. On a Lake Michigan beach, this trend was observed only in the shoaling wave zone (Miller and Zeigler, 1958). This is the first recognized sorting zone for a wave moving up a beach. It would suggest that at this point the energy of the wave is still sufficient to provide the expected sorting action. In the lacustrine environment the wave energy diminishes more rapidly due to the lower initial energy levels.

Finally, in general terms, it can be suggested that although the processes of wave action are similar between lake and marine, they are considerably diminished in the former. Reduced fetch, the lack of tides, and the relative shallowness of lakes all contribute to reduced wave energies.

The failure of the Klovan technique to distinguish between beach and dune on the basis of energy can be explained by examining the grain-sizes involved. All the samples gathered from Grand Beach were collected on sieves that ranged from 0.0Ø to 3.75Ø. 90 percent of this total was found in the range from 1Ø to 3Ø. G.S. Visher (1969) has shown that these values represent the saltation population of any depositional environment, regardless of the energy process. He found that 50 to 99 percent of beach material between 0.5Ø and 4.25Ø was a result of saltation activity. The range was determined by the Coarse Truncation and Fine Truncation points on the cumulative frequency curve, (Figure 25). For the dune 97 to 99 percent of movement was by saltation, with Coarse and Fine truncation points ranging from 1.0Ø to 4.0Ø. Sorting in both sand types was classified as excellent.

Similar associations between flexures in the size distribution curve and traction, saltation, and suspension populations were observed by Syed (1970). These studies were performed on samples from Lake Ontario beaches, while Visher's are from marine beaches. This seems to imply that in response to energy the marine and lacustrine environments are similar.

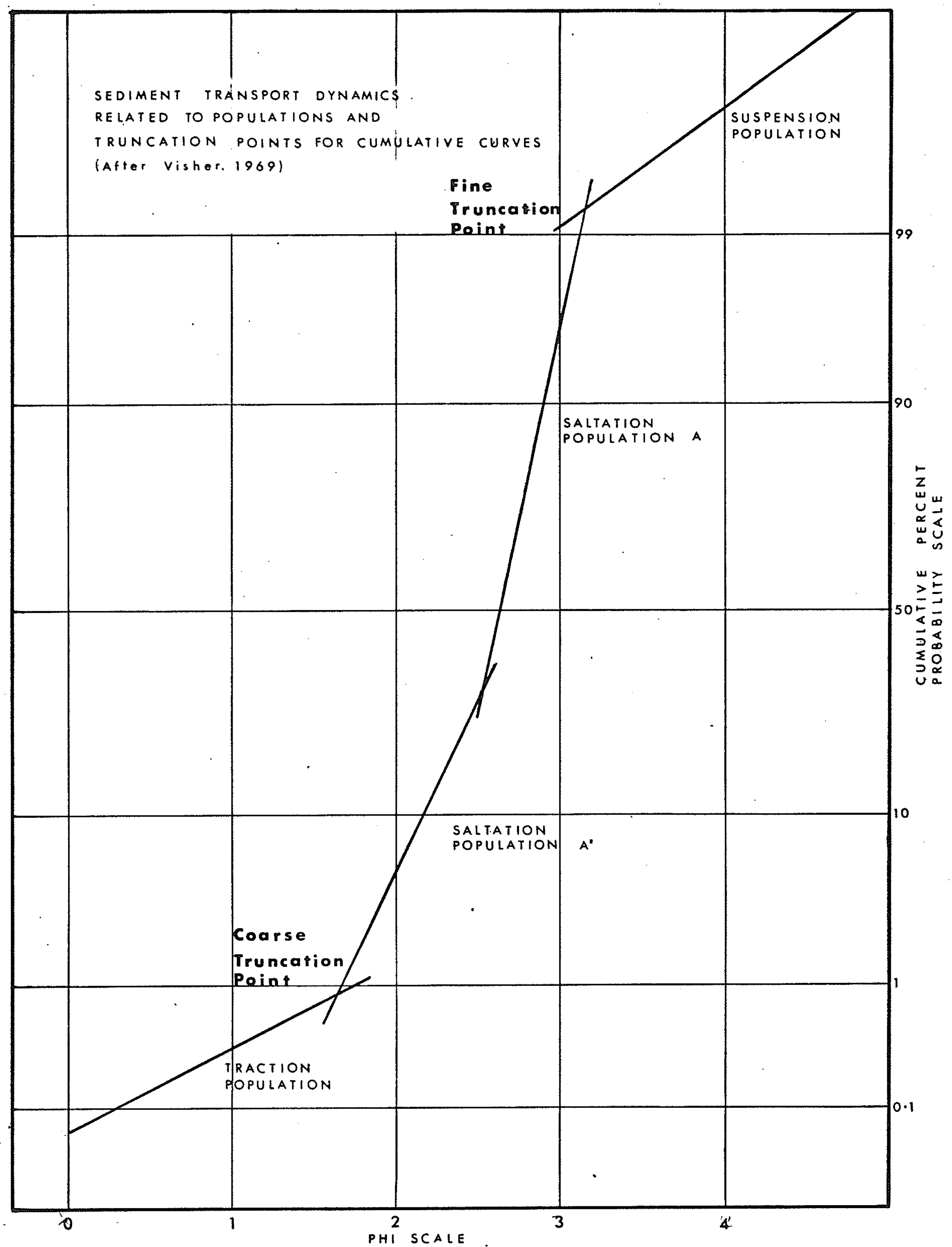

SEDIMENT TRANSPORT DYNAMICS
RELATED TO POPULATIONS AND
TRUNCATION POINTS FOR CUMULATIVE CURVES
(After Visher, 1969)
Fine Truncation Point
SUSPENSION POPULATION
SALTATION POPULATION A
SALTATION POPULATION A'
Coarse Truncation Point
TRACTION POPULATION
99
90
50
10
1
0·1
CUMULATIVE PERCENT PROBABILITY SCALE
0
1
2
3
4
PHI SCALE

FIGURE 24

If the energy input is quantitatively similar for beach and dune environments, and grain-size response is only slightly different, a different parameter must be found to provide distinction. The requirement is a parameter that can be easily measured. It must also be sensitive to similar energies, but react in a different manner.

Examination of the raw data in Appendix 1 shows comparative measurements of beach and dune samples. Grain-size measurements are similar, but heavy mineral percentages are markedly different. Five trends can be seen.

1. The ratio of heavy to light minerals is greater for the dune than for the beach.
2. Heavy minerals are found in a greater range of grain-sizes in the dune deposits than in the beach deposits.
3. Magnetite is almost non-existent in the beach samples, occurring only in sizes above 2.5Ø.
4. Magnetite is found in a majority of the grain-sizes of the dune samples.
5. There is a gradual increase in the quantity of magnetite with a decrease in grain-size for the dune samples.

The last observation agrees with the findings of Bradley (1959) at Mustang Island, Texas. His study determined that the average volume percentage of heavy minerals gradually increased from 0.04 percent for near-shore and beach samples, to 0.45 percent for adjacent dunes.

The relationship between a gradual inshore increase in heavy mineral percentage and a gradual inshore decrease in grain-size appears to be diagnostic. As the raw data shows, there is an increase in the percent of heavy minerals with a decrease in grain-size. It is suggested that this reflects the inability of wind action to frequently achieve the required energy to move these denser particles, while similar sized but lighter density particles may be removed. The result is a higher concentration of heavy minerals in the dunes.

Confirmation of this process should be reflected in higher volume percentages of heavy minerals in the fine grain-sizes of the dunes. (See Appendix 1).

While plotting factor scores does not provide any clear analysis of the depositional processes, it does provide a clearer separation of the two environments, thus showing that heavy minerals are a suitable diagnostic parameter. The following section attempts to explain why.

A key to using factor analysis to separate beach and dune environments seems to lie in the mechanical reaction of heavy minerals to a particular energy.

One theory is related to the concept that a heavy mineral should be studied using its 'hydraulic equivalent', rather than the usual parameters of size and shape.* Syed (1970) examined this idea and concluded that although a heavy mineral approximates its theoretical 'hydraulic equivalent' during deposition on a beach, it is the depositional shift that causes size differences after deposition.+ He concludes that although density controls the original deposition of heavy minerals on beaches, the difference between the size distribution of heavy and light minerals

* Hydraulic equivalence occurs when heavy mineral grains in suspension settle out faster than light grains of equal sizes and identical shapes under similar hydraulic conditions.

\+ Depositional Shift. The size difference between the light and heavy fraction cumulative curves at certain frequency levels.

is caused by selective sorting by breaking waves and wind at the site of deposition.

The implication of Syed's conclusion is that heavy minerals reflect most clearly the last depositional process experienced by the grains. However, in contrast Greenwood (1969) contends that, "... the dynamics of sedimentation and the energy levels present in different environments are readily recognised as influencing the resulting sedimentary deposits." He further states that the average particle size in a sedimentation unit represents the average size of material transported, regardless of mineralogic composition, and that this is a direct reflection of the kinetic energy of the depositing agent.

The present study suggests that the kinetic energy conditions at the site of deposition are not diagnostic. The work of Klovan (1966), Visher (1969), and Syed (1970) show that the different energies of wave and wind action result in the same transportation process, namely saltation. Grain-size distribution results of the Q-Mode factor analysis show that a high percentage (53%) of information is accounted for by one factor. Accepting Klovan's analysis of Factor 1 representing 'medium' energy, it would seem reasonable to conclude that this energy is representative of the energies of wind and wave action.

In contrast, heavy minerals, due to the depositional shift, do not appear to respond to similar kinetic energies in a similar manner. The factors that control deposition of heavy minerals react differently depending upon the agent of deposition. The factor analysis shows the reduced effect of kinetic energy. Factor 1 accounts for only 28 percent of the infomation in the heavy mineral matrix.

The problem of assigning geologic significance to the various factors still remains. However, the ability of factor analysis to discriminate between depositional environments is further enhanced by the results of this study.

Chapter VII

CONCLUSIONS

Determining the depositional environments of an ancient sedimentary deposit is a difficult problem. Several approaches have been attempted, most of which use statistical measures to characterize sedimentary deposits from different environments. Klovan (1966) proposed that factor analysis provided a method of data reduction and organization that showed significant trends among sedimentary samples on the basis of grain-size distribution.

Solohub (1970) tested several statistical approaches in different sedimentary environments. He determined that the Klovan technique provided the best discrimination between environments on the basis of energy at the site of deposition. The major exception was the separation of beach and dune deposits.

The Klovan technique was applied to beach and dune samples from Grand Beach, Manitoba. A Q-Mode factor analysis was run using grain-size and heavy mineral data. A plot of normalized factor components failed to distinguish between beach and dune samples. This held true for both grain-size and heavy mineral data.

A Biomed Q-Mode factor analysis was run on the same raw data as that used in the Klovan method. Factor scores were obtained as an integral part of the computed output. A reasonable separation of beach and dune samples was obtained by plotting grain-size by factor scores. The best separation was obtained by plotting the volume percentage of heavy minerals.

Although the heavy minerals provided a good separation using factor analysis, the causal analysis of the factors remains generally unknown. The Klovan suggestion that the first three factors represent various levels of kinetic energy appears to be confirmed. The high loadings on Factor 1, classified as 'medium' energy is drastically reduced when the volume percentage of heavy minerals are analysed.

Heavy minerals were found in greater concentrations in the dune samples than in the beach samples. They also showed an increased percentage with a decrease in grain-size. Light minerals and heavy minerals show a different response to similar levels of kinetic energy. Syed (1970) termed this process 'depositional shift' and showed that it occurred after a grain had been deposited.

The increased volume percentage of heavy minerals provides a diagnostic parameter for distinguishing between beach and dune environments. This appears to be true even in low energy lacustrine environments.

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APPENDIX 1

Sample #	Phi	Magnetite	Heavy Minerals Weight	Vol. %	Total Vol.
D1	0.00	-	-	-	-
	0.25	-	-	-	0.03
	0.50	-	-	-	0.02
	0.75	-	-	-	0.04
	1.00	-	0.02	5.40	0.37
	1.25	-	0.17	5.57	3.05
	1.50	0.01	0.40	3.48	11.76
	1.75	0.02	0.7;	3.89	18.73
	2.00	0.02	0.80	2.96	27.70
	2.25	0.04	0.75	2.96	26.60
	2.50	0.04	0.34	4.44	8.55
	2.75	0.05	0.16	10.24	2.05
	3.00	0.03	0.04	41.17	0.17
	3.25	0.01	0.02	30.00	0.10
	3.50	0.01	0.02	42.85	0.07
	3.75	-	-	-	-
D2	0.00	-	-	-	-
	0.25	-	-	-	0.03
	0.50	-	-	-	0.07
	0.75	-	-	-	0.09
	1.00	-	0.03	4.83	0.62
	1.25	-	0.19	5.62	3.38
	1.50	-	0.67	5.16	12.97
	1.75	0.01	0.90	3.90	23.31
	2.00	0.02	1.15	3.68	31.76
	2.25	0.03	0.95	4.72	20.73
	2.50	0.04	0.34	8.20	4.63
	2.75	0.06	0.12	17.47	1.03
	3.00	0.05	0.04	45.00	0.20
	3.25	0.03	0.01	40.00	0.10
	3.50	0.02	0.01	42.85	0.07
	3.75	-	-	-	-
D3	0.00	-	-	-	-
	0.25	-	-	-	0.02
	0.50	-	-	-	0.18
	0.75	-	0.03	4.34	0.69
	1.00	-	0.13	5.99	2.17
	1.25	-	0.19	4.75	4.00
	1.50	-	0.23	3.03	7.58
	1.75	-	0.27	2.07	13.00
	2.00	0.01	0.40	1.63	25.07
	2.25	0.01	0.68	2.19	31.45
	2.50	0.02	0.30	2.68	11.93
	2.75	0.04	0.16	6.09	3.28
	3.00	0.05	0.03	14.28	0.56
	3.25	0.02	0.01	42.85	0.07
	3.50	0.01	-	99.99	0.01
	3.75	-	-	-	-

Sample #	Phi	Magnetite	Heavy Minerals Weight	Vol. %	Total Vol.
D4	0.00	-	-	-	-
	0.25	-	-	-	0.01
	0.50	-	-	-	0.03
	0.75	-	-	-	0.11
	1.00	-	0.07	7.77	0.90
	1.25	-	0.17	4.49	3.78
	1.50	-	0.32	3.32	9.63
	1.75	-	0.40	2.63	15.20
	2.00	0.01	0.64	2.22	29.17
	2.25	0.02	0.68	2.53	27.65
	2.50	0.03	0.34	3.77	9.80
	2.75	0.05	0.18	8.61	2.67
	3.00	0.06	0.04	20.83	0.48
	3.25	0.02	0.01	50.00	0.06
	3.50	0.02	-	99.99	0.02
	3.75	0.01	-	99.99	0.01
D5	0.00	-	-	-	-
	0.25	-	-	-	0.06
	0.50	-	-	-	0.21
	0.75	-	0.02	6.06	0.33
	1.00	-	0.08	8.60	0.93
	1.25	-	0.21	5.55	3.78
	1.50	-	0.47	4.36	10.76
	1.75	0.01	0.72	3.75	19.46
	2.00	0.02	1.04	3.46	30.55
	2.25	0.04	0.84	3.67	23.96
	2.50	0.04	0.38	5.87	7.15
	2.75	0.07	0.17	12.63	1.90
	3.00	0.06	0.03	21.95	0.41
	3.25	0.02	0.01	42.85	0.07
	3.50	0.01	-	50.00	0.02
	3.75	-	-	-	-
D6	0.00	-	-	-	-
	0.25	-	-	-	0.01
	0.50	-	-	-	0.04
	0.75	-	-	-	0.10
	1.00	-	0.04	.645	0.62
	1.25	-	0.17	5.15	3.30
	1.50	-	0.38	3.91	9.70
	1.75	-	0.65	3.26	19.92
	2.00	0.02	0.88	2.95	30.44
	2.25	0.03	0.79	3.20	25.61
	2.50	0.04	0.35	5.05	7.72
	2.75	0.06	0.18	12.00	2.00
	3.00	0.06	0.04	23.80	0.42
	3.25	0.04	0.01	62.50	0.08
	3.50	0.01	-	50.00	0.02
	3.75	-	-	-	-

Sample #	Phi	Magnetite	Heavy Minerals Weight	Vol. %	Total Vol.
D7	0.00	-	-	-	-
	0.25	-	-	-	0.01
	0.50	-	-	-	0.06
	0.75	-	0.01	11.11	0.09
	1.00	-	0.07	6.25	1.12
	1.25	-	0.24	4.41	5.43
	1.50	-	0.33	3.34	9.86
	1.75	0.01	0.34	2.53	13.78
	2.00	0.02	0.48	2.07	24.13
	2.25	0.02	0.52	1.92	28.00
	2.50	0.03	0.31	2.78	12.23
	2.75	0.05	0.18	5.89	3.90
	3.00	0.07	0.13	25.97	0.77
	3.25	0.03	0.02	35.71	0.14
	3.50	0.02	0.01	50.00	0.06
	3.75	0.01	-	50.00	0.02
D8	0.00	-	-	-	-
	0.25	-	-	-	0.03
	0.50	-	-	-	0.08
	0.75	-	0.02	10.00	0.20
	1.00	-	0.07	6.25	1.12
	1.25	-	0.24	4.41	5.43
	1.50	-	0.33	3.34	9.86
	1.75	0.01	0.34	2.53	13.78
	2.00	0.02	0.48	2.07	24.13
	2.25	0.02	0.52	1.92	28.09
	2.50	0.03	0.31	2.78	12.23
	2.75	0.05	0.18	5.89	3.90
	3.00	0.05	0.03	26.66	0.30
	3.25	0.03	0.02	55.55	0.09
	3.50	0.02	0.01	75.00	0.04
	3.75	-	-	-	-
D9	0.00	-	-	-	-
	0.25	-	-	-	-
	0.50	-	-	-	0.02
	0.75	-	0.01	6.66	0.15
	1.00	-	0.09	8.57	1.05
	1.25	-	0.22	4.04	5.44
	1.50	-	0.36	3.29	10.93
	1.75	0.01	0.31	2.32	13.76
	2.00	0.02	0.54	2.25	24.78
	2.25	0.03	0.46	1.76	27.73
	2.50	0.04	0.27	2.70	11.44
	2.75	0.04	0.18	5.65	3.89
	3.00	0.07	0.11	26.08	0.69
	3.25	0.02	0.02	30.76	0.13
	3.50	0.01	0.01	33.33	0.06
	3.75	0.01	-	99.99	0.01

Sample #	Phi	Magnetite	Heavy Minerals Weight	Vol. %	Total Vol.
D10	0.00	-	-	-	-
	0.25	-	-	-	0.02
	0.50	-	-	-	0.07
	0.75	-	0.02	10.00	0.20
	1.00	-	0.05	7.14	0.70
	1.25	-	0.15	4.90	3.06
	1.50	-	0.49	4.24	11.54
	1.75	0.02	0.74	3.47	21.88
	2.00	0.03	0.98	3.19	31.66
	2.25	0.05	0.79	3.73	22.51
	2.50	0.05	0.34	6.59	5.91
	2.75	0.07	0.18	17.12	1.46
	3.00	0.04	0.03	25.00	0.28
	3.25	0.02	0.01	50.00	0.06
	3.50	0.01	0.01	66.66	0.03
	3.75	-	-	-	-
D11	0.00	-	-	-	-
	0.25	-	-	-	0.01
	0.50	-	-	-	0.06
	0.75	-	0.01	5.55	0.18
	1.00	-	0.06	5.04	1.19
	1.25	-	0.21	3.93	5.34
	1.50	-	0.32	3.14	10.17
	1.75	-	0.31	2.17	14.28
	2.00	0.01	0.34	1.58	22.09
	2.25	0.02	0.43	1.57	28.55
	2.50	0.03	0.28	2.40	12.89
	2.75	0.04	0.18	5.75	3.82
	3.00	0.05	0.03	10.66	0.75
	3.25	0.03	0.01	33.33	0.12
	3.50	0.02	0.01	60.00	0.05
	3.75	0.01	-	50.00	0.02
D12	0.00	-	-	-	-
	0.25	-	-	-	0.02
	0.50	-	-	-	0.07
	0.75	-	0.02	11.76	0.17
	1.00	-	0.04	5.26	0.76
	1.25	-	0.14	4.16	3.36
	1.50	-	0.31	3.44	9.00
	1.75	0.01	0.52	2.85	18.57
	2.00	0.03	0.66	2.44	28.27
	2.25	0.03	0.66	2.61	26.42
	2.50	0.03	0.35	4.11	9.23
	2.75	0.05	0.15	7.49	2.67
	3.00	0.04	0.02	15.00	0.40
	3.25	0.03	0.01	50.00	0.08
	3.50	0.02	0.01	50.00	0.06
	3.75	0.02	-	66.66	0.03

Sample #	Phi	Magnetite	Heavy Minerals Weight	Vol. %	Total Vol.
D13	0.00	-	-	-	-
	0.25	-	-	-	0.01
	0.50	-	-	-	0.06
	0.75	-	0.03	15.00	0.20
	1.00	-	0.05	5.68	0.88
	1.25	-	0.15	3.75	3.99
	1.50	-	0.26	3.19	8.13
	1.75	-	0.39	2.51	15.53
	2.00	0.01	0.54	2.05	26.80
	2.25	0.01	0.51	1.87	27.68
	2.50	0.03	0.29	2.78	11.49
	2.75	0.04	0.18	5.99	3.67
	3.00	0.06	0.04	14.49	0.69
	3.25	0.03	0.02	50.00	0.10
	3.50	0.02	0.01	75.00	0.04
	3.75	0.01	0.01	99.99	0.02
D14	0.00	-	-	-	-
	0.25	-	-	-	0.02
	0.50	-	0.01	6.66	0.15
	0.75	-	0.04	9.30	0.43
	1.00	-	0.06	4.87	1.23
	1.25	-	0.14	4.03	3.47
	1.50	-	0.16	2.93	5.46
	1.75	-	0.33	2.42	13.63
	2.00	0.01	0.48	1.91	25.63
	2.25	0.02	0.55	11.84	30.90
	2.50	0.03	0.33	2.67	13.44
	2.75	0.05	0.20	5.84	4.28
	3.00	0.08	0.05	16.88	0.77
	3.25	0.03	0.02	38.46	0.13
	3.50	0.01	0.01	50.00	0.04
	3.75	0.01	-	50.00	0.02
D15	0.00	-	-	-	-
	0.25	-	-	-	0.06
	0.50	-	0.02	8.33	0.24
	0.75	-	0.05	7.81	0.64
	1.00	-	0.08	5.06	1.58
	1.25	-	0.13	4.00	3.25
	1.50	-	0.17	3.09	5.49
	1.75	-	0.33	2.40	13.75
	2.00	0.02	0.50	1.90	27.36
	2.25	0.03	0.54	1.88	30.17
	2.50	0.04	0.30	2.73	12.44
	2.75	0.05	0.18	5.75	4.00
	3.00	0.05	0.02	10.44	0.67
	3.25	0.03	0.01	44.44	0.09
	3.50	0.01	0.01	66.66	0.03
	3.75	-	-	-	-

Sample #	Phi	Magnetite	Heavy Minerals Weight	Vol. %	Total Vol.
D16	0.00	-	-	-	-
	0.25	-	-	-	0.01
	0.50	-	-	-	0.04
	0.75	-	-	-	0.11
	1.00	-	0.05	5.00	1.00
	1.25	-	0.20	3.86	5.18
	1.50	-	0.26	3.24	8.01
	1.75	-	0.39	2.53	15.40
	2.00	0.01	0.49	1.97	25.27
	2.25	0.01	0.53	1.91	28.16
	2.50	0.03	0.32	2.90	12.05
	2.75	0.05	0.20	6.15	4.06
	3.00	0.04	0.03	14.00	0.50
	3.25	0.02	0.02	36.36	0.11
	3.50	0.02	0.02	50.00	0.08
	3.75	0.01	-	50.00	0.02
D17	0.00	-	-	-	-
	0.25	-	-	-	-
	0.50	-	-	-	-
	0.75	-	-	-	0.06
	1.00	-	0.09	26.47	0.34
	1.25	-	0.15	3.22	4.65
	1.50	-	0.19	2.82	6.72
	1.75	-	0.53	2.99	17.69
	2.00	0.02	1.00	3.08	33.04
	2.25	0.03	1.10	3.90	28.95
	2.50	0.04	0.52	6.60	8.48
	2.75	0.08	0.26	14.97	2.27
	3.00	0.04	0.02	12.50	0.48
	3.25	0.03	0.01	40.00	0.10
	3.50	0.01	0.01	66.66	0.03
	3.75	-	-	-	0.01
D18	0.00	-	-	-	-
	0.25	-	-	-	0.01
	0.50	-	-	-	0.06
	0.75	-	0.01	7.14	0.14
	1.00	-	0.04	9.52	0.42
	1.25	-	0.08	4.00	2.00
	1.50	-	0.27	3.20	8.43
	1.75	0.01	0.50	2.84	17.92
	2.00	0.01	0.97	2.78	35.20
	2.25	0.03	0.85	3.29	26.72
	2.50	0.03	0.38	5.71	7.18
	2.75	0.05	0.18	14.46	1.59
	3.00	0.04	0.03	17.50	0.40
	3.25	0.02	0.02	30.76	0.13
	3.50	0.02	0.01	50.00	0.06
	3.75	0.01	0.01	66.66	0.03

Sample #	Phi	Magnetite	Heavy Minerals Weight	Vol. %	Total Vol.
D19	0.00	-	-	-	-
	0.25	-	-	-	0.02
	0.50	-	-	-	0.11
	0.75	-	0.02	7.69	0.26
	1.00	-	0.04	5.79	0.69
	1.25	-	0.11	4.29	2.56
	1.50	-	0.32	3.43	9,32
	1.75	0.02	0.52	2.92	18.44
	2.00	0.02	0.85	2.65	32.76
	2.25	0.04	0.78	3.14	26.05
	2.50	0.04	0.34	5.24	7.24
	2.75	0.05	0.17	11.95	1.84
	3.00	0.04	0.02	17.64	0.34
	3.25	0.02	0.01	50.00	0.06
	3.50	0.01	0.01	50.00	0.04
	3.75	0.01	-	50.00	0.02
D20	0.00	-	-	-	-
	0.25	-	-	-	0.04
	0.50	-	0.01	4.34	0.23
	0.75	-	0.08	12.12	0.66
	1.00	-	0.08	4.73	1.69
	1.25	-	0.10	3.75	2.66
	1.50	-	0.10	2.80	3.56
	1.75	-	0.20	2.00	10.00
	2.00	0.01	0.40	1.56	26.22
	2.25	0.03	0.52	1.60	34.30
	2.50	0.03	0.38	2.70	15.14
	2.75	0.06	0.20	5.89	4.41
	3.00	0.06	0.04	12.04	0.83
	3.25	0.03	0.02	33.33	0.15
	3.50	0.02	0.01	42.85	0.07
	3.75	0.01	-	50.00	0.02
D21	0.00	-	-	-	-
	0.25	-	-	-	-
	0.50	-	-	-	0.02
	0.75	-	-	-	0.08
	1.00	-	0.03	7.89	0.38
	1.25	-	0.15	6.66	2.25
	1.50	-	0.25	2.72	9.16
	1.75	0.01	0.49	2.57	19.40
	2.00	0.03	0.70	2.31	31.56
	2.25	0.03	0.56	2.18	27.00
	2.50	0.04	0.25	3.80	7.63
	2.75	0.06	0.16	11.00	2.00
	3.00	0.03	0.02	13.51	0.37
	3.25	0.02	0.01	37.50	0.08
	3.50	0.01	0.01	66.66	0.03
	3.75	-	-	-	-

Sample #	Phi	Magnetite	Heavy Minerals Weight	Vol. %	Total Vol.
D22	0.00	-	-	-	-
	0.25	-	-	-	0.02
	0.50	-	-	-	0.10
	0.75	-	0.02	6.06	0.33
	1.00	-	0.07	5.60	1.25
	1.25	-	0.13	3.51	3.70
	1.50	-	0.20	2.82	7.07
	1.75	0.01	0.42	3.16	13.58
	2.00	0.01	0.43	1.67	26.30
	2.25	0.03	0.66	2.28	30.14
	2.50	0.03	0.29	2.55	12.53
	2.75	0.04	0.18	5.55	3.96
	3.00	0.07	0.04	13.92	0.79
	3.25	0.03	0.02	31.25	0.16
	3.50	0.02	0.01	50.00	0.06
	3.75	0.01	0.01	66.66	0.03
D23	0.00	-	-	-	-
	0.25	-	-	-	0.02
	0.50	-	-	-	0.08
	0.75	-	0.01	4.54	0.22
	1.00	-	0.05	6.94	0.72
	1.25	-	0.15	4.76	3.15
	1.50	-	0.48	4.76	10.08
	1.75	-	0.69	3.73	18.49
	2.00	0.02	0.88	2.92	30.78
	2.25	0.05	0.80	3.54	23.94
	2.50	0.05	0.30	4.03	8.67
	2.75	0.07	0.17	10.76	2.23
	3.00	0.05	0.04	26.47	0.34
	3.25	0.03	0.02	45.45	0.11
	3.50	0.02	0.02	57.14	0.07
	3.75	0.01	0.01	66.66	0.03
D24	0.00	-	-	-	-
	0.25	-	-	-	0.02
	0.50	-	-	-	0.15
	0.75	-	0.04	7.69	0.52
	1.00	-	0.09	5.35	1.68
	1.25	-	0.11	5.78	1.90
	1.50	-	0.08	2.50	3.19
	1.75	-	0.15	1.66	9.00
	2.00	0.01	0.37	1.44	26.26
	2.25	0.02	0.44	1.33	34.34
	2.50	0.02	0.29	1.95	16.40
	2.75	0.06	0.20	5.02	5.02
	3.00	0.07	0.11	18.00	1.00
	3.25	0.03	0.01	33.33	0.12
	3.50	0.01	0.01	66.66	0.03
	3.75	-	-	-	0.01

Sample #	Phi	Magnetite	Heavy Minerals Weight	Vol. %	Total Vol.
D25	0.00	–	–	–	–
	0.25	–	–	–	0.03
	0.50	–	–	–	0.10
	0.75	–	0.01	5.55	0.18
	1.00	–	0.04	6.66	0.60
	1.25	–	0.17	5.29	3.21
	1.50	–	0.53	4.89	10.83
	1.75	0.02	0.86	3.94	22.28
	2.00	0.03	1.08	3.51	31.59
	2.25	0.04	0.78	3.72	22.00
	2.50	0.04	0.35	5.78	6.74
	2.75	0.09	0.16	15.15	1.65
	3.00	0.04	0.02	22.22	0.27
	3.25	0.01	0.01	50.00	0.04
	3.50	0.01	–	50.00	0.02
	3.75	–	–	–	0.01
D26	0.00	–	–	–	–
	0.25	–	–	–	–
	0.50	–	–	–	0.02
	0.75	–	–	–	0.03
	1.00	–	0.04	19.04	0.21
	1.25	–	0.05	2.70	1.85
	1.50	–	0.21	2.68	7.81
	1.75	0.02	0.50	2.66	19.48
	2.00	0.02	0.73	2.30	32.48
	2.25	0.04	0.63	2.40	27.83
	2.50	0.05	0.31	4.58	7.86
	2.75	0.05	0.14	10.00	1.90
	3.00	0.03	0.02	17.85	0.28
	3.25	0.02	0.02	57.14	0.07
	3.50	0.01	–	50.00	0.02
	3.75	–	–	–	–
D27	0.00	–	–	–	–
	0.25	–	–	–	0.01
	0.50	–	–	–	0.05
	0.75	–	–	–	0.11
	1.00	–	0.03	9.37	0.32
	1.25	–	0.11	5.82	1.89
	1.50	0.01	0.30	4.42	7.00
	1.75	0.02	0.60	3.51	17.66
	2.00	0.03	0.78	2.73	29.62
	2.25	0.04	0.78	2.73	30.00
	2.50	0.05	0.40	4.50	10.00
	2.75	0.07	0.22	10.78	2.69
	3.00	0.06	0.03	15.51	0.58
	3.25	0.02	0.01	50.00	0.06
	3.50	0.01	–	50.00	0.02
	3.75	–	–	–	0.01

Sample #	Phi	Magnetite	Heavy Minerals Weight	Vol. %	Total Vol.
D28	0.00	-	-	-	-
	0.25	-	-	-	0.05
	0.50	-	-	-	0.09
	0.75	-	-	-	0.17
	1.00	-	0.14	25.45	0.55
	1.25	-	0.17	6.46	2.63
	1.50	0.01	0.49	5.23	5.55
	1.75	0.03	0.87	4.38	20.52
	2.00	0.03	1.05	3.60	30.00
	2.25	0.04	0.88	3.61	25.46
	2.50	0.06	0.45	6.19	8.23
	2.75	0.08	0.20	13.95	2.15
	3.00	0.04	0.04	17.02	0.47
	3.25	0.02	0.02	44.44	0.09
	3.50	0.01	-	50.00	0.02
	3.75	-	-	-	-
D29	0.00	-	-	-	-
	0.25	-	-	-	0.02
	0.50	-	-	-	0.07
	0.75	-	0.03	10.71	0.28
	1.00	-	0.18	12.08	1.49
	1.25	-	0. 35	6.86	5.10
	1.50	-	0.34	4.58	7.41
	1.75	-	0.47	4.26	11.02
	2.00	0.01	0.55	2.66	20.99
	2.25	0.03	0.42	1.43	31.27
	2.50	0.04	0.40	2.84	15.46
	2.75	0.06	0.27	6.08	5.42
	3.00	0.09	0.10	18.26	1.04
	3.25	0.04	0.02	31.57	0.19
	3.50	0.02	0.01	50.00	0.06
	3.75	0.01	-	-	0.01
D30	0.00	-	-	-	-
	0.25	-	-	-	-
	0.50	-	-	-	0.01
	0.75	-	-	-	0.06
	1.00	-	0.12	37.50	0.32
	1.25	-	0.21	10.00	2.10
	1.50	-	0.34	5.01	6.78
	1.75	0.01	0.53	2.64	18.42
	2.00	0.02	1.15	3.19	36.61
	2.25	0.03	0.99	3.89	26.20
	2.50	0.03	0.52	7.59	7.24
	2.75	0.04	0.22	16.35	1.59
	3.00	0.04	0.03	23.33	0.30
	3.25	0.02	0.01	75.00	0.04
	3.50	0.01	-	-	0.01
	3.75	-	-	-	-

Sample #	Phi	Magnetite	Heavy Minerals Weight	Vol. %	Total Vol.
B1	0.00	-	-	-	-
	0.25	-	-	-	-
	0.50	-	-	-	0.01
	0.75	-	-	-	0.03
	1.00	-	-	-	0.13
	1.25	-	0.10	10.98	0.91
	1.50	-	0.11	4.08	2.69
	1.75	-	0.38	2.44	15.52
	2.00	-	0.91	2.32	39.08
	2.25	-	0.82	2.40	34.11
	2.50	-	0.26	4.01	6.47
	2.75	0.01	0.13	17.28	0.81
	3.00	0.02	0.01	33.33	0.09
	3.25	0.01	-	50.00	0.02
	3.50	-	-	-	0.01
	3.75	-	-	-	-
B2	0.00	-	-	-	-
	0.25	-	-	-	-
	0.50	-	-	-	-
	0.75	-	-	-	0.02
	1.00	-	-	-	0.08
	1.25	-	0.05	6.49	0.77
	1.50	-	0.20	4.79	4.17
	1.75	-	0.35	2.53	13.80
	2.00	-	0.86	2.22	38.71
	2.25	-	0.83	2.40	34.57
	2.50	-	0.26	3.80	6.83
	2.75	0.02	0.11	15.11	0.86
	3.00	0.04	0.02	54.54	0.11
	3.25	0.02	-	66.66	0.03
	3.50	0.01	-	50.00	0.02
	3.75	-	-	-	-
B3	0.00	-	-	-	-
	0.25	-	-	-	0.03
	0.50	-	-	-	0.06
	0.75	-	0.01	9.09	0.11
	1.00	-	0.03	8.10	0.37
	1.25	-	0.17	10.75	1.58
	1.50	-	0.26	5.48	4.74
	1.75	-	0.34	2.60	13.03
	2.00	-	0.85	2.27	37.43
	2.25	-	0.70	2.09	33.44
	2.50	0.01	0.31	4.04	7.91
	2.75	0.03	0.14	18.27	0.93
	3.00	0.01	0.03	28.57	0.14
	3.25	0.01	-	50.00	0.02
	3.50	-	-	-	0.01
	3.75	-	-	-	-

Sample #	Phi	Magnetite	Heavy Minerals Weight	Heavy Minerals Vol. %	Total Vol.
B4	0.00	-	-	-	-
	0.25	-	-	-	0.01
	0.50	-	-	-	0.02
	0.75	-	-	-	0.07
	1.00	-	0.07	14.89	0.47
	1.25	-	0.18	5.35	3.36
	1.50	-	0.42	5.23	8.03
	1.75	-	0.60	2.58	23.19
	2.00	-	0.76	2.26	33.51
	2.25	-	0.59	2.31	25.49
	2.50	-	0.29	5.65	5.13
	2.75	0.01	0.06	12.96	0.54
	3.00	0.01	-	33.33	0.03
	3,25	-	-	-	0.01
	3.50	-	-	-	-
	3.75	-	-	-	-
B5	0.00	-	-	-	-
	0.25	-	-	-	0.01
	0.50	-	-	-	0.01
	0.75	-	-	-	0.02
	1.00	-	-	-	0.18
	1.25	-	0.06	5.40	1.11
	1.50	-	0.15	3.37	4.45
	1.75	-	0.42	2.46	17.03
	2.00	-	0.90	2.47	36.35
	2.25	-	0.83	2.50	33.15
	2.50	-	0.31	4.55	6.81
	2.75	0.01	0.05	8.10	0.74
	3.00	0.02	0.02	57.14	0.07
	3.25	0.01	-	50.00	0.02
	3.50	-	-	-	-
	3.75	-	-	-	-
B6	0.00	-	-	-	-
	0.25	-	-	-	0.01
	0.50	-	-	-	0.02
	0.75	-	-	-	0.05
	1.00	-	0.01	4.54	0.22
	1.25	-	0.07	4.60	1.52
	1.50	-	0.26	4.39	5.92
	1.75	-	0.42	2.47	16.96
	2.00	-	0.75	2.03	36.79
	2.25	-	0.69	2.17	31.69
	2.50	-	0.28	4.56	6.14
	2.75	0.01	0.07	12.69	0.63
	3.00	0.01	0.01	50.00	0.04
	3.25	-	-	-	0.01
	3.50	-	-	-	-
	3.75	-	-	-	-

Sample #	Phi	Magnetite	Heavy Minerals Weight	Vol. %	Total Vol.
B7	0.00	-	-	-	-
	0.25	-	-	-	-
	0.50	-	-	-	-
	0.75	-	-	-	0.01
	1.00	-	-	-	0.06
	1.25	-	0.01	2.22	0.45
	1.50	-	0.11	5.69	1.93
	1.75	-	0.28	2.36	11.86
	2.00	-	0.74	2.03	36.36
	2.25	-	0.83	2.10	39.40
	2.50	-	0.40	4.55	8.78
	2.75	0.01	0.09	9.52	1.05
	3.00	0.02	0.03	62.50	0.08
	3.25	0.01	-	50.00	0.02
	3.50	-	-	-	-
	3.75	-	-	-	-
B8	0.00	-	-	-	-
	0.25	-	-	-	0.01
	0.50	-	-	-	0.01
	0.75	-	-	-	0.03
	1.00	-	0.01	7.69	0.13
	1.25	-	0.05	4.80	1.04
	1.50	-	0.14	3.40	4.11
	1.75	-	0.39	2.52	15.47
	2.00	-	0.81	2.18	37.06
	2.25	-	0.80	2.29	34.84
	2.50	-	0.31	4.65	6.66
	2.75	0.01	0.04	10.00	0.50
	3.00	0.02	0.01	50.00	0.06
	3.25	0.01	-	50.00	0.02
	3.50	-	-	-	-
	3.75	-	-	-	-
B9	0.00	-	-	-	-
	0.25	-	-	-	0.05
	0.50	-	-	-	0.08
	0.75	-	0.03	18.75	0.16
	1.00	-	0.05	9.61	0.52
	1.25	-	0.07	3.55	1.97
	1.50	-	0.18	3.15	5.71
	1.75	-	0.39	2.46	15.80
	2.00	-	0.82	2.29	35.71
	2.25	-	0.79	2.44	32.28
	2.50	-	0.27	3.92	6.88
	2.75	0.02	0.08	13.88	0.72
	3.00	0.03	0.02	62.50	0.08
	3.25	0.01	-	-	0.01
	3.50	-	-	-	0.01
	3.75	-	-	-	-

Sample #	Phi	Magnetite	Heavy Minerals Weight	Heavy Minerals Vol. %	Total Vol.
B10	0.00	–	–	–	–
	0.25	–	–	–	0.01
	0.50	–	–	–	0.03
	0.75	–	0.02	20.00	0.10
	1.00	–	0.06	13.04	0.46
	1.25	–	0.09	3.75	2.40
	1.50	–	0.21	3.05	6.87
	1.75	–	0.55	2.64	20.79
	2.00	–	0.77	2.16	35.58
	2.25	–	0.67	2.36	28.29
	2.50	–	0.23	4.83	4.76
	2.75	0.01	0.03	7.84	0.51
	3.00	0.03	0.01	66.66	0.06
	3.25	0.01	–	50.00	0.02
	3.50	–	–	–	–
	3.75	–	–	–	–
B11	0.00	–	–	–	–
	0.25	–	–	–	0.01
	0.50	–	–	–	0.01
	0.75	–	–	–	0.05
	1.00	–	0.02	10.00	0.20
	1.25	–	0.06	4.16	1.44
	1.50	–	0.19	3.38	5.61
	1.75	–	0.39	2.43	16.00
	2.00	–	0.81	2.27	35.63
	2.25	–	0.74	2.17	34.03
	2.50	–	0.29	4.38	6.62
	2.75	0.01	0.05	9.37	0.64
	3.00	0.02	0.03	62.50	0.08
	3.25	0.01	–	50.00	0.02
	3.50	–	–	–	0.01
	3.75	–	–	–	–
B12	0.00	–	–	–	–
	0.25	–	–	–	0.01
	0.50	–	–	–	0.01
	0.75	–	–	–	0.06
	1.00	–	0.01	4.54	0.22
	1.25	–	0.05	3.78	1.32
	1.50	–	0.16	3.59	4.45
	1.75	–	0.38	2.21	17.18
	2.00	–	0.79	2.14	36.86
	2.25	–	0.67	2.07	32.23
	2.50	–	0.28	4.17	6.70
	2.75	–	0.07	10.29	0.68
	3.00	0.01	0.01	40.00	0.05
	3.25	–	–	–	0.03
	3.50	–	–	–	–
	3.75	–	–	–	–

Sample #	Phi	Magnetite	Heavy Minerals Weight	Heavy Minerals Vol. %	Total Vol.
B13	0.00	-	-	-	-
	0.25	-	-	-	-
	0.50	-	-	-	0.01
	0.75	-	-	-	0.02
	1.00	-	0.01	14.28	0.07
	1.25	-	0.03	4.61	0.65
	1.50	-	0.08	3.00	2.66
	1.75	-	0.36	2.56	14.05
	2.00	-	0.77	2.24	34.35
	2.25	-	0.89	2.36	37.68
	2.50	-	0.35	3.89	8.98
	2.75	-	0.11	9.90	1.11
	3.00	0.04	0.02	46.15	0.13
	3.25	0.01	0.01	66.66	0.03
	3.50	0.01	-	50.00	0.02
	3.75	-	-	-	0.01
B14	0.00	-	-	-	-
	0.25	-	-	-	0.01
	0.50	-	-	-	0.01
	0.75	-	0.02	22.22	0.09
	1.00	-	0.04	8.16	0.49
	1.25	-	0.10	3.96	2.52
	1.50	-	0.25	3.14	7.94
	1.75	-	0.54	2.63	20.52
	2.00	-	0.75	2.05	36.56
	2.25	-	0.60	2.24	26.78
	2.50	-	0.22	5.03	4.37
	2.75	0.01	0.03	8.00	0.50
	3.00	0.02	0.02	66.66	0.06
	3.25	0.01	-	33.33	0.03
	3.50	-	-	-	0.01
	3.75	-	-	-	-
B15	0.00	-	-	-	-
	0.25	-	-	-	0.01
	0.50	-	-	-	0.03
	0.75	-	-	-	0.07
	1.00	-	0.03	8.33	0.36
	1.25	-	0.09	5.29	1.70
	1.50	-	0.16	3.04	5.25
	1.75	-	0.35	2.36	14.80
	2.00	-	0.93	2.51	37.00
	2.25	-	0.74	2.19	33.71
	2.50	-	0.29	4.74	6.11
	2.75	0.02	0.08	14.28	0.70
	3.00	0.01	0.01	20.00	0.10
	3.25	0.01	-	50.00	0.02
	3.50	-	-	-	-
	3.75	-	-	-	-

Sample #	Phi	Magnetite	Heavy Minerals Weight	Vol. %	Total Vol.
B16	0.00	-	-	-	-
	0.25	-	-	-	0.02
	0.50	-	0.01	16.66	0.06
	1.75	-	0.04	25.00	0.16
	1.00	-	0.10	11.90	0.84
	1.25	-	0.17	5.21	3.26
	1.50	-	0.22	2.63	8.36
	1.75	-	0.47	2.52	18.60
	2.00	-	0.82	2.42	33.86
	2.25	-	0.71	2.40	29.54
	2.50	-	0.17	3.55	4.78
	2.75	0.01	0.05	12.50	0.48
	3.00	0.01	0.01	66.66	0.03
	3.25	-	-	-	0.01
	3.50	-	-	-	-
	3.75	-	-	-	-
B17	0.00	-	-	-	-
	0.25	-	-	-	-
	0.50	-	-	-	0.01
	0.75	-	-	-	0.05
	1.00	-	0.02	7.40	0.27
	1.25	-	0.08	4.79	1.67
	1.50	-	0.13	2.36	5.49
	1.75	-	0.37	2.58	14.29
	2.00	-	0.90	2.31	38.95
	2.25	-	0.77	2.40	32.00
	2.50	-	0.28	4.46	6.27
	2.75	0.01	0.09	14.28	0.70
	3.00	0.02	0.05	30.43	0.23
	3.25	0.01	-	33.33	0.03
	3.50	-	-	-	0.01
	3.75	-	-	-	-
B18	0.00	-	-	-	-
	0.25	-	-	-	0.01
	0.50	-	-	-	0.02
	0.75	-	-	-	0.03
	1.00	-	-	-	0.15
	1.25	-	0.04	4.16	0.96
	1.50	-	0.11	3.47	3.17
	1.75	-	0.32	2.80	11.40
	2.00	-	0.81	2.31	35.00
	2.25	-	0.83	2.18	38.06
	2.50	0.01	0.39	4.14	9.65
	2.75	0.02	0.11	10.07	1.29
	3.00	0.02	0.08	50.00	0.20
	3.25	0.01	0.01	66.66	0.03
	3.50	-	-	-	0.01
	3.75	-	-	-	-

Sample #	Phi	Magnetite	Heavy Minerals Weight	Heavy Minerals Vol. %	Total Vol.
B19	0.00	-	-	-	-
	0.25	-	-	-	0.05
	0.50	-	-	-	0.11
	0.75	-	0.04	13.10	0.29
	1.00	-	0.07	7.08	0.96
	1.25	-	0.15	3.79	3.95
	1.50	-	0.38	5.65	6.72
	1.75	-	0.41	2.33	17.57
	2.00	-	0.86	2.43	35.39
	2.25	-	0.73	2.53	28.81
	2.50	-	0.31	5.43	5.70
	2.75	0.01	0.03	6.55	0.61
	3.00	0.02	0.02	50.00	0.08
	3.25	0.01	0.01	50.00	0.04
	3.50	-	-	-	0.01
	3.75	-	-	-	-
B20	0.00	-	-	-	-
	0.25	-	-	-	0.01
	0.50	-	-	-	0.02
	0.75	-	-	-	0.04
	1.00	-	0.01	4.16	0.24
	1.25	-	0.10	7.46	1.34
	1.50	-	0.22	5.68	3.87
	1.75	-	0.37	2.28	16.16
	2.00	-	0.90	2.32	38.66
	2.25	-	0.82	2.49	32.83
	2.50	-	0.28	4.68	5.98
	2.75	0.01	0.04	7.24	0.69
	3.00	0.01	0.01	22.22	0.09
	3.25	0.01	0.01	66.66	0.03
	3.50	-	-	-	0.01
	3.75	-	-	-	-
B21	0.00	-	-	-	-
	0.25	-	-	-	-
	0.50	-	-	-	0.01
	0.75	-	-	-	0.02
	1.00	-	-	-	0.09
	1.25	-	0.07	8.53	0.82
	1.50	-	0.20	6.43	3.11
	1.75	-	0.34	2.24	15.17
	2.00	-	0.91	2.41	37.63
	2.25	-	0.94	2.67	35.08
	2.50	-	0.38	5.38	7.06
	2.75	0.02	0.08	12.50	0.80
	3.00	0.01	0.01	25.00	0.08
	3.25	0.01	0.02	60.00	0.05
	3.50	-	-	-	0.02
	3.75	-	-	-	-

Sample #	Phi	Magnetite	Heavy Minerals Weight	Vol. %	Total Vol.
B22	0.00	–	–	–	–
	0.25	–	–	–	–
	0.50	–	–	–	0.01
	0.75	–	–	–	0.03
	1.00	–	–	–	0.06
	1.25	–	0.02	3.70	0.54
	1.50	–	0.13	5.32	2.44
	1.75	–	0.28	2.15	13.01
	2.00	–	0.87	2.31	37.56
	2.25	–	0.82	2.15	38.10
	2.50	–	0.35	4.78	7.31
	2.75	0.01	0.05	7.69	0.78
	3.00	0.01	0.02	42.85	0.07
	3.25	0.01	0.01	50.00	0.04
	3.50	0.01	–	50.00	0.02
	3.75	–	–	–	–
B23	0.00	–	–	–	–
	0.25	–	–	–	0.01
	0.50	–	–	–	0.02
	0.75	–	–	–	0.04
	1.00	–	0.02	8.69	0.23
	1.25	–	0.07	4.66	1.50
	1.50	–	0.17	3.48	4.88
	1.75	–	0.37	2.05	18.00
	2.00	–	0.93	2.35	39.48
	2.25	–	0.67	2.00	33.38
	2.50	–	0.33	4.12	8.00
	2.75	0.01	0.04	8.33	0.60
	3.00	0.01	0.01	28.57	0.07
	3.25	0.01	–	33.33	0.03
	3.50	–	–	–	0.01
	3.75	–	–	–	–
B24	0.00	–	–	–	–
	0.25	–	–	–	0.02
	0.50	–	–	–	0.06
	0.75	–	0.01	10.00	0.10
	1.00	–	0.04	9.52	0.42
	1.25	–	0.12	5.91	2.03
	1.50	–	0.28	4.50	6.21
	1.75	–	0.41	2.37	17.25
	2.00	–	0.87	2.35	37.00
	2.25	–	0.69	2.29	30.11
	2.50	–	0.28	5.39	5.19
	2.75	0.01	0.05	9.67	0.62
	3.00	0.01	0.02	30.00	0.10
	3.25	0.01	0.01	40.00	0.05
	3.50	–	–	–	0.01
	3.75	–	–	–	–

Sample #	Phi	Magnetite	Heavy Minerals Weight	Vol. %	Total Vol.
B25	0.00	-	-	-	-
	0.25	-	-	-	0.01
	0.50	-	-	-	0.01
	0.75	-	-	-	0.04
	1.00	-	0.01	6.66	0.15
	1.25	-	0.09	8.65	1.04
	1.50	-	0.18	4.65	3.87
	1.75	-	0.41	2.89	14.15
	2.00	-	0.86	2.35	36.55
	2.25	-	0.81	2.33	34.72
	2.50	0.01	0.30	4.07	7.60
	2.75	0.02	0.10	13.79	0.87
	3.00	0.01	0.02	33.33	0.09
	3.25	0.01	0.02	42.85	0.07
	3.50	-	-	-	0.01
	3.75	-	-	-	-
B26	0.00	-	-	-	-
	0.25	-	-	-	-
	0.50	-	-	-	0.01
	0.75	-	-	-	0.07
	1.00	-	0.02	5.26	0.38
	1.25	-	0.13	6.91	1.88
	1.50	-	0.22	5.02	4.38
	1.75	-	0.39	2.68	14.52
	2.00	-	0.90	2.44	36.85
	2.25	-	0.86	2.57	33.46
	2.50	0.01	0.32	4.78	6.90
	2.75	0.01	0.08	10.34	0.87
	3.00	0.01	0.02	30.00	0.10
	3.25	0.01	0.01	33.33	0.06
	3.50	0.01	-	50.00	0.02
	3.75	-	-	-	-
B27	0.00	-	-	-	-
	0.25	-	-	-	0.01
	0.50	-	-	-	0.01
	0.75	-	-	-	0.05
	1.00	-	-	-	0.22
	1.25	-	0.15	11.11	1.35
	1.50	-	0.25	4.26	5.86
	1.75	-	0.43	2.50	17.15
	2.00	-	0.88	2.30	38.25
	2.25	-	0.84	2.68	31.31
	2.50	0.01	0.25	5.11	4.89
	2.75	0.01	0.03	6.77	0.59
	3.00	0.01	0.01	33.33	0.06
	3.25	0.01	-	50.00	0.02
	3.50	-	-	-	-
	3.75	-	-	-	-

Sample #	Phi	Magnetite	Heavy Minerals Weight	Heavy Minerals Vol. %	Total Vol.
B28	0.00	-	-	-	-
	0.25	-	-	-	-
	0.50	-	-	-	0.01
	0.75	-	-	-	0.03
	1.00	-	-	-	0.17
	1.25	-	0.04	4.00	1.00
	1.50	-	0.11	3.39	3.24
	1.75	-	0.48	2.90	16.55
	2.00	-	0.83	2.15	38.52
	2.25	-	0.80	2.45	32.62
	2.50	0.01	0.26	4.14	6.52
	2.75	0.01	0.09	14.92	0.67
	3.00	0.02	0.02	57.14	0.07
	3.25	0.01	0.01	50.00	0.04
	3.50	0.01	-	50.00	0.02
	3.75	-	-	-	-
B29	0.00	-	-	-	-
	0.25	-	-	-	0.02
	0.50	-	-	-	0.04
	0.75	-	-	-	0.07
	1.00	-	0.02	5.88	0.34
	1.25	-	0.08	4.08	1.96
	1.50	-	0.26	3.35	7.76
	1.75	-	0.56	2.51	22.28
	2.00	-	0.78	2.10	37.13
	2.25	-	0.57	2.25	25.25
	2.50	-	0.19	4.44	4.27
	2.75	0.01	0.04	9.61	0.52
	3.00	0.01	0.01	40.00	0.05
	3.25	0.01	-	50.00	0.02
	3.50	-	-	-	-
	3.75	-	-	-	-
B30	0.00	-	-	-	-
	0.25	-	-	-	-
	0.50	-	-	-	0.02
	0.75	-	-	-	0.04
	1.00	-	0.01	4.16	0.24
	1.25	-	0.06	4.41	1.36
	1.50	-	0.14	3.15	4.44
	1.75	-	0.37	2.36	15.63
	2.00	-	0.72	1.90	37.75
	2.25	-	0.68	2.09	32.50
	2.50	0.01	0.27	4.11	6.81
	2.75	0.02	0.09	14.66	0.75
	3.00	0.01	0.02	25.00	0.12
	3.25	0.01	0.01	33.33	0.06
	3.50	-	-	-	0.01
	3.75	-	-	-	-

APPENDIX 2

FACTOR SCORES OF GRAIN-SIZE DATA

FACTOR 1	FACTOR 2	FACTOR 3
-0.7377	-0.9180	-0.7204
-0.5190	-0.8260	-0.9037
-0.9937	-0.2754	0.3398
-0.8840	1.2262	-0.1734
-0.8010	-0.4871	-0.5290
-0.9220	-0.0717	-0.3038
-0.6416	-1.7355	-0.7850
-0.8820	-0.7323	-0.5324
-1.1468	-0.1529	0.8701
-0.8905	0.4430	-0.0670
-0.6362	-0.6347	-0.5221
-0.8670	-0.2406	-0.4788
-0.2509	-1.3253	-0.9484
-0.7026	0.7830	-0.3769
-0.8226	-0.5507	-0.1498
-0.9693	0.4348	0.6689
-0.5889	-0.2702	-0.6583
-0.4824	-1.3387	-0.4980
-1.2227	0.5619	1.5166
-0.7679	-0.5685	-0.4723
-0.5572	-0.9013	-0.8015
-0.5506	-1.5318	-0.7833
-0.4286	-1.6620	-0.4939
-0.9365	0.3673	0.2612
-0.6341	-0.4739	-0.6276
-0.4791	-0.3787	-0.6284
-0.8215	-0.2270	-0.4805
-0.7293	-0.3291	-0.7542
-1.0730	1.1167	0.0505
-0.6813	-0.1850	-0.5440
1.1142	1.4464	-1.0551
0.5211	2.5912	-0.3266
0.2298	-0.5896	2.7537
0.6588	0.6036	-0.2864
-0.8486	1.5128	2.7445
0.2293	0.8472	-0.1398
2.0093	0.2064	-0.3479
-0.2004	1.6107	0.5586
2.0136	0.1893	-0.7541
-0.3040	1.8507	0.5052
1.8434	0.3495	-0.2058
1.0182	1.0915	-0.3364
1.4234	0.0996	-0.2856
1.2594	-0.9230	1.2001
-0.0407	-0.9053	3.4401
1.9737	0.0694	-0.7461

FACTOR 1	FACTOR 2	FACTOR 3
0.5608	-0.0096	-0.4410
0.8481	0.6500	-0.7612
0.1084	0.8244	0.6041
1.1346	-1.7288	2.5415
0.3473	0.4707	-0.6096
1.9652	-0.7067	0.1484
0.9435	1.2403	-0.1846
1.3474	-2.1729	1.6007
-0.4088	1.9080	0.7804
0.0486	0.4353	-0.6423
0.5689	-0.4315	-0.3697
-0.0290	0.7527	0.7517
2.6350	-1.1952	0.0427
-0.3412	0.7742	-0.6547

FACTOR SCORES OF HEAVY MINERAL DATA

FACTOR 1	FACTOR 2	FACTOR 3
-0.4436	1.2354	1.3970
-0.4727	0.4088	0.8026
-0.2940	1.0604	0.8358
-0.0136	1.1857	0.0736
-0.1428	0.7630	0.2329
-0.4529	1.1905	-0.2240
-0.8736	1.1151	0.3460
-0.3684	0.7883	0.1294
0.2390	1.0345	-1.7931
-0.0142	0.9758	-1.2761
-0.3937	0.9157	-0.0840
-0.4957	0.7824	-0.3831
-0.3121	-0.2335	0.1227
-0.1057	1.2570	-1.4393
-0.0269	0.5865	0.3586
0.7575	1.7145	-3.9795
0.0196	0.5205	-0.1535
-0.4004	0.5561	0.3303
-0.2955	0.9051	0.6602
-0.5157	0.2580	1.3699
-0.2516	0.8986	1.6194
-0.6294	0.3632	0.6716
-0.5008	0.4156	0.1283
-0.0818	0.9789	0.0614
-0.1669	0.5803	0.7798
-0.0260	0.5064	0.6708
-0.2439	0.6719	1.2617
-0.2158	0.3541	0.0320
-0.4933	0.5069	0.1410
-0.6522	0.5782	0.0719
0.8474	-0.1813	0.2561
2.8726	0.4760	0.5123
-1.1019	-0.6174	-0.0244
-0.2911	-0.3531	0.2301
1.9777	-0.5954	0.1511
0.9503	-0.6202	0.5799
-0.6977	-1.0624	-0.5743
-0.7727	-1.0591	-0.1894
-0.7084	-0.5649	-0.3932
1.8936	-0.1526	-0.0004
-1.4814	-1.3274	-0.2333
0.1592	-1.2795	-0.3589
-0.7167	-1.2337	-0.4926
-0.7899	-0.9373	-1.2136
-0.7897	-0.8663	-1.0722
-0.9196	-1.2886	0.0417
0.8947	-0.9443	-0.1474
1.8697	-0.7614	-0.2359

FACTOR 1	FACTOR 2	FACTOR 3
1.1361	-0.6355	-0.4609
-1.3006	-0.7804	-1.1237
-0.2400	-0.6310	0.3377
-0.7572	-1.9043	-0.5869
1.1392	-1.7245	0.0056
-1.8452	-0.8275	-0.2165
2.0548	-0.5799	0.3283
-0.028-	-0.6394	-0.0526
0.5484	-0.7849	0.6213
2.2789	-0.7336	0.5149
0.0169	-0.9554	-0.1017
1.7601	0.7914	1.1347