UNIVERSITY OF MANITOBA

GRAND BEACH

A TEST OF GRAIN-SIZE DISTRIBUTION STATISTICS AS INDICATORS OF DEPOSITIONAL ENVIRONMENTS

A Dissertation

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Master of Science

by

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ABSTRACT

Sediments collected from the beach, aeolian, channel, lake delta and off-beach environments of Grand Beach, southern Lake Winnipeg, are used to test the ability of grain-size distribution statistics to determine depositional environments.

Five previously published techniques evaluated are:

(1) Diagram CM-Passega (1957).
(2) Graphical Parameters - Mason and Folk (1958).
(3) Moment Parameters - Friedman (1961).
(4) Discriminant Functions - Sahu (1964).
(5) Factor Analysis - Klovan (1966).

None of the five techniques reliably classified samples into the delineated environments. Factor analysis, however, gave results which reproduced energy conditions consistent with the known depositional environments.

The failure of every technique to classify samples into their correct depositional environments suggests that sediments of widely diverse environmental origin may have identical grain-size distributions. Thus, statistics cannot be used to differentiate between sediments from different environments if the grain-size distributions themselves are not different.

If the results observed for the recent sediments at Grand Beach are applicable to recent and ancient marine sediments, then grain-size distribution statistics cannot be used as indicators of specific depositional environments.

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CHAPTER I

INTRODUCTION

Statement of Problem

Several distinct methods of determining the depositional environment of clastic sediments through statistical analysis of grain-size distribution data have been published. This study has two primary objectives: first, to delineate the depositional environments of Grand Beach, an area of recent lacustrine sedimentation; and secondly, to evaluate the usefulness of several statistical techniques in determining depositional environments from grain-size distribution data using the Grand Beach area as a reference model.

Method of Study

Grand Beach was selected as a reference model because several contrasting depositional environments occur in a relatively small, easily accessible area.

Depositional environments at Grand Beach were first delineated according to topographic, sedimentologic, hydrographic and geographic criteria. Sediment samples collected from these environments were analyzed by sieve and pipette techniques to determine the weight percentages of sediment in standard size classes.

These data were then used to compute the depositional environments by means of five previously proposed statistical methods:

(1) CM Patterns, Passega (1957)

(2) Graphical Parameters, Masonand Folk (1958)

(3) Moment Parameters, Friedman (1961)

(4) Discriminant Functions, Sahu (1964)

(5) Factor Analysis, Klovan (1966)

The results of each of these methods were then compared to the reference model.

Method of Presentation

This dissertation is presented in two main parts.

The first part includes chapters describing field and laboratory studies of the Grand Beach recent sediments. Their minerology and provenance is also discussed.

The second part describes the results of five methods of statistical analysis of the grain-size data. Computer programs used to process the grain-size data are documented, and the progress made in the development of a system of multivariate statistical programs for the I.B.M. 360 computer is reported.

Acknowledgements

The writer is indebted to Dr. J. E. Klovan who first proposed this investigation and under whose supervision this report was prepared.

His guidance and assistance during the course of the study is greatly appreciated.

For sanctioning the study and for many helpful suggestions, the writer is indebted to Professor B. A. Hodson, Computing Science Department, University of Manitoba.

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The writer is grateful to Mr. G. Lashyn, International Business Machines representative at the University of Manitoba Computer Center for his advice in computer program development.

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CHAPTER II

DESCRIPTION OF THE STUDY AREA

Lake Winnipeg

Lake Winnipeg, a remnant of glacial Lake Agassiz (Davies, Bannatyne, Barry and McCabe, 1962), is a large freshwater lake entirely within the boundaries of Manitoba. The lake has a maximum length of 250 miles but is divided into two parts by a narrows (Figure 1) and several large islands.

The northern part of Lake Winnipeg receives water from many rivers, the largest being the Saskatchewan River. Lake Winnipeg is discharged by the Nelson River, flowing northward into Hudson Bay (Figure 1).

The southern part of Lake Winnipeg has a maximum length of 55 miles and a maximum width of 25 miles (Figure 2). This part of the lake has an average water depth of 40 feet (Government of Canada Bathymetric Map 6240, 1962). The Red and Winnipeg Rivers provide the main influx of water into the south part of Lake Winnipeg.

Records maintained since 1913 indicate the average water level of Lake Winnipeg is 713 feet above mean sea level (Province of Manitoba Water Bulletin, May 1967). During 1965 and 1966 the Lake Winnipeg drainage basin has received greater than average amounts of precipitation. This additional runoff water has caused lake level to rise and remain about four feet above average.

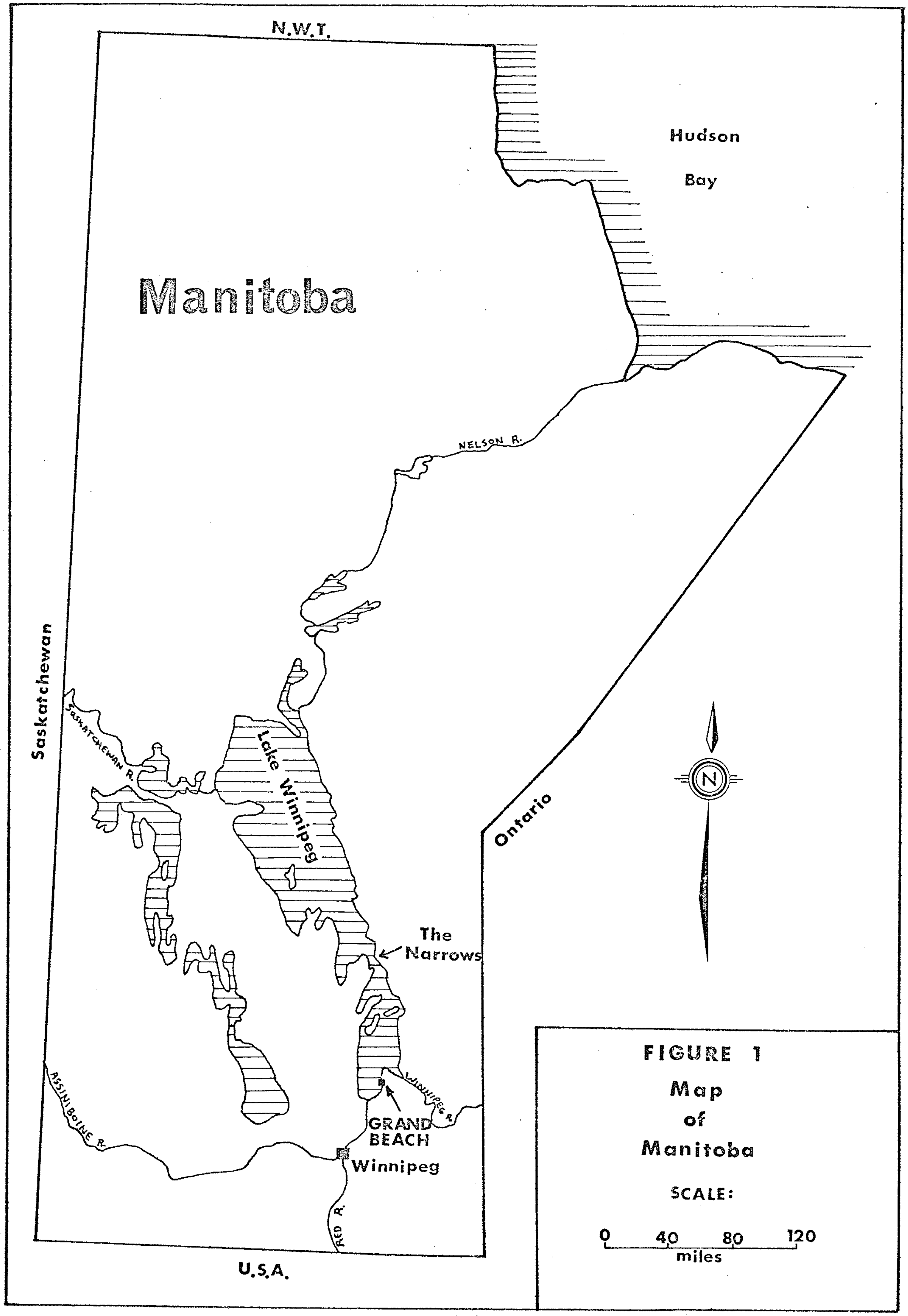


FIGURE 1

Map of Manitoba

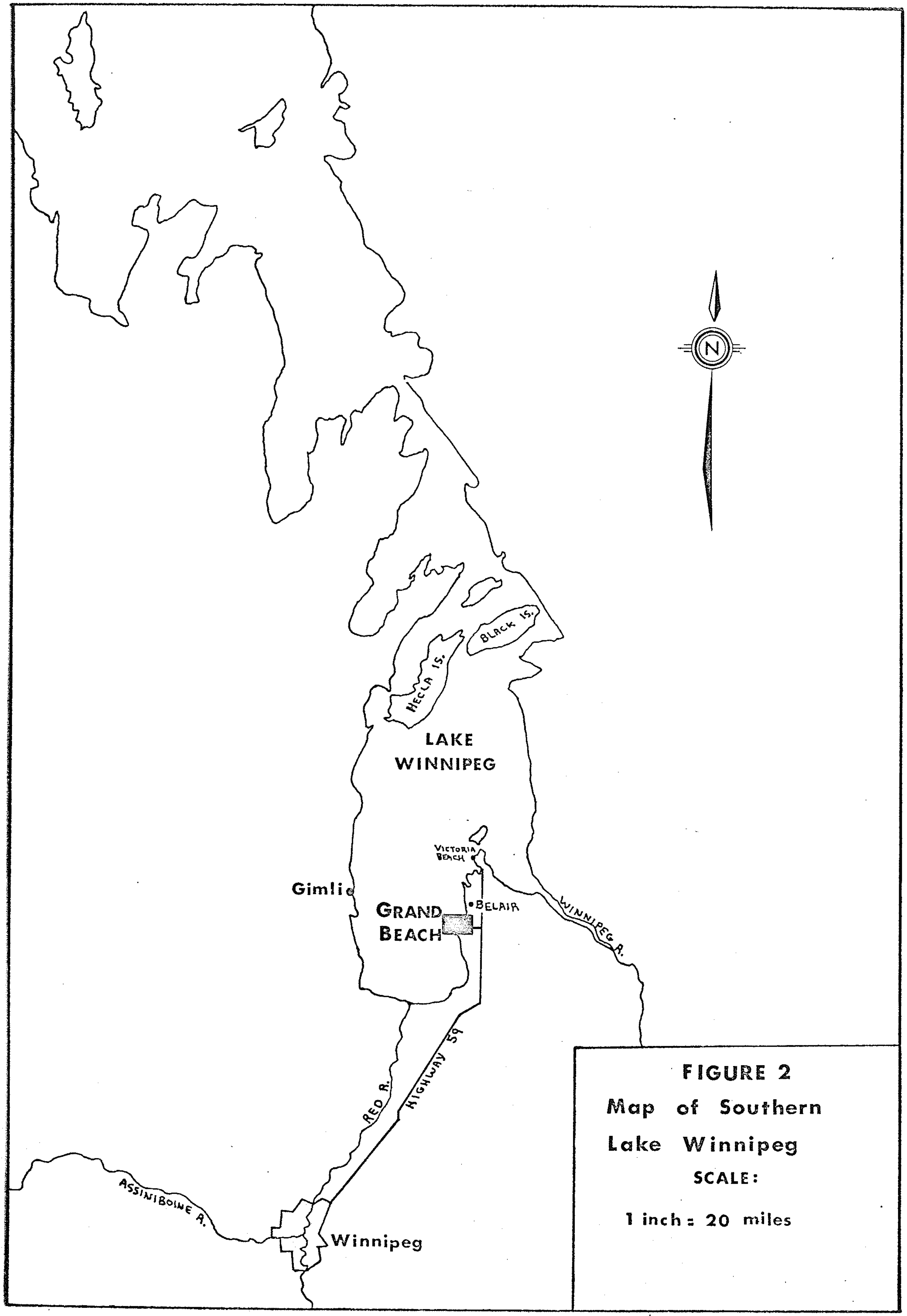


FIGURE 2
Map of Southern Lake Winnipeg
SCALE:
1 inch = 20 miles

Although Lake Winnipeg is not large enough to have noticeable lunar or solar tides, winds cause intermittent water level fluctuations in the order of several feet. Strong northerly winds pile up water at the south end of the lake; strong southerly winds generally have the opposite effect. Variations of Lake Winnipeg water level during the summer of 1966 are shown in Figure 3 (the dashed line is an estimate of lake level with wind effects removed and reflects the seasonal runoff cycle). Peak daily wind velocities for the South Lake Winnipeg region are listed in Table I. Wind velocities given are daily maximums, but undoubtedly reflect the directions and relative magnitudes of average wind forces during the summer of 1966. A comparison of these data indicates there is a strong correlation between peak wind velocity and water level and that there is often a lag of several hours between high winds and the resulting changes in lake level.

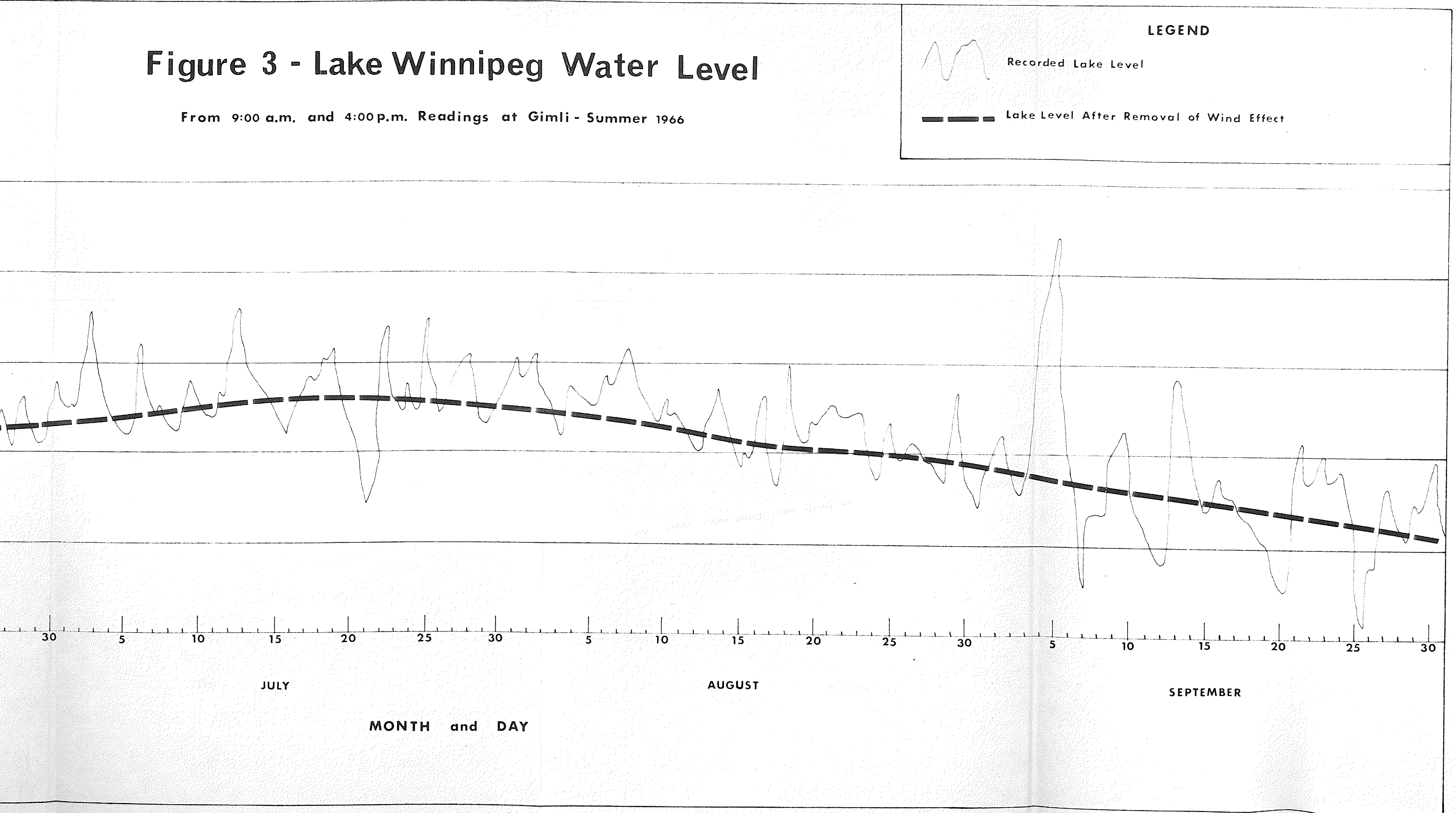
These intermittent fluctuations of lake level play a significant role in sediment transport and deposition along the south shore of Lake Winnipeg. A complete discussion of the effects of wind on sedimentation in the Grand Beach area is given in Chapter V.

Regional Geology and Physiography

Continental glaciation of the Pleistocene epoch has left the area along the east shore of southern Lake Winnipeg with a surficial covering of glacial drift. Because of this drift cover, Paleozoic bedrock rarely outcrops. A small subaqueous exposure of Paleozoic

Figure 3 - Lake Winnipeg Water Level

From 9:00 a.m. and 4:00 p.m. Readings at Gimli - Summer 1966



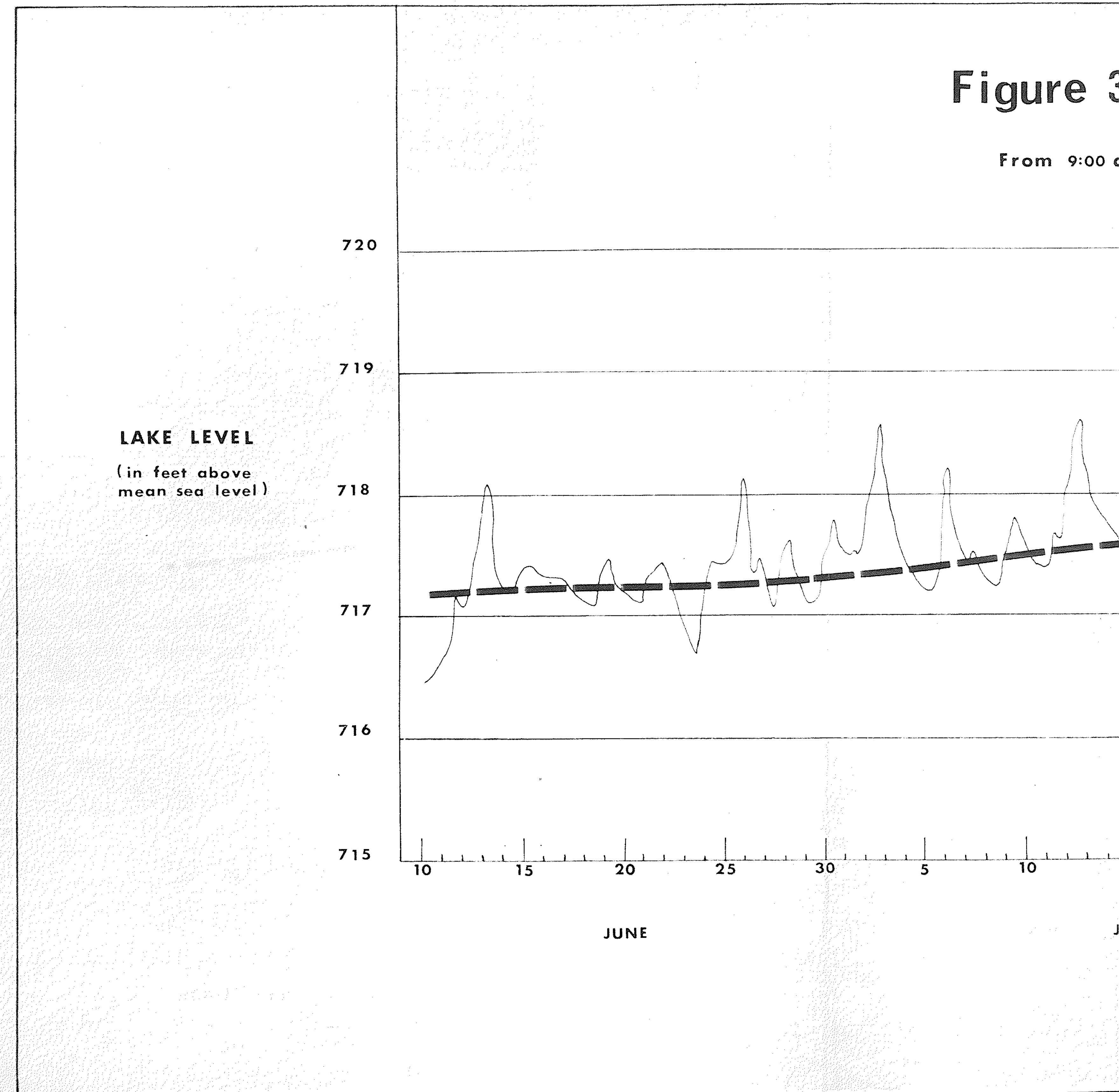


Figure 3
From 9:00 a
LAKE LEVEL
(in feet above mean sea level)
720
719
718
717
716
715
10
15
20
25
30
5
10
JUNE
J

TABLE I

PEAK DAILY WIND VELOCITIES RECORDED AT GIMLI - SUMMER 1966

DAY	MONTH							
	JUNE		JULY		AUGUST		SEPTEMBER	
	DIR.	VEL.	DIR.	VEL.	DIR.	VEL.	DIR.	VEL.
1	S	64	SW	70	------*		W	25
2	WNW	30	------		------		SSW	38
3	N	27	NE	34	NW	29	WNW	55
4	------		WSW	70	------		NW	57
5	------		W	49	NE	20	NW	31
6	WNW	34	NW	21	ENE	60	S	27
7	NNW	30	------		NE	36	S	47
8	------		NW	55	NNE	21	S	26
9	S	26	WNW	26	------		W	46
10	S	50	S	21	------		ENE	22
11	S	39	WSW	32	------		SSE	29
12	WSW	41	NW	31	ESE	28	N	39
13	N	31	------		NNE	20	N	37
14	------		------		------		------	
15	N	42	S	44	SSW	30	WSW	31
16	NW	23	SSW	34	WNW	25	------	
17	W	36	SSW	25	NW	63	WSW	28
18	W	56	NW	29	NW	23	SSW	24
19	NW	40	------		------		S	32
20	SE	31	S	31	------		SSW	44
21	S	34	WSW	35	NNE	25	NNW	36
22	SW	35	WNW	24	N	23	N	42
23	SW	48	------		NNW	21	NNE	22
24	E	38	SW	30	WSW	34	NNE	27
25	WSW	36	NW	26	WSW	25	WNW	24
26	WNW	33	E	25	------		WSW	46
27	S	43	WNW	30	ESE	24	W	25
28	W	55	------		WSW	42	ENE	25
29	SE	40	SSW	29	NNW	32	------	
30	WSW	47	WNW	26	WSW	58	NNW	23
31			------		ESE	35		

*------ SIGNIFIES A PEAK WIND VELOCITY LESS THAN 18 MILES PER HOUR

limestone occurs one mile north of Grand Beach. Paleozoic sandstone is present near Victoria Beach (Figure 2), some ten miles northeast of Grand Beach.

Thickness of glacial drift is generally less than 50 feet, but an exposure of glacial drift observed near Belair (Figure 2) has an estimated thickness of 200 feet.

Maximum regional topographic relief rarely exceeds 250 feet, and, in most cases, hills or ridges are due to drift deposits or local highs on the Paleozoic bedrock surface.

Location and Access of the Study Area

Grand Beach is situated on the east shore of Lake Winnipeg, approximately fifty miles northeast of Winnipeg (Figure 1). The area, popular as a summer resort, is readily accessible via paved highways, or by boat via Lake Winnipeg.

Physiography of the Study Area

The Grand Beach sand body is a bay-mouth bar (Johnson, 1919), formed by longshore transportation of unconsolidated sediments. A vertical air photograph mosaic of Grand Beach (Figure 4) illustrates the typical form of a bay-mouth bar and may be compared to examples by Johnson (1919) of bars along the Alaskan and Atlantic coasts of North America. Figure 4 also gives an interpretation of the pre-bar shape of the Lake Winnipeg shoreline based on the presence of Pleistocene sedimentary rocks. A complete discussion of this interpretation is presented in Chapter V. Figure 5 illustrates the contrast between


PHOTOGRAPHY DATE: MAY 22, 1960
N
SCALE IN FEET
1000 500 0 1000 2000 3000
Pre-Bar Shoreline
LAKE WINNIPEG
GRAND BEACH
CAN. NAT

FIGURE 4

FIGURE 5

Oblique air photograph showing contrast between the bar (center left) and the typical boulder shoreline (lower left).

the typical boulder beach shoreline (lower left) and the sandy bar shoreline.

The lagoon, the bay-mouth bar and Lake Winnipeg are the main physiographic features of the study area. These features are shown in oblique aerial photographs (Figures 5, 6 and 7), and a physiographic map (Figure 8).

A small intermittent creek, which has a noticeable flow only in the spring, feeds the lagoon at its southern end. The lagoon shoreline, except where adjacent to the bar, is boulder strewn. Vegetation along the lagoon shore varies from poplar and evergreen growth in high positions (Figure 6) to rushes and reeds in low swampy areas. Water plants flourish in the lagoon during the summer months. At its northern end, the lagoon is connected to Lake Winnipeg by a narrow channel bisecting the bay-mouth bar.

The bar has three main physiographic zones: (1) beach, (2) dune, and (3) swamp, each of which is generally parallel to the Lake Winnipeg shoreline.

The beach, a narrow strip of sand on the lakeward side of the bar, varies between 20 and 50 feet in width. A five-foot high wave-cut cliff (Figure 9), whose base is approximately three feet above lake level, separates the beach from the dune zone.

A 300-foot wide dune zone occurs adjacent to the beach (Figure 10). Dun height, about 25 feet near the beach, decreases lagoonward. Vegetation on the dunes is sparse, consisting

FIGURE 6

Oblique air photograph showing lagoon

(to left) bar and Lake Winnipeg

FIGURE 7

Oblique air photograph taken in 1964, showing the bar, the channel and the lagoon

FIGURE 9

Wave-cut cliff separating the beach from the aeolian dunes. Note erosion of the aeolian zone.

FIGURE 10

Photograph looking east along bar,

showing aeolian dunes

mainly of willows and low shrubs. Because of high water levels in recent years, the lakeward side of this zone has been eroded (Figures 9 and 11).

The dunes grade into a zone of willow swamp and occasional stagnant ponds (Figure 12). The thick cover of vegetation has stabilized the sand and serves to trap any sediment blown from the lake side of the bar. High water level has resulted in a flooding of the lagoon side of this zone. Willows were observed growing in several feet of water along the lagoon shore.

Except for the sandy bar shoreline, the Lake Winnipeg shore in the Grand Beach area is a rough boulder beach. A water depth of forty feet is reached, through a gradual increase, some two miles north of the bar (Government of Canada Bathymetric Map 6240, 1962). A subsqueous exposure of Paleozoic limestone occurs one mile north of the bar. This outcrop, a navigational hazzard marked by a buoy, is within several feet of the lake surface during periods of low lake level.

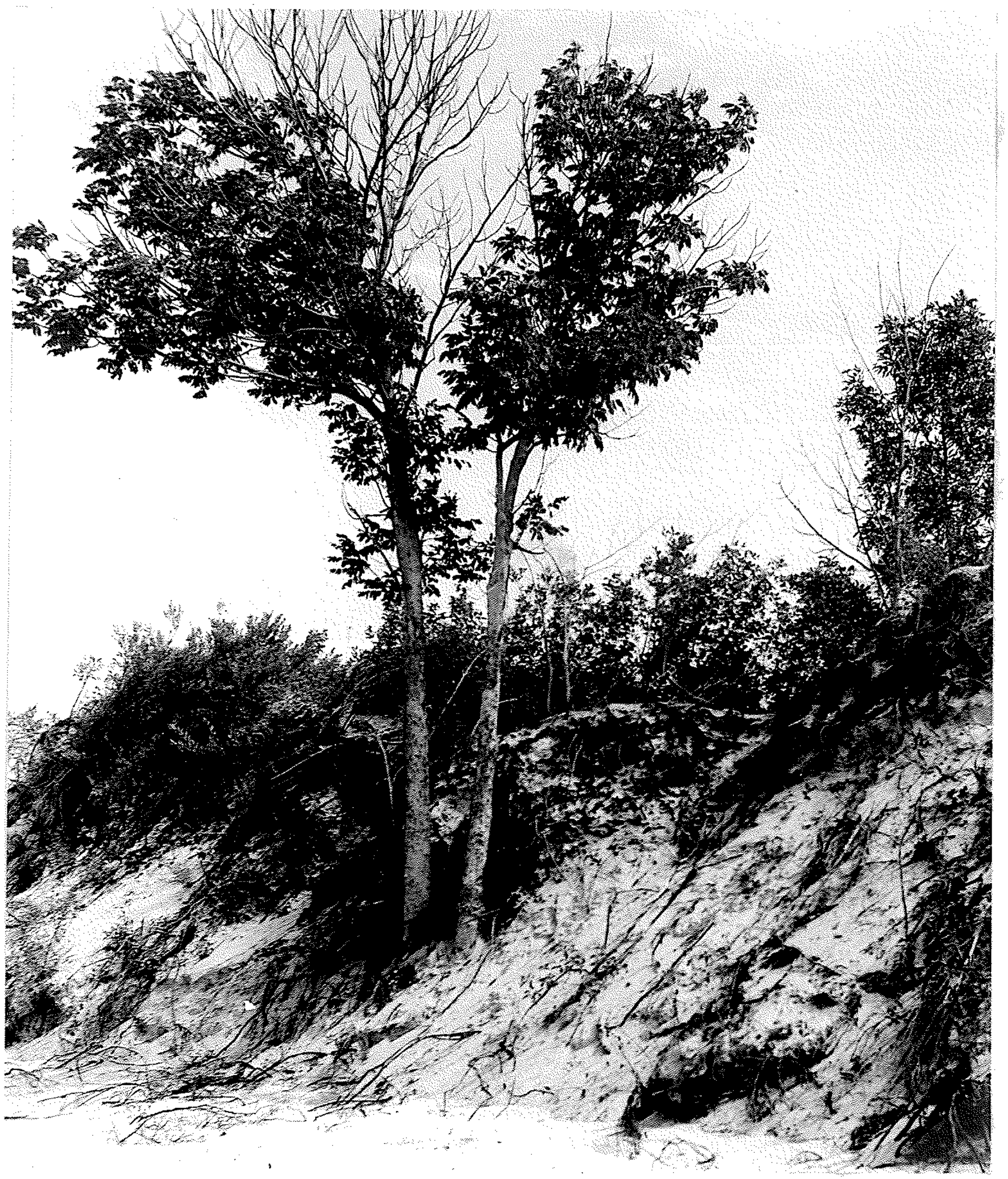


FIGURE 11

Tree on lake side of bar. Trunk was once partially buried by wind blown sand, now exposed by wave erosion

FIGURE 12

Photograph looking south from bar. Lagoon is in background. Note willow swamp and pond in foreground.

CHAPTER III

PROCEDURES OF THE FIELD AND LABORATORY STUDY

Sampling

A total of 136 sediment samples were collected from the bar, channel, lagoon and lake at Grand Beach. Samples 1 to 120 were taken during a five day interval in mid-June, 1966. Samples 121 to 136 were taken one day in mid-August, 1966.

In general, samples were only taken from the area east of and including the channel. The west half of the area was not suitable for sampling due to the development of roads, parking lots and other recreational facilities (Figure 8).

Locations of sample points on or near the shore were determined from aerial photographs. Compass bearings on two or more brightly painted markers placed on the beach and lagoon shores defined the locations of samples in the lake and lagoon.

The boat employed for sample collection was a sturdy sixteen foot skiff equipped with a ten horsepower outboard motor, a boat crane and winch. A Petersen dredge, sampling an area of one square foot, was used to collect the underwater sediments.

Sampling with the Petersen dredge required two men. One man ran the outboard motor, took compass bearings and reeled the winch. The second man bagged and labelled the samples. With careful opening of the dredge, it was possible to distinguish the portion of the sample that was on the immediate lake bottom. Only the top one-half inch of sediment was taken as a sample. This ensured that only the most recently deposited sediments were taken as samples. Sample size averaged 1,000 grams. Water depth was measured at each sample point by means of a calibrated sounding line.

Land samples were collected by scooping off the upper one-half inch of sediment from a one square foot area. Sample size averaged 1,000 grams.

Mechanical Analysis

A total of 90 samples was processed by sieve and pipette methods of grain-size analysis (Folk, 1961). Sediments were classified into grade sizes according to the phi (Ø) scale (Krumbein, 1934).

(1) Sieve Analysis - Sieve analyses were performed on 66 samples. Samples were oven dried, then examined under a binocular microscope for aggregates and shell fragments. Few samples contained aggregates. Any aggregates were destroyed by gently rubbing the sample with the fingers. Shell fragments were rare and in negligible amounts.

A Jones sample splitter was used to reduce samples to approximately 55 grams. Each sample was sieved for 15 minutes on a Ro-Tap shaking machine. The following eight-inch diameter screens were used: -1.5Ø, -1.0Ø, -0.5Ø, 0.0Ø, 1.5Ø, 2.0Ø, 2.5Ø, 3.0Ø, 3.5Ø, 4.0Ø, and pan. Sieve fractions were weighed to 0.001 grams on an electric balance.

(2) Pipette Analysis - Twenty-four samples, which contained more than three percent sediment finer than 4.0Ø, were analyzed by the pipette method.

Disaggregation was not necessary because the samples, stored in airtight plastic bags, were never allowed to dry. The amount of each sample taken for analysis was such that there was approximately 10 grams of sediment finer than 4.0Ø. Organic material was removed by soaking the samples in 50 milliliters of 35 percent hydrogen peroxide solution for 24 hours.

First, the samples were wet sieved through a 4.0Ø screen. Fractions retained on the screen were analyzed by sieving. Fractions finer than 4.0Ø were pipetted from one liter settling columns. Each liter column of water and sediment contained 0.300 grams of sodium hexametaphosphate dispersant. None of the samples flocculated. The following grade sizes were determined by pipette analysis: 4.5Ø, 5.0Ø, 5.5Ø, 6.0Ø, 7.0Ø, 8.0Ø, 9.0Ø and less than 9.0Ø. All weights were measured to 0.001 gram on an electric balance.

Additional Procedures

Rock types and particle sizes of gravels were determined by visual examination. Sands were examined under the binocular microscope for mineralogy and grain shape. The X-ray diffraction technique was used to determine the mineralogical composition of two clay samples.

CHAPTER IV

RESULTS OF THE FIELD AND LABORATORY STUDY

Data Presentation

Figure 13 shows the locations of the 136 samples collected and Figure 14 is a bathymetric map of the study area.

Results of sieve analyses are given in Table II (used later to test the statistical techniques of environment determination (Chapter VI)).

Table III gives the results of samples analyzed by sieve and pipette. Because of the high percentage of very fine material (particle diameters less than 9Ø), these analyses are incomplete. The main use of these analyses is to compare sand to silt and clay percentages at various localities.

Because of the limited usefulness of the pipette technique, only representative clay samples were analyzed. Grain-size distributions of gravel samples were visually estimated. This explains why Tables II and III present grain-size analyses for only 90 of the 136 samples collected.

Delineation and Description of the Environments

Ten different depositional environments are proposed for the Grand Beach area. These environments were differentiated from one another by observing differences in one or more of the following criteria:

TABLE II

GRAIN SIZE DATA - SAMPLES ANALYZED BY SIEVE

SAMP.	PERCENTAGES IN PHI UNITS												
	-1.5	-1.0	-0.5	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	PAN
25	0.0	0.0	0.0	0.03	0.19	1.09	4.55	18.04	27.33	41.20	5.34	1.23	1.01
26	0.0	0.09	0.01	0.04	0.15	0.49	1.34	17.65	46.73	27.97	3.68	1.05	0.79
27	0.0	0.19	0.16	0.39	3.13	13.48	33.16	32.81	8.18	5.29	1.98	0.57	0.66
31	0.88	2.04	3.00	4.95	17.22	30.49	27.85	7.47	1.13	2.21	1.45	0.62	0.71
32	0.0	0.09	0.38	1.63	13.91	28.53	28.15	18.23	5.60	3.25	0.18	0.02	0.02
33	0.22	0.40	2.12	4.46	20.40	30.62	27.65	12.96	0.87	0.22	0.04	0.02	0.02
34	0.0	0.08	0.06	0.12	0.78	2.27	8.26	28.13	29.26	28.50	2.21	0.22	0.10
35	0.0	0.0	0.0	0.02	0.14	0.46	1.91	11.25	35.25	49.81	1.08	0.05	0.04
36	0.0	0.04	0.05	0.04	0.32	1.83	9.26	29.11	32.46	25.91	0.83	0.07	0.07
37	0.0	0.0	0.0	0.0	0.04	0.23	1.07	7.69	24.43	59.32	6.72	0.40	0.11
38	0.0	0.0	0.0	0.02	0.08	0.48	2.04	11.32	24.78	53.47	7.22	0.56	0.02
39	0.0	0.0	0.02	0.02	0.13	0.67	2.46	9.64	17.40	48.59	18.91	1.86	0.29
40	0.09	0.19	0.05	0.28	0.83	1.07	1.71	3.97	7.71	41.01	34.77	7.12	1.21
41	0.0	0.0	0.0	0.02	0.07	0.09	0.12	0.92	4.80	47.83	36.73	7.97	1.47
51	0.0	0.08	0.05	0.20	20.36	51.34	21.24	5.98	0.66	0.08	0.0	0.0	0.0
52	0.0	0.0	0.0	0.02	0.19	2.29	7.88	31.16	38.60	19.31	0.49	0.04	0.02
53	0.0	0.0	0.0	0.0	7.57	49.04	40.83	2.18	0.27	0.08	0.03	0.0	0.0
54	0.0	0.0	0.0	0.0	0.26	4.37	16.00	40.92	29.62	8.70	0.10	0.02	0.02
55	0.0	0.0	0.0	0.02	0.28	3.53	35.70	55.88	4.21	0.37	0.02	0.0	0.0
56	0.0	0.0	0.0	0.0	1.39	11.10	27.68	40.94	15.41	3.40	0.06	0.02	0.0
57	0.0	0.0	0.0	0.0	0.26	1.38	31.54	64.21	2.55	0.06	0.0	0.0	0.0
58	0.0	0.0	0.0	0.0	0.22	2.76	11.49	45.18	32.71	7.55	0.08	0.02	0.0
59	0.0	0.0	0.0	0.0	0.02	0.03	2.88	74.04	21.76	1.20	0.03	0.02	0.02
60	0.0	0.0	0.0	0.0	0.25	4.25	29.89	50.45	13.20	1.91	0.04	0.0	0.0
61	0.0	0.0	0.0	0.0	0.0	0.10	9.79	72.54	16.63	0.88	0.02	0.02	0.02
62	0.0	0.0	0.0	0.03	3.48	14.80	27.74	36.54	14.42	2.93	0.05	0.02	0.0
63	0.0	0.0	0.05	0.31	3.72	12.45	19.94	30.77	23.54	8.99	0.16	0.03	0.03
64	0.0	0.0	0.0	0.0	0.04	1.57	14.00	44.98	31.26	7.99	0.12	0.02	0.02
65	0.0	0.0	0.02	0.10	0.89	7.11	21.72	66.21	3.75	0.14	0.02	0.02	0.02
66	0.0	0.0	0.02	0.04	9.39	51.65	34.36	4.19	0.31	0.04	0.0	0.0	0.0
67	0.0	0.0	0.0	0.0	0.42	6.51	25.93	44.20	18.11	4.70	0.11	0.02	0.0
68	0.0	0.0	0.0	0.02	0.28	2.14	13.05	37.46	30.67	15.78	0.47	0.06	0.08
69	0.0	0.0	0.0	0.0	0.10	1.60	7.26	29.82	42.44	18.57	0.18	0.02	0.0

(CONTINUED)

TABLE II (CONTINUED)

SAMP.	PERCENTAGES IN PHI UNITS												
	-1.5	-1.0	-0.5	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	PAN
70	0.0	0.0	0.0	0.16	3.82	29.82	51.84	12.11	2.07	0.18	0.0	0.0	0.0
71	0.0	0.0	0.0	0.0	0.04	0.23	17.39	72.77	9.34	0.21	0.02	0.0	0.0
72	0.0	0.0	0.0	0.02	0.15	1.35	9.07	42.88	34.92	11.33	0.26	0.02	0.02
73	0.0	0.0	0.0	0.0	0.26	3.10	21.15	53.81	18.05	3.47	0.12	0.02	0.02
74	0.0	0.0	0.0	0.09	0.81	7.08	33.93	44.20	11.07	2.69	0.10	0.02	0.02
75	0.0	0.0	0.0	0.0	0.09	0.98	15.50	57.56	20.32	5.36	0.16	0.02	0.02
80	0.0	0.0	0.0	0.02	0.14	0.72	4.54	38.51	44.14	11.63	0.19	0.05	0.07
83	0.0	0.13	0.14	0.27	1.32	3.66	9.99	23.44	26.58	28.98	4.18	0.96	0.35
85	0.0	0.09	0.63	3.37	10.45	6.66	7.09	18.27	21.44	27.20	2.87	0.85	1.07
86	0.0	0.0	0.0	0.0	0.15	2.38	14.80	34.68	27.91	18.48	1.02	0.21	0.16
90	0.0	0.04	0.02	0.02	0.15	0.26	0.84	12.05	32.82	46.32	5.98	1.12	0.37
91	0.0	0.0	0.07	0.02	0.22	0.42	1.11	4.07	11.13	51.34	25.14	5.40	1.09
92	0.0	0.04	0.02	0.02	0.06	0.14	0.37	2.00	8.03	44.16	31.78	11.02	2.37
98	0.0	0.0	0.0	0.0	0.02	0.26	1.04	10.86	32.61	51.78	2.96	0.33	0.12
102	0.0	0.02	0.04	0.10	0.17	0.29	0.54	1.97	9.00	58.47	23.34	4.86	1.20
107	0.12	0.09	0.14	0.20	0.72	1.55	2.83	6.69	11.96	45.10	23.70	5.78	1.12
110	0.0	0.0	0.05	0.17	0.45	0.90	2.39	9.92	23.42	51.86	7.96	2.04	0.84
121	0.93	0.68	1.13	2.33	9.28	22.06	33.01	23.80	5.89	0.83	0.03	0.02	0.02
122	0.0	0.0	0.02	0.06	0.37	4.19	27.28	50.19	15.35	2.46	0.04	0.02	0.02
123	0.0	0.05	0.03	0.03	0.15	1.62	18.05	54.65	21.66	3.65	0.07	0.02	0.02
124	0.0	0.07	0.07	0.11	0.41	2.01	16.16	51.49	24.04	5.45	0.13	0.04	0.02
125	0.07	0.05	0.08	0.18	0.77	3.45	20.75	55.39	16.94	2.21	0.07	0.02	0.02
126	0.0	0.0	0.02	0.02	0.08	0.36	3.23	46.87	42.67	6.51	0.18	0.04	0.02
127	0.0	0.0	0.0	0.0	0.05	0.24	1.36	13.69	39.33	43.57	1.60	0.12	0.05
128	0.0	0.0	0.0	0.0	0.13	0.38	1.03	0.93	29.31	58.84	8.36	0.84	0.19
129	0.27	0.58	1.04	1.48	4.75	11.17	27.54	41.67	10.12	1.34	0.03	0.01	0.01
130	0.21	0.21	0.33	0.50	1.88	5.81	20.12	49.65	18.09	3.12	0.05	0.01	0.01
131	0.0	0.0	0.0	0.01	0.10	0.39	4.22	37.60	40.39	16.60	0.58	0.07	0.04
132	0.0	0.03	0.03	0.05	0.23	1.07	8.12	45.40	34.63	9.90	0.41	0.07	0.05
133	0.49	0.33	0.40	0.56	1.88	3.55	11.69	36.07	26.57	17.13	1.15	0.12	0.07
134	0.27	0.24	0.31	0.55	1.51	3.16	12.07	46.59	26.52	8.29	0.39	0.06	0.04
135	0.08	0.03	0.08	0.10	0.39	1.05	4.06	23.53	37.47	31.63	1.42	0.11	0.05
136	0.0	0.0	0.02	0.02	0.09	0.33	1.61	13.94	31.74	44.89	6.44	0.91	0.02

TABLE III

GRAIN SIZE DATA - SAMPLES ANALYZED BY SIEVE AND PIPETTE

	PHI DIAM.	SAMPLE NUMBER 4	6	12	13	14	15	18	19
	-1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	-1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	-0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PERCENTAGES	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.14
IN	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.18
	2.5	3.06	0.0	0.0	0.0	0.18	0.12	0.53	8.47
PHI	3.0	0.24	0.0	0.22	0.24	0.37	0.62	1.58	30.74
	3.5	0.12	0.48	0.22	0.47	0.73	1.61	1.41	13.46
UNITS	4.0	0.12	0.16	0.43	0.47	0.91	1.49	0.70	4.02
	4.5	2.35	2.42	1.08	2.35	1.83	3.10	2.64	2.78
	5.0	2.35	2.42	1.08	1.18	2.74	2.48	0.88	1.04
	5.5	0.59	2.42	1.08	2.35	1.83	2.48	1.76	0.69
	6.0	2.35	0.81	2.16	1.18	3.66	1.86	2.64	0.35
	7.0	8.24	8.89	5.39	7.06	6.40	8.68	4.39	2.78
	8.0	8.82	7.27	8.62	8.24	9.14	8.06	9.67	4.51
	9.0	9.41	9.69	9.70	9.41	7.31	9.93	8.79	3.47
	LESS THAN 9.0	62.35	65.43	70.04	67.06	64.90	59.55	65.03	26.37

(CONTINUED)

TABLE III (CONTINUED)

	PHI DIAM.	SAMPLE NUMBER 20	21	22	23	24	28	29	30
	-1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	-1.0	0.07	0.0	0.0	0.0	0.0	0.26	0.0	0.0
	-0.5	0.02	0.0	0.0	0.0	0.0	0.21	0.0	0.0
	0.0	0.07	0.0	0.0	0.0	0.06	0.33	0.0	0.0
	0.5	0.21	0.0	0.0	0.0	0.14	1.40	0.0	0.0
PERCENTAGES	1.0	0.37	0.0	0.0	0.0	0.27	3.12	0.0	0.06
	1.5	0.60	0.31	0.0	0.0	0.65	6.74	0.87	0.12
IN	2.0	3.33	0.88	0.0	0.0	5.86	13.74	4.58	1.85
	2.5	16.82	4.68	3.69	0.43	21.41	20.86	12.71	15.40
PHI	3.0	57.88	37.30	16.05	2.37	53.62	41.36	31.49	59.69
	3.5	13.01	20.62	9.52	2.80	10.45	7.05	9.55	12.37
UNITS	4.0	3.17	3.99	3.98	1.94	2.93	1.12	2.53	2.35
	4.5	1.26	5.97	4.26	4.30	1.21	0.48	1.58	0.87
	5.0	0.23	1.73	2.84	1.08	0.30	0.24	0.79	0.10
	5.5	0.11	0.94	1.42	4.30	0.23	0.12	0.79	0.19
	6.0	0.11	1.10	2.13	3.23	0.15	0.24	1.58	0.29
	7.0	0.11	2.51	3.55	5.38	0.30	0.12	3.16	0.29
	8.0	0.34	2.36	6.39	8.60	0.23	0.24	1.97	0.39
	9.0	0.11	2.99	5.68	8.60	0.23	0.12	3.55	0.49
	LESS THAN 9.0	2.18	14.61	40.48	56.99	1.96	2.26	24.86	5.54

(CONTINUED)

TABLE III (CONTINUED)

PHI DIAM.	SAMPLE NUMBER 47	48	49	50	79	88	106	113
-1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.02	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.5	0.12	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PERCENTAGES 1.0	0.35	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.5	1.07	0.38	0.0	0.0	0.0	0.0	0.0	0.0
IN 2.0	3.39	1.45	0.0	0.0	0.0	0.0	0.0	0.0
2.5	9.93	5.25	1.78	0.71	0.0	0.24	0.0	0.33
PHI 3.0	40.37	23.44	8.63	2.47	0.07	0.24	0.12	0.16
3.5	26.26	20.09	10.27	4.95	0.07	1.71	0.12	0.16
UNITS 4.0	7.42	8.65	6.03	4.42	0.29	6.11	0.12	0.65
4.5	1.46	4.42	4.11	7.07	4.38	19.15	5.21	4.89
5.0	0.49	0.95	4.79	2.65	4.74	9.37	4.63	4.89
5.5	0.19	1.26	2.05	3.53	12.40	10.59	6.37	8.16
6.0	0.19	1.26	2.05	2.65	12.76	6.93	9.27	1.63
7.0	0.78	3.16	4.79	6.18	15.68	7.74	12.75	3.26
8.0	0.78	3.79	6.16	7.07	8.02	5.30	10.43	8.97
9.0	0.88	3.16	6.16	6.18	6.56	4.48	8.69	8.16
LESS THAN 9.0	6.33	22.74	43.15	52.12	35.01	28.12	42.29	58.73

(1) Topographic expression.

(2) Sediment type (composition and particle size).

(3) Water depth (if applicable).

(4) Location with respect to other environments.

The environments, whose areal distribution is shown in Figure 15, are:

(1) <u>Beach</u> - The beach is a 20 to 50 foot strip of land between the wave-cut cliff and the lake.

The beach sediments, sampled from the swash zone, are almost entirely sands with an average mean size of 1.39Ø and an average standard deviation of 0.29Ø. Scattered pebbles occur along the beach (Figure 16) but were not included in the grain-size analyses because they appear to have been transported by ice rafting (Chapter V).

A variety of recent sedimentary structures were observed along the beach. Among the more interesting structures observed were beach cusps (Figure 16), heavy mineral concentrations (Figure 17), and water formed ripples (Figures 18 and 19).

(2) <u>Aeolian</u> - The aeolian environment occurs between the wave-cut cliff and the lagoon shore and includes the dune and swamp topographic zones.

Sediments of this environment, sampled from or near the tops of dunes, are sands with an average mean size of 1.81Ø and an average standard deviation of 0.45Ø.

Wind ripples and aeolian cross bedding (Figure 20) are common sedimentary structures.

FIGURE 16

Photograph looking east along beach, showing beach cusp development. Note the paucity of pebbles along the beach.

FIGURE 17

Heavey mineral concentration at base of wave cut cliffs. Mainly magnetite, garnet and epidote.

FIGURE 18

Interference wave ripples. Note heavy mineral concentrations at crest of ripples. Also note ripples covered by later sediment at left edge of photo.

FIGURE 19

Wave ripples, becoming buried and preserved.

FIGURE 20

Aeolian cross bedding exposed in the wave-cut cliff.

(3) Channel - The channel, 100 to 300 feet wide, connects the lagoon to Lake Winnipeg. Water depths along the channel center line vary from four to seven feet. The northern limit of this environment is defined arbitrarily as where the channel begins to widen as it joins Lake Winnipeg. The southern limit is drawn where the dediments first contain more than three percent of material finer than 4.0Ø.

Sediments along the center line of the channel floor are sands with an average mean size of 1.51Ø, and an average standard deviation of 0.59Ø.

(4) Lake Delta - A fan shaped delta, some 1,800 feet long and 1,000 feet wide, occurs on the lake side of the channel. Water depth ranges from 3 to 15 feet. This environment is defined on the basis of water depth contours (Figure 14) which clearly show the shape and extent of the delta. There is no apparent difference between the sediments of this environment and those of the off-beach environment (below).

Sediments of the lake delta are sands with an average mean size of 2.45Ø, and an average standard deviation of 0.43Ø.

(5) Off-beach - The off-beach sediments are generally confined to a 1,000-foot wide belt along the bar shoreline, but may also occur in isolated off-shore patches (as in samples 85 and 86). Water depths are generally less than 15 feet, but may be as deep as 20 feet. The southern limit is the shoreline. The northern limit is arbitrarily defined as where the sediments first contain any pebbles or more than three percent of material finer than 4Ø.

All sands (except lake delta) sampled from the lake bottom are classed as belonging to the off-beach environment. The sediments have an average mean size of 2.14Ø, and an average standard deviation of 0.47Ø.

(6) <u>Transitional</u> - This environment, which varies from 800 to 2500 feet in width, occurs on the north side of the off-beach environment. The name transitional refers to changes in water depth (approximately 10 feet in the south and a maximum of 25 feet at the northern limit) occurring in this environment.

This environment contains gravels, sands and silts and clays in various proportions. The sand proportion is highest at the southern boundary of the environment. Gravels and hard indurated clays (thought to be Pleistocene deposits, Chapter V) are most abundant midway between the two boundaries. Silts and clays are most abundant in the northern part of the environment.

(7) <u>Deepwater</u> - The deepwater lake is the northern-most environment sampled and its southern boundary ranges from one-half to one mile north of the bar. Water depths are not less than 20 feet.

Sediments of this environment are silts and clays with less than five percent sand, and probably represent the southern edge of the blanket of sediment forming the bottom of the greater part of south Lake Winnipeg. Gravels were not observed in this environment.

(8) <u>Reef</u> - Paleozoic limestone outcrops about one mile north of the bar. This reef (the word reef is used in the mariner's sense) forms a pronounced high on the lake bottom, and comes to within eight feet of the surface at its highest point.

(9) Lagoon Delta - A fan shaped delta, similar in shape and size to the lake delta, occurs on the lagoon side of the channel. Water depth ranges from five to twelve feet.

Sediments of this environment are sands (at least 15 percent) and silts and clays (at least 3 percent). These percentages define the areal distribution of the lagoon delta. Sand content is highest near the channel mouth and lowest at the boundary with the lagoonal environment.

(10) Lagoonal - The lagoon is a body of water, some 8000 feet long and 2500 feet wide, separated from Lake Winnipeg by the baymouth bar. Water depth averages twelve feet.

Lagoonal sediments are silts and clays with less than 15 percent sand.

Mineralogy and Texture of the Sediment

(1) Gravels - Approximately 70 percent of the gravel grains are igneous and metamorphic rock fragments. Carbonate (limestone and dolomite) rock fragments account for the remaining 30 percent.

Pebbles are the most common grain-size; cobbles are rare. Boulders may also be present but were not collected due to limitations of the sampling device used. Gravel grains are, on the average, subrounded (based on the roundness scale of Powers (1953)).

(2) Sands - Visual estimates of the overall average mineralogical composition of sands are as follows: Quartz - 96 percent, Feldspar - 3 percent, heavy minerals - 1 percent.

Approximately 75 percent of the quartz grains subrounded to rounded with a frosted and pitted surface. The remainder is angular to subangular, with a vitreous luster and a freshly fractured appearance.

Feldspars, most abundant in the coarser sand grades, are generally subangular, pink plagioclase.

Heavy minerals consist primarily of magnetite, horneblende, garnet and epidote with traces of muscovite, rutile and topaz.

Cumulative percent curves of representative beach, aeolian, channel, lake delta and off-beach sands are given in Figures 21 to 25 inclusive.

(3) Silts and Clays - The most abundant mineral in the silt fraction is subangular quartz. Magnetite and trace amounts of horneblende and muscovite, constitute from one to ten percent of total silt.

Clays range in color from blue-gray to brown. They are slightly calcareous and many have a sulphurous odour which is probably due to the decay of contained organic material. X-ray diffraction analyses of sample 79 (deepwater environment) and sample 6 (lagoonal environment) indicate that the clays belong to the montmorillonite group of clay minerals. Much of the clay fraction consists of particles with colloidal dimensions (the largest size for colloidal particles is about ten on the phi scale).

(4) Rock Outcrop - The one rock outcrop in the study area (the reef environment) consists of pale gray, flaggy, dolomitic limestone.

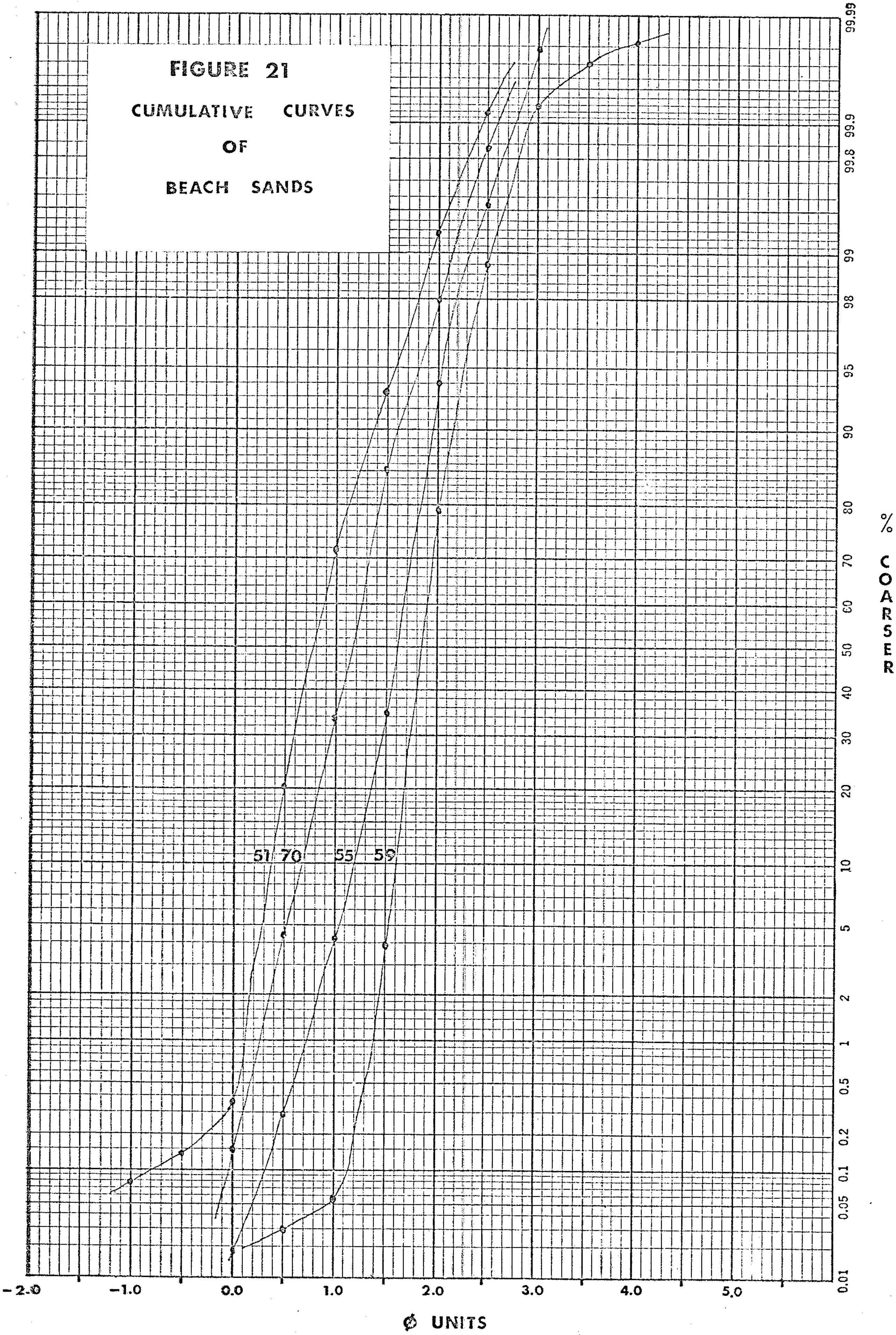


FIGURE 21
CUMULATIVE CURVES
OF
BEACH SANDS
51 70
55
59
-2.0
-1.0
0.0
1.0
2.0
3.0
4.0
5.0
Ø UNITS
% COARSER
99.99
99.9
99.8
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01

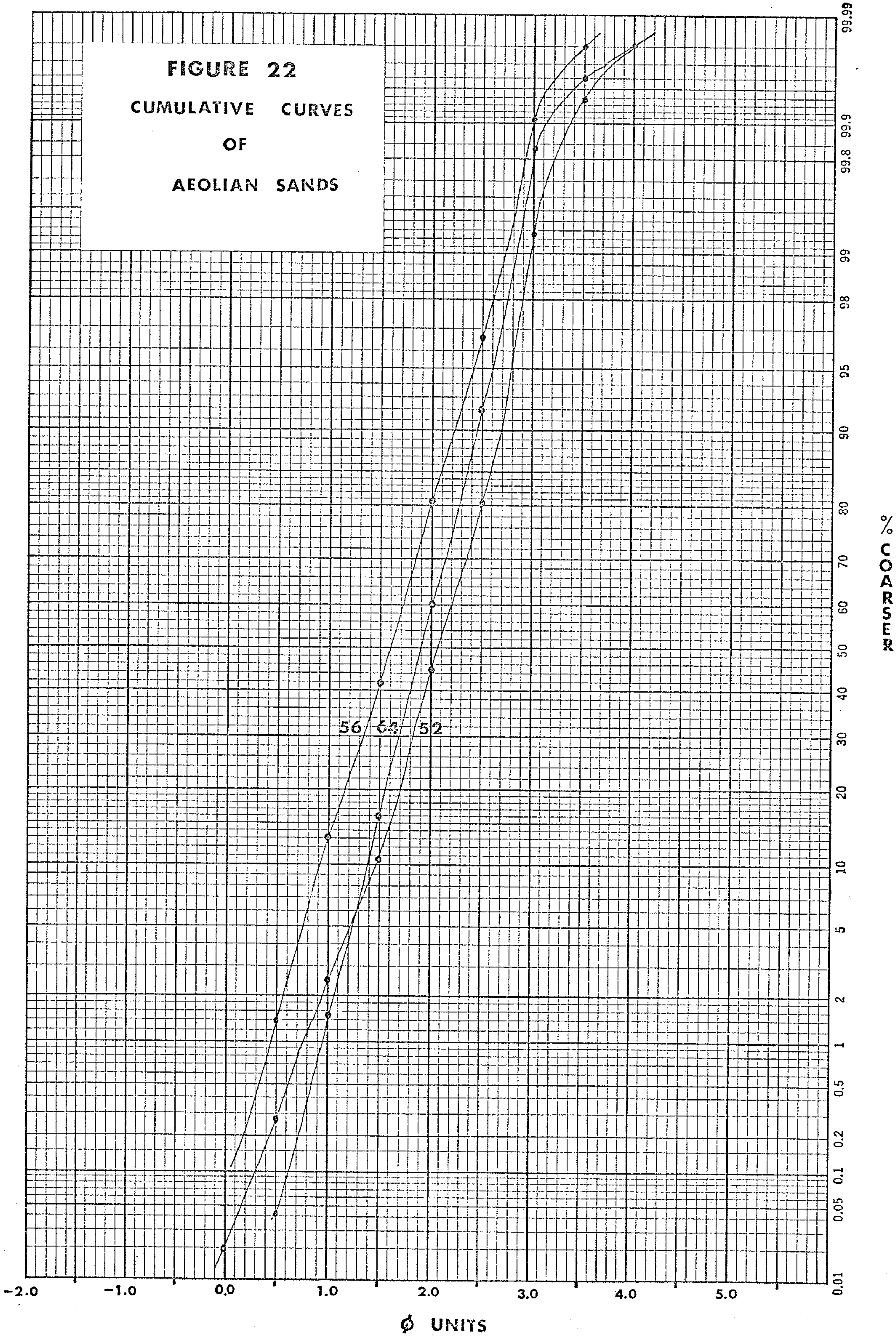


FIGURE 22

CUMULATIVE CURVES OF AEOLIAN SANDS

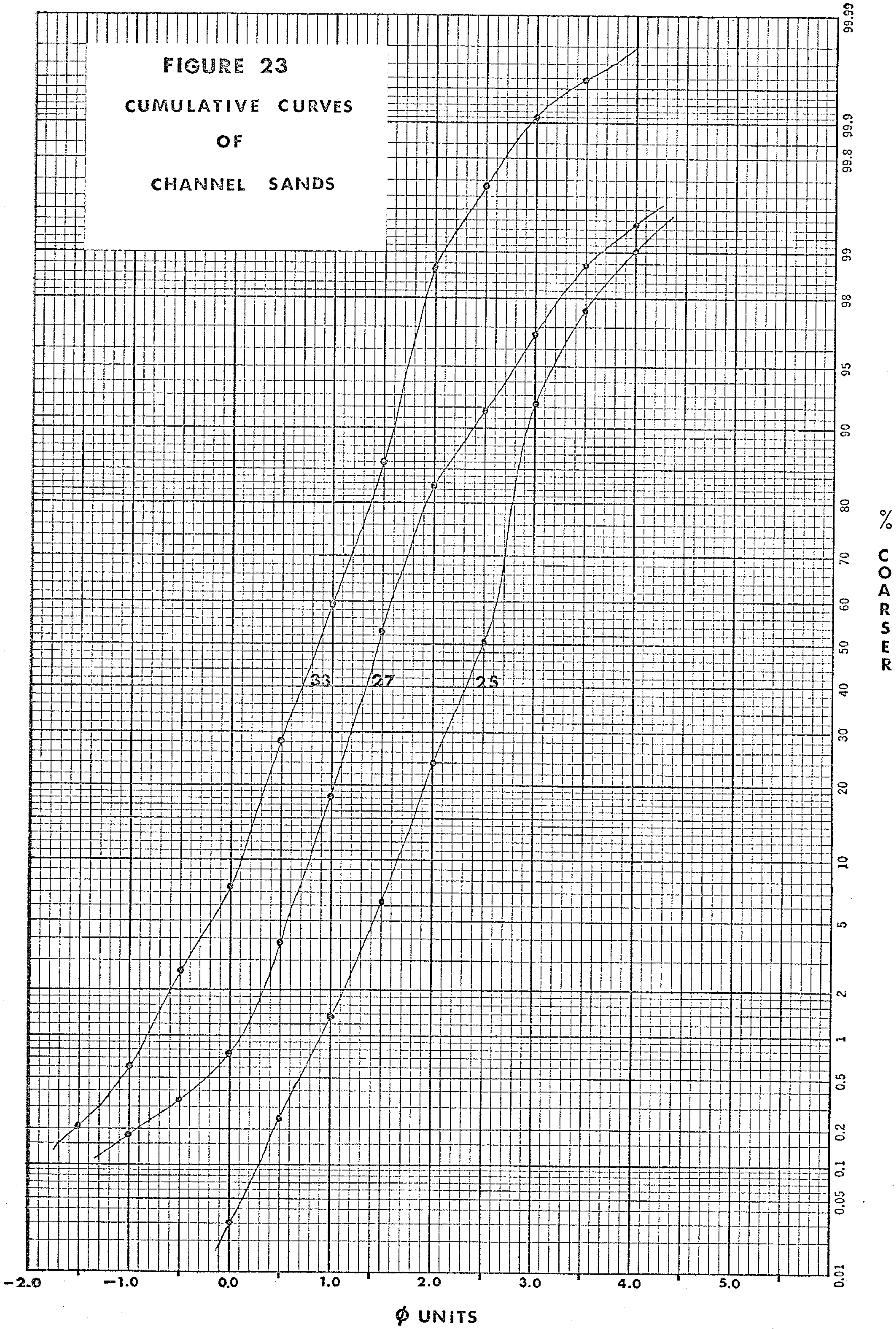


FIGURE 23
CUMULATIVE CURVES
OF
CHANNEL SANDS
33
27
25
-2.0
-1.0
0.0
1.0
2.0
3.0
4.0
5.0
φ UNITS
% COARSER
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99

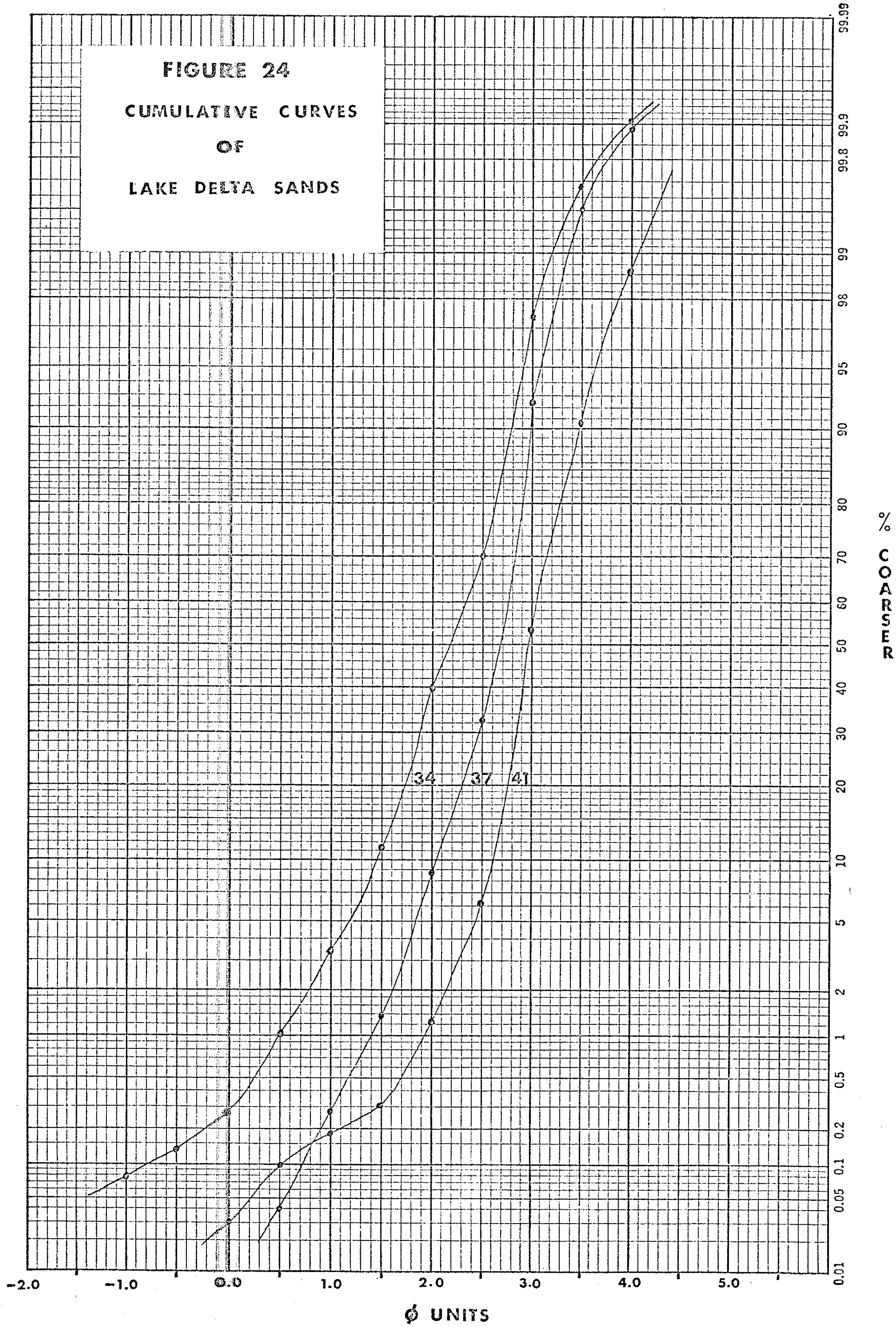


FIGURE 24
CUMULATIVE CURVES
OF
LAKE DELTA SANDS
34
37
41
-2.0
-1.0
0.0
1.0
2.0
3.0
4.0
5.0
ϕ UNITS
% COARSER
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99

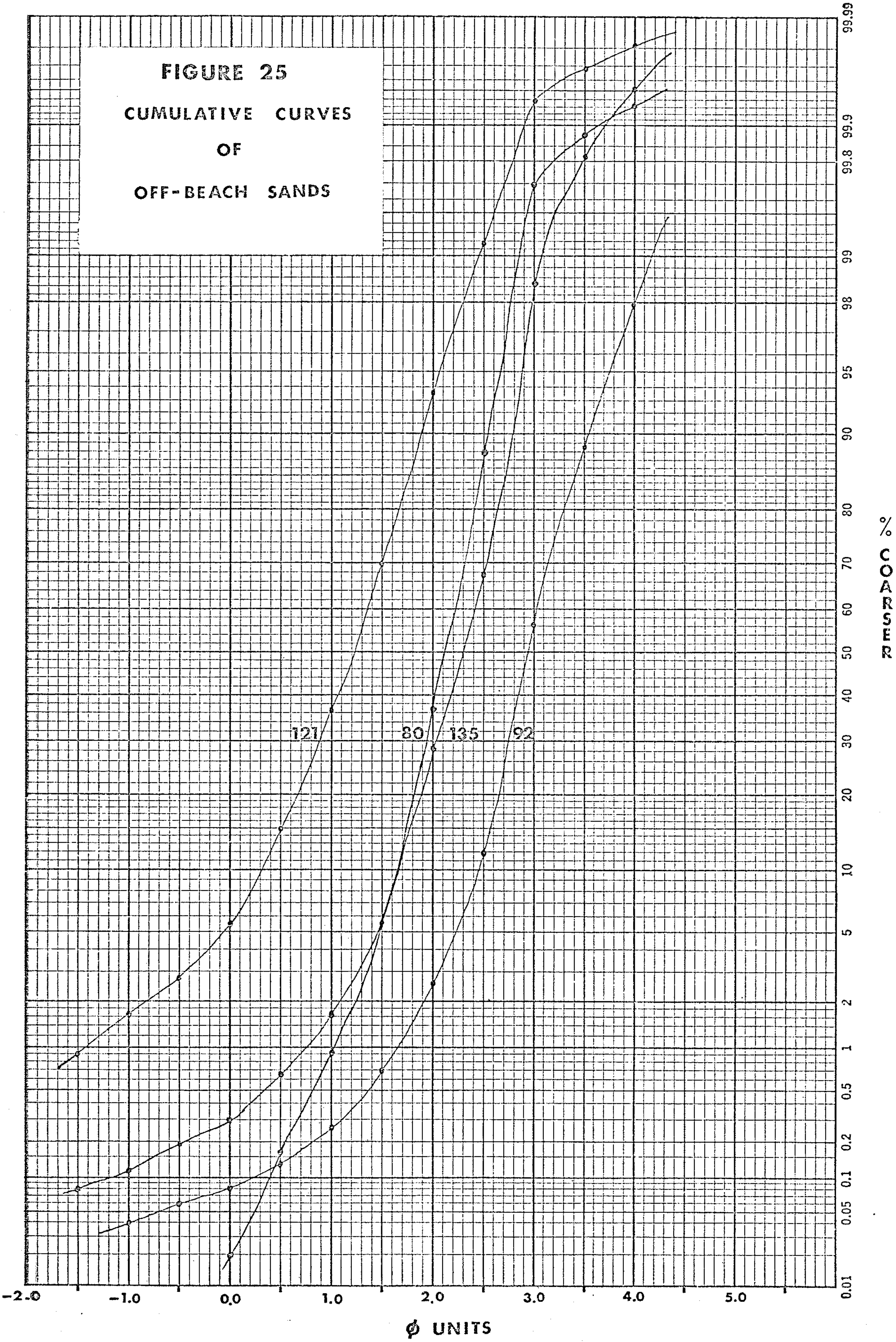


FIGURE 25
CUMULATIVE CURVES
OF
OFF-BEACH SANDS
121
80
135
92
-2.0
-1.0
0.0
1.0
2.0
3.0
4.0
5.0
ϕ UNITS
% COARSER
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99

CHAPTER V

INTERPRETATION OF PROVENANCE AND DISPERSAL OF THE SEDIMENTS

Although the primary objectives of this study are to delineate depositional environments and to evaluate several statistical methods of determining depositional environments from grain-size data, sufficient geologic evidence is available to allow an interpretation of the recent geologic history of the Grand Beach area. The conclusions regarding the recent geologic history of the area are illustrated by two interpretive cross sections in Figure 26 (in pocket).

The Grand Beach bay-mouth bar is interpreted as being a Post Pleistocene geologic feature. Two lines of evidence support this conclusion.

Firstly, bar sands and lagoonal and deepwater clays and silts are superposed on Pleistocene glacial terrain. Glacial drift deposits are present at each end of the bar and along the lagoon shoreline so that gravels of the transitional environment undoubtedly represent subaqueous exposures of these glacial deposits.

Comparison of bar sediments with Pleistocene and Paleozoic sediments exposed in the surrounding region provide a second line of evidence. Wallace and McCartney (1928) reported that the 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."

The present study supports their conclusion. The frosted and pitted variety of quartz grains found at Grand Beach is typical of the Winnipeg Sandstone. Subangular quartz grains with a freshly fractured appearance are undoubtedly derived from glacial drift deposits.

The Winnipeg Sandstone source beds are exposed near Victoria Beach (Wallace and McCartney, 1928; Macauley, 1952) some ten miles northeast of Grand Beach. Deposits of Pleistocene sands and silts are exposed near Belair (Figure 2), and in places, form a 50 foot cliff along the lakeshore (Figure 27). Transportation of sediment from these source areas is primarily by a south trending longshore current (a result of the prevailing northwest winds) along the east shore of the lake.

The initial accumulation of sediment forming the bar has been interpreted in the following manner. The prevailing winds, as illustrated in Figure 26 (Map), initiated two separate forces on sediment particles:

(1) The longshore current, carrying its load of sediment, swept down the shoreline from X to Y. Because of the abrupt change in the direction of the shoreline at Y, the current tended to flow westward across the mouth of the bay.

(2) Wave action tended to drive the sediments back into the open bay-mouth as they reached Y.

Apparently, the longshore current was the predominant force and sediments were swept westward across the bay-mouth. Current velocity decreased in the deeper water and sediments were deposited.

FIGURE 27

Photograph on Lake Winnipeg shore near Belair.

Pleistocene glacial drift is exposed by 50-foot cliff.

Wave action, rather than driving the sediments back into the bay, was constructive and contributed to increasing the height of the bar forming on the lake bottom. A similar current from the west prevented sediments from being swept around promontory Z and thence out of the Grand Beach area. These processes appear to have acted continuously throughout the evolution of the bar.

In addition to producing longshore currents, wind played an important role in forming the channel and the lake and lagoon deltas. With northerly winds and the consequent rise in water, sediment laden water rushed into the lagoon via the channel. As the channel widened into the lagoon, water velocity decreased and sediments were deposited forming the lagoon delta. With a drop in wind velocity, or southerly winds, water flowed out of the lagoon through the channel and a similar delta was formed on the lakeward side of the bar. This process is analagous to that forming tidal deltas in marine environments (Johnson, 1919; Baars, 1963).

Most of the bar is composed of sediments deposited by water. Aeolian sands account for only the surficial covering of sediment on the subaerialy exposed portion of the bar. The beach is the only source for the aeolian sands (Figure 26). High water levels of recent years have caused dune sediments to be eroded and redeposited on the beach. Ice rafting of sediment into the area was observed during the spring of 1966. This mechanism is undoubtedly responsible for the occurrence of the occasional scattered pebbles along the beach.

Clays occurring at Grand Beach are probably derived through the reworking of glacial deposits. Erosion of glacial clay deposits, commonly forming the Lake Winnipeg shoreline, contributes fine sediment to the lake. In addition, Red River, flowing over glacial deposits, carries fine material to the lake. Professor A. Baracos of the University of Manitoba Soil Testing Laboratory reports that colloidal montmorillionite is found in the clays of the Red River Valley (personal communication, 1966). The mechanism by which these colloidal clays are deposited at Grand Beach is not fully understood. Possibly, electrolytes in the lake water induce flocculation and subsequent precipitation. The slightly calcareous nature of the clays is attributed to redeposition of glacial rock flour.

As illustrated in Figure 26, the gravels of the transitional environment are remnants of the Pleistocene glaciation and are not the result of present day sedimentation at Grand Beach. Non-deposition of recent sediments in this environment suggests that water energy levels between water depths of 15 and 25 feet are too low to transport sand particles, yet high enough to prevent the deposition of silts and clays. This suggests a wave base of about 25 feet for this part of the lake. The sheltered location and quieter water of the lagoon allow silts and clays to settle out in only five feet of water.

The limestone exposure forming the reef is the Ordovician Red River Formation (Manitoba Mines Branch Map 65-1, 1965). Non-deposition of recent sediments in this environment again suggests water energies high enough to prevent silt and clay deposition.

CHAPTER VI

STATISTICAL ANALYSES OF GRAIN-SIZE DATA OF THE GRAND BEACH SEDIMENTS

Introduction

Several statistical techniques which purport to assign depositional environments to sediment samples from their grain-size distribution have been proposed in the literature (Passega (1957), Mason and Folk (1958), Friedman (1959), Sahu (1964), and Klovan (1966)). The gross depositional environments at Grand Beach provide a model to evaluate these five techniques.

Most quantitative techniques applied to grain-size distribution data have been developed through the study of recent marine sediments. The Grand Beach area is lacustrine, but is directly comparable to many present day marine situations:

(1) The size, shape and mode of formation of the bay-mouth bar is similar to coastal features described by Johnson (1919).

(2) North winds have a fetch of some fifty miles and ten-foot waves have been observed near Grand Beach. This is analogous to conditions of a sheltered sea coast. Southern Lake Winnipeg, however, is shallower than most coastal bays or inlets of comparable size.

(3) Because of the shallow wave base (approximately 25 feet) at Grand Beach, silts and clays are deposited much closer to shore than in a similar marine situation.

(4) Although Lake Winnipeg does not have noticeable tides, wind produces analogous, though irregular, fluctuations of water level.

Marine tidal deltas described by Johnson (1919), and Baars (1963) are similar to the deltas delineated at Grand Beach.

(5) Ice rafting of sediments in the area may be compared with that occurring along northern sea coasts.

The author contends that these similarities justify the use of a lacustrine model to test statistical methods of depositional environment determination which are commonly applied to marine sediments.

All methods use the same basic data, namely the results of grain-size analyses of 66 recent sediment samples from beach, aeolian, channel, lake delta and off-beach environments at Grand Beach (Table II). The statistical study is limited to sandy sediments because:

(1) Most of the proposed techniques have been developed for study of sand grade sediments.

(2) Complete grain-size distributions are not available for clays at Grand Beach.

(3) To date, there is no completely satisfactory method available for determining the grain-size distribution of ultra (particles with colloidal dimensions) fine-grained sediments.

Each of the five techniques is described and evaluated in a similar manner:

(1) The technique is described.

(2) The 66 grain-size analyses are considered to be from unknown depositional environment(s). The technique is then applied to the "unknowns" and their possible depositional environment(s) are interpreted according to criteria proposed by the author of the method.

(3) The results thus obtained are compared to the environmental situation previously determined at Grand Beach.

Most techniques involve considerable computation. Wherever possible, these computations were performed by digital computer. Programs used in the statistical study are documented in Chapter VII.

Diagram CM-Passega (1957)

(A) Description - The statistical parameters used by this method are C (the one percentile particle diameter in microns), and M (the fifty percentile particle diameter in microns) for each sample. The values of C and M are taken from cumulative frequency curves and when plotted on logarithmic paper, form a pattern CM. Sample points may fall anywhere on the graph except below the line C = M, which is called limit C = M. The fine fraction is defined as the weight percent of particles with diameters less than 125 microns (3Ø). Fine fraction percentages may be contoured directly on the diagram.

The parameters were selected after a study of transportation processes (Passega, 1957). Fine and coarse fractions of a sediment often act independently of one another, and should be treated separately. The coarse fraction (characterized by C) is most representative of the environment as a whole. Parameter M gives a measure of the average coarseness of the sediment. Fine fractions are defined by the percentage lines on the diagram CM.

Passega (1957) interprets the distribution of sample points and the shape of a diagram CM as reflecting the processes of sediment deposition. He gives numerous examples of patterns CM constructed with grain-size data of sediments with know depositional environments.

(B) Test of the Technique - Values of C and M for the 66 samples are given in Table IV.

Figure 28 is a diagram CM constructed from the test data with the samples as "unknowns". The shape of the CM pattern bears a remarkable resemblance to examples of beach deposits given by Passega (1957, Figures 11A, 11B and 12). The following features, taken by Passega to be indicative of beach deposition, may be observed in Figure 28:

(1) Beach sediments usually have median diameters greater than 125 microns.

(2) The CM pattern is wide and long.

(3) Coarse sediments are widely distributed on the diagram; finer sediments are more concentrated.

(4) Medium grain-size of a beach pattern has a sharply defined minimum value, whereas the maximum size is not as sharply defined.

(5) The fine particle percentage lines are almost parallel to the ordinate.

Because the pattern illustrated in Figure 28 is almost identical to that shown by Passega for typical beaches (Passega, 1957, Figures 11A, 11B and 12), it is concluded that the "unknown" sediment

TABLE IV

PARTICLE DIAMETERS AT 1 AND 50 PERCENTILES

SAMPLE	1 PERCENTILE DIAM.(C) MICRONS	50 PERCENTILE DIAM.(M) MICRONS
25	532	179
26	463	198
27	933	356
31	2713	547
32	1165	470
33	1803	547
34	712	219
35	448	176
36	595	225
37	376	162
38	441	166
39	430	154
40	801	130
41	262	127
51	927	578
52	574	232
53	841	521
54	611	272
55	603	334
56	732	328
57	547	332
58	578	268
59	376	272
60	611	321
61	432	287
62	790	344
63	865	304
64	521	270
65	712	325
66	835	532
67	642	312
68	582	253
69	536	227

(CONTINUED)

TABLE IV (CONTINUED)

SAMPLE	1 PERCENTILE DIAM.(C) MICRONS	50 PERCENTILE DIAM.(M) MICRONS
70	829	448
71	463	308
72	532	255
73	599	299
74	693	330
75	503	285
80	490	238
83	829	216
85	1329	237
86	566	255
90	392	173
91	438	141
92	321	128
98	379	170
102	384	140
107	774	145
110	599	165
121	2676	432
122	633	312
123	563	289
124	633	283
125	737	301
126	438	250
127	392	184
128	406	159
129	1866	344
130	1165	308
131	457	233
132	551	257
133	1741	261
134	1240	274
135	616	204
136	406	174

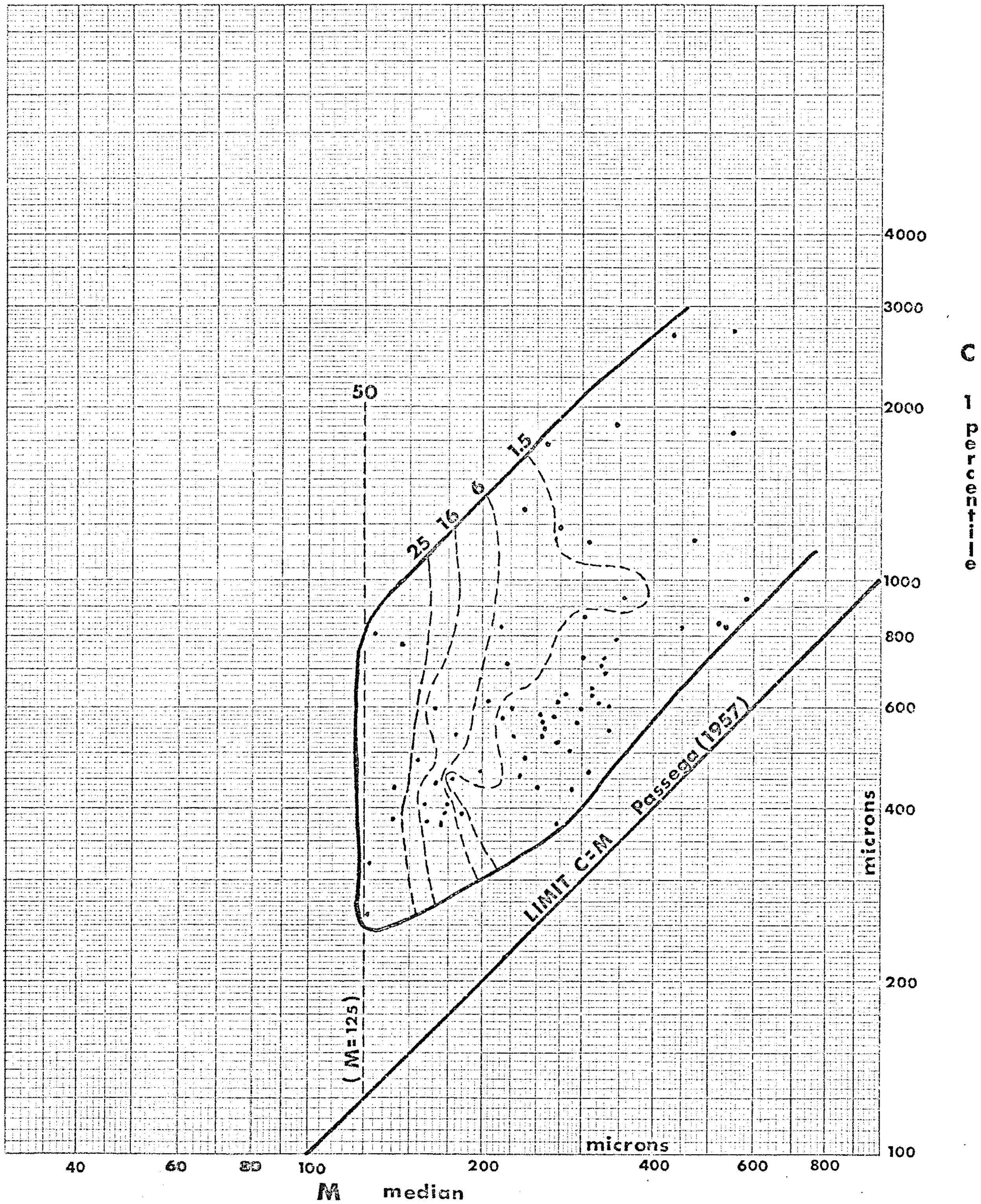


FIGURE 28

DIAGRAM CM – GRAND BEACH SEDIMENTS

• "unknown" sample

--- Percentage finer than 125 microns

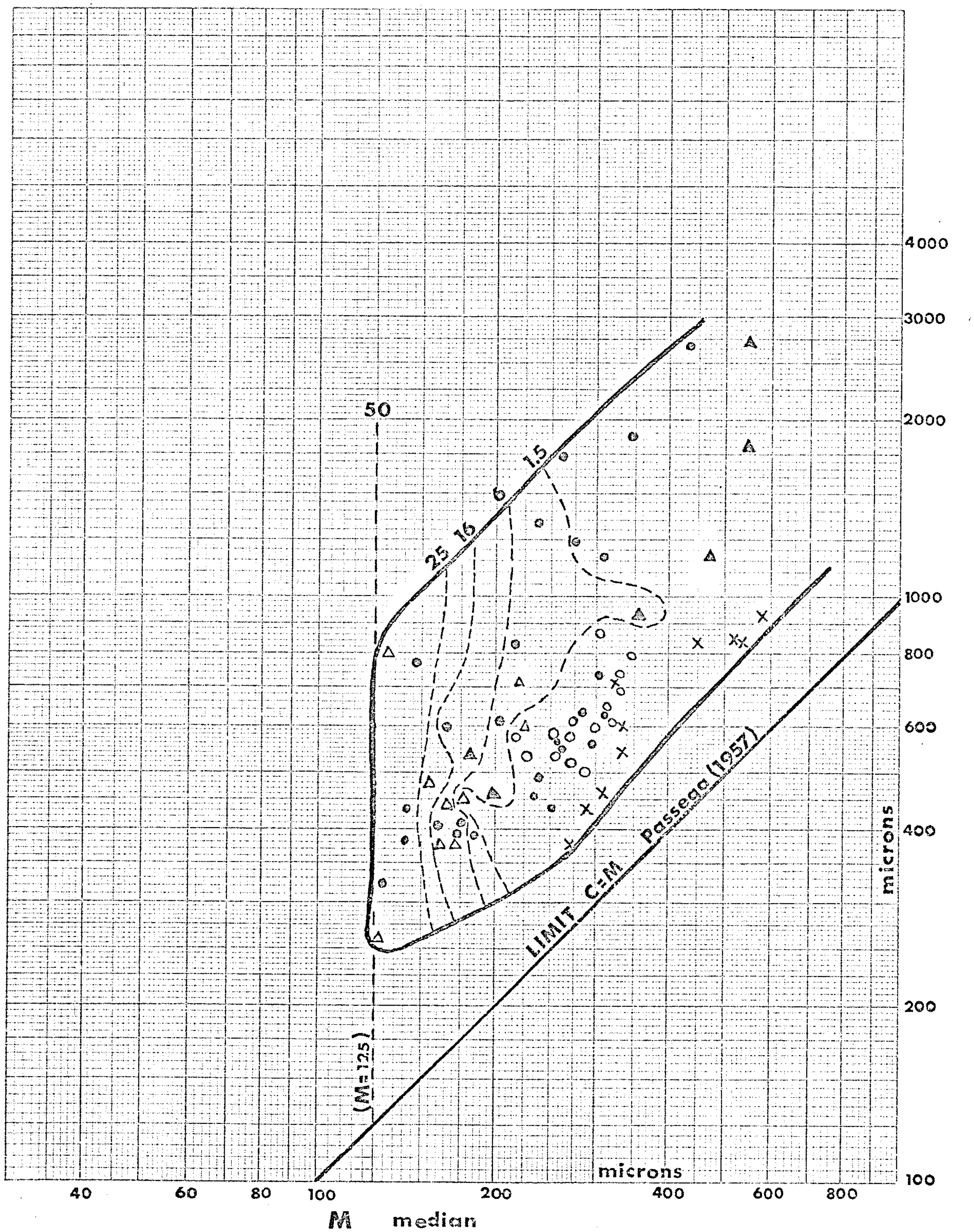


FIGURE 29

DIAGRAM CM – GRAND BEACH SEDIMENTS

Sample Code:

× beach Δ lake delta
o aeolian • off-beach
▲ channel

--- Percentage finer than 125 microns

samples were deposited on a beach. No other depositional processes or environments are recognizable on the diagram CM.

Figure 29 is the same diagram CM but with the known depositional environments of the test samples shown by different symbols. It is obvious the diagram CM technique has failed to differentiate between samples from any of these environments and has left the false impression that all samples are from a beach.

Graphical Parameters - Mason and Folk (1958)

(A) Description - This technique uses the graphical statistical parameters developed by Folk and Ward (1957).

The four parameters and the formulae for their calculation are:

(1) Mean size (M_Z)

$$M_Z = \frac{\emptyset 16 + \emptyset 50 + \emptyset 84}{3}$$

(2) Inclusive graphic standard deviation (σ_I)

$$\sigma_I = \frac{\emptyset 84 - \emptyset 16}{4} + \frac{\emptyset 95 - \emptyset 5}{6.6}$$

(3) Skewness (Sk_I)

$$Sk_I = \frac{\emptyset 16 + \emptyset 84 - 2\emptyset 50}{2(\emptyset 84 - \emptyset 16)} + \frac{\emptyset 5 = \emptyset 95 - 2\emptyset 50}{2(\emptyset 95 - \emptyset 5)}$$

(4) Kurtosis (K_G)

$$K_G = \frac{\emptyset 95 - \emptyset 5}{2.44 \times (\emptyset 75 - \emptyset 25)}$$

where Ø5 is the phi diameter at the 5th percentile of the distribution, etc. The percentiles are taken from the cumulative frequency curve drawn for each sample.

Mason and Folk (1958) suggest that a plot of skewness against kurtosis provides the best means for distinguishing between beach, dune and aeolian flat environments of Mustang Island, Texas. The mean size and standard deviation (a measure of sorting) could not be used to delineate environments because of the very uniform nature of the source sediments. Differences in transportation mechanisms in the three environments affected the tails of the distribution curve and these differences were reflected in the values of skewness and kurtosis. Skewness is a measure of the symmetry of the distribution curve. Normal curves have a skewness value of 0.00. Curves with an excess of fine material have positive skewness and those with an excess of coarse material have negative skewness. Kurtosis measures the ratio of sorting within the central 90 percent of the distribution to sorting of the central 50 percent and is thus a rough measure of the peakedness of the distribution curve. Normal curves have a kurtosis value of 1.00. Curves which have better sorting in the central 50 percent of the distribution than in the central 90 percent are excessively peaked and have kurtosis values greater than 1.00. Conversely, curves with better sorting in the central 90 percent of the distribution than in the central 50 percent are deficiently peaked and have kurtosis values less than 1.00.

(B) Test of the Technique - The computed graphical statistical parameters for the 66 Grand Beach test samples are given in Table V (computed by program 1, Chapter VII).

Plots of skewness versus kurtosis and inclusive graphic standard deviation versus mean size are given in Figures 30 and 31

TABLE V

GRAPHICAL PARAMETERS

SAMPLE	PARAMETERS				
	MEDIAN	MEAN	ST. DEV.	SKEW.	KURT.
25	2.48	2.38	0.52	-0.24	1.02
26	2.34	2.34	0.41	-0.01	1.05
27	1.49	1.49	0.61	0.08	1.26
31	0.87	0.84	0.79	-0.01	1.51
32	1.09	1.11	0.63	0.11	1.03
33	0.87	0.87	0.59	-0.05	0.99
34	2.19	2.16	0.52	-0.14	0.93
35	2.51	2.42	0.35	-0.39	1.07
36	2.15	2.12	0.48	-0.13	0.86
37	2.63	2.58	0.36	-0.25	1.21
38	2.59	2.51	0.42	-0.27	1.17
39	2.70	2.64	0.50	-0.21	1.22
40	2.94	2.93	0.52	-0.17	1.43
41	2.98	3.01	0.36	0.13	1.09
51	0.79	0.82	0.39	0.18	1.09
52	2.11	2.09	0.46	-0.12	0.97
53	0.94	0.93	0.29	-0.04	0.97
54	1.88	1.87	0.47	-0.06	1.04
55	1.58	1.55	0.28	-0.14	1.02
56	1.61	1.60	0.49	-0.03	1.05
57	1.59	1.57	0.23	-0.12	1.07
58	1.90	1.91	0.41	0.00	1.07
59	1.88	1.88	0.21	0.08	1.21
60	1.64	1.64	0.38	0.01	1.06
61	1.80	1.80	0.24	0.05	1.23
62	1.54	1.51	0.54	-0.07	0.99
63	1.72	1.68	0.64	-0.11	0.93
64	1.89	1.91	0.41	0.04	1.02
65	1.62	1.57	0.32	-0.30	1.26
66	0.91	0.93	0.32	0.08	1.02
67	1.68	1.69	0.46	0.04	1.08
68	1.98	2.00	0.48	0.01	0.94
69	2.14	2.11	0.42	-0.14	0.94

(CONTINUED)

TABLE V (CONTINUED)

SAMPLE	PARAMETERS MEDIAN	MEAN	ST. DEV.	SKEW.	KURT.
70	1.16	1.14	0.37	-0.03	1.10
71	1.70	1.70	0.23	0.02	1.11
72	1.97	1.99	0.41	0.03	1.00
73	1.74	1.74	0.39	0.02	1.17
74	1.60	1.59	0.42	-0.01	1.12
75	1.81	1.83	0.36	0.10	1.23
80	2.07	2.07	0.36	0.02	0.97
83	2.21	2.16	0.63	-0.17	0.95
85	2.08	1.80	0.97	-0.39	0.93
86	1.97	2.00	0.53	0.04	0.91
90	2.53	2.50	0.41	-0.12	1.04
91	2.83	2.85	0.44	0.01	1.26
92	2.97	3.00	0.46	0.08	1.10
98	2.56	2.48	0.36	-0.32	1.02
102	2.84	2.87	0.38	0.10	1.34
107	2.79	2.74	0.60	-0.19	1.53
110	2.60	2.53	0.47	-0.22	1.27
121	1.21	1.18	0.62	-0.12	1.05
122	1.68	1.67	0.38	-0.02	1.11
123	1.79	1.80	0.36	0.03	1.17
124	1.82	1.83	0.40	0.04	1.15
125	1.73	1.71	0.39	-0.06	1.25
126	2.00	2.02	0.31	0.09	1.27
127	2.44	2.39	0.35	-0.22	0.98
128	2.65	2.63	0.31	-0.05	1.11
129	1.54	1.45	0.57	-0.29	1.22
130	1.70	1.67	0.48	-0.14	1.31
131	2.10	2.11	0.38	0.03	0.93
132	1.96	1.99	0.40	0.07	1.05
133	1.94	1.97	0.59	-0.05	1.12
134	1.87	1.89	0.47	-0.04	1.12
135	2.29	2.25	0.43	-0.17	0.95
136	2.52	2.46	0.43	-0.18	0.97

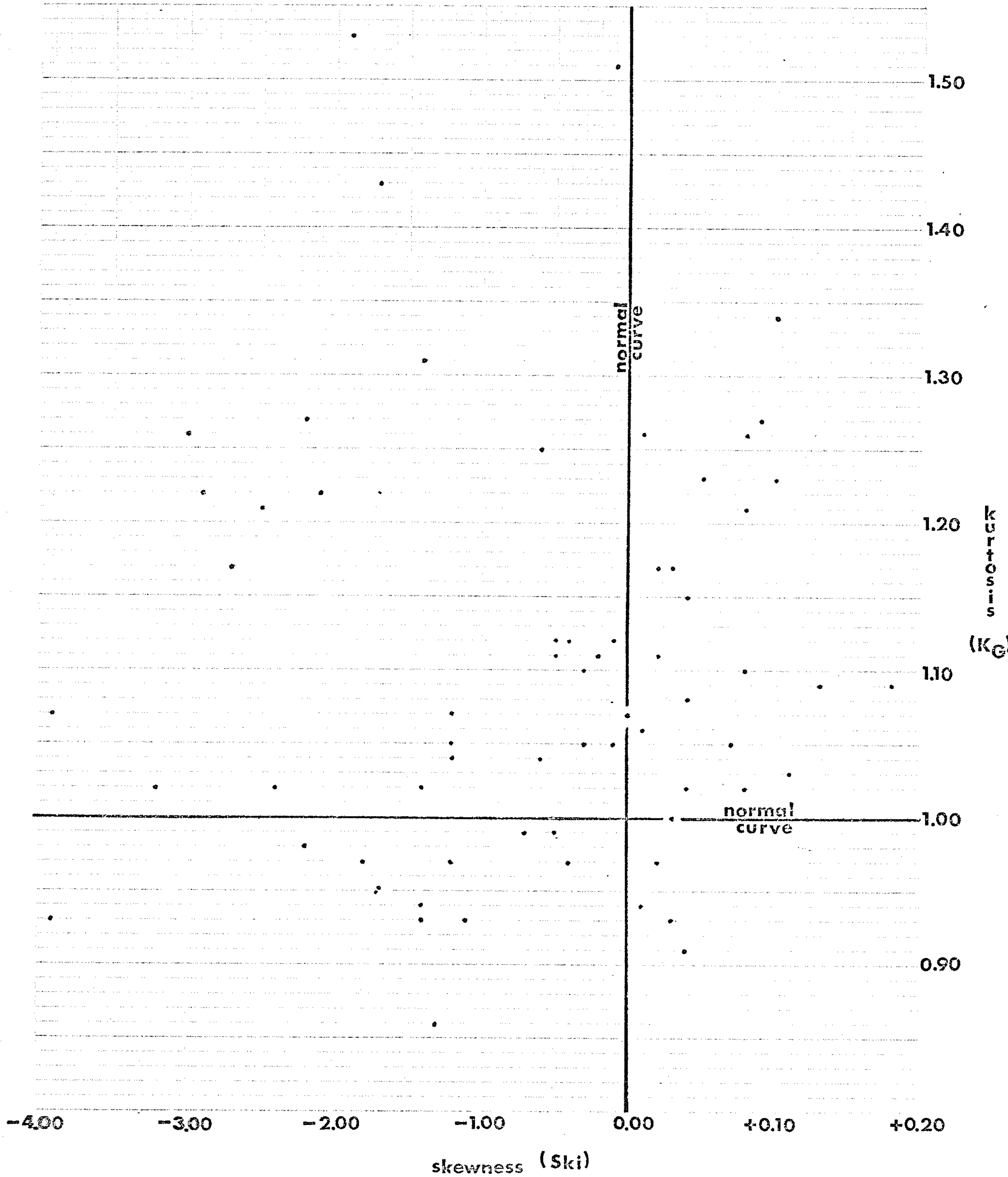


FIGURE 30

PLOT OF SKEWNESS AGAINST KURTOSIS (graphic) – GRAND BEACH SEDIMENTS

• 'unknown' sample

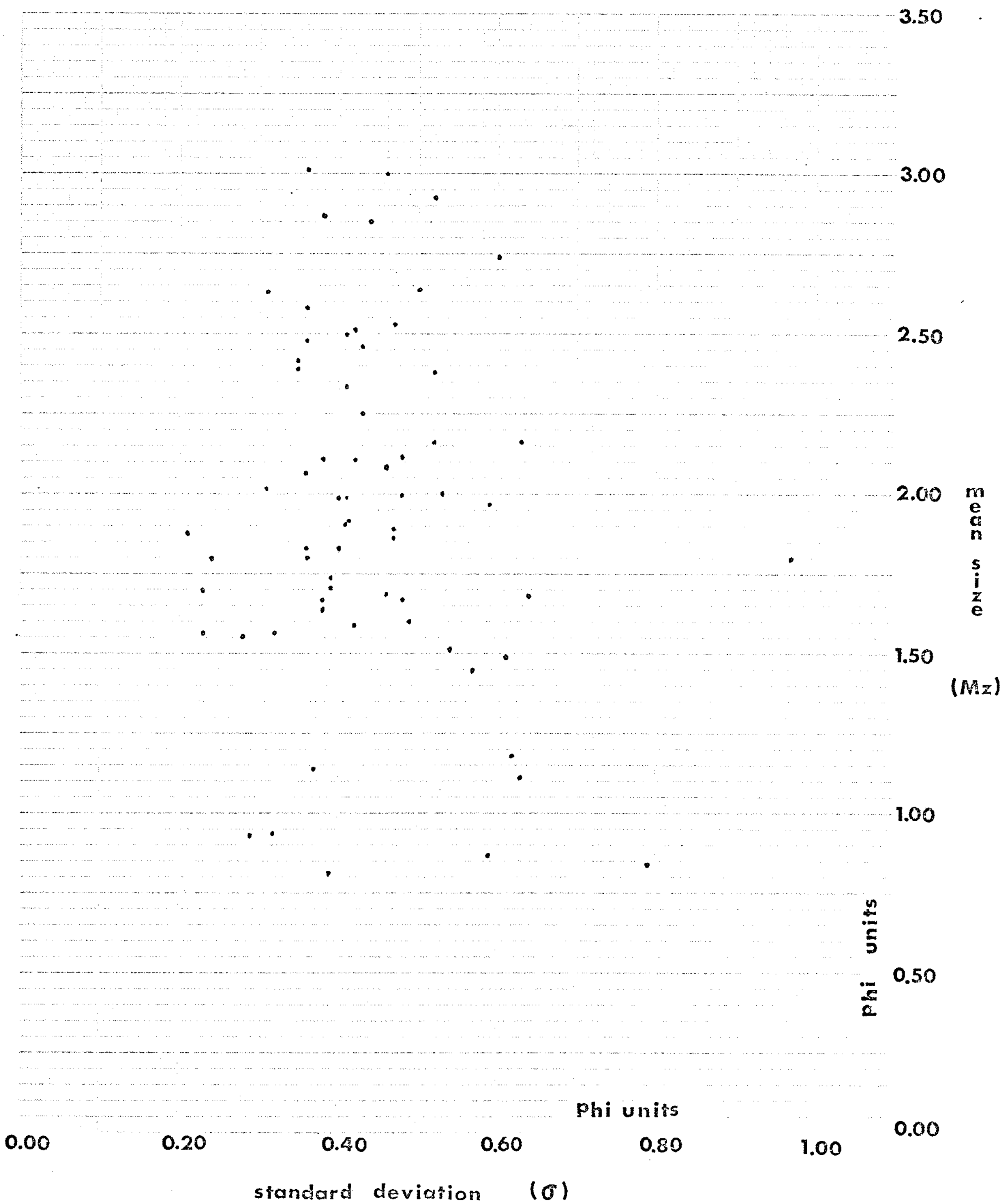


FIGURE 31

PLOT OF STANDARD DEVIATION AGAINST MEAN (graphic) – GRAND BEACH SEDIMENTS

• 'unknown' sample

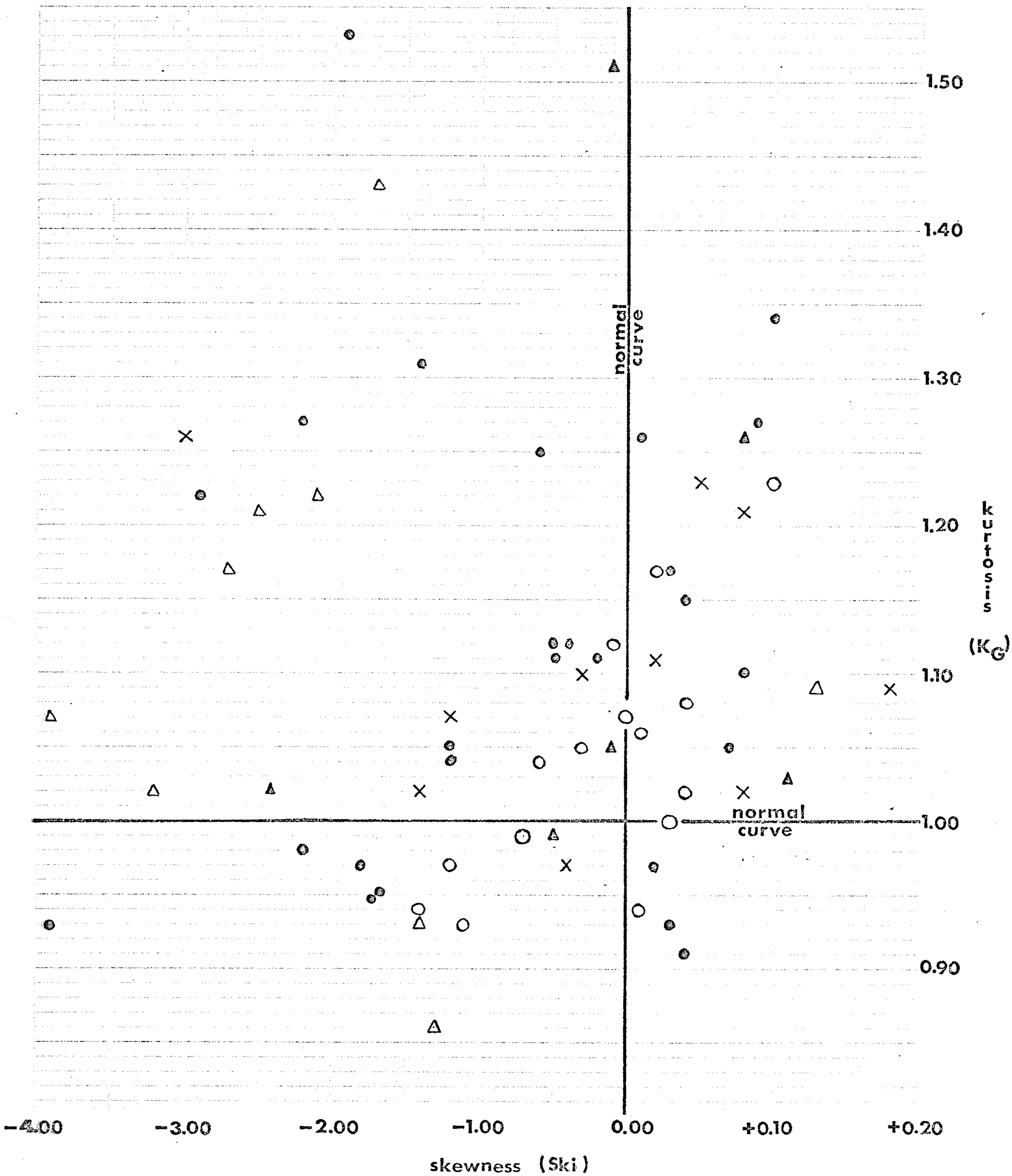


FIGURE 32

PLOT OF SKEWNESS AGAINST KURTOSIS (graphic) – GRAND BEACH SEDIMENTS

Sample Code:

X beach ▲ channel ● off-beach
O aeolian △ lake delta

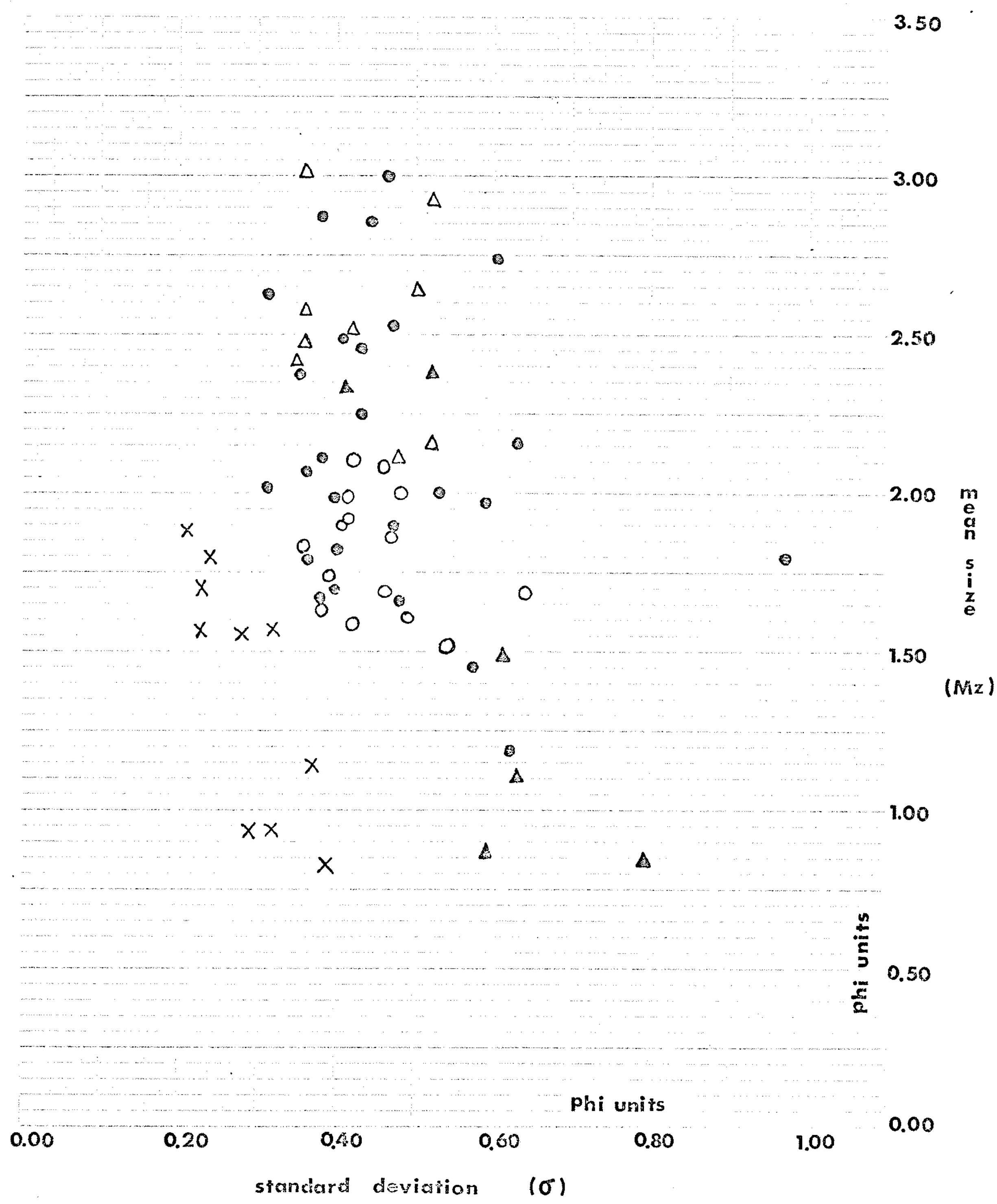


FIGURE 33

PLOT OF STANDARD DEVIATION AGAINST MEAN (graphic) – GRAND BEACH SEDIMENTS

Sample Code:

X beach ▲ channel • off-beach

O aeolian △ lake delta

inclusive. The lack of sample clusters or trends between samples on these diagrams makes it virtually impossible to determine the depositional environments for the individual test samples.

The plot of skewness against kurtosis for the same samples, now identified as to their depositional environments, is given in Figure 32. Samples from known environments are scattered and intermixed. Skewness and kurtosis appear to have little value in differentiating the depositional environments at Grand Beach.

Figure 33 gives the plot of inclusive graphic standard deviation against mean with samples environmentally identified. Beach samples are completely separated from those of other environments. Aeolian samples tend to form a cluster, but are intermixed with samples from the other environments. However, this partial separation of environments is apparent only when the depositional environments of the samples are known.

<u>Moment Parameters - Friedman (1961)</u>

(A) <u>Description</u> - The statistical parameters used by Friedman (1961) are the mean ($\bar{X}_\emptyset$), standard deviation ($\sigma_\emptyset$) skewness ($\alpha 3_\emptyset$) and kurtosis ($\alpha 4_\emptyset$). These parameters are called the first to fourth moments (respectively) of the grain-size distribution. The formulae for calculating the moment parameters are:

(1) Mean ($\bar{X}_\emptyset$) - First moment

$$\bar{X}_\emptyset = 1/100 \sum fm_\emptyset$$

where, f is the frequency of the grade sizes,

m_ϕ is the midpoint of each grade size in phi units

(2) Standard deviation (σ_ϕ - Second moment

$$\sigma_\phi = (\Sigma f(m_\phi - \bar{X}_\phi)^2/100)^{\frac{1}{2}}$$

(3) Skewness ($_{3\phi}$) - Third moment

$$\alpha_{3\phi} = (1/100)\ \sigma_\phi^{-3}\ \Sigma f(m_\phi - \bar{X}_\phi)^3$$

(4) Kurtosis ($_{4\phi}$) - Fourth moment

$$\alpha_{4\phi} = (1/100)\ \sigma_\phi^{-4}\ \Sigma f(m_\phi - \bar{X}_\phi)^4$$

Friedman (1961) proposed that dune, beach and river sands could be differentiated by the four moment parameters which he interpreted to reflect differences in the mode and energy of sedimentary transportation (as did Mason and Folk, 1958, for their graphical parameters). He claimed, however, that the moment parameters were more sensitive to differences in the grain-size distribution than the corresponding graphical parameters.

(B) Test of the Technique - The moment parameters for the test samples are given in Table VI (computed by program 2, Chapter VII).

Considering the test samples as "unknowns", four scatterplots of pairs of moment parameters are given in Figures 34 to 37 inclusive. The dashed lines separating the different environments are reproduced from Friedman (1961). The four scatterplots are:

(1) Figure 34 - Plot of mean size against skewness. According to Friedman (1961), dune sands should plot above the dashed line. Beach sands should plot below the dashed line.

(2) Figure 35 - Plot of kurtosis against skewness. River sands should have a positive skewness. Beach sands should show a negative skewness.

(3) Figure 36 - Plot of standard deviation against skewness. Beach sands should fall to the left of the dashed line and river sands to the right.

(4) Figure 37 - Plot of standard deviation against mean. This scatterplot is separated into three areas. One area defines dune sands, the second defines river sands, and the third is an area where sands may be from either dune or river environments. Friedman (1961), after Von Englehardt (1940), proposed that the ratio of the grain size of quartz to a heavy mineral could be used to distinguish river sands from dune sands in this field of overlap. The technique of Von Englehardt (1940) has not been evaluated in this study.

The same four scatterplots, with samples environmentally identified, are given in Figures 38 to 41. These show:

(1) Figure 38 - Plot of mean against skewness. This scatterplot classifies about two-thirds of the beach and aeolian sands correctly. Lake delta sands plot as beach sands. Off-beach sands occur in both fields.

(2) Figure 39 - Plot of Kurtosis against skewness. Only four of the ten beach samples fall in the beach part of the scatterplot. Some channel, aeolian and off-beach sands plot as rivers. The remainder of the samples are in the beach zone.

(3) Figure 40 - Plot of standard deviation against skewness. Most of the samples plot as beach sands. Twelve samples from various environments plot as river sands.

TABLE VI

MOMENT PARAMETERS

SAMPLE	PARAMETERS MEAN	ST. DEV.	SKEW.	KURT.
25	2.39	0.57	-0.21	4.07
26	2.34	0.49	-0.09	7.81
27	1.54	0.68	0.62	5.22
31	0.86	0.88	0.42	5.54
32	1.13	0.66	0.32	3.25
33	0.85	0.63	-0.37	3.39
34	2.14	0.59	-0.66	4.45
35	2.43	0.41	-1.14	5.22
36	2.11	0.54	-0.53	3.91
37	2.57	0.41	-0.86	5.13
38	2.51	0.46	-0.38	4.54
39	2.63	0.54	-0.83	4.64
40	2.85	0.67	-1.98	10.61
41	3.00	0.42	-0.17	6.19
51	0.82	0.43	0.51	3.98
52	2.08	0.49	-0.43	3.33
53	0.94	0.34	0.21	4.09
54	1.86	0.49	-0.18	3.05
55	1.56	0.33	-0.30	4.02
56	1.59	0.51	-0.06	2.99
57	1.59	0.28	-0.69	4.08
58	1.90	0.44	-0.26	3.44
59	1.86	0.26	1.06	6.45
60	1.64	0.40	0.06	3.47
61	1.79	0.28	0.55	6.03
62	1.51	0.55	-0.12	2.79
63	1.67	0.65	-0.28	2.72
64	1.90	0.44	0.02	3.11
65	1.58	0.37	-1.08	5.99
66	0.92	0.36	0.27	3.45
67	1.69	0.48	0.06	3.10
68	1.98	0.51	-0.09	3.13
69	2.10	0.46	-0.46	3.21

(CONTINUED)

TABLE VI (CONTINUED)

SAMPLE	PARAMETERS MEAN	ST. DEV.	SKEW.	KURT.
70	1.14	0.40	0.20	3.78
71	1.71	0.27	-0.12	4.58
72	1.98	0.44	-0.10	3.41
73	1.74	0.42	0.10	4.02
74	1.58	0.46	0.12	3.88
75	1.82	0.39	0.39	4.02
80	2.06	0.40	-0.14	4.35
83	2.14	0.69	-0.61	4.25
85	1.87	0.99	-0.57	2.74
86	2.00	0.55	0.07	2.99
90	2.49	0.47	-0.55	6.81
91	2.82	0.52	-0.89	7.13
92	2.98	0.51	-0.48	6.90
98	2.48	0.41	-0.65	4.36
102	2.85	0.47	-0.98	10.56
107	2.71	0.69	-1.51	8.12
110	2.53	0.56	-0.87	6.43
121	1.14	0.71	-0.99	5.48
122	1.67	0.43	-0.01	4.11
123	1.78	0.41	-0.19	5.75
124	1.81	0.45	-0.42	6.14
125	1.70	0.44	-0.90	9.40
126	2.01	0.36	-0.01	5.02
127	2.40	0.40	-0.62	3.87
128	2.62	0.38	-0.84	8.19
129	1.41	0.65	-1.31	6.28
130	1.65	0.55	-1.40	8.61
131	2.10	0.42	0.03	3.46
132	1.97	0.44	-0.22	5.38
133	1.91	0.70	-1.41	7.86
134	1.82	0.59	-1.49	9.40
135	2.23	0.52	-1.21	8.02
136	2.46	0.47	-0.52	4.22

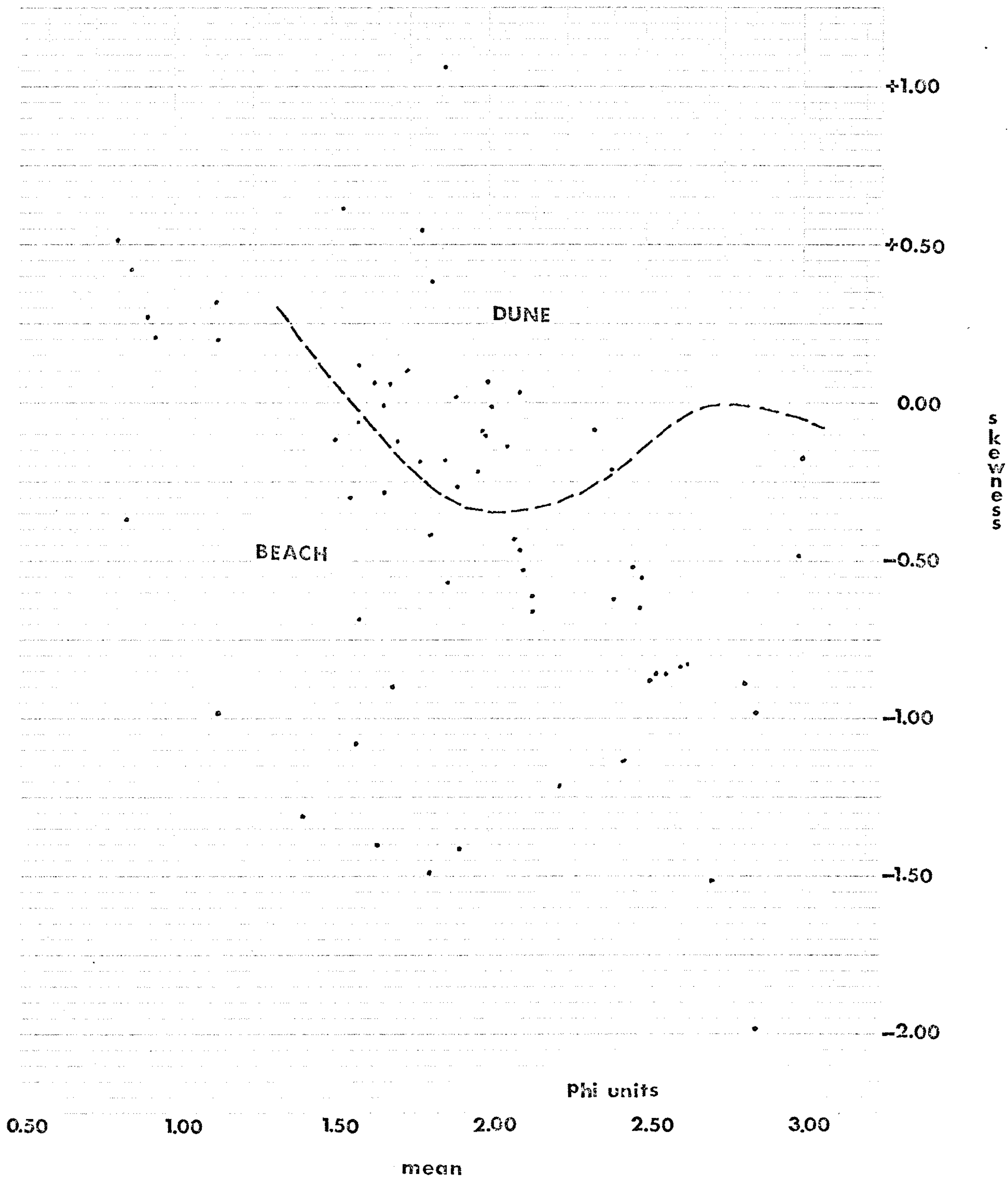


FIGURE 34

PLOT OF MEAN AGAINST SKEWNESS (moments) — GRAND BEACH SEDIMENTS

• 'unknown' sample

--- Friedman (1961)

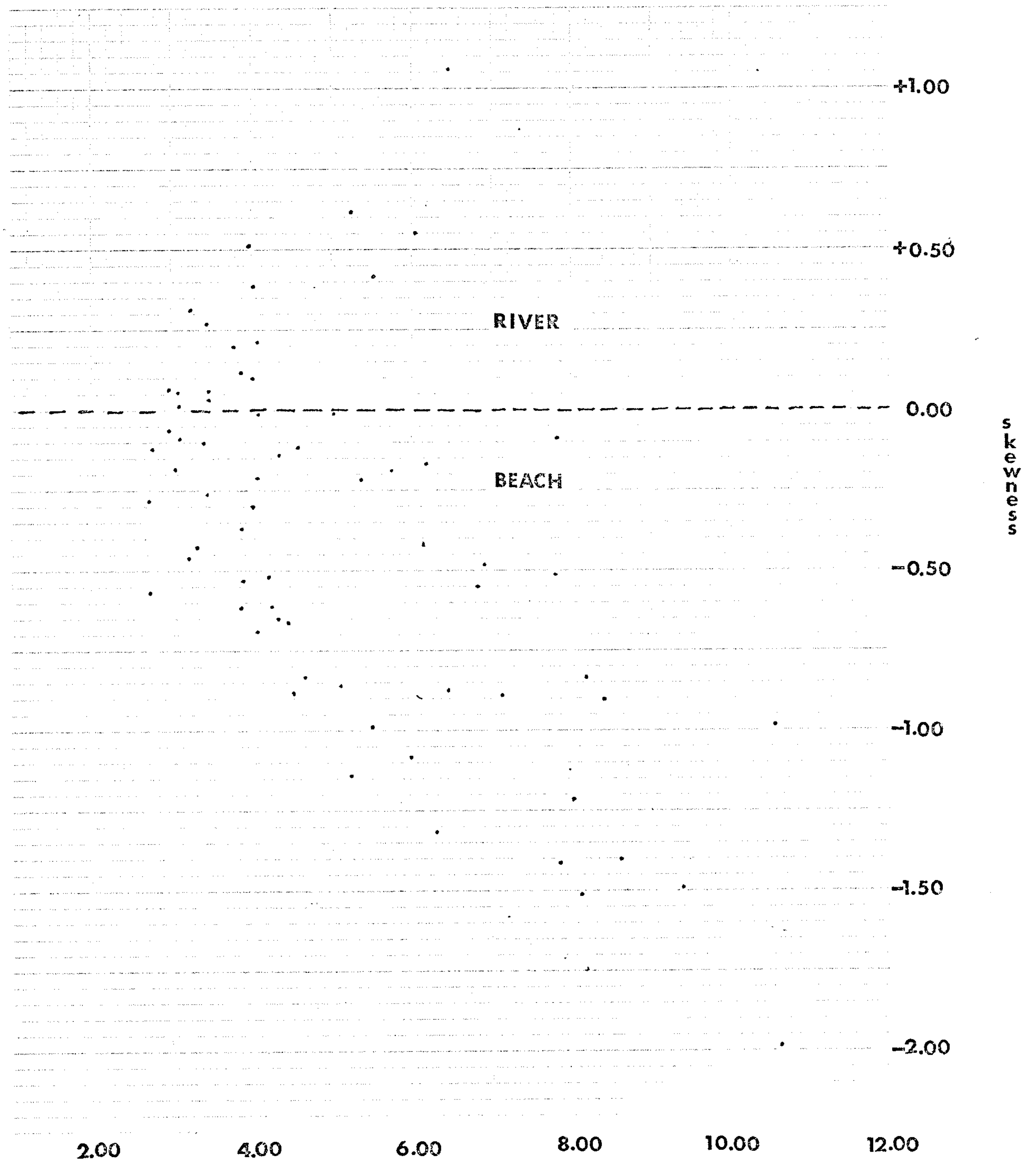


FIGURE 35

PLOT OF KURTOSIS AGAINST SKEWNESS (moments) — GRAND BEACH SEDIMENTS

• 'unknown' sample
--- Friedman (1961)

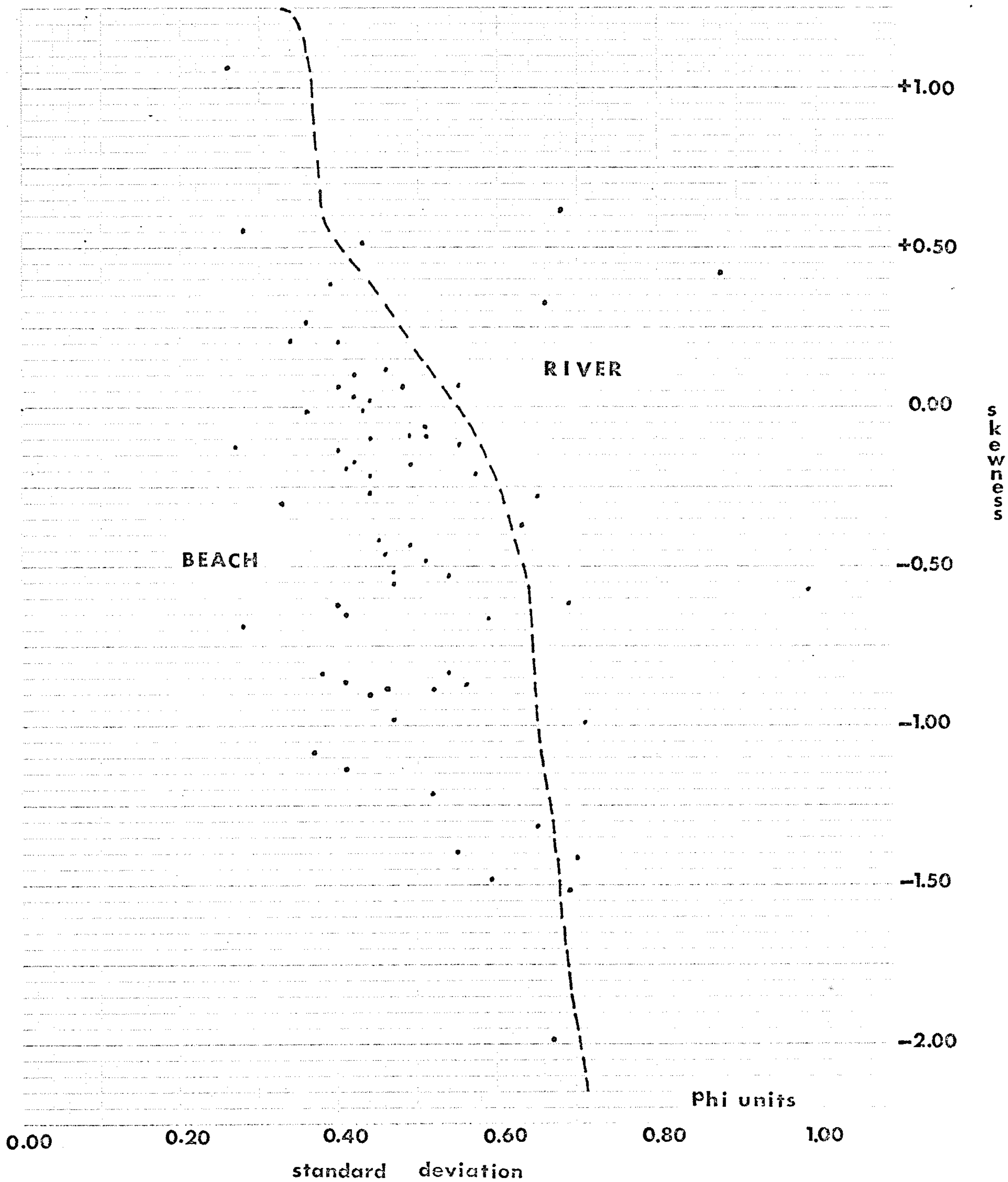


FIGURE 36

PLOT OF STANDARD DEVIATION AGAINST SKEWNESS (moments)– GRAND BEACH SEDIMENTS

• 'unknown' sample

--- Friedman (1961)

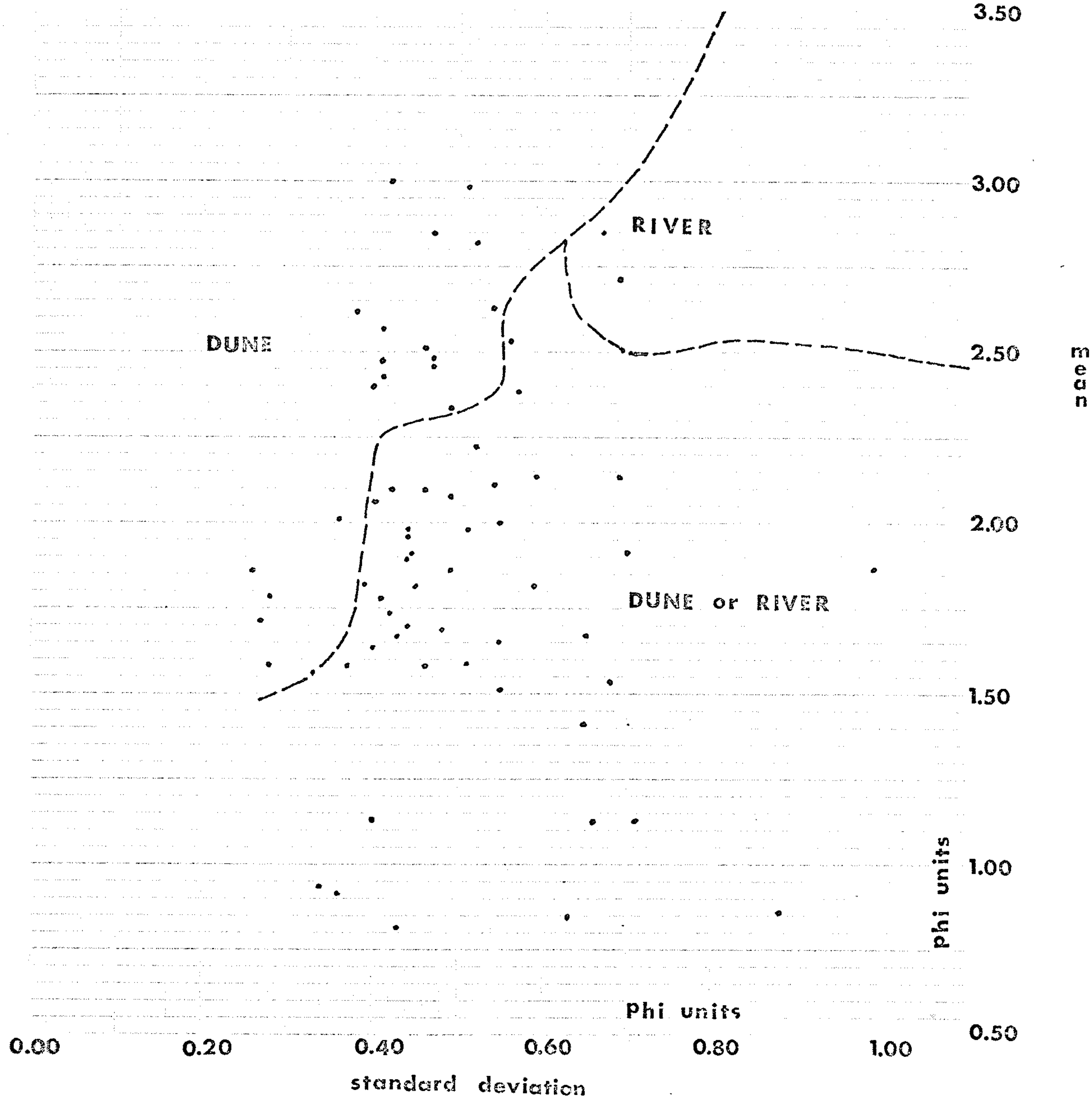


FIGURE 37

PLOT OF STANDARD DEVIATION AGAINST MEAN (moments)– GRAND BEACH SEDIMENTS

• 'unknown' sample
--- Friedman (1961)

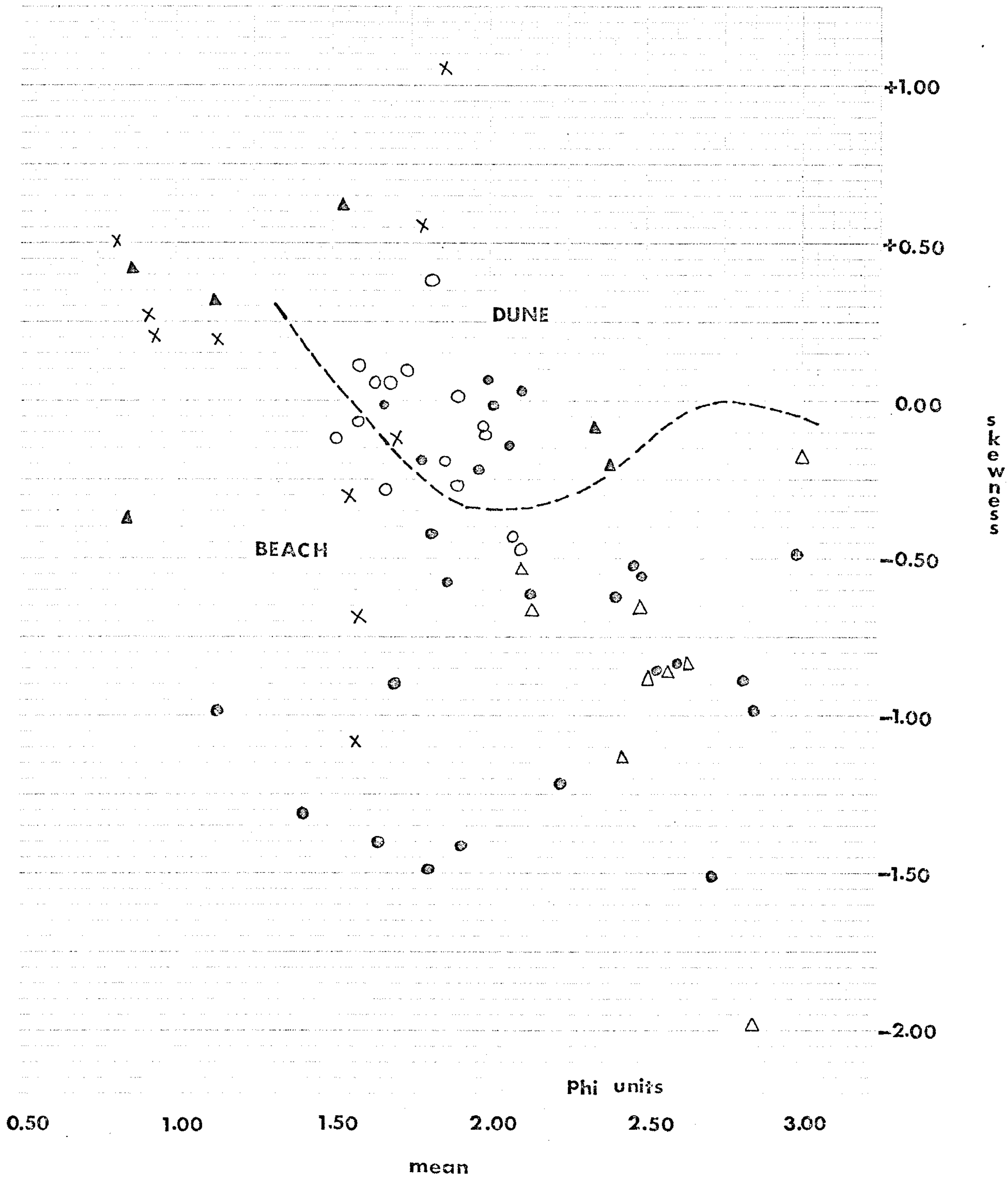


FIGURE 38

PLOT OF MEAN AGAINST SKEWNESS (moments) — GRAND BEACH SEDIMENTS

Sample Code:

× beach　▲ channel　● off-beach　--- Friedman (1961)

○ aeolian　△ lake delta

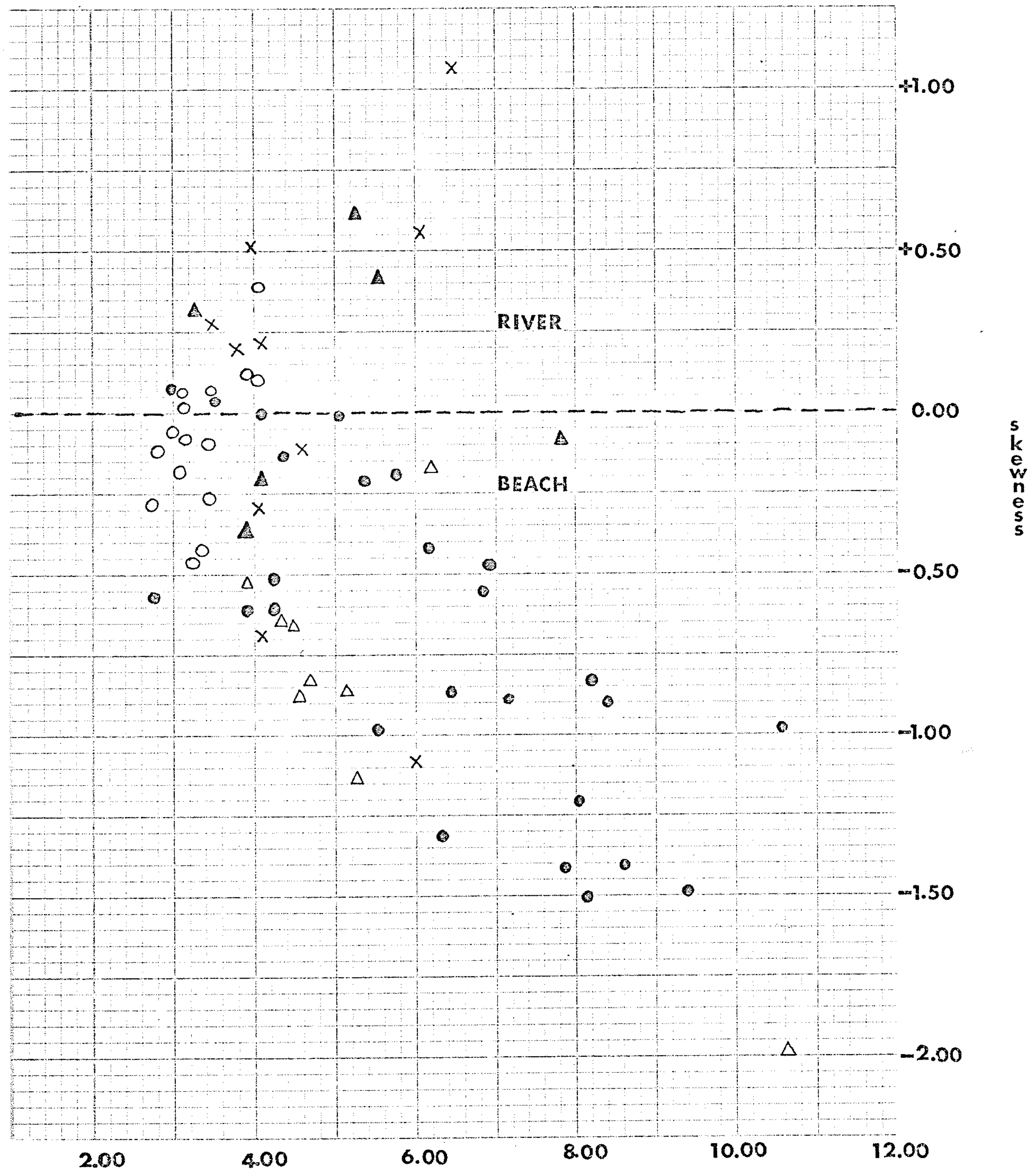


FIGURE 39

PLOT OF KURTOSIS AGAINST SKEWNESS (moments) — GRAND BEACH SEDIMENTS

Sample Code:

× beach ▲ channel • off-beach ---Friedman (1961)

○ aeolian △ lake delta

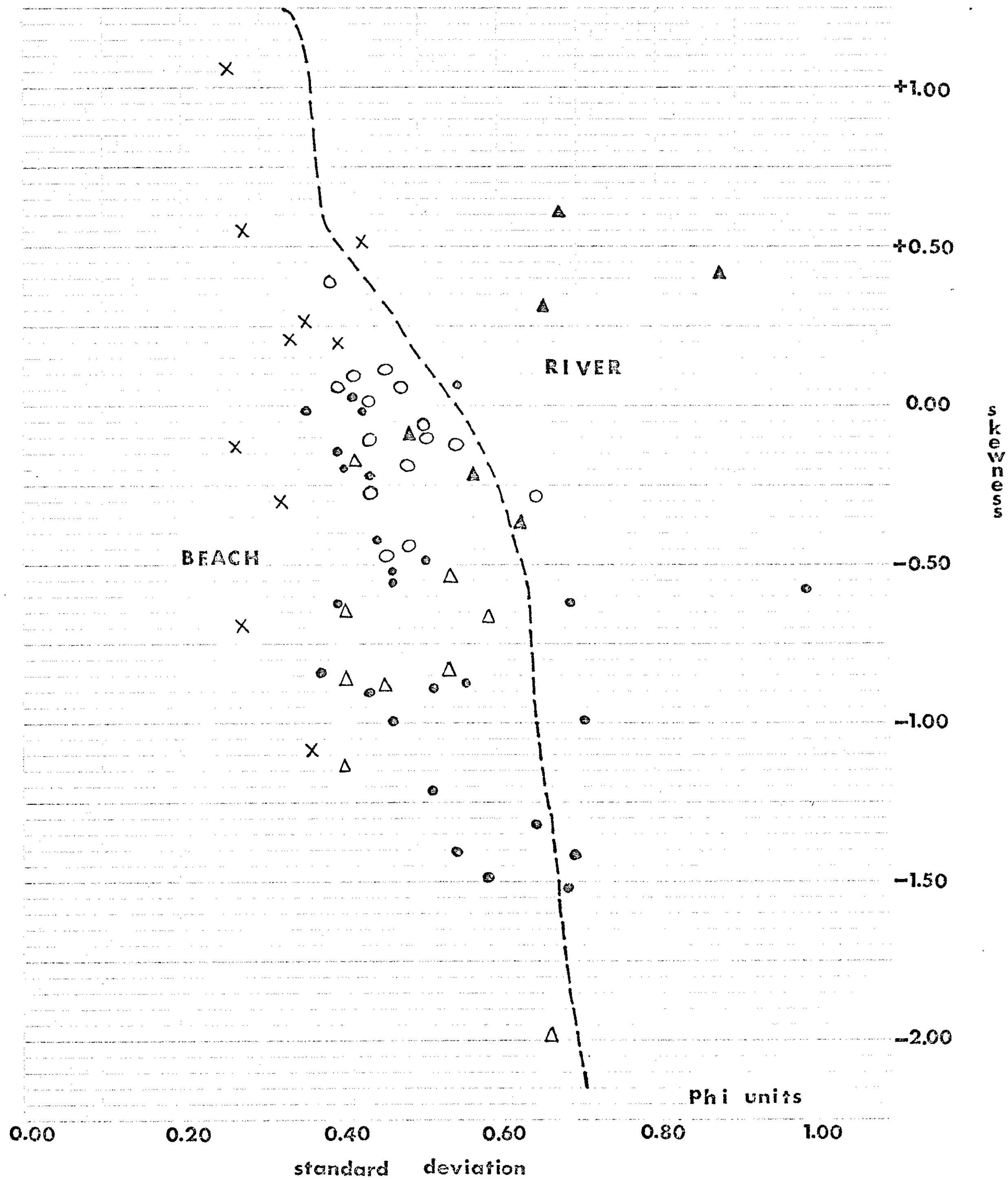


FIGURE 40

PLOT OF STANDARD DEVIATION AGAINST SKEWNESS (moments)– GRAND BEACH SEDIMENTS

Sample Code:

× beach ▲ channel ● off-beach --- Friedman(1961)

○ aeolian △ lake delta

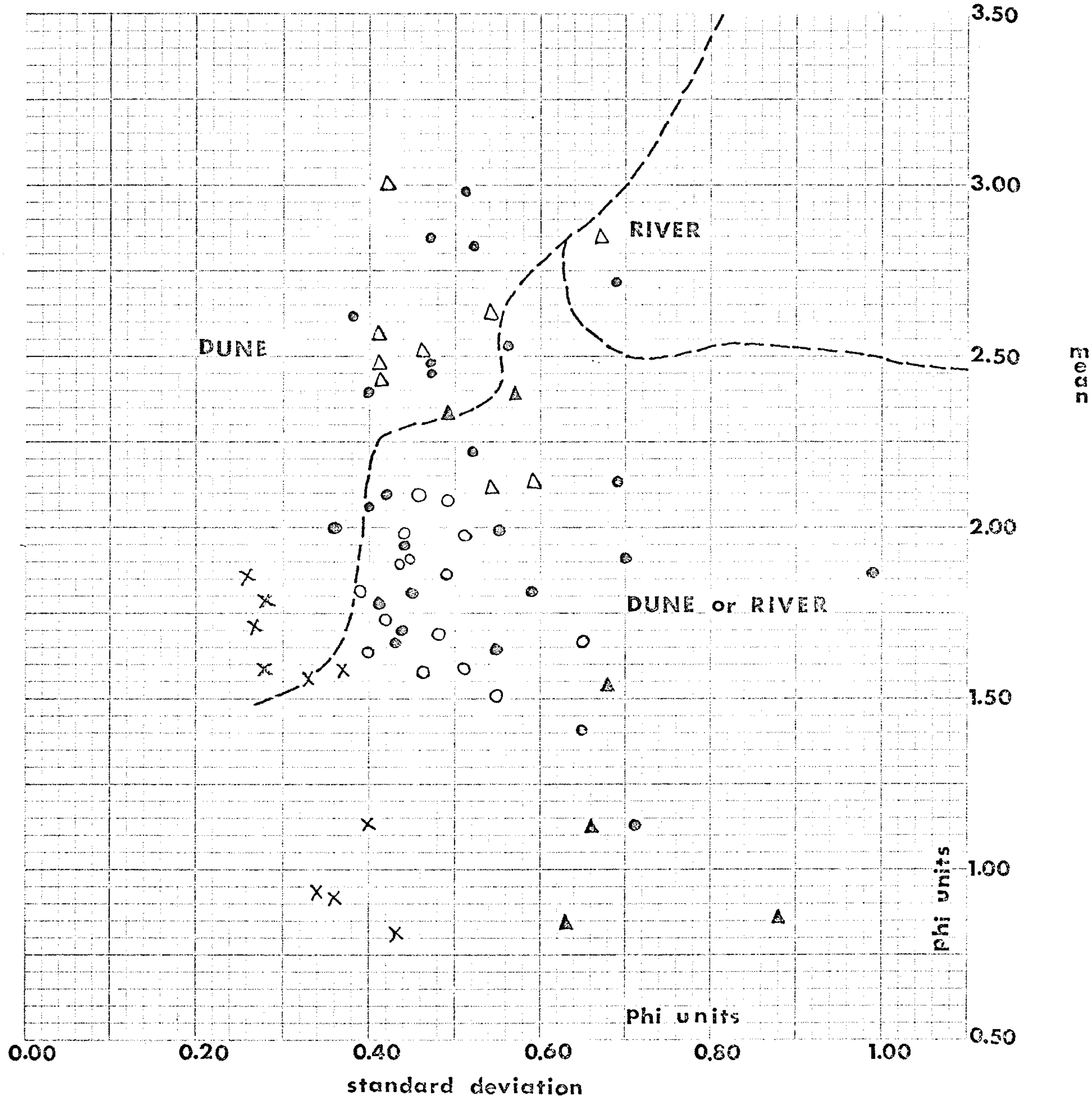


FIGURE 41

PLOT OF STANDARD DEVIATION AGAINST MEAN (moments)— GRAND BEACH SEDIMENTS

Sample Code:

X beach ▲ channel • off-beach --- Friedman (1961)
o aeolian △ lake delta

(4) Figure 41 - Plot of standard deviation against mean. All aeolian sands plot between the dune and river fields. Some beach, off-beach and lake delta sands plot in the dune field of the scatterplot. Two samples, one off-beach and one lake delta, plot in the river field.

The moment technique, at its present state of development, is limited by the fact that only beach, dune and river sands have been considered. When attempting to reconstruct an ancient depositional setting, a geologist cannot assume that these are the only environments present in the area being investigated.

The moment parameters fail to distinguish reliably between beach and aeolian environments at Grand Beach. Further, several samples are classified as coming from a river environment, when in fact, no such environment exists at Grand Beach. The technique also fails to indicate the depositional environments of samples from settings other than dune, beach or river.

These results are consistent with those obtained by Gees (1965) who concluded that the moment parameters may not be a reliable means of determining the depositional environments of sandy sediments.

Discriminant Functions - Sahu (1964)

(a) Description - Sahu (1964) empirically established four discriminant functions (based on the graphical parameters of Folk and Ward, 1957), which were shown to differentiate between the following environments:

(1) Aeolian

(2) Beach

(3) Shallow Agitated Marine

(4) Fluvial (deltaic)

(5) Turbidite

The discriminant functions proposed by Sahu (1964) were developed in the following manner:

(1) Sediment samples were taken from known depositional environments.

(2) The graphical parameters (Folk and Ward, 1957) of the grain-size distribution were computed.

(3) Samples were classified into groups on the basis of their known depositional environments. For example, aeolian samples were one group, beach samples were another group, etc. Then the graphical parameters for the samples of the predetermined groups were used as data for a multivariate discriminant function analysis (explanation below). The end result of the analysis was a suite of characteristic discriminant functions which could be used to assign depositional environments to samples of unknown environmental origin.

According to Sahu (1964), the advantage of using discriminant functions (rather than the graphical parameters alone) was that once a set of discriminant functions has been developed from a group of samples from known environments, even a single sample may be classified into a specific depositional environment. He also concluded that the discriminant functions are the best possible means of distinguishing between adjacent environments which have similar energy conditions.

The discriminant function proposed are:

(1) Discriminant function Y_1 is used to differentiate between aeolian and beach environments.

$$Y_1 = -3.5688\ M_z + 3.7016\ \sigma_I^2 - 2.0766\ Sk_I + 3.1135\ K_G$$

where, M_z is the graphic mean.

σ_I^2 is the variance (inclusive graphic standard deviation squared).

Sk_I is the graphic skewness, and

K_G is the graphic Kurtosis.

A Y_1 value less than (-2.7411) indicates aeolian deposition and a Y_1 value greater than (-2.7411) indicates beach deposition.

(2) Discriminant function Y_2 is used to differentiate between beach and shallow agitated marine environments.

$$Y_2 = 15.6534\ M_z + 65.7091\ \sigma_I^2 + 18.1071\ Sk_I + 18.5043\ K_G$$

A Y_2 value less than 65.3650 indicates beach deposition and a Y_2 value greater than 65.3650 indicates shallow agitated water deposition.

(3) Discriminant function Y_3 is used to differentiate between shallow agitated marine and fluvial (deltaic) environments.

$$Y_3 = 0.2852\ M_z - 8.7604\ \sigma_I^2 - 4.8932\ Sk_I + 0.0482\ K_G$$

A Y_3 value less than (-7.4190) indicates fluvial (deltaic) deposition and a Y_3 value greater than (-7.4190) indicates shallow marine deposition.

(4) Discriminant function Y_4 is used to differentiate between fluvial (deltaic) and turbidity current deposition.

$$Y_4 = 0.7215\ M_z - 0.4030\ \sigma_I^{\ 2} + 6.7322\ Sk_I + 5.2927\ K_G$$

A Y_4 value less than 9.8433 indicates turbidity current deposition and a Y_4 value greater than 9.8433 indicates fluvial (deltaic) deposition.

Samples are assigned to environments by a process of elimination. For example, the following steps would be followed in classifying a sample with the discriminant functions indicated.

Y_1 = (-1.3273) Sample is not aeolian.

Y_2 = (68.4641) Sample is not beach.

Y_3 = (-2.5254) Sample is shallow agitated marine.

Y_4 = (5.2486) This discriminant function is not needed because the sample has been classified as shallow agitated marine.

(B) <u>Test of the Technique</u> - Table VII gives the known environments, the discriminant functions and the environments as computed from the discriminant functions for the test samples (Computed by program 1, Chapter VII). The graphical parameters used in the computation of the discriminant functions are those given in Table V.

The technique correctly classifies nine of the ten beach samples. Eight of the aeolian samples are also classified as coming from a beach. All lake delta samples and sixteen of the off-beach samples are classified as belonging to the aeolian environment.

TABLE VII

DISCRIMINANT FUNCTIONS AND COMPUTED ENVIRONMENTS

SAMPLE	KNOWN ENVIR.	DISCRIMINANT FUNCTIONS Y1	Y2	Y3	Y4	COMP. ENVIR. (SAHU)
25	CHANNEL	-3.8298	69.5674	-0.4545	5.4332	AEOLIAN
26	CHANNEL	-4.4341	66.8934	-0.7150	7.1432	AEOLIAN
27	CHANNEL	-0.1878	72.2201	-3.1340	8.1147	SHALLOW AGITATED
31	CHANNEL	4.0043	81.4059	-5.0409	8.2615	SHALLOW AGITATED
32	CHANNEL	0.4909	64.6621	-3.6538	6.8058	BEACH
33	CHANNEL	1.4069	54.2306	-2.5556	5.3942	BEACH
34	LAKE DELTA	-3.5262	66.2339	-1.0267	5.3988	AEOLIAN
35	LAKE DELTA	-4.0503	58.8223	1.5664	4.7881	AEOLIAN
36	LAKE DELTA	-3.7418	62.2246	-0.7746	5.1410	AEOLIAN
37	LAKE DELTA	-4.4340	67.0714	0.8337	6.5549	AEOLIAN
38	LAKE DELTA	-4.1221	67.7354	0.5304	6.0939	AEOLIAN
39	LAKE DELTA	-4.2917	76.3390	-0.3258	6.8155	AEOLIAN
40	LAKE DELTA	-4.6589	86.7925	-0.5958	8.4659	AEOLIAN
41	LAKE DELTA	-7.1049	78.2250	-0.8655	8.7273	AEOLIAN
51	BEACH	0.6251	46.1282	-1.9111	7.5082	BEACH
52	AEOLIAN	-3.4294	62.3499	-0.6366	5.7641	AEOLIAN
53	BEACH	0.1116	37.4039	-0.2303	5.5110	BEACH
54	AEOLIAN	-2.5040	61.9726	-1.0734	6.3656	BEACH
55	BEACH	-1.7646	46.0395	0.4704	5.5696	BEACH
56	AEOLIAN	-1.4592	59.8381	-1.4679	6.3928	BEACH
57	BEACH	-1.8518	45.6757	0.6194	5.9479	BEACH
58	AEOLIAN	-2.8635	60.9978	-0.9025	6.9766	AEOLIAN
59	BEACH	-2.9393	56.3993	-0.1982	8.2979	AEOLIAN
60	AEOLIAN	-2.0460	54.7988	-0.7950	6.8040	BEACH
61	BEACH	-2.4933	55.8314	-0.2006	8.1301	BEACH
62	AEOLIAN	-1.0437	60.0761	-1.7603	5.7504	BEACH
63	AEOLIAN	-1.3273	68.4641	-2.5254	5.2486	SHALLOW AGITATED
64	AEOLIAN	-3.1089	60.1648	-1.0354	6.9501	AEOLIAN
65	BEACH	-0.6590	49.1270	1.0888	5.7581	BEACH
66	BEACH	0.0826	41.5453	-0.9683	6.6067	BEACH
67	AEOLIAN	-1.9529	60.9949	-1.4869	7.1128	BEACH
68	AEOLIAN	-3.3927	64.1264	-1.4850	6.3948	AEOLIAN
69	AEOLIAN	-3.6626	59.4964	-0.1965	5.4882	AEOLIAN

(CONTINUED)

TABLE VII (CONTINUED)

SAMPLE	KNOWN ENVIR.	DISCRIMINANT FUNCTIONS Y1	Y2	Y3	Y4	COMP. ENVIR. (SAHU)
70	BEACH	-0.1004	46.6524	-0.6765	6.4017	BEACH
71	BEACH	-2.4743	50.9442	-0.0123	7.1841	BEACH
72	AEOLIAN	-3.4185	61.4846	-1.0365	6.8956	AEOLIAN
73	AEOLIAN	-2.0639	59.3232	-0.8882	7.5261	BEACH
74	AEOLIAN	-1.5212	56.9172	-0.9750	6.9533	BEACH
75	AEOLIAN	-2.4092	61.8283	-1.0647	8.4435	BEACH
80	OFF-BEACH	-3.9365	59.2067	-0.5805	6.6656	AEOLIAN
83	OFF-BEACH	-2.9571	74.2224	-1.9783	5.2968	AEOLIAN
85	OFF-BEACH	0.7345	100.2385	-5.7983	3.2398	SHALLOW AGITATED
86	OFF-BEACH	-3.3508	66.9141	-1.9933	6.3747	AEOLIAN
90	OFF-BEACH	-4.8144	67.1139	-0.1194	6.4483	AEOLIAN
91	OFF-BEACH	-5.5493	81.1601	-0.9078	8.7213	AEOLIAN
92	OFF-BEACH	-6.6766	82.5590	-1.3033	8.4684	AEOLIAN
98	LAKE DELTA	-4.5377	60.3191	1.1953	4.9460	AEOLIAN
102	OFF-BEACH	-5.7296	81.2967	-0.8863	9.7887	AEOLIAN
107	OFF-BEACH	-3.2860	91.6614	-1.3929	8.6278	AEOLIAN
110	OFF-BEACH	-3.7854	73.6459	-0.0884	6.9429	AEOLIAN
121	OFF-BEACH	0.7232	60.9152	-2.3821	5.4984	BEACH
122	OFF-BEACH	-1.8958	55.8026	-0.6286	6.8698	BEACH
123	OFF-BEACH	-2.3335	58.8769	-0.7046	7.6267	BEACH
124	OFF-BEACH	-2.4674	60.9624	-0.9890	7.5746	BEACH
125	OFF-BEACH	-1.5452	58.5213	-0.4396	7.3508	BEACH
126	OFF-BEACH	-3.0909	62.8328	-0.6301	8.7276	AEOLIAN
127	OFF-BEACH	-4.5577	59.7881	0.7077	5.3651	AEOLIAN
128	OFF-BEACH	-5.4647	66.9809	0.2387	7.4073	AEOLIAN
129	OFF-BEACH	0.4223	60.9222	-0.9019	5.3855	BEACH
130	OFF-BEACH	-0.7601	62.9028	-0.7998	7.1113	BEACH
131	OFF-BEACH	-4.1652	60.1484	-0.7477	6.5596	AEOLIAN
132	OFF-BEACH	-3.3573	62.3223	-1.1147	7.3789	AEOLIAN
133	OFF-BEACH	-2.1373	73.7127	-2.2336	6.8563	SHALLOW AGITATED
134	OFF-BEACH	-2.3432	64.3043	-1.1908	6.9628	BEACH
135	OFF-BEACH	-4.0565	61.8254	-0.1123	5.4490	AEOLIAN
136	OFF-BEACH	-4.6992	65.3619	0.0300	5.6152	AEOLIAN

The great majority of samples from the lake bottom are classified as aeolian and many of the samples near and on the bar are classified as beach sediments. If the samples were truly "unknown" and results of this technique plotted on a map, a land area (aeolian sediments) would be expected to the north and a water area (beach sediments) to the south. This is a complete 180 degree reversal of the actual situation at Grand Beach.

From the above summary of results, it appears that the particular set of discriminant functions developed by Sahu are not capable of differentiating between the environments at Grand Beach and may not be universally applicable.

Factor Analysis - Klovan (1966)

(A) Description - Klovan (1966) proposed the use of factor analysis for determining depositional environments from grain-size distribution data. He ascribed the following advantages to the technique:

(1) It uses all available data, namely the raw weight percents of grain-size analyses.

(2) It does not rely upon "arbitrary" statistical parameters.

(3) Complex, multi-dimensional situations are amenable to treatment.

(4) Samples may be classified into groups without prior knowledge of their spatial positions.

Briefly, the rationale behind the technique is as follows.

A sample of clastic sediment may be thought of as a vector in N dimensional space, where N is the number of grain-size classes into which the sample has been divided. The position of this sample in N space is uniquely determined by the amount of sediment in each of the grade sizes.

One measure of similarity between any two samples is the cosine of the angle between the two sample vectors. This similarity coefficient has been defined by Imbrie and Purdy (1962) as cosine theta, who also provide a formula for its computation. Cosine theta ranges from 0.0, indicating complete dissimilarity to 1.0 indicating perfect proportional similarity between the samples. A matrix of cosine theta coefficients for a number of samples is the starting point for a Q-mode factor analysis.

Factor analysis is a multivariate statistical technique which may be applied to determine the underlying causes or factors responsible for the coefficients observed in a similarity matrix (Imbrie and Van Andel, 1964). Specifically, a Q-mode factor analysis evaluates relationships between sample vectors based on N variables.

The principal components procedure of the Q-mode analysis attempts to account for most of the information in the cosine theta matrix with the least number of independent dimensions (factors) as possible. This is accomplished by erecting mutually orthogonal axes in N dimensional space, such that the first axis accounts for most of the information, the second axis accounts for most of the remaining information, etc. The amount of variance accounted for by each factor axis is proportional to the size of the eigenvalues of the cosine theta matrix.

To facilitate interpretation, the principal components factor axes may be rotated by the varimax procedure. Sample vectors are projected onto the factor axes. The size of these projections, termed factor loadings, indicate the extent of influence of the factor on the sample. The sum of squared loadings for a sample is the sample communality which indicates how much of the sample's variance has been explained by the entire set of factor axes. A communality of 1.0 indicates a perfect explanation. Squaring the factor loading yields factor components. These may be normalized by dividing the factor components of each sample by the sample communality. This operation simplified the plotting of results on maps or diagrams.

Klovan (1966) applied this technique to the recent sediments of Barataria Bay, using the grain-size data of Krumbein and Aberdeen (1937). He concluded that the factors obtained from the Q-mode analysis of these sediments represent differing types of energy present at the site of deposition. The proportions of the different energy types (as shown by the varimax factor loadings or normalized varimax factor components) determine the grain-size distribution of the sediments deposited at any particular locality.

Klovan (personal communication, 1966) suggested that once a factor model has been developed for a particular area, additional samples could be classified into the scheme by the use of multiple-discriminant analysis. In this method, the suites of similar samples into which the additional or "unknown" samples are to be classified are determined by the factor analysis. Each suite (group) of similar samples may be thought of as forming a cluster of sample points in multidimensional space (Cooley and Lohnes, 1962). Discriminant functions are lines which best separate the groups and are represented as mutually orthogonal axes in discriminant space. The maximum number of discriminant functions for a particular problem is the lesser of the two numbers G-1 and N (where G is the number of groups and N is the number of variables measured for each sample). The number of discriminant functions defines the dimensionality of the discriminant space.

Discriminant scores for a sample are the co-ordinates (position) of the sample point along the discriminant functions. After the discriminant functions are computed for a number of groups, "unknown" samples may be assigned to the group to which they show the most similarity. The degree of similarity between a sample and a group depends on:

(1) The dispersion of the group in discriminant space.

(2) The distance, in discriminant space, between the sample and the group centroid (the position of the mean of all samples forming the group).

The dispersion of a group of samples is roughly proportional to the area occupied by the samples in discriminant space. The dispersion of a group of samples may be shown by centours (centile contours). These may be represented as ellipses about the centroid in two dimensions, ellipsoids in three dimensions, and hyper ellipsoids in dimensionalities greater than three. The chi square test (Cooley and Lohnes, 1962), by considering both the group dispersion and the distance between the sample point and the group centroid, gives a relative measure of the similarity of the sample to the group. A value of 0.00 for this test indicates that the "unknown" sample falls precisely on the group centroid and thus perfectly conforms to the group. Large values of chi-square indicate that the "unknown" sample is less similar to the group.

(B) Test of the Technique - A Q-mode factor analysis was computed for 56 of the 66 test samples (computed by program 3, Chapter VII). Ten samples (numbers 27, 38, 53, 59, 62, 69, 74, 91, 126 and 132) were excluded from the factor analysis and are used to test multiple-discriminant analysis as a method of classifying "unknown" samples into the factor model.

The cosine theta similarity matrix for the 56 test samples is given in Table VIII. Eigenvalues, percent sums of squares and cumulative sums of squares for the principal components factor analysis are given in Table IX. Three factors account for 95 percent of the information in the cosine theta matrix. Following the reasoning of Klovan (1966), this suggests that there were three main types of energy acting upon the sediments in the area of deposition. Sample communalities and normalized varimax factor components are given in Table X. Communalities are high, indicating that most of the variance in the data has been explained by the use of three factors. The normalized varimax factor

TABLE VIII

Cos Theta Matrix

60	61	63	64	65	66	67	68	70	71	72
.465	0.462	0.680	0.679	0.378	0.090	0.552	0.797	0.170	0.413	0.737
.463	0.486	0.725	0.762	0.343	0.045	0.570	-0.846	0.114	0.404	0.828
.493	0.243	0.601	0.316	0.415	0.945	0.511	0.325	0.895	0.303	0.260
.699	0.484	0.782	0.548	0.628	0.903	0.719	0.545	0.910	0.533	0.491
.561	0.340	0.642	0.382	0.504	0.919	0.573	0.375	0.879	0.397	0.321
.697	0.696	0.859	0.878	0.615	0.169	0.772	0.949	0.294	0.650	0.913
.317	0.314	0.580	0.573	0.213	0.039	0.417	0.709	0.087	0.255	0.647
.717	0.714	0.879	0.904	0.626	0.169	0.793	0.965	0.304	0.665	0.936
.219	0.211	0.455	0.431	0.139	0.022	0.306	0.582	0.055	0.167	0.502
.263	0.252	0.465	0.440	0.196	0.048	0.339	0.579	0.091	0.218	0.500
.132	0.114	0.286	0.247	0.089	0.041	0.187	0.371	0.058	0.097	0.296
.056	0.042	0.205	0.166	0.021	0.004	0.107	0.298	0.010	0.027	0.218
.326	0.147	0.486	0.197	0.298	0.962	0.358	0.204	0.765	0.184	0.160
.728	0.741	0.892	0.935	0.635	0.158	0.806	0.975	0.285	0.682	0.967
.914	0.896	0.965	0.997	0.847	0.283	0.956	0.987	0.461	0.870	0.986
.987	0.896	0.836	0.830	0.968	0.394	0.956	0.772	0.649	0.942	0.756
.985	0.879	0.955	0.909	0.927	0.514	0.993	0.876	0.708	0.902	0.856
.978	0.932	0.809	0.834	0.987	0.317	0.944	0.770	0.562	0.972	0.765
.888	0.913	0.935	0.998	0.839	0.204	0.931	0.982	0.368	0.875	0.995
.000	0.922	0.905	0.907	0.962	0.386	0.990	0.859	0.628	0.949	0.848
.922	1.000	0.813	0.916	0.964	0.138	0.913	0.853	0.310	0.990	0.883
.905	0.813	1.000	0.941	0.816	0.515	0.954	0.945	0.650	0.804	0.921
.907	0.916	0.941	1.000	0.851	0.212	0.945	0.984	0.396	0.885	0.992
.962	0.964	0.816	0.851	1.000	0.317	0.935	0.785	0.501	0.989	0.792
.386	0.138	0.515	0.212	0.317	1.000	0.412	0.220	0.886	0.194	0.160
.990	0.913	0.954	0.945	0.935	0.412	1.000	0.913	0.629	0.927	0.899
.859	0.853	0.945	0.984	0.785	0.220	0.913	1.000	0.392	0.818	0.990
.628	0.310	0.650	0.396	0.501	0.886	0.629	0.392	1.000	0.392	0.316
.949	0.990	0.804	0.885	0.989	0.194	0.927	0.818	0.392	1.000	0.836
.848	0.883	0.921	0.992	0.792	0.160	0.899	0.990	0.316	0.836	1.000
.984	0.968	0.914	0.955	0.965	0.293	0.986	0.909	0.506	0.972	0.913
.958	0.984	0.894	0.965	0.954	0.209	0.963	0.923	0.407	0.975	0.935
.744	0.797	0.875	0.956	0.671	0.098	0.814	0.965	0.223	0.730	0.983
.669	0.639	0.849	0.839	0.574	0.220	0.747	0.922	0.338	0.600	0.873
.593	0.564	0.811	0.760	0.512	0.292	0.675	0.853	0.342	0.525	0.799
.857	0.830	0.947	0.968	0.776	0.248	0.911	0.996	0.427	0.802	0.973
.329	0.335	0.585	0.585	0.232	0.029	0.427	0.718	0.077	0.275	0.658
.090	0.076	0.254	0.219	0.045	0.009	0.148	0.352	0.021	0.056	0.273
.296	0.297	0.552	0.545	0.200	0.027	0.393	0.684	0.071	0.240	0.619
.090	0.073	0.276	0.233	0.042	0.012	0.155	0.385	0.023	0.052	0.294
.210	0.188	0.396	0.356	0.152	0.065	0.277	0.494	0.095	0.164	0.411
.280	0.269	0.512	0.488	0.198	0.050	0.366	0.633	0.092	0.226	0.556
.822	0.601	0.836	0.646	0.742	0.822	0.827	0.624	0.928	0.658	0.575
.998	0.935	0.918	0.928	0.962	0.368	0.994	0.882	0.601	0.955	0.875
.968	0.974	0.912	0.972	0.949	0.243	0.976	0.928	0.449	0.967	0.938
.955	0.964	0.926	0.985	0.928	0.237	0.972	0.950	0.433	0.950	0.960
.984	0.973	0.904	0.947	0.973	0.293	0.982	0.896	0.500	0.979	0.903
.367	0.375	0.633	0.642	0.258	0.035	0.471	0.764	0.090	0.307	0.715
.145	0.124	0.415	0.381	0.044	0.017	0.241	0.539	0.036	0.074	0.460
.984	0.880	0.921	0.870	0.946	0.529	0.979	0.825	0.719	0.913	0.807
.983	0.959	0.933	0.957	0.960	0.341	0.990	0.914	0.535	0.963	0.917
.743	0.797	0.876	0.953	0.675	0.093	0.814	0.975	0.219	0.732	0.983
.860	0.857	0.947	0.975	0.797	0.245	0.912	0.996	0.401	0.825	0.981
.921	0.944	0.937	0.995	0.889	0.227	0.952	0.974	0.395	0.917	0.983
.568	0.585	0.785	0.815	0.470	0.090	0.660	0.901	0.183	0.520	0.870
.365	0.372	0.611	0.614	0.271	0.040	0.461	0.742	0.096	0.313	0.683

73	75	80	83	85	86	90	92	98	102	107	110	121	122	123
0.529	0.562	0.755	0.963	0.940	0.829	0.987	0.758	0.981	0.833	0.869	0.971	0.316	0.493	0.554
0.551	0.589	0.894	0.922	0.877	0.847	0.915	0.551	0.889	0.596	0.667	0.822	0.283	0.502	0.595
0.401	0.320	0.187	0.319	0.429	0.354	0.102	0.075	0.096	0.075	0.140	0.124	0.894	0.474	0.352
0.628	0.558	0.407	0.488	0.553	0.567	0.216	0.094	0.202	0.103	0.191	0.213	0.972	0.687	0.586
0.479	0.403	0.240	0.330	0.442	0.397	0.082	0.022	0.073	0.024	0.098	0.094	0.918	0.545	0.432
0.759	0.784	0.910	0.994	0.949	0.962	0.898	0.575	0.877	0.635	0.711	0.844	0.498	0.724	0.782
0.386	0.423	0.693	0.911	0.898	0.740	0.996	0.728	0.998	0.827	0.840	0.975	0.200	0.348	0.417
0.780	0.803	0.938	0.985	0.932	0.973	0.873	0.515	0.850	0.574	0.656	0.804	0.510	0.746	0.805
0.275	0.310	0.532	0.844	0.847	0.629	0.972	0.836	0.983	0.932	0.921	0.997	0.135	0.243	0.296
0.312	0.343	0.514	0.835	0.832	0.628	0.937	0.932	0.934	0.972	0.986	0.975	0.176	0.284	0.327
0.161	0.184	0.299	0.640	0.646	0.423	0.754	0.993	0.738	0.947	0.972	0.823	0.101	0.144	0.168
0.083	0.108	0.222	0.589	0.600	0.353	0.734	0.995	0.725	0.960	0.967	0.817	0.034	0.067	0.089
0.262	0.197	0.111	0.209	0.333	0.222	0.038	0.011	0.034	0.014	0.065	0.053	0.765	0.315	0.221
0.799	0.824	0.981	0.946	0.884	0.969	0.810	0.411	0.778	0.452	0.551	0.712	0.505	0.760	0.830
0.953	0.956	0.948	0.855	0.781	0.976	0.599	0.236	0.560	0.253	0.375	0.507	0.694	0.933	0.965
0.953	0.918	0.629	0.574	0.502	0.775	0.221	0.047	0.194	0.045	0.155	0.196	0.824	0.977	0.926
0.966	0.932	0.765	0.713	0.654	0.877	0.382	0.124	0.350	0.129	0.251	0.329	0.885	0.985	0.948
0.959	0.936	0.637	0.561	0.488	0.768	0.212	0.041	0.183	0.037	0.146	0.186	0.767	0.971	0.937
0.944	0.959	0.965	0.837	0.761	0.963	0.589	0.215	0.548	0.227	0.351	0.487	0.626	0.912	0.964
0.984	0.958	0.744	0.669	0.593	0.857	0.329	0.090	0.296	0.090	0.210	0.280	0.822	0.998	0.968
0.968	0.984	0.797	0.639	0.564	0.830	0.335	0.076	0.297	0.073	0.188	0.269	0.601	0.935	0.974
0.914	0.894	0.875	0.849	0.811	0.947	0.585	0.254	0.552	0.276	0.396	0.512	0.836	0.918	0.912
0.955	0.965	0.956	0.839	0.760	0.968	0.585	0.219	0.545	0.233	0.356	0.488	0.646	0.928	0.972
0.965	0.954	0.671	0.574	0.512	0.776	0.232	0.045	0.200	0.042	0.152	0.198	0.742	0.962	0.949
0.293	0.209	0.098	0.220	0.292	0.248	0.029	0.009	0.027	0.012	0.065	0.050	0.822	0.368	0.243
0.986	0.963	0.814	0.747	0.675	0.911	0.427	0.148	0.393	0.155	0.277	0.366	0.827	0.994	0.976
0.909	0.923	0.965	0.922	0.853	0.996	0.718	0.352	0.684	0.385	0.494	0.633	0.624	0.882	0.928
0.506	0.407	0.223	0.338	0.342	0.427	0.077	0.021	0.071	0.023	0.095	0.092	0.928	0.601	0.449
0.972	0.975	0.730	0.600	0.525	0.802	0.275	0.056	0.240	0.052	0.164	0.226	0.658	0.955	0.967
0.913	0.935	0.983	0.873	0.799	0.973	0.658	0.273	0.619	0.294	0.411	0.556	0.575	0.875	0.938
1.000	0.993	0.827	0.720	0.643	0.899	0.401	0.123	0.364	0.126	0.248	0.336	0.746	0.992	0.997
0.993	1.000	0.858	0.738	0.660	0.908	0.440	0.148	0.402	0.154	0.273	0.369	0.673	0.970	0.998
0.827	0.858	1.000	0.871	0.798	0.943	0.703	0.283	0.661	0.304	0.417	0.581	0.474	0.778	0.863
0.720	0.738	0.871	1.000	0.964	0.944	0.919	0.637	0.901	0.693	0.765	0.878	0.516	0.694	0.739
0.643	0.660	0.798	0.964	1.000	0.878	0.904	0.644	0.891	0.710	0.770	0.877	0.535	0.618	0.659
0.899	0.908	0.943	0.944	0.878	1.000	0.749	0.405	0.719	0.444	0.547	0.678	0.643	0.878	0.913
0.401	0.440	0.703	0.919	0.904	0.749	1.000	0.774	0.996	0.852	0.874	0.981	0.199	0.360	0.432
0.123	0.148	0.283	0.637	0.644	0.405	0.774	1.000	0.763	0.964	0.978	0.846	0.056	0.103	0.131
0.364	0.402	0.661	0.901	0.891	0.719	0.996	0.763	1.000	0.860	0.868	0.986	0.180	0.326	0.393
0.126	0.154	0.304	0.693	0.710	0.444	0.852	0.964	0.860	1.000	0.985	0.928	0.058	0.105	0.134
0.248	0.273	0.417	0.765	0.770	0.547	0.874	0.978	0.868	0.985	1.000	0.932	0.159	0.227	0.258
0.336	0.369	0.581	0.878	0.877	0.678	0.981	0.846	0.986	0.928	0.932	1.000	0.187	0.304	0.357
0.746	0.673	0.474	0.516	0.535	0.643	0.199	0.056	0.180	0.058	0.159	0.187	1.000	0.807	0.703
0.992	0.970	0.778	0.694	0.618	0.878	0.360	0.103	0.326	0.105	0.227	0.304	0.807	1.000	0.980
0.997	0.998	0.863	0.739	0.659	0.913	0.432	0.131	0.393	0.134	0.258	0.357	0.703	0.980	1.000
0.990	0.995	0.895	0.776	0.698	0.936	0.484	0.164	0.445	0.171	0.295	0.403	0.690	0.970	0.998
0.999	0.993	0.813	0.699	0.624	0.884	0.374	0.103	0.336	0.103	0.225	0.309	0.745	0.991	0.995
0.444	0.483	0.769	0.931	0.907	0.787	0.990	0.685	0.984	0.771	0.801	0.946	0.224	0.401	0.480
0.200	0.234	0.509	0.816	0.821	0.585	0.970	0.836	0.979	0.923	0.912	0.986	0.091	0.171	0.225
0.957	0.920	0.701	0.649	0.609	0.827	0.302	0.080	0.271	0.081	0.201	0.261	0.903	0.980	0.934
0.998	0.989	0.833	0.729	0.663	0.904	0.408	0.123	0.370	0.126	0.250	0.340	0.774	0.991	0.994
0.826	0.860	0.995	0.910	0.842	0.960	0.758	0.355	0.721	0.386	0.491	0.650	0.470	0.777	0.861
0.910	0.924	0.949	0.934	0.879	0.996	0.732	0.390	0.701	0.426	0.531	0.660	0.641	0.882	0.926
0.970	0.982	0.935	0.827	0.758	0.960	0.563	0.221	0.524	0.234	0.355	0.476	0.662	0.941	0.983
0.646	0.681	0.902	0.976	0.934	0.910	0.939	0.585	0.920	0.652	0.717	0.870	0.372	0.602	0.680
0.437	0.475	0.722	0.933	0.914	0.772	0.999	0.773	0.994	0.849	0.876	0.979	0.227	0.396	0.467

124	125	127	128	129	130	131	133	134	135	136
0.598	0.504	0.978	0.935	0.439	0.534	0.811	0.815	0.665	0.959	0.992
0.648	0.526	0.955	0.806	0.428	0.563	0.912	0.837	0.724	0.978	0.919
0.346	0.401	0.105	0.074	0.635	0.449	0.187	0.356	0.337	0.177	0.117
0.581	0.627	0.234	0.134	0.811	0.668	0.407	0.571	0.568	0.350	0.238
0.423	0.482	0.092	0.029	0.698	0.524	0.236	0.406	0.408	0.190	0.100
0.818	0.739	0.919	0.775	0.667	0.765	0.944	0.957	0.867	0.982	0.914
0.469	0.358	0.992	0.968	0.292	0.394	0.748	0.722	0.549	0.936	0.993
0.840	0.760	0.906	0.737	0.685	0.786	0.965	0.967	0.888	0.981	0.889
0.344	0.248	0.935	0.992	0.199	0.279	0.604	0.610	0.419	0.842	0.968
0.369	0.287	0.880	0.956	0.245	0.314	0.586	0.612	0.435	0.804	0.938
0.199	0.143	0.665	0.807	0.126	0.162	0.368	0.410	0.251	0.579	0.756
0.119	0.065	0.637	0.808	0.049	0.082	0.296	0.339	0.172	0.531	0.733
0.221	0.266	0.043	0.019	0.485	0.317	0.106	0.239	0.225	0.097	0.047
0.866	0.781	0.861	0.647	0.693	0.808	0.991	0.967	0.913	0.961	0.827
0.980	0.944	0.655	0.402	0.887	0.959	0.947	0.980	0.990	0.822	0.627
0.902	0.955	0.248	0.053	0.973	0.947	0.632	0.778	0.853	0.450	0.260
0.942	0.962	0.423	0.206	0.991	0.975	0.763	0.878	0.919	0.612	0.416
0.913	0.965	0.237	0.036	0.955	0.951	0.641	0.778	0.864	0.445	0.252
0.980	0.936	0.649	0.383	0.853	0.948	0.961	0.973	0.994	0.821	0.617
0.955	0.984	0.367	0.145	0.984	0.983	0.743	0.860	0.921	0.568	0.365
0.964	0.973	0.375	0.124	0.880	0.959	0.797	0.857	0.944	0.585	0.372
0.926	0.904	0.633	0.415	0.921	0.933	0.876	0.947	0.937	0.785	0.611
0.985	0.947	0.642	0.381	0.870	0.957	0.953	0.975	0.995	0.815	0.614
0.928	0.973	0.258	0.044	0.946	0.960	0.675	0.797	0.889	0.470	0.271
0.237	0.293	0.035	0.017	0.529	0.341	0.093	0.245	0.227	0.090	0.040
0.972	0.982	0.471	0.241	0.979	0.990	0.814	0.912	0.952	0.660	0.461
0.950	0.896	0.764	0.539	0.825	0.914	0.975	0.996	0.974	0.901	0.742
0.433	0.500	0.090	0.036	0.719	0.535	0.219	0.401	0.395	0.183	0.096
0.950	0.979	0.307	0.074	0.913	0.963	0.732	0.825	0.917	0.520	0.313
0.960	0.903	0.715	0.460	0.807	0.917	0.983	0.981	0.983	0.870	0.683
0.990	0.999	0.444	0.200	0.957	0.998	0.826	0.910	0.970	0.646	0.437
0.995	0.993	0.483	0.234	0.920	0.989	0.860	0.924	0.982	0.681	0.475
0.895	0.813	0.769	0.509	0.701	0.833	0.995	0.949	0.935	0.902	0.722
0.776	0.699	0.931	0.816	0.649	0.729	0.910	0.934	0.827	0.976	0.933
0.698	0.624	0.907	0.821	0.609	0.663	0.842	0.879	0.758	0.934	0.914
0.936	0.884	0.787	0.585	0.827	0.904	0.960	0.996	0.960	0.910	0.772
0.484	0.374	0.990	0.970	0.302	0.408	0.758	0.732	0.563	0.939	0.999
0.164	0.103	0.685	0.836	0.080	0.123	0.355	0.390	0.221	0.585	0.773
0.445	0.336	0.984	0.979	0.271	0.370	0.721	0.701	0.524	0.920	0.994
0.171	0.103	0.771	0.923	0.081	0.126	0.386	0.426	0.234	0.652	0.849
0.295	0.225	0.801	0.912	0.201	0.250	0.491	0.531	0.355	0.717	0.876
0.403	0.309	0.946	0.986	0.261	0.340	0.650	0.660	0.476	0.870	0.979
0.690	0.745	0.224	0.091	0.903	0.774	0.470	0.641	0.662	0.372	0.227
0.970	0.991	0.401	0.171	0.980	0.991	0.777	0.882	0.941	0.602	0.396
0.998	0.995	0.480	0.225	0.934	0.994	0.861	0.926	0.983	0.680	0.467
1.000	0.987	0.534	0.277	0.921	0.989	0.894	0.947	0.993	0.726	0.517
0.987	1.000	0.417	0.172	0.958	0.997	0.812	0.897	0.964	0.623	0.410
0.534	0.417	1.000	0.937	0.337	0.453	0.813	0.771	0.613	0.967	0.989
0.277	0.172	0.937	1.000	0.129	0.208	0.576	0.561	0.359	0.829	0.962
0.921	0.958	0.337	0.129	1.000	0.966	0.699	0.834	0.889	0.534	0.338
0.989	0.997	0.453	0.208	0.966	1.000	0.831	0.916	0.972	0.654	0.443
0.894	0.812	0.813	0.576	0.699	0.831	1.000	0.966	0.936	0.933	0.776
0.947	0.897	0.771	0.561	0.834	0.916	0.966	1.000	0.972	0.902	0.757
0.993	0.964	0.613	0.359	0.889	0.972	0.936	0.972	1.000	0.792	0.593
0.726	0.623	0.967	0.829	0.534	0.654	0.933	0.902	0.792	1.000	0.948
0.517	0.410	0.989	0.962	0.338	0.443	0.776	0.757	0.593	0.948	1.000

TABLE VIII

Cos Theta Matrix

SAMPLES	25	26	31	32	33	34	35	36	37	39	40	41	51	52	54
25	1.000	0.910	0.176	0.314	0.168	0.946	0.980	0.922	0.954	0.932	0.745	0.717	0.090	0.857	0.693
26	0.910	1.000	0.117	0.272	0.120	0.927	0.911	0.936	0.795	0.754	0.544	0.492	0.057	0.940	0.768
31	0.176	0.117	1.000	0.959	0.989	0.270	0.107	0.267	0.088	0.124	0.111	0.066	0.936	0.248	0.381
32	0.314	0.272	0.959	1.000	0.974	0.459	0.219	0.463	0.168	0.201	0.135	0.075	0.886	0.452	0.604
33	0.168	0.120	0.989	0.974	1.000	0.293	0.086	0.294	0.055	0.090	0.063	0.012	0.928	0.283	0.440
34	0.946	0.927	0.270	0.459	0.293	1.000	0.891	0.996	0.808	0.792	0.578	0.525	0.166	0.968	0.887
35	0.980	0.911	0.107	0.219	0.086	0.891	1.000	0.868	0.970	0.913	0.703	0.687	0.044	0.804	0.589
36	0.922	0.936	0.267	0.463	0.294	0.996	0.868	1.000	0.767	0.743	0.520	0.462	0.161	0.985	0.912
37	0.954	0.795	0.088	0.168	0.055	0.808	0.970	0.767	1.000	0.967	0.809	0.810	0.026	0.669	0.449
39	0.932	0.754	0.124	0.201	0.090	0.792	0.913	0.743	0.967	1.000	0.925	0.916	0.049	0.645	0.457
40	0.745	0.544	0.111	0.135	0.063	0.578	0.703	0.520	0.809	0.925	1.000	0.995	0.043	0.421	0.264
41	0.717	0.492	0.066	0.075	0.012	0.525	0.687	0.462	0.810	0.916	0.995	1.000	0.006	0.352	0.183
51	0.090	0.057	0.936	0.886	0.928	0.166	0.044	0.161	0.026	0.049	0.043	0.006	1.000	0.157	0.260
52	0.857	0.940	0.248	0.452	0.283	0.968	0.804	0.985	0.669	0.645	0.421	0.352	0.157	1.000	0.938
54	0.693	0.768	0.381	0.604	0.440	0.887	0.589	0.912	0.449	0.457	0.264	0.183	0.260	0.938	1.000
55	0.369	0.325	0.501	0.694	0.572	0.599	0.209	0.615	0.137	0.194	0.092	0.023	0.324	0.614	0.837
56	0.510	0.519	0.601	0.791	0.658	0.731	0.374	0.751	0.268	0.305	0.166	0.087	0.457	0.763	0.928
57	0.362	0.316	0.428	0.633	0.510	0.595	0.197	0.609	0.128	0.186	0.085	0.018	0.266	0.610	0.833
58	0.679	0.774	0.303	0.535	0.370	0.878	0.577	0.904	0.430	0.436	0.243	0.161	0.200	0.940	0.994
60	0.465	0.463	0.493	0.699	0.561	0.697	0.317	0.717	0.219	0.263	0.132	0.056	0.326	0.728	0.914
61	0.462	0.486	0.243	0.484	0.340	0.696	0.314	0.714	0.211	0.252	0.114	0.042	0.147	0.741	0.896
63	0.680	0.725	0.601	0.782	0.642	0.859	0.580	0.879	0.455	0.465	0.286	0.205	0.486	0.892	0.965
64	0.679	0.762	0.316	0.548	0.382	0.878	0.573	0.904	0.431	0.440	0.247	0.166	0.197	0.935	0.997
65	0.378	0.343	0.415	0.628	0.504	0.615	0.213	0.626	0.139	0.196	0.089	0.021	0.298	0.635	0.847
66	0.090	0.045	0.945	0.903	0.919	0.169	0.039	0.169	0.022	0.048	0.041	0.004	0.962	0.158	0.283
67	0.552	0.570	0.511	0.719	0.573	0.772	0.417	0.793	0.306	0.339	0.187	0.107	0.358	0.806	0.956
68	0.797	0.846	0.325	0.545	0.375	0.949	0.709	0.965	0.582	0.579	0.371	0.298	0.204	0.975	0.987
70	0.170	0.114	0.895	0.910	0.879	0.294	0.087	0.304	0.055	0.091	0.058	0.010	0.765	0.285	0.461
71	0.413	0.404	0.303	0.533	0.397	0.650	0.255	0.665	0.167	0.218	0.097	0.027	0.184	0.682	0.870
72	0.737	0.828	0.260	0.491	0.321	0.913	0.647	0.936	0.502	0.500	0.296	0.218	0.160	0.967	0.986
73	0.529	0.551	0.401	0.628	0.479	0.759	0.386	0.780	0.275	0.312	0.161	0.083	0.262	0.799	0.953
75	0.562	0.589	0.320	0.558	0.403	0.784	0.423	0.803	0.310	0.343	0.184	0.108	0.197	0.824	0.956
80	0.755	0.894	0.187	0.407	0.240	0.910	0.693	0.938	0.532	0.514	0.299	0.222	0.111	0.981	0.948
83	0.963	0.922	0.319	0.488	0.330	0.994	0.911	0.985	0.844	0.835	0.640	0.589	0.209	0.946	0.855
85	0.940	0.877	0.429	0.553	0.442	0.949	0.898	0.932	0.847	0.832	0.646	0.600	0.333	0.884	0.781
86	0.829	0.847	0.354	0.567	0.397	0.962	0.740	0.973	0.629	0.628	0.423	0.353	0.222	0.969	0.976
90	0.987	0.915	0.102	0.216	0.082	0.898	0.996	0.873	0.972	0.937	0.754	0.734	0.038	0.810	0.599
92	0.758	0.551	0.075	0.094	0.022	0.575	0.728	0.515	0.836	0.932	0.993	0.995	0.011	0.411	0.236
98	0.981	0.889	0.096	0.202	0.073	0.877	0.998	0.850	0.983	0.934	0.738	0.725	0.034	0.778	0.560
102	0.833	0.596	0.075	0.103	0.024	0.635	0.827	0.574	0.932	0.972	0.947	0.960	0.014	0.452	0.253
107	0.869	0.667	0.140	0.191	0.098	0.711	0.840	0.656	0.921	0.986	0.972	0.967	0.065	0.551	0.375
110	0.971	0.822	0.124	0.213	0.094	0.844	0.975	0.804	0.997	0.975	0.623	0.817	0.053	0.712	0.507
121	0.316	0.283	0.894	0.972	0.918	0.498	0.200	0.510	0.135	0.176	0.101	0.034	0.765	0.505	0.694
122	0.493	0.502	0.474	0.687	0.545	0.724	0.348	0.746	0.243	0.284	0.144	0.067	0.315	0.760	0.933
123	0.554	0.595	0.352	0.586	0.432	0.782	0.417	0.805	0.296	0.327	0.168	0.089	0.221	0.830	0.965
124	0.598	0.648	0.346	0.581	0.423	0.818	0.469	0.840	0.344	0.369	0.199	0.119	0.221	0.866	0.980
125	0.504	0.526	0.401	0.627	0.482	0.739	0.358	0.760	0.248	0.287	0.143	0.065	0.266	0.781	0.944
127	0.978	0.955	0.105	0.234	0.092	0.919	0.992	0.906	0.935	0.880	0.665	0.637	0.043	0.861	0.655
128	0.935	0.806	0.074	0.134	0.029	0.775	0.968	0.737	0.992	0.956	0.807	0.808	0.019	0.647	0.402
129	0.439	0.428	0.635	0.811	0.698	0.667	0.292	0.685	0.199	0.245	0.126	0.049	0.485	0.693	0.887
130	0.534	0.563	0.449	0.668	0.524	0.765	0.394	0.786	0.279	0.314	0.162	0.082	0.317	0.808	0.959
131	0.811	0.912	0.187	0.407	0.236	0.944	0.748	0.965	0.604	0.586	0.368	0.296	0.106	0.991	0.947
133	0.815	0.837	0.356	0.571	0.406	0.957	0.722	0.967	0.610	0.612	0.410	0.339	0.239	0.967	0.980
134	0.665	0.724	0.337	0.568	0.408	0.867	0.549	0.888	0.419	0.435	0.251	0.172	0.225	0.913	0.990
135	0.959	0.978	0.177	0.350	0.190	0.982	0.936	0.981	0.842	0.804	0.579	0.531	0.097	0.961	0.822
136	0.992	0.919	0.117	0.238	0.100	0.914	0.993	0.889	0.968	0.938	0.756	0.733	0.047	0.827	0.627

SAMPLES	55	56	57	58	60	61	63	64	65	66	67	68	7
25	0.369	0.510	0.362	0.679	0.465	0.462	0.680	0.679	0.378	0.090	0.552	0.797	0.1
26	0.325	0.519	0.316	0.774	0.463	0.486	0.725	0.762	0.343	0.045	0.570	-0.846	0.1
31	0.501	0.601	0.428	0.303	0.493	0.243	0.601	0.316	0.415	0.945	0.511	0.325	0.8
32	0.694	0.791	0.633	0.535	0.699	0.484	0.782	0.548	0.628	0.903	0.719	0.545	0.9
33	0.572	0.658	0.510	0.370	0.561	0.340	0.642	0.382	0.504	0.919	0.573	0.375	0.8
34	0.599	0.731	0.595	0.878	0.697	0.696	0.859	0.878	0.615	0.169	0.772	0.949	0.2
35	0.209	0.374	0.197	0.577	0.317	0.314	0.580	0.573	0.213	0.039	0.417	0.709	0.0
36	0.615	0.751	0.609	0.904	0.717	0.714	0.879	0.904	0.626	0.169	0.793	0.965	0.3
37	0.137	0.268	0.128	0.430	0.219	0.211	0.455	0.431	0.139	0.022	0.306	0.582	0.0
39	0.194	0.305	0.186	0.436	0.263	0.252	0.465	0.440	0.196	0.048	0.339	0.579	0.0
40	0.092	0.166	0.085	0.243	0.132	0.114	0.286	0.247	0.089	0.041	0.187	0.371	0.0
41	0.023	0.087	0.018	0.161	0.056	0.042	0.205	0.166	0.021	0.004	0.107	0.298	0.0
51	0.324	0.457	0.266	0.200	0.326	0.147	0.486	0.197	0.298	0.962	0.358	0.204	0.7
52	0.614	0.763	0.610	0.940	0.728	0.741	0.892	0.935	0.635	0.158	0.806	0.975	0.2
54	0.837	0.928	0.833	0.994	0.914	0.896	0.965	0.997	0.847	0.283	0.956	0.987	0.4
55	1.000	0.958	0.993	0.806	0.987	0.896	0.836	0.830	0.968	0.394	0.956	0.772	0.6
56	0.958	1.000	0.936	0.894	0.985	0.879	0.955	0.909	0.927	0.514	0.993	0.876	0.7
57	0.993	0.936	1.000	0.814	0.978	0.932	0.809	0.834	0.987	0.317	0.944	0.770	0.5
58	0.806	0.894	0.814	1.000	0.888	0.913	0.935	0.998	0.839	0.204	0.931	0.982	0.3
60	0.987	0.985	0.978	0.888	1.000	0.922	0.905	0.907	0.962	0.386	0.990	0.859	0.6
61	0.896	0.879	0.932	0.913	0.922	1.000	0.813	0.916	0.964	0.138	0.913	0.853	0.3
63	0.836	0.955	0.809	0.935	0.905	0.813	1.000	0.941	0.816	0.515	0.954	0.945	0.6
64	0.830	0.909	0.834	0.998	0.907	0.916	0.941	1.000	0.851	0.212	0.945	0.984	0.3
65	0.968	0.927	0.987	0.839	0.962	0.964	0.816	0.851	1.000	0.317	0.935	0.785	0.5
66	0.394	0.514	0.317	0.204	0.386	0.138	0.515	0.212	0.317	1.000	0.412	0.220	0.8
67	0.956	0.993	0.944	0.931	0.990	0.913	0.954	0.945	0.935	0.412	1.000	0.913	0.6
68	0.772	0.876	0.770	0.982	0.859	0.853	0.945	0.984	0.785	0.220	0.913	1.000	0.3
70	0.649	0.708	0.562	0.368	0.628	0.310	0.650	0.396	0.501	0.886	0.629	0.392	1.0
71	0.942	0.902	0.972	0.875	0.949	0.990	0.804	0.885	0.989	0.194	0.927	0.818	0.3
72	0.756	0.856	0.765	0.995	0.848	0.883	0.921	0.992	0.792	0.160	0.899	0.990	0.3
73	0.953	0.966	0.959	0.944	0.984	0.968	0.914	0.955	0.965	0.293	0.986	0.909	0.5
75	0.918	0.932	0.936	0.959	0.958	0.984	0.894	0.965	0.954	0.209	0.963	0.923	0.4
80	0.629	0.765	0.637	0.965	0.744	0.797	0.875	0.956	0.671	0.098	0.814	0.965	0.2
83	0.574	0.713	0.561	0.837	0.669	0.639	0.849	0.839	0.574	0.220	0.747	0.922	0.3
85	0.502	0.654	0.488	0.761	0.593	0.564	0.811	0.760	0.512	0.292	0.675	0.853	0.3
86	0.775	0.877	0.768	0.963	0.857	0.830	0.947	0.968	0.776	0.248	0.911	0.996	0.4
90	0.221	0.382	0.212	0.589	0.329	0.335	0.585	0.585	0.232	0.029	0.427	0.718	0.0
92	0.047	0.124	0.041	0.215	0.090	0.076	0.254	0.219	0.045	0.009	0.148	0.352	0.0
98	0.194	0.350	0.183	0.548	0.296	0.297	0.552	0.545	0.200	0.027	0.393	0.684	0.0
102	0.045	0.129	0.037	0.227	0.090	0.073	0.276	0.233	0.042	0.012	0.155	0.385	0.0
107	0.155	0.251	0.146	0.351	0.210	0.188	0.396	0.356	0.152	0.065	0.277	0.494	0.0
110	0.196	0.329	0.186	0.487	0.280	0.269	0.512	0.488	0.198	0.050	0.366	0.633	0.0
121	0.824	0.885	0.767	0.626	0.822	0.601	0.836	0.646	0.742	0.822	0.827	0.624	0.9
122	0.977	0.985	0.971	0.912	0.998	0.935	0.918	0.928	0.962	0.368	0.994	0.882	0.6
123	0.926	0.948	0.937	0.964	0.968	0.974	0.912	0.972	0.949	0.243	0.976	0.928	0.4
124	0.902	0.942	0.913	0.980	0.955	0.964	0.926	0.985	0.928	0.237	0.972	0.950	0.4
125	0.955	0.962	0.965	0.936	0.984	0.973	0.904	0.947	0.973	0.293	0.982	0.896	0.5
127	0.248	0.423	0.237	0.649	0.367	0.375	0.633	0.642	0.258	0.035	0.471	0.764	0.0
128	0.053	0.206	0.036	0.383	0.145	0.124	0.415	0.381	0.044	0.017	0.241	0.539	0.0
129	0.973	0.991	0.955	0.853	0.984	0.880	0.921	0.870	0.946	0.529	0.979	0.825	0.7
130	0.947	0.975	0.951	0.948	0.983	0.959	0.933	0.957	0.960	0.341	0.990	0.914	0.5
131	0.632	0.763	0.641	0.961	0.743	0.797	0.876	0.953	0.675	0.093	0.814	0.975	0.2
133	0.778	0.878	0.778	0.973	0.860	0.857	0.947	0.975	0.797	0.245	0.912	0.996	0.4
134	0.853	0.919	0.864	0.994	0.921	0.944	0.937	0.995	0.889	0.227	0.952	0.974	0.3
135	0.450	0.612	0.445	0.821	0.568	0.585	0.785	0.815	0.470	0.090	0.660	0.901	0.1
136	0.260	0.416	0.252	0.617	0.365	0.372	0.611	0.614	0.271	0.040	0.461	0.742	0.0

TABLE IX

EIGENVALUES, PERCENT SUMS OF SQUARES AND CUMULATIVE SUMS OF SQUARES FOR THE PRINCIPAL COMPONENTS OF THE GRAND BEACH FACTOR ANALYSIS

FACTOR	EIGENVALUES	PERCENT SUMS OF SQUARES	CUMULATIVE SUMS OF SQUARES
1	36.0910	64.45	64.45
2	12.3075	21.98	86.43
3	4.9474	8.83	95.26
4	1.8012	3.22	98.48
5	0.4210	0.75	99.23
6	0.3055	0.54	99.77
7	0.1124	0.20	99.97
8	0.0079	0.02	99.99

TABLE X

NORMALIZED VARIMAX FACTOR COMPONENTS WITH THREE ROTATED FACTORS

SAMP.	COMM.	FACTOR 1	FACTOR 2	FACTOR 3
25	0.9918	0.1705	0.8286	0.0009
26	0.6740	0.3030	0.6887	0.0083
31	0.9711	0.0497	0.0041	0.9462
32	0.9888	0.2178	0.0113	0.7710
33	0.9567	0.1022	0.0002	0.8976
34	0.9923	0.4581	0.5369	0.0051
35	0.9581	0.0852	0.9140	0.0009
36	0.9815	0.5159	0.4807	0.0033
37	0.9682	0.0190	0.9310	0.0000
39	0.9583	0.0218	0.9749	0.0033
40	0.7664	0.0013	0.9837	0.0150
41	0.7742	0.0156	0.9757	0.0087
51	0.8683	0.0115	0.0006	0.9879
52	0.9430	0.0202	0.3794	0.0004
54	0.9862	0.8540	0.1215	0.0245
55	0.9064	0.8608	0.0000	0.1392
56	0.9890	0.7925	0.0221	0.1855
57	0.8974	0.9141	0.0005	0.0854
58	0.9804	0.8645	0.1106	0.0046
60	0.9645	0.6677	0.0074	0.1050
61	0.9385	0.9920	0.0061	0.0019
63	0.9773	0.7016	0.1339	0.1644
64	0.9893	0.3855	0.1074	0.0071
65	0.9071	0.9287	0.0000	0.0712
66	0.9322	0.0159	0.0001	0.9840
67	0.9877	0.8612	0.0332	0.1056
68	0.9900	0.7554	0.2367	0.0099
70	0.8862	0.1333	0.0000	0.8667
71	0.9210	0.9835	0.0006	0.0159
73	0.9762	0.8292	0.1704	0.0005
74	0.9870	0.9378	0.0208	0.0414
75	0.9835	0.9548	0.0328	0.0124
80	0.9127	0.7618	0.2344	0.0038
83	0.9954	0.3745	0.6068	0.0187
85	0.9475	0.2756	0.6613	0.0631
86	0.9937	0.6984	0.2820	0.0197
90	0.9862	0.0876	0.9113	0.0011
92	0.6066	0.0053	0.9880	0.0067
98	0.9709	0.0666	0.9325	0.0009
102	0.9084	0.0040	0.9916	0.0045
107	0.9046	0.0041	0.9844	0.0115
110	0.9818	0.0380	0.9612	0.0008
121	0.9897	0.3665	0.0024	0.6311
122	0.9769	0.9010	0.0125	0.0865
123	0.9933	0.9512	0.0287	0.0201
124	0.9972	0.9343	0.0493	0.0165
125	0.9839	0.9443	0.0136	0.0421
127	0.9510	0.1387	0.8582	0.0031
128	0.9827	0.0046	0.9954	0.0000
129	0.9849	0.7721	0.0056	0.2224
130	0.9936	0.9156	0.0232	0.0612
131	0.9480	0.7019	0.2951	0.0030
133	0.9964	0.7212	0.2604	0.0183
134	0.9934	0.8937	0.0945	0.0118
135	0.9602	0.3535	0.6459	0.0006
136	0.9904	0.1085	0.8910	0.0005

components show the relative influence of the three types of energy for each sample. Normalized factor components (with samples as "unknowns") are plotted on a triangular diagram in Figure 42. Samples fall along two sides of the triangle, which indicates there is a gradation between energy types (factors) two and one, and a similar gradation between energy types one and three. Samples are absent from the central portion and bottom edge of the triangle. This suggests a lack of gradation between energy types two and three.

The three samples (numbers 61, 128 and 51) closest to the corners of the triangle are considered to be end members in the sense that all other samples may be considered as mixtures of them. Figure 43 gives cumulative frequency curves for the three end members. Figure 44 is a plot of the three end members and several samples along the trend between them. The most striking feature of the diagram is the regular increase in mean grain-size from factor two along the trend to factor one. A similar increase in mean grain-size is apparent on the trend from factor one to factor three.

This remarkable regularity in the variation of mean grain-size is probably best interpreted in terms of average kinetic energy. Krumbein and Sloss (1963), Sahu (1964), Visher (1965) and Pettijohn, Potter and Siever (1965) have all interpreted mean grain-size in much the same manner; that it is dependent upon the average kinetic energy at the site of deposition. However, in the present interpretation, it is recognized that kinetic energy itself is composed of three component types, which combined in various proportions, determine the mean grain-size of a sediment sample. For convenience, these three types have been labeled:

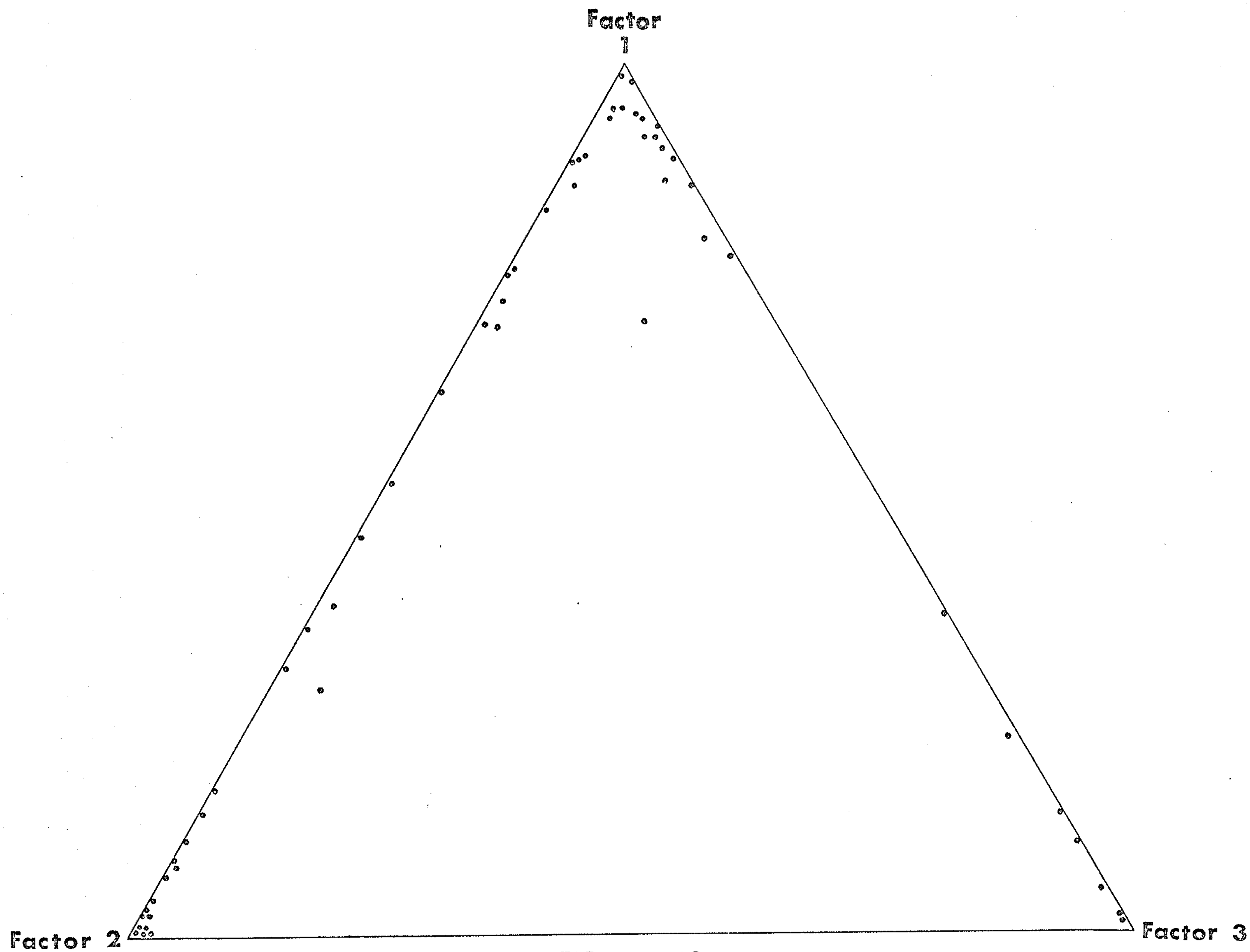


FIGURE 42

Plot of Normalized Factor Components

• 'unknown' sample

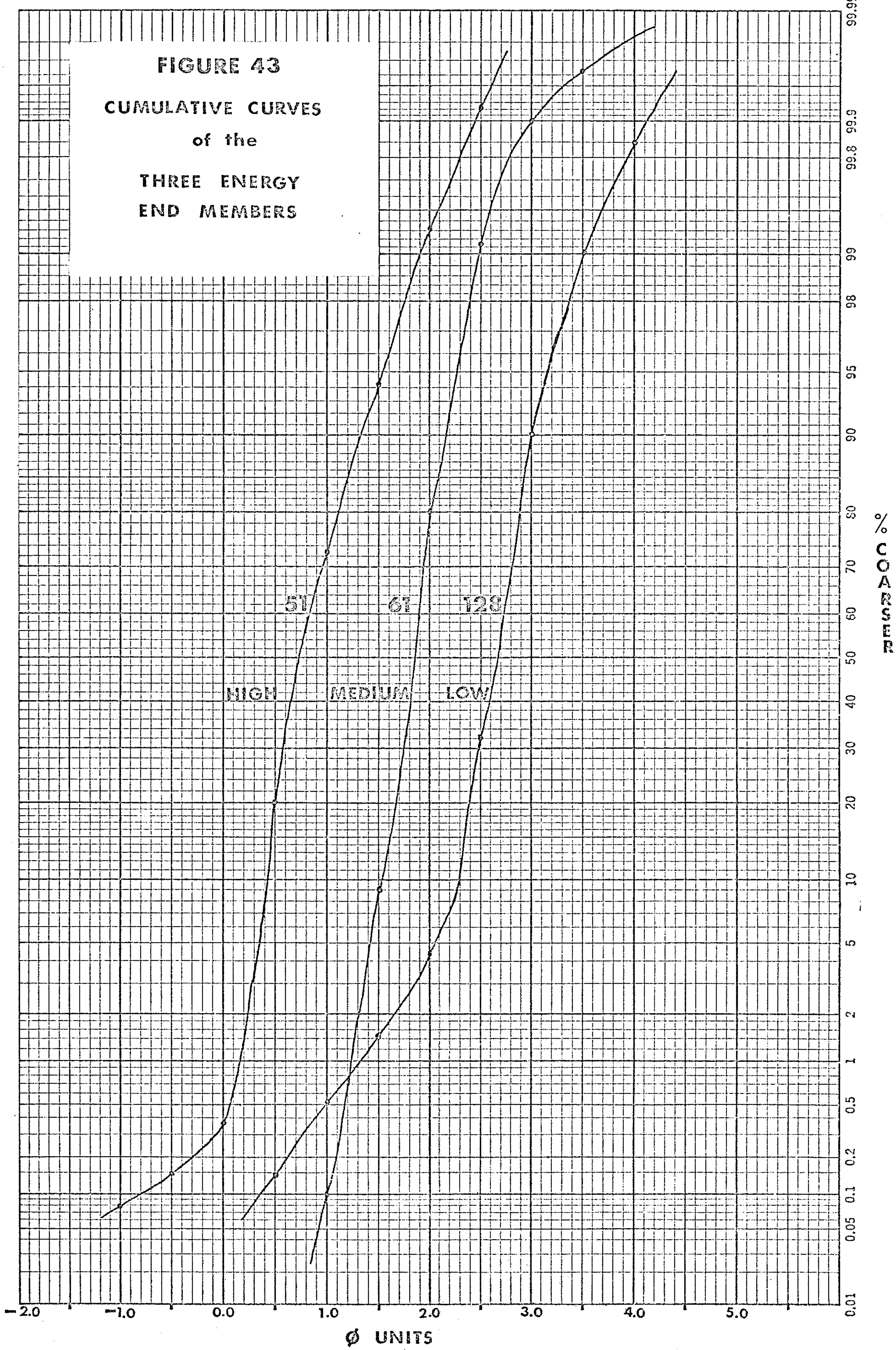


FIGURE 43
CUMULATIVE CURVES
of the
THREE ENERGY
END MEMBERS
51
61
128
HIGH
MEDIUM
LOW
-2.0
-1.0
0.0
1.0
2.0
3.0
4.0
5.0
Ø UNITS
99.99
99.9
99.8
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01
% COARSER

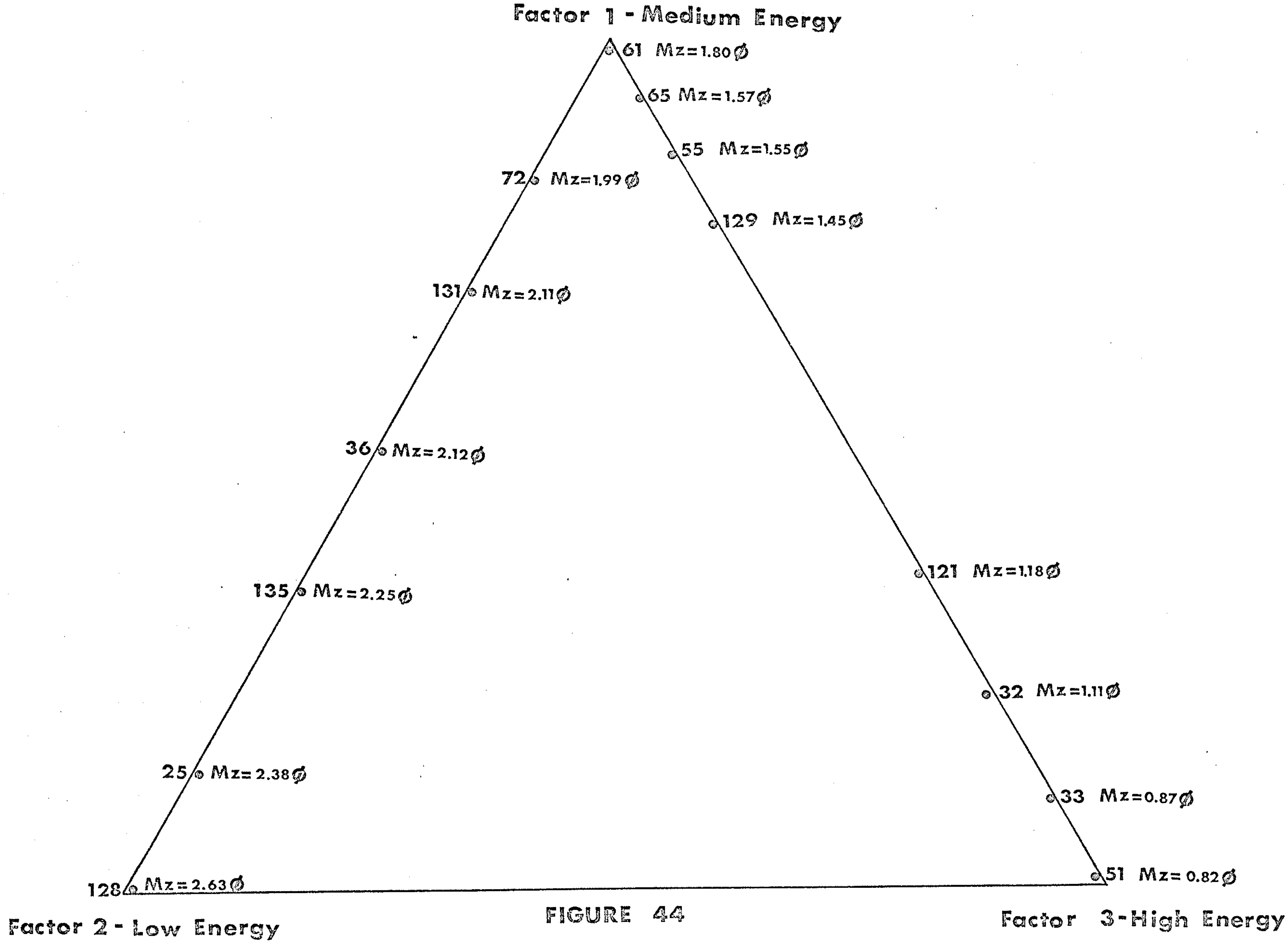


FIGURE 44

Plot of Normalized Factor Components of the Energy End Members and Several Intermediate Samples medium energy (factor 1), low energy (factor 2), and high energy (factor 3). It must be stressed that these are independent energy types and that the term "medium" does not imply a half and half mixture of low and high energy types. The type of energy and the magnitude of the energy, however, are themselves interrelated. For example, considering sample 61 (primarily influenced by factor 1), and sample 51 (primarily influenced by factor 3), it is here implied that not only has sample 51 been deposited in a higher average kinetic energy than sample 61, but also by different type of kinetic energy. In summary, the average kinetic energy at the site of deposition increases from kinetic energy type 2 (factor 2) to kinetic energy type 1 (factor 1) to kinetic energy type 3 (factor 3).

Although mean grain-size, used alone, will give a good indication of the variation of average kinetic energy, it fails to take into account the fact that sediment deposition has been controlled by three independent types of kinetic energy. It follows that one statistical parameter, such as mean grain-size, cannot portray adequately such a multidimensional situation.

The following observations for the test samples are similar to those made by Klovan for the sediments of Barataria Bay:

(1) There is a spectrum of kinetic energy types. Few samples have been influenced by only one type of energy.

(2) Some combinations of energy types are common, other combinations never occur.

(3) There is virtually no intermixing of the highest and the lowest types of energy in the test area.

To check the validity of this interpretation, the areal distribution and relative amounts (from the normalized factor components) of the three types of energy are mapped on Figure 45. The energy distributions in the known environments are:

(1) Beach samples - range from high to medium energy.

(2) Aeolian samples - mainly influenced by medium energy.

(3) Channel samples - influenced by high energy at the center of the channel. Energy levels become lower as the channel opens into the lagoon and the lake.

(4) Lake delta samples - influenced by low energy.

(5) Off beach samples - show a gradation from high energy at the shoreline, to medium energy near the shoreline and finally to low energy conditions for samples from water depths greater than five feet.

Figure 46 illustrates the distribution of the samples from known environments on the triangular diagram of factor components. The intermixing and overlap of samples from the various environments further illustrates the futility of attempting to assign a specific depositional environment to samples of unknown environmental origin by means of grain-size distribution data.

Although factors analysis does not assign samples to specific environments, it does depict energy conditions which are consistent with the known depositional environments at Grand Beach.

Samples processed by the Q-mode factor analysis were divided into three groups on the basis of the dominant energy type influencing the samples. This was determined from the normalized factor components (Table X). The groups are:

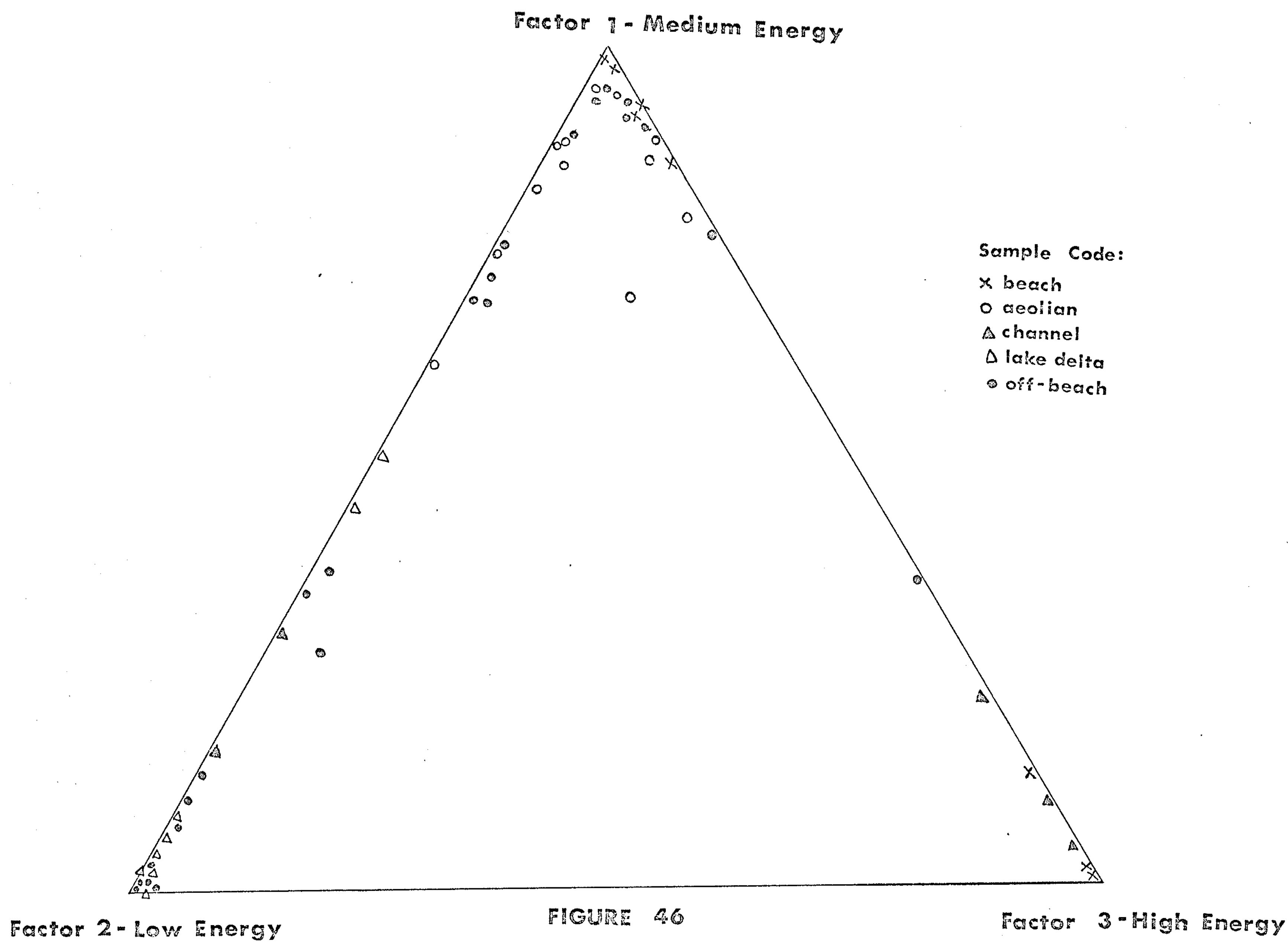


FIGURE 46

Plot of Normalized Factor Components

(1) Group 1 - 28 samples mainly influenced by medium energy (Factor 1).

(2) Group 2 - 21 samples mainly influenced by low energy (Factor 2).

(3) Group 3 - 7 samples mainly influenced by high energy (Factor 3).

Discriminant functions, group centroids and group dispersions were computed for the three groups (Program 4, Chapter VII).

Two discriminant functions separate the groups. The scaled coefficients (Cooley and Lohnes, 1962, page 119) of these two discriminant functions are given in Table XI. The absolute magnitude of the coefficients indicate the relative contribution of each variable to group separation along the discriminant functions. For example, the amount of sediment contained in the 0.50 to 1.00Ø size class contributes a great deal to group discrimination along discriminant function one, whereas the amount of sediment in the 2.50 to 3.00Ø class has negligible affect on group discrimination along discriminant function one.

Figure 47 shows the position of the group centroids and group dispersions in two dimensional discriminant space. The magnitude of the group dispersions are represented by 95 percent centours (these were drawn by scaling off two group standard deviations along the two discriminant functions). The three groups fall in different parts of the diagram with no overlap, suggesting that the groups are significantly different from one another. Results of analysis of variance (the F test

TABLE XI

SCALED COEFICIENTS OF THE TWO DISCRIMINANT FUNCTIONS SEPARATING THE THREE GROUPS

VARIABLE (PHI SIZES)	DISF.1	DISF.2
GREATER THAN -1.5	-1.02	-0.31
-1.5 TO -1.0	0.73	-0.48
-1.0 TO -0.5	-0.73	2.59
-0.5 TO 0.0	0.14	-2.36
0.0 TO 0.5	-0.69	0.03
0.5 TO 1.0	-1.53	-0.28
1.0 TO 1.5	-1.26	0.73
1.5 TO 2.0	-0.62	3.24
2.0 TO 2.5	-1.31	2.71
2.5 TO 3.0	-0.05	-1.64
3.0 TO 3.5	-0.61	2.56
3.5 TO 4.0	-1.18	0.36
LESS THAN 4.0	0.90	-0.73

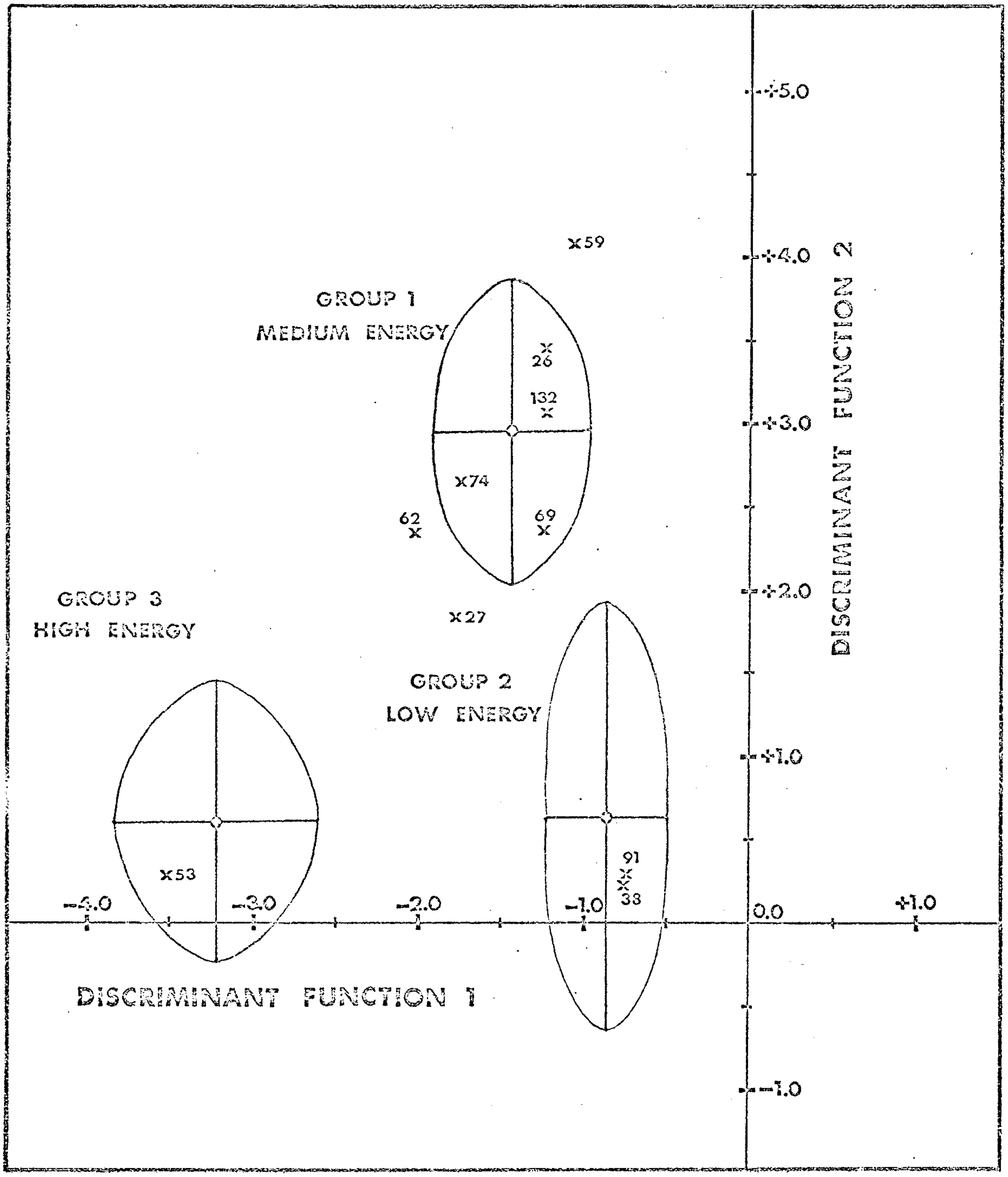


FIGURE 47

GROUP CENTROIDS, GROUP DISPERSIONS AND POSITIONS OF THE UNKNOWN SAMPLES IN TWO DIMENSIONAL DISCRIMINANT SPACE

Legend:

o group centroid x 'unknown' sample

95% contours are drawn

- Cooley and Lohnes, 1962, page 34) support this conclusion.

Discriminant scores, chi squares, probabilities of group membership and group classifications for the "unknown" samples are given in Table XII (computed by program 5, Chapter VII). The locations of these samples are plotted on Figure 45 and their positions in discriminant space are given in Figure 47. A crude measure of the similarity between a sample and a group is the distance between the sample and the group centroid.

Multiple-discriminant analysis appears to have classified the samples into the correct groups. For example, samples 62, 69 and 74 are classified as having been influenced mainly by medium energy and in fact occur in the aeolian environment. A lake delta sample (number 38) and an off-beach sample (number 91) belong to the low energy group which is consistent with the results of the factor analysis. Sample 27, although classified as a medium energy sediment, appears to show the gradation between the high energy at the middle of the channel and the low energy conditions present where the channel widens into the lagoon.

TABLE XII

DISCRIMINANT SCORES, CHI SQUARES, PROBABILITIES OF GROUP MEMBERSHIP, AND CLASSIFICATION OF THE UNKNOWN SAMPLES

SAMP.	DISCRIM. SCORES		CHI SQUARES			PROB. OF GRP. MEMBER.			CLASSIF.
	DISF1.	DISF2.	GRP1.	GRP2.	GRP3.	GRP.	GRP2.	GRP3.	(ENERGY)
27	-1.79	1.85	5.99	28.99	20.06	1.00	0.00	0.00	MEDIUM
38	-0.76	0.23	65.99	0.44	120.69	0.00	1.00	0.00	LOW
53	-3.52	0.30	83.84	387.99	0.95	0.00	0.00	1.00	HIGH
59	-1.07	4.05	6.61	37.93	72.57	1.00	0.00	0.00	MEDIUM
62	-2.04	2.32	6.29	45.46	18.80	1.00	0.00	0.00	MEDIUM
69	-1.25	2.38	3.61	7.38	38.33	0.89	0.11	0.00	MEDIUM
74	-1.76	2.67	1.56	23.21	28.06	1.00	0.00	0.00	MEDIUM
91	-0.75	0.25	65.96	0.48	120.95	0.00	1.00	0.00	LOW
126	-1.23	3.46	1.61	20.17	52.57	1.00	0.00	0.00	MEDIUM
132	-1.23	3.06	0.98	14.42	45.04	1.00	0.00	0.00	MEDIUM

CHAPTER VII

COMPUTER PROGRAMS

Introduction

All programs used in this study are programmed in the International Business Machine System 360 Disc Operating System Fortran IV language. Because this language is machine independent, the programs may be run on any System 360 Computer with a Fortran compiler and adequate core storage. The Fortran logical unit assignments in the five programs are:

Unit 1 - Card Reader

Unit 2 - Card Punch

Unit 3 - Online Printer

Units 4, 5 and 6 - Scratch areas on disk or tape

The running times given for the program include compilation, Fortran source deck listings for the programs are given in the appendix. Abbreviated descriptions of the programs are given below.

Program 1 - Graphical Parameters

This program computes the graphical parameters of grain-size distribution curves (Folk and Ward, 1957) and the discriminant functions of Sahu (1964) for any number of samples. The program requires 2,680 bytes of core storage and Fortran logical units 1 and 3.

Programmers - Programmed in I.B.M. 1620 Fortran II by W. McLellan (University of Manitoba). Converted to I.B.M. 360 D.O.S. Fortran IV by J. Solohub (University of Manitoba).

Input - No control cards are required by this program. Input data are the percentile particle diameters (in phi units) read from a cumulative curve. The data are punched one sample per card in Format (I5, 7F6.2). The first five columns of the sample card are reserved for the sample identification number. The phi diameters (Ø5, Ø16, Ø25, Ø50, Ø75, Ø84 and Ø95) follow the identification. A nine must be punched in card column 80 of the last sample.

Output - All output is printed. The output listing includes: the percentile diameters, the graphical parameters and the discriminant functions.

Time Required - Less than 3 minutes for 66 samples on a 360 model 65 machine.

Program 2 - Moment Parameters

This program computes the moment parameters (Friedman, 1961) of the grain-size distribution and cumulative percents for size analyses in the -1.5 to +14.0 phi size range. The program assumes analyses at half-phi intervals from -1.5 to +6.0 phi, and full phi intervals from +6.0 to 14.0 phi. Any number of samples may be entered into the program. The program requires 2,332 bytes of core storage and Fortran logical units 1 and 3.

Programmers - Programmed in I.B.M. 1620 Fortran II by W. McLellan (University of Manitoba). Converted to I.B.M. 360 D.O.S. Fortran IV by J. Solohub (University of Manitoba).

Input - No control cards are required by this program. The data are the raw weights of sieve and/or pipette analyses. Each sample requires two data cards. The first card has the sample identification number in card columns one to five, followed by the raw weights for: -1.5∅, -1.0∅, -0.5∅, 0.0∅, 0.5∅, 1.0∅, 1.5∅, 2.0∅, 2.5∅, 3.0∅, 3.5∅ and 4.0∅. This card is in Format (I5, 12F6.2). The second data card for each sample has the first five card columns blank followed by the raw weights for: 4.5∅, 5.0∅, 5.5∅, 6.0∅, 7.0∅, 8.0∅, 9.0∅, 10.0∅, 11.0∅, 12.0∅, 13.0∅ and 14.0∅. This card is in Format (5X, 12F6.2). A nine must be punched in card column 80 of the second card of the last sample.

Output - All output is printed. Output includes cumulative percents and moment parameters of the grain-size distribution.

Time Required - Approximate running time is three minutes for 66 samples on a 360 model 65 machine.

Program 3 Q-Mode Factor Analysis

This program computes a complete Q-mode factor analysis for up to 80 samples and 15 variables. The reader is referred to Imbrie and Van Andel (1964) who describe the technique in detail. The Fortran source deck consists of a main program with two subroutines. The program requires 41,884 bytes of core storage and Fortran logical units 1 and 3.

Programmer - Programmed by J. E. Klovan (University of Calgary).

Input -

Control card 1 contains:

Col.	F.M.T.	PARAM.
1-60	15A4	TITLE - The Job Title

Control card 2 contains:

Col.	F.M.T.	PARAM.
1-2	12	NV - Number of Samples
3-6	14	NS - Number of Variables
7-11	F5.2	QUIT - Stop Criterion

Stop criterion is the amount of variance to be explained by the factor analysis. Usually set between 90.00 and 100.00 percent.

These two control cards are followed by the data matrix which has samples as columns and variables as rows. Statement 52 controls the format of the input data.

Output - All output is printed. Output includes: cosine theta matrix, principal components factor matrix, varimax factor matrices and normalized varimax factor matrices.

Time Required - Less than four minutes of computer time for 56 samples and 13 variables on a 360 model 65 machine.

Program 4 - Multiple Discriminant Analysis

This program computes multiple-discriminant functions for up to 15 groups and 15 variables. The reader is referred to Cooley and Lohnes (1962) for a complete description of this technique. The Fortran source deck consists of a main program with nine subroutines. The program requires 42,832 bytes of core storages and Fortran logical units 1, 2, 3, 4, 5 and 6.

Programmers - Programmed in I.B.M. 704 Fortran by W. W. Cooley (Harvard University) and P. R. Lohnes (University of New Hampshire). Converted to I.B.M. 360 D.O.S. Fortran IV by J. E. Klovan (University of Calgary).

Input -

Control card 1 contains:

Col.	F.M.T.	PARAM.
1	I1	L - 0 if data cards are input - 1 if matrices are input
2-3	I2	K - number of groups
4-5	I2	M - number of variables
6-15	F10.0	QUIT- stop criterion

Stop criterion is the highest percentage of variance to be contributed by a discriminant function (usually set at about 5.0).

The following two control cards precede each set of cards for each group (read in by subroutine CORREL).

Control card 2 contains:

Col.	F.M.T.	PARAM.
1-2	F2.0	T - number of variables
3-7	I5	NG - number of samples in group
8-14		- blank columns
15-17	I3	IPROB - group number

The group numbers are consecutive (i.e. the first group is 001, the second group is 002, and so on).

Control card 3 contains:

Col.	F.M.T.	PARAM.
1-72	18A4	TITLE - Group Title

These two control cards are followed by the data cards for the group. The variables must be columns and the samples must be rows. The first 12 columns of the sample cards are reserved for the sample name. Input is controlled by format statement number one in subroutine VARFT.

Following the last deck of data, a terminal control card is required.

Control card 4 contains:

Col.	F.M.T.	PARAM.
1-4	F4.0	GN(1) number of samples in Group 1
4-8	F4.0	GN(2) number of samples in Group 2
8-12	F4.0	GN(3) number of samples in Group 3
-	-	-
-	-	- and so on until the numbers of samples in the last group of data

<u>Output</u> - Printed output includes: the pooled W matrix, total deviation sums of squares and cross products matrix, total

correlation matrix, the A matrix, eigenvalue of the variables, scaled vector of the discriminant functions and the group centroids and dispersions in reduced space.

Punched output includes: the discriminant vectors, group centroids and group dispersions. These punched matrices are used in program 5 (classification) to classify unknown samples into the discriminant groups.

Time Required - Approximately seven minutes for 56 samples in three groups on a 360 model 65 machine.

Program 5 - Classification

This program classifies samples into groups with previously computed (by program 4) discriminant functions. A sample is classified into the group to which it shows the most similarity. For a complete description of this technique, the reader is referred to Cooley and Lohnes (1962). Any number of samples may be entered into the program. The program requires 19,208 bytes of core storage and Fortran logical units 1 and 3.

Programmers - Programmed in I.B.M. 704 Fortran by W. W. Cooley (Harvard University) and P. R. Lohnes (University of New Hampshire). Converted to I.B.M. 360 D.O.S. Fortran IV by J. E. Klovan (University of Calgary).

Input -

Control card 1 contains:

Col.	F.M.T.	PARAM.
1-2	12	Kg - Number of groups
3-4	12	M - Number of variables
5-6	12	N - Number of discriminant functions

This card is followed by the punched output of the multiple discriminant analyis (program 4). Next come the data cards for the samples to be classified. Variables must be in the same order as they were for the multiple-discriminant analysis. The first 12 columns for each card are reserved for sample identification. Format card number one controls the input data.

Output - All output is printed. Output for each sample is: the discriminant scores, the classification chi squares and the probability of group membership.

Time Required - Less than one minute to classify ten samples into three previously computed groups on a 360 model 65 machine.

Multivariate Statistical Programs for the I.B.M. 360 Computer

The Multivariate Statistical Analyzer is the name given to a system of Fortran II statistical programs for I.B.M. 7090-7094 computers. The programmers are: W. W. Cooley (Harvard University), P. R. Lohnes (University of New Hampshire), and K. J. Jones (Harvard University). Jones (1964) gives complete descriptions of the programs in the users' manual.

Klovan (University of Calgary) and Solohub (University of Manitoba) have converted part of this system to I.B.M. 360 Fortran IV. This language conversion was undertaken for several reasons:

(1) The trend among many Universities and research institutions to acquire large scale I.B.M. 360 computers.

(2) The versatility and sophistication of the programs make them valuable research tools.

(3) The increased use of multivariate statistics by scientists and research workers of all disciplines.

The converted programs total some 10,000 Fortran statements. The last stage in the conversion, machine testing of programs, is currently in progress.

CHAPTER VIII

SUMMARY AND CONCLUSIONS

The Grand Beach bay-mouth bar, situated on the southeast shore of Lake Winnipeg, is a Post Pleistocene geologic feature. Recent sediments forming the bar have been transported into the Grand Beach area by wind produced longshore currents. Ten depositional environments are proposed for the Grand Beach area on the basis of topographic, sedimentologic, hydrographic and geographic criteria.

Five published statistical techniques, which supposedly indicate depositional environments from grain-size distribution data were tested on recent sandy sediments from aeolian, beach, channel, lake delta and off-beach environments of Grand Beach. None of the techniques could classify samples reliably into the environments delineated above. Factor analysis, however, gave results which reproduced energy conditions consistent with the known depositional environments. Samples may be classified into the factor scheme by multiple-discriminant analysis.

Why did every statistical technique fail to classify samples into their correct depositional environments? Apparently, the reason for the failure of these techniques is that the grain-size distribution is not necessarily different for sediments of widely diverse environmental origin. Obviously, sediments sampled in ten feet of water are from a quite different environment than sediments sampled from the top of a dune. But the different types and amounts of kinetic energy acting upon the sediments may produce identical grain-size distributions. It is therefore concluded that no matter how intricate or sophisticated are the statistics applied to sediments from different environments, no differentiation can be made if the grain-size distributions themselves are not different.

If these results observed for the recent sediments at Grand Beach are applicable to recent and ancient marine sediments, then grain-size distribution data cannot be used as indicators of specific depositional environments. Factor analysis, however, may be applied to grain-size distribution data to yield valuable information about the energy conditions at the site of sediment deposition.

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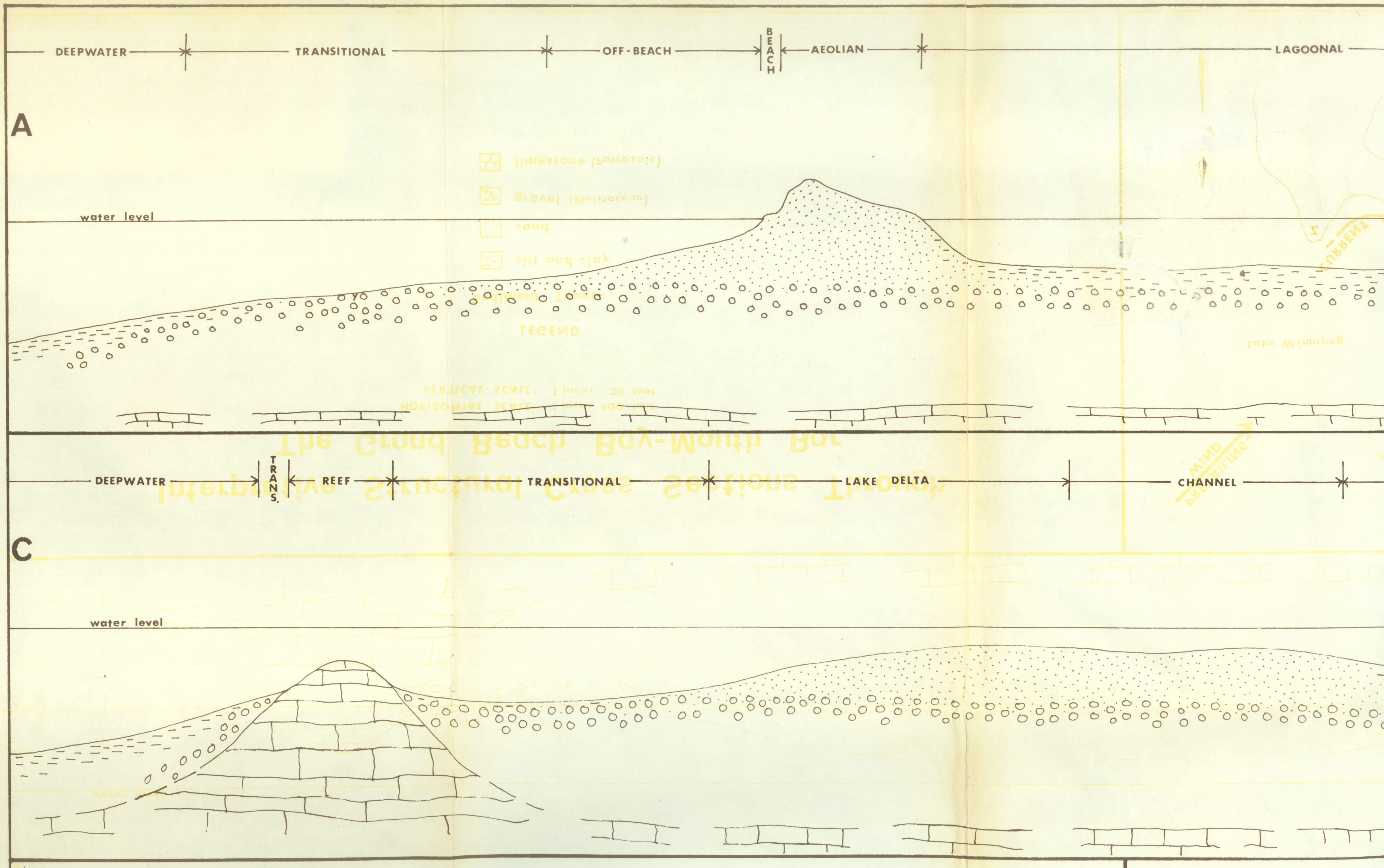
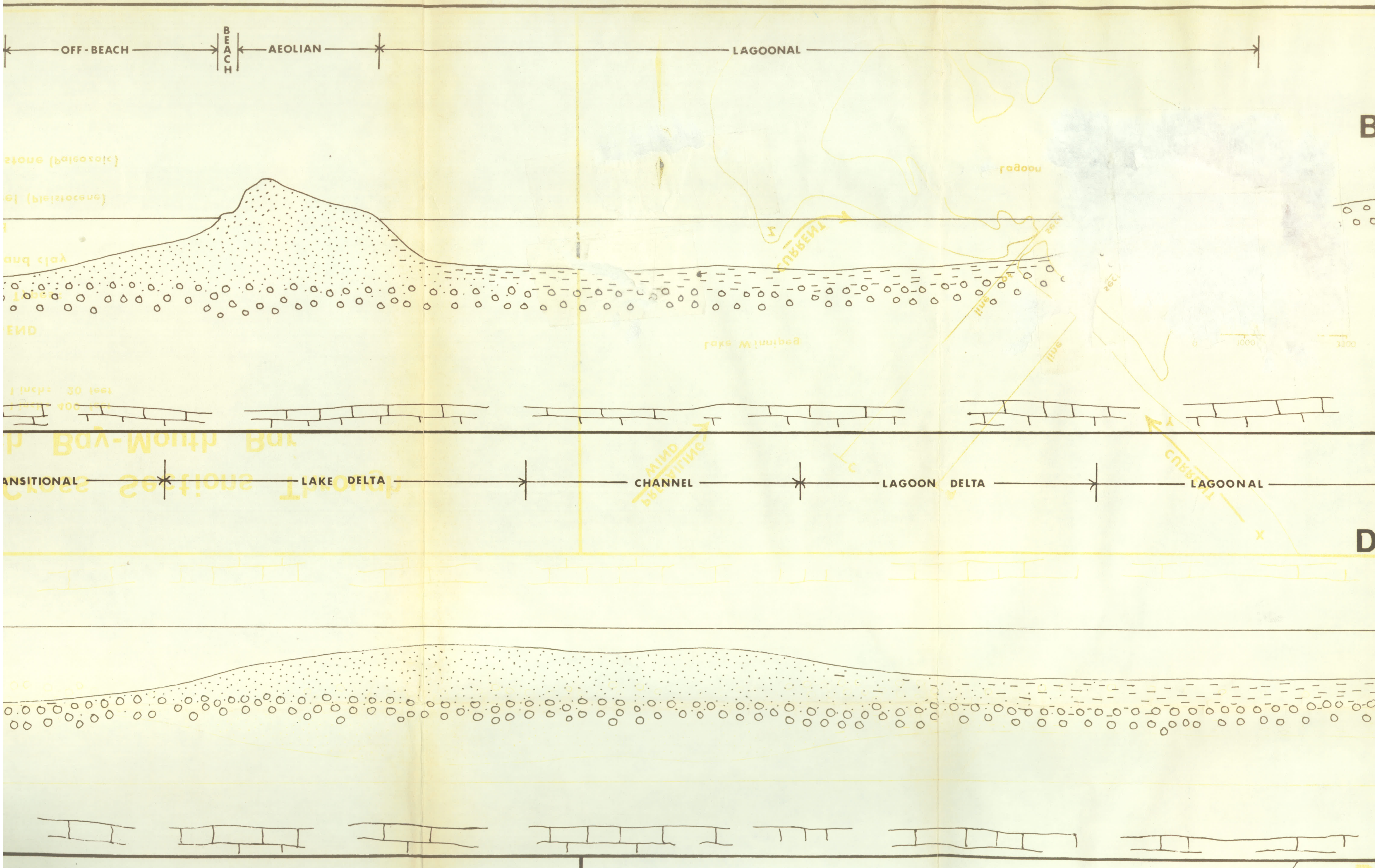
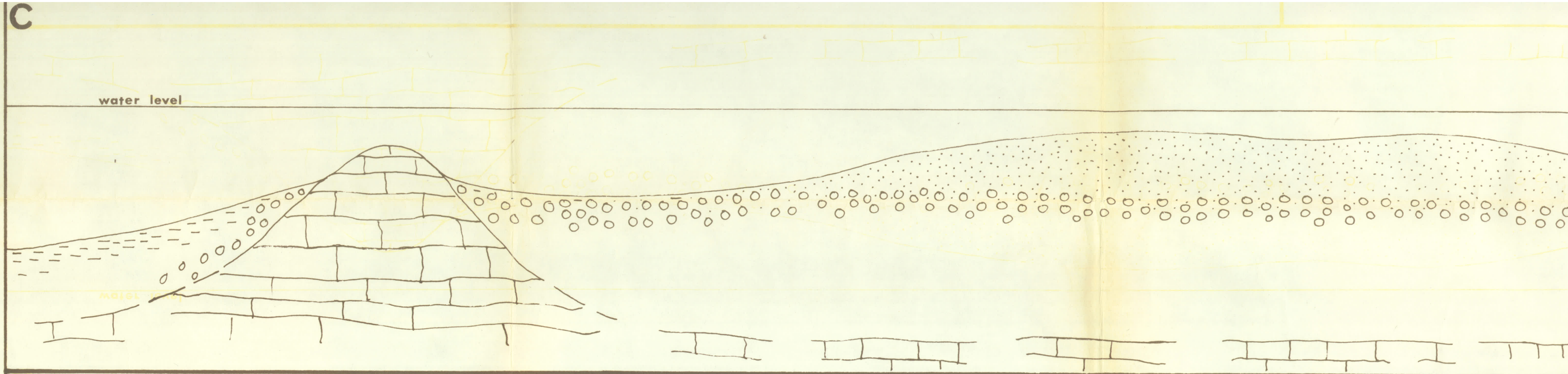
APPENDIX

Fortran Source Deck Listings of Computer

Programs 1, 2, 3, 4 and 5


DEEPWATER
TRANSITIONAL
OFF-BEACH
BEACH
AEOLIAN
LAGOONAL
A
water level
DEEPWATER
TRANS.
REEF
TRANSITIONAL
LAKE DELTA
CHANNEL
C
water level


OFF-BEACH
BEACH
AEOLIAN
LAGOONAL
B
ANSITIONAL
LAKE DELTA
CHANNEL
LAGOON DELTA
LAGOONAL
D



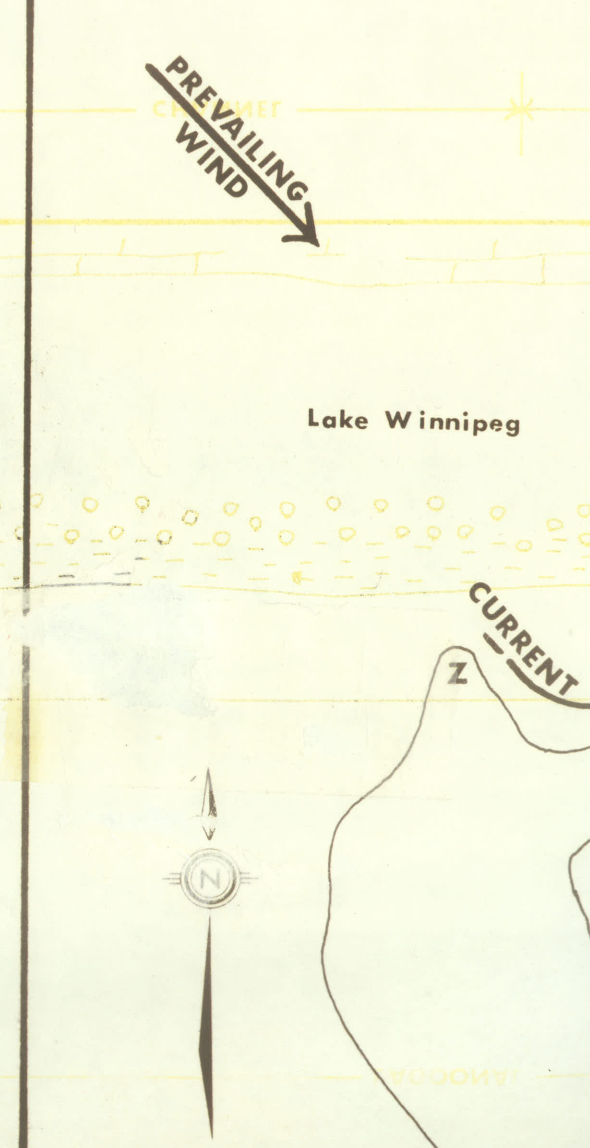
Interpretive Structural Cross Sections Through The Grand Beach Bay-Mouth Bar

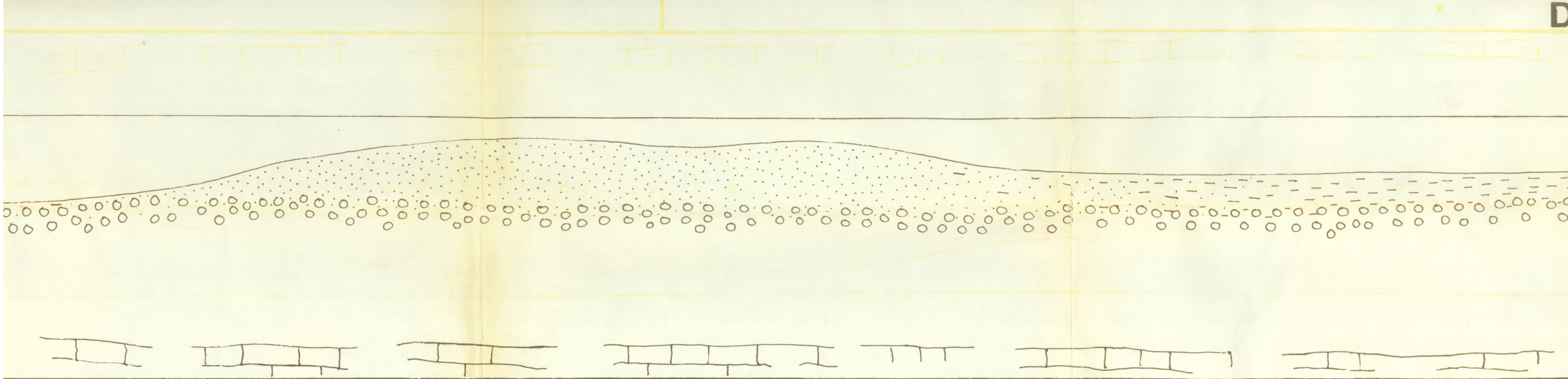
HORIZONTAL SCALE: 1 inch = 400 feet
VERTICAL SCALE: 1 inch = 20 feet

LEGEND

Sediment Types:

- silt and clay
- sand
- gravel (Pleistocene)
- limestone (Paleozoic)





Cross Sections Through
h Bay-Mouth Bar

1 inch= 400 feet
1 inch= 20 feet

END

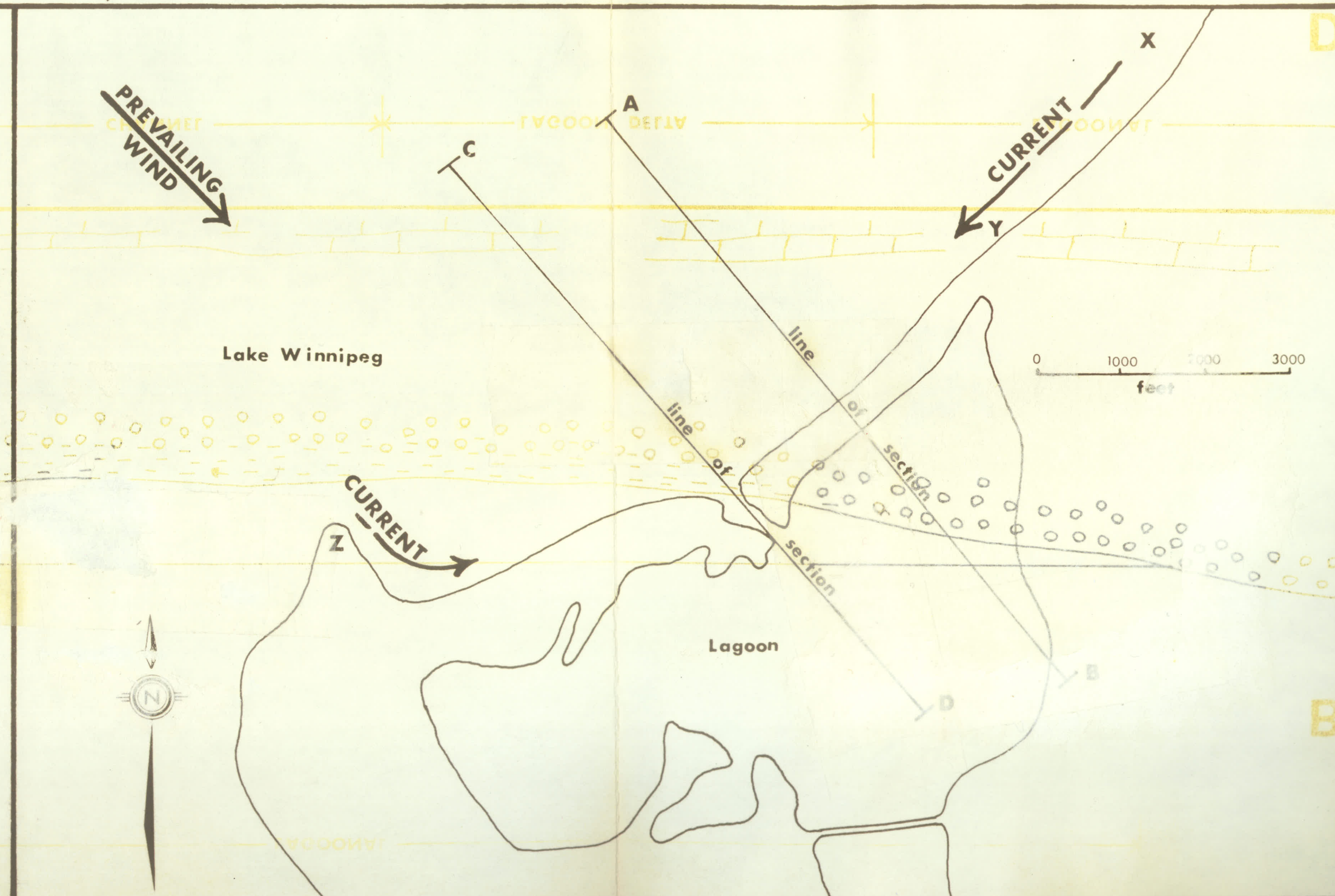
Types:

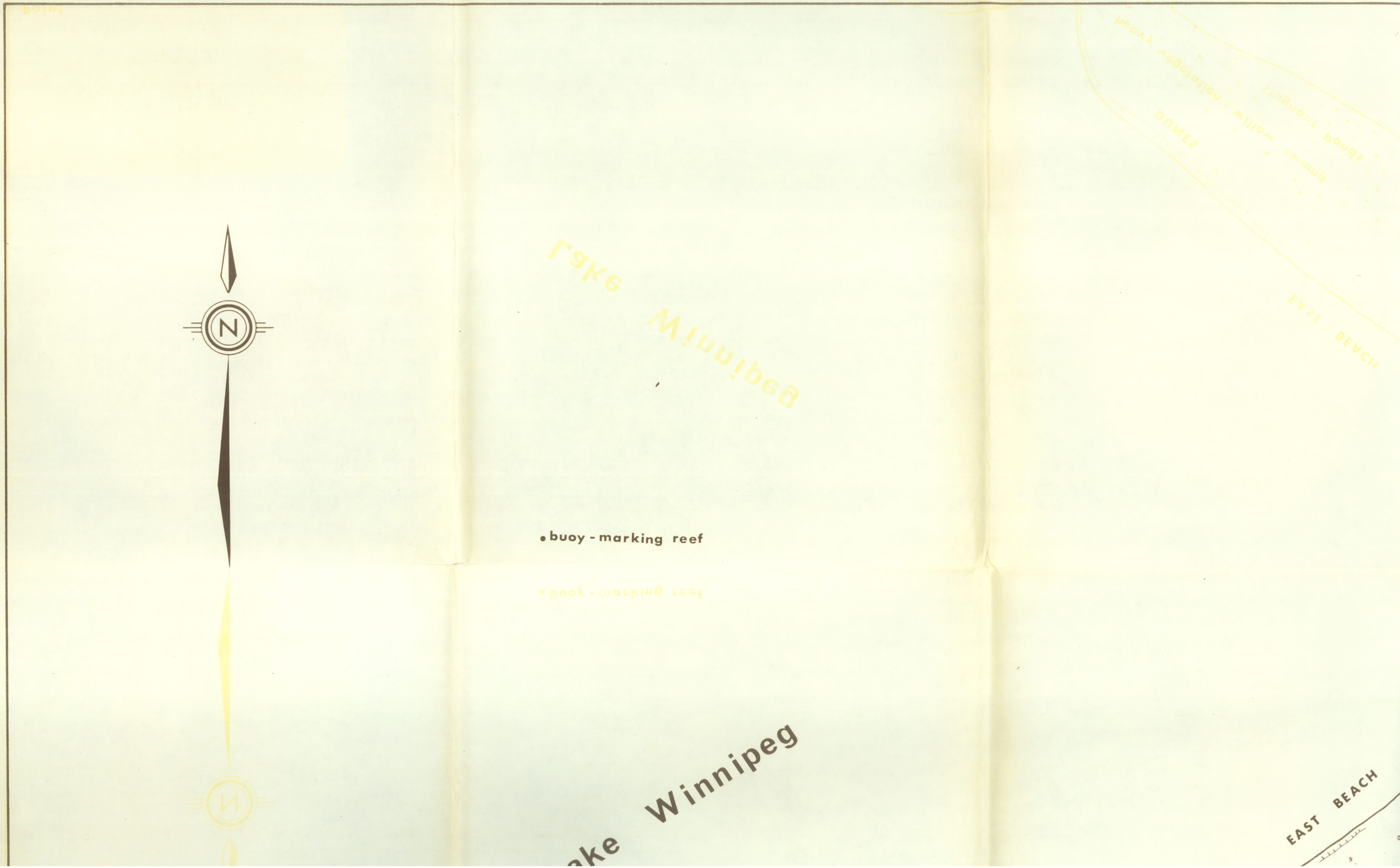
and clay

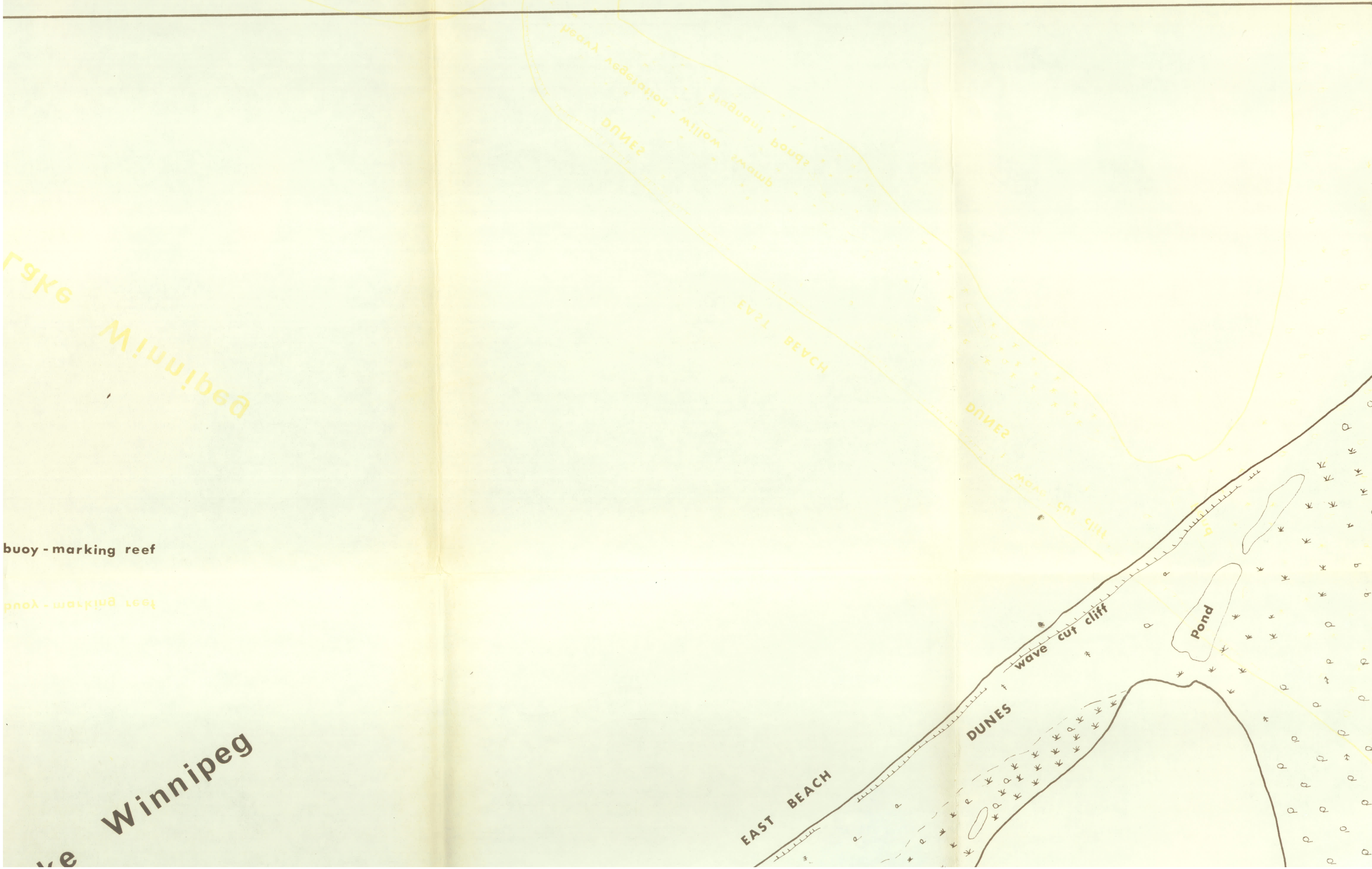
l

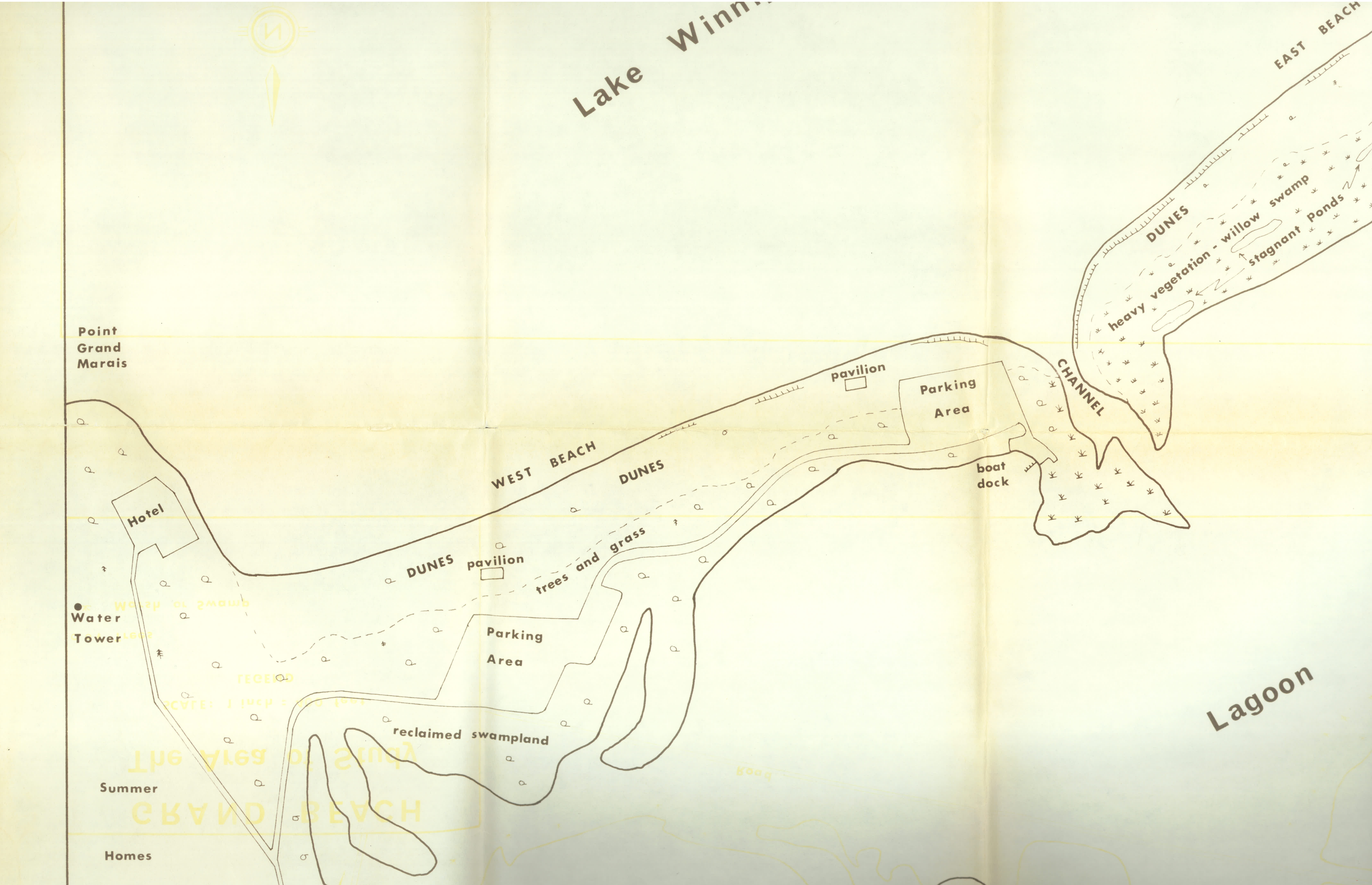
el (Pleistocene)

stone (Paleozoic)

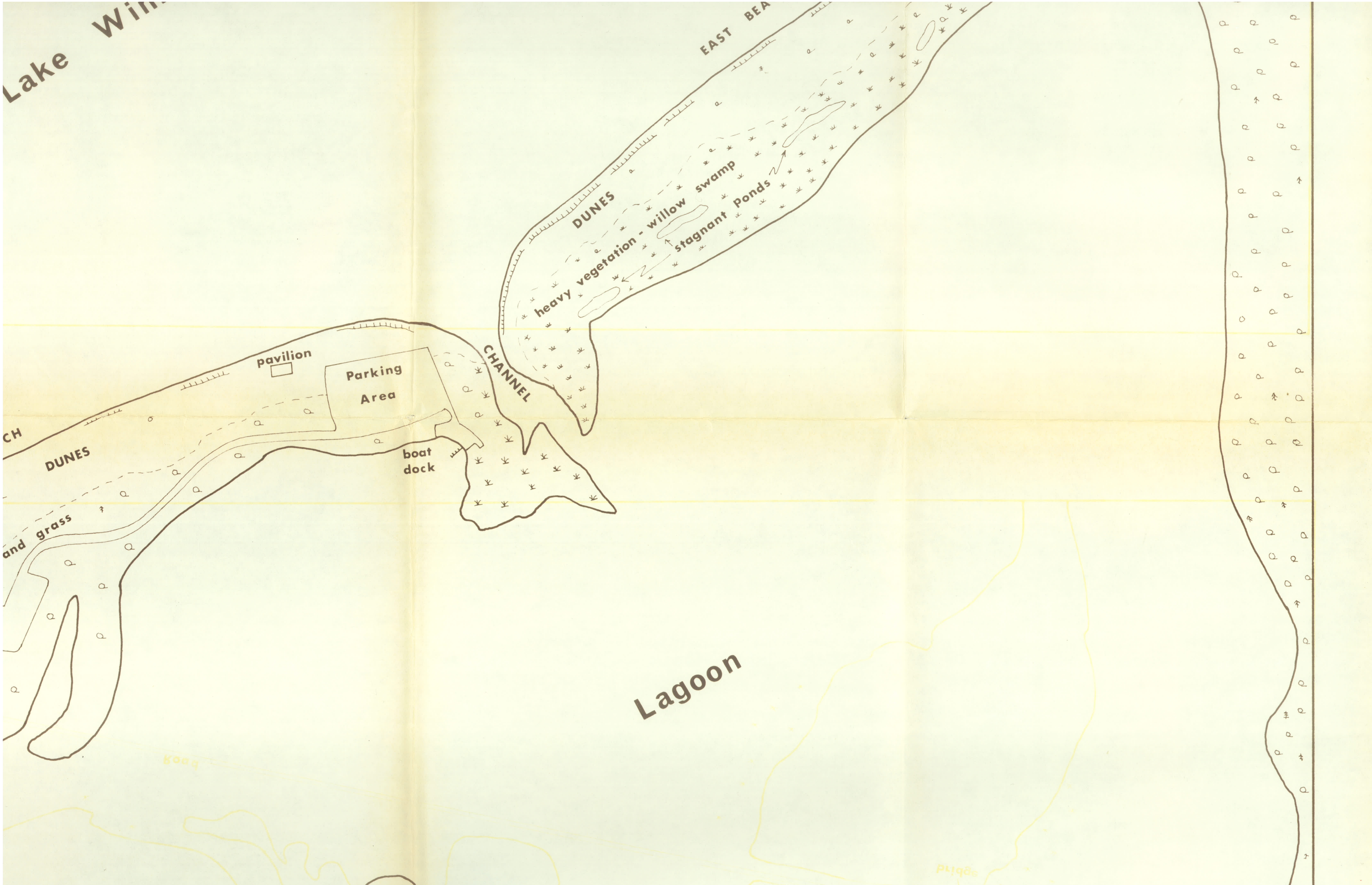



N
buoy - marking reef
Winnipeg
EAST BEACH

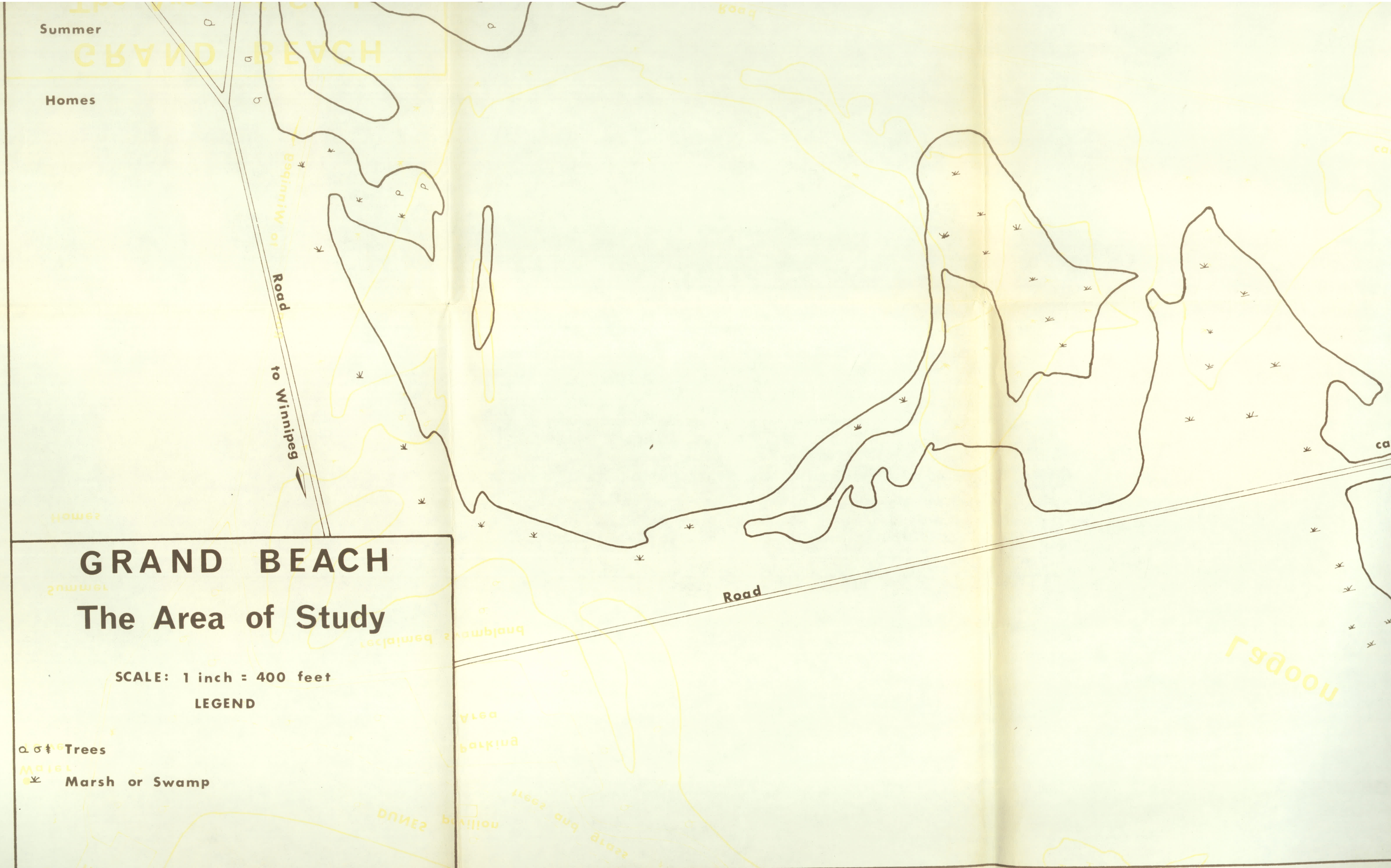

buoy - marking reef
Winnipeg
EAST BEACH
DUNES
wave cut cliff
pond

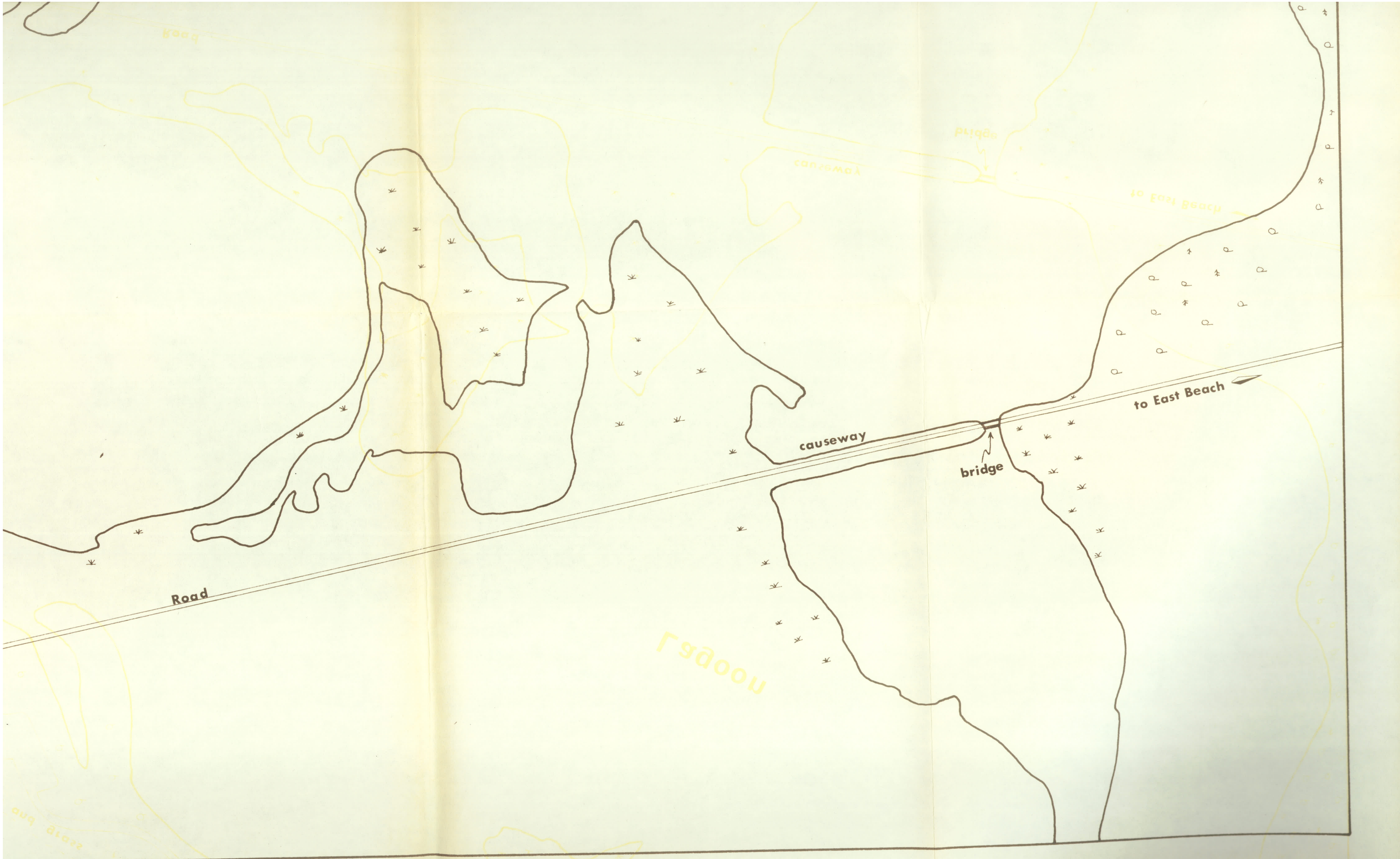


Lake Winni
EAST BEACH
DUNES
heavy vegetation - willow swamp
stagnant Ponds
CHANNEL
Point
Grand
Marais
pavilion
Parking
Area
WEST BEACH
DUNES
boat
dock
Hotel
DUNES
pavilion
trees and grass
Water
Tower
Parking
Area
reclaimed swampland
Lagoon
Summer
Homes



Lake
DUNES
heavy vegetation - willow swamp
stagnant Ponds
CHANNEL
pavilion
Parking Area
boat dock
DUNES
Lagoon


Summer
Homes
Road to Winnipeg
Road
GRAND BEACH
The Area of Study
SCALE: 1 inch = 400 feet
LEGEND
Trees
Marsh or Swamp



causeway
bridge
to East Beach
Road

N
D
0.4
DEEPWATER
D
0.4
DEEPWATER
8.3
OFF-BEACH
S
REEF
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T
TRANSITIONAL
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OFF-BEACH
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D
DEEPWATER
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D
1.3
OFF-BEACH
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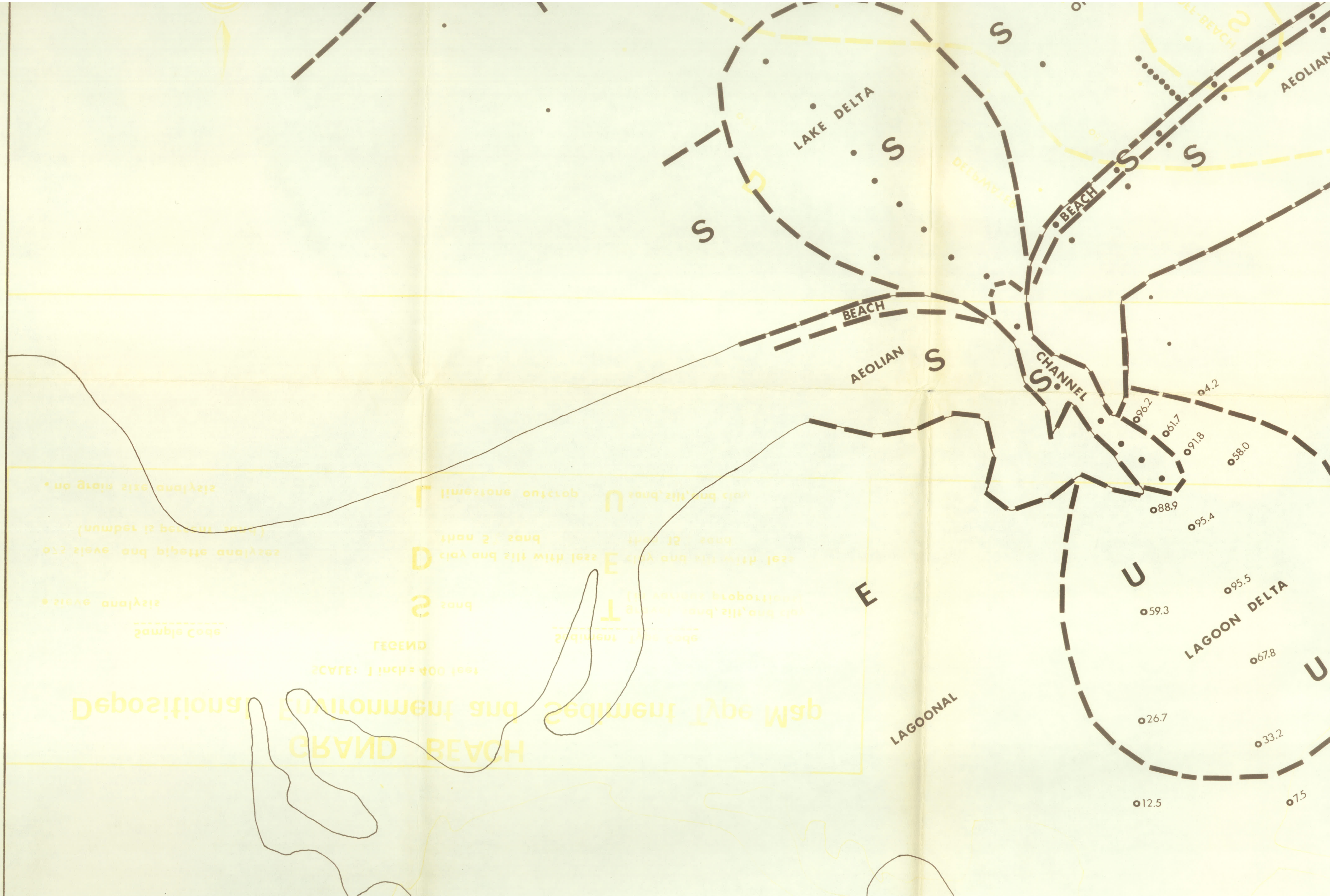
LAKE DELTA
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S
S
S
S
S
S
BEACH
BEACH
AEOLIAN
AEOLIAN
CHANNEL
S
4.2
96.2
61.7
91.8
58.0
88.9
95.4
E
U
95.5
59.3
LAGOON DELTA
67.8
U
LAGOONAL
26.7
33.2
12.5
7.5

LAKE DELTA
S
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S
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S
BEACH
AEOLIAN
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AEOLIAN
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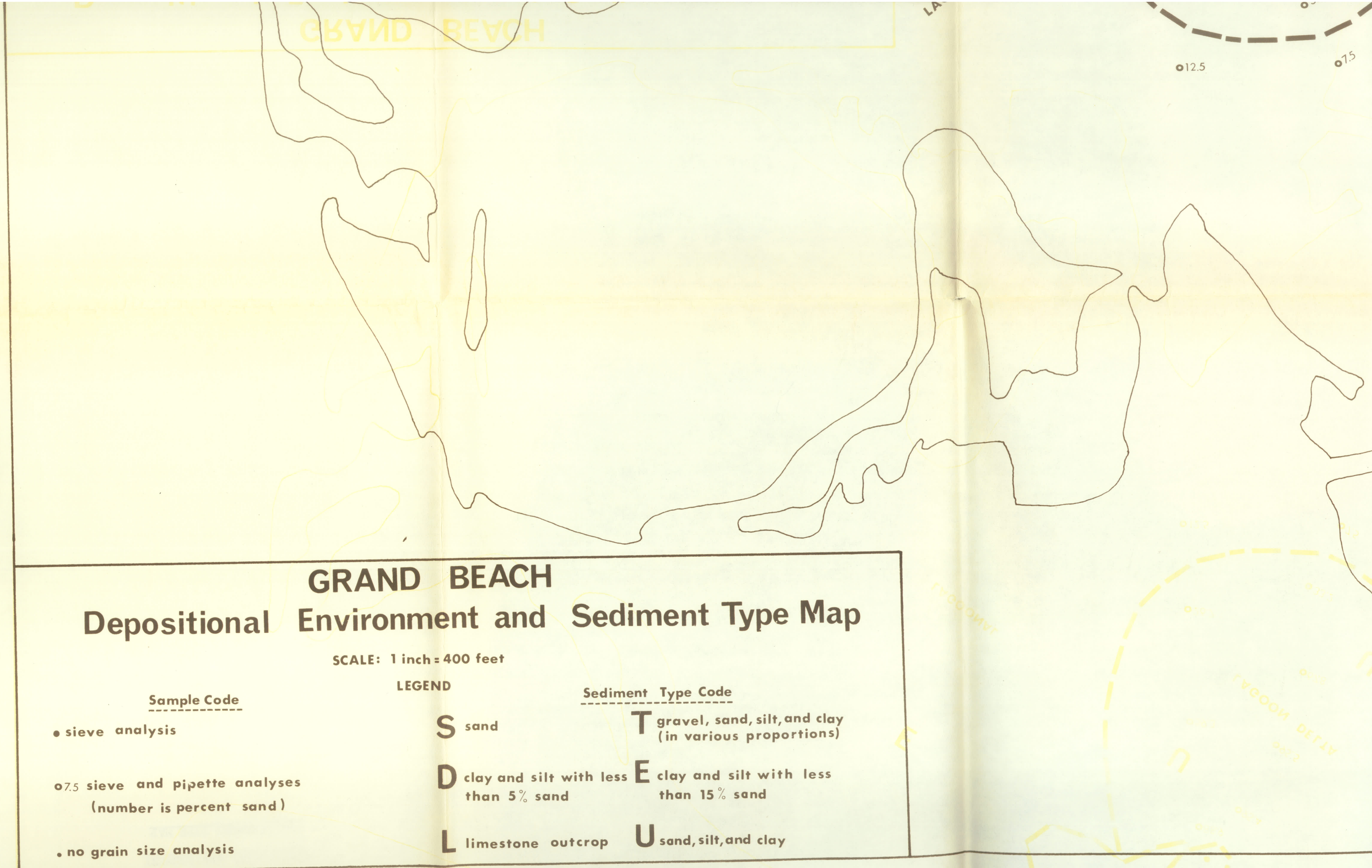
12.5
7.5
GRAND BEACH
Depositional Environment and Sediment Type Map
SCALE: 1 inch = 400 feet
LEGEND
Sample Code
• sieve analysis
o7.5 sieve and pipette analyses
(number is percent sand)
• no grain size analysis
S sand
D clay and silt with less than 5% sand
L limestone outcrop
Sediment Type Code
T gravel, sand, silt, and clay (in various proportions)
E clay and silt with less than 15% sand
U sand, silt, and clay

26.7
33.2
12.5
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E
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H
Sediment Type Map
Sediment Type Code
T gravel, sand, silt, and clay (in various proportions)
lt with less
and
E clay and silt with less than 15% sand
outcrop
U sand, silt, and clay

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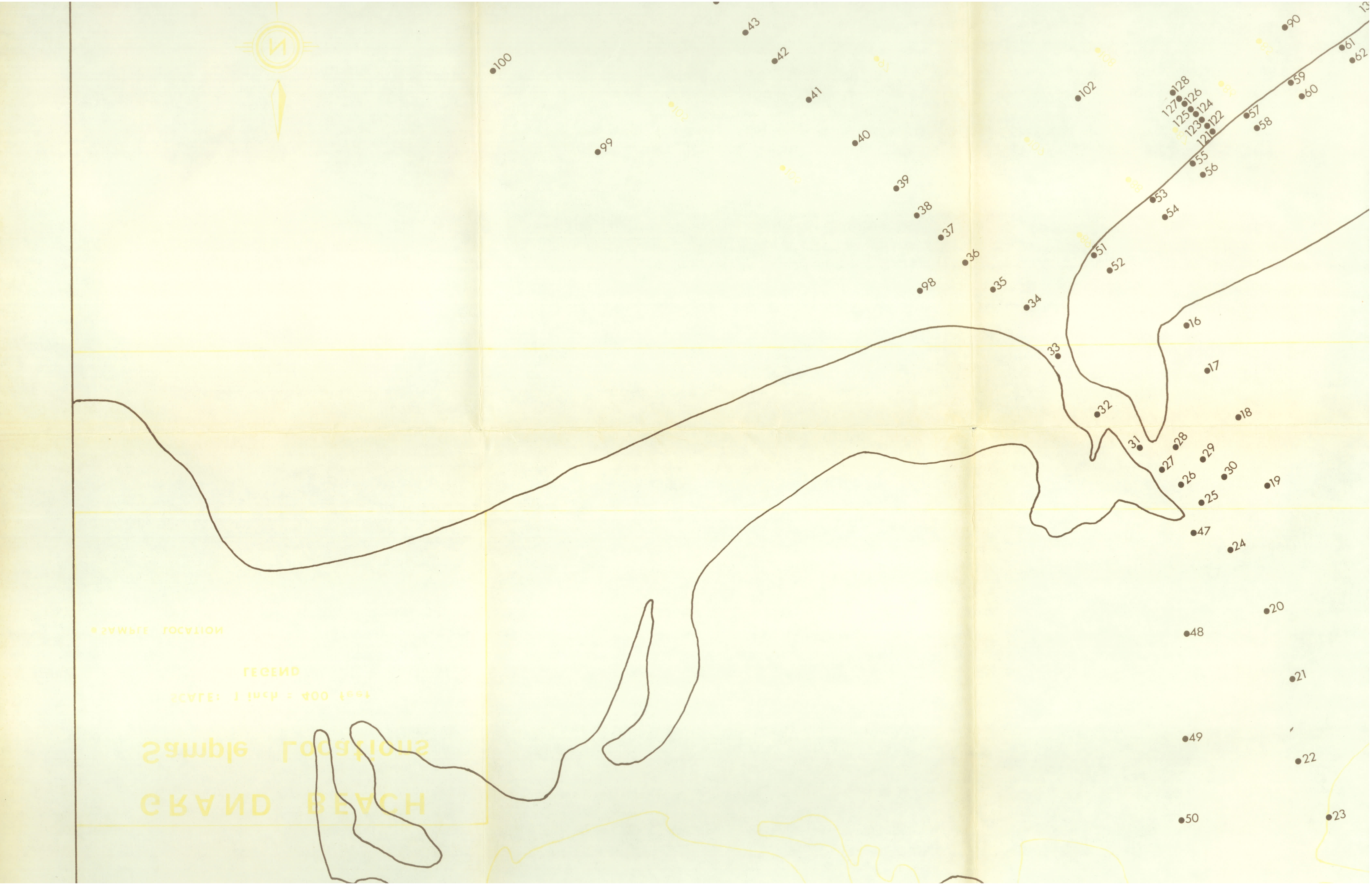

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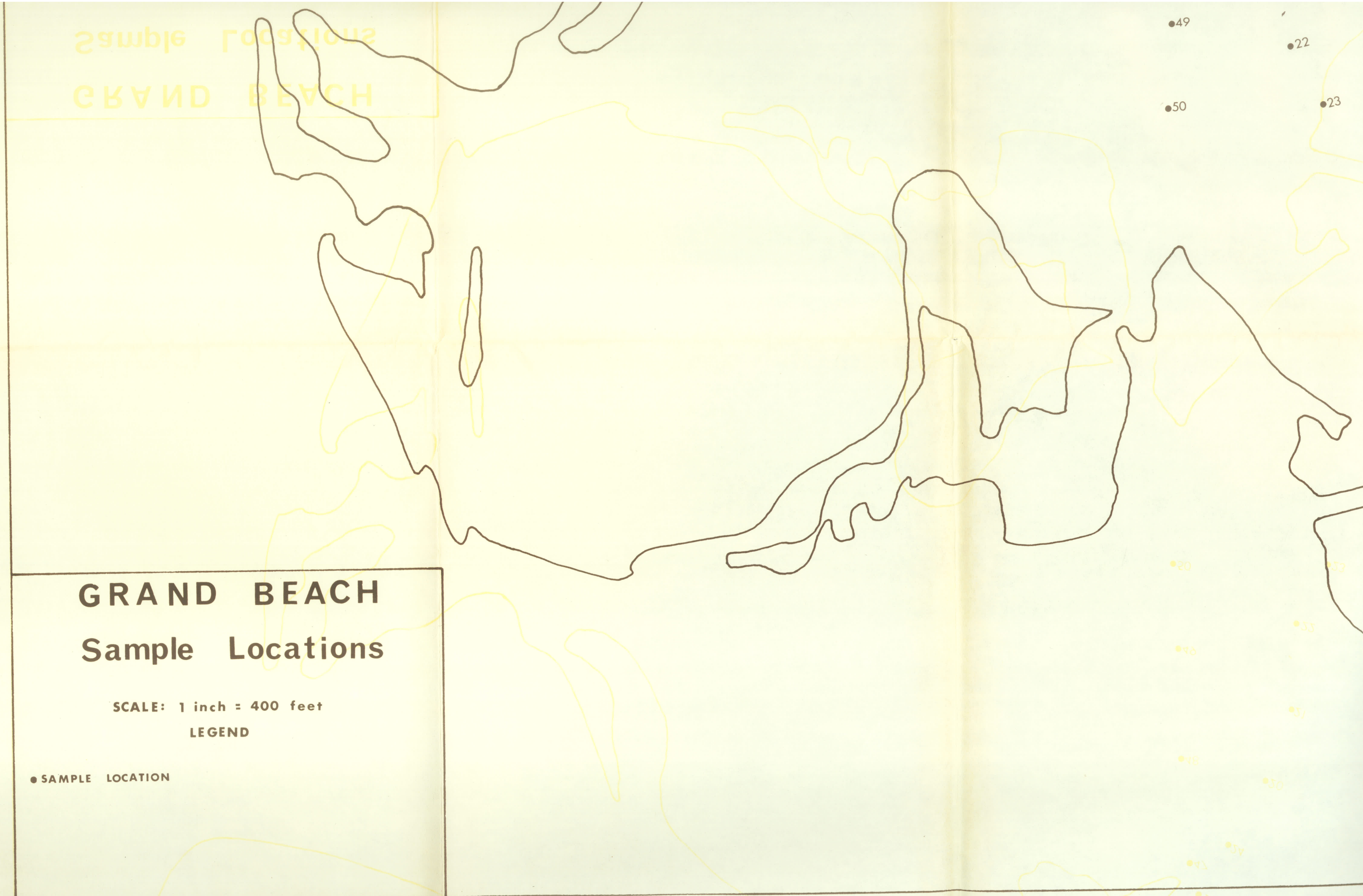
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GRAND BEACH
Sample Locations
SCALE: 1 inch = 400 feet
LEGEND
● SAMPLE LOCATION

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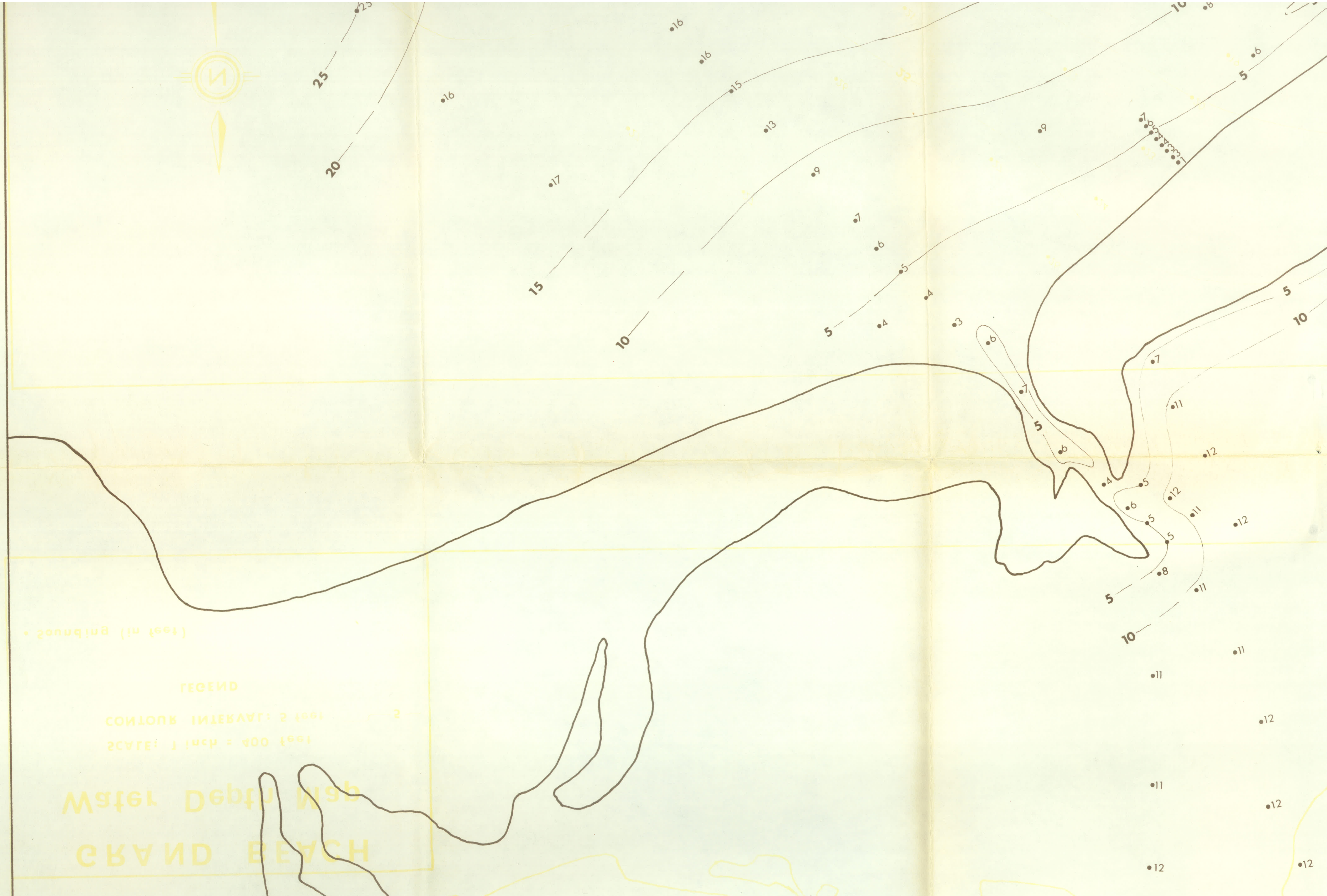

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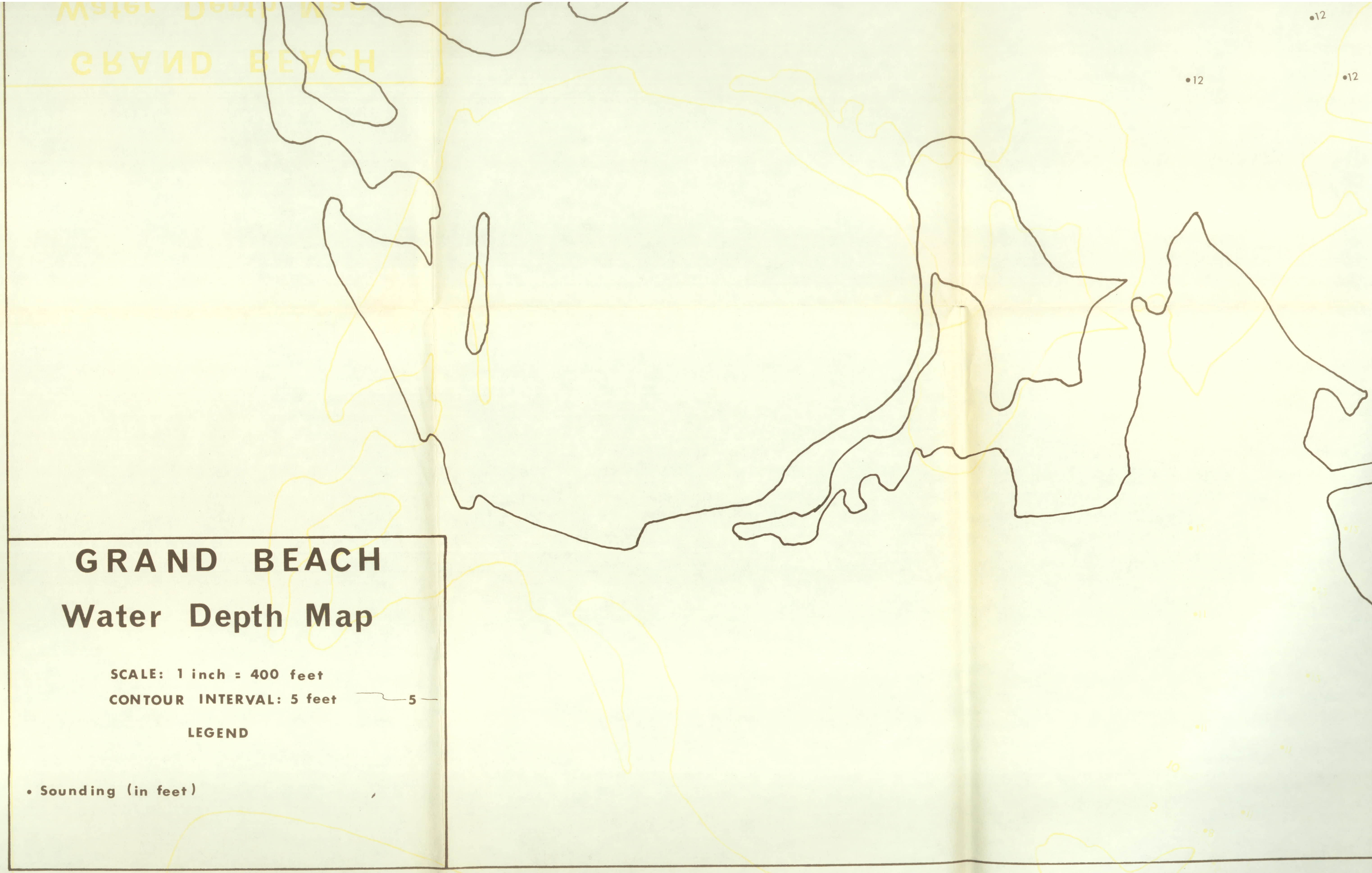

•12
•12
•12
GRAND BEACH
Water Depth Map
SCALE: 1 inch = 400 feet
CONTOUR INTERVAL: 5 feet
5
LEGEND
• Sounding (in feet)


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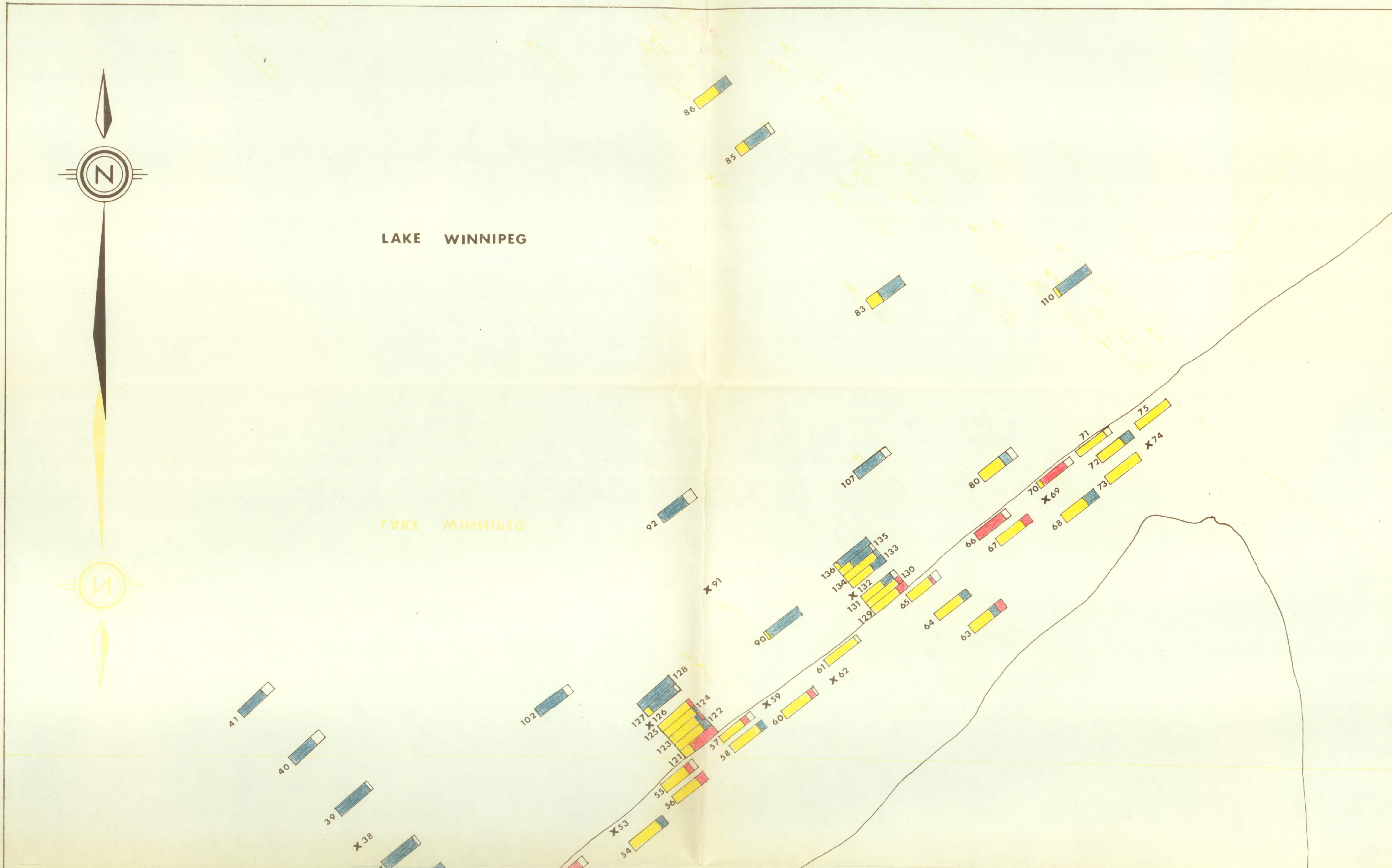

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LAKE WINNIPEG
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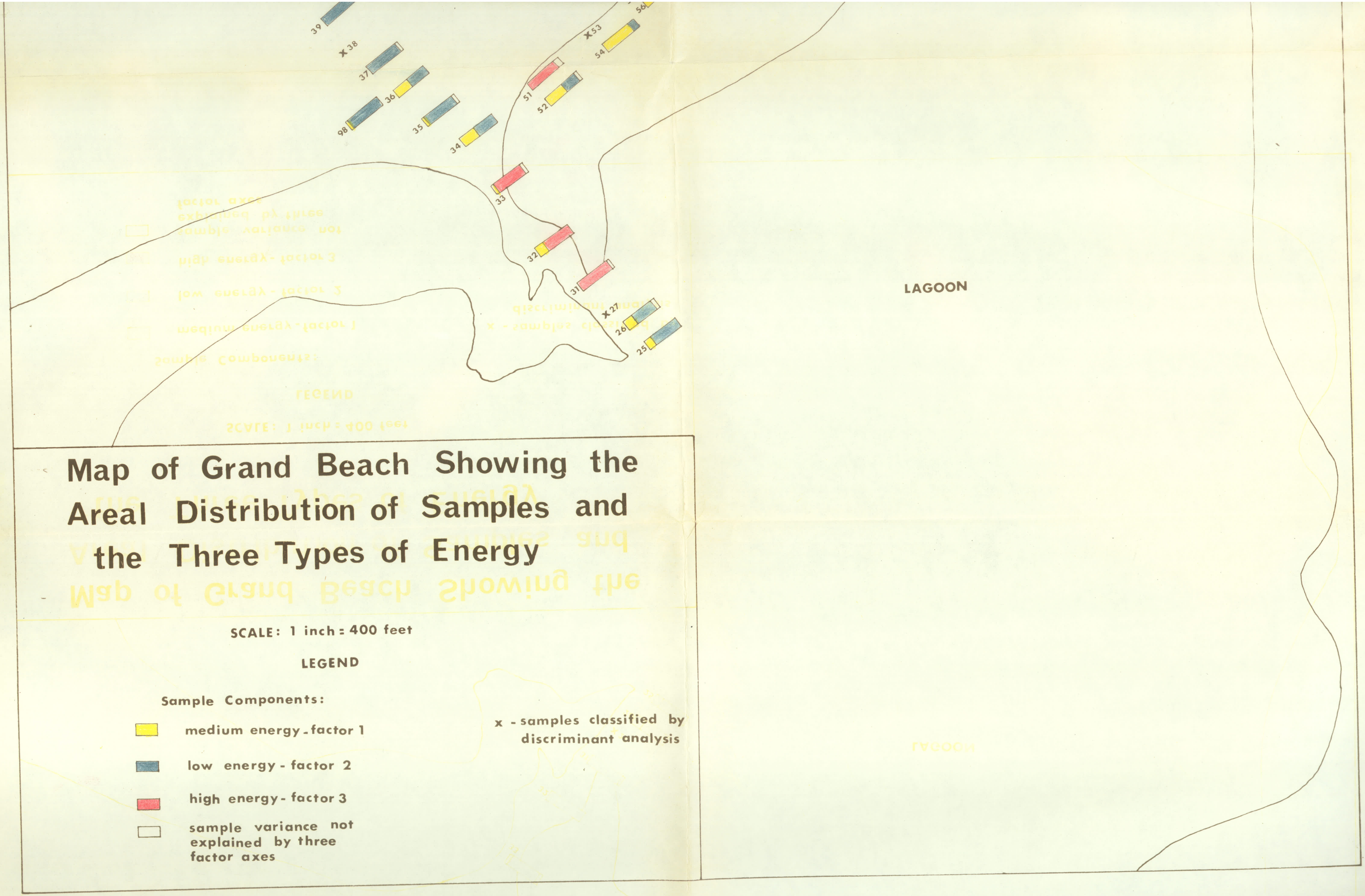

Map of Grand Beach Showing the Areal Distribution of Samples and the Three Types of Energy