UNIVERSITY OF MANITOBA

GRAND BEACH

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

A Dissertation

Submitted to the Graduate School

In Partial Fulfillment

of the Requirements for the Degree

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.

TABLE OF CONTENTS

Chapter I

Chapter II

Chapter III

Chapter IV

Page

Chapter VIII

LIST OF ILLUSTRATIONS

LIST OF TABLES

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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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.

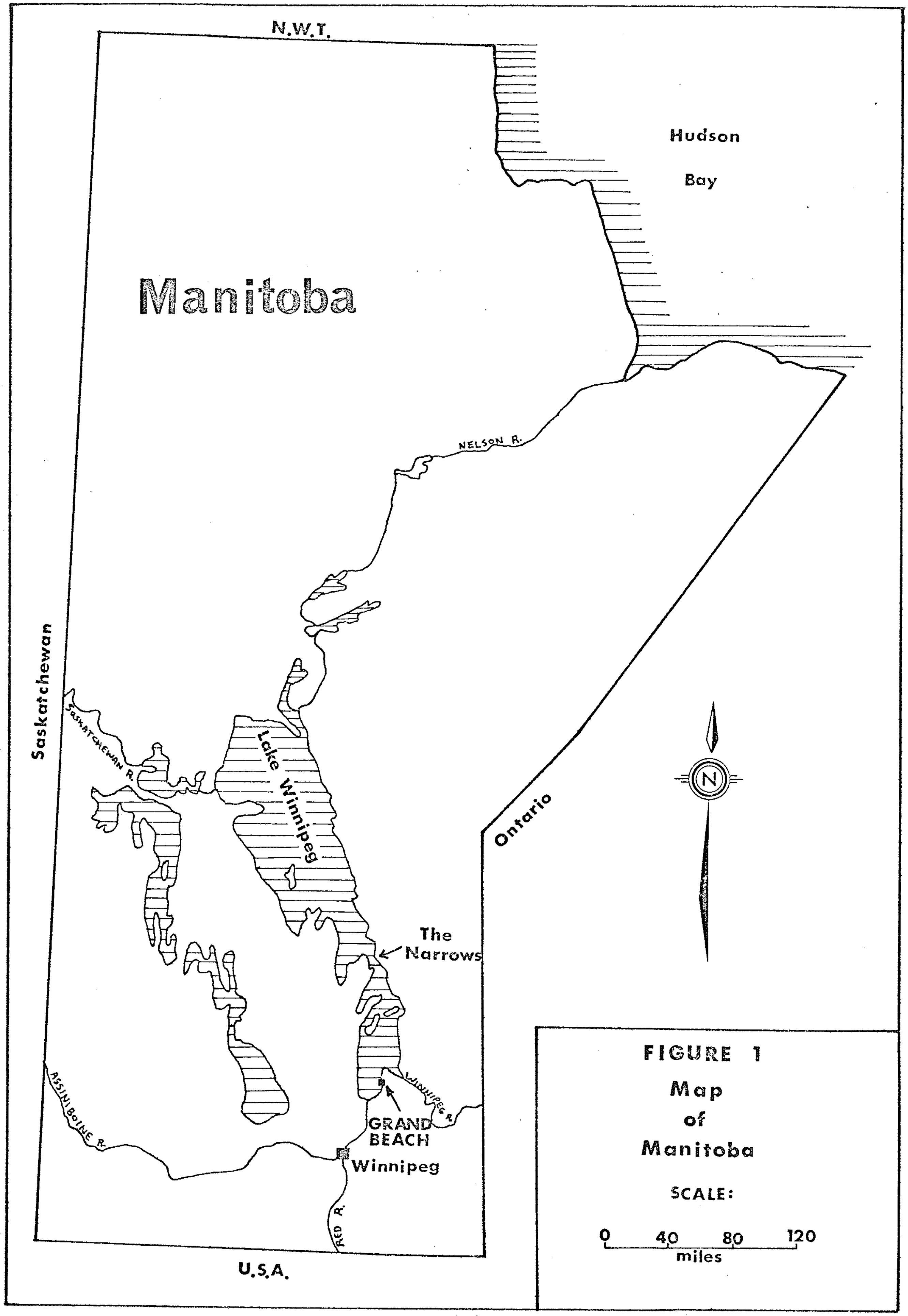

FIGURE 1

Map of Manitoba

SCALE:

0 40 80 120
miles

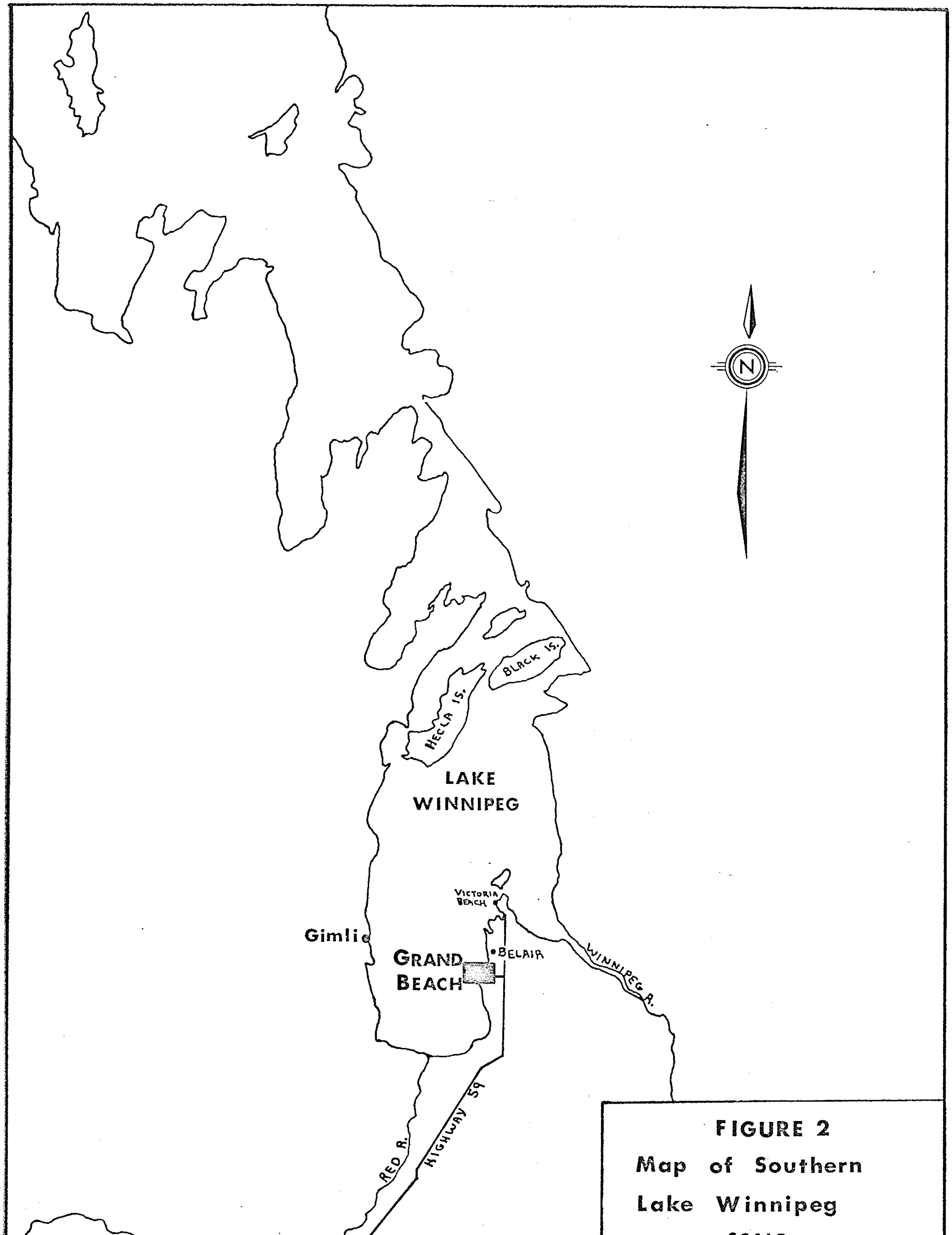

FIGURE 2
Map of Southern
Lake Winnipeg
SCALE:
1 inch = 20 miles

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

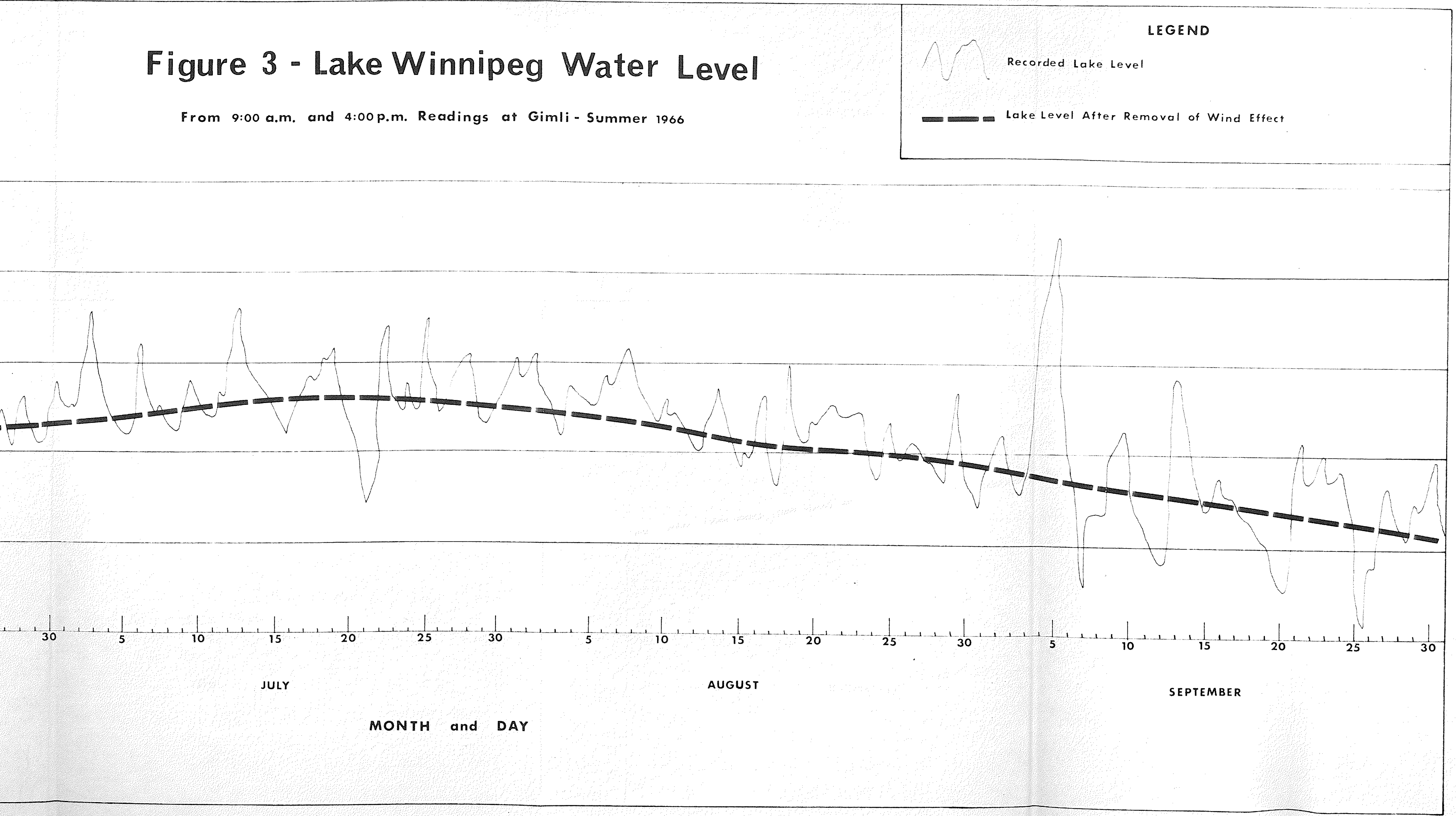

Figure 3

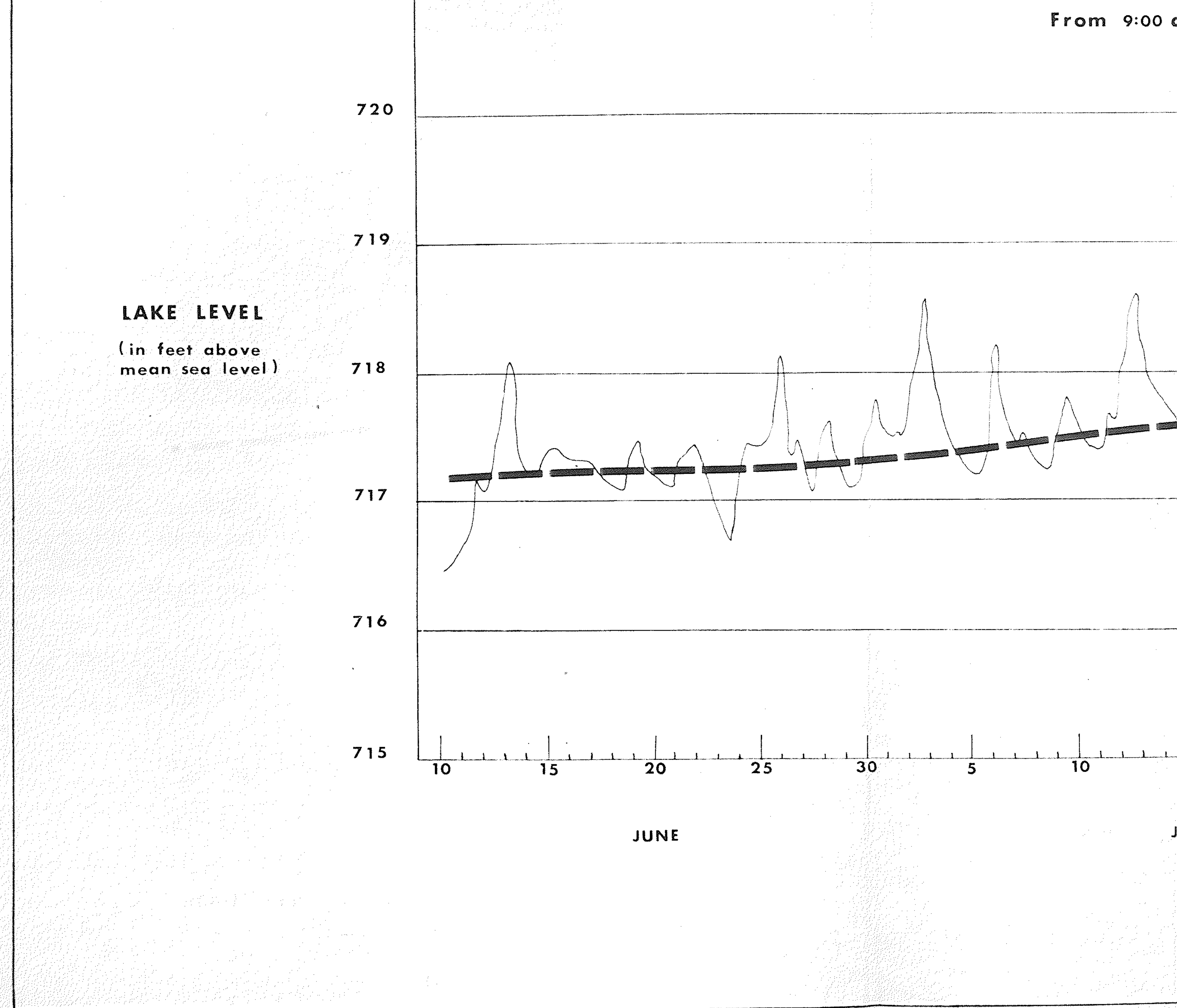
From 9:00 a
LAKE LEVEL
(in feet above mean sea level)
720
719
718
717
716
715
10
15
20
25
30
5
10
JUNE
J

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

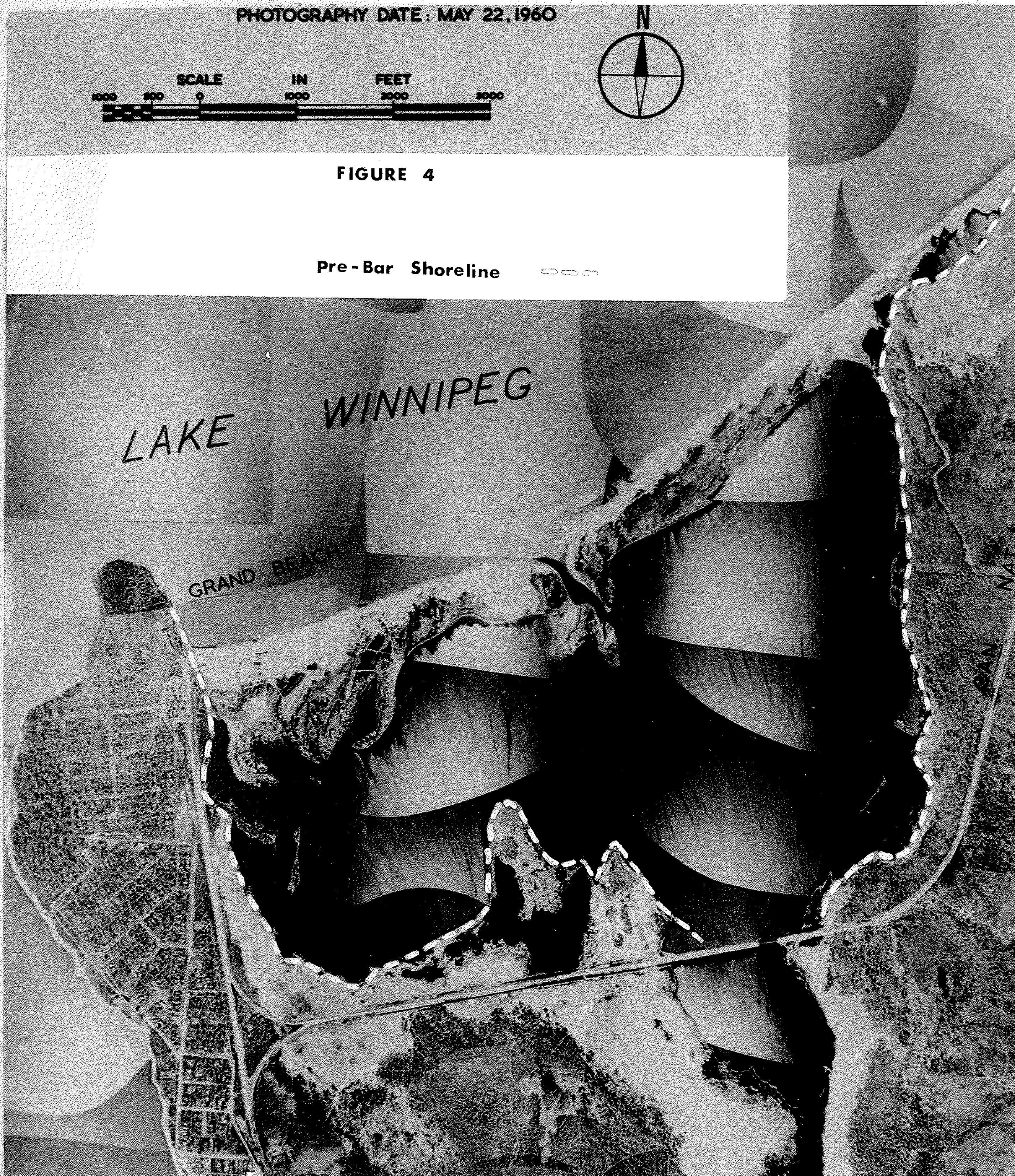
PHOTOGRAPHY DATE: MAY 22, 1960
N
SCALE IN FEET
1000 500 0 1000 2000 3000
Pre-Bar Shoreline
LAKE WINNIPEG
GRAND BEACH

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 9

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

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.

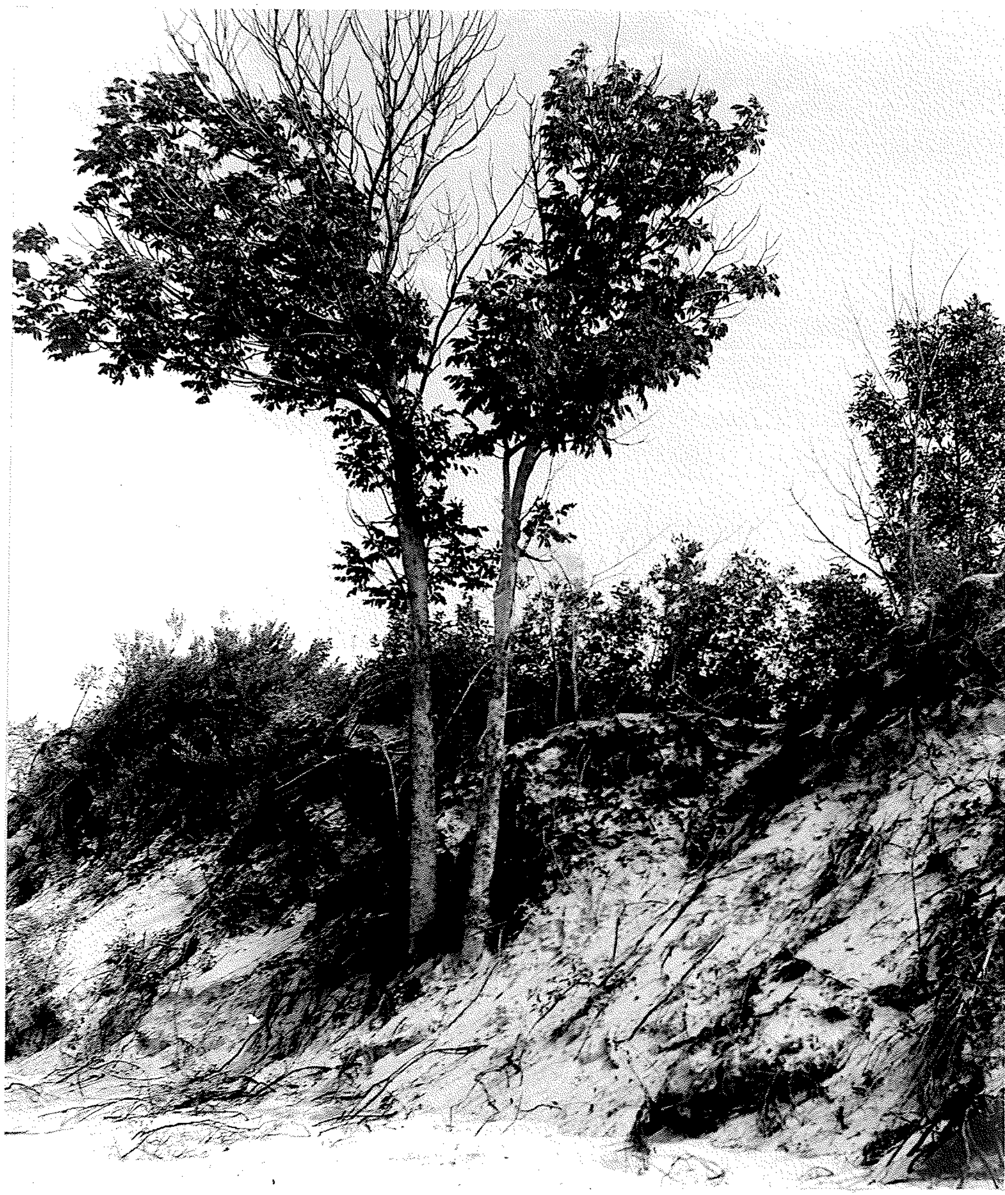

FIGURE 11

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

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 4.0∅, 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 4.0∅. 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 4.0∅ screen. Fractions retained on the screen were analyzed by sieving. Fractions finer than 4.0∅ 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: 4.5∅, 5.0∅, 5.5∅, 6.0∅, 7.0∅, 8.0∅, 9.0∅ and less than 9.0∅. 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 9∅), 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) Beach - 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) Aeolian - 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.