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# Time-Series Study of the Foreshore Zone in a Non-Tidal Environment

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# TIME-SERIES STUDY OF THE FORESHORE ZONE IN A NON-TIDAL ENVIRONMENT

by

Randall Thomas Kerhin

A Thesis
Submitted to the
Faculty of The Graduate College
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of the
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# INTRODUCTION

A 30-day time-series study of the non-tidal foreshore zone in southeastern Lake Michigan was conducted during the summer of 1970. The study was part of a more comprehensive program to study the processes of the beach and nearshore system (Fox and Davis, 1970a, 1970b, 1971; Davis and Fox, 1971). The study area is located two miles north of Holland, in Ottawa County, Michigan.

A time-series is a set of observations taken at a definite interval of time. The foreshore zone parameters, which include foreshore width, foreshore slope, net erosion and deposition, and collection of sediment samples were taken at 12-hour intervals. Various wave and weather parameters associated with the major program were measured at 2-hour intervals for the entire 30-day period.

The foreshore zone is an isolated segment of the beach and nearshore system, yet the importance of monitoring the foreshore zone lies in that this area marks the intersection of the ocean-land-atmosphere system. Two basic goals of the study are: to investigate and to determine the pattern of sedimentation and its relationships with the nearshore processes; and to determine the relationship of the nearshore processes with the foreshore geometry parameters, including width, slope, and net erosion and deposition. Supplemental objectives are the interaction of the foreshore parameters and the development of a process-response model. The use of statistical analysis aided the evaluation of the foreshore and wave and weather data.

# PREVIOUS WORK

A considerable amount of material has been published on the beach environment and processes. D. W. Johnson's (1919) classic textbook was the first to treat the beach environment in its entirety, from wave generation and theory to the response of the shoreline. Similar textbooks by Guilcher (1958), King (1959) and Zenkovich (1967) have introduced additional material about the beach environment. Such organizations as the Coastal Engineering Research Center, the Office of Naval Research, and the Coastal Studies Institute at Louisiana State University have promoted the study of the beach environment from both laboratory and field approaches.

The accessibility of the foreshore zone has permitted a sizable amount of research in this area. Most of the research has been conducted along the coastal seaboards in a tidal environment with very little attention given to the non-tidal environment. Lewis (1931) was one of the first observers to record the relationship between erosion and deposition and the varying swash conditions on a natural beach. More recent work has been conducted by Harrison and Krumbein (1964) and Harrison, and others (1968) on the beach environment at Virginia Beach, Virginia. They conducted a time-series study to investigate the process-response relationship in the land-ocean-atmosphere system. From this study, Harrison (1969) programmed a linear multiregression analysis to establish predictor equations for 1) net change of quantity of foreshore sands, 2) advance and retreat of the shoreline, and 3) mean slope of the foreshore. Dolan (1965) and Dolan, Ferm, and MacArthur (1969) studied a similar process-response relationship along the outer banks at Bodie Island, North Carolina. Preliminary results show that of the energy factors selected, wave height and still-water level are most significant whereas wave period and wave angle are least significant in predicting the beach geometry. Both the Virginia Beach and Bodie Island studies were conducted in a tidal environment. As of this date, the author is not aware of any similar process-response study conducted in a non-tidal environment.

Although, the process-response model of the foreshore zone has not been extensively investigated, certain aspects of the foreshore zone have been studied. One aspect receiving considerable attention in the laboratory and the field is the relationship between foreshore slope and grain size. Bascom (1951), through field observations on the California coast, established a positive relationship between grain size and foreshore slope. Many researchers have noted this relationship in the field and the laboratory. Hulsey (1962) and Coleman (1969) investigated this relationship along the eastern shore of Lake Michigan, and both concluded that the grain size-foreshore slope relationship was not evident in the beaches studied.

The importance of the groundwater table in the foreshore zone was first recognized by Bagnold (1940) in his wave tank experiments. Emery and Foster (1948) conducted field experiments on the relationship of beach characteristics and the changing groundwater table by measuring the beach permeability. Grant (1948) reported on the influence of the water table to an aggrading and degrading beach and on the velocity of the backwash. Recently, Duncan (1964) related the position of the water table to sediment distribution by swash-backwash erosion or deposition. He reported that for a low water table, swash erosion and deposition predominate whereas for a high water table, backwash erosion and deposition predominate.

Krumbein (1938) found that the sediment distribution of coarse to fine up the foreshore shows greater local variation than the distribution along the foreshore. Evans (1939) studied the transportation of sediment in the foreshore and concluded that the process of beach drift effects only the sediment with a grain size of 0.25mm to 0.60mm. Miller and Zeigler (1958) established a theoretical model for the sediment-size distribution of the foreshore and obtained similar results as Krumbein. Fox, Ladd, and Martin (1966) found finer grain size and better sorting with a decrease in energy up the foreshore near South Haven, Michigan.

Nagata (1961) used an electromagnetic-type current meter to measure the deformation pattern of orbital wave velocity in the foreshore. Schiffman (1965) obtained energy and sediment data across the swash-surf zone and defined a distinct depositional environment between the swash-surf zone; the transition zone. Strahler (1966) surveyed a series of profiles across the foreshore to determine the pattern of erosion and deposition in a single tidal cycle. He reported that with rising tides, a scour channel is produced with sediments transported onshore and offshore. Giese (1966, 1968) reported that the dynamic zone of erosion is the mid-swash area with sediments being transported to the plunge step or the foreshore reach (top). A second aspect of his research was a study of the shape sorting of pebbles to determine the effects of the amount of foreshore infiltration per wave on swash zone mechanics.

# TERMINOLOGY

A lack of standardized terms among coastal geologists enables the researcher to modify the terminology to fit the specific needs of his study. Terminology may be modified to include the geomorphic features or the energy condition of the environment, or it may be modified to depict a tidal or non-tidal environment. Four excellent references presenting coastal terminology are currently available (Weigel, 1953; King, 1959; Beach Erosion Board, 1961; Russell, 1969); however, the terminology used in this report has been modified to fit a non-tidal environment (Figure 1).

The coastal environment is comprised of two zones; the nearshore zone and the beach zone. The nearshore zone extends from the plunge step and includes the bar and trough topography, or low and ball topography as defined by Evans (1940). According to Davis and McGreary (1965), in southeastern Lake Michigan the offshore bars are continuous for many miles and the profiles are fairly constant with minor variations following storms. The same relationship of nearshore bars was found to exist in the area investigated.

The plunge step is a topographic feature with a distinct change in slope. The beach zone is the area between the plunge step and the wave-cut dune cliffs. Within the beach zone, the backshore zone and the foreshore zone are differentiated. The backshore zone is the upper extent of the beach zone which remains dry under normal wave activity and includes the berm. Hulsey (1962) attempted to differentiate the backshore zone into the mid-beach and back-beach

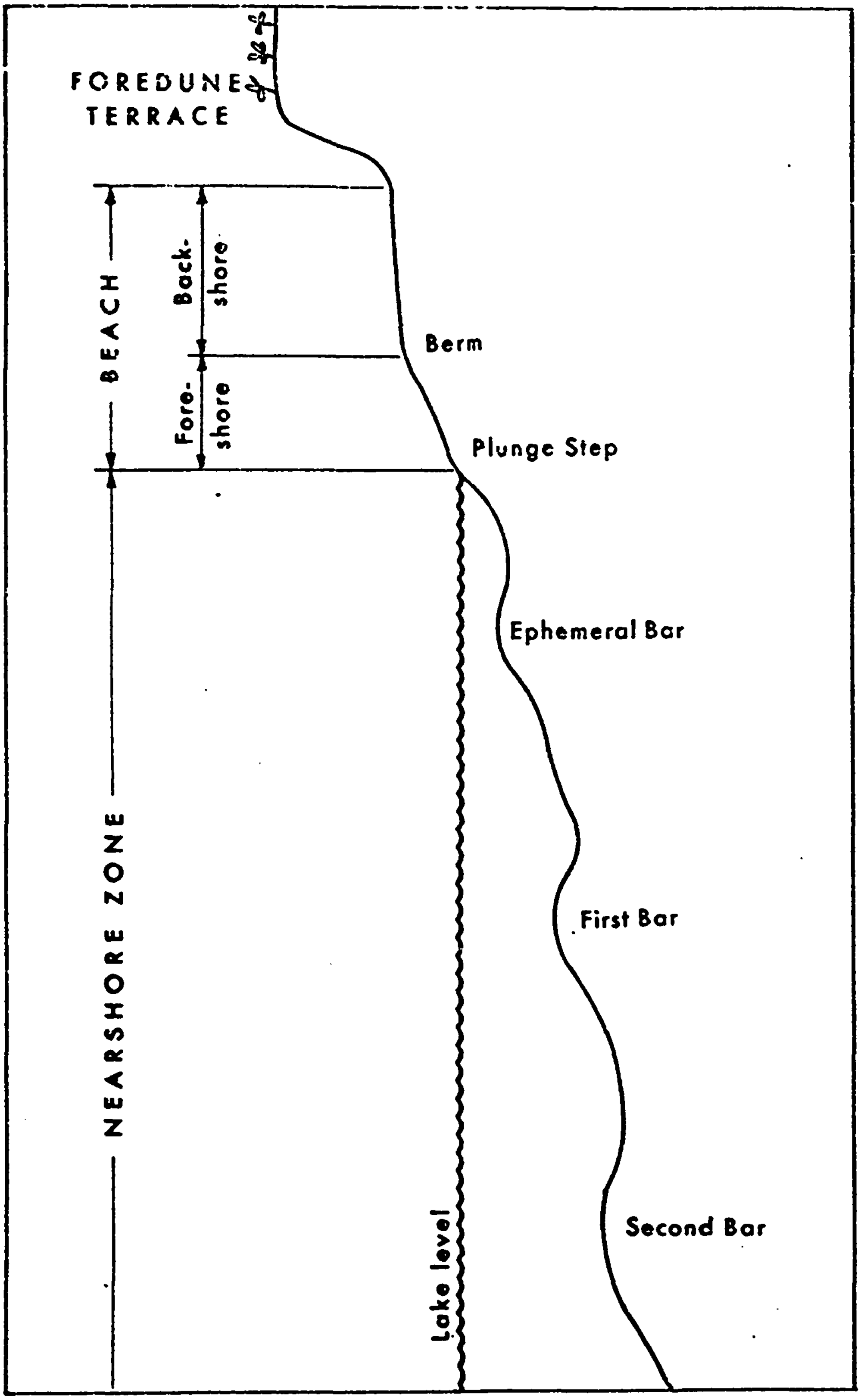


Figure 1. Terminology of coastal environment.

by differences in median grain size. He concluded, statistically, that no difference existed between the two zones. The foreshore zone is the area between the plunge step and the furthest wave runup under any given energy conditions. This means that the ratio of the foreshore width to the backshore width varies with the energy conditions. Under high energy conditions in eastern Lake Michigan, the foreshore width greatly exceeds the backshore width with the reverse holding true under low energy conditions. During two days of the study, the backshore did not exist, by definition, because the wave runup reached the wave-cut cliffs.

Ingle (1966) subdivided the beach environment into three dynamic zones; swash zone, surf zone, and breaker zone. The boundary between the surf zone and swash zone is the effective seaward limit of the backwash. Schiffman (1965) established a fourth zone between the surf zone and swash zone which he termed, the transition zone. The transition is that area where backwash collides with the leading edge of the surf zone and is characterized by high turbulence, bimodal sand-size distribution and a broad energy spectrum. Miller and Zeigler (1958) characterized this area as the breaker zone which includes the plunge step when present.

In a non-tidal environment, the transition zone of Schiffman (1965) or breaker zone of Miller and Zeigler (1958) is included in the foreshore zone. Under low energy conditions, the transition zone is not apparent. The effective seaward limit of the backwash is at the plunge step. Only under high energy conditions does a transition zone become apparent.

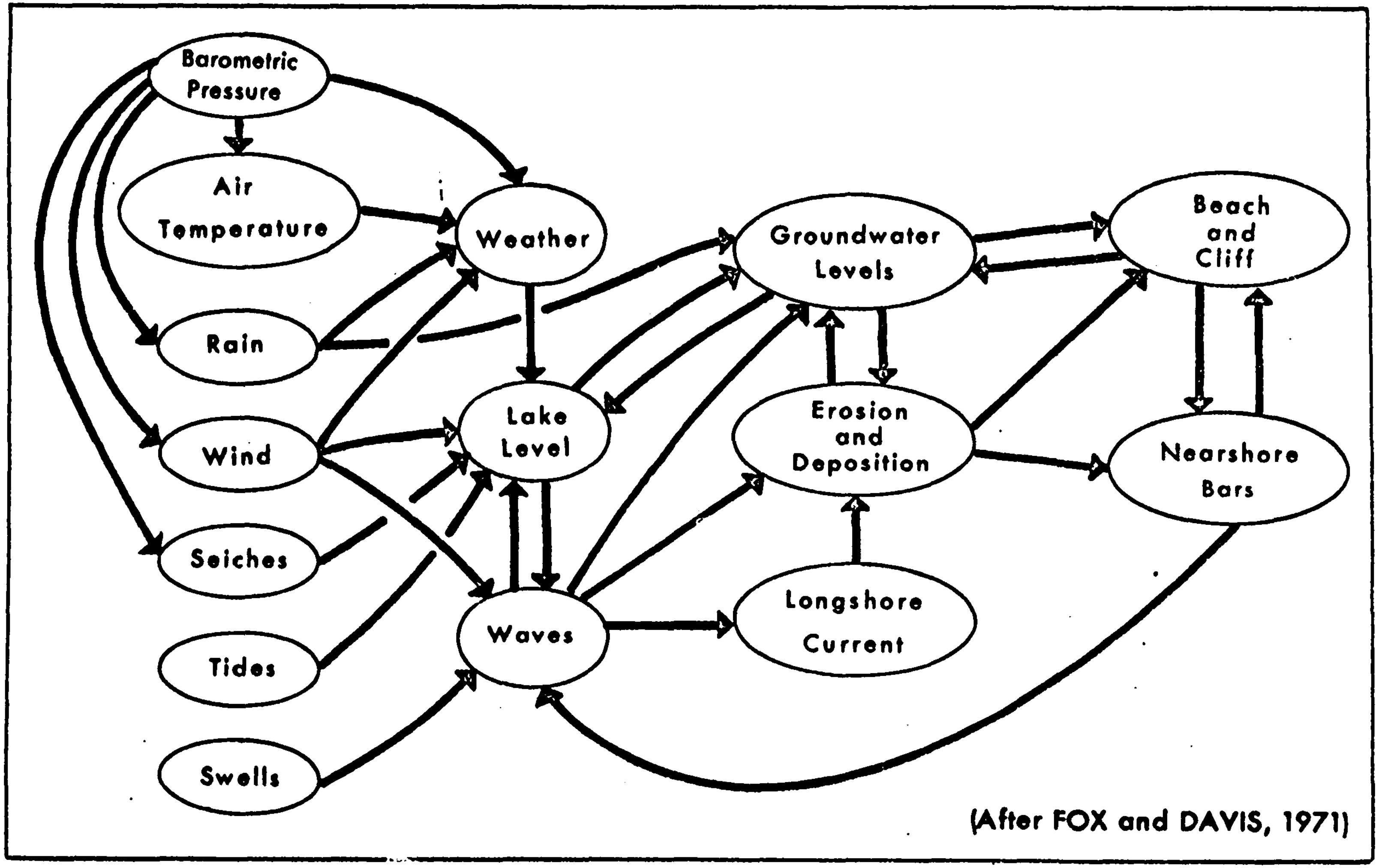
Through observational data an incoming wave train breaks in the nearshore zone. After reforming, the wave train "feels" the plunge step and begins to curl. Due to the high energy factor the wave may travel a considerable distance up the foreshore before actually plunging. This area of actual plunge will be designated as the inshore margin. At initiation of the backwash, the effective seaward limit is a function of the sequence of wave trains. If a secondary wave train is encountered (waves with shorter than average wave length), then the effective seaward limit of the backwash is at the inshore margin. With a sequence of wave trains at the average wave length, the effective seaward limit of the backwash is at the plunge step. The transition zone (Schiffman, 1965) varies with the energy conditions and patterns of the wave trains in a non-tidal environment. At best, it can be observationally differentiated. Although no actual energy profiles were attempted, high turbulence was indicated by the tremendous amount of sediment in suspension.

## Beach Processes

During the 30-day study period, 18 wave and weather parameters were measured at two-hour intervals beginning at 8:00 A. M. June 29th and continuing until 6:00 A. M. July 28th (Fox and Davis, 1971). From these 18 parameters, nine were selected as significant in the foreshore zone. The nine parameters are: 1) wind speed, 2) barometric pressure, 3) lake level, 4) groundwater level approximately 15 feet shoreward from the plunge step, 5) wave type, 6) breaker period, 7) breaker height, 8) angle of incidence of breaking wave, and 9) longshore current velocity. The true nature of the interaction among wave and weather parameters is not fully understood. Figure 2 shows a general pattern of the interaction among these parameters. Generally, barometric pressure initiates the conditions prevailing in the lake. One parameter showing partial independency from barometric pressure is lake level. Although, lake level is effected by the short duration of barometric pressure, the increase of precipitation over a long-term period raises the lake level, independent of barometric pressure. For a more complete discussion of the wave and weather parameters, the reader is referred to articles by Fox and Davis (1970a, 1970b, 1971).

## Foreshore Dynamics

Deep-water wave motion is oscillatory with small mass transport in the direction of wave propagation (Weigel, 1961). When waves enter the nearshore zone and reach a depth of one-half the wave length, they begin to "feel bottom". Waves start to slow down, decrease in length, and increase in height and steepness while the wave period is maintained. Wave motion transforms to translatory motion with an actual mass transport of water in the direction of propagation. When the wave height is approximately equal to the water depth, the wave breaks (Shepard, 1963). Under high energy conditions, waves break in the nearshore zone and after reforming, waves approach the foreshore zone and break at the plunge step. During low energy conditions, waves traverse the nearshore zone and initially break directly on the foreshore.



(After FOX and DAVIS, 1971)

Figure 2. Flow chart of nearshore processes.

As an incoming wave breaks, the uprush of water across the foreshore zone is known as the swash. The swash has lost the nature of wave motion and is propagated by inertia with initial movement as a continuous mass of water (Zenkovich, 1967). After reaching a certain position on the beach face, the swash divides into separate tongues as observed by formation of swash marks. There is a decrease in velocity and depth, a transformation from turbulent to laminar flow, and a conversion of kinetic to potential energy as the swash reaches termination (Zenkovich, 1967). The loss of energy is due to foreshore friction, slope of the foreshore, and volume lost due to infiltration.

After the swash reaches its limit, the backwash cycle begins and there is a reconversion of the potential energy of the swash to kinetic energy of the backwash. Backwash is a result of gravity and returns along the steepest foreshore gradient. Velocity is initially low with laminar flow prevailing. There is a gradual, then rapid acceleration of the backwash with an instantaneous change from backwash to swash (Schiffman, 1966). The magnitude of the backwash velocity is dependent on slope of the foreshore, volume of swash, volume lost due to infiltration, and addition of water rising from the effluent zone to the backwash (Schiffman, 1966). Grant (1948) also noted that when the backwash velocity is greater than (gravity x height of flow)$^{\frac{1}{2}}$, a hydraulic jump or roll wave results. If repeated in the same position on the foreshore, a small gravel-lined scour channel develops.

Minor sedimentary structures are also associated with the backwash cycle. The rapid acceleration near the termination of the backwash cycle causes upper flow regime structures, (antidunes) to form (Figure 3). Located on the lower foreshore, the antidunes are quickly erased by the next incoming swash. In the initial stage of the backwash cycle where lower flow regime conditions prevail, rhomboid ripple marks are formed. Demarest (1947) studied the formation of rhomboid ripple marks and stated that their formation, given a proper slope of 6 to 12 degrees, results from a thin sheet of water following the true backwash.

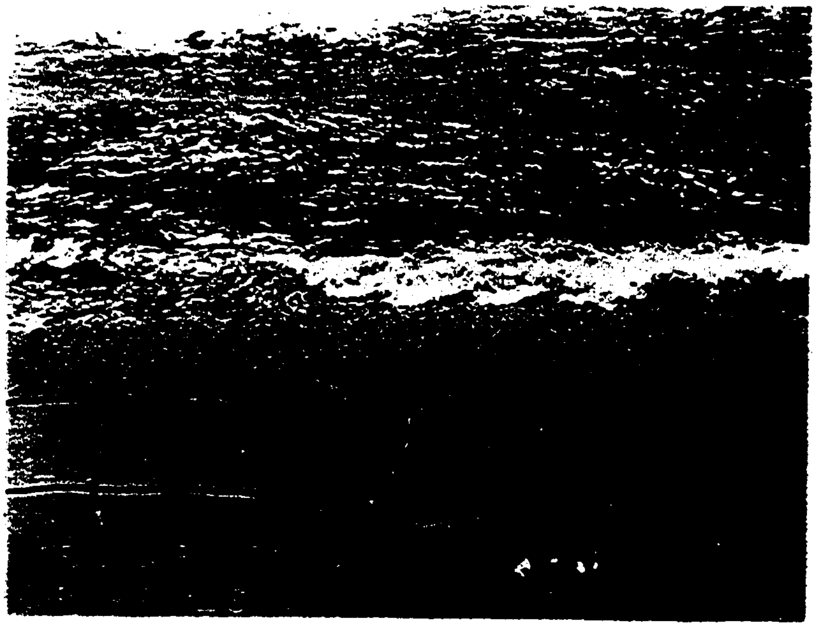


Figure 3 Minor sedimentary structures associated with backwash cycle.

## DESCRIPTION OF AREA

### Location

The area of investigation is located on the eastern shore of Lake Michigan, 2 miles north of Holland in Ottawa County, Michigan, Sec. 21, T. 5 N., R. 16 W. (Figure 4). Dunes border the general area with some to the south of the study area reaching heights of 150 feet.

### Pleistocene History

The coastal region on the western rim of the Michigan Basin has been greatly influenced by Pleistocene glaciation. The geomorphic form of the coast is a result of the advance and retreat of the glacial ice fronts, and erosion and redeposition of glacial drift by wave activity. Three distinct types of sediments were deposited either directly or indirectly by glacial activity: 1) lacustrine sands, 2) beach and dune sands, and 3) morainal sediments (Figure 5). Bedrock exposures are sparse in the area due to the erosive ability of the glacial ice fronts and the thick accumulation of the glacial drift (Hough, 1958).

The early Lake Michigan beaches in the study area are referred to as the Glenwood Stage. The Glenwood Stage recorded the highest strandline in eastern Michigan (640 feet above sea level) at approximately 11,000 to 14,000 y.b.p. (Flint, 1957). Well-developed shoreline features including sand and gravel beaches, spits and bars, and wave-cut terraces are representative of the Glenwood

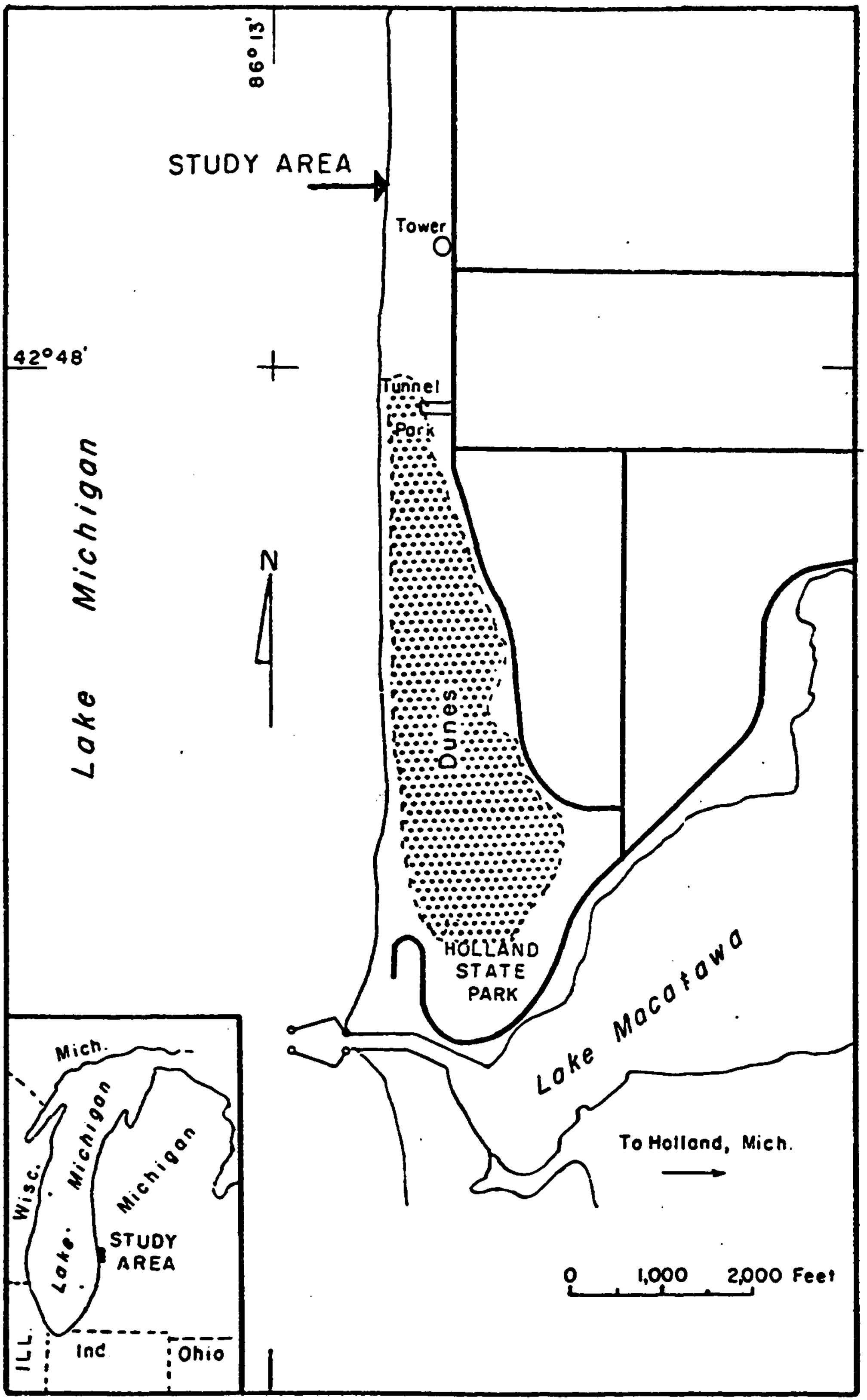


Figure 4. Index map of study area.

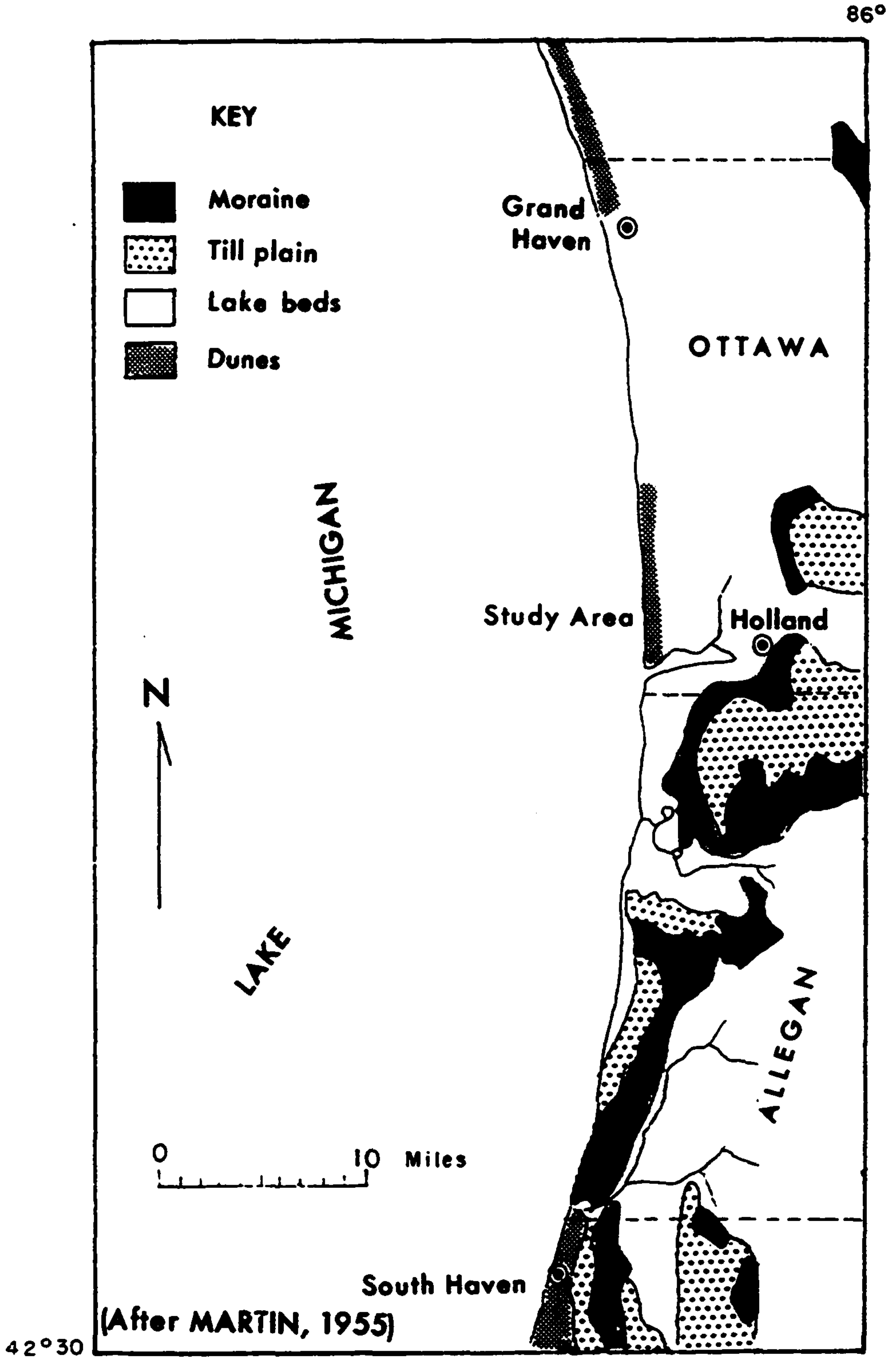


Figure 5. Surficial geology of western Michigan.

Stage (Hough, 1958). Pulsation of the Glenwood Stage, as recorded by three high-water phases, allowed wave activity to rework a wide zone of glacial deposits.

In addition to influencing the geomorphic form of the modern coastline, the influence of glaciation is reflected in the sediment size available for deposition on modern beaches. In southeastern Lake Michigan the Lake Border moraine is directly adjacent to the coastline (Figure 5). Beaches are primarily sand and gravel with local boulder fields in the nearshore environment. The beach near Pier Cove, Michigan is typical of this type of sediment size distribution. Davis (1970), theorized a bottom profile for the beach environment which shows the effect of the glacial drift.

Near the area of investigation, the Lake Border moraine is approximately 15 to 25 miles from shore and lacustrine, dune, and beach deposits occur between the moraine and the shoreline. Modern beach sediments are mainly sand-sized. Gravel is deposited with sand during high energy conditions, but not in sufficient amounts to produce a bimodal distribution. The primary source of sediments is the easily erodable beach, dune, and lacustrine sands of the glacial high-water phases. The morainal deposits are not a direct source of sediment. Rivers which enter Lake Michigan do not add a significant amount of sediment to the beach environment (Hough, 1935).

## Modern Coastal Environment

Three primary factors control the formation and configuration of the beach environment: geomorphology of the adjacent land, quantity and type of material, and physical lake conditions. In the previous section, the relationship of Pleistocene history to the first two factors was explained. This relationship is dependent on long-term geologic circumstances. The last factor, physical lake conditions, is dependent on long-term and short-term variations, namely seasonal and daily variations.

The shoreline maintained a north-south orientation with a beach width of 25 to 30 feet during the study period (Figure 6). The landward boundary of the beach zone is marked by three to four foot high wave-cut cliffs in the dunes. The dunes are stabilized as a result of vegetation, but south of the study area near Tunnel Park (Figure 4), the dunes contain blowout features. Dunes are not unique to the study area. The entire eastern shore of Lake Michigan is noted for massive dunes. The primary causes are the prominent westerly wind direction across Lake Michigan and the abundant sediment supply.

Type and quantity of beach material is dependent upon the Pleistocene history of the area as discussed in the previous section. The sediment distribution is unimodal and the average grain size ranges from fine to coarse sand. The sediments are well-sorted according to Folk's (1968) terminology and have sorting values of approximately 0.50 phi units. The grains are subangular to rounded. Compositionally, the sands are dominated by quartz and contain minor amounts of carbonate, feldspar, and rock fragments. Heavy minerals, garnet and magnetite also occur in small percentages (Hulsey, 1962). Selective sorting by wave action causes surface concentrations of

Figure 6. Shoreline configuration of study area.

heavy minerals on days following considerable erosion. These lag concentrations of heavy minerals usually occur along bands at the upper extent of the foreshore.

According to Weigel (1964) the quantity of beach material added to the environment is dependent on the contribution by rivers and by direct erosion of the adjacent land. The contribution of sand to Lake Michigan beaches by rivers is not significant. Direct erosion of the adjacent land is a function of the long-term and short-term variations in physical lake conditions. The extent of direct erosion on Lake Michigan shores accelerated greatly during the past three years. The main reason for this acceleration was the rise in the lake level since 1964 (Figure 7). The actual quantity of material added to beach environment by direct erosion is not known.

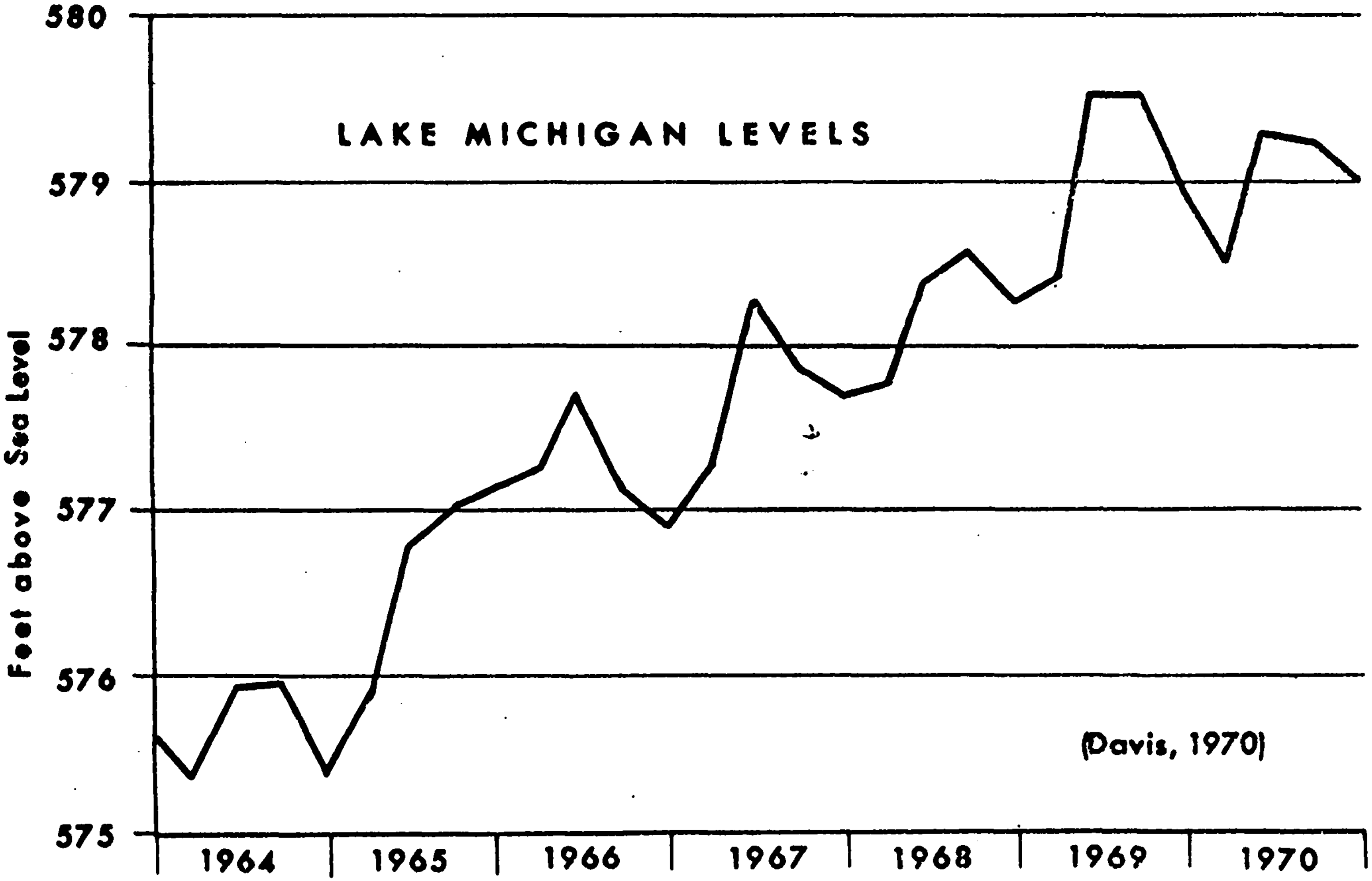


Figure 7. Level of Lake Michigan from 1964 to 1970.

Once the configuration and formation of the beach is developed, the beach environment is subject to physical lake conditions. As shown by the flow chart of beach processes (Figure 2), the controlling factor is barometric pressure. As a low pressure system is developing offshore the barometric pressure starts to fall. In a low-pressure system, the wind circulation is in a counterclockwise rotation. As the low pressure system approaches, the wind direction and subsequent breaker angle is out of the southwest and the longshore current direction is to the north. With the passage of the low pressure system, barometric pressure is lowest and begins to rise. The wind direction shifts around to the northwest and there is a subsequent shift in the breaker angle. The longshore current direction is then to the south (Fox and Davis, 1970b; 1971).

Barometric pressure only initiates the formation of the beach processes. The actual development of the wave parameters is a combination of wind velocity, duration of the wind at that velocity, and fetch. With the wind direction from the northwest, breaker height and longshore current velocity reach a greater magnitude than when the wind direction is from the southwest. For the study area (Figure 4), the fetch is greater to the northwest. Fourier analyses at Stevensville, Michigan and the present study area (Fox and Davis, 1970a) indicate that falling and rising stages of barometric pressure have a greater influence on the wave parameters than the high and low points. A 6-12 hour lag time occurs between changes in barometric pressure and wave parameters. The lag reflects the time required for the wind direction to shift and generate waves in the new direction.

Coastal currents of Lake Michigan are much the same as those described by Shepard and Inman (1951). The coastal current which flows parallel to shore and constitutes a uniform drift develops a counterclockwise eddy system (Hough, 1958). The dominant cause seems to be westerly wind direction coupled with a low pressure system passing over the lake. The second current system is the nearshore system which is divided into three parts: 1) mass transport of water by wave activity, 2) longshore current, and 3) rip currents. The mass transport of water and resultant longshore current direction is a function of the breaker angle which is related to wind direction and barometric pressure. Accordingly, longshore current reverses direction with each new approaching low pressure system. The net sediment transport which reflects the dominant longshore current direction in the study area is to the south. Hulsey (1962) reported net sand movement to the north, however, Hands (1970) concluded a southerly net transport direction. The author tends to agree with Hands for two reasons: 1) greater magnitude of the longshore current velocity to the south, and 2) buildup of sediments on the northside of Lake Macatawa Harbor entrance (Figure 4). No actual measurements of net sand transport were taken during the study period.

# EXPERIMENTAL TECHNIQUES

## Field Methods

In order to evaluate the interaction of the process-response model in nature, a time-series of field observations was conducted. Foreshore measurements taken at 12-hour intervals included amount of erosion and deposition, foreshore width, and foreshore slope. Surface samples were also collected.

Three profile locations at 50 foot spacings were selected with each profile having six permanent elevation stakes at 5 foot intervals (Figure 8). The stakes were $\frac{1}{4}$ inch diameter plastic rods cut to one-foot lengths and fastened with epoxy to the top of 12-ounce cans. The stakes were placed at the top of the plunge step on the initial day of the study (June 29) and surveyed with respect to a control point, the lake level monitoring pipe (Figure 9). The height of each permanent stake above the foreshore surface was measured to determine the amount of erosion or deposition for each 12-hour period. Accuracy of the measurement was to the nearest 0.05 feet. The amount of erosion or deposition was determined by the difference between the stake heights of two observation periods.

Two problems were encountered during the study which may have contributed to errors in measuring. One was the removal of stakes during extensive erosion of the foreshore. When this occurred the stake was replaced and resurveyed. Difficulties were also encountered in measuring the stakes when a high backwash velocity

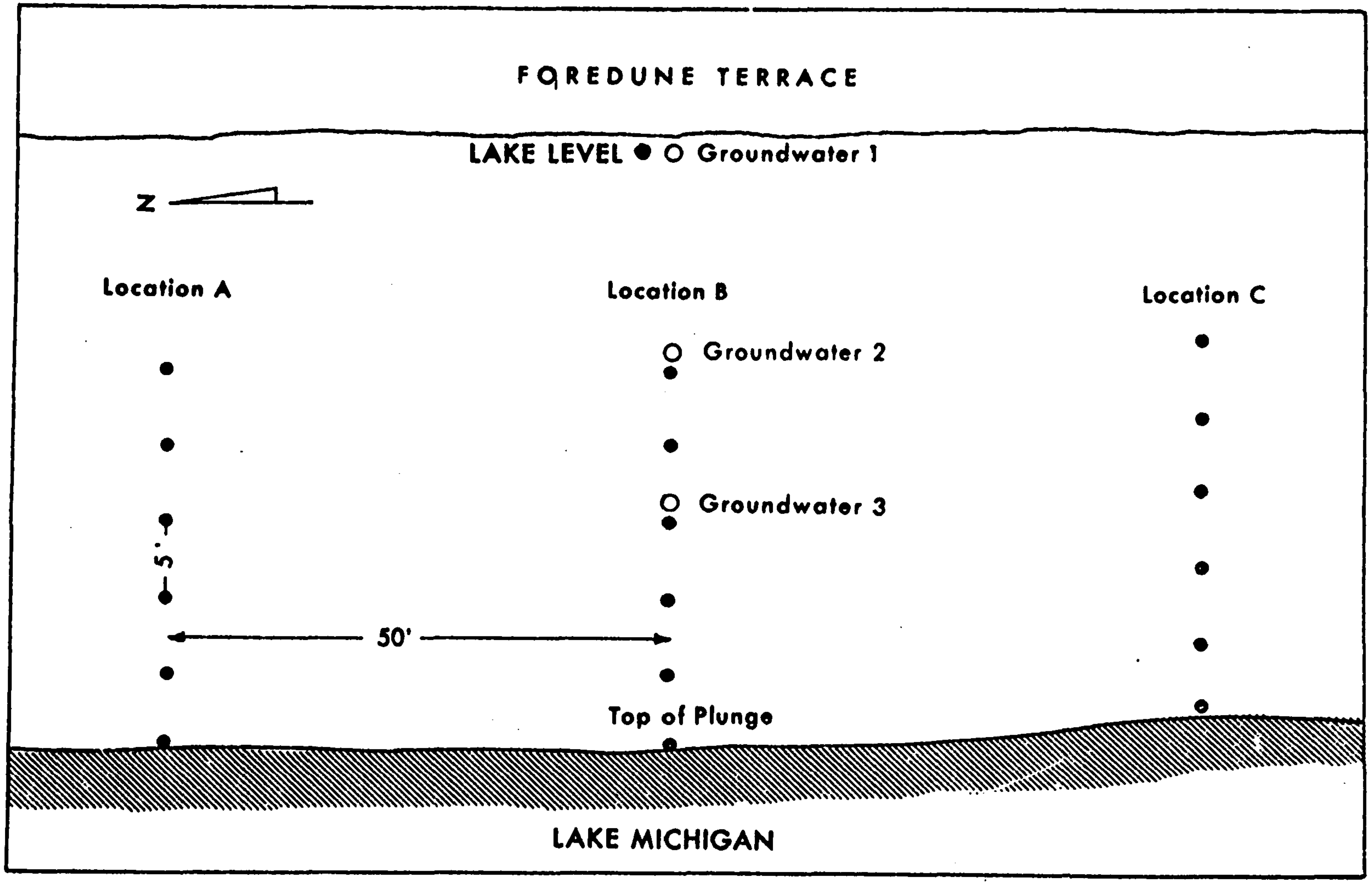


Figure 8. Areal distribution of profile locations and stakes.

Figure 9. Profile location B showing six permanent elevation stakes (white) and groundwater level monitoring pipe (center).

and resulting instability of the foreshore surface was present. Measurements taken after the backwash cycle permitted reduction of this error.

The slope of the foreshore was determined independently of the foreshore profiles by use of an inclinometer and a beveled board. The board was placed near the upper extent of the foreshore zone and parallel to the flow of the backwash. Three readings were taken with the mean value recorded to the nearest degree.

By definition the foreshore zone is the area between the top of the plunge to the furthest extent of the wave runup. The greatest traverse of ten consecutive wave runups was marked and the distance from the top of the plunge step to the furthest extent was recorded and considered the swash width.

## Sand sample collection

A systematic sampling program was designed to evaluate the areal variation of textural parameters. Samples were collected at the plunge step, the mid-foreshore, and the upper-foreshore at each profile location. Sample positions were a function of the foreshore width and were spatially noncontrolled (Anan, 1969). Random sampling with respect to the parent population was assumed from the changing of the sampling locations. The characteristics of the samples showed no visible systematic variations from the characteristics of the deposit at the sampling locations, thus assuring random sampling (Krumbein and Pettijohn, 1938).

The sampling design was a stratified sampling technique (Griffith, 1967). An Otto microsplitter tray allowed collection of the upper few millimeters of sediment, presumably the upper sedimentation unit. Samples were collected after the backwash cycle to allow any sediment in transport to be deposited. High turbulence at the plunge step hindered the collection of the plunge step sample during high energy conditions. Samples were placed in plastic sampling bags and recorded with the following identification.

701 - 2A1
Sample location
Profile location
Time
Date

Time refers to the first or second observation period during a particular day. The measurement times were 8:00 A. M. and 8:00 P. M. Profile locations were designated as to geographic location A, B, or C (Figure 8). Sample location indicates the location of the sample relative to the nearest stake. For example, sample numbers 2A1, 2A3, and 2A5 indicate that the plunge step sample was collected at stake 1, the mid-foreshore sample at stake 3, and the upper foreshore sample at stake 5.

Any sampling error introduced in the results of the textural analysis parameters can be attributed to operator error and sampling program design. Sampling bias may also be introduced in that the thickness of the sediment collected may not represent the true thickness of sediment under swash activity at that time. No efforts were made to evaluate the effects of the sampling error.

## Laboratory Methods

All samples were ovendried and initially split with a riffle splitter to allow for presence of gravel-size particles. If a gravel-size fraction existed, the sample was split to 20 grams and then hand-sieved to separate the gravel and sand fractions. The fraction retained on the -1.00 phi sieve was cataloged for later analysis. The sand-size fraction was reweighed to insure a 15-20 gram quantity. Sediments lacking any gravel-size grains were transferred to a microsplitter and split to a 15-20 gram fraction.

The prepared sample was analyzed by a Benthos Model 3410 Rapid Sediment Analyzer (Figure 10). The Benthos RSA is patterned after the Woods Hole Sediment Analyzer (Zeigler, Whitney, and

Hayes, 1960). The RSA is designed to process large numbers of samples and analyze them according to natural conditions. The measurement of the grains is by a pressure differential between two columns of water having a common hydraulic head. The change caused by the introduction of the sediment within one of the columns is measured by a water pressure transducer with the output fed to a Hewlett-Packard X-Y recorder. The size distribution analysis is based on the density, angularity, and volume (Schlee, 1966).

Each 15-20 gram sample was split into equal portions to permit at least two size analyses per sample. The sample was placed on the introduction gate of the RSA and moistened to prevent any premature falling of the grains. The introduction gate was then inverted onto the water column. A microswitch in the introduction gate activates the X-Y recorder and the time base sweep at a rate of 2 sec/cm. The curve produced on the X-Y recorder displayed pressure versus fall time which can be interpreted by fall-rate particle-size tables (Figure 11).

The curves were interpolated through the initial water disturbances and represent a 100% frequency curve. The 16, 50, and 84 percentiles were located on the curve by the use of a Gerber variable scale which selects 100 equal divisions of a line at one setting. Reading the phi units from the curves was facilated by the use of a size-time overlay. The overlay used was patterned after that devised by Schlee (1966) which is calibrated in terms of the Wentworth scale from corrected fall times. The overlay was made of transparent plastic sheet with vertical lines corresponding to

Figure 10. Benthos Rapid Sediment Analyzer

the fall times. The overlay was placed over the size distribution curve with the zero point of the overlay coinciding with the point of instant sediment introduction. The 16,50, and 84 percentiles were read and recorded in phi units. Using Schlee (1966) fall times, Swift and Sanford (1970) compared grain size distribution by means of a Benthos Rapid Sediment Analyzer and sieving. Their report showed that the RSA overestimates the mean diameter of fine samples and underestimates the diameter of coarse samples relative to sieving and that Schlee's (1966) overlay overcompensates for acceleration due to grain interaction. Therefore, Swift and Sanford (1970) modified the fall times to fit the Benthos Rapid Sediment Analyzer. This modification of the fall times is applicable to experimentation where absolute values of the textural

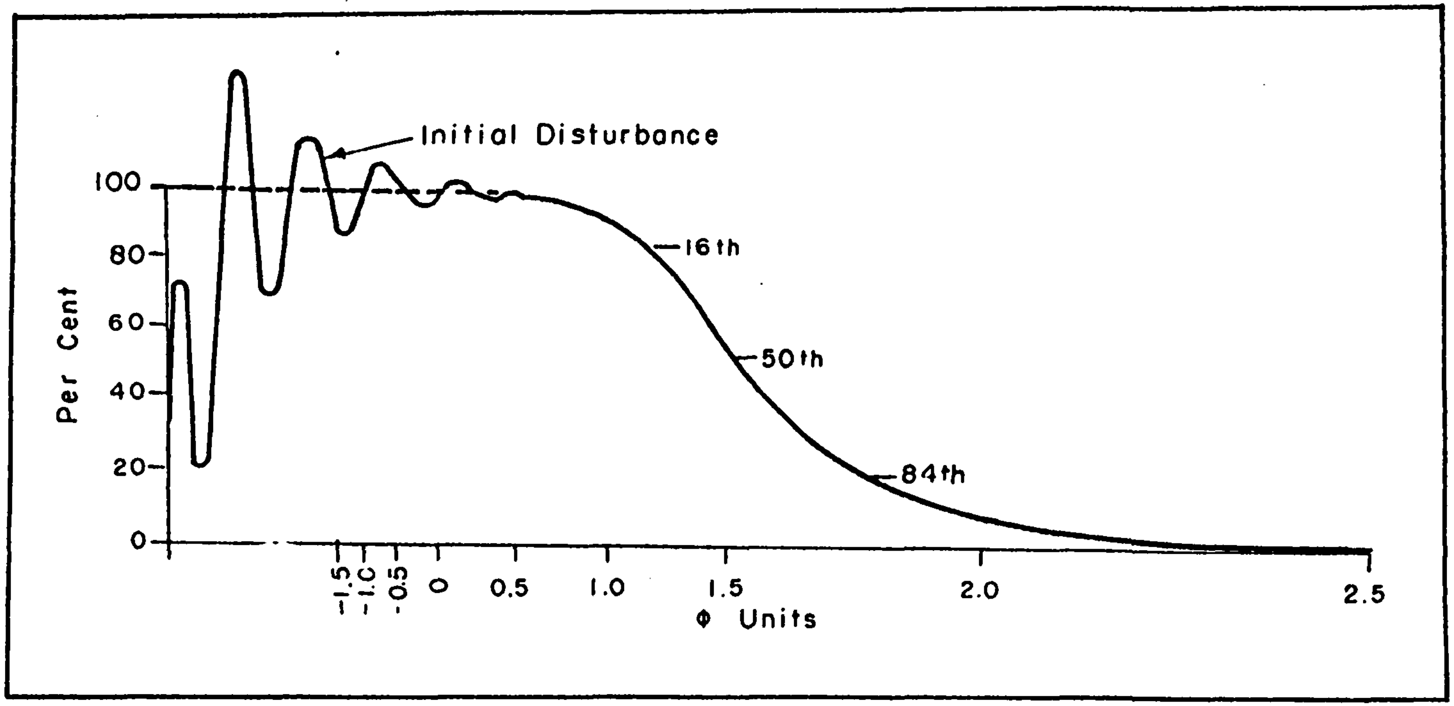


Figure 11. Size distribution curve produced by the RSA.

parameters is desired. The absolute values of the textural parameters in this study are not as critical as is the reproducability of the parameters. Thus, the textural parameters obtained by the use of Schlee's (1966) overlay are acceptable. Reproduction of the curves was excellent.

Due to sensitivity of the water pressure transducer, any background noise entering the laboratory was recorded on the X-Y recorder. When this occurred, the analysis was disregarded and a new sample was prepared. Operation time was 3-4 minutes for preparation and analysis of a sample and 1-2 minutes for interpretation of the curve in phi units.

The sediment fraction greater than -1.00 phi was hand sieved at $\frac{1}{4}$ phi intervals. Raw weights of the samples were measured on an Ainsworth Right-a-Scale to the nearest 0.001 gram. The size fraction retained on each sieve was weighed and recorded.

### Computation of textural parameters

A Fortran IV program was written to calculate the grain size parameters from the 16,50, and 84 percentiles (Appendix C). The percentiles were keypunched on an IBM 029 keypunch and analyzed on a PDP-10 computer. The graphic method as illustrated by Folk and Ward (1957) was selected as the procedure of calculating the grain size parameters. The graphic method measures the central portion (68%) of a normal distribution curve. The selection of this method is based on the assumption that any significant relationship between physical lake conditions and grain size parameters would be evident in the central portion of the curve. McCammon (1962) discussed the efficiency of the graphic method of determining mean size and sorting. His results show that the graphic mean is evaluated at 88% efficient and graphic standard deviation at 54% efficient. Thus, efficiency improves as more of the tail of the sample is taken into account.

The grain size parameters computed were the graphic mean, the graphic standard deviation and the graphic skewness (Folk, 1968):

1) $$\text{Graphic Mean} = \frac{\phi 16 + \phi 50 + \phi 84}{3}$$

2) $$\text{Graphic Standard Deviation} = \frac{\phi 84 - \phi 16}{2}$$

3) $$\text{Graphic Skewness} = \frac{\phi 16 + \phi 84 - 2\phi 50}{(\phi 84 - \phi 16)}$$

A Fortran IV program was written to calculate the average of the two sets of values obtained for each sample. Appendix B lists the grain-size parameters after this final averaging calculation.

Analysis of samples by two different methods (sieving and settling tube) poses difficulties in obtaining the actual grain-size parameters. No effort was made in this study to combine the results of the two analyses into a single grain-size distribution.

## Net erosion and deposition

Net erosion and deposition were determined from longitudinal profile plots of the foreshore zone. The profiles were drawn on a 1:2 scale for two consecutive observation periods. The profiles were superimposed with the area between the profiles determined by a planimeter. King (1966) defines the area between superimposed profiles as the sweep zone. King also stated that a narrow sweep zone indicates stable state of equilibrium under the temporary wave conditions whereas a wide sweep zone indicates an unstable state of equilibrium (Figure 12). This definition will be used to determine the state of equilibrium of the foreshore zone under any given wave condition.

A total of 13 foreshore parameters were obtained from field and laboratory research. The parameters include mean grain size, sorting, and skewness of the plunge step, mid-foreshore, and upper-foreshore sediments. Also included are foreshore slope, foreshore width, net erosion and deposition, and migration of plunge step.

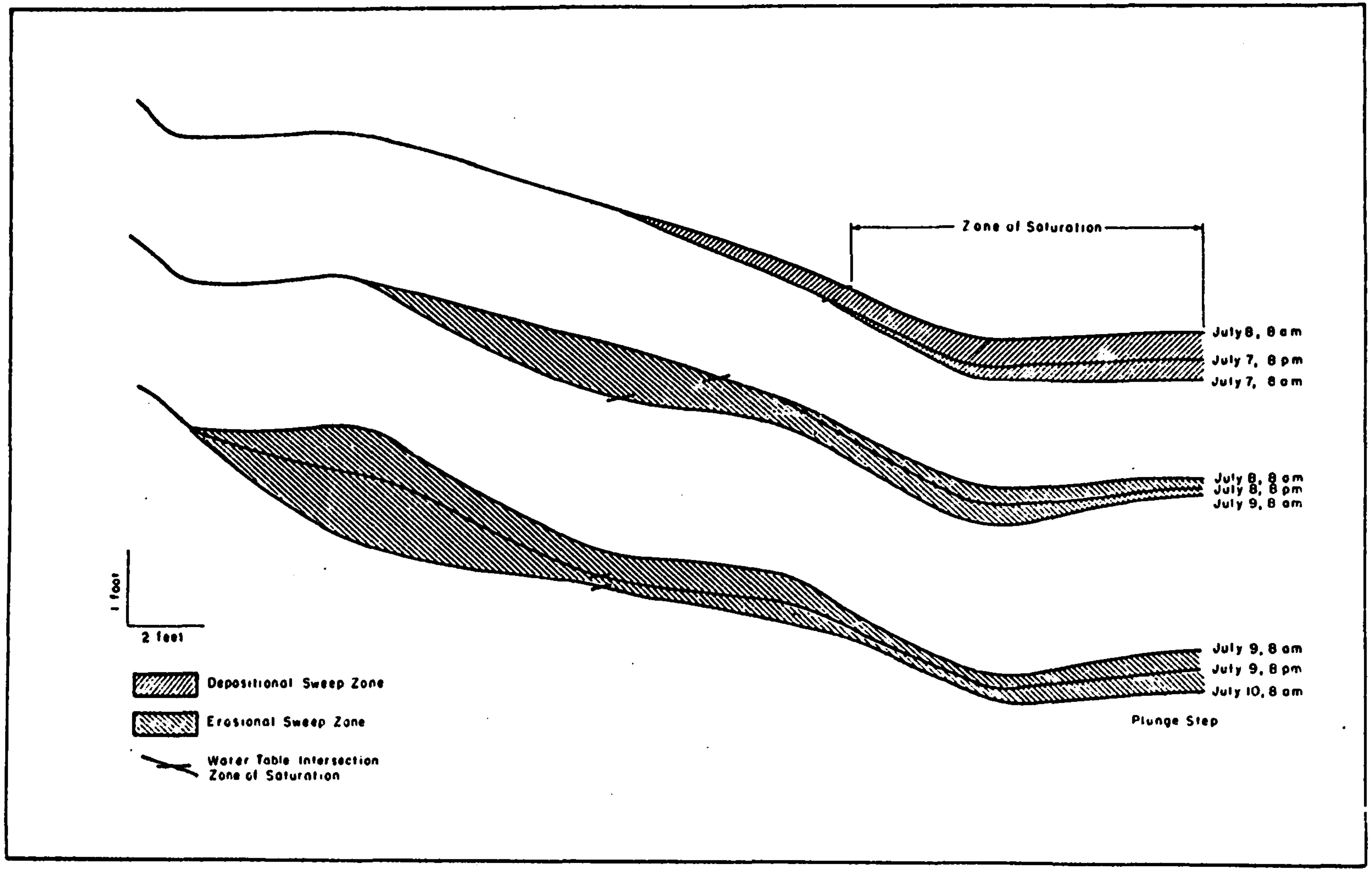


Figure 12. Superimposed longitudinal profiles for depositional and erosional conditions at profile location B.

## ANALYSIS OF OBSERVATIONAL DATA

Evaluations of quantitative data can only be expressed by the use of statistical analysis. Statistical techniques must be so designed as to answer certain questions posed by the experiment. The questions to be answered by the statistical analysis of this study are:

1) Is there any significant variation between the response measurements made on the adjacent profile locations or can the measurements be combined into a single measurement?

2) To what degree are the process parameters interrelated and to what degree are the response parameters interrelated? Is there any significant correlation between the process and response parameters?

3) Can a combination of process parameters better explain the variation of the response parameters and in what order of significance?

The processes and responses show a linear relationship and there is no reason to assume a non-linear relationship. Scattergrams of a selected process variable and certain response measurements show that although dispersion occurs, a linear relationship seems to be present (Figure 13).

In the evaluation of these complex variables, the manipulations chosen were the analysis of variance, linear correlation, and linear stepwise regression. The analysis of variance (Library Program #1.91), linear correlation (Library Program #1.21), and linear stepwise regression (Library Program #1.81) were written by the staff of the Computer Center, Western Michigan University and computed on a PDP-10 computer.

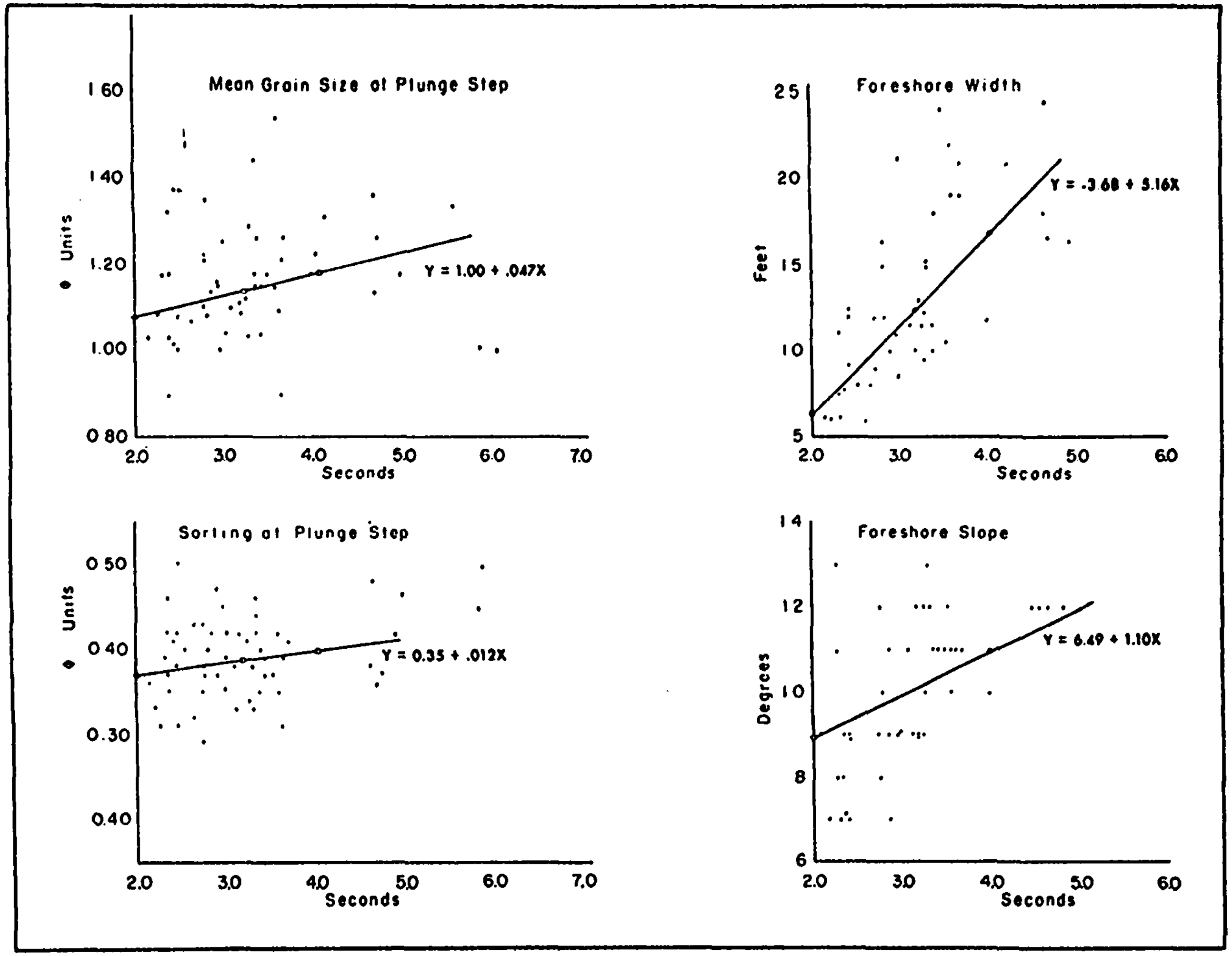


Figure 13. Scattergrams of wave period with four selected foreshore parameters.

## Analysis of Variance

The analysis of variance is a two-way classification, random effects model with no replications. The factors of variation are profile location, observation time, and interaction of profile location and time. The computations involved determining the sum of squares (s.s.) of the deviations of the observations minus the arithmetic mean ( $(x-\bar{x})^2$), degrees of freedom or number of observations minus one (N-1). and mean square or variance ($\sigma^2$) which is defined as the sum of square divided by the degree of freedom ( $\frac{(x-\bar{x})^2}{N-1}$). Table 1 shows the F-ratio and variance components associated with the data of the mean grain size at the plunge step. Where T is observational time, L is profile location and TL is the residual factor.

TABLE 1

ANALYSIS OF VARIANCE FOR MEAN GRAIN SIZE OF PLUNGE STEP

| SOURCE | SUM OF SQUARES | DEGREE OF FREEDOM | MEAN SQUARE | F-RATIO | VARIANCE COMPONENTS |
|---|---|---|---|---|---|
| T | 2.656 | 58 | 0.045 | 2.789 $(\sigma_T^2/\sigma_{TL}^2)$ | 37.4 $(\sigma^2+(N-1)_T\sigma_T^2)$ |
| L | 0.028 | 2 | 0.014 | 0.862 $(\sigma_L^2/\sigma_{TL}^2)$ | 0.0 $(\sigma^2+(N-1)_L\sigma_L^2)$ |
| TL | 1.904 | 116 | 0.016 |  | 62.6 $(\sigma^2)$ |
| TOTAL | 4.588 | 176 |  |  |  |

The F-ratio was selected at alpha equal to 0.05 to determine if significant variation existed between profile location and observation time. The variance component is expressed as a percentage of variation associated with each factor (Krumbein and Miller, 1953).

The analysis of variance for the 13 foreshore parameters measured shows no significant variation when the profiles are treated collectively. Thus variation between locations along the beach is of little significance when compared to the variation from measurement period to measurement period. Similar results were reported by Krumbein (1961) and Dolan (1965). This analysis enabled the foreshore measurements at each profile location to be combined into a single set of measurements per 12-hour period.

Each foreshore parameter entered the analysis of variance and the source of variation of each parameter was investigated. Two interesting variations resulted from this analysis. The mean grain size of the mid-foreshore and upper-foreshore samples showed no significant variation as to profile location or time suggesting that the source of variation is contributed by factors not taken into consideration. The residual (TL) component of variance for the mid-foreshore and upper-foreshore samples is 99% and 89%, respectively. In conclusion, the variability of these two parameters must be accounted for by some source other than profile location or time. Perhaps physical lake conditions, swash zone dynamics, or bias in sampling design are responsible.

Sorting values obtained from the mid-foreshore samples do show significant variation as to profile location and time. The profile location component of variance (M) accounts for only 2% of the total variability however, the time component of variance accounts for 43 per cent. Although no limits were determined for the component of variance, the small percentage of the profile location variation permits the hypothesis of a single measurement to be accepted.

A similar analysis of variance was computed for the nine beach processes. The program was designed to test the variation between day (24-hour period) and hour (2-hour period) sampling periods. All nine beach processes exhibited significant variation during a 24-hour period. Based on the analysis of variance, the beach processes can be reduced to a single set of measurements per 12-hour period. The reduction of data excludes the significance of time-lag of the processes to the responses and operates on an instantaneous process-response system. Harrison (1969) derived predictor equations for foreshore changes by using a time-lag of processes to responses; for example, a 3-hour time-lag in the ratio of wave runup/hydraulic head to the net change of quantity of foreshore sand.

Appendix D lists the analysis of variance for the process and response parameters. F-ratios and the component of variance are also included.

## Linear Correlation

The linear correlation program measures the relationships of mutually exclusive pairs of variables. The Pearson product-moment method was selected for the linear correlation since actual quantities are measurable (Snedecor and Cochran, 1967). The calculation is in the form of the coefficient of correlation (r) which measures the degree of association between two variables and the coefficient of determination ($r^2$). The latter shows the proportion of the variation of the Y variable attributable to the association with the X variable. A student "t" test was also computed to determine the level of significance. Using standard statistic tables (Snedecor and Cochran, 1967), a t-value of 2.004 and a coefficient of correlation of 0.255 or greater is significant at 95 percent level.

The flow chart (Figure 2) clearly defines the interrelation of the process parameters. A summary of the values for beach processes is in Table 2 and the degree of association (r) illustrated in Table 3.

TABLE 2

SUMMARY OF NEARSHORE PROCESSES

| PROCESSES | HICH VALUE | LOW VALUE | MEAN VALUE |
|---|---|---|---|
| WIND SPEED | 30.2 mph | 0.0 mph | 7.16 mph |
| BAROMETRIC PRESSURE | 30.22 in | 29.61 in | 29.89 in |
| LAKE LEVEL | 1.48 ft | 0.13 ft | 0.38 ft |
| GROUNDWATER LEVEL | 2.75 ft | 0.73 ft | 1.06 ft |
| BREAKER PERIOD | 6.91 sec | 1.60 sec | 3.14 sec |
| BREAKER HEIGHT | 3.50 ft | 0.05 ft | 0.84 ft |
| BREAKER ANGLE | -49.0° | 0.0° | -1.81° |
| LONGSHORE CURRENT VELOCITY | 3.73 ft/sec | 0.0 ft/sec | 0.02 ft/sec |

As expected, strong negative correlation exists between barometric pressure and the wave parameters and groundwater level. Generally with falling barometric pressure, there is an increase in the breaker height and wave period, with a subsequent rise in the groundwater level. Eighty percent of the increase in groundwater can be attributed to an increase in breaker height and wave period as determined from the coefficient of determination ($r^2$) (Table 3). The breaker angle shifts to the northwest generating a longshore current direction to the south (Fox and Davis, 1970a, 1971). At the point of breaker angle reversal, the longshore current velocity decreases until the new longshore current direction is generated (Figure 15D). Wave type

## TABLE 3

## CORRELATION MATRIX FOR NEARSHORE PROCESSES INTERACTION

| | | $X_1$ | $X_2$ | $X_3$ | $X_4$ | $X_5$ | $X_6$ | $X_7$ | $X_8$ | $X_9$ |
|---|---|---|---|---|---|---|---|---|---|---|
| WIND SPEED | $X_1$ | -1.00 | -0.61 | -0.02 | 0.68 | -0.55 | 0.60 | 0.80 | -0.01 | 0.17 |
| BAROMETRIC PRESSURE | $X_2$ | | -1.00 | 0.12 | -0.68 | 0.48 | -0.49 | -0.63 | 0.03 | -0.05 |
| LAKE LEVEL | $X_3$ | | | 1.00 | 0.20 | 0.11 | 0.29 | 0.22 | 0.03 | 0.27 |
| GROUNDWATER LEVEL | $X_4$ | | | | 1.00 | -0.60 | 0.85 | 0.91 | 0.33 | 0.39 |
| WAVE TYPE | $X_5$ | | | | | 1.00 | -0.45 | -0.59 | -0.11 | -0.10 |
| BREAKER PERIOD | $X_6$ | | | | | | 1.00 | 0.90 | 0.35 | 0.46 |
| BREAKER HEIGHT | $X_7$ | | | | | | | 1.00 | 0.25 | 0.40 |
| BREAKER ANGLE | $X_8$ | | | | | | | | 1.00 | 0.76 |
| LONGSHORE CURRENT VELOCITY | $X_9$ | | | | | | | | | 1.00 |

transforms from surging to spilling waves with decrease in barometric pressure (Figures 14A and 15A). The maximum energy conditions are reached after barometric pressure has reached its low point and begins to rise. Lake level shows significant correlation with wave period and is related to the long period storm swells piling water against the eastern shore of the lake.

The foreshore zone shows a tendency to respond as a unit to the beach processes yet each section, lower, middle, and upper, displays some degree of independence. Foreshore response parameters are summarized in Table 4 and the correlation matrix for the interaction of the foreshore response parameters is shown in Table 5. Textural parameters of the foreshore sediments show a gradation in mean size and sorting with the finest and best sorted sediments at the upper foreshore (Figure 16). The sediments are negatively skewed at the plunge step and positively skewed at the upper-foreshore (Figure 16). Significant positive correlation between grain size at each sampling location reflects the trend of the foreshore to respond as a unit with the mean grain size of the mid-foreshore and upper-foreshore sediments showing the strongest correlation (Table 5). Sorting and skewness display strong positive correlation across the foreshore. Within each sampling location, mean grain size and sorting show the strongest positive correlation at the plunge step (Table 5). The correlation decreases across the foreshore with no correlation evident between mean grain size and sorting in the upper-foreshore (Table 5). Sorting and skewness exhibit significant correlation at each location. As the mean grain size becomes finer, sorting is better (Figure 16).

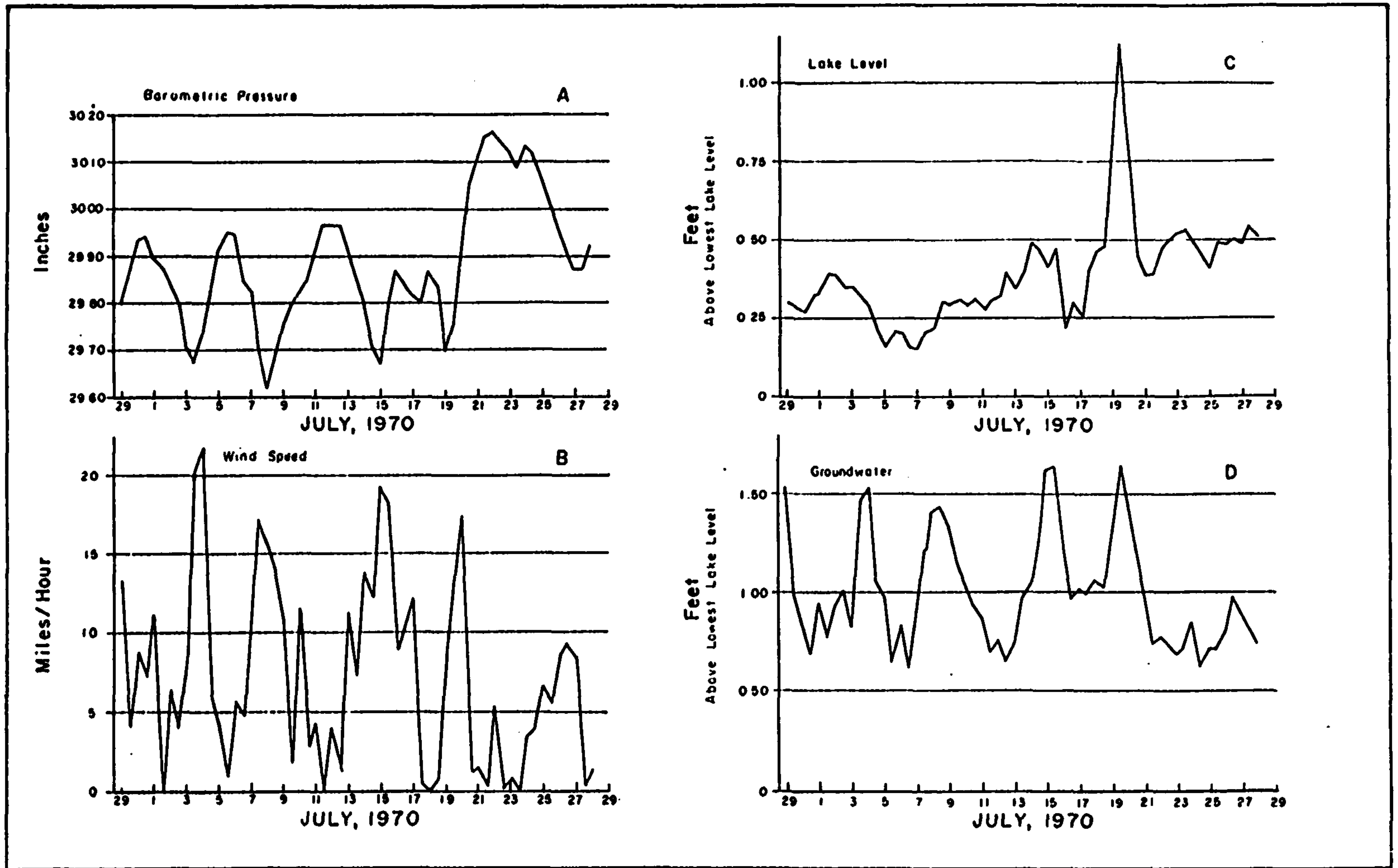


Figure 14. Variation of barometric pressure, wind speed, lake level, and groundwater level with time.

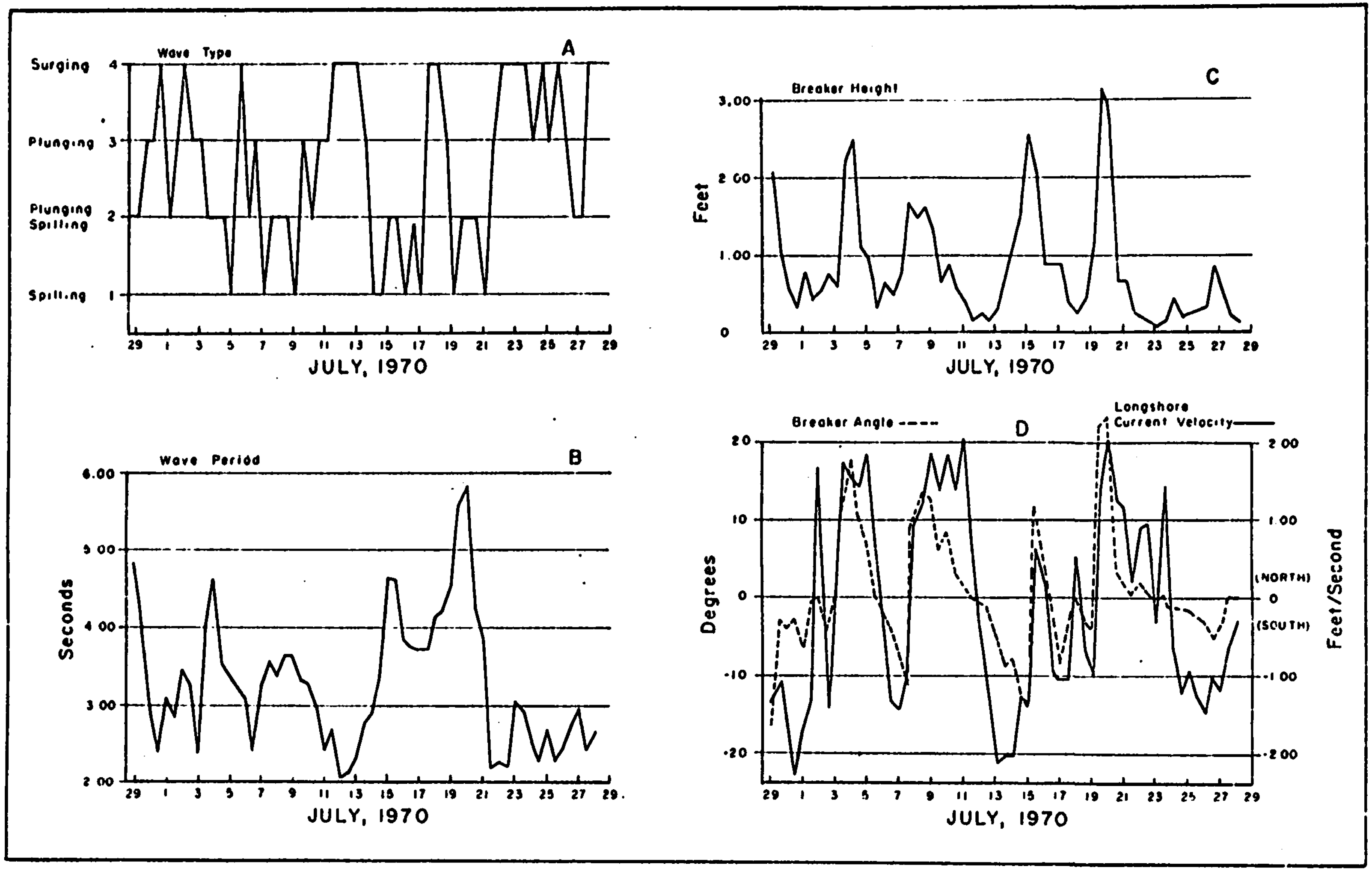


Figure 15. Variation of wave type, wave period, wave height, wave angle, and longshore current velocity with time.

## TABLE 4

## SUMMARY OF FORESHORE PARAMETERS

| PARAMETER | HIGH VALUE | LOW VALUE | MEAN VALUE |
|---|---|---|---|
| MEAN GRAIN SIZE AT PLUNGE STEP | 1.54Ø | 0.83Ø | 1.14Ø |
| SORTING AT PLUNGE STEP | 0.53Ø | 0.29Ø | 0.39Ø |
| SKEWNESS AT PLUNGE STEP | -0.29 | 0.00 | -0.09 |
| MEAN GRAIN SIZE AT MID-FORESHORE | 1.44Ø | 1.07Ø | 1.26Ø |
| SORTING AT MID-FORESHORE | 0.45Ø | 0.22Ø | 0.32Ø |
| SKEWNESS AT MID-FORESHORE | -0.26 | 0.00 | -0.05 |
| MEAN GRAIN SIZE AT UPPER FORESHORE | 1.66Ø | 1.40Ø | 1.54Ø |
| SORTING AT UPPER FORESHORE | 0.37Ø | 0.20Ø | 0.27Ø |
| SKEWNESS AT UPPER FORESHORE | -0.24 | 0.00 | 0.03 |
| FORESHORE SLOPE | 13.0° | 7.0° | 10.0° |
| FORESHORE WIDTH | 27.0 ft | 4.0 ft | 12.5 ft |
| NET EROSION AND DEPOSITION | -9.03 ft$^2$ | 0.04 ft$^2$ | -0.39 ft$^2$ |
| MIGRATION OF PLUNGE STEP | -4.23 ft | 0.00 ft | -0.05 ft |

## TABLE 5

## CORRELATION MATRIX OF FORESHORE PARAMETERS INTERACTION

| | | $Y_1$ | $Y_2$ | $Y_3$ | $Y_4$ | $Y_5$ | $Y_6$ | $Y_7$ | $Y_8$ | $Y_9$ | $Y_{10}$ | $Y_{11}$ | $Y_{12}$ | $Y_{13}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MEAN GRAIN SIZE AT PLUNGE STEP | $Y_1$ | -1.00 | -0.30 | 0.21 | 0.26 | 0.14 | 0.21 | 0.28 | 0.18 | 0.27 | 0.47 | 0.52 | -0.42 | 0.23 |
| SORTING AT PLUNGE STEP | $Y_2$ | | 1.00 | -0.70 | -0.33 | 0.65 | -0.54 | -0.12 | 0.42 | -0.36 | 0.01 | 0.25 | 0.04 | 0.07 |
| SKEWNESS AT PLUNGE STEP | $Y_3$ | | | 1.00 | 0.34 | -0.53 | 0.52 | 0.28 | -0.29 | 0.34 | 0.16 | -0.09 | -0.12 | -0.22 |
| MEAN GRAIN SIZE AT MID-FORESHORE | $Y_4$ | | | | 1.00 | -0.47 | 0.28 | 0.55 | -0.27 | 0.24 | 0.00 | -0.12 | -0.07 | 0.05 |
| SORTING AT MID-FORESHORE | $Y_5$ | | | | | 1.00 | -0.47 | -0.17 | 0.72 | -0.49 | 0.29 | 0.60 | -0.23 | 0.08 |
| SKEWNESS AT MID-FORESHORE | $Y_6$ | | | | | | 1.00 | 0.41 | -0.21 | 0.37 | 0.25 | 0.02 | -0.12 | 0.10 |
| MEAN GRAIN SIZE AT UPPER FORESHORE | $Y_7$ | | | | | | | 1.00 | -0.10 | 0.22 | 0.13 | 0.00 | -0.05 | 0.04 |
| SORTING AT UPPER FORESHORE | $Y_8$ | | | | | | | | 1.00 | -0.43 | 0.51 | 0.52 | -0.43 | -0.16 |
| SKEWNESS AT UPPER FORESHORE | $Y_9$ | | | | | | | | | 1.00 | 0.04 | -0.07 | -0.07 | 0.16 |
| FORESHORE SLOPE | $Y_{10}$ | | | | | | | | | | 1.00 | 0.61 | -0.35 | -0.19 |
| FORESHORE WIDTH | $Y_{11}$ | | | | | | | | | | | 1.00 | -0.32 | 0.16 |
| NET EROSION AND DEPOSITION | $Y_{12}$ | | | | | | | | | | | | 1.00 | 0.04 |
| MIGRATION OF PLUNGE STEP | $Y_{13}$ | | | | | | | | | | | | | 1.00 |

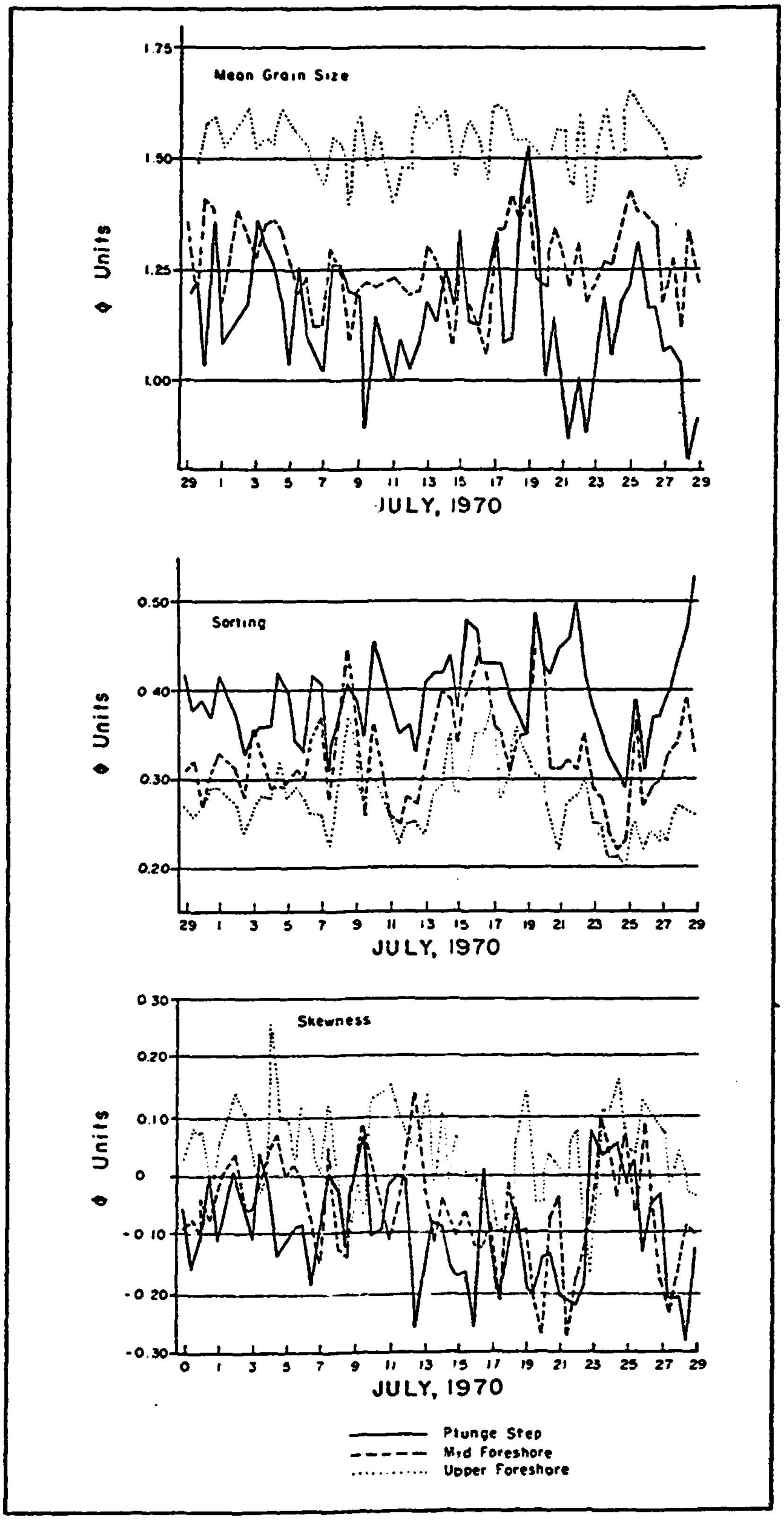


Figure 16. Variation of the foreshore textural parameters with time.

Strong correlation is evident between the foreshore geometry parameters: width, slope, and erosion and deposition. As the foreshore increases in width, the foreshore slope steepens and net erosion occurs under increasing wave activity (Figures 15 and 17). A narrow foreshore zone is associated with a flat foreshore slope and net accumulation (Figure 17). In an erosional response of the foreshore, the initial area of erosion is the lower foreshore, approximately the inshore margin (Figure 18, July 8, 8 am). The upper foreshore is less responsive to erosion and results in a steepening of the foreshore slope. With an increasing foreshore width, the area of maximum volume of erosion moves progressively across the foreshore, similar to Strahler's (1966) findings during a tidal cycle (Figure 18, July 8 to 9). A wave-cut berm develops at the upper foreshore (Figure 18, July 8, 8 pm), with a concentrated band of heavy minerals (Figure 19). Once the foreshore slope approaches 11 to 12 degrees, the slope tends to stabilize and the area of erosion shifts to the upper foreshore (Figure 18, July 8, 8 pm to 9, 8 pm). The foreshore responds by developing a planar upper foreshore (Figures 19, July 9, 8 pm, 20). The maximum volume of erosion of the foreshore precedes the planar stage of the erosional sequence. In a depositional sequence initial accumulation is at the lower foreshore, thus flattening the foreshore slope with a narrow foreshore width (Figure 21).

Analysis of the textural parameters and foreshore geometry interaction indicates that sorting of mid-foreshore and upper-foreshore sediments shows the strongest positive correlation with the foreshore geometry parameters (Figures 16 and 17). As the foreshore width and slope increases, sorting becomes poorer across

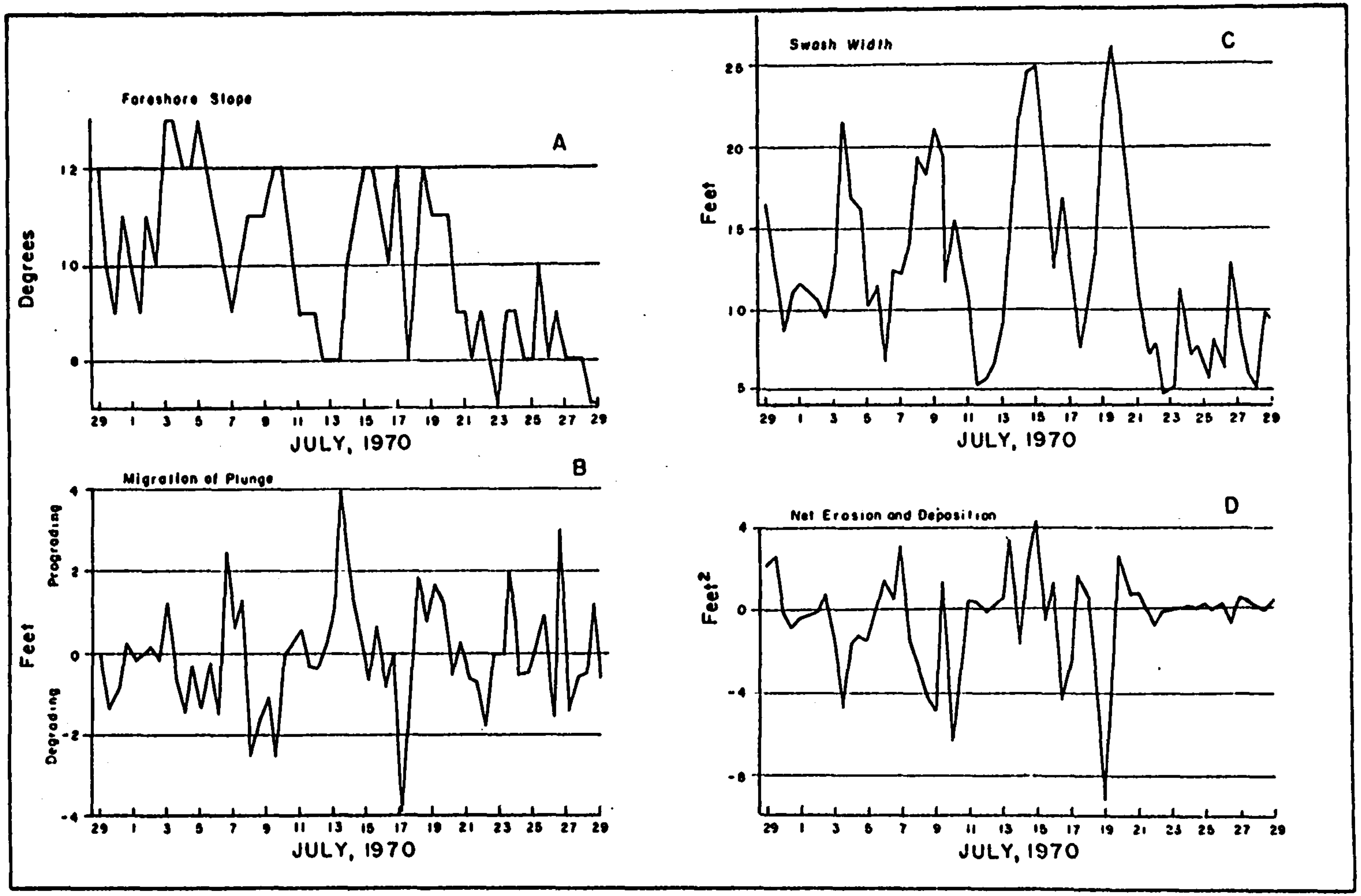


Figure 17. Variation of the foreshore geometry parameters with time.

Figure 19. Wave-cut berm and heavy mineral deposit at upper foreshore.

Figure 20.. Planar upper foreshore during an erosional sequence

Figure 19. Wave-cut berm and heavy mineral deposit at upper foreshore

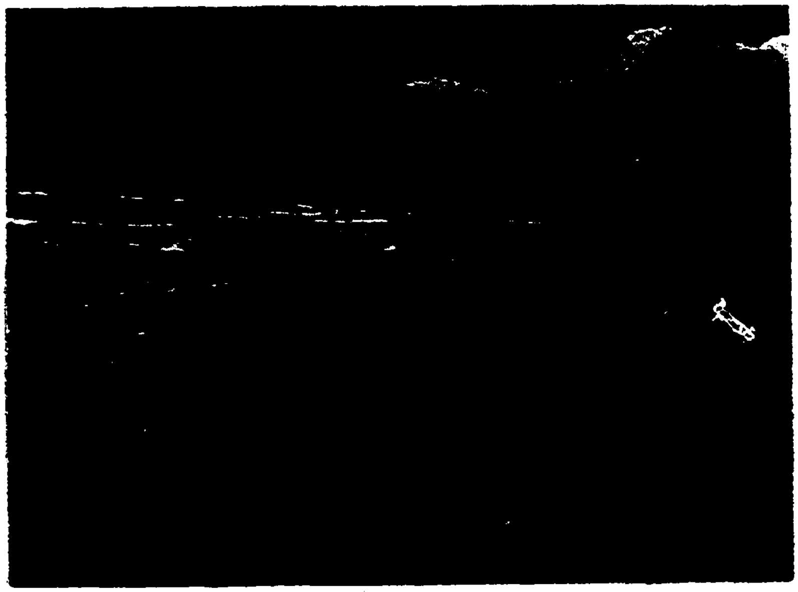


Figure 20. Planar upper foreshore during an erosional sequence

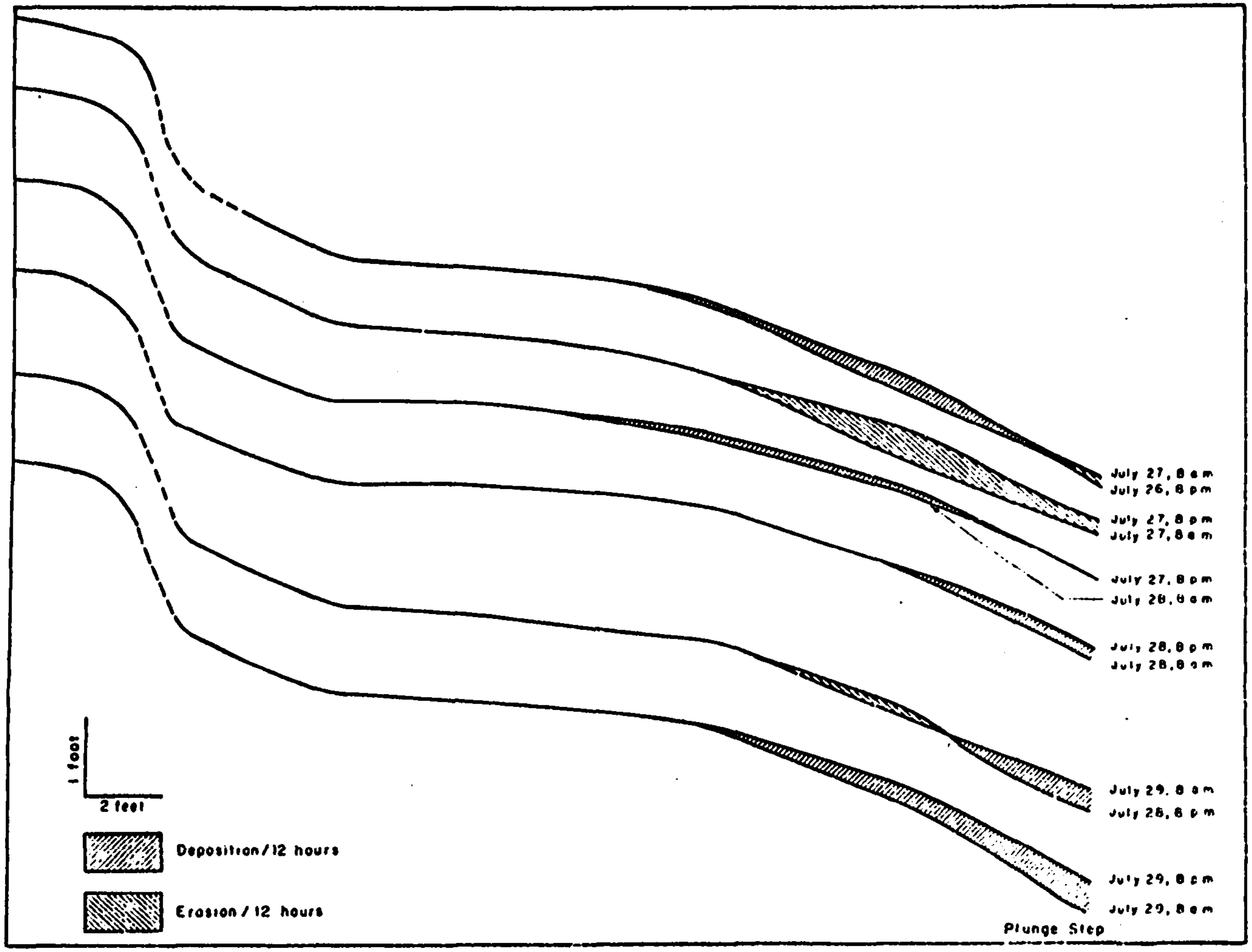


Figure 21. Longitudinal profiles of a depositional sequence at profile location B.

the foreshore. The only correlation between mean grain size and the foreshore geometry is at the plunge step. The sediments exhibit a positive correlation with the foreshore geometry.

The linear correlation analysis was also computed to determine the nearshore process-foreshore response interaction. Table 6 gives the correlation matrix for the interaction of the process and response parameters. The strongest correlation is between physical lake conditions and foreshore geometry. The foreshore width reflects the energy conditions prevailing at that particular time as exhibited by the strong correlation between foreshore width and the wave parameters (Figures 15 and 17C). Correspondingly, foreshore slope exhibits strong correlation with wave parameters. Net erosion and deposition is significantly correlated with the breaker angle and the longshore current velocity (Figures 15D and 17D). Generally, net erosion responds to a northwest breaker angle and a southerly longshore current velocity. The maximum volume of erosion occurred during July 19 and 20 during which time the maximum longshore current velocity was recorded.

Considering the textural parameters, mean grain size at the plunge step shows significant positive correlation with the physical lake condition, that is fine mean grain size with increasing energy conditions (Figures 15 and 16). Sorting values at the plunge step indicate that poorer sorting is associated with high energy. The anomalous relationship of poorer sorting and finer grain size with high energy conditions may be explained by the processes operating on the foreshore. When high energy conditions exist, erosional conditions are operating and the poorly sorted sediments exposed on

## TABLE 6

## CORRELATION MATRIX OF NEARSHORE PROCESSES-FORESHORE RESPONSES

| | | WIND SPEED | BAROMETRIC PRESSURE | LAKE LEVEL | GROUNDWATER LEVEL | WAVE TYPE | BREAKER PERIOD | BREAKER HEIGHT | BREAKER ANGLE | LONGSHORE CURRENT VELOCITY |
|---|---|---|---|---|---|---|---|---|---|---|
| PLUNGE STEP | MEAN GRAIN SIZE | 0.38 | -0.49 | 0.13 | 0.32 | -0.15 | 0.27 | 0.35 | -0.18 | -0.03 |
| | SORTING | 0.08 | 0.00 | 0.22 | 0.27 | -0.22 | 0.21 | 0.23 | 0.20 | 0.22 |
| | SKEWNESS | 0.03 | -0.06 | -0.18 | -0.06 | 0.04 | -0.10 | -0.08 | 0.01 | -0.05 |
| MID-FORESHORE | MEAN GRAIN SIZE | -0.02 | 0.09 | 0.13 | 0.00 | 0.20 | 0.00 | -0.00 | -0.10 | -0.08 |
| | SORTING | 0.35 | -0.45 | 0.25 | 0.48 | -0.44 | 0.39 | 0.48 | 0.10 | 0.27 |
| | SKEWNESS | 0.15 | -0.07 | -0.29 | 0.01 | -0.04 | 0.05 | 0.02 | 0.10 | 0.02 |
| UPPER FORESHORE | MEAN GRAIN SIZE | 0.10 | -0.03 | -0.02 | 0.02 | -0.03 | 0.03 | -0.01 | -0.17 | -0.10 |
| | SORTING | 0.22 | -0.49 | -0.01 | 0.45 | -0.41 | 0.28 | 0.33 | 0.19 | 0.20 |
| | SKEWNESS | 0.08 | 0.02 | -0.17 | -0.19 | -0.01 | -0.11 | -0.11 | -0.14 | -0.20 |
| | SLOPE | 0.49 | -0.60 | -0.24 | 0.56 | 0.47 | 0.54 | 0.58 | 0.35 | 0.29 |
| | WIDTH | 0.68 | -0.70 | 0.19 | 0.83 | -0.66 | 0.72 | 0.84 | 0.18 | 0.25 |
| | NET EROSION DEPOSITION | -0.18 | 0.31 | 0.06 | -0.21 | 0.25 | -0.04 | -0.14 | -0.25 | -0.29 |
| | MIGRATION OF PLUNGE | -0.04 | 0.0 | 0.27 | -0.10 | 0.11 | -0.05 | 0.04 | 0.21 | -0.20 |

the foreshore surface may represent mixtures of previously deposited sediments and/or sediment in transport. Gravel (Figure 22) occurs in plunge step sands during high energy conditions and may represent the sediment under wave and swash activity; whereas, the sand may be reworked from previously deposited sedimentation units. Perhaps the sediments exposed on the foreshore surface are finer because they are dominated by previously deposited finer grained sediments reworked under erosional conditions.

The sampling program design and the separation of the sand and gravel may have contributed to this anomalous relationship. The analysis of the textural parameters does indicate an increase in the maximum grain size of the plunge step sediments with increasing energy conditions; whereas, the sands exhibit a finer mean grain size.

## Linear Stepwise Regression

Expected responses of the foreshore zone are evident in the linear correlation analysis. First, the foreshore geometry responds significantly to the physical lake conditions. High waves, long period waves, and a northwest breaker angle are closely related to a wide, steep, eroding foreshore zone. Similarly, small waves, short period waves, and a southwest breaker angle are associated with a narrow, flat, foreshore. Secondly, the response of the textural parameters to the physical lake conditions varies across the foreshore. Generally high energy conditions produce coarse, poorly sorted sediments at the plunge step and poorly sorted sediments at the upper foreshore.

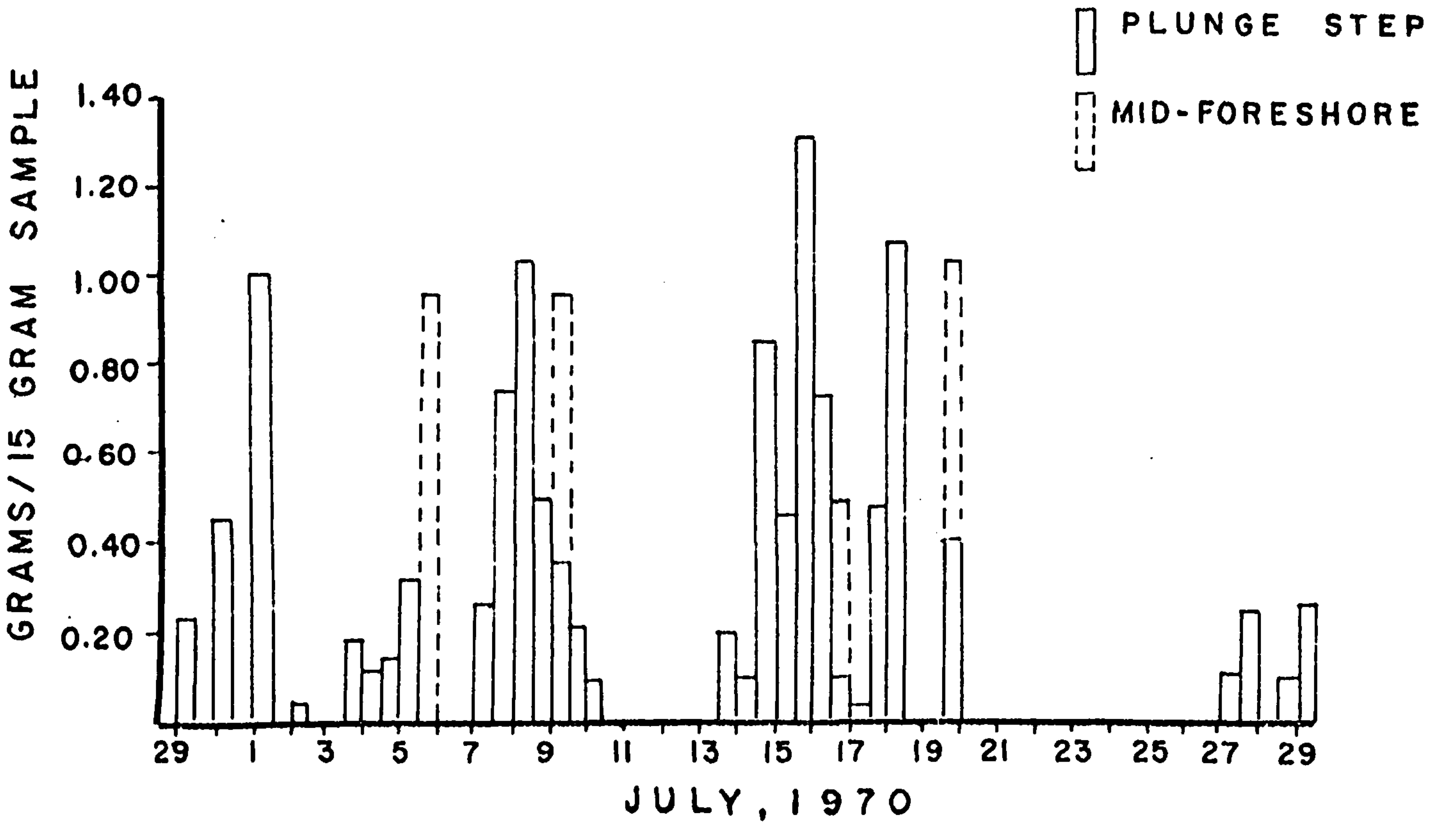


Figure 22. Occurrence of >2mm fraction.

## Foreshore geometry - energy relationships

Analysis of the processes acting on the foreshore slope indicates that barometric pressure is the strongest contributor to variation in foreshore slope. In order of decreasing significance, breaker angle, lake level, and wave period also contribute to the total explained variation. Fifty-nine per cent of the total variation of the foreshore slope is explained by the combination of these parameters (Table 7), whereas only 30 per cent of the variation is associated with any single process. As the breaker angle shifts to the northwest, rising lake level and longer period waves cause the foreshore to steepen (Figures 14C, 15B,D, and 17D). This relationship is contrary to Bascom's (1951) statement that slope flattens with an increase in energy and steepens with decrease in energy. According to King (1959), longer period waves will produce more swash with a proportional increase in the backwash, if permeability remains constant. The resultant is a flattened slope. A relationship between wave period and backwash volume was observed, but no consideration of the net erosion and deposition interaction with the foreshore was made.

As mentioned in the section on linear correlation, foreshore width is a good indicator of the physical lake conditions. The total explained variation (81%) is contributed by four process parameters. Breaker height is the strongest contributor and barometric pressure, wave type, and lake level add significant contributions (Table 7). With increasing energy conditions, breaker height, wave type, and lake level increase the volume and landward extent of water operating on the foreshore and the foreshore width is the area under

## TABLE 7

### REGRESSION ANALYSIS AT F-VALUE OF 2.00

| | FORESHORE PARAMETER | BEACH PROCESSES IN ORDER OF SIGNIFICANCE | $R^2$ | R | F |
|---|---|---|---|---|---|
| PLUNGE STEP | MEAN GRAIN SIZE | Barometric Pressure, Lake Level, Breaker Angle | .325 | .570 | 8.68* |
| | SORTING | Groundwater Level, Barometric Pressure | .134 | .367 | 4.28* |
| | SKEWNESS | Lake Level | .035 | .188 | 2.05 |
| MID-FORE-SHORE | MEAN GRAIN SIZE | Wave Type | .041 | .203 | 2.41 |
| | SORTING | Groundwater Level, Wave Type, Lake Level, Barometric Pressures | .383 | .619 | 11.20* |
| | SKEWNESS | Lake Level | .081 | .292 | 5.22* |
| UPPER-FORE-SHORE | MEAN GRAIN SIZE | No Variables Entered | 0 | 0 | 0 |
| | SORTING | Barometric Pressure, Breaker Angle, Wave Type, Wind Speed | .344 | .587 | 6.98* |
| | SKEWNESS | Longshore Current Velocity | .041 | .204 | 2.44 |
| | FORESHORE SLOPE | Barometric Pressure, Breaker Angle, Lake Level, Breaker Period | .587 | .766 | 18.86* |
| | FORESHORE WIDTH | Breaker Height, Barometric Pressure, Wave Type, Lake Level | .813 | .901 | 57.81* |
| | NET EROSION AND DEPOSITION | Barometric Pressure, Longshore Current Velocity, Breaker Period, Wave Type, Lake Level | .335 | .581 | 5.30* |
| | MIGRATION OF PLUNGE STEP | Lake Level, Longshore Current Velocity | .157 | .396 | 5.14* |

* Denotes Significance at 95% confidence level

wave influence.

The primary process factors explaining the total variation of net erosion and deposition are similar to the parameters explaining variation in foreshore slope and width. Barometric pressure is the strongest contributor and longshore current velocity, wave period, wave type, and lake level are significant factors (Table 7).

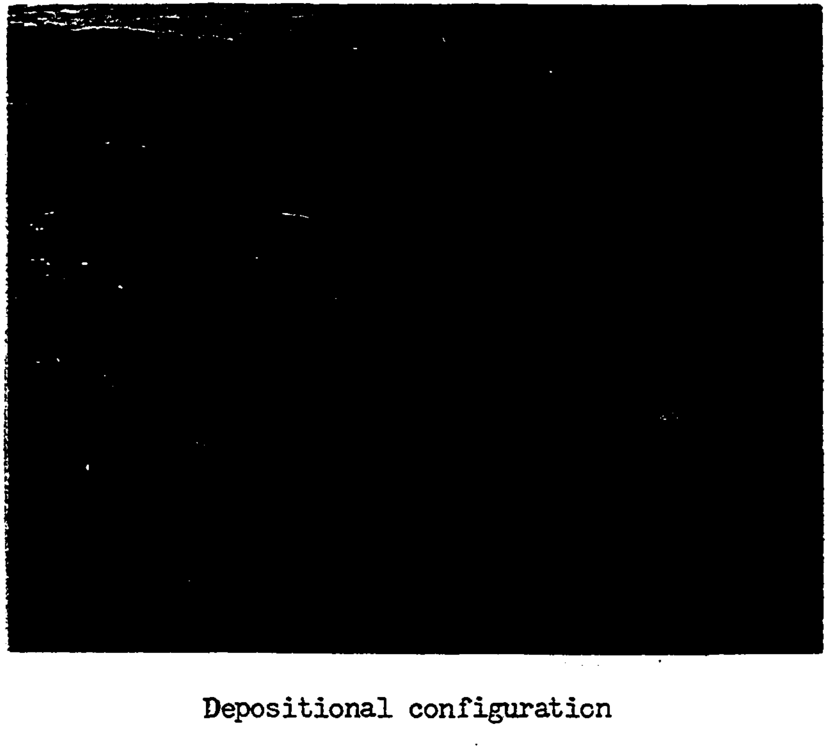
Figures 16 and 18 show the relationship of erosion and deposition to the longshore current. With a northerly longshore current, net deposition occurs on the foreshore. In contrast, a southerly longshore current develops an erosional response on the foreshore. During high energy of July 14 and 15, the dominant longshore current velocity was to the north with deposition occurring on the foreshore. The maximum longshore current velocity during the study period developed a southerly direction on July 19 and 20, and more erosion occurred than during any other time during the study period.

The area directly south of the study area has a beach width of approximately 20 feet with high dunes at the backshore (Figure 23). With high energy conditions, the swash runup is reflected off the base of the dunes with backshore and dunal sediments in transport. In contrast, at the wide beach of the study area, the swash terminates its flow and deposits the sediment in transport with no apparent erosion by the backwash cycle. The general profile configuration is slightly concave upward during erosional conditions and convex during depositional conditions (Figure 24). As the backwash velocity approximates the swash velocity, a concave equilibrium profile develops (Longinov, in Zenkovich, 1968, p. 272), because of backwash erosion of the lower foreshore. Backwash is a function of the volume of the swash,

Figure 23 Area immediately to the south of study area.

foreshore slope, volume lost to infiltration, and effluent from the groundwater. Longer period waves increase the volume of the swash and the proportional backwash and steepen the foreshore slope; therefore, the backwash velocity approaches the swash velocity with development of a concave profile. Low backwash velocity and deposition are associated with a convex profile. Similar profile configurations were also reported by Rector (1954) in a wave tank experiment. The volume lost to infiltration and addition from the groundwater can be inferred from the observational data. The slight response of the upper foreshore sediments to variations in the process parameters results in a more or less constant infiltration rate because infiltration is basically a function of the textural parameters (Krumbein and Monk, 1942). Because of the rise in the

Erosional configuration



Depositional configuration

Figure 24 Profile configuration of foreshore in an erosional and depositional sequence.

groundwater level increases the area of saturation of the foreshore during runup, groundwater effluent will contribute to the volume of the backwash. Duncan (1966) documented the role of groundwater in erosion and deposition, and reported that with a high groundwater table, backwash erosion and deposition dominate. No relationship was evident in the present study between groundwater and net erosion and deposition (Figures 16 and 18).

Migration of the plunge step corresponds with erosion and deposition of the foreshore. Longshore current velocity and lake level are the strongest significant factors associated with the migration (Figures 14C, 15D, and 17B). A prograding plunge step occurs with a dominant longshore current velocity to the north.

To summarize, in the foreshore geometry-energy relationship, along with wave period, longshore current velocity and lake level, barometric pressure is a strong contributor in explaining the source of variation. Barometric pressure is the initiating factor in the physical lake conditions. With increasing energy, the foreshore zone approached equilibrium conditions before maximum wave conditions developed (Figures 14, 15, and 17). For example, maximum net erosion generally precedes the maximum wave conditions and indicates that during maximum energy conditions, the foreshore zone is temporarily in equilibrium.

## Textural parameters - energy relationship

As evident in the linear correlation analysis (Table 6), mean grain size becomes finer with increasing energy conditions, as sorting of the sediments becomes poorer. The pebble occurrence indicates that the maximum size of the sediment becomes coarser under high energy condition especially at the plunge step (Figure 22). Considering the sand-size fraction, the regression analysis confirms the hypothesis of decreasing response across the foreshore (Table 7). The total explained variation (34%) of the mean grain size at the plunge step is explained by barometric pressure, lake level and breaker angle; whereas, 18 per cent of the total explained variation for the mid-foreshore and upper-foreshore is explained by having all nine parameters enter the regression analysis (Figures 14, 15 and 16). The sorting-energy relationship is significant at each location with groundwater being the dominant factor for sorting at the plunge step and mid-foreshore (Figures 14, 15 and 16). Both locations lie within the zone of saturation and are subjected to the backwash cycle if Duncan's (1966) hypothesis is accepted. Barometric pressure, breaker angle, and wave type contribute to the 34 per cent explained variation of sorting at the upper-foreshore.

## Unexplained variation

Although most of the process-response relationships are statistically significant, the level of unexplained variance is relatively high. The magnitude of the unexplained variation ranges from 20 to 80 per cent with an average of approximately 40 per cent. Part of the unexplained variation may be assigned as follows:

1) The process-response model as presented was operating on an instantaneous event system. As noted by many researchers (Harrison, 1968) a notable time-delay of the processes to the responses occurs in the beach system. The factors influencing the time-delay are the initial configuration and nature of the beach environment and the

intensity of the processes needed to modify this environment.

2) The inadequacy of the sampling program to represent the sediments under swash activity especially during erosional condition contributed to the high level of unexplained variation. Samples taken under erosive conditions may represent textural size distributions developed during depositional conditions.

3) In selection of the process and response parameters, significant variables may not have been considered or measurable. No consideration was given to the interaction among the process parameters and response parameters in the analysis. Also, measurable data were not taken for the energy conditions of the swash-backwash cycle.

# SYNTHESIS OF OBSERVATIONAL DATA

The cyclic nature of the wave and weather parameters offers ample opportunity to develop a generalized model of foreshore response. Three response phases are recognizable: 1) a low energy-depositional phase, 2) a high energy-erosional phase, and 3) a transitional phase.

Physical lake conditions operating in the depositional phase are of relatively low energy. Barometric pressure rises with small breaker heights, short period waves, and low groundwater table. Breaker angle is small with low velocity longshore currents. The foreshore is in a rebuilding stage with deposition in the lower foreshore developing a convex upward profile configuration. The foreshore width is small with a gentle foreshore slope. Textural parameters show gradational size and sorting changes across the foreshore. The mean grain size is fine with good sorting.

The erosional phase is indicative of storm conditions (high energy) operating on the foreshore. This phase develops because barometric pressure has reached its low point and is rising with increasing breaker height and long period waves causing a subsequent rise in the lake and groundwater levels. The breaker angle is dominantly from the northwest direction generating a southerly longshore current. The initial stage of this phase is erosion of the lower foreshore thereby steepening the foreshore slope to equilibrium at 11 to 12 degrees. Maximum erosion occurs during this stage of the erosional response of the foreshore and a wave-cut berm develops at the upper-foreshore. Coarse lag sediments accumulate at the plunge step and a band of concentrated heavy minerals at the upper-foreshore. As the foreshore width increases with increasing energy, the inshore margin and erosional response move progressively across the foreshore developing a planar profile. The foreshore slope is eventually stabilized with a concave upward equilibrium configuration. The amount of net erosion is less than the initial stage of erosion. Texturally, sediments are fine and poorly sorted at the plunge step and poorly sorted at the upper-foreshore. The plunge step sediments exhibit an increase in the maximum grain size with the occurrence of gravel.

The third phase is transitional between the depositional phase and erosional phase of the foreshore. The energy conditions are intensifying but the breaker angle is from the southwest generating a northerly longshore current velocity. Relatively high energy conditions exist in the nearshore environment but deposition occurs on the foreshore. The dominant factor is the breaker angle and longshore current velocity and direction. The sediment being deposited on the foreshore greatly exceeds the erosional ability of the wave parameters, thus developing a high energy depositional phase. This transitional phase suggests a rythmitic migration pattern of major sedimentary structures (protuberances and major cusps) along the beach. Direction of migration is function of the longshore current direction, migrating away from the study area during the erosional phase and migrating into the area during the transitional phase. Confirmation of the rythmitic pattern of sedimentary structures must take into account the regional variation of the beach and nearshore environment. The scope of the study limits the evidence for this hypothesis.

# CONCLUSIONS

Field and laboratory investigations of the foreshore zone in southeastern Lake Michigan permit the following generalizations:

1) Textural parameters exhibit a gradation in size and sorting across the foreshore. Coarser, more poorly sorted, negatively skewed sediments occur at the plunge step and finer, well sorted, positively skewed sediments occuring at the upper-foreshore.

2) Foreshore geometry parameters exhibit significant interaction. A wide, steep foreshore is associated with an eroding foreshore; whereas, a narrow, gentle foreshore occurs with net accumulation. The foreshore slope is a function of the volume of erosion or deposition on the lower foreshore.

3) Barometric pressure is the most persistent variable of all the nearshore processes entering the regression analysis. Barometric pressure is the initiating process in the development of the energy condition prevailing in Lake Michigan.

4) Groundwater level and lake level are also significant factors in producing variations in textural parameters. Low barometric pressure and high groundwater and lake levels indicate high energy conditions and are associated with fine, poorly sorted sediment with a significant gravel fraction at the plunge step grading to fine, poorly sorted sediment at the upper-foreshore. The textural parameters exhibit a decreasing response to process across the foreshore zone. Anomalous values

of mean size and sorting at the plunge step suggest the inability to properly sample sediments under wave and swash activity at that particular time. Fine, poorly sorted sediment with a significant gravel fraction occur under high energy condition. The gravel fraction may represent the sediments under wave and swash activity.

5) Wave processes (breaker height, breaker period, breaker angle, and longshore current velocity) are the major source of variation influencing foreshore geometry. With high energy conditions the foreshore is wide, steep and eroding. With low energy conditions, the foreshore is narrow, gently sloping, and accumulating sediments.

6) The general pattern of the foreshore response is distinguishable into three phases: 1) a low energy-depositional phase, 2) a high energy-erosional phase, and 3) a transitional phase. The transitional phase may represent systematic migration of major sedimentary structures.

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# APPENDIX A

Beach process data after reduction of the data from 2-hour intervals to 6-hour intervals.

DA = DATE (JUNE 29 - JULY 28)
TM = TIME (8=8:00 AM, 20-8:00 PM)
WS = WIND SPEED
BP = BAROMETRIC PRESSURE
LL = LAKE LEVEL
EG = GROUNDWATER LEVEL
WT = WAVE TYPE
BP = BREAKER PERIOD
BH = BREAKER HEIGHT
BA = BREAKER ANGLE
LCU = LONGSHORE CURRENT VELOCITY

| DA | TM | WS | BP | LL | EG | WT | BP | BH | BA | LCU |
|---|---|---|---|---|---|---|---|---|---|---|
| 29 | 20 | 13.75 | 29.81 | 0.31 | 1.52 | 2. | 4.38 | 2.09 | -13.33 | -1.74 |
| 30 | 8 | 4.13 | 29.87 | 0.29 | 0.98 | 3. | 3.97 | 1.09 | -17.83 | -2.32 |
| 30 | 20 | 8.72 | 29.94 | 0.27 | 0.82 | 3. | 2.96 | 0.59 | -17.52 | -2.41 |
| 1 | 8 | 7.23 | 29.95 | 0.32 | 0.72 | 4. | 2.38 | 0.32 | -20.33 | -0.31 |
| 1 | 20 | 11.05 | 29.92 | 0.34 | 0.96 | 2. | 3.10 | 0.78 | -17.33 | -2.67 |
| 2 | 8 | 2.72 | 29.96 | 0.39 | 0.78 | 3. | 2.34 | 0.42 | -13.17 | -2.23 |
| 2 | 20 | 6.43 | 29.95 | 0.36 | 0.93 | 4. | 3.49 | 0.52 | 16.33 | -2.24 |
| 3 | 8 | 4.27 | 29.82 | 0.36 | 1.21 | 3. | 3.25 | 0.74 | -14.17 | -2.41 |
| 3 | 20 | 5.52 | 29.71 | 0.30 | 0.82 | 3. | 2.39 | 0.53 | -2.33 | 0.27 |
| 4 | 8 | 20.33 | 29.66 | 0.32 | 1.49 | 2. | 4.75 | 2.23 | 16.67 | 1.19 |
| 4 | 20 | 24.83 | 29.76 | 0.28 | 1.55 | 2. | 4.65 | 2.50 | 14.50 | 1.81 |
| 5 | 8 | 6.23 | 29.65 | 0.21 | 1.08 | 2. | 3.53 | 1.12 | 13.83 | 1.23 |
| 5 | 20 | 4.42 | 29.91 | 0.16 | 0.98 | 1. | 3.36 | 0.97 | 17.67 | 0.72 |
| 6 | 8 | 2.87 | 29.94 | 0.21 | 0.66 | 4. | 3.21 | 2.34 | 7.33 | 0.25 |
| 6 | 20 | 5.63 | 29.93 | 0.20 | 0.83 | 2. | 3.36 | 2.64 | -5.20 | -0.19 |
| 7 | 8 | 4.92 | 29.85 | 0.16 | 0.62 | 3. | 2.41 | 0.49 | -13.33 | -2.51 |
| 7 | 20 | 12.17 | 29.83 | 0.16 | 0.84 | 1. | 3.21 | 0.79 | -14.52 | -0.76 |
| 8 | 8 | 17.10 | 29.76 | 0.21 | 1.21 | 2. | 3.58 | 1.67 | -9.50 | -1.19 |
| 8 | 20 | 15.67 | 29.63 | 0.22 | 1.41 | 2. | 3.38 | 1.49 | 9.83 | 0.91 |
| 9 | 8 | 6.93 | 29.72 | 0.30 | 1.43 | 2. | 3.66 | 1.61 | 12.50 | 1.45 |
| 9 | 20 | 5.57 | 29.76 | 0.29 | 1.36 | 1. | 3.65 | 1.32 | 18.67 | 1.38 |
| 10 | 8 | 1.97 | 29.80 | 0.31 | 1.15 | 3. | 3.33 | 0.63 | 14.33 | 2.52 |
| 10 | 20 | 11.68 | 29.92 | 0.28 | 1.04 | 2. | 3.28 | 0.67 | 18.83 | 2.87 |
| 11 | 8 | 2.82 | 29.85 | 0.31 | 0.95 | 3. | 2.99 | 0.56 | 14.67 | 2.32 |
| 11 | 20 | 4.22 | 29.92 | 0.27 | 0.88 | 3. | 2.42 | 0.42 | 21.83 | 2.27 |
| 12 | 8 | 2.02 | 29.97 | 0.31 | 0.72 | 4. | 2.59 | 0.18 | 5.67 | 2.23 |
| 12 | 20 | 4.32 | 29.97 | 0.32 | 0.74 | 4. | 2.05 | 0.24 | -3.50 | -2.27 |
| 13 | 8 | 1.17 | 29.97 | 0.39 | 0.64 | 4. | 2.16 | 2.16 | -12.22 | -0.14 |
| 13 | 20 | 11.43 | 29.92 | 0.34 | 0.75 | 4. | 2.37 | 0.30 | -21.83 | -2.42 |
| 14 | 8 | 7.22 | 29.55 | 0.41 | 0.97 | 3. | 2.79 | 2.71 | -19.17 | -2.89 |
| 14 | 20 | 13.97 | 29.82 | 0.42 | 1.06 | 1. | 2.91 | 1.27 | -19.17 | -2.82 |
| 15 | 8 | 12.33 | 29.71 | 0.46 | 1.25 | 1. | 3.41 | 1.54 | -12.52 | -1.24 |
| 15 | 20 | 19.35 | 29.67 | 0.42 | 1.61 | 2. | 4.57 | 2.58 | -14.33 | -1.43 |
| 16 | 8 | 15.53 | 29.82 | 0.47 | 1.63 | 2. | 4.56 | 2.02 | 6.52 | 1.22 |
| 16 | 20 | 8.93 | 29.87 | 0.22 | 1.17 | 1. | 2.84 | 0.83 | 2.22 | 2.34 |
| 17 | 8 | 12.62 | 29.84 | 0.37 | 0.95 | 2. | 2.74 | 0.87 | -10.52 | -0.85 |
| 17 | 20 | 12.25 | 29.82 | 0.25 | 1.01 | 1. | 2.72 | 0.87 | -12.17 | -2.85 |
| 18 | 8 | 2.43 | 29.81 | 0.42 | 0.99 | 4. | 2.72 | 2.41 | -12.33 | -2.32 |
| 18 | 20 | 2.22 | 29.87 | 0.45 | 1.06 | 4. | 3.16 | 0.27 | 5.33 | 2.23 |
| 19 | 8 | 2.62 | 29.54 | 0.47 | 1.03 | 3. | 3.26 | 0.46 | -7.22 | -0.31 |
| 19 | 20 | 8.63 | 29.72 | 0.72 | 1.29 | 1. | 3.52 | 1.14 | -11.33 | -0.42 |
| 20 | 8 | 13.42 | 29.76 | 1.13 | 1.65 | 2. | 5.60 | 3.19 | 13.83 | 2.49 |
| 20 | 20 | 17.42 | 29.93 | 0.75 | 1.43 | 2. | 5.84 | 2.63 | 20.83 | 2.85 |
| 21 | 8 | 1.27 | 30.26 | 0.44 | 1.22 | 2. | 3.28 | 0.66 | 12.33 | 0.41 |
| 21 | 20 | 1.27 | 30.11 | 0.38 | 0.92 | 1. | 2.99 | 2.66 | 11.72 | 2.13 |
| 22 | 8 | 2.32 | 30.16 | 0.38 | 0.75 | 3. | 2.32 | 0.23 | 1.33 | 2.20 |
| 22 | 20 | 5.23 | 30.17 | 0.46 | 0.78 | 4. | 2.37 | 0.21 | 8.33 | 0.21 |
| 23 | 8 | 2.00 | 30.14 | 0.57 | 0.74 | 4. | 2.30 | 0.13 | 9.17 | 0.00 |
| 23 | 20 | 2.72 | 30.12 | 0.52 | 0.72 | 4. | 3.02 | 0.29 | -3.17 | -2.24 |
| 24 | 8 | 2.20 | 30.09 | 0.53 | 0.74 | 4. | 2.93 | 2.14 | 13.33 | 2.27 |
| 24 | 20 | 3.23 | 30.14 | 0.49 | 0.85 | 3. | 2.58 | 2.42 | -6.83 | -2.13 |
| 25 | 8 | 3.93 | 30.12 | 0.44 | 0.67 | 4. | 2.28 | 0.20 | -12.33 | -2.19 |
| 25 | 20 | 6.50 | 30.07 | 0.41 | 0.72 | 3. | 2.70 | 0.26 | -9.33 | -0.15 |
| 26 | 8 | 5.47 | 30.01 | 0.48 | 0.72 | 4. | 2.28 | 2.29 | -13.83 | -0.28 |
| 26 | 20 | 5.52 | 29.95 | 0.48 | 0.92 | 3. | 2.44 | 0.34 | -15.17 | -2.30 |
| 27 | 8 | 9.15 | 29.91 | 0.57 | 0.97 | 2. | 2.75 | 0.85 | -11.52 | -0.56 |
| 27 | 20 | 7.98 | 29.35 | 0.48 | 0.91 | 2. | 2.93 | 2.54 | -13.17 | -2.34 |
| 28 | 8 | 2.23 | 29.98 | 0.54 | 0.81 | 4. | 2.49 | 2.22 | -6.67 | 0.00 |
| 28 | 20 | 1.33 | 29.93 | 0.51 | 0.74 | 4. | 2.42 | 2.14 | -2.83 | 0.02 |

# APPENDIX B

Foreshore data after reduction of the data from three locations to one location.

DA = DATE (JUNE 29 - JULY 29)
TM = TIME (8=8:00 AM, 20=8:00 PM)
MdP = MEAN GRAIN SIZE AT PLUNGE STEP
SP = SORTING AT PLUNGE STEP
SKP = SKEWNESS AT PLUNGE STEP
MdM = MEAN GRAIN SIZE AT MID-FORESHORE
SM = SORTING AT MID-FORESHORE
SKM = SKEWNESS AT MID-FORESHORE
MdT = MEAN GRAIN SIZE AT UPPER-FORESHORE
ST = SORTING AT UPPER-FORESHORE
SKT = SKEWNESS AT UPPER-FORESHORE
SL = FORESHORE SLOPE
WD = FORESHORE WIDTH
NED = NET EROSION AND DEPOSITION
MPS = MIGRATION OF PLUNGE STEP

| DA | TM | MdP | SP | SKP | MdM | SN | SLM | MdT | ST | SKT | SL | WD | NED | CPS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| [illegible] | 22 | 1.19 | 2.42 | -2.25 | 1.36 | 2.31 | -2.24 | 1.49 | 2.27 | 2.23 | 12. | 19.43 | 2.2287 | 2.27 |
| [illegible] | [illegible] | 1.12 | 2.34 | -2.21 | 1.24 | 2.37 | -2.27 | 1.52 | 2.29 | 2.25 | 12. | 11.87 | 2.5153 | -1.33 |
| [illegible] | 22 | 1.14 | 2.33 | -2.24 | 1.42 | 2.27 | -2.24 | 1.49 | 2.27 | 2.27 | 9. | 5.93 | -2.2467 | -2.41 |
| [illegible] | 9 | 1.37 | 2.37 | 2.21 | 1.39 | 2.31 | -2.27 | 1.62 | 2.29 | -2.21 | 11. | 11.23 | -2.7953 | 2.37 |
| [illegible] | 22 | 1.25 | 2.42 | -2.22 | 1.27 | 2.37 | -2.22 | 1.43 | 2.23 | 2.25 | 9. | 11.43 | -3.4633 | -2.17 |
| [illegible] | 22 | 1.15 | 2.37 | 2.23 | 1.39 | 2.31 | 2.24 | 1.58 | 2.27 | 2.24 | 11. | 18.47 | -2.1133 | 2.27 |
| [illegible] | 9 | 1.19 | 2.31 | -2.24 | 1.34 | 2.28 | -2.25 | 1.42 | 2.24 | 2.11 | 12. | 9.57 | 2.7233 | -2.15 |
| [illegible] | 22 | 1.37 | 2.37 | -2.21 | 1.27 | 2.34 | -2.25 | 1.53 | 2.27 | 2.23 | 13. | 12.57 | -1.3527 | 1.27 |
| [illegible] | 9 | 1.32 | 2.35 | 2.24 | 1.30 | 2.33 | -2.27 | 1.55 | 2.28 | -2.32 | 13. | 21.33 | -4.9422 | -2.57 |
| 4 | 22 | 1.27 | 2.35 | -2.27 | 1.37 | 2.29 | 2.25 | 1.56 | 2.29 | 2.27 | 12. | 16.97 | -1.9233 | -1.28 |
| 5 | 9 | 1.76 | 2.42 | -2.23 | 1.34 | 2.29 | 2.27 | 1.51 | 2.37 | 2.12 | 12. | 16.13 | -1.3467 | -2.17 |
| 5 | 22 | 1.24 | 2.47 | -2.21 | 1.28 | 2.30 | 2.24 | 1.58 | 2.26 | 2.20 | 13. | 18.57 | -1.6433 | -1.17 |
| 6 | 3 | 1.77 | 2.34 | -2.24 | 1.22 | 2.31 | 2.22 | 1.49 | 2.23 | 2.23 | 12. | 11.57 | -2.2733 | -2.28 |
| 6 | 22 | 1.11 | 2.37 | -2.27 | 1.24 | 2.37 | -2.21 | 1.53 | 2.24 | 2.11 | 11. | 5.53 | 1.4333 | -1.47 |
| 7 | 5 | 1.79 | 2.42 | -2.24 | 1.11 | 2.35 | -2.27 | 1.44 | 2.29 | 2.28 | 12. | 12.17 | 2.5927 | 2.78 |
| 7 | 22 | 1.23 | 2.41 | -2.21 | 1.13 | 2.37 | -2.15 | 1.44 | 2.26 | 2.21 | 9. | 13.27 | 3.2487 | 2.67 |
| 5 | 8 | 1.27 | 8.31 | 2.21 | 1.31 | 2.28 | 2.25 | 1.56 | 2.23 | 2.12 | 12. | 19.37 | -1.9433 | 1.33 |
| 8 | 22 | 1.27 | 2.37 | -2.23 | 1.25 | 2.35 | -2.23 | 1.54 | 2.32 | -2.22 | 11. | 19.17 | -2.8497 | -2.58 |
| 8 | 3 | 1.21 | 2.41 | -2.21 | 1.12 | 2.45 | -2.24 | 1.42 | 2.37 | -2.12 | 11. | 21.27 | -4.1927 | -1.57 |
| 9 | 22 | 1.22 | 2.34 | -2.27 | 1.21 | 2.38 | 2.23 | 1.52 | 2.34 | -2.21 | 11. | 19.37 | -4.5787 | -1.27 |
| 10 | 9 | 2.59 | 2.48 | 2.27 | 1.23 | 2.28 | 2.27 | 1.49 | 2.28 | -2.25 | 12. | 11.57 | 1.3927 | -2.57 |
| 10 | 22 | 1.15 | 2.44 | -2.25 | 1.22 | 2.37 | -2.21 | 1.57 | 2.31 | 2.13 | 12. | 15.57 | -6.2622 | -8.17 |
| 11 | 22 | 1.22 | 2.34 | -2.25 | 1.24 | 2.25 | -2.22 | 1.41 | 2.26 | 2.15 | 9. | 9.35 | 2.3722 | 8.67 |
| 12 | 3 | 1.22 | 2.35 | -2.27 | 1.22 | 2.25 | -2.26 | 1.49 | 2.23 | 2.11 | 9. | 5.93 | 2.3233 | -2.33 |
| 12 | 22 | 1.27 | 2.34 | 2.21 | 1.19 | 2.28 | -2.26 | 1.43 | 2.25 | 2.29 | 9. | 5.47 | -2.2467 | -2.37 |
| 13 | 9 | 1.79 | 2.33 | -2.21 | 1.21 | 2.27 | 2.24 | 1.52 | 2.25 | 2.24 | 9. | 5.57 | 2.1227 | 2.37 |
| 13 | 22 | 1.19 | 2.41 | -2.25 | 1.31 | 2.31 | -2.22 | 1.57 | 2.24 | 2.13 | 9. | 9.25 | 2.5233 | 1.37 |
| 14 | 3 | 1.24 | 2.42 | -2.24 | 1.27 | 2.35 | -2.29 | 1.55 | 2.25 | -2.21 | 9. | 15.17 | 3.2967 | 4.17 |
| 14 | 22 | 1.26 | 2.42 | -2.28 | 1.22 | 2.42 | -2.24 | 1.51 | 2.32 | 2.12 | 12. | 21.53 | -1.8333 | 1.57 |
| 15 | 9 | 1.26 | 2.44 | -2.25 | 1.29 | 2.39 | -2.25 | 1.47 | 2.35 | -2.21 | 11. | 24.57 | 2.2833 | 2.47 |
| 15 | 22 | 1.35 | 2.35 | -2.25 | 1.31 | 2.34 | -2.29 | 1.54 | 2.28 | 2.26 | 12. | 24.57 | 4.2927 | -2.97 |
| 16 | 9 | 1.14 | 2.48 | -2.27 | 1.17 | 2.42 | -2.25 | 1.59 | 2.32 | 2.22 | 12. | 18.47 | -8.7533 | 2.97 |
| 16 | 22 | 1.13 | 2.47 | -2.21 | 1.12 | 2.43 | -2.22 | 1.54 | 2.35 | 2.22 | 11. | 12.97 | 1.3927 | -2.83 |
| 17 | 3 | 1.21 | 2.42 | -2.25 | 1.27 | 2.44 | -2.12 | 1.49 | 2.35 | -2.25 | 12. | 16.83 | -4.2167 | 2.37 |
| 17 | 22 | 1.35 | 2.33 | 8.21 | 1.34 | 2.35 | -2.29 | 1.63 | 2.35 | -2.24 | 12. | 12.17 | -2.8633 | -4.23 |
| 18 | 3 | 1.29 | 2.43 | -2.15 | 1.35 | 2.35 | -2.22 | 1.62 | 2.29 | -2.11 | 9. | 7.43 | 1.3627 | -2.33 |
| 18 | 23 | 1.22 | 2.35 | -2.21 | 1.43 | 2.31 | -2.21 | 1.55 | 2.31 | -2.27 | 9. | 12.53 | 2.9227 | 1.97 |
| 19 | 8 | 1.45 | 2.35 | -2.22 | 1.37 | 2.35 | -2.29 | 1.59 | 2.35 | 2.26 | 12. | 13.77 | -3.4133 | 2.57 |
| 19 | 22 | 1.54 | 2.35 | -2.27 | 1.42 | 2.35 | -2.28 | 1.54 | 2.33 | 2.14 | 11. | 22.53 | -9.2367 | 1.77 |
| 22 | 9 | 1.34 | 2.47 | -2.23 | 1.24 | 2.45 | -2.22 | 1.51 | 2.31 | -2.22 | 11. | 27.13 | -2.7222 | 1.33 |
| 22 | 22 | 1.21 | 2.43 | -2.22 | 1.21 | 2.44 | -2.26 | 1.52 | 2.32 | -2.26 | 11. | 21.43 | 2.8822 | -8.47 |
| 21 | 9 | 1.25 | 2.42 | -2.24 | 1.35 | 2.31 | -2.27 | 1.59 | 2.25 | 2.23 | 9. | 15.33 | 1.9367 | 8.37 |
| 21 | 22 | 1.77 | 2.43 | -2.27 | 1.31 | 2.31 | -2.74 | 1.56 | 2.22 | 2.21 | 9. | 12.97 | 1.6533 | -2.62 |
| 22 | 9 | 2.37 | 2.44 | -2.27 | 1.21 | 2.32 | -2.34 | 1.45 | 2.27 | -2.21 | 9. | 7.13 | -2.2222 | -2.77 |
| 22 | 22 | 1.22 | 2.52 | -2.21 | 1.32 | 2.31 | -2.27 | 1.52 | 2.28 | 2.26 | 9. | 7.37 | -2.7267 | -1.87 |
| 23 | 3 | 2.39 | 2.42 | -2.23 | 1.18 | 3.35 | -2.14 | 1.42 | 2.32 | -2.24 | 9. | 4.47 | 2.7267 | -2.37 |
| 23 | 22 | 1.23 | 2.38 | -2.24 | 1.23 | 2.29 | -2.25 | 1.54 | 2.25 | -2.25 | 7. | 4.53 | 2.2633 | 2.22 |
| 24 | 3 | 1.29 | 2.35 | 2.27 | 1.28 | 2.29 | 2.29 | 1.62 | 2.25 | 2.12 | 9. | 11.33 | -2.2522 | 2.27 |
| 24 | 22 | 1.27 | 2.32 | 2.23 | 1.27 | 2.24 | 2.25 | 1.51 | 2.21 | 2.10 | 9. | 7.27 | 2.1467 | -7.57 |
| 25 | 3 | 1.18 | 2.31 | 2.25 | 1.37 | 2.22 | -2.25 | 1.52 | 2.21 | 2.15 | 9. | 7.83 | 2.1497 | -2.57 |
| 25 | 22 | 1.22 | 2.29 | 2.24 | 1.44 | 2.23 | 2.27 | 1.66 | 2.27 | 2.24 | 9. | 5.47 | 2.3422 | 2.17 |
| 26 | 5 | 1.72 | 2.39 | -2.22 | 1.39 | 2.34 | -2.25 | 1.64 | 2.24 | 2.23 | 10. | 8.33 | 2.2427 | 8.93 |
| 26 | 22 | 1.17 | 2.31 | 2.23 | 1.38 | 2.27 | -2.25 | 1.52 | 2.27 | 2.12 | 8. | 6.82 | 2.2667 | -1.47 |
| 27 | 9 | 1.17 | 2.37 | -2.24 | 1.35 | 2.29 | 2.28 | 1.58 | 8.24 | 2.29 | 9. | 12.73 | -2.7133 | 3.23 |
| 27 | 22 | 1.77 | 2.37 | -2.28 | 1.19 | 2.37 | -2.27 | 1.55 | 2.23 | 2.27 | 9. | 7.92 | 2.6122 | -1.43 |
| 28 | [illegible] | 1.18 | 2.47 | -2.24 | 1.29 | 2.33 | -2.17 | 1.52 | 2.23 | -2.21 | 9. | 5.53 | 2.4933 | -2.97 |
| 28 | 22 | 1.75 | 2.43 | -2.27 | 1.12 | 2.34 | -2.22 | 1.44 | 2.27 | 2.24 | 9. | 4.77 | 2.1467 | -2.57 |
| 39 | 3 | 2.83 | 2.47 | -2.27 | 4.35 | 2.39 | -2.16 | 1.51 | 2.23 | -2.33 | 7. | 9.53 | 2.2782 | 1.27 |
| 39 | 23 | 2.92 | 2.53 | -2.26 | 1.23 | 2.33 | -2.29 | 1.45 | 2.24 | -2.24 | 7. | 9.43 | 2.4367 | -2.77 |

# APPENDIX C

Computer programs written by the author that aided in the preliminary analysis of the data. Program 1 computes the textural parameters, mean grain size, sorting, and skewness, from the 16, 50, and 84 percentiles. Program 2 and Program 3 reduce the foreshore and process data, respectfully, by computing the mean average.

## Program 1 - Textural Parameters

```
10      READ (5, 2, Err=7) N, M, A, B, C
 2      FORMAT (A5, I5, 3F6.2)
        ZM = (A+B+C)/3.
        TG = (C-A)/2.
        SK = ((A+C) - 2.*B)/(C-A)
 4      WRITE (30,3) N, M, ZM, TG, SK
 3      FORMAT (1X, 'SAMP. NO.', 2X, A5, 2X, 'DATE'. 2X, I5, 2X,
        'MEAN  GR. SZ=', 1X, F10.4, 2X, 'ST. DEV=', 1X, F10.4,
        2X, 'SK=', 1X, F1C.41)
        GO TO 10
 5      CALL EXIT
 7      WRITE (30,3) N,M,A,B,C
        END
```

Data Designation in Read Statement

N = DATE
M = TIME
A = Profile Location A
B = Profile Location B
C = Profile Location C

## Program 2. - Reduction of Foreshore Data

```
      CALL IFILE (1, ' FOR 22')
      CALL OFILE (30, 'EDEP')
      MCOUNT = 0
10    NCOUNT = 0
 1    READ (1,2) N, M, PA, PB, PC, GA, GB, GC, TA, TB, TC, D, F, G, H
 2    FORMAT (2I2, 1X, 2F5.2, F6.2, 2F5.2, F6.2, 2F5.2, F6.2, F3.0,
      F5.2, F7.3, F6.2)
      MCOUNT = MCOUNT + 1
      NCOUNT = NCOUNT + 1
      IF (NCOUNT-1) 3,3,4
 3    SA = PA
      SB = PB
      SC = PC
      RA = GA
      RB = GB
      RC = GC
      UA = TA
      UB = TB
      UC = TC
      VA = D
      WA = F
      XA = G
      YA = H
      TO TO 1
 4    SA = PA + SA
      SB = PB + SB
      SC = PC + SC
      RA = GA + RA
      RB = GB + RB
      RC = GC + RC
      UA = TA + UA
      UB = TB + UB
      UC = TC + UC
      VA = D + VA
      WA = F + WA
      XA = G + XA
      YA = H + YA
      IF (NCOUNT-3) 1,6,6
 6    SSA = SA/3.
      SGB = SB/3.
      SSC = SC/3.
      RRA = RA/3.
      RRB = RB/3.
      RRC = RC/3.
      UUA = UA/3.
      UUB = UB/3.
      UUC = UC/3.
      VVA = VA/3.
```

```
      WWA = WA/3.
      XXA = XA/3.
      YYA = YA/3.
      WRITE (30,7) N, M, SSA, SSB, SSC, RRA, RRB, RRC, UUA, UUB, UUC,
      VVA, WWA, XXA, YYA.
 7    FORMAT (1X, I3, I3, 1X, F6.2, 1X, F6.2, 1X, F7.2, 1X, F6.2, 1X,
      F6.2, 1X, F7.2, 1X, F6.2, 1X, F6.2, 1X, F7.2, 1X, F4.0, 1X,
      F6.2, 1X, F9.4, 1X, F7.2)
      IF (MCOUNT, EQ. 177) GO TO 99
      GO TO 10
99    CALL EXIT
      END
```

Data Designation in Read Statment

N = Date
M = Time
PA = Plunge step mean grain size
PB = Plunge step sorting
PC = Plunge step skewness
GA = Mid-foreshore mean grain size
GB = Mid-foreshore sorting
GC = Mid-foreshore skewness
TA = Upper foreshore mean grain size
TB = Upper foreshore sorting
TC = Upper foreshore skewness
D = Foreshore slope
F = Foreshore width
G = Net erosion and deposition
H = Migration of plunge step

## Program 3 - Reduction of Beach Processes

```
        CALL IFILE (5, 'IWAVE')
        CALL OFILE (30, 'WAVE')
        MCCUNT = 0
 10     NCOUNT = 0
  1     READ (5.2) N, M, A, B, C, D, E, F, G, H, R
  2     FORMAT (2I2, F4.1, 4X, F6.2 6X, F5.2, 10X, F5.2, 4X, F2.0,
        4X, 2F5.2, 5X, F4.1, F5.2)
        MCOUNT = MCOUNT + 1
        NCOUNT = NCOUNT + 1
        IF (NCOUNT - 1) 3,3,4
  3     AA = A
        BB = B
        CC = C
        DD = D
        EE = E
        FF = F
        GG = G
        HH = H
        RR = R
        GO TO 1
  4     AA = A + AA
        BB = B + BB
        CC = C + CC
        DD = D + DD
        EE = E + EE
        FF = F + FF
        GG = G + GG
        HH = H + HH
        RR = R + RR
        IF (NCOUNT - 6) 1, 6, 6
  6     SAA = AA/6.
        SBB = BB/6.
        SCC = CC/6.
        SDD = DD/6.
        SEE = EE/6.
        SFF = FF/6.
        SGG = GG/6.
        SHH = HH/6.
        SRR = RR/6.
        WRITE (30, 7) N, M, SAA, SBB, SCC, SDD, SEE, SFF, SGG, SHH, SRR
  7     FORMAT (1X, I3, I3, 1X, F6.2, 1X, F7.2, 1X, F6.2, 1X, F6.2, 1X,
        F4.0, 1X, F6.2, 1X, F6.2, 1X, F6.2, 1X, F6.2)
        IF (MCOUNT. EQ. 354) GO TO 99
        GO TO 10
 99     CALL EXIT
        END
```

Data Designation in Read Statement

N = Date
M = Time
A = Wind Speed
B = Barometric Pressure
C = Lake Level
D = Groundwater Level
E = Wave Type
F = Breaker Period
G = Breaker Height
H = Breaker Angle
R = Longshore Current Velocity

# APPENDIX D

## Analysis of Variance

The analysis of variance is listed for the beach processes and the foreshore responses. Computed in the analysis is the sum of squares, degrees of freedom, mean square, and F-ratio. The variance components were hand-calculated. The computation formulas are listed in the text. The source of variations for the beach processes are H is the Hour factor, D is the Day factor, and HD is the residual factor. For the foreshore parameters, the source of variations are T is time, L is profile location and TL is the residual factor. The asterisk denotes significance at the 95 per cent confidence level.

## BEACH PROCESSES

| Parameter | Source of Variation | Sum of Squares | Degrees of Freedom | Mean Square | F-Ratio | Variance Component % |
|---|---|---|---|---|---|---|
| WIND SPEED | H | 1155.112 | 11 | 105.019 | 4.36* | 5.3 |
| | D | 9423.743 | 29 | 324.951 | 13.49* | 48.3 |
| | HD | 7683.447 | 319 | 24.080 | | 46.4 |
| BAROMETRIC PRESSURE | H | 0.064 | 11 | 0.005 | 3.31* | 0.7 |
| | D | 5.853 | 29 | 0.201 | 118.08* | 90.1 |
| | HD | 0.549 | 319 | 0.001 | | 9.2 |
| LAKE LEVEL | H | 0.106 | 11 | 0.009 | 1.16 | 0.1 |
| | D | 7.355 | 29 | 0.253 | 30.70* | 71.1 |
| | HD | 2.636 | 319 | 0.008 | | 28.8 |
| GROUNDWATER LEVEL | H | 0.373 | 11 | 0.033 | 1.19 | 0.2 |
| | D | 22.862 | 29 | 0.788 | 27.80* | 69.0 |
| | HD | 9.044 | 319 | 0.028 | | 30.8 |
| WAVE TYPE | H | 26.230 | 11 | 2.384 | 2.55 | 2.8 |
| | D | 276.013 | 29 | 9.517 | 10.18* | 42.2 |
| | HD | 298.019 | 319 | 0.934 | | 55.0 |
| WAVE PERIOD | H | 4.480 | 11 | 0.407 | 1.03 | 0.1 |
| | D | 188.132 | 29 | 6.487 | 16.46* | 55.7 |
| | HD | 125.655 | 319 | 0.393 | | 43.2 |
| BREAKER HEIGHT | H | 2.053 | 11 | 0.186 | 0.77 | 0 |
| | D | 137.942 | 29 | 4.756 | 19.68* | 60.9 |
| | HD | 77.084 | 319 | 0.241 | | 39.1 |
| BREAKER ANGLE | H | 1540.497 | 11 | 140.045 | 1.45 | 0.6 |
| | D | 50724.346 | 29 | 1749.115 | 18.21* | 40.8 |
| | HD | 30624.427 | 319 | 96.001 | | 58.6 |
| LONGSHORE CURRENT VELOCITY | H | 2.140 | 11 | 0.194 | .47 | 0 |
| | D | 164.984 | 29 | 5.689 | 13.70* | 51.8 |
| | HD | 130.592 | 319 | 0.409 | | 48.2 |

## FORESHORE PARAMETERS

| Parameter | Source of Variation | Sum of Squares | Degrees of Freedom | Mean Square | F-Ratio | Variance Component % |
|---|---|---|---|---|---|---|
| MEAN GRAIN SIZE AT PLUNGE STEP | T | 2.650 | 58 | 0.045 | 2.78* | 37.4 |
| | L | 0.028 | 2 | 0.014 | 0.86 | 0 |
| | TL | 1.904 | 116 | 0.016 | | 62.6 |
| SORTING AT PLUNGE STEP | T | 0.407 | 58 | 0.007 | 2.17* | 28.1 |
| | L | 0.005 | 2 | 0.002 | 0.86 | 0 |
| | TL | 0.375 | 116 | 0.003 | | 71.9 |
| SKEWNESS AT PLUNGE STEP | T | 1.262 | 58 | 0.021 | 1.44* | 13.0 |
| | L | 0.004 | 2 | 0.002 | 0.16 | 0 |
| | TL | 1.742 | 116 | 0.015 | | 87.0 |
| MEAN GRAIN SIZE AT MID-FORESHORE | T | 31.360 | 58 | 0.540 | 1.00 | 0 |
| | L | 1.590 | 2 | 0.795 | 1.48 | 1.0 |
| | TL | 62.154 | 116 | 0.535 | | 99.0 |
| SORTING AT MID-FORESHORE | T | 0.481 | 58 | 0.008 | 3.36* | 43.1 |
| | L | 0.016 | 2 | 0.008 | 3.05* | 2.0 |
| | TL | 0.286 | 116 | 0.002 | | 54.9 |
| SKEWNESS AT MID-FORESHORE | T | 1.718 | 58 | 0.029 | 1.53* | 14.6 |
| | L | 0.116 | 2 | 0.058 | 3.00 | 2.8 |
| | TL | 2.243 | 116 | 0.019 | | 82.6 |
| MEAN GRAIN SIZE AT UPPER FORESHORE | T | 0.573 | 58 | 0.009 | 1.30 | 9.1 |
| | L | 0.031 | 2 | 0.015 | 2.07 | 1.5 |
| | TL | 0.878 | 116 | 0.007 | | 89.4 |
| SORTING AT UPPER FORESHORE | T | 0.269 | 58 | 0.004 | 3.16* | 41.9 |
| | L | 0.002 | 2 | 0.001 | 0.89 | 0 |
| | TL | 0.170 | 116 | 0.001 | | 58.1 |
| SKEWNESS AT UPPER FORESHORE | T | 0.448 | 58 | 0.007 | 1.07 | 2.4 |
| | L | 0.035 | 2 | 0.017 | 2.46 | 2.3 |
| | TL | 0.831 | 116 | 0.007 | | 95.3 |
| FORESHORE SLOPE | T | 416.033 | 58 | 7.173 | 3.10* | 47.7 |
| | L | 1.435 | 2 | 0.717 | 0.31 | 0 |
| | TL | 267.898 | 116 | 2.309 | | 52.3 |
| FORESHORE WIDTH | T | 5123.090 | 58 | 88.329 | 9.84* | 74.6 |
| | L | 21.082 | 2 | 10.541 | 1.17 | 0 |
| | TL | 1040.31 | 116 | 8.968 | | 25.3 |

## FORESHORE PARAMETERS

| Parameter | Source of Variation | Sum of Squares | Degrees of Freedom | Mean Square | F-Ratio | Variance Component % |
|---|---|---|---|---|---|---|
| NET EROSION AND DEPOSITION | T | 871.256 | 58 | 15.021 | 1.95* | 24.2 |
| | L | 7.242 | 2 | 3.621 | 0.47 | 0 |
| | TL | 889.495 | 116 | 7.668 | | 75.8 |
| MIGRATION OF PLUNGE STEP | T | 340.501 | 58 | 5.870 | 2.16* | 28.0 |
| | L | 1.016 | 2 | 0.508 | 0.18 | 0 |
| | TL | 313.905 | 116 | 0.706 | | 72.0 |

# APPENDIX E

## Linear Stepwise Regression

The function of the stepwise regression is to select the independent variable that contributes most to the explanation of the dependent variable variation. The procedure is repeated till each independent variable enters the regression equation in order of their contribution to the dependent variable. This particular stepwise regression has the additional feature of selecting the significant level in which each independent variable may enter the regression equation. Two stepwise regression analyses were computed for the process-response, one with an F-value of 0.0 and a second with an F-value of 2.00. An F-value = 0.0 allows each independent variable to enter the regression equation. Preliminary analysis of the computer printouts allow arbitrary selection of an F-value = 2.00 for a second analysis.

The Appendix lists both analyses for each dependent variable (Foreshore parameters). The upper section is the analysis of the F-value equal to 2.00 listing the independent variable in order of significant contribution. The second section is with an F-value of 0.0, also listing the independent variables in their order of significant contribution. The coefficient of determination ($R^2$), coefficient of multiple regression ($R$), and F-value are included for each stepwise regression analysis. The asterisk by the F-value denotes significance of the regression equation at the 95% level.

| FORESHORE RESPONSE PARAMETERS | BEACH PROCESSES PARAMETERS | $R^2$ | R | F |
|---|---|---|---|---|
| MEAN GRAIN SIZE AT PLUNGE STEP | Barometric Pressure, Lake Level, Breaker Angle | .325 | .570 | 8.68* |
| | Barometric Pressure, Lake Level, Breaker Angle, Wind Speed Breaker Type, Breaker Height, Breaker Period, Groundwater Level, Longshore Current Velocity | .346 | .589 | 2.83* |
| SORTING AT PLUNGE STEP | Groundwater Level, Barometric Pressure | .134 | .367 | 4.28* |
| | Groundwater Level, Barometric Pressure, Wave Type, Lake Level, Wind Speed, Breaker Period, Breaker Height, Longshore Current Velocity, Breaker Angle | .188 | .433 | 1.27 |
| SKEWNESS AT PLUNGE STEP | Lake Level | .035 | .188 | 2.05 |
| | Lake Level, Wave Type, Wind Speed, Breaker Height, Breaker An., Barometric Pressure, Longshore Current Velocity, Breaker Period, Groundwater Level | .072 | .269 | 0.41 |
| MEAN GRAIN SIZE AT MID-FORESHORE | Wave Type | .041 | .203 | 2.41 |
| | Wave Type, Groundwater Level, Longshore Current Velocity, Barometric Pressure, Breaker Height, Wind Speed, Lake Level, Breaker Period, Breaker Angle | .161 | .401 | 1.02 |
| SORTING AT MID-FORESHORE | Groundwater Level, Wave Type, Lake Level, Barometric Pressure, | .383 | .619 | 11.20* |
| | Groundwater Level, Wave Type, Lake Level, Barometric Pressure, Longshore Current Velocity, Breaker Period, Breaker Angle, Wind Speed, Breaker Height | .420 | .648 | 3.87* |
| SKEWNESS AT MID-FORESHORE | Lake Level | 0.081 | 0.292 | 5.22* |
| | Lake Level, Wind Speed, Breaker Angle, Breaker Height, Breaker Period, Wave Type, Groundwater Level, Longshore Current Velocity, Barometric Pressure | 0.162 | .403 | 1.08 |
| MEAN GRAIN SIZE AT UPPER-FORESHORE | No variable entered | 0 | 0 | 0 |
| | Breaker Angle, Breaker Period, Breaker Height, Wind Speed Groundwater Level, Longshore Current Velocity, Wave Type, Barometric Pressure, Lake Level | .131 | .362 | .805 |

| FORESHORE RESPONSE PARAMETERS | BEACH PROCESSES PARAMETERS | $R^2$ | R | F |
|---|---|---|---|---|
| SORTING AT UPPER-FORESHORE | Barometric Pressure, Breaker Angle, Wave Type, Wind Speed, | .344 | .587 | 6.98* |
| | Barometric Pressure, Breaker Angle, Wave Type, Wind Speed, Groundwater, Breaker Period, Longshore Current Velocity, Breaker Height, Lake Level | .377 | .614 | 3.24* |
| SKEWNESS AT UPPER-FORESHORE | Longshore Current Velocity | .041 | .204 | 2.44 |
| | Longshore Current Velocity, Groundwater Level, Wind Speed, Breaker Angle, Breaker Period, Wave Type, Breaker Height, Barometric Pressure, Lake Level | .191 | .438 | 1.26 |
| FORESHORE SLOPE | Barometric Pressure, Breaker Angle, Lake Level, Breaker Period, | .587 | .766 | 18.86* |
| | Barometric Pressure, Breaker Angle, Lake Level, Breaker Period, Wave Type, Groundwater Level, Breaker Height, Wind Speed, Longshore Current Velocity | .602 | .776 | 8.10* |
| FORESHORE WIDTH | Breaker Height, Barometric Pressure, Wave Type, Lake Level, | .813 | .901 | 57.87* |
| | Breaker Height, Barometric Pressure, Wave Type, Lake Level, Breaker Angle, Longshore Current Velocity, Wave Period, Groundwater Level, Wind Speed | .823 | .908 | 25.16* |
| NET EROSION AND DEPOSITION | Barometric Pressure, Longshore Current Velocity, Wave Period, Wave Type, Lake Level | .335 | .581 | 5.30* |
| | Barometric Pressure, Longshore Current Velocity, Wave Period, Wave Type, Lake Level, Breaker Angle, Wind Speed, Breaker Height, Groundwater Level | .375 | .615 | 3.24* |
| MIGRATION OF PLUNGE STEP | Lake Level, Longshore Current Velocity | .157 | .396 | 5.14* |
| | Lake Level, Longshore Current Velocity, Groundwater Level Barometric Pressure, Breaker Height, Breaker Angle, Wind Speed, Wave Type, Wave Period | .208 | .456 | 1.41 |